2021-22 Annual Report
Sierra Nevada Bighorn Sheep Recovery Program

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Figure 1. *Camera placed with the intention of documenting Sierra Nevada red fox, instead caught Sierra bighorn on the Cirque Crest in the Taboose herd during the fall. Note male posture in background indicating rutting behavior.*

Executive Summary

For the second consecutive year, the range-wide Sierra bighorn population increased, reaching 277 females. Although still short of the highest count of 316 females in 2016, the growth of most herds this year indicates a rebound from the heavy winters of 2016-17 and 2018-19. More specifically, we had the highest count ever at Williamson of 22 females and a count equal to the highest count at Bubbs of 17 females. Fortunately, this year was not as plagued with wildfire and smoky conditions as 2020. We were able to survey all 14 herds (Figure 2) in the summer, although technically the best count at Convict included both summer and winter data. Surveys included the first "good" quality count at Wheeler in 4 years. Unfortunately, the Olancha population declined for the first time since it was introduced in 2013, likely due to lower adult survival. Although not rebounding, the count of 17 females at Langley indicates this previous source herd has stopped declining.

In addition to summer surveys, we were able to have both spring and fall bighorn captures. In the spring, we successfully translocated 7 bighorn from Baxter to Laurel including 4 females, 3 of which were pregnant. We were hoping these animals would make use of higher elevation (~10,000 ft) habitat within

Laurel Creek, but as Laurel animals tend to do, some of the newly translocated bighorn have already wandered beyond the herd unit boundary.

In the eastern Sierra region, we accounted for 55 mountain lions which exceeds the highest count from last year of 54. This includes the highest counts ever for three of the four count areas: northern, central, and Olancha. Additionally, 27 lions were captured and collared. These new collars helped to identify the 20 bighorn mortalities from lion predation, although 13 of these mortalities were from uncollared lions indicating more effort is needed to identify which lions are preying on bighorn. We documented two high elevation mountain lion kills, one in Wheeler near Meriam Peak at 3482 m (11,424 ft) in May and one in Langley at 3575 m (11,729 ft) in the Miter Basin in September. We successfully translocated a female lion along with her two 22-month-old offspring to the San Bernardino mountains to prevent them from killing additional Sierra bighorn.

And finally, we published a rigorous evaluation of disease risk to Sierra bighorn. This new method considers the likelihood of Sierra bighorn movements when identifying potential overlap between Sierra bighorn and domestic sheep.

Introduction

As we move to recover Sierra bighorn, we pursue the principles of adaptive management. As such, we strive to learn from our monitoring and research, and base our management on sound science. We are continually enhancing our understanding of the ecology of Sierra bighorn as exemplified in the work we publish. Some recent publications on Sierra bighorn illustrate our efforts and include Berger et al. 2022, Forshee et al. 2022, Anderson et al. 2022, Gammons et al. 2021, Denryter et al. 2021a, 2021b, 2022, Stephenson et al. 2020, and Spitz et al. 2020. Sierra bighorn came close to extinction in the 1990s, and that prompted their listing as federal and state endangered. Our science informs the actions that are needed to prevent extinction and move towards a sustainable population. An ever-changing climate complicates gaining reliable knowledge and the application of that knowledge. Consequently, our monitoring and research is continuous and designed to evaluate and predict population responses to a range of variable environmental factors.

Through multiple collaborations with universities and other partners, we continue to develop additional projects that address increasingly complex questions. New technologies such as improved remotely-sensed imagery are enabling us to model nutritional landscapes that characterize the quality and quantity of forage available to bighorn and how it fluctuates with winter severity. By defining the nutritional landscape in which bighorn live, we will get closer to defining nutritional carrying capacity, determining how many bighorn can live in the Sierra Nevada, and evaluate our recovery goals from a nutritional perspective. We plan to analyze our recovery goals further and ensure that populations will be viable over the long-term. This endeavor has become more complicated as we gain understanding of how the climate is changing in the Sierra, and the potential for whiplash between droughts and severe winters increases. In addition, without an understanding of the nutritional status of a population, we cannot determine whether mortality causes, such as predation, are additive or are simply replacing another cause. Our data on body condition is extensive and powerful with respect to quantifying nutritional status of bighorn populations. Several of our projects are designed to clarify the role of predation in limiting bighorn population growth and what drives variation in predation.

Sierra bighorn tend to do well in drought years, and this year proved the rule rather than the exception. Under drought conditions in the Sierra Nevada, bighorn are able to move more freely throughout their alpine winter ranges, vacillating migrants readily traverse between high and low elevation winter ranges, and there is plenty of moisture from snowpack and ground water to produce good forage during summer. The drought continued through the winter of 2021-22, but conditions were not as dry as the previous winter, with statewide precipitation at 76% of average, and temperatures generally above average with a notable September heat wave, that did not affect the Sierra Nevada (California Department of Water Resources 2022). We are using future climate projections to model the effects of a changing climate on bighorn population growth. What will be the extent of the snowpack in the next 100 years? At what elevation will precipitation fall as snow versus rain? How will this influence forage for bighorn and the depth of snow on their winter ranges?

Additional projects will inform how we address and respond to human activities such as disease risk from domestic sheep grazing, recreational climbing, and backcountry skiing. Finally, another research focus will guide how we implement future bighorn translocations. Disease management, migration, nutrition, predation, and climate all influence translocation options and decisions. Many such variables interact to determine the potential success of translocations and will be incorporated into our future planning. Modeling a large number of variables is necessary but challenging. Getting to recovery requires viable populations across a broad spectrum of geography and environmental conditions. That distribution will not occur without an adequate level of protecting existing populations and restoring formerly occupied habitat.

This report summarizes monitoring efforts for Sierra bighorn and mountain lions that occupy the Recovery Area during May 2021 – April 2022. As we learn more about the ecology of Sierra bighorn and how they respond to limiting factors, we continue to adapt our management. The foundation of our bighorn monitoring is documenting demography (population size and vital rates) and behavior (habitat use and migration). Our research adds additional monitoring as needed to answer more complicated questions. Currently, additional data collection includes nutritional condition and disease surveillance of bighorn, forage quantity and quality, winter severity, alternate prey availability for lions, and human recreation within bighorn habitat.

Data and summaries in this report are preliminary and are subject to change contingent upon further interpretation, analyses, and review (see Appendix B for details).

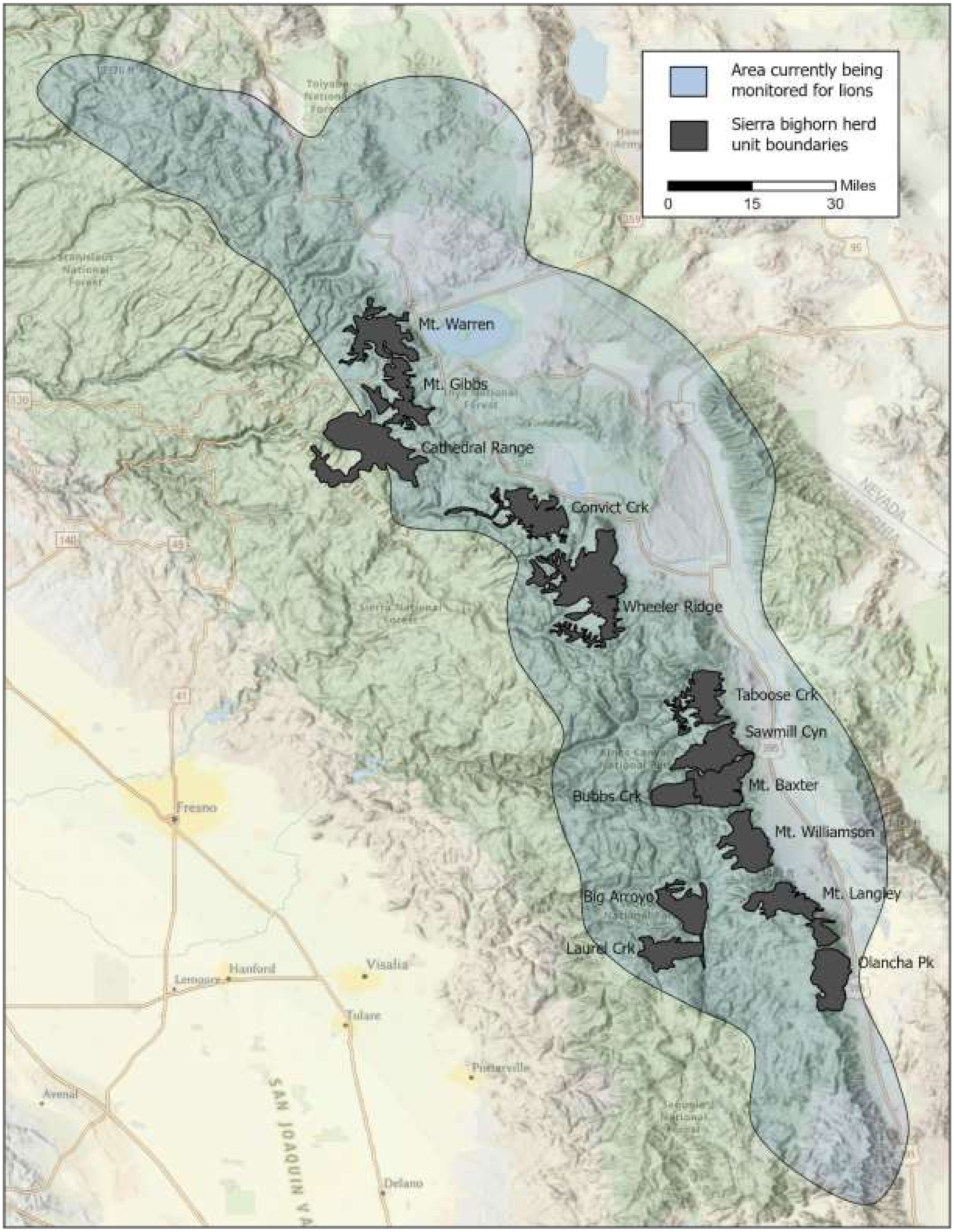

Figure 2. *Overview map of Sierra bighorn herd units, and the mountain lion monitoring area. The lion monitoring area reflects large lion home ranges as defined by GPS collars. Intensive capture and survey effort for lions occurred east of the Sierra crest within California.*

Population Monitoring and Recovery Goals

For the second consecutive year, the Sierra bighorn population increased, this year by 17 females, bringing the range-wide estimate up to 277 females (including 50 yearling females), 128 lambs, and an estimated 185 males (at least 32 yearlings; Figure 3). This year's population estimates are based on minimum counts, while past estimates include both minimum counts and mark-resight estimates. Males are estimated based on a 2:3 male:female ratio (Appendix B, Methods). Populations continued to rebound but have not yet exceeded the numbers seen prior to losses from the snowy winters of 2016-17 and 2018-19. This winter was mild with minimal losses and growth in three of the four recovery units.

