2019-20 Annual Report
Sierra Nevada Bighorn Sheep Recovery Program

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Executive Summary

In the last three years, there has been an unexpected decline in the Sierra bighorn population, which is currently estimated to be just under 500 with 249 females, 81 lambs, and 166 males. During the California drought of 2012-2016, the range-wide population increased from 202 to 314 females, and Sierra bighorn experienced low levels of lion predation and mild winters. Then came the nearly record-breaking winter of 2016-17 during which ~100 females died, or 30% of all known females (not including lambs). Another heavy winter quickly followed in 2018-19 during which ~75 females died, or 25% of all known females. Most of these losses were associated with deep snow conditions, but there was also extreme lion predation at Langley (Gammons et al. 2021), which had previously been one of the largest source herds. These major losses have delayed downlisting for at least another five years, and perhaps longer if we have more heavy snow winters or extreme predation. These declines have not only limited our capacity to augment new herds, which are just getting established, but have also reduced some source herds and other herds to concerningly low levels.

Figure 1. *Capture of six Sierra bighorn from the Wheeler herd for translocation to the Warren herd in March 2020.*

Fortunately, 2019 was a relatively mild winter and Sierra bighorn experienced average levels of survival and fecundity. This spring we successfully translocated six females from Wheeler into Warren (Figure 1), because the Warren population had declined to a single female and three males. Olancha, which was reintroduced in 2013, is now the fourth largest of all herds and has been the most productive of the recently reintroduced herds. This year we greatly increased our mountain lion monitoring efforts, including adding a count zone associated with Olancha. We had the highest mountain lion count for the region (N=50). Additionally, we successfully translocated a lion that was known to prey upon Sierra bighorn out of Warren, one of the more sensitive herds. The Sierra Nevada Bighorn Sheep Recovery Program is focused on reducing any further losses through mountain lion management and bolstering any small herds through translocation when source herds allow.

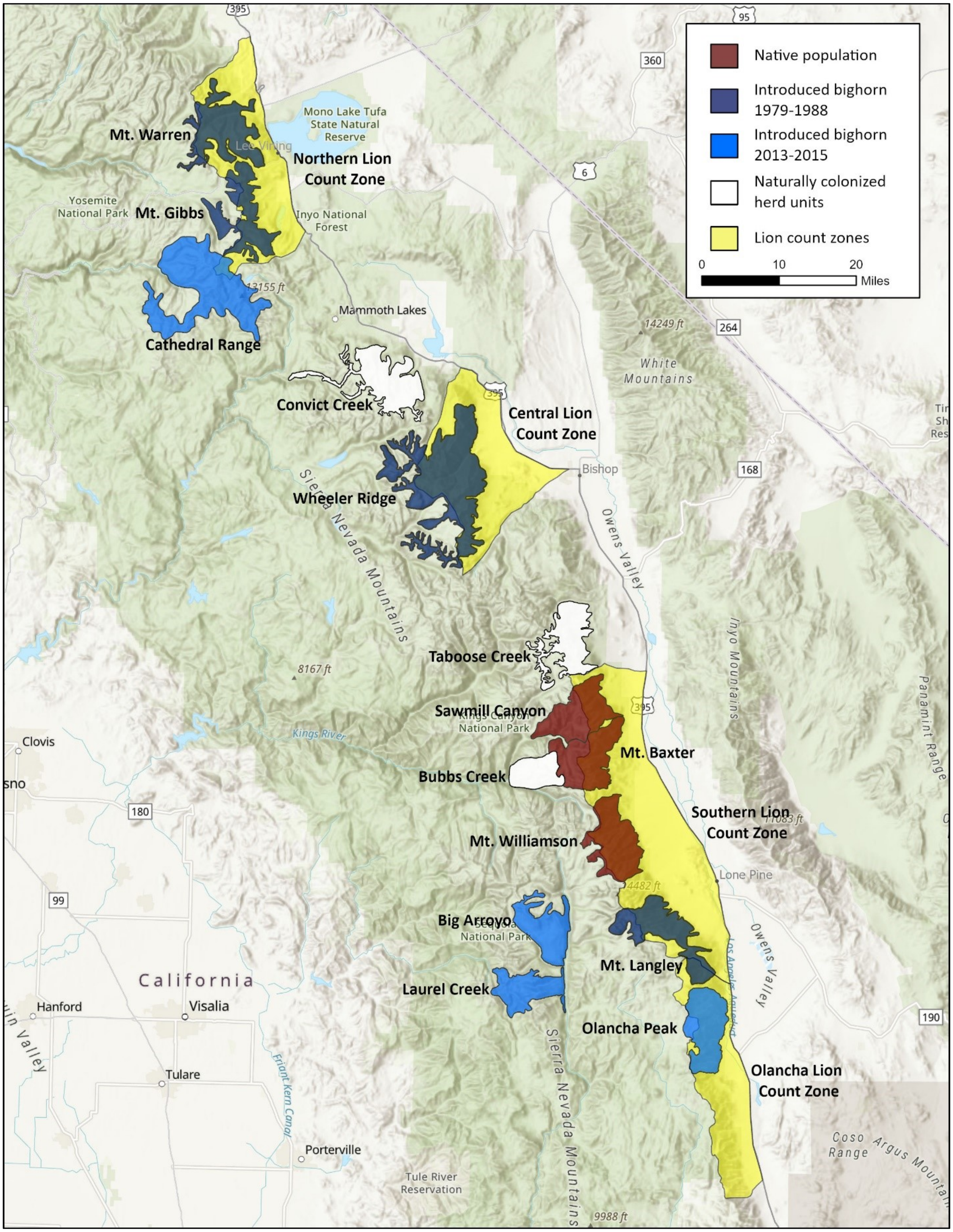

__Figure 2__. Overview of Sierra bighorn herd units and mountain lion count zones.

Introduction and 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 starting in 1878, as well as a series of translocations that began in 1979 (Bleich et al. 1990) that established the Warren, Wheeler, and Langley herds, as well as unintentionally creating 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 (testing back to 2001), and we have observed no 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 2010a), and the top two causes of mortality are predation by mountain lion (*Puma concolor*) and winter death in the form of starvation or avalanche.

This report summarizes the activities of the Sierra Nevada Bighorn Sheep program (hereafter Recovery Program) from May 1, 2019 to April 30, 2020. 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 ‘2019’ to represent the animal year May 1, 2019 – April 30, 2020, beginning with lambing season and including the winter of 19-20. For lions, the 2019 year is from July 1, 2019 to June 30, 2020. “Source” herds (Wheeler, Sawmill, Baxter, and Langley) have contributed to recent reintroductions (starting in 2013) that have developed “new” herds (Cathedral, Big Arroyo, Laurel, and Olancha). Data and summaries in this report are preliminary and are subject to change contingent upon further interpretation, analyses, and review.

Population Monitoring and Recovery Goals

Over the last twenty years, the range-wide population of Sierra bighorn has increased five-fold, from a low of 65 females in 2000, to a high of 317 adult and yearling females in 2016 (Figure 3). These population estimates are largely based on minimum counts in combination with some mark-resight estimates (Appendix B, Methods). This year, we accounted for 249 females, 81 lambs, and estimated 166 males for a total of 496 Sierra bighorn (Table 1). Males are estimated using a 2:3 ram:ewe ratio because survey and collaring efforts are focused on females and are known to miss males (Methods). Females receive more focus because they are the main drivers of Sierra bighorn population dynamics.

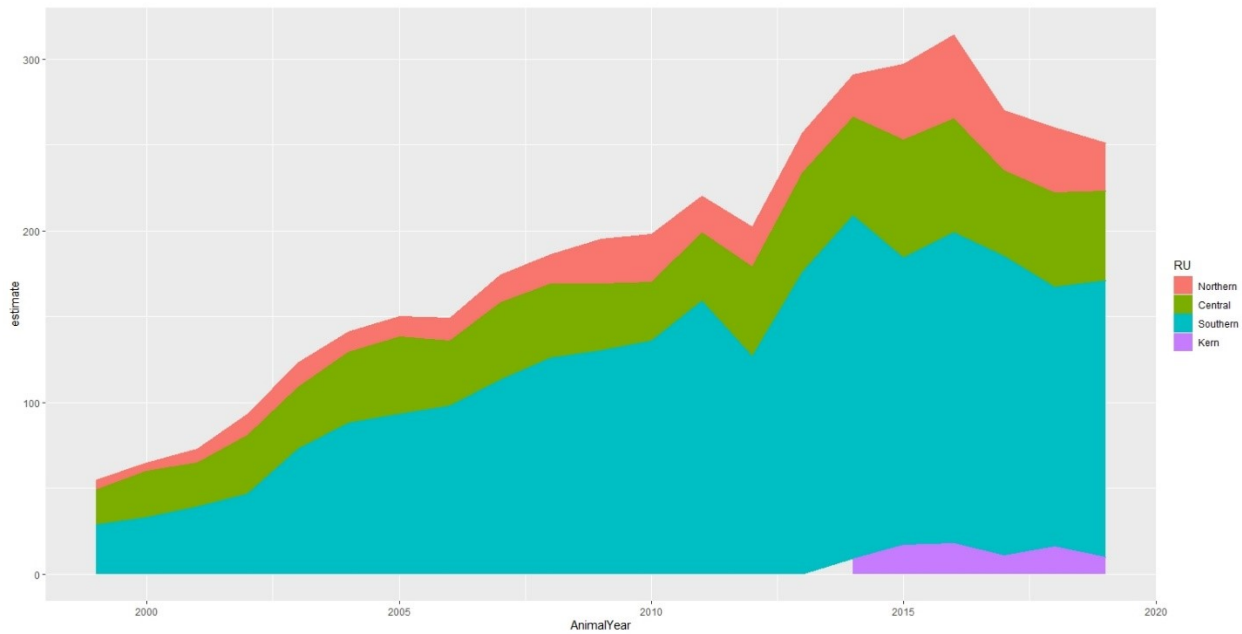

Figure 3. *Range-wide female Sierra bighorn population abundance since 1999. Range-wide numbers are calculated using annual herd values based on reconstructed minimum counts and Mark-Resight estimates, as well as the most recent survey results for herds not surveyed annually. Herd counts are combined across the animal year (May 1 – April 30). Because some herds are counted 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.*

Minimum counts are derived from ground surveys and occasionally compiled from multiple visits within a herd and season; they are almost always underestimates. Here we report the highest count for each herd which typically occurs in the summer for most herds, but sometimes occurs in the following winter or spring (Table 1). Because surveys span summer through winter into spring, they don't necessarily show the impact of a given winter. However, they do show the population has declined during the last three years, which is likely due to large losses in the 2016-17 and 2018-19 winters in which there was a 30% loss of females (~100) and a 25% loss of females (~75), respectively (Greene et al. 2017, 2019).

