2016-17 Annual Report

Sierra Nevada Bighorn Sheep Recovery Program

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Figure 1. Sierra bighorn at Wheeler Ridge. Photo Credit: Steve Yaeger

Executive Summary

This report covers monitoring, management, and conservation activities carried out between May 1, 2016 and April 30, 2017 by the California Department of Fish and Wildlife's (CDFW) Sierra Nevada Bighorn Sheep Recovery Program. The 2016-17 year was the second wettest year on record for the central Sierra Nevada, which received 73 inches of precipitation (>600 inches of snow in some locations). Although the precipitation was a welcome relief from four years of drought, the impact on Sierra Nevada bighorn sheep (*Ovis canadensis sierrae*; hereafter bighorn) was severe.

Multiple lines of evidence support our estimate that more than 100 females died this winter, or roughly 30% of the known population of females. While more severe than recent big winters, the year-end counts including recruitment only indicate a net loss of 56 ewes, a testament to the resilience of Sierra bighorn. Although most of these mortalities were related to big winter conditions (e.g., caused by malnutrition or avalanche), this includes 17 lion kills, most of which occurred at Langley. Individual collared female mortality varied from 0-80% between herds during the winter and annual collared female survival rates varied by herd from 33-90%. We also documented 9 uncollared and 48 collared ram mortalities that included 8 of the 9 rams translocated during the fall. This is the greatest loss of individuals, as well as the greatest range-wide proportional loss, the Sierra Nevada Bighorn Sheep Recovery Program (hereafter Recovery Program) has documented in a single year. Encouragingly, Sierra bighorn are still distributed across 14 herds, but some herds (Laurel and Convict) are small (<7 females) and may require augmentation to persist. Overall, these losses will extend the timeline for achieving downlisting goals.

Although we cannot predict or reduce the severity of a given winter, we implemented measures to lessen the impact of those events on bighorn in the future. To promote recovery, we have applied the conservation principles of representation, redundancy, and resiliency. In practice, the increased distribution (representation), diversity of occupied habitats (representation), increased connectivity among herds (resiliency), and number of herds

(redundancy) reduces the likelihood of extinction of Sierra bighorn. Climatic threats such as drought and severe winters are mitigated by ensuring that a diverse metapopulation exists (resiliency). Through translocations, Sierra bighorn now occupy alpine habitats that provide some of the most nutritious summer range but where winters can be severe (representation). In a changing climate, these herds may experience buffering due to warming. Additional winter risk may be compensated for since individuals that winter in the alpine are far less vulnerable to predation by mountain lions (resiliency).

Through the efforts of a coalition of stakeholders, the threat of disease from domestic sheep in Mono County was reduced. Previous risk assessment models identified two parcels in Mono County as high risk for contact between domestic sheep and bighorn, and in January, Mono County supervisors voted to stop domestic sheep grazing on these two parcels. In addition, the Recovery Program removed two mountain lions from Langley in response to 18 known lion kills in that area.

Introduction

Conservation of endangered species should include consideration of the potential for catastrophic events to reduce population sizes. Severe weather, predation, and disease are threats that have the potential to cause significant mortality. Population level effects of catastrophes may be mitigated by using a recovery framework that includes the principles of representation, resiliency, and redundancy (Wolf et al. 2015). Recent progress towards meeting recovery goals for Sierra bighorn has expanded their distribution across a diversity of historic habitats, increased the number and size of herds, and increased connectivity among herds. Habitat conservation, translocations, predator management, and disease management have all been implemented and contribute towards reducing the vulnerability of Sierra bighorn to periodic catastrophes and ultimately extinction.

We monitor population sizes, demographic rates, and habitat use to inform management decisions on translocations, augmentations, disease risk, and predator management. In addition, we work to reduce the potential for disease transmission from domestic sheep, and we promote bighorn recovery through public outreach. For brevity, we refer to herds and herd units using single descriptive keywords such as ‘Olancha’ for the Olancha Peak herd unit; we refer to Sierra Nevada bighorn sheep as ‘bighorn;’ and we use ‘2016’ to represent the animal year May 1, 2016 to April 30, 2017.

Big Winter

The central Sierra Nevada had the second wettest water year on record with 72.7 inches of precipitation (Figure 2). This is in sharp contrast to four previous years of drought. The timing of storms this winter was similar to other winters, with the first significant storm (>1 foot of snow in 24 hours) occurring in mid-December, followed by a series of storms in January and February, and one last significant storm in April (Figure 3).

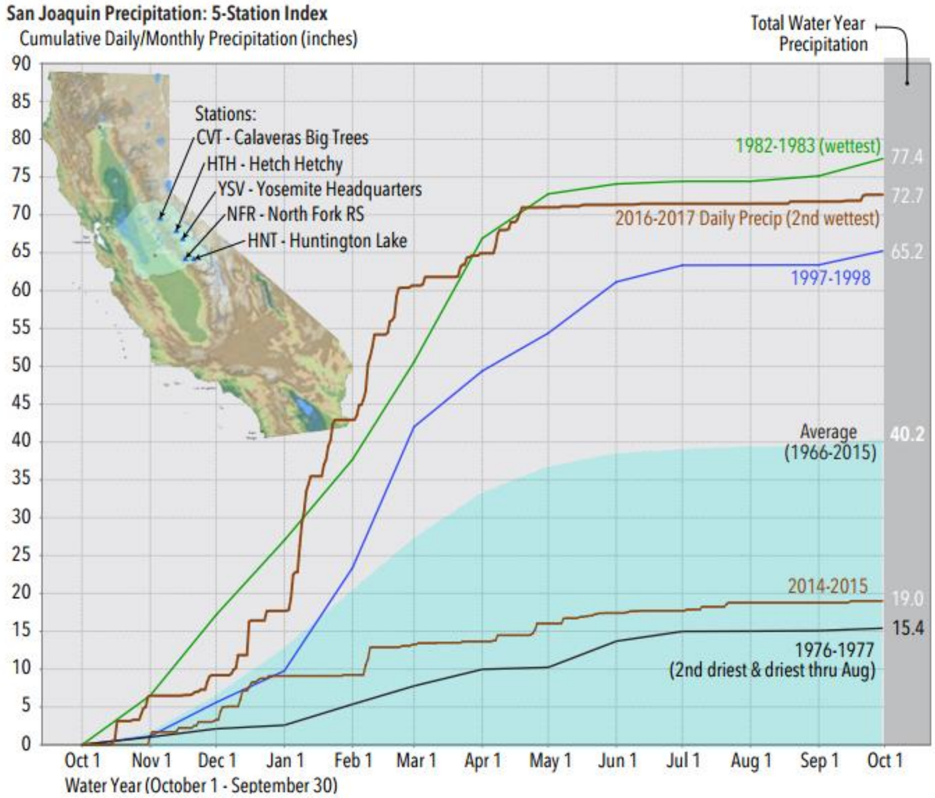


Figure 2. History of San Joaquin drainage annual precipitation beginning in 1966 (Anderson 2017).

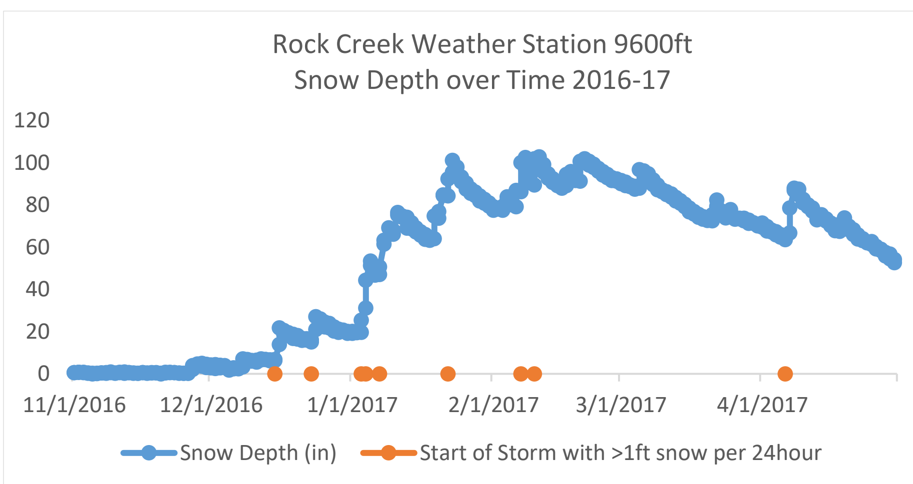


Figure 3. Storm timing and snow depth at Rock Creek weather station in the Sierra Nevada during the 2016-17 winter.