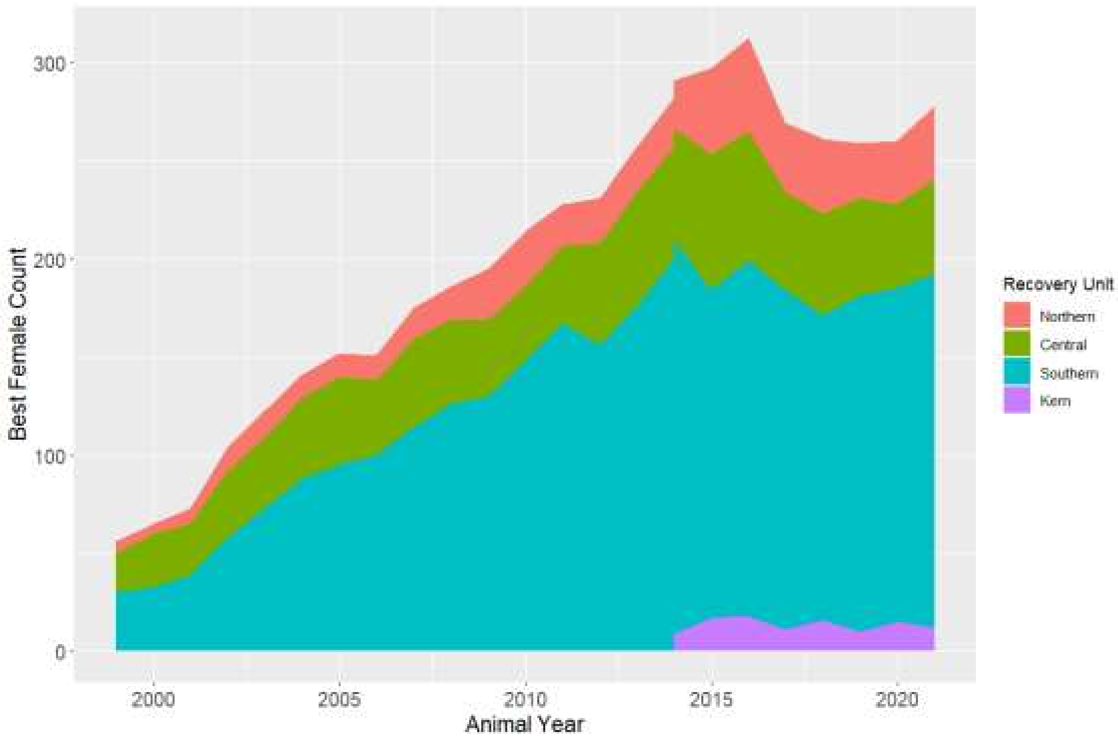

Figure 3. *Range-wide female Sierra bighorn population abundance since 1999. Range-wide numbers are calculated using annual herd values based on reconstructed minimum counts and mark-resight estimates, as well as the most recent survey results for herds not surveyed annually. Herd counts are combined 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 in this graph.*

The Recovery Plan (U.S. Fish and Wildlife Service 2007) specifies minimum counts are used to assess progress toward downlisting goals, requiring at least 305 females with specific geographic targets in four Recovery Units (Figure 4). Each Recovery Unit consists of 2-7 herd units (Figure 2). Currently only the Southern Recovery Unit is meeting downlisting goals, but the Central Recovery Unit is getting close. The Kern Recovery Unit continues to decline, driven by losses in Big Arroyo and Laurel (Figures 4 and 5).

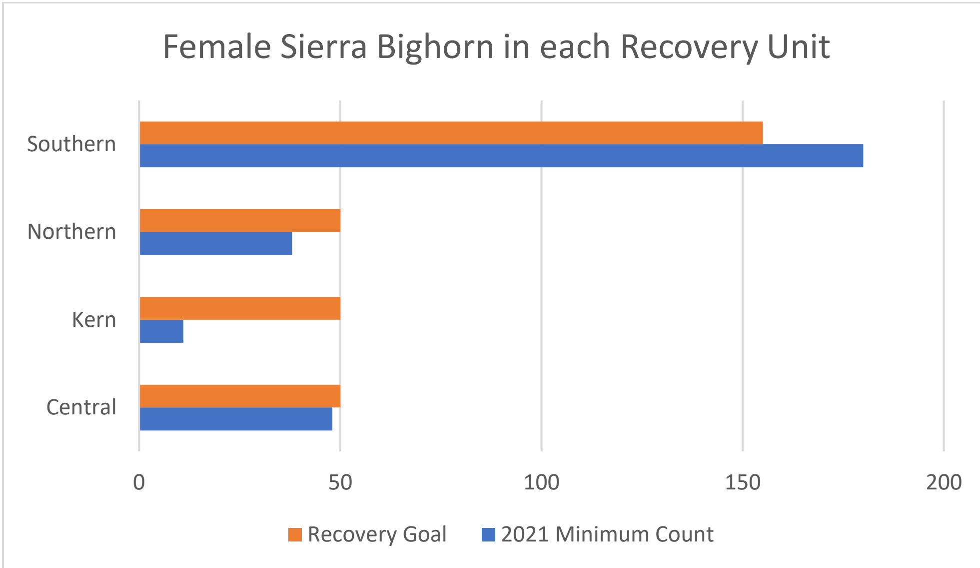

Figure 4. *Abundance and distribution of female Sierra bighorn across Recovery Units compared to downlisting goals in 2021.*

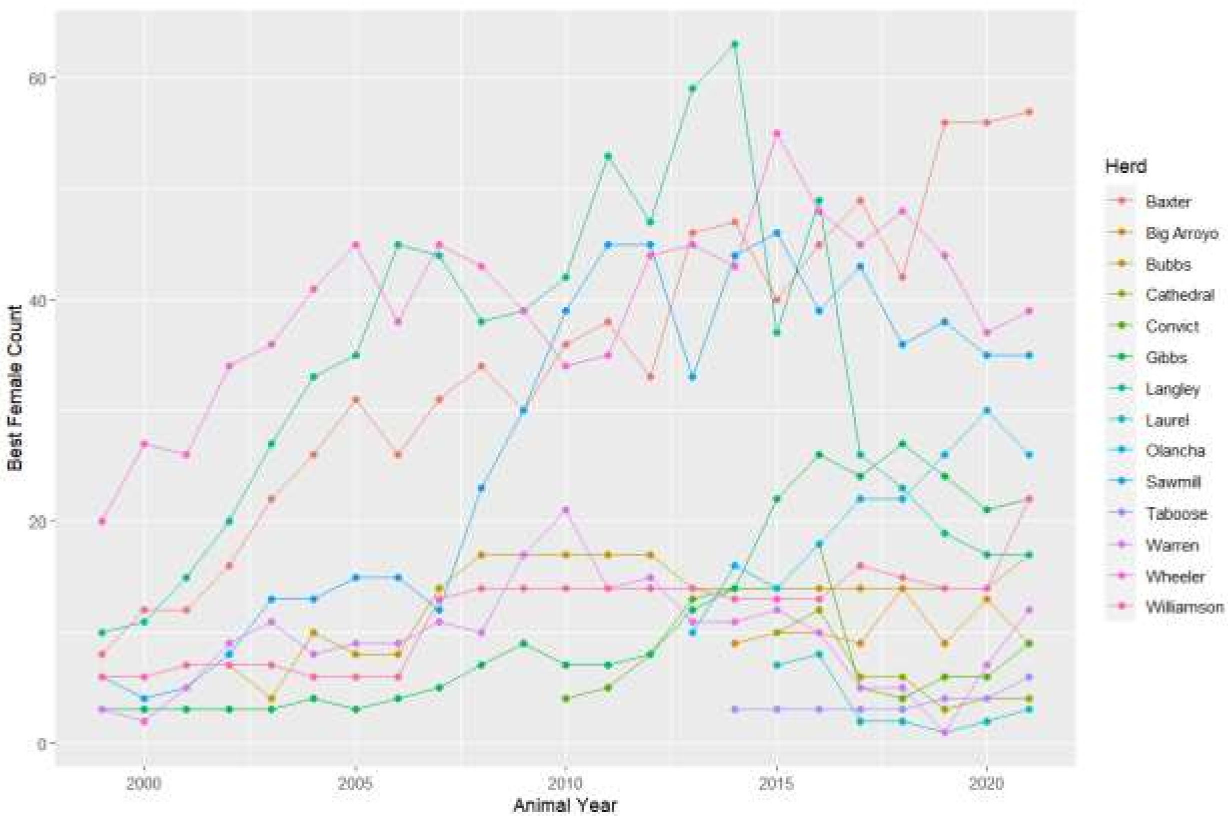

Figure 5*. Range-wide female Sierra bighorn population abundance since 1999. Range-wide numbers are calculated using annual herd values based on the most recent survey results for each herd as reconstructed minimum counts or mark-resight estimates. Herd counts are combined across summer and spring (post winter; May 1 – April 30), and therefore do not show the impacts of a given winter.*

Capture, Collaring, and Translocation

This fall we captured 14 bighorn from Baxter and Williamson including 9 females and 5 males. This included females in both Williamson demes, which we hope will improve our ability to count that herd. In the spring we captured 12 bighorn, including 7 (4 females, 3 males) that were translocated from Baxter to Laurel. In addition to the translocated bighorn, 2 additional females were caught and released at Baxter with camera collars, and 3 bighorn (2 females and 1 male) were caught and released at Cathedral. Prior to this capture, there were only two older collars remaining at Cathedral. The Cathedral bighorn were caught and processed on Parson's Plateau and these new collars will hopefully help keep track of the Cathedral population which has continued to explore habitat around the Parson's Plateau area.

Laurel Translocation

Prior to this spring translocation, Laurel had previously received two translocations: the initial spring translocation in 2014 of 11 bighorn, including 7 females (all pregnant), from Sawmill and Baxter, and subsequently an augmentation in fall, 2016, of 4 males from Wheeler. Unfortunately, instead of forming a cohesive group in Laurel Creek, Laurel bighorn have tended to scatter in small groups that frequently travel far outside the herd unit boundaries. Our 2021 count at Laurel included only 6 bighorn: 2 adult females (S382), 2 lambs, and 2 yearling males. These bighorn had been recently located on the east side of the Kern River. In the fall, the collared female died of unknown cause. It is possible other uncollared Laurel bighorn exist, but we have been unable to locate them, as Laurel bighorn have not yet established areas of repeated use. With this translocation, which included 4 females (3 pregnant) and 3 males, we are hoping to establish a Laurel herd that persists and utilizes the upper reaches of Laurel Creek.

2021 Demographic Rates

Adult and lamb survival tended to be highest in 2021 in larger herds that have been established for longer periods of time (Figure 6). The majority of herds currently exhibit adult female survival rates that are inadequate for solid population growth. Although the pattern is less clear, measures of fecundity, including lamb:ewe and yearling:ewe ratios tended to be highest in smaller herds and some of the newer herds, with some exceptions (Figure 7).

This is the first time Olancha's population has decreased since it was introduced in 2013 (Figure 5), from 30 females in 2020 to 26 females in 2021 (Table 1 and Figure 5). In contrast, this year we had the highest count ever recorded at Williamson, with 22 females and 47 total bighorn (Table 1 and Figure 8). This high count included both the Barnard deme to the south and Williamson deme to the north. We have not counted bighorn in the Williamson deme for several years, but we were able to capture and collar a female in that deme last fall. In addition, we got lucky by finding a group of 19 in which there were no collars. We also documented a high count at Bubbs of 17 females without any collars, which ties with 2008 as the highest previous count. Additionally, Warren, which received an augmentation in March 2020, had notably high lamb survival and is exhibiting impressive population growth; the group of females with lambs totaled 19 in August. Furthermore, there is high cohesion in the Warren ewe group which is not always observed following augmentations, but is likely beneficial for population growth.