The Recovery Plan (U.S. Fish and Wildlife Service 2007) specifies that minimum counts are used to assess progress toward downlisting goals. Downlisting requires at least 305 females with specific targets for each of four Recovery Units (Figure 4), and each recovery unit includes 2-7 herds. Currently both the Southern and Central Recovery Units meet downlisting minimums, while the Northern and Kern Recovery Unit targets have not yet been met (Figure 4).

Table 1. Reconstructed minimum counts (MC) of Sierra bighorn during May 1, 2019 – April 30, 2020. Lambs not identified by sex. Female and lamb estimates are expected to be more accurate than male estimates because there are more collared females and survey routes are designed around them. However, all minimum counts are underestimates. Year-end population is reduced by all known mortality that occurred after the survey and before the end of the year.

Herd	Female Adult	Female Yrlng	Female Total	Lambs	Male Adult	Male Yrlng	Male Total	MC Population	Year End Females	Mortality post survey	Notes
Olancha	22	4	**26**	13	8	2	10	**49**	24	S280, S278	
Laurel	1	0	**2**	0	1	0	1	**3**	2	M352	No observations in 2019. In 2020 2 adult females seen, so presumed present in 2019
Big Arroyo	8	1	**9**	4	5	1	6	**19**	9	none	Possible lamb mortality because S287 was seen without a lamb later in the summer
Langley	18	1	**19**	5	14	3	17	**41**	17	S264, M178	
Williamson[w]	14	0	**14**	4	5	0	5	**23**	14	none	
Baxter	46	10	**56**	15	28	5	33	**104**	53	S439, M174, S531	Summer count females and lambs; winter count males
Sawmill	29	9	**38**	9	20	4	24	**71**	36	S326, M165,	Censored females S165, S255 and male S393 prior to survey
Bubbs (2018)	4	1	**5**	4	2	1	3	**12**	5		No consistent annual surveys
Taboose	3	1	**4**	2	5	1	6	**12**	4		Females & lambs (identified as yrlngs) from May 2020; males from 2018
Wheeler[w]	36	8	**44**	13	23	3	26	**83**	37	S417, 6 translocated	Known poor count, only 6/12 female collars seen
Convict[w]	4	2	**6**	3	2	0	2	**11**	6	none	
Cathedral	3	0	**3**	0	0	0	0	**4**	3	none	Includes 1 unclass-ified yrlng & female S365 but not Gibbs male S488
Gibbs	19	3	**22**	9	16	3	19	**50**	20	S191, S145	
Warren	1	0	**1**	0	2	1	3	**4**	7		6 females translocated in
Totals	**208**	**40**	**249**	**81**	**131**	**24**	**155**	**486**			

[w] Winter counts, other surveys conducted in summer

During 2019, 13 of the 14 herds were counted from the ground (Appendix A). The only exception was Bubbs, where we considered our 2018 count to be a better estimate for the whole herd than our single summer observation. While most summer surveys were of high quality, the winter surveys at Baxter and Wheeler were quite poor because < 65% of collared females were seen. Notable reductions in herd size included Warren which decreased from 5 to 1 female, Cathedral which declined from 6 to 3 females, and Big Arroyo which dropped from 14 to 9 females. In the spring Warren received 6 females from Wheeler (Figure 1). The most notable increase occurred at Olancha which grew from 23 to 26 females making it the most successful of the “new” herds to date. The 2019 distribution includes all 12 essential herds identified in the Recovery Plan (Criteria B2, SNBS Recovery Plan 2007), and two non-essential herds (Bubbs and Cathedral, see Figure 2).

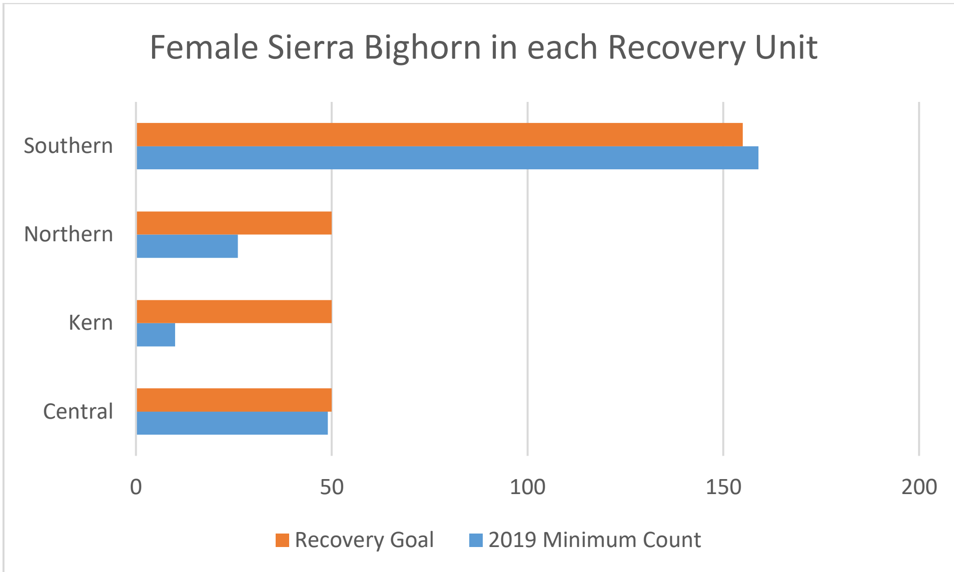

Figure 4. *Abundance and distribution of female Sierra bighorn across recovery units compared to downlisting goals.*

Collaring and Translocation Efforts

Capturing Sierra bighorn provides the opportunity to determine body condition, pregnancy status, test for disease, measure genetic diversity, and deploy collars. Capturing animals is critical for translocations, and collaring animals enables us to monitor habitat use, disease risk, vital rates, and estimate herd size. Power analyses indicate we need to maintain collars on 35% of the female population in order to detect a 10% change in survival over 10 years (German 2010). 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). This spring we captured a total of 14 females from the Baxter, Sawmill, and Wheeler herds.

In general capture and collaring activities were reduced in accordance with CDFW guidelines to minimize the potential to spread Coronavirus disease. However, on March 20, with a reduced capture crew, we were able to capture and translocate 6 females from Wheeler to Warren (Figures 1 and 2). This included 4 pregnant adult females and 2 yearling females, one of which was pregnant. Translocated animals were captured from Pine Creek in Wheeler and released into Lundy Canyon at Warren. Augmentation of the Warren herd had been desired for many years but was delayed due to disease risk posed by the grazing of domestic sheep on Mono County properties. Following the removal of domestic sheep from Mono County's Conway and Mattly allotments in 2017, the opportunity existed to augment the Warren herd. However, the severe winters of 2016-17 and 2018-19 delayed the decision to proceed with an augmentation. Mild conditions and minimal snow in spring 2020 provided suitable conditions for translocation.

On March 26, we captured an additional 8 adult females from Baxter and Sawmill. This included the re-capture of Baxter female S223 who had sustained neck injuries from previous collars and was therefore released without any collars. The seven other captured animals had not been captured before. A camera collar was placed on Sawmill female S541, programmed to record for fifty minutes every day during the lambing season (April 16 – May 31st) and drop off May 31st to detect birth, possible lamb predation events, and diet composition (Figure 5). All other animals were released with both a VHF and GPS collar.

Figure 5. Spring 2020 camera collar images from Sawmill female S541 showing foraging on Eriogonum fasiculatum *and interaction with another ewe.*

At year-end there were 107 marked females including 49 functional GPS collars and 81 functional VHF collars. For males, there were 45 marked males with 14 functional GPS collars and 31 functional VHF collars. The majority of collared Sierra bighorn have both a VHF and GPS collar.

2019 Demographic Rates

Here we report female population size (Figure 6) and estimated survival rates for collared animals and lambs (Figure 7) as well as observed ratios (Figure 8) for each herd. Notably, Olancha, which was initially re-established in 2013, is now the fourth largest herd. Olancha also had moderate to high survival rates and fecundity based on observed ratios. Due to small samples sizes, we are not able to calculate all vital rates for all herds and most estimates have large confidence intervals. This means that individual herd year vital rates should be interpreted cautiously.

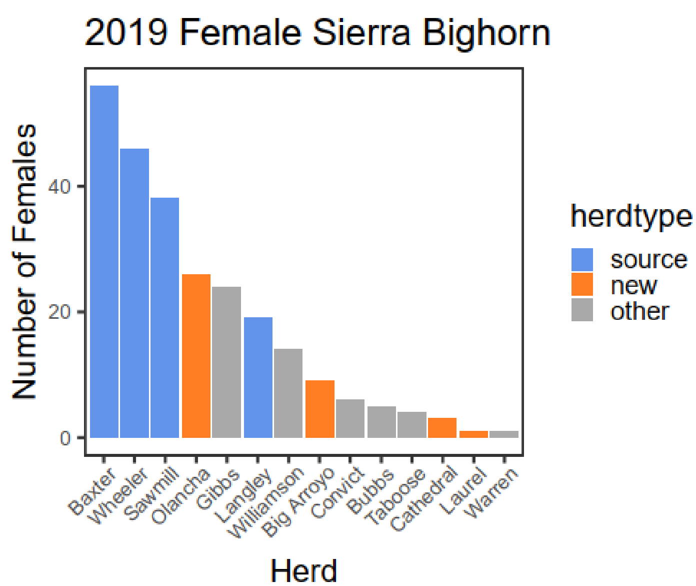

Figure 6. 2019 Reconstructed minimum counts of female Sierra bighorn. Bubbs herd count from 2018.