Severe winters cause bighorn mortality from avalanche and malnutrition. Several weather stations near or within Sierra bighorn habitat reported more than 10 feet of snow on the ground in April 2017, in contrast to the drought years of 2013-16, which had <5 feet and sometimes <1 foot of snow (Figure 4). Since the recovery program began in 2000, there have been three years with April snow depth >10 feet (2017, 2011 and 2006, location variable), and all have resulted in substantial bighorn mortality. If the last 67 years are an indicator of future climate conditions, heavy snowfall winters will continue sporadically. Bighorn recovery requires herds that are able to persist through these conditions.

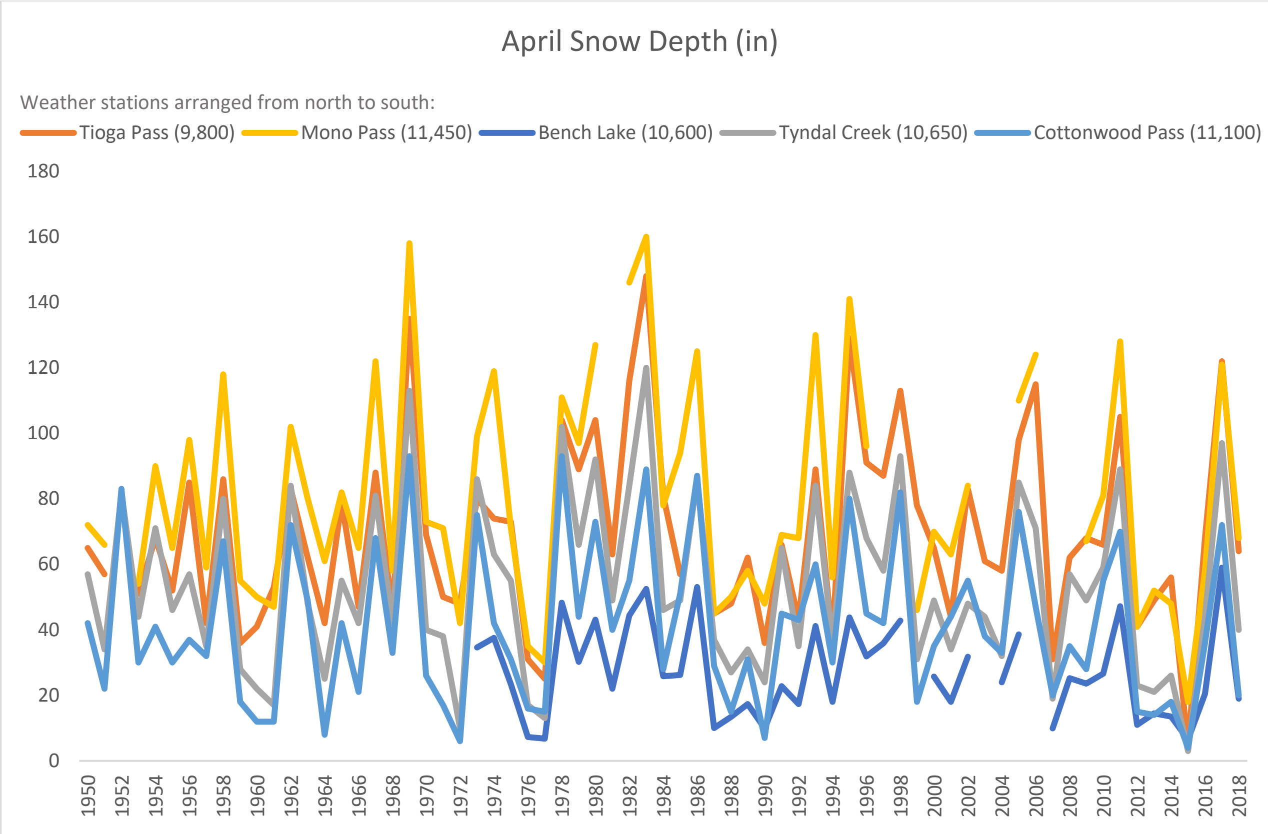


Figure 4. April snow depth (in) since 1950 at 5 high elevation sites in the Sierra Nevada. Mono Pass weather station is out of the Rock Creek drainage. Data compiled from California Data Exchange Center, Department of Water Resources (https://cdec.water.ca.gov/).

Population Impacts from the Big Winter and Cause Specific Mortality

We estimate roughly 100 females died in the big winter of 2016-17 (based on pre- and post-winter minimum counts; Table 1). The proportion of collared females known to have died varied greatly among herds, from 80% in Convict to 0% in Olancha (Figure 5). Laurel and Convict are particularly concerning because the high levels of loss have reduced these already small herds to very low numbers (N=2 and N=6, respectively). Augmentation may be necessary to maintain these herds.

Olancha was least impacted by the big winter, most likely because it has abundant low elevation winter range, and it is both the southernmost herd and the herd with the lowest overall elevation. In addition, both Baxter and Gibbs had low levels of winter mortality. The low mortality at Baxter may be explained by its central location and extensive low elevation winter range. In contrast, Gibbs is a northern herd that does not have any low elevation winter range (Figure 5), but excellent summer range allowing for significant fat reserves. Gibbs bighorn winter in the alpine, typically above 11,000 ft. At Langley, the majority of collared female mortality (N=9/14, 64%) was caused by mountain lion predation on animals wintering on low elevation winter range.

We used two methods to estimate total female mortality (Table 1). Based on the percentage of collared females in each herd and the known collared female mortality, we estimated that 107 females died during this time period (Table 1). Using minimum counts before and after the big winter, we estimate that 104 females died over the winter (Table 1). Although both methods have some uncertainty, their similarity supports an estimate of roughly 100 female mortalities, or 30%, based on the 2015 year-end estimates and assuming a 50% sex ratio of lambs (Greene et al. 2016).