Fortunately, the four-year decline at Langley from 49 females in 2016, to 17 females in 2020, seems to be slowing and the population was steady this year with 17 females counted (Table 1 and Figure 8). We detected only one collared female mortality, in the high country near Iridescent Lake, from lion predation. We hope this represents a turning point for this population.

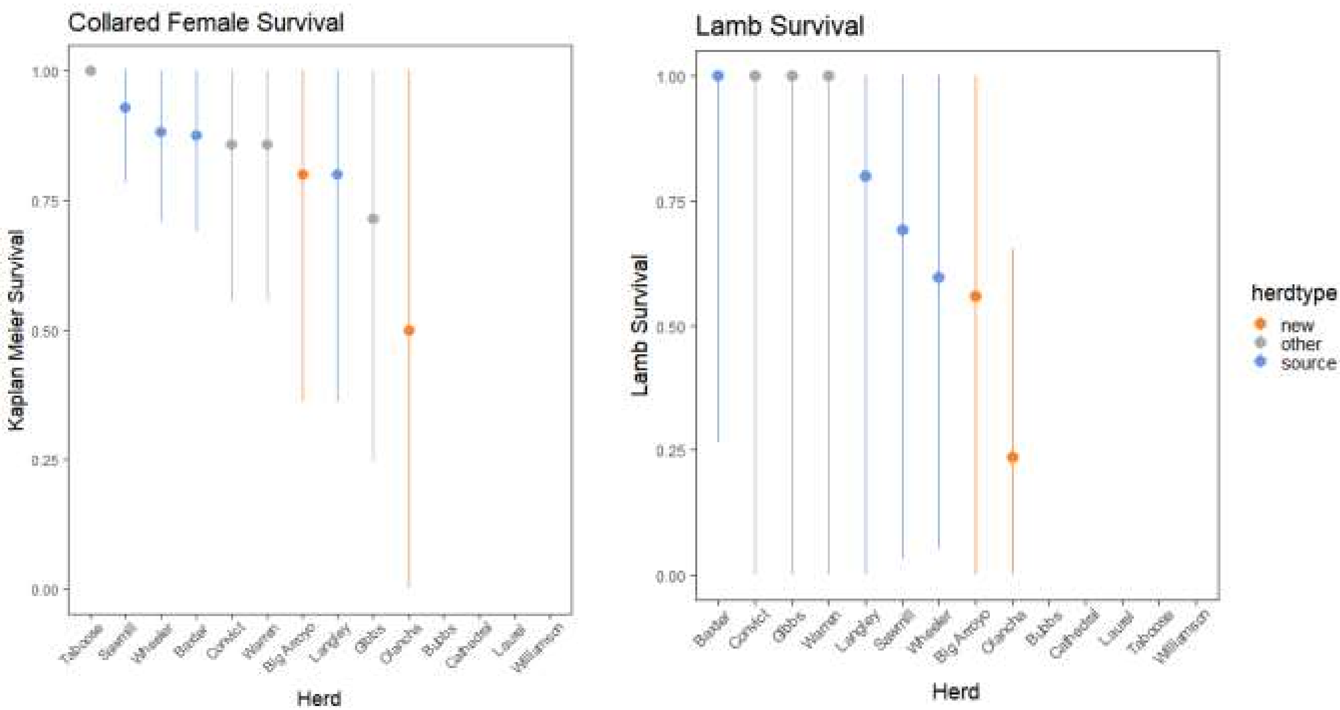

***Figure 6**. 2021 collared female and lamb survival with 95% confidence intervals, for herds with >3 collared females. Female survival estimated using Kaplan Meier, and lamb survival estimated using age ratios.*

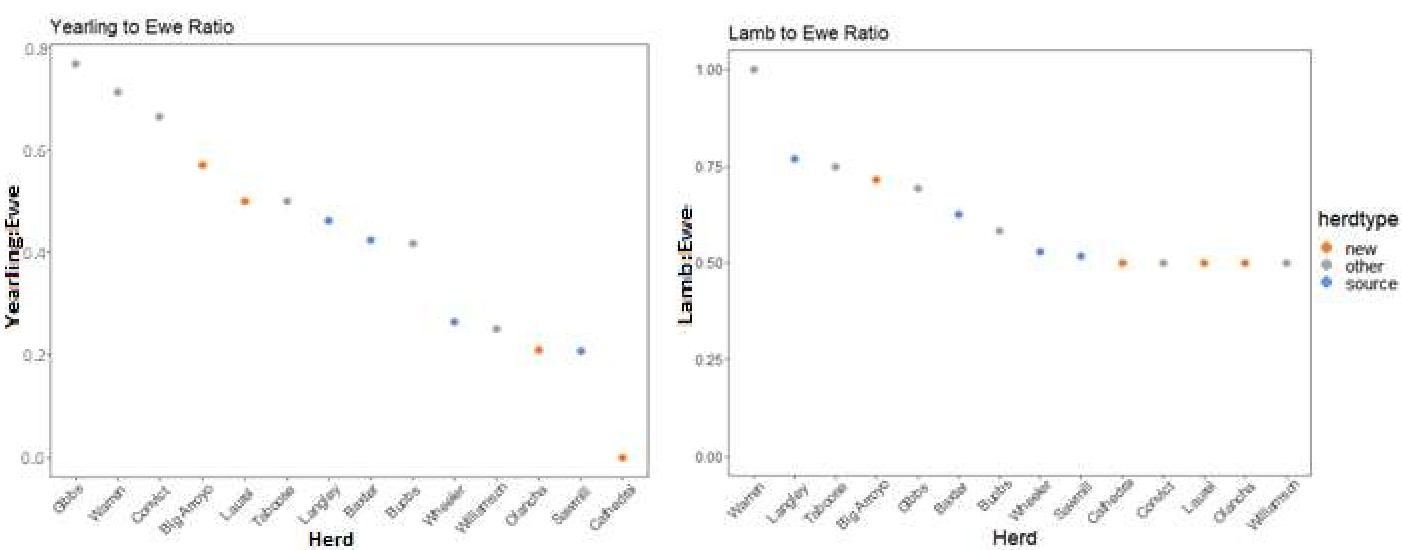

***Figure 7.** Observed ratios of lambs and yearlings (males and females combined) to adult females by herd in 2021.*

***Table 1**. Reconstructed minimum counts (MC) of Sierra bighorn during May 1, 2021 – April 30, 2022. 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 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.*

Herd	Female Adult	Female Yrlng	Female Total	Lambs	Male Adult	Male Yrlng	Male Total	MC Population	Year End Females	Mortality post survey	Notes
Olancha[W]	25	1	**26**	12	11	4	15	**53**	26	none	
Laurel	2	1	**3**	1	1	0	1	**5**	6	S382	4 translocated into Laurel March 2022
Big Arroyo	7	1	**8**	5	5	3	8	**21**	8	none	
Langley	14	3	**17**	10	11	3	14	**41**	16	S479	Lion kill in Miter Basin
Williamson	20	2	**22**	10	4	3	7	**40**	21	S591	1 unclassified yrlng added to total count
Baxter	43	14	**57**	25	22	5	27	**109**	55	S584, S517	Females and lambs from summer count; males from winter
Sawmill	31	3	**35**	15	11	3	14	**65**	34	S539	Includes 1 unknown aged female and 1 yearling of unknown sex
Bubbs	12	3	**17**	7	4	2	6	**30**	17	none	No collars, 2 unknown aged females
Taboose	4	1	**6**	3	5	1	6	**12**	6	none	Males from 2018 count. Includes 1 unknown aged female
Wheeler	35	4	**39**	18	17	5	22	**79**	37	S576, S504	1st "good" count in 4 years
Convict[C]	6	3	**9**	4	5	1	6	**19**	8	S345	Lion kill on McGee Mountain
Cathedral	4	0	**4**	2	0	0	0	**8**	4		Includes 2 unclassified yearlings in total count
Gibbs	13	9	**22**	9	22	1	23	**54**	20	S519, S564	
Warren	7	5	**12**	7	2	1	3	**22**	10	S535, M193	All adult females had collars. Adult males from 2020 count
Totals	**223**	**50**	**277**	**128**	**120**	**32**	**152**	**557**	**268**		

[W] Winter counts, other surveys conducted in summer [C] Data combined from winter and summer surveys