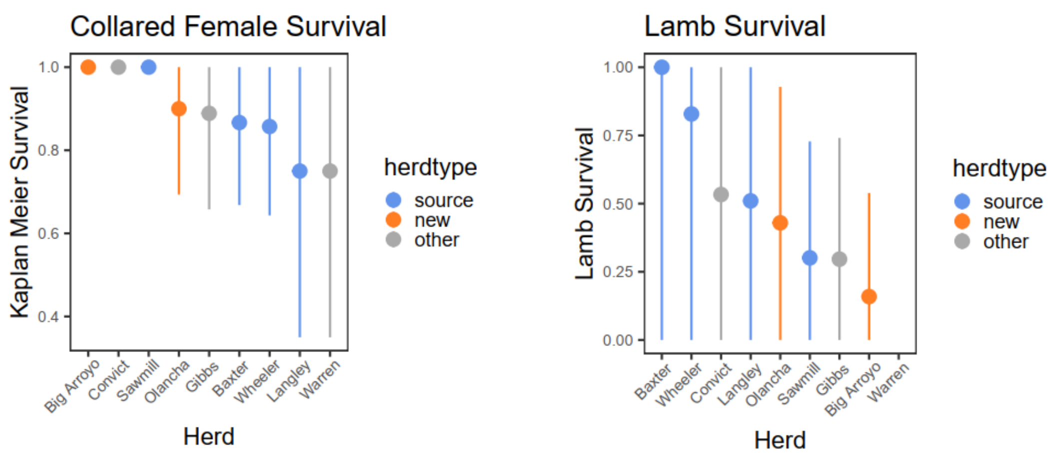

Figure 7. *Collared female and lamb survival estimates by herd with 95% confidence intervals. Female survival estimated using Kaplan Meier and lamb survival estimated using age ratios.*

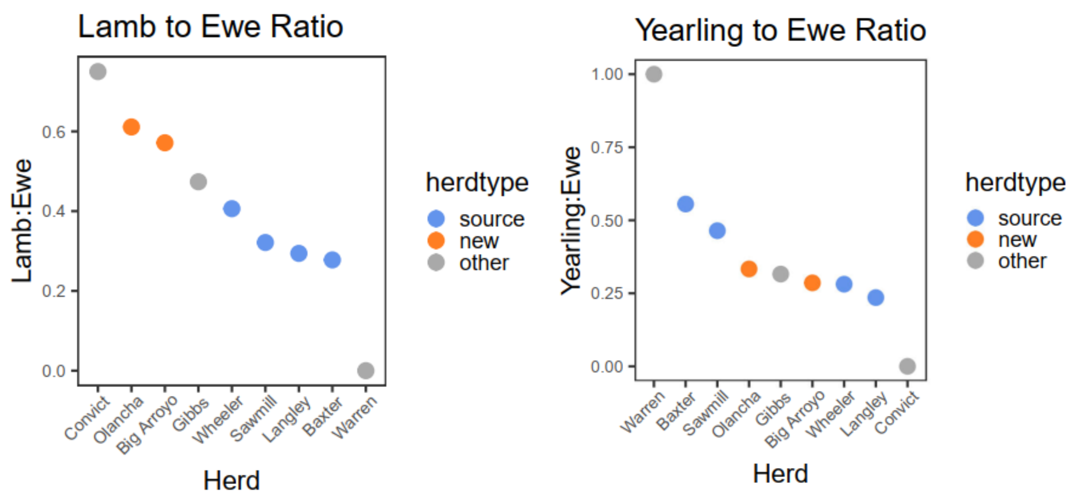

Figure 8. *Observed ratios of lambs and yearlings (males and females combined) to adult females by herd.*

2019 Cause-Specific Mortality

We detected 31 mortalities on 18 collared and 13 uncollared bighorn (Figure 9). The only cause of death identified this year was predation (N=20; Figure 10), the majority by mountain lion but also a single bobcat predation event on a collared female at Gibbs near Walker Lake. Uncollared animal mortalities are biased toward predation as cause because many are encountered by investigating collared lion clusters or by searching in areas of known high lion predation. We expect to detect higher collared female mortality because more females are collared, however as a proportion of collars present, the collared female mortality rate was 11% (12/107) and the collared male mortality rate was 13% (6/45).

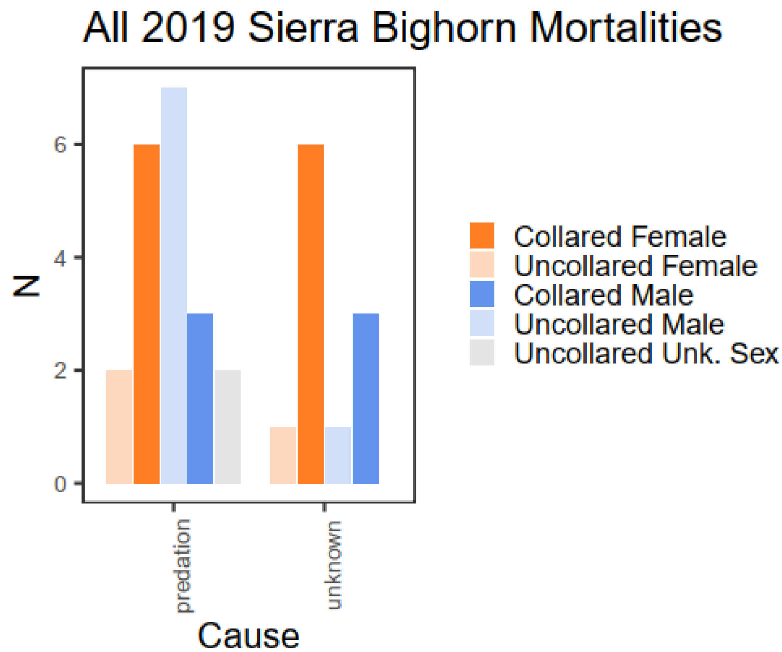

Figure 9. *All Sierra bighorn mortalities detected in 2019.*

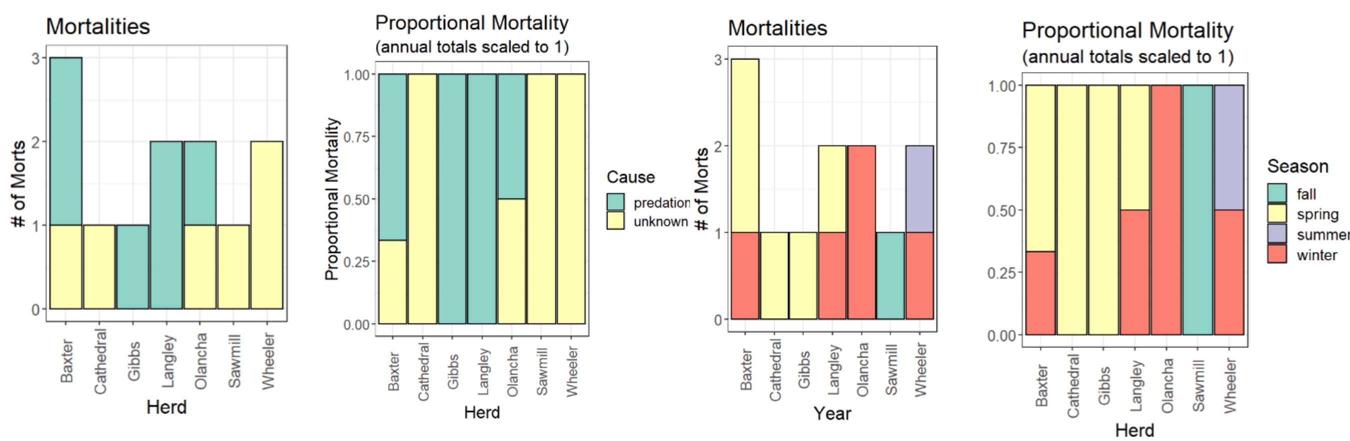

Figure 10. *Cause-specific and seasonal mortality of collared Sierra bighorn females in 2019 within each herd.*

One particularly noteworthy mortality was observed first-hand by Yosemite National Park's wildlife biologist Sarah Stock (excerpted from Voices in the Wind; Stock 2019):

> *… I was not accustomed to seeing bighorns so close and so low in the trees. [Fourteen] bighorns foraged in the meadows among the old abandoned mines and whitebark pines on the northwestern flank of Mount Lewis along Yosemite's eastern boundary.*
>
> *…Suddenly the pastoral scene in my scope changed from tranquil to turmoil as the bighorns scattered across the slope. …Just as suddenly, they came back together and resumed their foraging. …Minutes later, the bighorns exploded again, and this time they were literally running for their lives. Their pursuer, golden brown, powerful, and larger than life, filled my field of view and my senses. The pursuit by predator of prey unfolded before me as the mountain lion closed in on three of the bighorns. In a strange twist of events, the bighorns unexpectedly turned and launched back in the same direction they'd come, in the direction of*

the lion. Surprised, the lion's agility gave way to awkwardness as it struggled to reverse momentum and direction. After a fraction of a second lost, it quickly resumed the chase. In the next moment a large boulder split the trajectory of the three bighorns, and the smallest one went left while the other two went right. The small bighorn made a desperate leap over the boulder toward the others. The lion followed, soared over the boulder and they both disappeared from view.

… A minute later, I saw the lion emerge from behind the boulder carrying the freshly killed lamb in its mouth, lumbering toward the cover of a nearby willow thicket. And there it disappeared from view. I memorized the location of the kill and the hiding spot before taking my eyes from the scope.

Range-wide and Long-term Demographic Rates

We focus on female vital rates because Sierra bighorn populations tend to be driven by female survival (Johnson et al. 2010a). Over the last 20 years, annual collared adult female survival averaged 0.88, ranging from 0.62 to 1 (Figure 11b, Methods); this year it was about average at 0.89. Winters with large snowfall tend to have lower survival. High survival often occurs in drought years, although heavy lion predation episodes can occur regardless of winter conditions. Female yearling survival is generally lower than adult survival and more variable (Figure 11b), but also highly correlated with adult survival (R^2=0.59). Yearling survival averages 0.57, ranging from 0.35 to 0.88; this year it was slightly below average at 0.45.