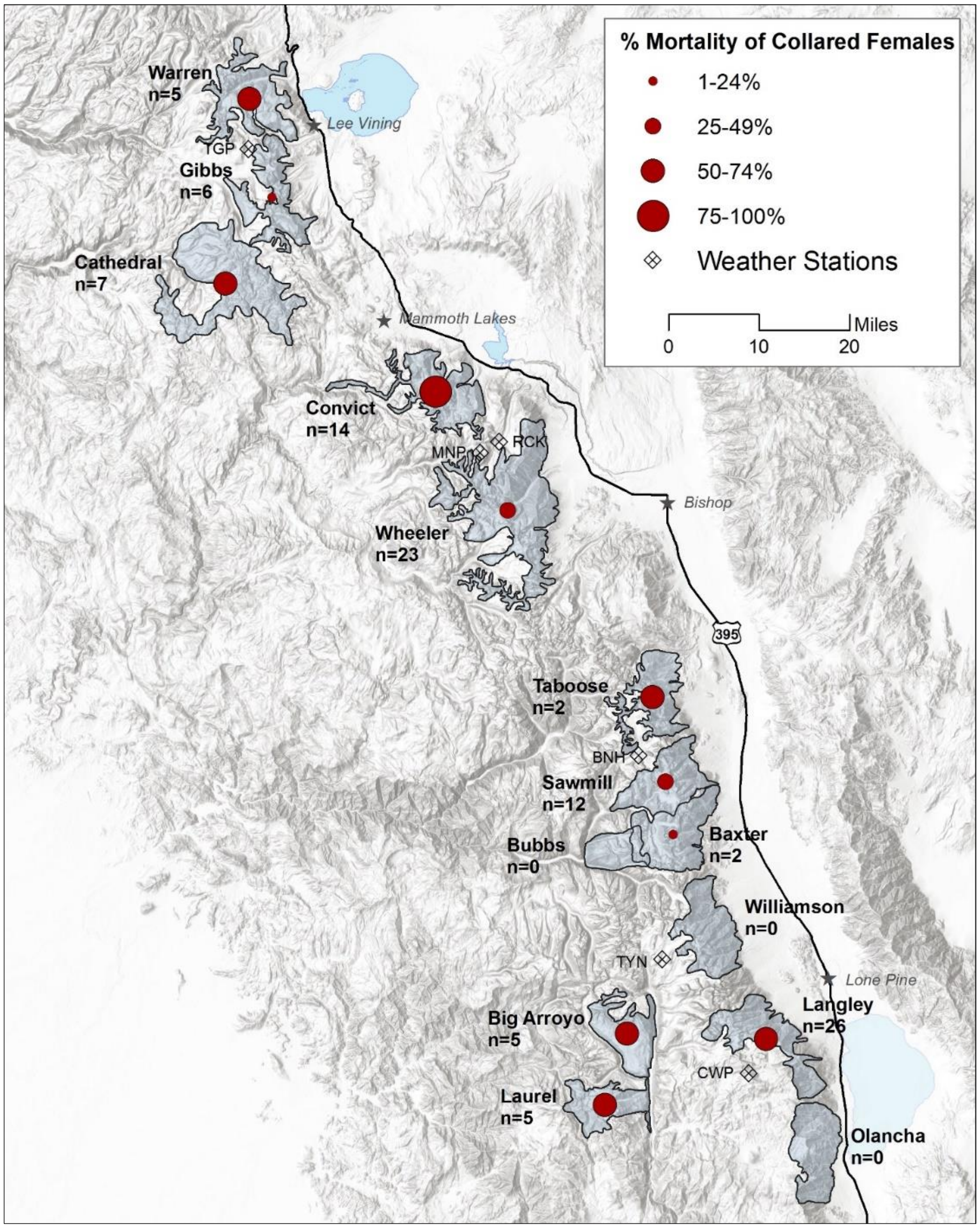


Figure 5. Herd units occupied by Sierra bighorn sheep as of April 30, 2017. Also shown is the proportion of collared female mortality experienced in each herd.

In total, we documented 74 ewe mortalities, including 68 collared and 6 uncollared animals this year. Uncollared mortalities are found while in the field for other reasons, such as when investigating collared mountain lion clusters or other bighorn mortalities (e.g., avalanches, which may involve a group of bighorn). Despite having an unprecedented amount of mortality this year, we were able to identify the cause of death of more than half of the collared female mortalities (Figure 6a). This involved an incredible effort from field staff, particularly since the majority of mortality occurred in winter (Figure 6b) and across all herds except Bubbs (Figure 6c). In addition, we documented 57 ram mortalities, including 48 collared and 9 uncollared individuals. Collared rams died from unknown cause (N=25), avalanche (N=9), malnutrition (N=7), lion predation (N=5), rock fall (N=1), and bobcat predation (N=1). Finally, there were 10 mortalities of unknown sex, 6 from mountain lion predation, and 4 from unknown cause. In general, our cause specific mortality data is likely biased to include more lower elevation predation events as they tend to be easier to access and investigate.

Table 1. Estimates of female Sierra bighorn mortality in the winter of 2016-17. Includes all female mortalities from November 1, 2016 - April 30, 2017. We estimated the total female mortality from collar ratios by herd with the equation: [% collared female mortality] * [female MC pre-winter] summed across herds. We estimated total female mortality from MC with the equation: [female MC post-winter] - ([female MC pre-winter] + 0.5 * [lambs MC pre-winter]), where MC is minimum count.

Herd	# collared females in November 2016	Female MC pre-winter	Lambs MC pre-winter	Season Year	Est. % females collared	# collared female mortality	% collared female mortality	Est. Total female mortality from collar ratios	Projected adult and yearling females	Female MC post-winter	Season Year	Est. Total female mortality from MC
Olancha	9	18	6	summer 2016	0.50	0	0.00	0	21	22	summer 2017	-1
Laurel	7	8	3	summer 2016	0.88	4	0.57	5	10	2	summer 2017	8
Big Arroyo	8	10	5	summer 2016	0.80	4	0.50	5	13	9	summer 2017	4
Langley	21	49	16	summer 2016	0.43	11	0.52	26	57	25	summer 2017	32
Williamson	4	13	4	summer 2016	0.31	0	0.00	0	15	17	winter 2017	-2
Baxter[w]	19	41	20	spring 2016	0.46	1	0.05	2	51	48	spring 2017	3
Sawmill	17	42	16	summer 2016	0.40	5	0.29	12	50	45	summer 2017	5
Bubbs* (2013)	3	12	9	summer 2013	0.25	0	0.00	0	12	12	summer 2017	0
Taboose* (2014)	2	3	0	summer 2014	0.67	1	0.50	2	3	1	summer 2017	2
Wheeler[w]	18	58	17	spring 2016	0.31	7	0.39	23	67	49	spring 2017	18
Convict	11	18	8	summer 2016	0.61	8	0.73	13	22	6	summer 2017	16
Cathedral	10	12	0	summer 2016	0.83	6	0.60	7	12	6	summer 2017	6
Gibbs	13	27	11	summer 2016	0.48	3	0.23	6	33	25	summer 2017	8
Warren	2	10	5	summer 2016	0.20	1	0.50	5	13	6	summer 2017	7
Totals	**143**	**321**	**120**		**7**	**51**	**5**	**107**	**377**	**273**		**104**

[w] MC (minimum counts) conducted during the winter of 2016-17

* MC conducted in earlier year, designated by parenthesis

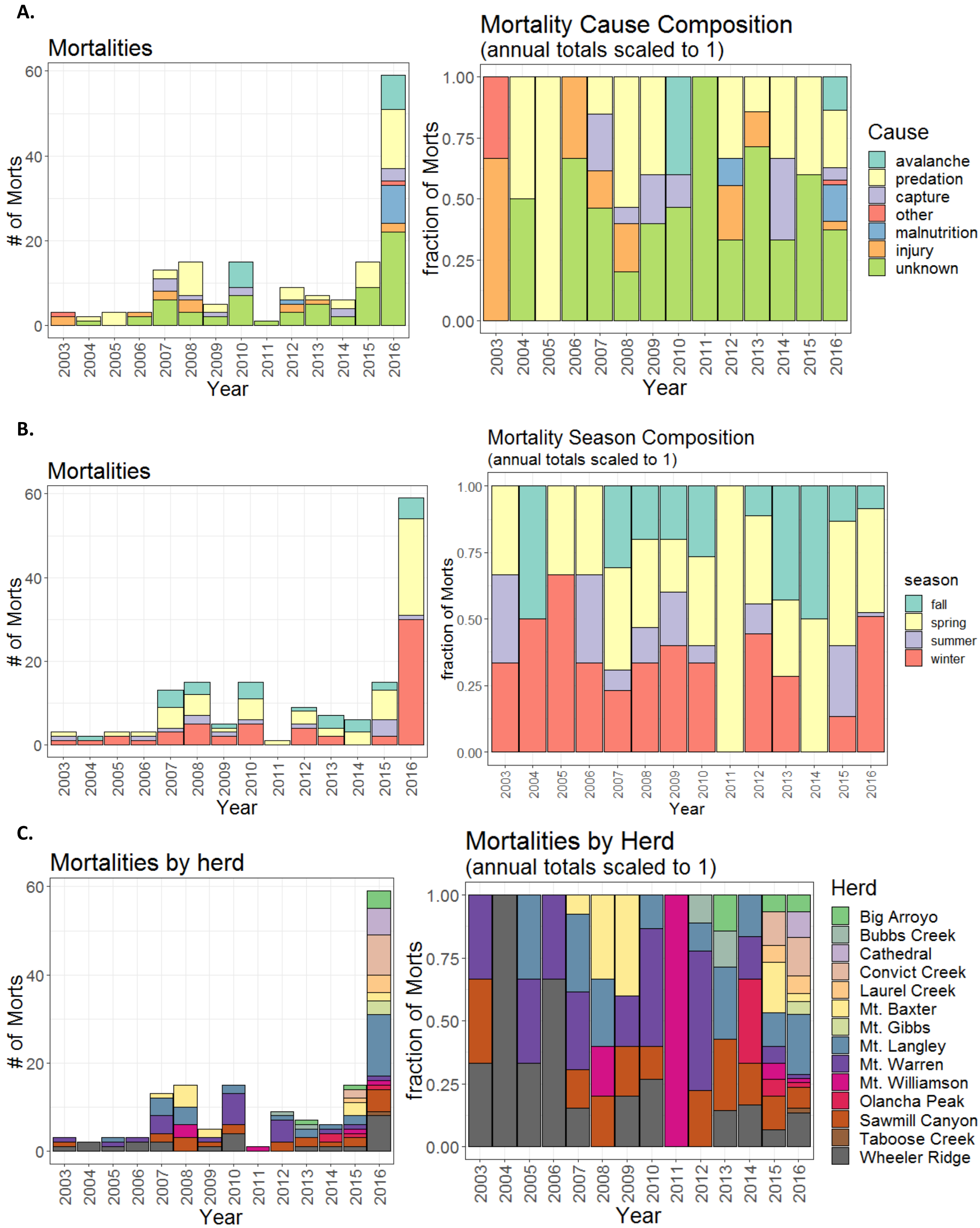


Figure 6. Collared female Sierra bighorn mortality by A). cause of death, B). season, and C). herd, as compared for the last 14 years. The numbers of collared females generally increased with time, as did the distribution of collars across herds. This does not include censored animals, because their cause and date of death are unknown.