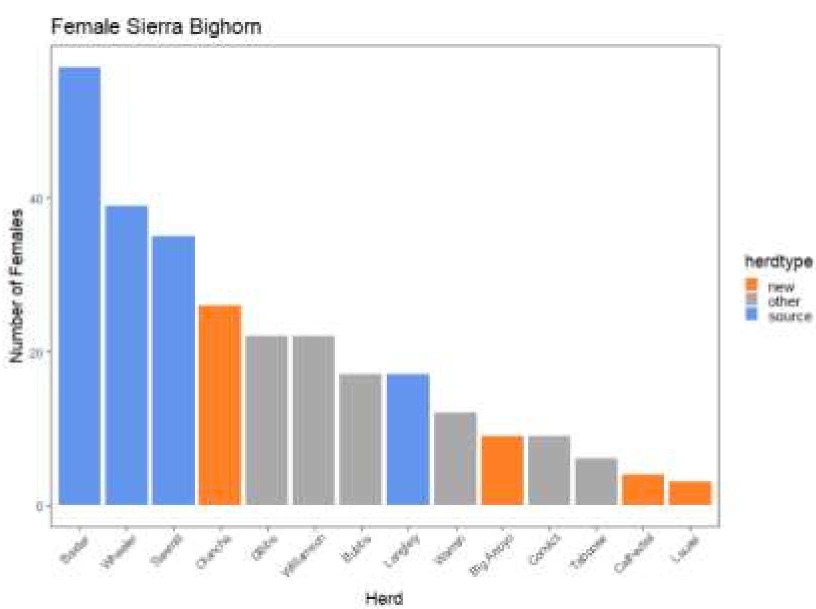

***Figure 8.** 2021 Reconstructed minimum counts of female Sierra bighorn.*

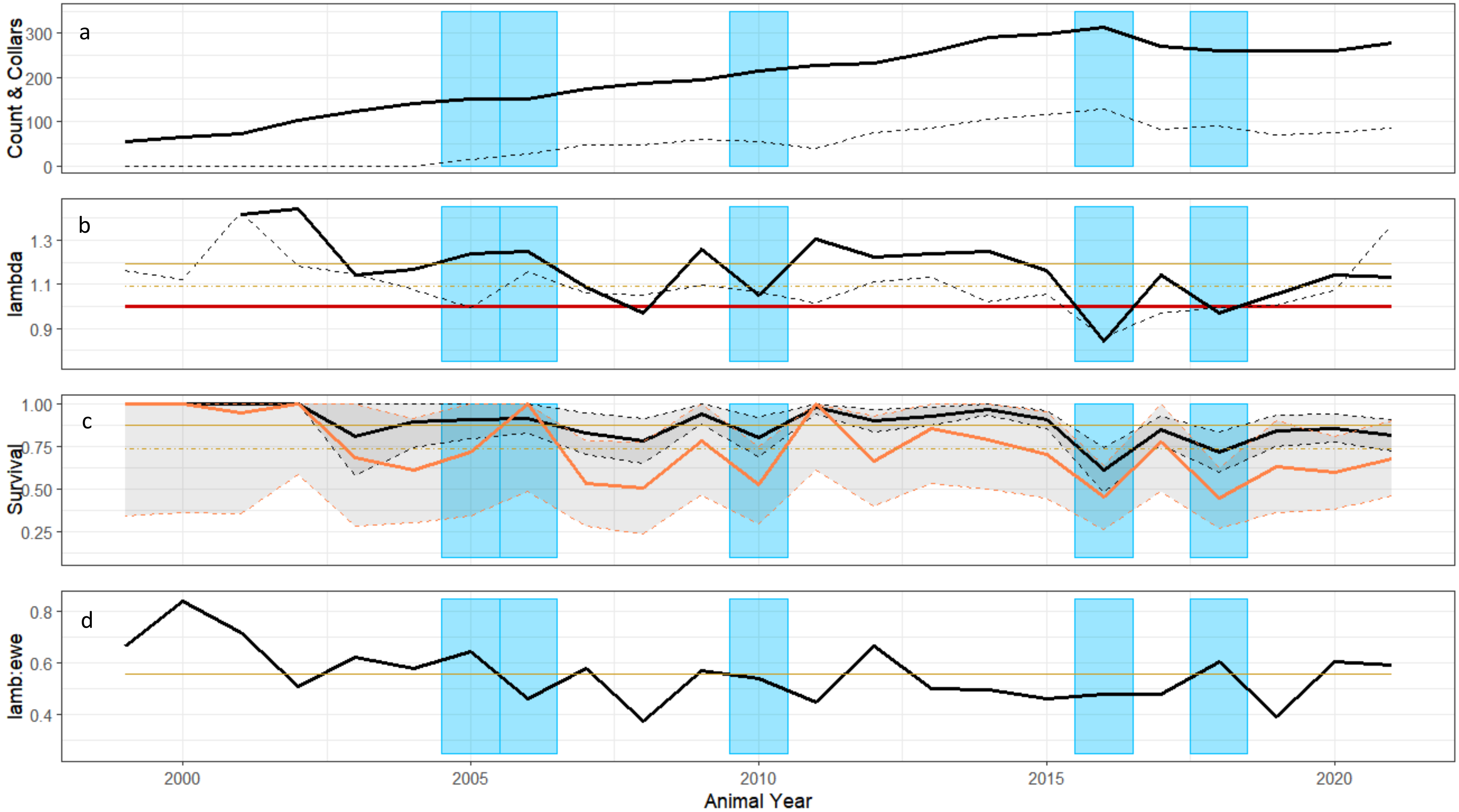

Figure 9*. Long-term and range-wide female Sierra bighorn population estimates and vital rates, 1999-2021; winters with >150% average snow are highlighted in blue:*

- *a) Total female population estimate (solid black line) and collared females (dashed black line).*
- *b) Lambda calculated from eigenvalues derived from vital rates and lambda from minimum counts (dashed 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.*

Range-wide and Long-term Demographic Rates

The Sierra bighorn population grew for the second consecutive year with slightly below average survival and slightly above average recruitment rates (Figure 9). Range-wide survival was 82% compared to long-term average of 87%. As a guideline we use an adult female survival of 90% as being necessary for a population to grow. The range-wide lamb:ewe ratio was 59/100 compared to the long-term average of 56/100. Unfortunately, the population has still not returned to its peak size of 2016. The current survival and recruitment rates are inadequate for population growth. In particular, the Kern Recovery Unit appears to be struggling, while the Central Recovery Unit appears to be climbing back up toward its previous peak population size. As indicated by lambda (population growth rate) in Figure 9, since 2017 the population has exhibited negative or low growth rates in many years.

Range-wide Cause-Specific Mortality

We detected 34 mortalities in 2021, including 18 collared females (Figure 10). Mortalities were widespread across the range, occurring in most herds (11/14) and those herds with no mortality (Cathedral, Taboose, and Bubbs) had few collared bighorn to assist with detection. Half of the collared bighorn mortalities were attributed to lion predation (13/26), but there were also 5 mortalities from avalanche, which is surprising for a mild winter (Figure 10). These avalanche mortalities occurred in 5 herds (Gibbs, Wheeler, Warren, Baxter, and Williamson). Two of the avalanche mortalities occurred after an early October storm including a collared female at Warren (S535) west of the red rocks in the Lundy drainage, and another collared female at Gibbs (S564) above Kidney Lake. These are the earliest avalanche mortalities that the program has detected. Lion predation occurred in 8 herds (Big Arroyo, Convict, Wheeler, Baxter, Sawmill, Olancha, Gibbs, and Langley). The other 8 collared bighorn died from unknown cause. Additionally, 8 uncollared animal mortalities were detected from collared lion clusters from five different lions (L200f, L174m, L213m, L212m, L187m) in four herds (Sawmill, Wheeler, Baxter, and Warren). Mortalities reported in this section include reclassifications (described below).

There were substantially more mortalities detected at Olancha, but a similar proportion to previous years. Olancha had its highest count last year (30 females), and this year the herd had its highest detected mortality count (5 collared females). Due to the extreme terrain within Olancha Canyon, we are frequently unable to access or locate mortalities to identify the cause of death. One mortality was due to lion predation, three others were not able to be investigated for various reasons (rugged terrain, no signal from ground, etc.), and there was too little evidence to identify cause for the final mortality. This increase in adult mortality likely caused the Olancha population to decrease for the first time since it was introduced in 2013.

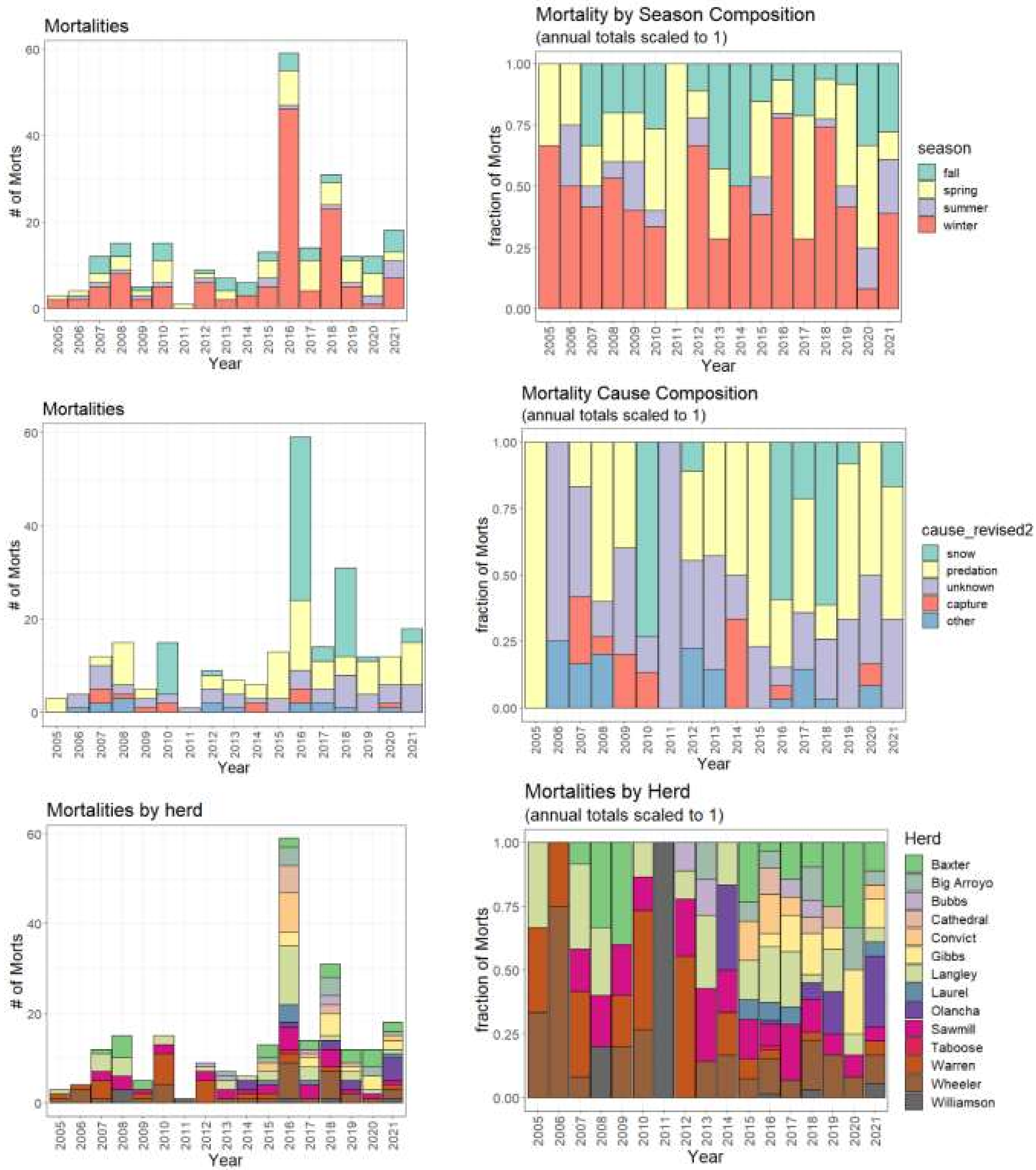

Figure 10. *Collared female Sierra bighorn mortality 2005-2021 by cause of death and herd. The category "snow" includes death by avalanche and malnutrition during winter and spring. The number of mortalities (left) is influenced by the number of collared females at a given time which trends with the 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 that were reclassified after investigation during the reclassifcation review (see Mortality Reclassification).*

Mortality Reclassification

The Recovery Program has documented 618 Sierra bighorn mortalities from bighorn years 2000-2021. Prior to this effort, the cause of death for ~35% of collared Sierra bighorn mortalities was not able to be determined and identified as “unknown”. We undertook a desktop review of all mortalities in an effort to reduce the amount with unknown cause (Greene 2023). Two general strategies were used in this review: one focused on lion predation and the other on mortalities related to snow.

Phil Johnston reviewed photos of mortality investigations for evidence of mountain lion predation. If plucked hair or broken long bones were present in photos, these mortalities were flagged as possible “lion predation”. This list was then reviewed by a staff panel with extensive experience in the program. In particular, the panel focused on how snow conditions might influence the likelihood of lion predation at a specific location. For example, an animal that died in the Big Arroyo herd in February 2017 was excluded from reclassification to lion predation (even if plucked hair and broken long bones were present in photos) because the Kern River region was blanketed in deep snow that year. Staff concluded that in numerous cases, lions may have scavenged bighorn carcasses after snowmelt had occurred.

We identified “snow” as a mortality cause category that includes mortalities related to snow, such as avalanche or starvation brought on by a deep snowpack. Particularly during the severe winters of 2016-17 and 2018-19 when the program documented 30% and 25% female mortality, respectively, it became apparent that many of these snow-related mortalities ended up classified as “unknown” because deep snow often limited access for months. By the time investigations occurred, there was not much left to investigate and typically any remains were scavenged, often by multiple scavengers. However, with GPS collars and survival flights, we frequently know the location and timing of death, and under conditions of heavy snow this is sufficient to identify the cause of death as snow-related.