The pregnancy rate for adult females is 85% (117/137) and 55% for yearling females (6/11). Average lamb:ewe ratio was 0.46 (range from 0.33 to 0.64); 2019 had the lowest ratio recorded (0.33). This year the yearling:female ratio was 0.29, slightly lower than the 20-year average of 0.37 (range from 0.21 to 0.62), and yearling female to adult female ratio was 0.19, slightly lower than the long-term average 0.21 (range from 0.12 to 0.33). Average lambda was 1.10 with a minimum of 0.80 and a maximum of 1.28; 2019 lambda was 1.03 (Figure 11c, Methods), indicating a growing population (lambda values >1 indicate population growth). Lambda consistently drops below 1 during heavy snow winters and the only other time range-wide lambda dropped below 1 was during 2008, likely due to high predation rates in Sawmill and Baxter.

We estimate 58% of pregnant females are observed with a lamb, or in other words, 42% of pregnant females are never observed with a lamb. This discrepancy between pregnancy and observed lamb rates could be caused by in utero losses, stillbirth, or undetected neonatal predation. In addition to mountain lions and bobcats, it is possible that lambs may be killed by different predators including coyote, golden eagle, black bear, and gray fox (Sawyer and Lindzey 2002).

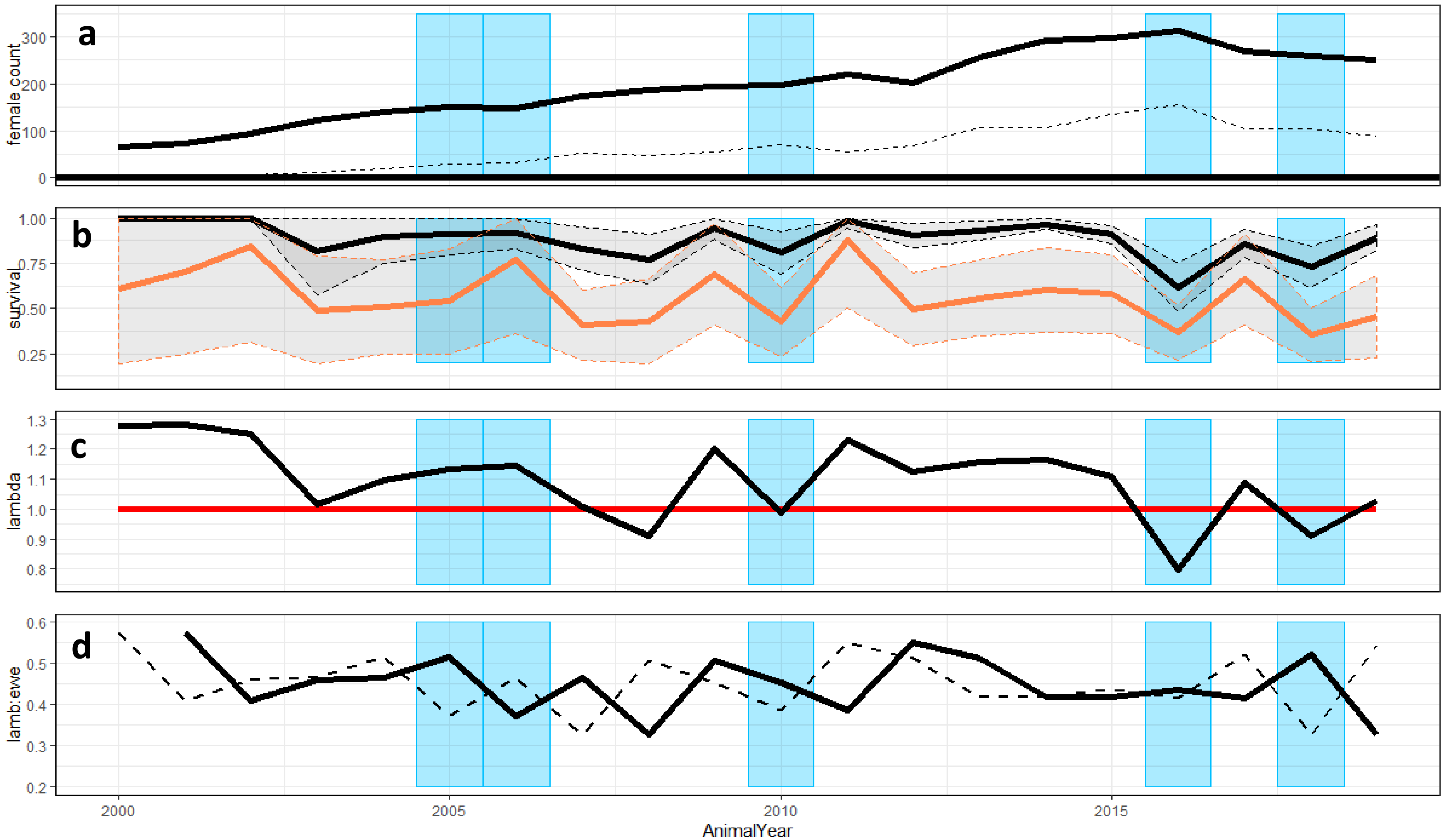

Figure 11. *Long-term and range-wide female Sierra bighorn population estimates and vital rates, 1999-2019. Heavy snow winters (>150% average snow depth in April) are highlighted in blue.*

- a) *Total female population estimate (solid line) and number of collared females (dashed line)*
- b) *Adult survival (black line) and lamb to yearling survival (sienna line) with 95% confidence intervals*
- c) *Lambda calculated from eigenvalues derived from vital rates. Red line at 1 differentiates growing vs. declining population*
- d) *Lamb:ewe ratios: dashed line is within the same time period; solid line is one year delay (e.g., wet winter may effect following year recruitment)*

Range-wide and Long-term Cause-Specific Mortality

Since 2005, we have identified 204 collared female mortalities (Figure 12). Sierra bighorn typically die in the winter and spring. Cause of death was unable to be determined for 41% (N=83) of collared females. Predation was the highest known cause of death at 28% (N=57), followed by 19% from snow (includes avalanche and starvation, N=38). In general, snow deaths can be more difficult to access and investigate because they often occur deeper into the mountains and at higher elevations throughout the winter and spring (Greene 2020). For this reason, we think our data probably underrepresent snow deaths during heavy winters. From 2005-2019 we consistently increased the distribution of collared females (Figure 11a), and collared female mortality has been detected in all 14 herds (Figure 12). Additionally, 54 collared females have been censored; censored animals are presumed dead after they have not been observed for two years.

Collared male Sierra bighorn generally die of the same causes proportionally as females. Since 2005, we have detected 130 collared male mortalities. At 28%, predation was the most common documented cause of death (N=36), followed by 19% from snow (N=25). Additionally, 35 collared males have been censored.

Uncollared animal mortalities are also detected, typically in association with lion monitoring. For example, we often find uncollared bighorn mortalities while investigating collared lion clusters or while searching in areas of high lion predation. Occasionally bighorn mortalities are encountered opportunistically during surveys or other field activities. Since 2000, we have documented 132 uncollared animal mortalities: 76 lion kills, 34 from unknown cause, 14 from snow (11 from avalanche and 3 from starvation), 4 from rockfall, 2 from hypothermia, 1 from capture, and 1 from domestic dog. There are almost two times more male uncollared mortalities detected (63) than female (34), although the sex of some remains cannot be determined (36). This may represent the higher mortality rate of males, or it could also be that male remains are more persistent or more easily detected and identified as male.

Although data is limited, it seems detected lamb mortalities generally have the same causes as adults. Of the five neonatal lambs collared, two died from unknown cause, one from starvation, one from rockfall (within 48 hours), and one is presumed to have survived the year. Additionally, from 44 lambs captured during the fall at ~6 months of age, we have documented five collared lamb mortalities: three from predation and two from unknown cause.

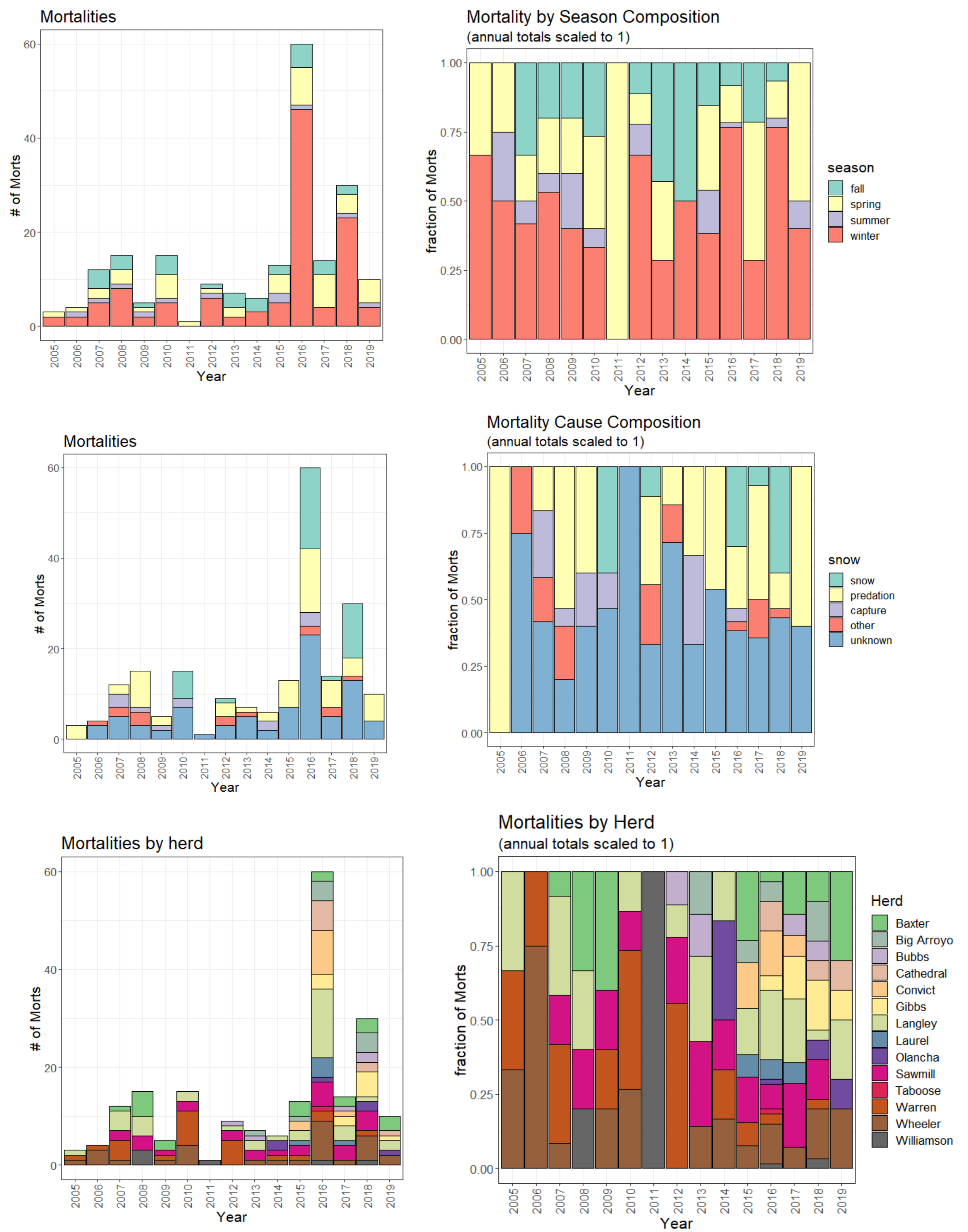

Figure 12. *Collared female Sierra bighorn mortality 2005-2019 by cause of death and herd. The category snow includes death by avalanche and malnutrition during winter and spring. The number of mortalities (left) is influenced by the number of collared females at a given time, which trends with the overall 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.*