During 2005-2016 we documented 152 collared female mortalities. Nearly half (49%; 74/152) of those mortalities occurred during the two years with noticeably larger snowfall (2010 and 2016). Most mortalities from malnutrition or avalanche occurred during those big winter years (N=23), compared with average or drought years (N=1; Figure 7). A female is 24 times more likely to die from malnutrition or avalanche during a big winter (95% C.I. 3.4-175). However, it is important to consider that the cause of death was not determined for 42% of collared female mortalities (64/152). We are less able to determine the cause of death when the carcass cannot be accessed promptly. Because malnutrition and avalanche deaths often occur at higher elevations and in areas that are more difficult to access, particularly in winter, it is likely that malnutrition and avalanche deaths may be the true cause of death for a larger proportion of unknown-cause mortalities than known-cause mortalities.

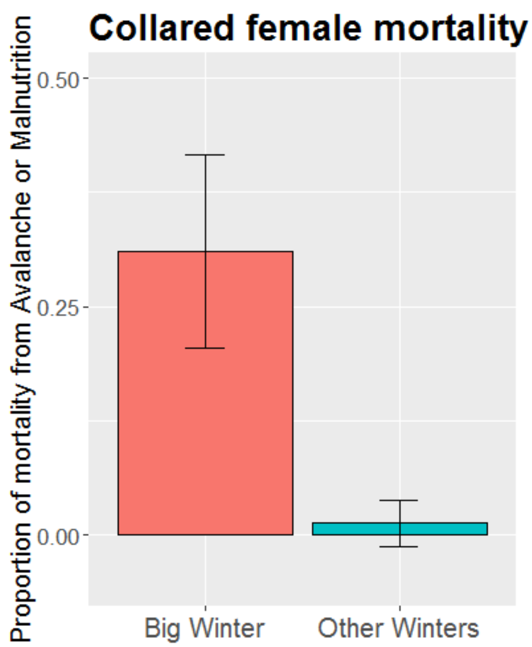


Figure 7. Collared Sierra bighorn female mortality from malnutrition and avalanche between 2005-2016. Big winters include 2010-11 and 2016-17. Nearly all malnutrition and avalanche deaths occur during these two big winters.

Geographic Distribution

As of April 30, 2017, Sierra bighorn occupy 14 herds, from north to south: Warren, Gibbs, Cathedral, Convict, Wheeler, Taboose, Sawmill, Baxter, Bubbs, Williamson, Big Arroyo, Laurel, Langley, and Olancha (Figure 5). This meets the downlisting criteria for distribution, although numeric goals have not yet been achieved (Figure 8).

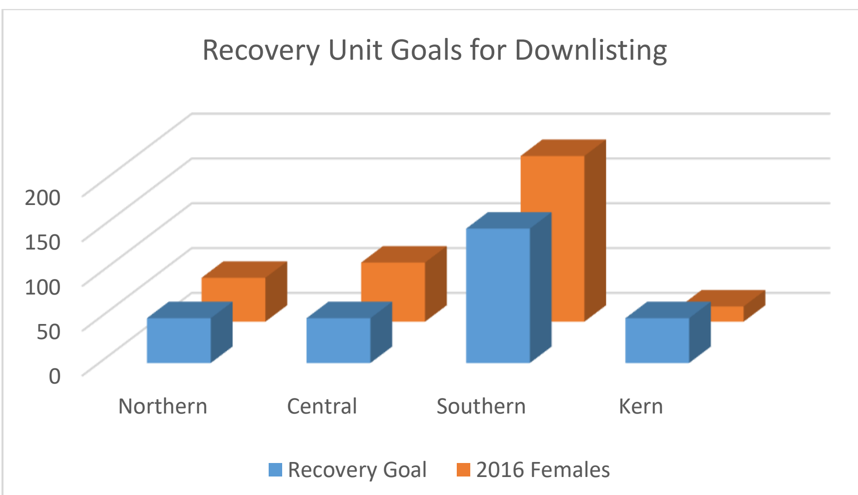


Figure 8. Adult and yearling female Sierra bighorn in each recovery unit relative to downlisting recovery goals.

Population Dynamics: Population Size

When bighorn were listed as an endangered species in 1999, the entire range-wide population was estimated to be 95-129 adults including at least 49 adult females (Wehausen 1999). In 2016, we estimated a total population size of 675, which included 317 yearling and adult ewes, 120 lambs, and an estimate of 238 rams based on a ram:ewe ratio of 3:4 (Figure 9).

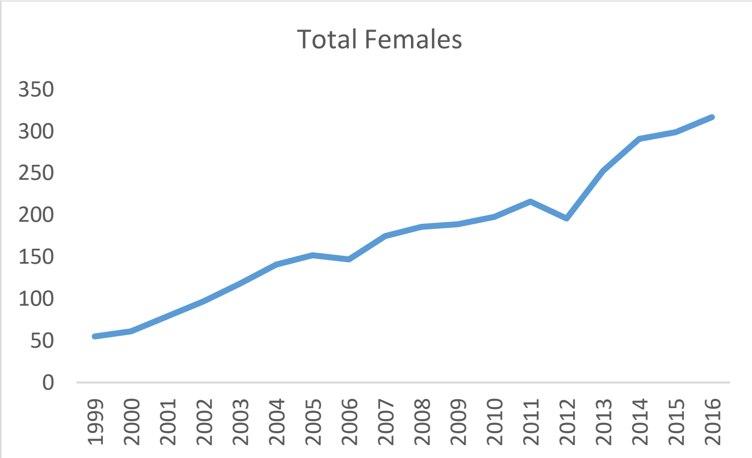


Figure 9. Range-wide total female population abundance since 1999 of Sierra bighorn. This does not include the impacts of the big winter for most of the herds because they were counted the previous summer. Data includes the highest reconstructed minimum counts as well as Mark-Resight estimates with CV < 0.15. Counts combine surveys from different seasons, selecting for the highest count each year.

Because most herds are counted in the summer (except for Baxter and Wheeler), this population estimate does not include the impacts of the big winter (see Population Impacts from the Big Winter). We estimate female numbers using a combination of reconstructed minimum counts and Mark-Resight estimates with a CV < 0.15. The most common way minimum counts are "reconstructed" is to add in collared individuals known to be alive but not seen during the survey. We use a ram:ewe ratio instead of the minimum count of rams (N=220) because our survey and collaring efforts are directed toward females. Although we have observed a ram:ewe ratio as high as 1 in some herds, in general we observe a higher ram mortality rate and therefore use 0.75 as a more conservative and realistic estimate of ram numbers.

Although some changes in population estimates, particularly within a few years, may be driven by the completeness of minimum counts or accuracy of Mark-Resight estimates, the overall trends likely represent true population trajectories and align with our collar-based vital rates. The largest three herds, Wheeler, Baxter, and Langley, each contain just under 50 females (Figure 10). At the time of these surveys, we were above the numeric goals for downlisting in the central and southern recovery units and nearing the goal of 50 females in the northern recovery unit (N=49; Figure 8). We are still short 33 females in the Kern recovery unit.

We categorize bighorn populations in terms of various management objectives. Populations we consider to be large enough to serve as a source for translocation stock (ewe population > 40) are called source herds (USFWS, 2007). Bighorn are periodically removed from these herds to augment existing herds or reestablish herds in historical locations. New herds are those reestablished since 2013.