Based on mortalities previously identified as “avalanche” or “starvation”, mortalities were flagged that occurred at elevations >9200 feet in the winter and spring months from years with snow that was > 150% of average (2010-11, 2016-17, 2018-19) for reclassification as “snow”. Mortalities at Olancha were excluded because there have been no snow-related mortalities documented there, likely due to the lower overall elevation and the presence and use of low elevation habitat. Flagged mortalities were then reviewed by a staff panel with extensive experience, as in the lion predation review. After this initial review, we expanded potential reclassifications to include any mortalities with unknown cause that did not occur in the summer or at Olancha, and the panel conducted a second round of review.

The mortality review effort resulted in 81 reclassifications, including the addition of 17 lion kills, 54 snow-related mortalities, 1 starvation mortality, and 2 avalanche mortalities. Additionally, 6 mortalities were clarified from “unknown” to “unknown not predation,” and one switched from avalanche to unknown. This effort reduced our “unknown” category from 35% to <20% (Figures 11 and 12). Original classifications are preserved in the dataset and reclassifications are identified as methodologically different to be included or excluded in future analyses as researchers see fit.

In general, collared animal mortality cause tends to look different than uncollared animal mortality cause (Figures 11 and 12). Uncollared animal mortalities are often detected from collared mountain lion clusters or in areas with mountain lion predation, so the proportion of predation-related mortalities is much higher in uncollared bighorn compared to collared bighorn. In general, collared bighorn mortalities are likely more representative of population level effects when herds have a sufficient proportion of collared bighorn.

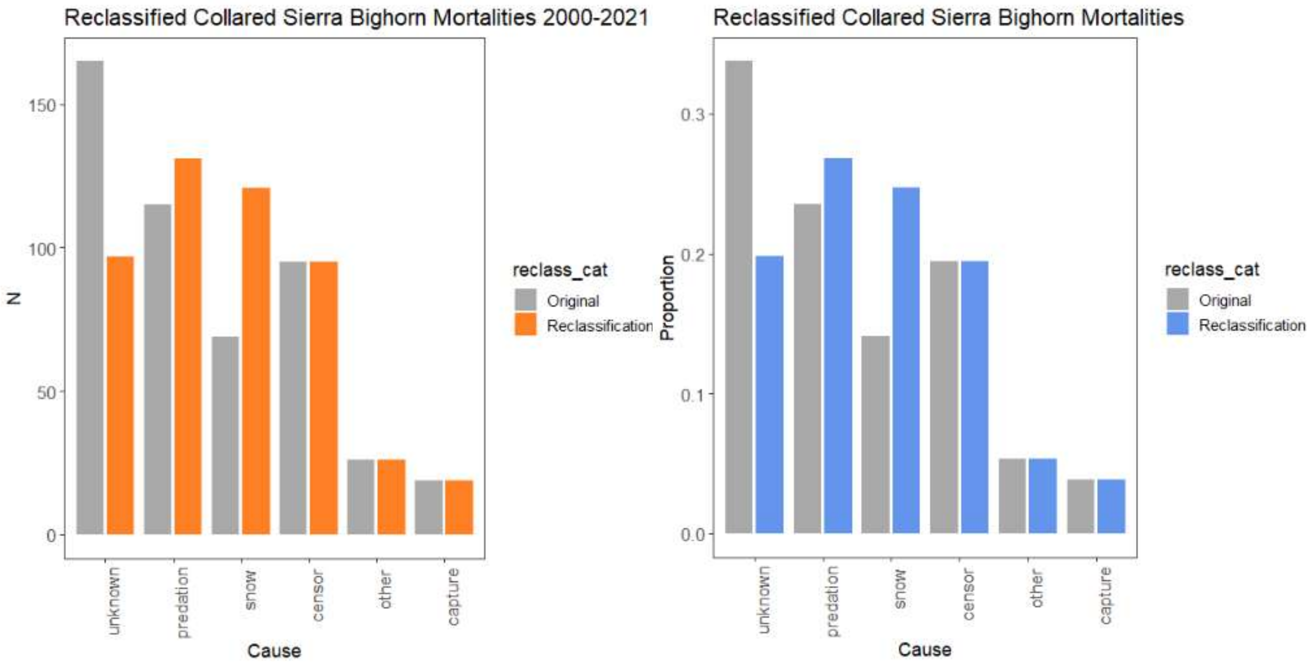

__Figure 11.__ Reclassification of collared Sierra bighorn mortalities by number and proportion.

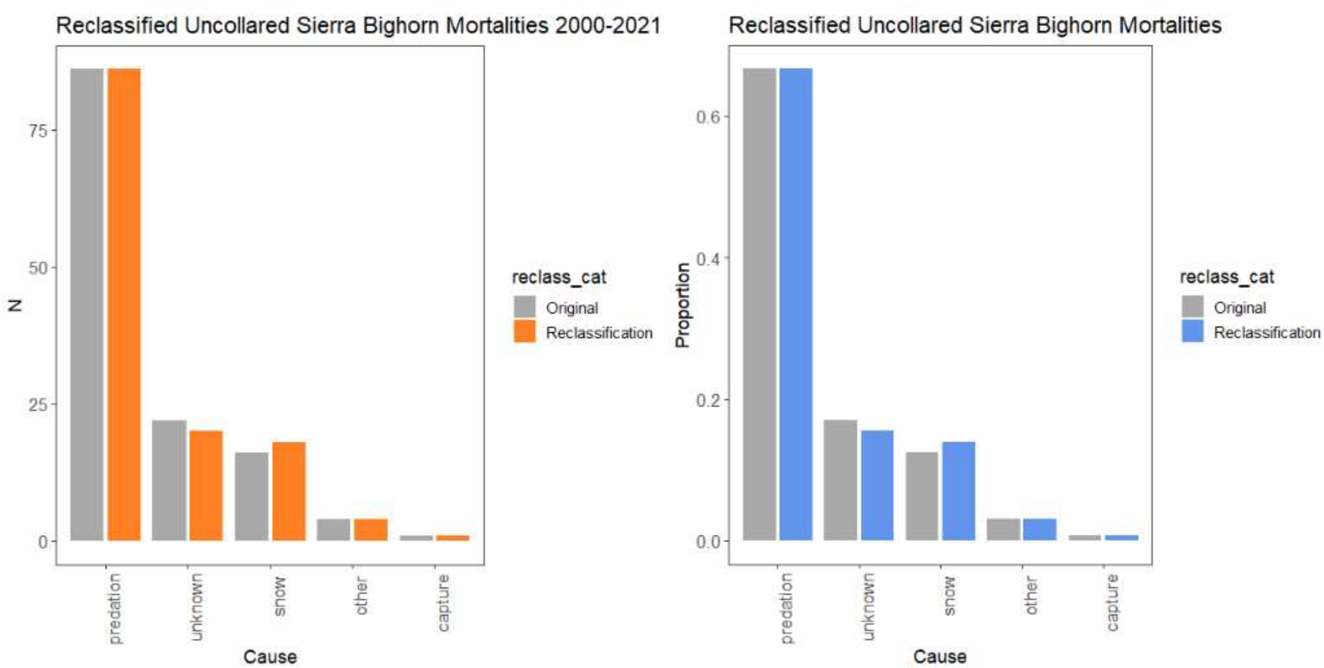

__Figure 12.__ Reclassification of uncollared Sierra bighorn mortalities by number and proportion.

Most reclassifications were of collared bighorn mortalities. After reclassification, the overall predation rate increased from 24 to 27%, and snow-related mortalities increased from 14 to 25%. The large increase in snow-related mortality is understandable because high altitude carcasses are frequently difficult to access and therefore may initially be classified as unknown cause.

After reclassification, predation is still the number one cause of Sierra bighorn mortality, but this is now closely followed by snow-related mortality. After 2022-23 winter's losses are tabulated next year, we expect snow-related losses may be greater than predation losses when data is compiled over the long-term. Predation losses tended to be spread out in time, occurring almost every year, while snow-related losses tend to occur largely within years that have deep snowpacks.

Sierra Bighorn Movements

Post-Translocation Movements at Laurel

Laurel bighorn are infamous for not staying in what we technically have identified as the "Laurel herd unit", and the group of 7 (4 females, 3 males) translocated this spring from Baxter to the high elevation of Laurel Creek were no exception. Three of the females were pregnant, and all bighorn were deployed with GPS and VHF collars. Newly translocated bighorn tended to stay in two areas for the remainder of the year: on the Laurel ridge between Laurel and Rattlesnake Creeks where previous Laurel bighorn traveled, and in the high country associated with Shotgun Creek and Little Kern River. The latter area was relatively new terrain for Laurel bighorn and included areas outside the western boundary of the Laurel herd unit. On a foray, Male S600 made his way to Lion Creek, more than 5.5 miles south of the southern border of the Laurel herd, but fortunately he returned to the herd before the end of the year (Figure 13).

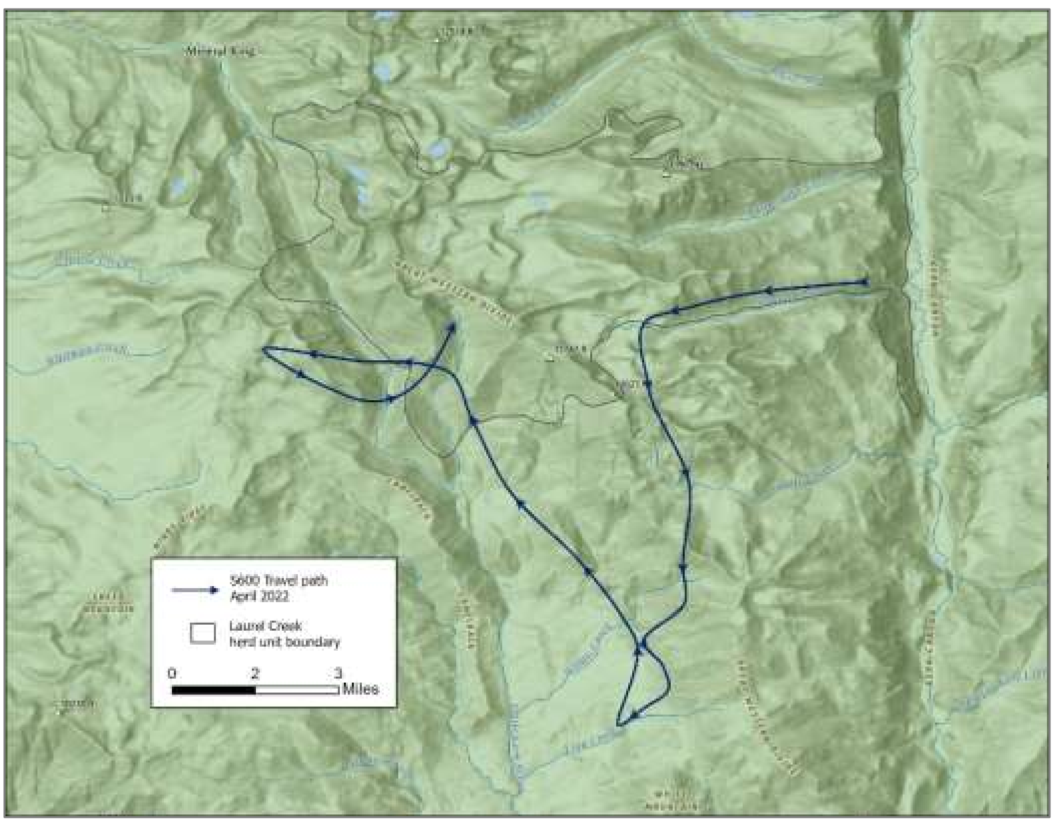

Figure 13. *Sierra bighorn male S600 was translocated into Laurel on March 23, 2022 and quickly made a foray to Lion Creek. He was back in Laurel herd unit boundaries by April 30, 2022.*

Convict Herd Continues Questing North

Three females in the Convict herd traveled outside of the herd unit boundary to the north, roughly one mile farther than had previously been documented, just above Tobacco Flat. One (S526) appears to have traveled to this area above Tobacco Flat on her own (or with uncollared bighorn) from November 12-15, 2021, and the other two females (S569 and S571) used the same area later in the winter December 6-17, 2021 (Figure 14). At this time, it is unclear if the forays toward Tobacco Flat are beneficial and will be continued, or if they are exploratory. In 2017, Convict bighorn pushed north across McGee Creek, allowing them access to south-facing slopes that melt off earlier in winter, which they continue to use.