New Herd Establishment

Beginning in 2013 four new herds, Olancha, Laurel, Big Arroyo, and Cathedral, were re-introduced via translocations from source herds, Wheeler, Sawmill, Baxter, and Langley. These new herds were immediately challenged by two of the heaviest snow winters in the last twenty years. During the 2016-17 and 2018-19 winters, Big Arroyo, Laurel, and Cathedral all had reduced survival rates and mortalities caused by avalanche and starvation. These winters did not seem to reduce survival at Olancha, likely because it is the farthest south and lowest elevation of all occupied herds. As of 2019, Olancha is the only one of these herds that appears to be growing naturally, in that it has more females in it now than have been introduced into it. Laurel and Cathedral each have less than five females, making them vulnerable to stochastic extirpation. Along with Big Arroyo, these three herds are expected to need further augmentation.

In this second wave of reintroductions, Wheeler, Sawmill, Baxter, and Langley were utilized as “source” herds and provided a total of 62 females and 31 males to help create new herds and augment other herds as needed. In addition to removals for translocations, these source populations have lost individuals due to heavy snow winters (Greene et al. 2019) and lion predation (Gammons et al. 2021). To protect source herds, we require there be a minimum of 40 females present in a herd before any are removed for translocation (Few et al. 2015). By the end of animal year 2019, Baxter was the only herd in which we counted over 40 females. While Sawmill and Wheeler are close to this threshold, Langley has declined to 19 females following extreme predation in 2016 (Gammons et al. 2021), followed by continued predation since then. In 2013 and 2015, 18 females were removed from Langley for translocation. At this point it is uncertain how long it will take Langley to become a source population again.

Winter Sensitivity

In the last twenty years, five winters have had notably large snowpacks (2005, 2006, 2010, 2016, 2018; Figure 11). During 2010, 2016, and 2018, range-wide survival was notably lower (Figure 11b), and snow associated mortality was the most frequent cause of mortality identified (Figure 12). Herd level analyses (Greene et al. 2017, Greene et al. 2019) indicate that five herds were highly sensitive to winter impacts (Cathedral, Big Arroyo, Warren, Laurel, and Convict), three herds were moderately sensitive (Gibbs, Wheeler, and Sawmill), and three herds were not sensitive to winter conditions (Baxter, Langley, and Olancha). Although Langley did show reduced survival in 2016, it was entirely driven by lion predation; not a single Langley mortality has been directly associated with snow in the form of avalanche or malnutrition. However, heavy snow may have changed winter range use to make predation more likely, or more severe.

Impacts during the winters of 2005 and 2006 are not as apparent as in other heavy snow winters. However, the proportion of animals in herd units that are highly sensitive to heavy snow has shifted in the last 20 years (Figure 13). The proportion of animals in high sensitivity herds increased due to natural growth in these herds, particularly during the California drought of 2012-2016 and from translocations into new herds. Three of the four newly established herds were highly sensitive to severe winters.

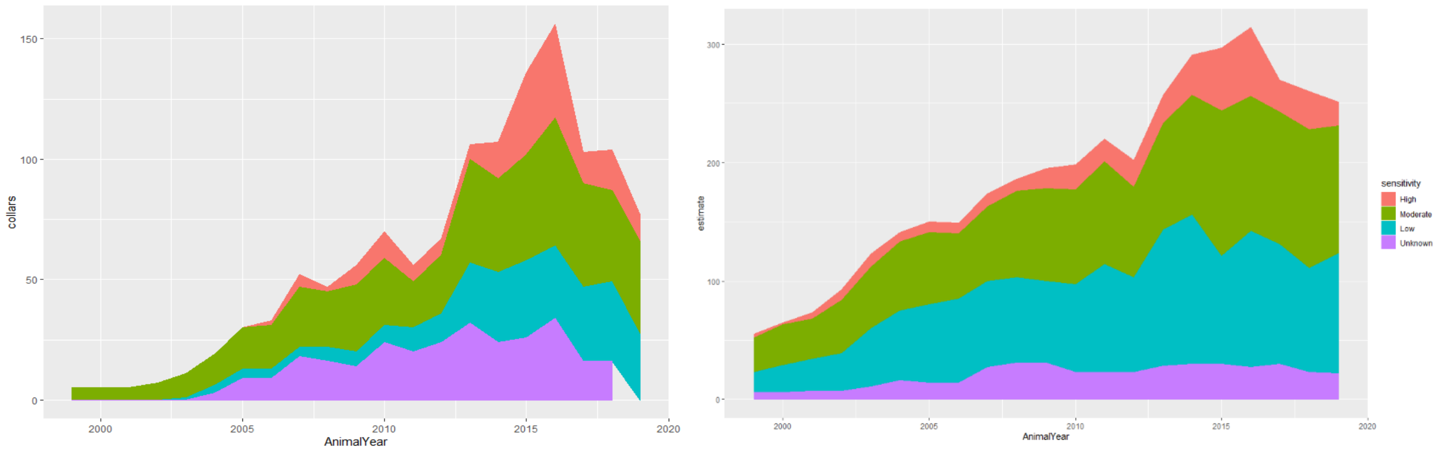

Figure 13. *Abundance of collared (left) and total (right) female Sierra bighorn in herds with low, moderate, high, or unknown sensitivity to heavy snow. The proportion of animals in herds that are highly sensitive to winter impacts has tended to increase, particularly with the translocations that began in 2013. This may explain why heavy snow winters in 2005-06 and 2006-07 did not have as much of an impact as 2010-11, 2016-17, or 2018-19.*

Winter sensitivity is likely impacted by the quality of the winter range as well as the proportion of animals that migrate and use the winter habitat effectively. For example, Big Arroyo animals tend to use low elevation winter habitat, but they still experienced high winter mortality, indicating that Big Arroyo may not have high quality winter habitat available during heavy snow winters. However, it may also be that animals in this newly established herd were not familiar enough with the region to know where to find high quality winter habitat. For example, prior to 2016, Convict animals rarely migrated to low elevation habitat (Spitz et al. 2018) and they experienced a 75% mortality rate in 2016, the highest winter mortality of all herds. Beginning in 2017, Convict animals developed a novel migration and began using lower elevation south-facing habitat on the north side of McGee Creek (Greene et al. 2019). This may explain the difference between winter survival in 2016-17 of 25% to 100% in 2018-19. At Convict, it may be the lack of migratory behavior and not a limitation in the available habitat itself that drives winter sensitivity. However, it is not clear how to quickly develop and promote migratory behavior, particularly in newly occupied herds that have no individuals with historic geographic knowledge. It is likely this process will require time, additional augmentations, and will potentially result in lower survival until these critical habitats are encountered and movement patterns are established. As an alternative to low elevation winter range, bighorn using optimal summer range can accumulate abundant fat reserves that increase survival during winter (Stephenson et al. 2020, Denryter et al. 2022). Nevertheless, newly introduced herds likely require time to develop adequate knowledge of optimal forage and to establish successful patterns of habitat selection.

Mountain Lion Monitoring and Management

Minimum Counts

We monitored 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 used all available evidence to produce minimum counts of mountain lions in each count zone, following techniques described in McBride et al. (2008; Methods). 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 may include transient animals. Until this year minimum counts were focused in three distinct count zones based around Sierra bighorn herd units which have been impacted by mountain lion predation. The Northern count zone overlaps the Warren, Gibbs, and Cathedral herds; the Central count zone overlaps the Wheeler herd; and the Southern count zone overlaps the Sawmill, Baxter, Williamson, and Langley herds (Figure 1). In 2013 the Olancha herd was established, and since that time we have documented four adult ewes and one adult ram killed by lions there. Because of this, we created the Olancha count zone and conducted a minimum count there this year (Figure 1). We also created a minimum count for mountain lions in the eastern Sierra outside of the count zones. We focused on trying to count every animal present within the count zones (Figure 14). Lion minimum counts reported in this section reflect animals counted July 1, 2019-June 30, 2020.