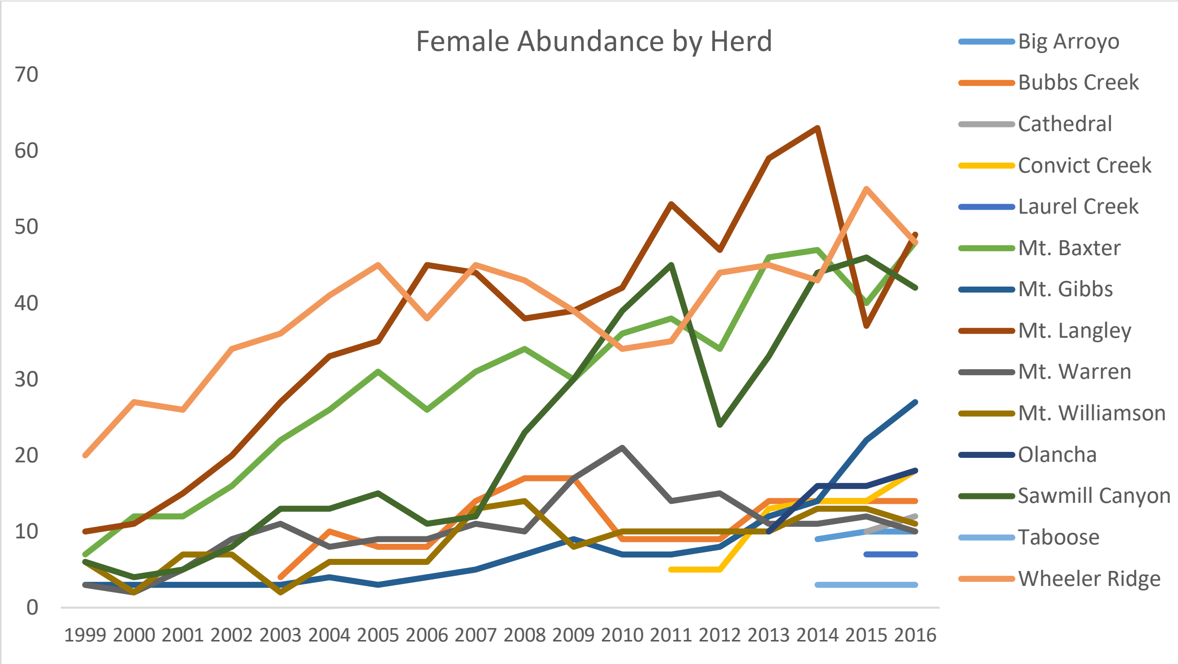


Figure 10. Estimated female Sierra bighorn sheep within each herd. This does not include the impacts of the big winter for most of the herds because they were counted in the previous summer. This includes the highest reconstructed minimum counts as well as Mark-Resight estimates with CV < 0.15. It uses abundance from different seasons, depending on the survey success in a given year and season. Newly reintroduced herds are first counted in the animal year following reintroduction to avoid double counting.

Population Dynamics: Survival

Sierra bighorn population trajectories are typically driven by adult female survival (Johnson et al. 2010). Here we report Kaplan-Meier survival rates (Kaplan and Meier 1958) for herds with at least 3 collars, with an average 10 collars per herd per year for source herds, and an average of 8 collars per herd per year for new herds (Figure 11 and Figure 12). Unlike the population estimates (Figures 9 and 10), these survival rates do include the impact of the big winter and collared animal survival through April 30, 2017.

Three of the lowest survival rates we have ever documented occurred this year at Langley (37%), Cathedral (40%), and Big Arroyo (50%). Heavy snowpack was directly responsible for the decreased survival at Cathedral and Big Arroyo, while Langley survival was reduced by predation.

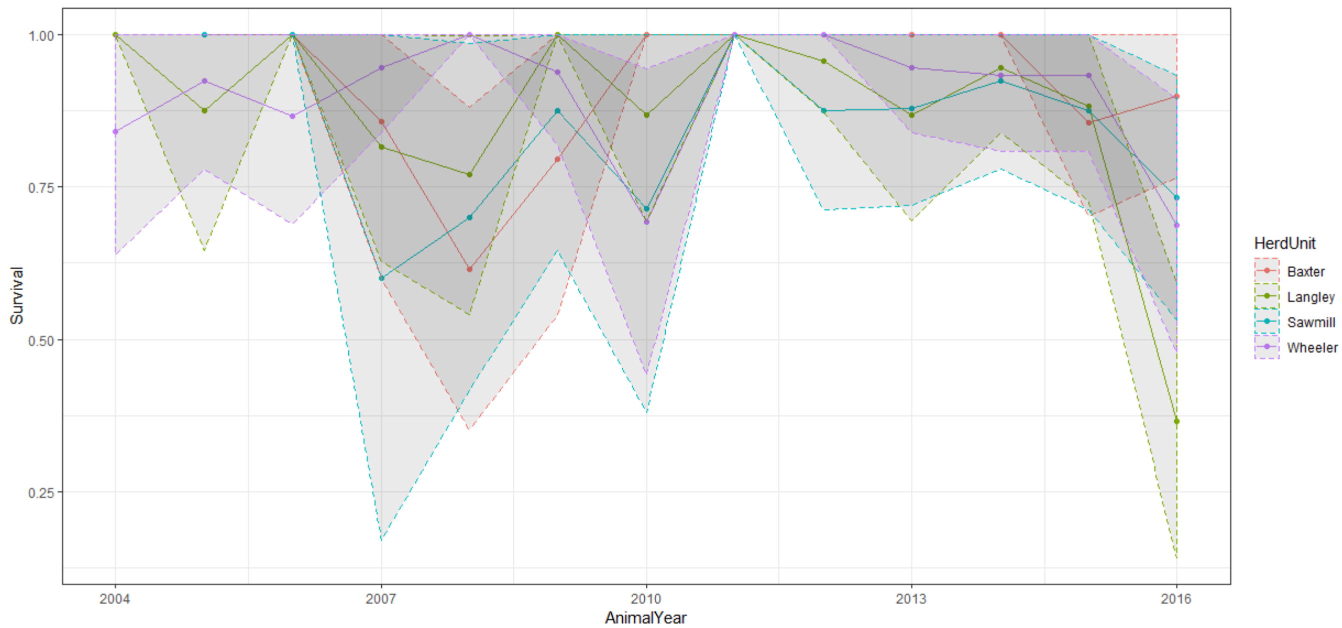


Figure 11. Kaplan Meier Survival rates with 95% confidence intervals from collared female Sierra bighorn for source herds from 2004-2016, using the sheep year of May 1-April 30. Confidence intervals cannot be calculated when there is 100% marked animal survival.

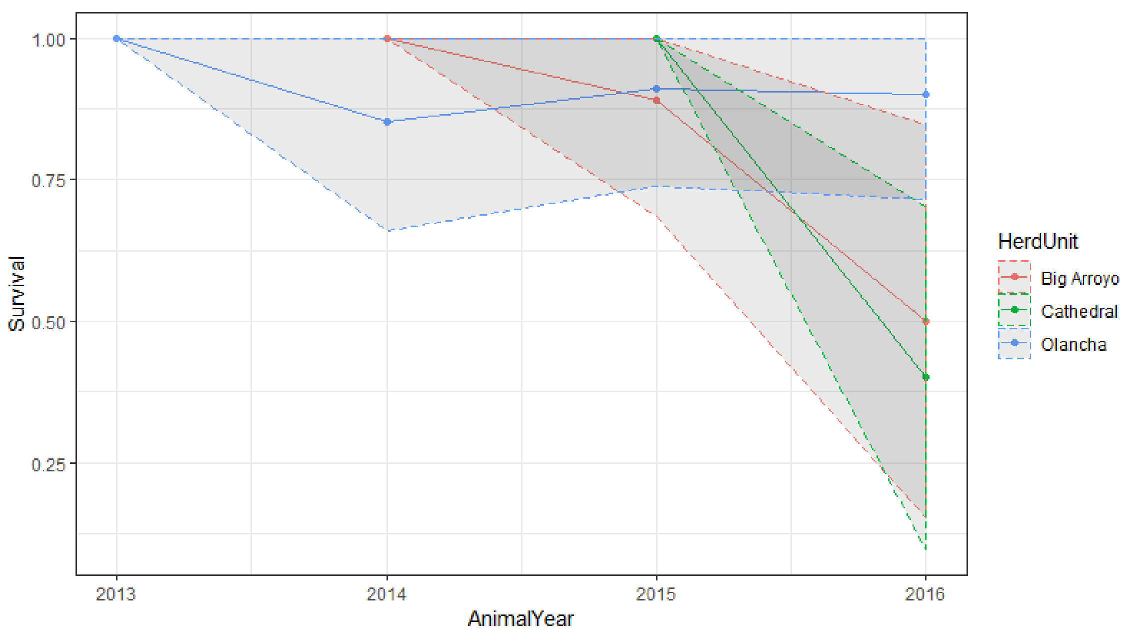


Figure 12. Kaplan Meier Survival rates with 95% confidence intervals from collared female Sierra bighorn for 3 newly established herds from 2013-2016, using the sheep year of May 1-April 30. Confidence intervals cannot be calculated when there is 100% marked animal survival.