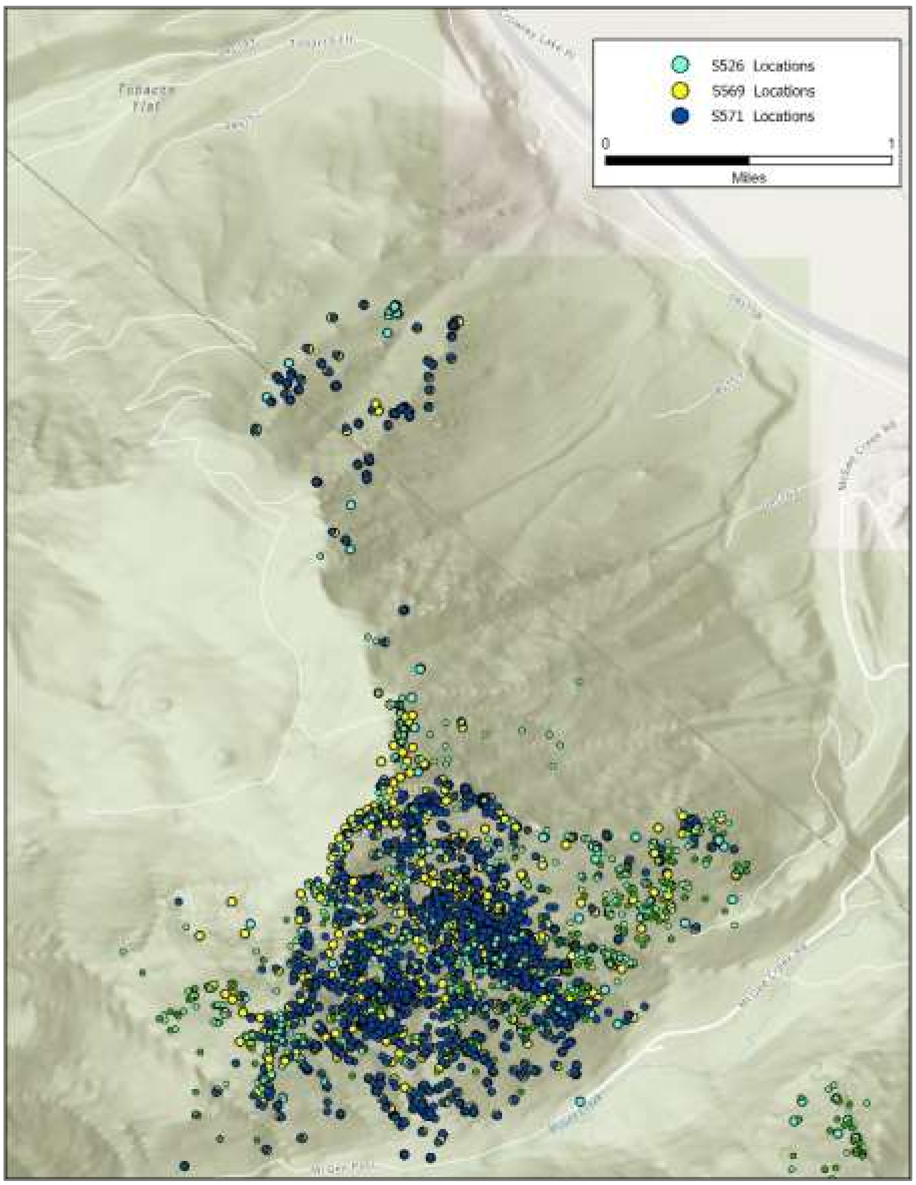

Figure 14. *Three Convict Sierra bighorn females traveled north from areas of typical use on McGee Mountain. One (S526) traveled north on November 12-15, 2021, and two others (S569, S571) traveled north from December 6-17, 2021.*

Mountain Lion Monitoring and Management

Minimum Counts

In the 2021 lion count year we documented a minimum of 55 mountain lions in the eastern Sierra population: 22 adult females, 10 adult males, and 23 subadults (Figure 15). This is the highest minimum lion count our program has ever produced, exceeding last year's high of 54 mountain lions (Greene et al. 2021). Fourteen lions were detected in the northern count zone, 16 in the central, 13 in the southern, and 7 in the Olancha count zone. In addition, 9 lions were detected in the eastern Sierra population but outside of any count zone. 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 as 1 for the total minimum count. GPS collars were used to track 37 of the 55 lions for at least part of the count year. The 18 lions that were not tracked with functional collars 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 (Appendix B).

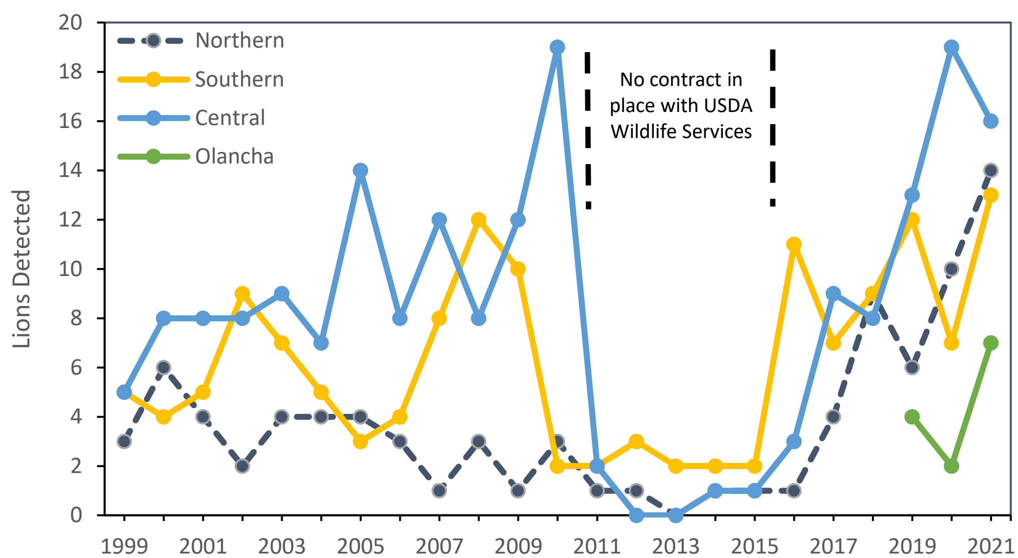

***Figure 15.** Minimum counts of mountain lions in eastern Sierra count zones, 1999-2021. Efforts to monitor lions have varied over time.*

Captures

We captured 27 lions, including 18 females (13 adults and 5 subadults) and 9 males (6 adults and 3 subadults), which is slightly lower than last year's count of 30 captured animals, but higher than the annual average of 10.1 lions per year from 1999-2017 (excluding 2012-2015 when no captures occurred).

Predation on Sierra Bighorn

We identified a minimum of 20 Sierra bighorn killed by mountain lions between May 1, 2021 – April 30, 2022 (10 adult females, 9 adult males, and 1 lamb of unknown sex; Figure 16). This is double the number of lion-killed bighorn detected in the previous year, and higher than the annual average from 1999-2019 of 8.52. Only 7 of the 20 bighorn killed by mountain lions were detected via GPS-collared mountain lion feeding clusters, and the remaining 13 were either detected via collared bighorn mortality signals or opportunistically. These 13 bighorn were killed by lions that were not collared at the time the predation occurred. Resident mountain lions utilizing areas of rugged terrain are more difficult to detect in camera and track surveys, and once they are detected they may be extremely difficult to capture and collar. In 2019 our ability to detect mountain lion predation on Sierra bighorn in the Baxter herd was almost entirely dependent on identifying lion GPS clusters indicating feeding sites, rather than mortality alerts from collared bighorn or opportunistic investigations. The 13 bighorn mortalities due to predation by uncollared mountain lions in 2021 occurred in the Wheeler, Baxter, Convict, Gibbs, Big Arroyo, Langley, and Olancha herds. This implies that multiple uncollared lions are continuing to have impacts on vulnerable Sierra bighorn populations, and that we are likely only detecting a fraction of the actual predation events occurring in these herds. However, in herds where we have sufficient collared bighorn, we are detecting mortalities on a proportional basis, meaning the collared animals are representative of the entire deme or herd. And on larger scales, like the range-wide level, data indicates collared animals are representative of uncollared animals as well.

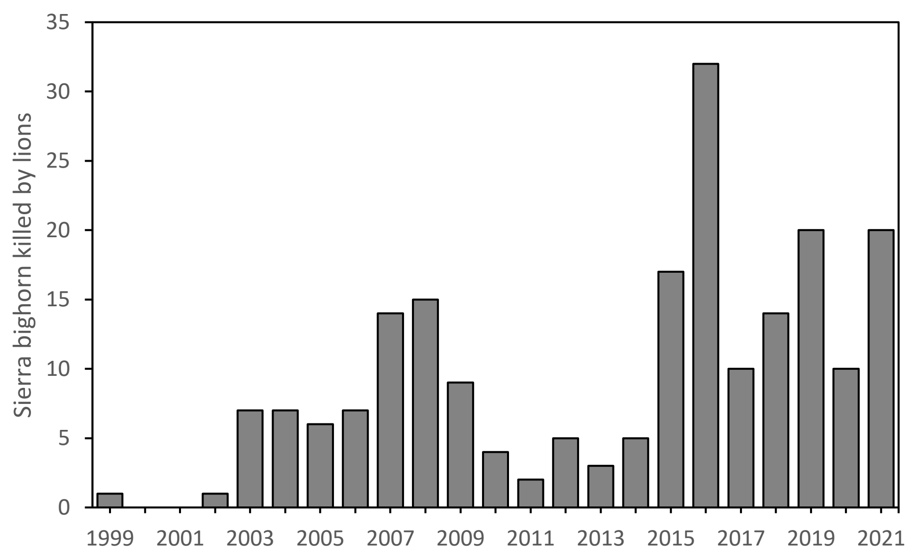

Figure 16. *Sierra bighorn mortalities caused by mountain lions from 1999-2021. Efforts to detect predation events (both in staff hours and collars on lions and bighorn) have varied over time, as has the population size of Sierra bighorn.*

Nine predation events were documented in the Baxter and Sawmill herds, 4 of which were attributed to uncollared lions. We detected one predation event in each of the Gibbs, Big Arroyo, Langley, Olancha, and Convict herds, and it is likely that more than one mountain lion was responsible for these mortalities given the distances between the herds. We detected 5 predation events in the Wheeler herd, an increase from the 2 mortalities detected in 2020; 4 were attributed to uncollared lions. L148m, a Wheeler resident male with a failed GPS collar from 2018, was recaptured on 3/27/22. L148m preyed on several bighorn in the Wheeler herd after being recaptured and fitted with a functional GPS collar, and it is possible that he was responsible for some of the bighorn kills that were attributed to uncollared lions.