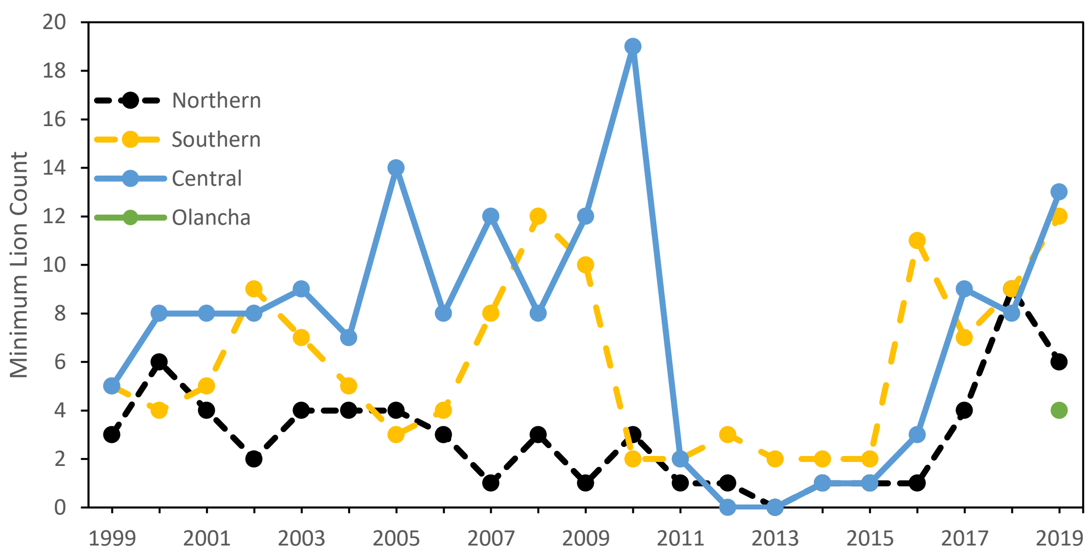

Figure 14. *Mountain lion minimum counts by zone from 1999-2019.*

In 2019 we documented a minimum of 50 mountain lions in the eastern Sierra population (Figure 15). Six lions were detected in the Northern count zone, 13 in the Central, 12 in the Southern, and 4 in the Olancha count zone (Figure 14). Seventeen additional lions were detected in the eastern Sierra population outside of any count zone. Minimum counts summed across zones exceeded the total minimum count for the eastern Sierra because individual lions detected in multiple count zones were added to the tally for each zone, but they were only counted as 1 for the total minimum count of 50 lions. Half of the detected lions (25/50) were collared. Three unmarked lions were counted by documented mortalities. The remaining 22 lions were identified by physical evidence, including unique markings, unique tracks, photographs, and visual observations. This year's mountain lion minimum count is the highest our monitoring program has ever recorded, with the previous high of 37 recorded the prior year. This could indicate an increase in mountain lion density, or it may reflect an increase in effort and area investigated.

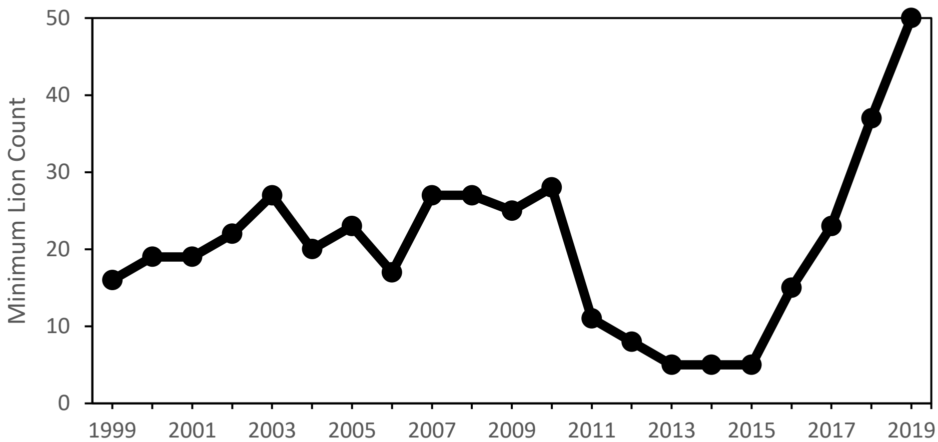

Figure 15. *Mountain lion minimum counts in the eastern Sierra region. Note that 2019 includes an additonal count zone, Olancha, as well as 17 individuals counted outside count zones.*

Identifying unmarked individual lions becomes increasingly difficult as the density of unmarked animals rises. In cases where detections of unmarked, indistinguishable lions vastly outnumber detections of marked or uniquely featured lions we infer that our minimum count is likely an underestimate. This is the case in the Central count zone, where we strongly suspect that the minimum count of 13 lions is an underestimate of the actual number of animals present.

Captures

We captured 17 lions, including 9 females (7 adults and 2 subadults) and 8 males (4 adults and 4 subadults), which is substantially higher than the 10 animals captured the previous year and the annual average of 10.1 lions per year from 1999-2017 (excluding 2012-2015 when no captures occurred). The higher number of lions captured this year is likely to due to a combination of factors which affected effort, strategy, and capture opportunities. This year we began closely following mortality notifications from GPS-collared deer as a method of detecting and trapping uncollared lions, which was very effective. The addition of lion-focused staff with prior capture and tracking experience may also have contributed to increased capture success. Although our increased minimum count of lions this year does not necessarily indicate an increase in the lion population, an increasing population may also be a contributing factor in our increased capture rate.

Predation on Sierra Bighorn

We identified a minimum of 19 Sierra bighorn killed by mountain lions this year (7 adult females, 10 adult males, 1 adult of unknown sex, and 1 lamb of unknown sex). This is an increase from the previous year when we documented a minimum of 13 Sierra bighorn killed, and from the annual average from 1999-2019 of 8.52 (Figure 16). The apparent increase in predation may be due to enhanced detection from increased deployment of collars on Sierra bighorn and lions, which provide our primary means of collecting predation observations through mortality notifications and lion feeding clusters. Conversely, this may indicate an increase in lion predation.

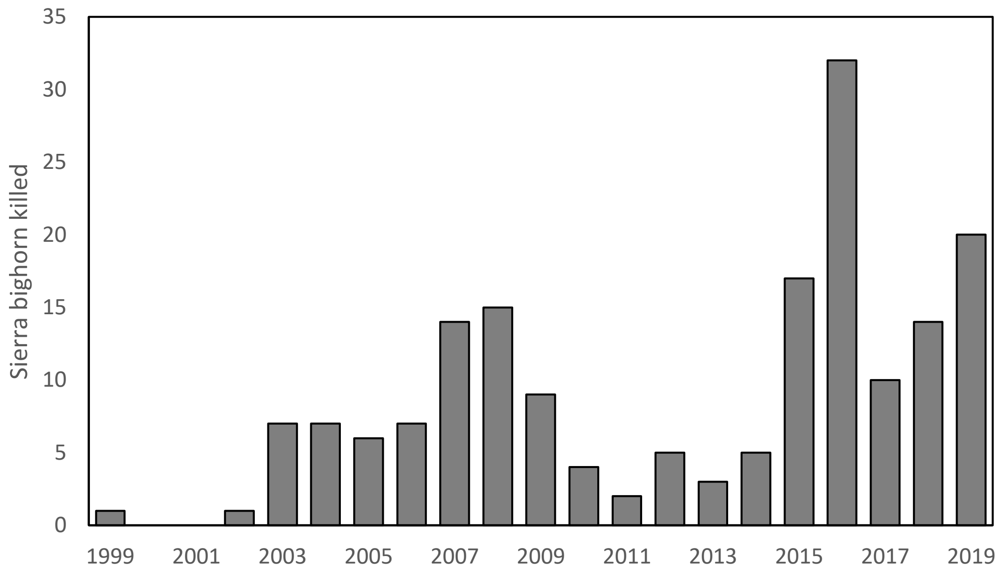

Figure 16. *Sierra bighorn mortalities caused by mountain lions from 1999-2019. Efforts to detect predation events (both in staff hours and collars on lions and bighorn) have varied over time, as has the population size of Sierra bighorn.*

Mountain lion predation continues to impact almost half of Sierra bighorn herds to varying degrees. This year lion predation was documented at Baxter (N=9), Gibbs (N=1), Langley (N=3), Olancha (N=2), Sawmill (N=1), and Wheeler (N=4). The substantial increase in documented predation at Baxter (Figure 17), and the continued impact of predation at Langley are both concerning.

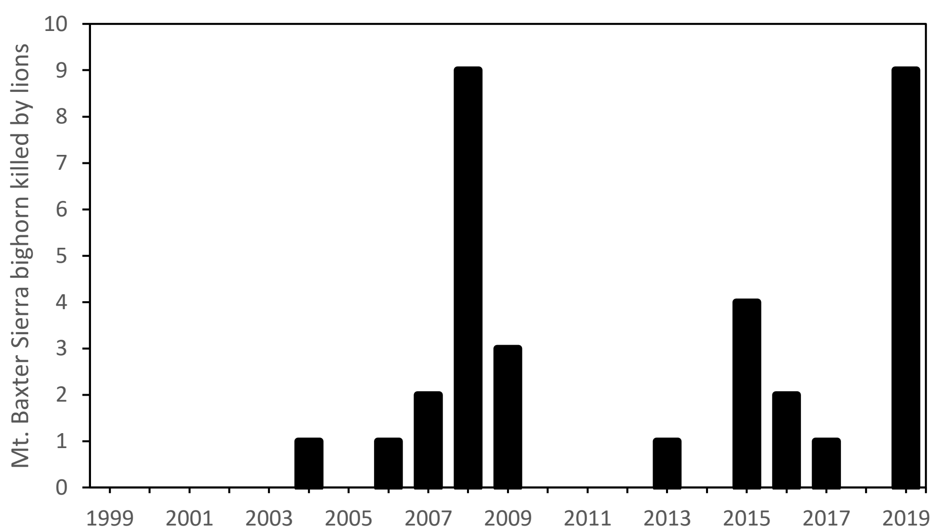

Figure 17. *Sierra bighorn mortalities caused by mountain lions from 1999-2019 in the Baxter herd unit. Efforts to detect predation events (both in staff hours and collars on lions and bighorn) have varied over time, as has the population size of Sierra bighorn.*

Baxter offers an example of the importance of GPS collars for detecting predation, and on the stochasticity of predation levels that herds experience from year to year (Figure 17). Last year we documented no predation in the Baxter herd. This year, however, we documented 9 instances of lion predation, far exceeding the average annual predation rate of 1.57 (1999-2019) in that herd (Figure 17). Eight of these predation instances were identified because the predating lion was GPS-collared, and the remaining mortality was detected because a VHF-collared ewe transmitted a mortality signal. Five individual lions were responsible for the eight Sierra bighorn kills detected by lion clusters. Male L147 (estimated 2 years old at capture on 3/5/18) killed 1 ewe and 3 rams, female L168 (estimated 8 years old at capture on 6/4/2019) killed 1 ram, male L165 (estimated 1 year old at capture on 4/14/2019) killed 1 ram and another bighorn whose sex could not be determined, male L166 (estimated 1 year old at capture on 5/24/2019) killed 1 ram, and female L178 (estimated 7 years old at capture on 4/12/2020) killed 1 ewe. The arrival of 3 subadult males (L147, L165, and L166) that targeted Baxter bighorn is an example of how herds that typically experience low or no predation may suddenly become substantially impacted due to stochastic changes in lion presence. The two adult females (L168 and L178) were mature animals who have may have been resident for many years, although whether they predated on Sierra bighorn before they were collared is unknown. Having more lion collars in Baxter has been critical to improving our understanding of predation impacts, which will help inform and increase efficacy in mountain lion management.