Based on visual assessment, source herd survival tends to be asynchronous, possibly as a function of the variable nature of predation on the landscape, with somewhat synchronous decreases in years with large snowfall as occurred in 2010 and 2016 (Figure 11). In fact, the reduction in survival observed in Wheeler and Sawmill was almost identical in 2010 and 2016, indicating larger snowpack winters tend to reduce survival in these herds to ~70%.

Despite its proximity and general similarity to Sawmill, at Baxter, survival does not appear to be reduced during winters with heavy snowfall.

In the newly established herds, annual survival varied dramatically in response to the big winter. Big Arroyo and Cathedral experienced low survival (50% and 40% respectively), while survival at Olancha remained high (90%). These divergent survival patterns may be driven by differences in snowfall in the occupied winter ranges. Low elevation winter range at Big Arroyo still had significant snow cover, and all Cathedral animals except 1 female stayed high throughout the winter in windswept areas surrounded by snow. In contrast, due to its southern location and lower elevation overall, as well as a clear and easy connection to very low elevation winter range with sparse snow, animals in Olancha did not experience a heavy snowpack and could move down from the snow as needed.

Low numbers of collared females in some herds in some years, particularly during the earlier years, results in larger confidence intervals. Additionally, some of the variation in collared female survival is driven by the discrete nature of small numbers which can lead to large, but not necessarily meaningful, increases or decreases to the percent change. However, this problem is less prevalent in later years, when we tended to have a higher number of collared females. Over time, we have also distributed collars across more herds (as reintroductions and natural colonization events occurred). The inconsistency of collar numbers and distribution is important to consider when looking at cause specific mortality for the last 14 years (Figure 6a-c).

Reproduction and Recruitment

We estimate fecundity, or annual reproductive success, from the ratio of lambs to ewes. Here we report the observed lamb:ewe ratio for all annually monitored herds (Table 2). For herds in which we have a near census on the population we also calculate the lamb:ewe ratio and the lamb survival from minimum counts directly (Table 3). Averaged across herds, observed lamb:ewe ratios were similar in 2015 (47%) and 2016 (49%; Table 2). During spring captures, pregnancy rates averaged 85% in adult females (N=121), while observed lamb:ewe ratios were much lower (range 20-67%; Table 2). Some of this difference may be explained by lower pregnancy rates observed in yearlings (55%, N=9) which are counted as adults due to the timing of lamb:ewe counts. Alternately the difference could be explained by undetected losses that occurred in utero or as neonatal mortalities (Gilbert et al. 2014).

Table 2. Estimated Sierra bighorn lamb survival based on observed juvenile age class ratios in animal years 2015 and 2016. Lamb survival capped at 100%. For herds counted in winter 2017 (Baxter and Wheeler, [w]), survival is from winter 2016 to winter 2017, or from 9 to 21 months of age. For herds counted in summer 2016, survival is from summer 2015 – summer 2016, or from 3 to 15 months of age. Due to survey timing, the impact of the winter of 2016-17 is shown here for Baxter and Wheeler but not the other herds.

	2016 Lamb:Ewe			2015 Lamb:Ewe			2016 Yearling:Ewe		
Herd	**Date**	**N**	**%**	**Date**	**N**	**%**	**N**	**%**	**Lamb Survival Estimate**
Olancha	9/27-28	6:12	50%	8/24	4:9	44%	7:12	58%	100%
Big Arroyo	6/8-8/18	5:8	63%	5/12-13	2:5	40%	4:8	50%	100%
Langley	9/5-9/8	16:40	40%	9/1-3	20:26	77%	12:40	30%	39%
Baxter[w]	1/17/17	20:37	54%	3/9/16	15:26	58%	12:37	32%	56%
Sawmill	9/13-15	16:30	53%	3/10/16	7:33	21%	9:31	29%	100%
Wheeler[w]	2/14	17:41	41%	2/9-10/16	19:46	41%	5:41	12%	30%
Convict	7/13/16	8:12	67%	9/16-23/15	8:11	73%	7:12	58%	80%
Cathedral	7/12/16	2:10	20%	7/15-16/16	2:9	22%	2:10	20%	90%
Gibbs	7-8/2016	11:22	50%	7/1/15	10:18	56%	10:22	45%	82%
Warren	8/24-26/16	5:9	56%	6/30-7/1/15	4:10	40%	3:9	33%	83%
Totals			**49%**			**47%**		**37%**	**76%**

Table 3. Estimated Sierra bighorn lamb survival based on minimum counts of lambs in 2015 and yearlings in 2016 for select herds in which population data is near census. Lamb survival is from 3 to 15 months of age.

Herd	2016 Lamb:Ewe from MC		2015 All Lambs	2016 All Yearlings	Estimated Lamb Survival
Olancha	6:14	43%	7	7	100%
Big Arroyo	5:9	56%	4	4	100%
Convict	8:13	62%	8	7	88%
Cathedral	0:10	NA	2	2	100%
Gibbs	11:22	50%	10	10	100%
Warren	5:9	56%	4	3	75%
Average		**53%**			**94%**

In addition to fecundity, we also estimate lamb survival based on the ratio of observed age classes across 2 years ([2016 Yearling:Ewe]/[2015 Lamb:Ewe]; Table 3) as well as based on minimum counts for herds with near-census minimum counts (Table 3). Because Baxter and Wheeler are counted in the winter, we estimate lamb survival is from 9 to 21 months of age, which includes the winter of 2016-17. All other herds are counted in summer, in which lamb survival is estimated from 3 to 15 months of age and does not include winter 2016-17. This explains the low lamb survival in Baxter and Wheeler (56% and 30% respectively) compared to most other herds (82-100%), with the exception of Langley (39%) (Table 2).

In order to better understand why lamb:ewe ratios are lower than pregnancy rates, we started a two-year lambing study. Vaginal implant transmitters (VITs) were placed in 10 pregnant ewes in March 2016, and these ewes and their lambs were tracked through birth and for several months after birth (Table 4). After removing 1 female who was killed by a mountain lion before giving birth, the lamb:ewe ratio of the study animals was 5:9, or 55%, similar to lamb:ewe ratios observed during surveys (Tables 2 and 3). Of the 4 females that were never seen with viable lambs, 1 stillbirth was recovered, and the 3 others remain a mystery. Despite being investigated within 48 hours of the VIT dropping, no lambs were observed. We were unable to differentiate between 3 possible outcomes: a) lambs were born viable and depredated, b) lambs were born non-viable and depredated, or c) the pregnancy was terminated in a manner that did not involve dropping the VIT. However, the third option does not seem likely because bedsites with blood and mucous were discovered at 2 of the 3 sites. In addition, VITs dropped prematurely in 2 of the 9 cases; lambing sites were later determined by clustered female locations.

Table 4. Results from Sierra bighorn lamb project that tracked 10 pregnant females with vaginal implant transmitters (VITs) and their lambs. VITs were placed in March 2016.