L200f, an adult female, was captured on 5/8/21 on the Sawmill winter range after preying on 2 adult ewes in April 2021. L200f and her two dependent subadults (L209f and L210f) preyed on one Baxter adult ram in January 2022.

Reproduction

We documented 22 adult females, and 7 of them were confirmed to have offspring. Five of these adult females were documented with at least 2 offspring, and the remaining 2 adults were documented with at least 1 offspring.

Predation Management – Lion Translocations

The 2021 year represented a shift in our translocation strategy based on outcomes from prior translocations, which had provided four valuable insights: 1) adult male lions tend to exhibit homing behavior, returning quickly to their former range, 2) release sites must hold sufficient wild prey populations, 3) family group cohesion can be maintained through translocation, and 4) dispersal-aged subadult mountain lions can survive translocation and establish a home range as an adult. Although derived from a small sample size, we used the above information to plan and implement successful translocations, where success would be defined by 1) a reduction in predation risk to Sierra bighorn (translocated lions do not return to their former ranges), and 2) survival of translocated lions.

On 1/27/22 we captured and translocated L200f and her two 22-month-old dependent subadults, L209f and L210f, to the San Bernardino Mountains (Figure 17). As of the end of this reporting period all three of these lions are alive and have established new home ranges where they are capturing wild prey. None of these lions have been involved in documented cases of livestock predation or human-wildlife conflict, and none of them have exhibited homing behavior. This translocation met our definition for success and demonstrates the viability of mountain lion translocations for partially mitigating predation risk for Sierra bighorn.

We wish to clarify decisions discussed in the previous report (2020-21) regarding the translocation of adult male lions. The adult lions L147m and L176m were translocated as an alternative to lethal removal because of predation on Sierra bighorn. One goal of lion translocations has been to evaluate their feasibility on a range of lion sex and age classes. L147m demonstrated strong homing behavior after being translocated north along the Sierra Nevada into a location with abundant mule deer. Subsequently, he was moved a greater distance to the southeast away from the Sierra Nevada. L147m and L176m were moved to the east Mojave south of I-15 where ungulate prey such as mule deer were in proximity (L176m preyed on a desert bighorn shortly after being translocated). Given their homing instinct, the hope was that the Mojave Desert would function as a barrier to prevent their return to the Sierra. The region of the eastern Mojave where they were moved has adequate prey to the southeast. Unfortunately, their homing instinct drove them to return to the northwest through a desert landscape with patchily distributed food; on their return they did cross I-15 without incident. Adult male lions decline in condition when returning home regardless of prey availability (they are more interested in finding mates in their former home range than in food) and that contributed to the mortality of these 2 translocated males. Homing behavior of adult males is likely to be a challenge to successful translocation of adult males.

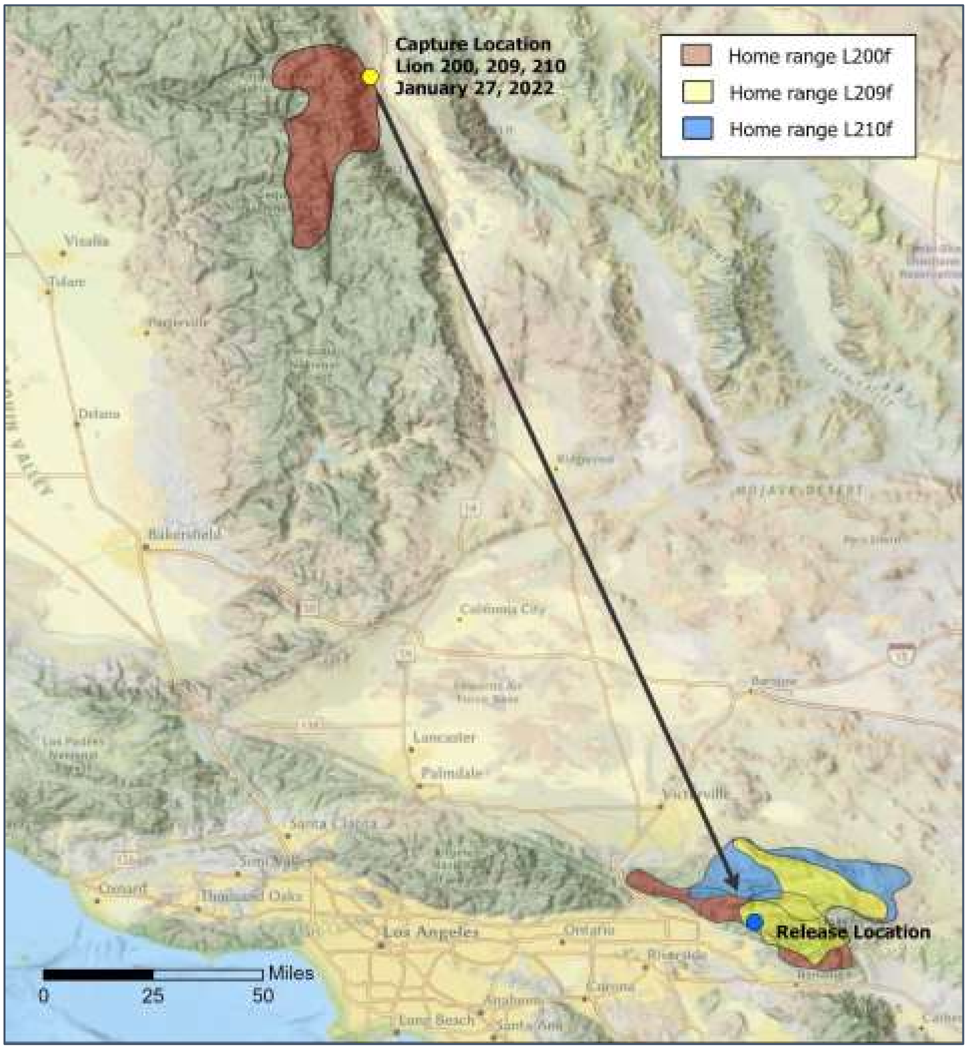

Figure 17. *In January 2022, a female lion and her 2 subadults were translocated from the Sawmill herd to the San Bernardino Mountains to protect Sierra bighorn. Pre- and post-translocation home ranges are shown.*

Lion Survival and Mortality

The estimated annual survival rate for the 37 collared lions was 0.94 for females (±0.06 SE), and we documented zero adult male mortalities, which is unusual given the previous year's adult male survival rate of 0.56 (±0.29 SE) and the 20-year average of 0.68 (±0.30 SE). Subadult survival was typically low at 0.40 (±0.47 SE). Among the 55 lions detected in the eastern Sierra this year we documented 7 mortalities, due to public safety removal (n=1), predation by other mountain lions (n=1), poaching (n=1), vehicle strike (n=2), physical injury (n=1), and unknown cause (n=1).

Disease Management

We recently published a Sierra bighorn disease risk analysis method that we use to assess risk posed by domestic sheep grazing in proximity to the recovery area (Anderson et al. 2022). The method combines habitat modeling and a cost distance analysis to predict where bighorn are most likely to travel on the landscape. We contrasted our model with earlier approaches that used the distance between bighorn locations and grazing allotments to assess risk. Our model better quantifies the risk of contact between bighorn and domestic sheep because it characterizes how bighorn prefer to travel in rugged terrain. Allotments located in bighorn habitat pose greater risk even if they are farther from occupied habitat.

We identified a risk threshold using the cost distance model to identify where grazing posed the greatest threat to Sierra bighorn. Sixteen grazing allotments lie either partially or completely within the polygon identified as high risk to Sierra bighorn. Risk is mitigated to varying degrees in these allotments using a variety of mitigation measures such as natural and man-made barriers, timing of grazing, and animal husbandry practices. Our risk model will be updated routinely to evaluate risk as bighorn habitat selection and movement patterns change.

Future Management

Adult female survival rates of 82%, such as that observed during this reporting period, simply are inadequate for promoting the population growth needed for Sierra bighorn to reach recovery. Habitat of high quality is not a limitation to population growth of Sierra bighorn; the recovery area is almost entirely designated Wilderness, and the remainder is public land. Most endangered species suffer from a lack of habitat, and that is not the case for Sierra bighorn. The historic population size of Sierra bighorn was undoubtedly substantially larger than the current population, and that historic range is still intact. This unique subspecies declined because of diseases from domestic sheep, but fortunately those diseases are not found in Sierra bighorn today although it is still a risk. In this report, we discuss that mountain lion predation was the largest known cause of mortality of Sierra bighorn during the past 20 years. The inability to manage mountain lion predation was a detriment to the Recovery Program in recent years. Translocation of mountain lions that prey on Sierra bighorn is now an effective method for mitigating lion predation. The Recovery Program has demonstrated that moving female and subadult lions can be implemented with positive outcomes for both lions and bighorn. Female and subadult lions do not exhibit the homing behavior characteristic of adult males and can successfully establish home ranges following release in a new environment.

Given the current high abundance of mountain lions in the eastern Sierra, managing lion predation is critical for protecting herds of Sierra bighorn and ensuring the availability of translocation stock. As long as lion numbers remain high or predation persists, we will continue to translocate lions that prey on Sierra bighorn. Identifying the specific lions that prey on Sierra bighorn requires collaring all lions that use bighorn habitat and intensively monitoring their feeding behavior. Once a lion is identified that kills bighorn, it often requires multiple attempts to capture it for translocation, and this can only occur when the terrain is suitable, and the lion can be safely carried to a transport vehicle. It requires enormous effort and commitment by program staff to monitor bighorn and lions over such an extensive area. The historic range for Sierra bighorn exceeded 10,000 km^2. The area over which we are monitoring lions now exceeds 20,000 km^2 and this only includes lions that are captured and collared east of the Sierra crest but then range far to the west (Figure 2). Lions, males in particular, have very large home ranges, but male and female home ranges can overlap considerably. The lion population in the Sierra Nevada is one of the healthiest in the state with respect to population viability and genetic diversity. We manage lions using a surgical approach in which we translocate lions that are documented preying on Sierra bighorn.