We documented three instances of lion predation in the Langley herd this year, which is concerning given the Langley herd's population decline that began with the extreme lion predation event of 2016-17 when 19 Langley bighorn were killed (Gammons et al. 2021). This year, we detected an uncollared adult female lion using the Langley herd unit, through photographs and tracks at the kill-site of a collared Langley ewe. Two lions were removed from Langley in 2016 in response to the high losses to predation documented at that time, but the Langley herd is still being impacted by lion predation. No lion removals have occurred in Langley since 2016.

Reproduction

We documented 16 adult female lions, and 10 of them were confirmed to have at least one offspring. Five of the 10 females with offspring were documented with at least two young.

Predation Management

Since April 2017 there have been no lethal removals of mountain lions for the protection of Sierra bighorn, and this year we translocated a predating lion as a means of mitigating the impact of predation on vulnerable herds. Lion L172 was a transient subadult female initially captured in the Wheeler herd who preyed on a Wheeler ram shortly after capture. Lion L172 then traveled north to the Warren herd unit in an apparent dispersal movement, and began to use bighorn habitat in Lundy Canyon, a crucial and heavily used area for the Warren herd. The Warren herd has experienced losses to avalanche, winter conditions, and predation; recent translocation efforts have attempted to reverse those losses. We deemed that allowing a known bighorn-predating lion to inhabit Lundy Canyon posed too great a risk to the recovery of the Warren herd and threatened to undo the success achieved by the translocations. Lion L172 was captured and translocated 50 air-miles north to the Slinkard/Little Antelope Wildlife Area where she was released (Figure 18). Since Lion L172 was an actively dispersing subadult lion, we considered this action an assisted dispersal. Lion L172 traveled north initially from the release site but shortly turned southward and returned to Lundy Canyon. She quickly turned north again and proceeded to establish a home range on the eastern edge of Lake Tahoe. Lion L172's ability to survive translocation, establish a home-range, and refrain from further predation of Sierra bighorn warrants further study into the use of lion translocation as a non-lethal predation-mitigation strategy.

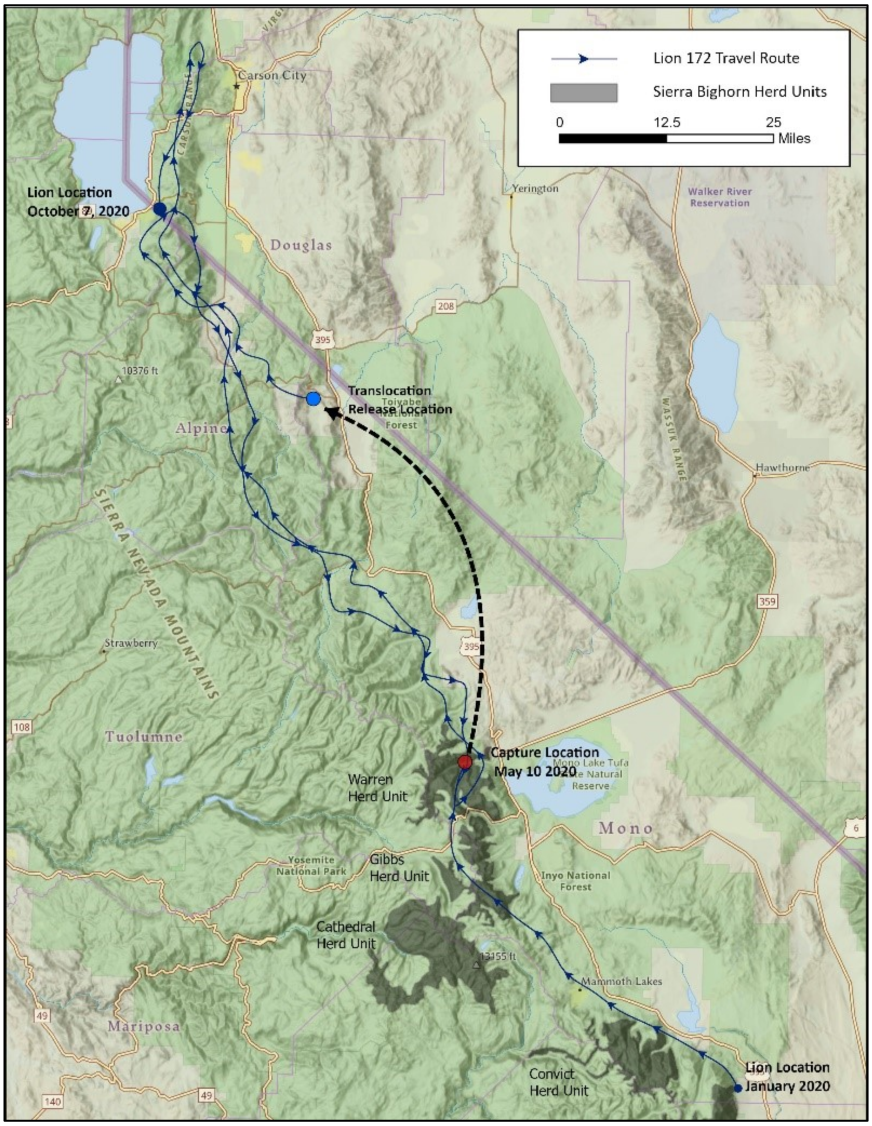

Figure 18. In May 2020, Female lion L172 was translocated from Warren north outside of Sierra bighorn range.

Disease Management

Recovery of Sierra bighorn requires that management of domestic sheep and goats is sufficient to prevent disease transmission to bighorn sheep. Extensive progress has been made in reducing the risk of disease transmission since listing. Nevertheless, grazing of domestic sheep and goats on private and public land continues to impose some risk. The Recovery Program works with managers and landowners to find solutions that will eliminate such risk. The small percentage of land in the eastern Sierra that is in private ownership (~2%), in addition to the federal and state “endangered” listing status, makes the management of disease risk a feasible goal compared to many regions that support bighorn sheep in the western U.S.

Future Management

In order to meet recovery goals, we anticipate that additional translocations will be required. The Kern Recovery Unit remains the furthest from its goal of 50 adult and yearling females. An additional 10 and 15 ewes should be added to the Big Arroyo and Laurel herd units, respectively, based on population modeling (Few et al. 2015). The decline of the Langley herd will prevent its use as translocation stock for several years (Gammons et al. 2021). Consequently, only 3 herds (Baxter, Sawmill, and Wheeler) are potentially large enough to support removals for translocations, but such removals should only occur when counts indicate that those herds are above the recommended threshold of 40 females. Translocation of additional young rams should occur in the Kern Recovery Unit. Ram augmentation is not recommended in the Warren herd because of the risk of contact with domestic sheep if forays to the north were to occur.

The Northern Recovery Unit may reach recovery goals without additional augmentation but would benefit from translocations as well. The Cathedral herd was created with 10 females and should receive an additional 10 females to ensure adequate genetic diversity. Population growth rates will determine what levels of translocation are needed.

Recent increases in predation indicate that management of mountain lions will be necessary to ensure adequate population growth in the source herds used for translocation. Generally, adult female survival greater than 90% is necessary for population growth, and this may not occur in herds that experience lion predation. Relocation of mountain lions that prey on ewes should occur promptly to protect source herds and small herds.

Aknowledgements

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Appendix A: 2019 Detailed Herd Unit Summaries

Olancha

Olancha was surveyed September 26-28, but only 60% (6/10) of collared females and 0% (0/3) of collared males were observed. During February 7-8, we surveyed Olancha again and observed 89% (8/9) of collared females. However, even though more collared females were observed in the winter, the summer female count was higher, while the lamb and male counts were higher in the winter. Combining these surveys resulted in a reconstructed minimum count of 22 adult females, 4 yearling females, 13 lambs, 8 adult males, 2 yearling males, and 1 unknown-aged male (Table 1). In 2019, female adult survival was 0.9, estimated female lamb to yearling survival was 0.43, and the observed lamb:ewe ratio was 0.5.

We detected 4 mortalities in Olancha. We were unable to determine the cause of death for 2 of them: in September male S358 was found relatively intact, and in February female S280's collar switched to a mortality signal but was unable to be located before her collar stopped transmitting. Additionally, 2 animals (female S278 and male S476) died of lion predation in the spring.

GPS collar data shows female S494 moved north from Round Mountain and joined the rest of the Olancha herd, all of which predominantly use Olancha Peak, Falls, and Olancha Canyon, as well as two smaller unnamed drainages north of Olancha Canyon. Male S493 remained at low elevation throughout the summer.

Laurel

There were technically no observations of Laurel animals in 2019. However, 2 adult females (including S382) and 2 lambs were seen May 20, 2020, from which we can derive a minimum count in 2019 of 2 adult females and 1 adult male (S352; Table 1). We are rarely able to identify cause of death at Laurel because it is typically not accessible in winter. Male S352 died in December of unknown cause, and after his death, we no longer had any functional GPS collars in Laurel. Since reintroduction in 2014 of 7 females and 4 males, the population has generally been declining.

Big Arroyo

In the summer of 2019, there were 4 collared females (44%), and we accounted for 8 adult females, 1 yearling female, 4 lambs, and 6 adult males (Table 1). All 6 collared animals (2 males, 4 females) were seen. Adult female survival was 1, female lamb to yearling survival was 0.16, and the observed lamb:ewe ratio was 0.5. One female (S287) was seen early in the summer with a lamb but later in the summer without a lamb. We cannot be certain this represents a mortality because later in the summer, females will spend time away from their lambs. This was the only potential mortality documented in Big Arroyo. Based on GPS-collared animal locations, 3 of 4 females migrated and spent time in high elevation summer habitat in the Kaweahs.