Herd	ID	VIT Drop	Outcome for Mother	Lamb ID	Lamb Status
Langley	S177	4/20/2016	VIT site had bed with blood and mucous, no lamb seen 4/12 or 9/7. Died 1/14/17 from lion predation.	NA	NA
	S425	5/12/2016	Lamb present and captured. Died 2/19/17 from unknown cause, not predation.	S434	Died 11/6/16, unknown cause
	S426	5/6/2016	VIT site had bed but no blood or mucous. Unknown lamb status 6/21, no lamb 9/7.	NA	NA
Wheeler	S240	6/9/2016	No birth-site found at VIT location. Clustered 6/25, recovered female stillborn lamb. Died 5/24/17 from fall.	no ID	Stillborn
	S417	5/16/2016	Lamb present, not accessible. Seen with lamb 6/14/16.	no ID	Presumed alive
	S419	4/17/2016	VIT site had blood and mucous, no lamb seen. Repeatedly observed through the summer, never with lamb.	NA	NA
	S420	NA	Died 5/25/16 from lion predation, fetus partially consumed.	NA	NA
Convict	S222	5/22/2016	Lamb present and captured. Died 1/26/17 from avalanche.	S435	Died 1/25/17, unknown cause
	S423	5/24/2016	Lamb present and captured. Died 1/27/17 from unknown cause.	S436	Died 1/1/17, malnutrition
	S424	4/7/2016	VIT site had no bed. Clustered 4/25, observed with lamb. Died 1/24/17 of hypothermia with unidentified lamb.	no ID	Probably died 1/24/17 with mother

Population Monitoring: Herd Unit Surveys

Each year we perform ground surveys to estimate the female population size of various herds. Although we also count rams, our focus is on females because they drive population trajectories (Johnson et al. 2010). We try to survey source herds (>40 individuals) and newly reintroduced herds annually. Smaller herds are surveyed as conditions and resources allow. Here we report the survey results for this year, but also include the most recent surveys for herds that we did not survey this year (e.g. Bubbs 2013; Table 5). Most of the surveys summarized here were conducted in the summer of 2016 before the big winter. Detailed survey summaries are reported in Appendix A.

Table 5. Minimum count data and Mark-Resight estimates (MR Est) of Sierra Nevada bighorn sheep from surveys conducted from May 1, 2016 to April 30, 2017. MR Est is for female yearlings and adults combined. Lambs are not identified by sex.

Herd	Ewes				Lambs	Rams			Total
	Adult	Yrlng	Total	MR Est		Adult	Yrlng	Total	
Olancha	14	4	18	-	6	6	3	9	33
Laurel	6	1	7	-	3	1	3	4	14
Big Arroyo	9	1	10	-	5	4	3	7	22
Langley	43	6+	49	47 (31-73)	16	16	7+	23	90+
Williamson (rams 2014)	10	1	11	-	4	8	2	10	25
Baxter[W]	42	6	48	-	20	34	6	40	108
Sawmill[C]	35	7	42	-	16	16	6	22	80
Bubbs (2013)	12	1	14*	-	9	5	1	6	27
Taboose (2014)	2	1	3	-	0	15	2	17	20
Wheeler[W]	45	3	48	70 (43-114)	17	36	3	39	104
Convict	13	5	18	-	8	12	2	14	40
Cathedral	10	2	12	-	0	1	0	0	12
Gibbs	22	5	27	-	11	14	5	19	57
Warren	9	1	10	-	5	8	2	10	25
Totals	**272**	**38**	**317**	**323**	**120**	**176**	**38**	**220**	**567**

Most surveys conducted in summer; [W] = winter surveys; [C] = data combined from winter and summer surveys. + count includes 1 yearling of unclassified sex, so the overall count is 1 higher than the sum of adults and yearlings. * count includes 1 female of unclassified age, so the overall count is 1 higher than the sum of adults and yearlings.

We use ‘survey’ to refer to a systematic effort to cover the known range of female habitat used within a given herd. Surveys result in a minimum count or a Mark-Resight (MR) estimate. Minimum counts make use of telemetry and satellite collar locations. In addition, minimum counts may be augmented or reconstructed based on additional observations and collared animals not seen. MR population estimates are derived from the ratio of marked to unmarked individuals and are developed from observations in which telemetry was not used. In addition to surveys, we also make opportunistic observations. A collared animal is censored after two years without visual or radio telemetry observation; censor date is one month after the last observation. Censoring and additional observations can cause the population estimates to change slightly from when they are initially reported (therefore there may be discrepancies between past annual reports). Reported minimum counts are the highest count for the given age class and sex, after accounting for and combining different survey efforts and opportunistic observations.

Table 6. Sierra bighorn sheep estimates as of April 30, 2017 after accounting for known mortalities and translocations. This is likely an overestimate of the population because known mortalities are often collared animals, and collared animals represent only a proportion of the total population. It particularly overestimates lamb survival, as very few lambs are collared.

Herd	Ewes			Lambs	Rams			Total
	Adult	Yrlng	Total		Adult	Yrlng	Total	
Olancha	14	4	18	6	5	3	8	32
Laurel	2	1	3	3	1	3	4	10
Big Arroyo	5	1	6	5	1	3	4	15
Langley	29	5	34	9	14	5	19	61**
Williamson (rams 2014)	10	1	11	4	8	2	10	25
Baxter^{W}	41	6	47	20	33	6	39	106
Sawmill^{C}	30	7	37	16	8	6	14	65***
Bubbs (2013)	10	1	12*	9	5	1	6	27
Taboose (2014)	1	0	1		3	0	3	4
Wheeler^{W}	41	3	44	16	36	3	39	99
Convict	5	5	10	6	9	2	11	27
Cathedral	4	2	6	0	0	0	0	6
Gibbs	19	5	24	11	11	5	16	51
Warren	8	1	9	5	5	2	7	21
Totals	**219**	**47**	**262**	**110**	**139**	**41**	**180**	**549**

Most surveys conducted in summer; W = winter surveys; C = data combined from winter and summer surveys. + count includes one yearling of unclassified sex so the overall count is one higher than the sum of adults and yearlings. * count includes 1 female of unclassified age, so the overall count is 1 higher than the sum of adults and yearlings. ** overall count reduced by 1 because there was 1 yearling mortality of unknown sex. *** overall count reduced by 2 because there were 2 uncollared adult mortalities of unknown sex.

Survey timing varies between herds. The best survey results for Baxter and Wheeler usually occur in winter (Jan-Apr), when animals tend to congregate at lower elevations. Most other herds are surveyed in the summer (June-Sept), although big snow winters can provide unique winter survey opportunities. Because surveys occur at different times of year for different herds, our best estimates for each herd (Table 5) do not represent a single snapshot in time. Therefore, we also tabulate all known animals at the end of the reporting period, including all translocations and known mortalities for that period (Table 6). For smaller herds that are not monitored annually (e.g. Taboose, Bubbs, Williamson), we use a static estimate based on the most recent count.

Survey success is driven by persistence and luck. Sometimes bighorn congregate in areas where it is easy to count and identify them, and other times bighorn may be spooked and scatter, not to be seen again during the survey. It can take multiple attempts to get a good count of a given herd, and in some years we are unable to get a good count (detailed summaries of survey attempts in Appendix A). A count is considered “good” if at least 20% of the females are collared and if at least 80% of collared females are seen.

We also try to assess which counts may be complete counts, or censuses, of a given herd. As the number of females increases above 20, censuses are less likely, but at low numbers, particularly when there is a high proportion of collars (e.g. newly translocated herd) census data is common for the first few years. To assess this we look at the previous year count in addition to all known gains (translocations or immigration) and losses (known mortalities, translocations or emigration, and censored animals).

Table 7. Comparison of Sierra bighorn minimum counts by herd in 2015 and 2016, including all known gains (translocations in), and losses (known mortalities, translocations out, and censored animals).

	2015 (Year End)				2016 (MC)			
Herd	**Adult Females**	**Yearling Females**	**Total Females**	**Known Gains - Losses**	**Adult Females Projected for 2016**	**Adult Females Counted in 2016**	**Difference**	**Census Assessment**
Olancha	13	3	16	0	16	14	-2	2 more female yearlings in 2016 than lambs in 2015 count. 2015 not a census
Laurel	6	0	6	0	6	6	0	2015 and 2016 likely census
Big Arroyo	8	1	9	0	9	9	0	2015 and 2016 likely census
Langley	32	4	36	0 (1-1)	36	43	7	2015 count not a census
Baxter[W]	33	7	40	-1	39	41	2	2015 count not a census
Sawmill[C]	40	4	44	0	44	35	-9	2016 probably not a census
Wheeler[W]	50	5	55	-6	49	45	-4	Difficult to interpret
Convict*	10	1	13	0	13	13	0	2015 and 2016 likely census
Cathedral	10	0	10	0	10	10	0	2015 and 2016 likely census
Gibbs	19	3	22	0	22	22	0	2015 and 2016 likely census
Warren	9	2	11	0	11	10	-1	2015 and 2016 likely census
Totals	**230**	**30**	**262**	**-7**	**255**	**248**	**-7**	

* includes 1 female of unknown age.