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Appendix A. 2021 Herd Unit Summaries

Olancha

Olancha was surveyed on January 13, 2022, with a total count of 53 bighorn: 25 adult females, 1 yearling female, 12 lambs, 11 adult males, and 2 yearling males. Prior to the survey, 5 collared female mortalities were detected (S271, S475, S277, S557, S275). One collared female (out of 5) was not seen but assumed to be alive and counted. All five collared males were seen. This is the first year our count declined in Olancha since it was re-introduced in 2013. The cause of death for S275 was identified as lion predation north of Olancha Canyon, but the others were unknown cause. Three died in the notoriously convoluted and cliffy Olancha Canyon and were not able to be investigated due to treacherous terrain. The fifth died in Walker Canyon and was scavenged and cause of death was not able to be determined. No particularly noteworthy or novel movements or habitat use was detected from GPS-collared bighorn, although there appeared to be more use at mid elevations in Cartago Canyon than in 2020. However, this area has seen use in previous years.

Laurel

Laurel was surveyed on June 2, 2021, as a group of 5: 2 adult females, 1 yearling female, 1 lamb, and 1 adult male. This included S382, the only collared female in Laurel, whose GPS collar is no longer working. The group was located on the east side of the Kern River, and as this was early in the year, it is possible that another lamb was born later. In September, S382 died of unknown cause. Further monitoring of the remnant Laurel herd, particularly any that use habitat east of the Kern River, will be difficult to monitor with no collars in a vast area. On March 23, 2022, seven bighorn were translocated from Baxter to Laurel at mid elevation (~9000 ft) on the west side of the Kern River. This included 4 adult females (3 pregnant) and 3 males (1 yearling). Those translocated bighorn tended to stay in two areas for the rest of the year; on the Laurel ridge between Laurel and Rattlesnake Creeks, and in the high country associated with Shotgun Creek and Little Kern River. In April, S600 did make a foray 7.5 linear miles to the south on the east side of the Little Kern River. Laurel bighorn are infamous for not staying in what we technically think of as the “Laurel herd unit;” apparently, they have not read the translocation plan.

Big Arroyo

Observations from June and September were combined for a count of 21 bighorn this summer: 7 adult females, 1 yearling female, 5 lambs, 5 adult males, and 3 yearling males. All collared bighorn (4 females, 2 males) were seen. However, it seems probable this is not a census because there were four fewer females than projected from 2020 counts. We detected two mortalities: collared female S288 died from lion predation near the High Sierra trail junction on the west side of the Kern River in August (not included in count) and male S491 died of snow-related cause in Chagoopa Bowl in January. Female S582 used an area in the 9 Lakes Basin near Mt. Stewart at the north end of the Big Arroyo herd unit in October that had previously only been used by males. In general, bighorn tended to use familiar habitat in the Kaweahs and along the Big Arroyo and Kern River.

Langley

Langley was successfully surveyed in the summer during August 23-27, accounting for 41 bighorn: 14 adult females, 3 yearling females, 10 lambs, 11 adult males, and 3 yearling males. This included one collared female not seen but assumed alive. We documented one female mortality from mountain lion predation after the survey in September. There are no functional GPS collars in Langley; the last capture was in 2017. Ground observations and flights did not detect any novel habitat use. For the second winter, there was no use detected in low elevation winter habitat in Carrol Creek, N and S Lubkin, or Diaz Creek.

Williamson

We accounted for 40 bighorn in Williamson during a summer survey: 20 adult females, 2 yearling females, 10 lambs, 4 adult males, 3 yearling males, and 1 unclassified yearling. The count included all known collared bighorn in Williamson (3 females, 2 males). This was the highest count ever recorded for Williamson and included bighorn in both the Barnard and Williamson demes. We have not counted bighorn in the Williamson deme for several years but were able to capture and collar a female in that deme last fall. In addition, we got lucky by finding a group of 19 in which there were no collars, also in the Williamson deme. In November, 6 adult bighorn were captured (5 females, 1 male). Two mortalities were detected over the winter, one male from avalanche in a slide path off the NE ridge of Tunnabora Peak, and one female from unknown cause in Williamson Creek. The new collars appear to include both the Williamson and Barnard demes. Williamson deme bighorn tended to stay east of the crest in Shepherds Creek up to Junction Peak. Barnard deme bighorn tended to use several canyons south of Shepherds Creek and used both sides of the crest around Mt. Barnard. A GPS-collared male also spent time east of Mt. Bradley during March.

Baxter

This year we accounted for 109 bighorn: 43 adult females, 14 yearling females, 25 lambs, 22 adult males, and 5 yearling males. Our highest count of females and lambs occurred in the summer, and our highest count of males occurred during the winter.

In the fall we caught 8 bighorn including 4 females (one recapture) and 4 males. The recaptured female (S544) had previously been identified as having a potentially tight collar, but her neck showed no signs of distress, and she was released with a camera collar. Nine bighorn were caught the following spring: 7 were translocated to Laurel, and two additional females were released back into Baxter. Translocated bighorn included 4 adult females (3 pregnant) and 3 males (1 yearling).

We detected eight mortalities at Baxter. This included two collared male mortalities in the late spring of 2021 from unknown cause and lion predation. Additionally, two collared bighorn died in the fall, one female from lion predation and one male from avalanche. In the spring, there were 4 additional mortalities from lion predation: one collared female, 2 uncollared males, and one mortality of unknown sex.

Some interesting movements were detected from GPS collars in Baxter: male S584 traveled along the Mt. Rixford ridge, frequently south and east of Kearsarge Peak. In November, male S598 traveled from Baxter to Williamson and stayed there through the spring. Also, there was mixed use from Sawmill and Baxter females north of the Sawmill Pass trail east of the crest. This included Sawmill S514 and S515 (Acrodectes deme) in December and March, respectively, as well as Baxter S517 in May. These bighorn also overlap spatially when using the west side of the drainage east of Acrodectes.

Sawmill

During the summer, we accounted for 65 bighorn in Sawmill: 31 adult females, 3 yearling females, 1 female of unknown age, 15 lambs, 11 adult males, 3 yearling males, and 1 yearling of unknown sex. This includes S543 and her lamb, who are technically classified as a Sawmill bighorn but were observed with Taboose bighorn on Birch Mountain this summer. Mixing between the Goodale deme of Sawmill and the Taboose herd makes it challenging to count these herds separately.

We detected three mortalities from lion predation in winter, 2 uncollared males and 1 collared female. We detected no novel or noteworthy habitat use from GPS collars. However, we now have 2 GPS-collared males using the Window and Pyramid Peak drainage. We know bighorn use this area from aerial, ground, and past GPS collar data, but it has been a while since we have had GPS collars there.

Bubbs

Based on several summer observations, we accounted for 30 bighorn: 12 adult females, 3 yearling females, 2 unknown aged females, 7 lambs, 4 adult males, and 2 yearling males. This count incorporated observations from Recovery Program staff along with opportunistic observations from former staff and desert bighorn staff. One collared male (S596) identified as a "Baxter" animal spent a lot of time within the Bubbs herd unit: summer in the 60 Lakes Basin and spring around 9,000 ft in Gardiner Creek. Another "Baxter" male (S586) traveled through Bubbs, including 60 Lakes Basin and Gardiner Basin in the summer. Attempts to capture in Bubbs were unsuccessful, and due to the lack of collars no further observations, movements, or mortalities were detected.

Taboose

In August a group was located on the north side of Birch Mountain in which we accounted for 10 Taboose bighorn: 4 adult females, 1 yearling female, 2 females of unknown age, 3 lambs, and 1 yearling male. This group included Sawmill female S543 (Goodale deme) and her lamb, but we counted them in the Sawmill herd. Also, it seems likely there are more males in Taboose than we observed, so we used the 2018 count of 6 males (5 adults and 1 yearling) in the population count. During the fall, several Taboose bighorn were caught on cameras at Southfork Pass and Taboose Lake that were intended to photograph Sierra Nevada red fox (Figure 1). We were not able to add any bighorn to our minimum count based on these photos. No captures occurred or mortalities were detected within Taboose. GPS-collared bighorn showed most use east of the crest from Red Mountain Creek to the South fork of Big Pine Creek drainage. There was some limited use west of the crest in the Palisade Lakes area.

Wheeler

The highest minimum count at Wheeler was calculated by combining survey efforts from August and September, resulting in a count of 79 bighorn: 35 adult females, 4 yearling females, 18 lambs, 17 adult males, and 5 yearling males. Only a single female collar was not seen out of 16. This is the first good count of females at Wheeler in 4 years based on the proportion of collared females seen (15/16). In contrast, the male count was not good, with only 2 of 7 collars observed. The Wheeler herd count is still lower than it was prior to the removal of 6 females in 2019 for translocation to Warren.

We detected 7 mortalities at Wheeler. Lions preyed on 2 males in the fall, and 3 males and 1 female in the spring. In addition, 1 female died of avalanche in the spring at the bottom of Levergate Canyon

(7100 ft). Male (S405) was preyed on near Merriam Peak in May at 11,424 ft. In winters with more snow, this area would have been difficult for a lion to access in May.

Convict

Using a compilation of observations throughout the year, we accounted for 19 bighorn: 6 adult females, 3 yearling females, 4 lambs, 5 adult males, and 1 yearling male, which included all collared bighorn (6 females, 2 males). It also includes female S345 who died in the spring from lion predation on a cliff band below the summit plateau of McGee Mountain. No other mortalities were detected. In November and December, 3 females (S526, S569, S571) ventured farther north on the east side of McGee Mountain toward Tobacco Flat.

Gibbs

During July 5-7, we accounted for 54 bighorn, including 13 adult females, 9 yearling females, 9 lambs, 22 adult males, and 1 yearling male. This included observations of all collared bighorn (7/7 females and 5/5 males). We detected 2 collared female mortalities in the fall: one from lion predation and one from avalanche. The avalanche mortality was relatively early, on October 25th above Kidney Lake. No unusual habitat use or movements were detected from GPS collars.

Warren

On August 9, all known Warren females were seen in a group of 19: 7 adult females, 5 yearling females, and 7 lambs. Additionally, one 2-year-old male that is thought to be the offspring of S522 was seen in May. No other males were seen, but based on previous years' observations we believe there are 2 more adult males. In November, we documented one collared female mortality from avalanche, and in March one uncollared yearling female mortality from lion predation above Lundy resort. The latter mortality was detected from a lion (L187m) GPS cluster. Warren GPS collars showed use west and lower along Kavanaugh Ridge than had been documented; in general Shepherd's Crest and areas north of Lundy Canyon received consistent regular use. No bighorn use around Camiaca Peak was detected.

Cathedral

Based on a single brief observation in June near the summit of Fletcher Peak, we detected 8 bighorn: 4 adult females, 2 lambs, and 2 unclassified bighorn. This higher-than-expected count indicates that we missed some bighorn in previous years. The only collared female (S365) was observed, and the unclassified bighorn are thought to be yearling females, but they were not seen long enough to be definitively classified. In the spring, 3 bighorn were captured, including a recapture of female S365, an adult female, and a yearling male. The yearling male (S608) was not given a GPS collar because his neck is expected to expand significantly as he grows. S608 was noticeably fat, with a body condition score of 5. GPS collars showed use on Parson's Plateau, as well as the uppermost reaches of the Lyell fork of the Merced River near Mt. Lyell.

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 (Figure 2). 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 ‘2021’ to represent the animal year May 1, 2021 – April 30, 2022, beginning with lambing season and including the winter of 21-22. 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. 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 (Figure 3) 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. 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, 2021 - April 30, 2022.

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.