Langley

Langley bighorn were observed throughout the summer, and the herd had 9 collared females, or 47% of all known females in the herd. The best minimum count occurred during September 17-26 when we documented 18 adult females, 1 yearling female, 14 adult rams, and 3 yearling rams (Table 1). One collared female and one collared male were not observed during the survey. In 2019, adult female survival was 0.75, female lamb to yearling survival was 0.51, and lamb:ewe ratio was 0.28. There were 5 mortalities: 3 from mountain lion predation, including an uncollared male M177 and a collared female S264, both in Diaz Creek, and female S343 in Tuttle Creek. Male S211 was censored and uncollared female M178 was opportunistically found wedged between boulders in a gully, but whether the cause of death was rockfall or avalanche could not be determined. GPS collar data indicates no novel habitat use this year.

Williamson

A spring survey on low elevation range at Williamson during April 17-21 provided a minimum count of 14 adult females, 4 lambs, and 5 adult males (Table 1). Female S481 was not seen but presumed alive. Male S454 was censored in the fall prior to the survey. There were only two functional GPS collars in 2019, one male and one female. Female S481 belongs to the southern “Barnard” deme of the Williamson herd, and there are no functional GPS collars in the northern Williamson deme. In general, this herd has notoriously vast and convoluted habitat, and with so few collars it is likely our minimum count is a significant underestimate. Since 1998, minimum counts have ranged from 3-15. We continue to attempt to capture and collar animals in Williamson, particularly in the northern “Williamson” deme.

Baxter

During the 2019 summer survey August 27-29, there were 14 collared females (25%), and we accounted for 86 Sierra bighorn, including 46 adult females, 10 yearling females, 15 lambs, 11 adult males, and 4 yearling males (Table 1). We consider this a good survey because most collared females were seen (13/14). Adult female survival was 0.87, estimated female lamb to yearling survival was 1, and the observed lamb:ewe ratio was 0.21.

Subsequent winter/spring surveys resulted in the highest male count of 33 individuals including 22-28 adult males and 5-8 yearling males. Ranges are reported due to age classification uncertainty. Three collared males were never seen but presumed to be alive. Collaring lions in the area increased our ability to detect lion predation. We detected 10 bighorn mortalities, of which 90% were lion predation. This included 5 detected from lion clusters (3 males, 1 female, 1 unk sex), 2 lion predation mortalities detected from collared bighorn (females S439 and S531), 2 lion predation mortalities detected opportunistically (males M159 and M173), and 1 collared female (S298) died of unknown cause.

One female (S223) was recaptured due to concerns about collar fit and was released without any collars due to neck sores. Another previously uncollared female was captured and collared. No unusual or novel habitat use was detected from GPS collars in 2019.

Sawmill

During the 2019 summer survey, there were 14 collared females (37%), and we accounted for 29 adult females, 9 yearling females, 9 lambs, 20 adult males, and 4 yearling males (Table 1). We observed 8/9 collared females and 1/4 collared males. Adult female survival was 1, estimated yearling survival was 0.30, and lamb:ewe ratio was 0.24. We detected 1 uncollared female mortality from mountain lion predation, 1 female mortality from unknown cause (S326), and censored 2 males (S395, S258). In the spring we captured 6 previously uncollared females to help with monitoring efforts. We detected no particularly unusual or noteworthy movements from GPS collars.

Bubbs

There are currently no collars in this herd. There was a single opportunistic observation on July 4th of 2 adult females and 1 lamb. For summary purposes, we will assume the 2018 count of 5 females is an appropriate estimate (Table 1). The highest recorded count in Bubbs was 17 females in 2008. We continue to attempt to capture animals in this herd to help with monitoring, but with no collars as lead-ins it has been very challenging.

Taboose

In June we had a single observation at Taboose of 2 adult males. We were, however, able to deduce a minimum count based on a May 2020 count of at least 2 adult females and 2 lambs in 2019 (Table 1). There are two collared females in Taboose and the one with a functional GPS collar visited the south fork of Big Pine Creek, Birch Mountain, and Tinnemaha Mountain, generally staying east of the crest for the entire year.

Wheeler

The best minimum count at Wheeler included a compilation of observations from December 31, 2019 - January 13, 2020. We accounted for 38 adult females, 7 yearling females, 12 lambs, 23 adult males, and 3 yearling males (Table 1). Only 6 of 10 collared females were observed, and 23% of females were collared. This is the second consecutive year with a poor count at Wheeler. The count is likely an underestimate due to the high number of collared females not seen, indicating we also missed some uncollared females. In 2019, adult survival was 0.86, yearling survival was 0.60, and lamb:ewe ratio was 0.33. We detected 8 mortalities, including 4 from mountain lion predation (males S505 and S383, uncollared male M171 opportunistically, and uncollared male M169 from lion cluster), and 4 from unknown cause (females S182 and S417, male S509, uncollared male M181). In the spring we translocated 6 females (4 adults, 2 yearlings) from Wheeler to Warren; all but one (a yearling) was pregnant. There were no unusual movements detected from GPS-collared animals.

Convict

In February, this small herd was observed during February 25-26 and included 4 adult females, 2 yearling females, 3 lambs, and 2 adult males (Table 1). All known collars were seen (3 adult females, 1 male) and this may be a census. No mortalities or captures occurred. No unusual movements were detected, and animals continued crossing to the south side of McGee Creek in winter.

Gibbs

During a summer survey, Yosemite NPS biologist Sarah Stock and others observed a mountain lion prey upon an uncollared lamb. The summer survey resulted in 19 adult females, 3 yearling females, 9 lambs (after accounting for the observed mortality), 16 adult males, and 3 yearling males (Table 1). All 9 female collars were observed, and 3 of 4 male collars were observed. This is a good survey and may be a census. In addition to the observed lion predation, we detected one bobcat predation on a collared adult female (S191). Gibbs ram S487 that had previously visited the Cathedral herd unit remained in Gibbs, and GPS-collared animals did not visit Donohue Peak between Cathedral and Gibbs as they have in the past.

Warren

The summer count at Warren included only 4 animals: a single collared female (S522), 2 adult males, and 1 yearling male (Table 1). A public observer did claim to see a group of 5 animals on the south flank of Virginia Peak, but these animals were not confirmed. In the spring of 2020, 6 females were translocated into Lundy Canyon in the Warren herd from Wheeler. All 6 females were previously uncollared, 5 were pregnant, and 2 were yearlings. We detected one mortality opportunistically, an uncollared male from unknown cause near Summit Lake. Prior to the augmentation, female S522 spent time near Camiaca Peak, Excelsior Mountain, and Black Mountain, as well as the red rocks on the north side of Lundy Canyon. Post reintroduction, the animals did not move far from the release location on the north side of Lundy Lake between March and April. One female lion (L172) was translocated out of Warren in May 2020.

Cathedral

Based on a single observation in June 2019 from Parson's Plateau, our minimum count is 3 adult females and 1 unclassified yearling (Table 1). This includes the one collared female remaining in Cathedral. Prior to this observation we recovered a female mortality from unknown cause (S367).

Appendix B: Methods

Sierra Bighorn Population Estimation

Although minimum counts are not a statistical estimation and therefore do not have 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 animals 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 animals that were not observed 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 observation. In addition, for herds with near census counts, a count from a given year can often indicate that there must have been more animals present in the previous year than were counted. In this case, additional animals may be added to a previous year 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 animals, we only include translocated animals 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 animals 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.

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 Over-Winter Mortality Estimation

We used two different methods to estimate over-winter female mortalities for each herd unit: collar survival and minimum counts. We evaluated impacts on the herd scale because winter conditions are similar within each herd. We used and compared two methods because each of these methods has limitations. Relying only on the ratio of collared female mortalities assumes that uncollared animals die at the same rate as collared females. Particularly in herds with a small number of collars, the ratio of collared animals lost may not accurately represent the losses within the herd. Minimum counts also have their limitations, as they rarely account for all animals. In addition, two of the largest herds, Baxter and Wheeler, are counted in the middle of winter; therefore, these counts may only represent a proportion of winter losses. Although neither of these methods is perfect, the similarity in both estimates supports the validity of the overall estimate. When either collar data or minimum counts were unavailable for a herd year, the alternate method was used for that herd to generate range-wide annual mortality.

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 et al. 2010a, Johnson et al. 2010b, 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.

Mountain Lion Estimation

Mountain lion minimum counts are determined by summing the number of marked individuals, unmarked individuals reported dead (e.g., vehicle collisions, depredation killing), and uniquely identifiable unmarked individuals documented via detection at collared Sierra bighorn mortalities as well as through extensive track and trail camera surveys. We use methods adapted from McBride et al. (2008) and further described in Davis et al. (2012) to distinguish unmarked individual lions from each other and avoid double-counting, considering detections of unmarked individuals to be distinct if they occurred >9.6 linear km apart for females and >16.1 linear km for males within a 24-hr. period. When track observations are used to distinguish between unmarked individuals, only tracks <24 hrs. old are used. Track age is verified by wind, rain, or snow events, or evidence that tracks occurred the night prior to a survey, such as those occurring over vehicle tracks from the previous day. To avoid overestimating lion abundance, we do not reconstruct presumed incomplete counts by assuming that females initially captured when ≥30 months old were born within the study area (e.g., Logan and Sweanor 2001; Robinson et al. 2008). Individuals are only counted when there is direct physical evidence of their presence. Minimum counts may include transient animals. If the same individual is identified in multiple count zones, it is added to the count for each zone, but only as a single individual in the range-wide count. The range-wide count is lower than adding the individual count zones together when known individuals move through multiple count zones.

While counts conducted in this manner can be used to determine that there were at least a certain number of individuals present, we currently do not have a quantitative procedure for determining how close minimum counts are to true abundance. Instead, we rely on a subjective measure of completeness, based on (1) the rate at which previously undetected lions within a year are found (i.e., this rate should decline as counts approach a census) and (2) whether counts of animals in subsequent years reveal that a substantial number of animals were potentially undetected in previous years. So, while including transients could result in an over-estimate of abundance, we think it is more likely that the true abundance is often higher than the minimum count, and there is some possibility that if survey effort is not intense enough, true abundance could be substantially higher than minimum counts. Despite these concerns, such counts are considered the most reliable method to monitor lion population density and demography (Cougar Management Guidelines Working Group 2005).

To have confidence in minimum counts and make comparisons of count data between years within the same area or within years between areas, it is critical to obtain counts in the same area over multiple years, maintain a high proportion of collared lions in the area being counted, and survey consistently to the point at which by the end of a count period, detections are only of individuals that have been previously identified.