Capture and Collaring Efforts

Capture provides the opportunity to determine body condition, pregnancy status, and test for various diseases and genetic diversity. Collared animals are critical for monitoring habitat use, disease risk, vital rates, and for estimating herd size. Power analyses indicate that we need to maintain radio collars on 35% of the female population in order to detect a 10% change in survival over 5 years (German 2010). During the survey season, 45% of females were collared, and 34% had functional GPS collars (Figure 13), however this proportion is not evenly distributed across herds. During reintroductions, all animals are initially collared, while the source herds are much closer to the target mark ratio of 35% (Figure 14). Most capture and collaring efforts focus on females, as they tend to drive population dynamics. However, males are also collared at lower proportions (N=76, across 14 herds), to identify habitat use and the potential for contact with domestic sheep.

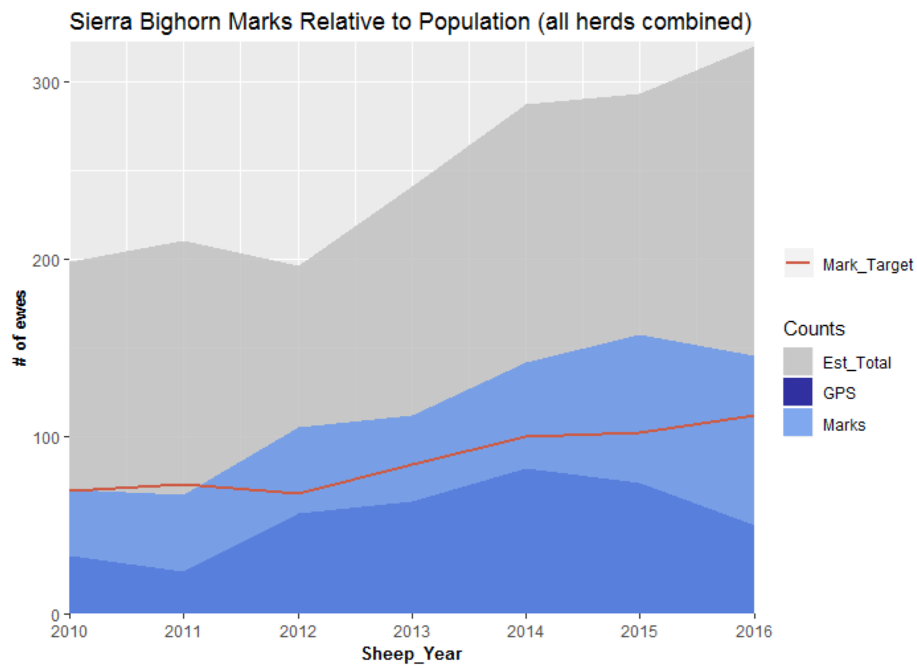


Figure 13. Number of collared female Sierra bighorn from 2010-2016. Overall range-wide female population estimate shown in grey; all marked animals shown in light blue including VHF, GPS, and non-functional collars; and all functional GPS collars shown in dark blue. Red line shows the target proportion of the population estimate (35%). Sheep year is from May 1 of that year to April 30 of the following year. Collar status was assessed at the time of the survey and includes winter mortalities for herds surveyed in winter (Baxter and Wheeler) but not other herds.

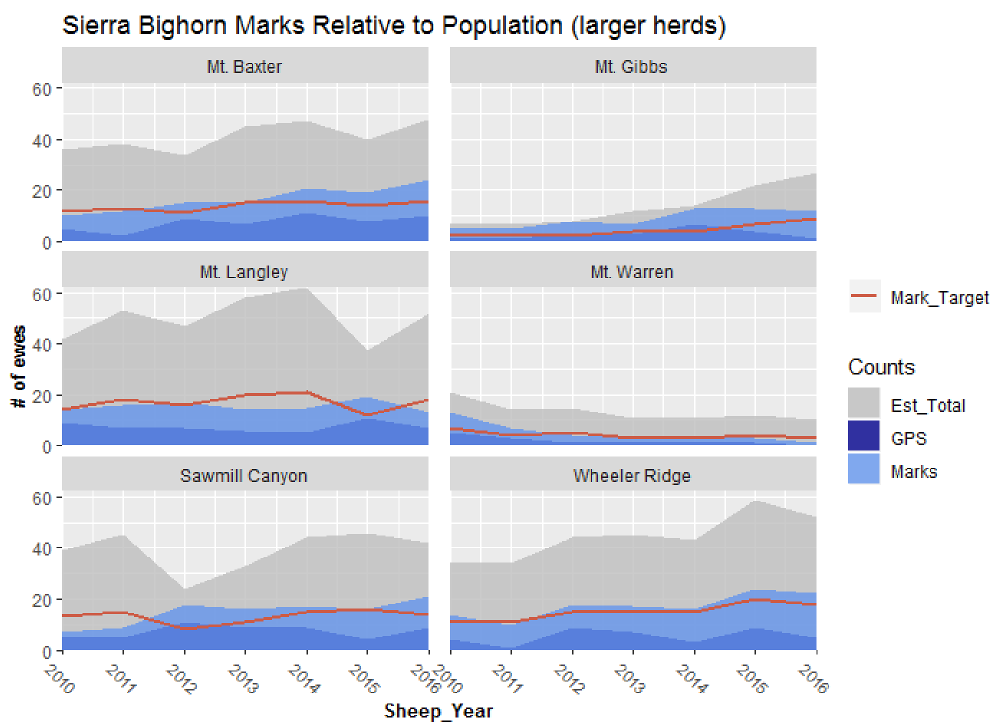


Figure 14. Number of collared female Sierra bighorn in larger herds from 2010-2016. Female population estimate shown in grey; all marked animals shown in light blue including VHF, GPS, and non-functional collars; and all functional GPS collars shown in dark blue. Red line shows the target proportion of the population estimate (35%). Sheep year is from May 1 of that year to April 30 of the following year. Collar status was assessed at the time of the survey and includes winter mortalities for herds surveyed in spring (Baxter and Wheeler) but not other herds.

During October 26 – November 2, we caught and collared 25 Sierra bighorn across 4 herds (Wheeler, Sawmill, Baxter, and Langley). Captured animals included 11 lambs, 5 adult females, and 9 adult males. Five rams were translocated into Cathedral, and 4 rams were translocated into Laurel.

During March 20 – 24, we caught and collared 18 adult females and 1 female lamb across 4 herds (Wheeler, Sawmill, Baxter, and Langley). Thirteen animals were pregnant and given VITs. There were 3 capture-related mortalities that occurred after release, 2 females at Wheeler (S467 and S469), and 1 female at Langley (S470). S467 died from trauma caused by a broken pelvis and associated hemorrhaging. She appeared healthy in base camp but seemed to have trouble moving after her release. S469 died approximately a week after capture, and a necropsy revealed no external or internal injuries. The timing of her death indicates it was likely capture-related. At Langley, S470 showed limited movement post capture. Her stillborn was recovered April 4, and she died April 10, 17 days after capture. A necropsy revealed severe pneumonia in cranioventral lung lobes with no evidence of puncture. The best guess for cause of death was aspiration pneumonia secondary to being captured. Capture mortality may have been higher this spring because animals were in poor condition after the big winter. In addition to the 3 collared animal capture mortalities, 1 uncollared female (M134) was found intact and dead within the region of capture at Wheeler and estimated to have died 6 days after capture; necropsy and lab results were inconclusive. Since she was unmarked we have no way of knowing if she was in the area during the time of capture and if her cause of death was capture-related.

All captures were conducted by Leading Edge Aviation using a net-gun fired from a helicopter. All captured animals were processed in basecamp. Translocated animals were moved by both transport boxes in trucks and by helicopter to release sites. All other animals were transported by helicopter to be released near where they were captured. *Mycoplasma ovipneumoniae* (*M. ovi*) was not detected by PCR, and ELISA results from blood serum indicated no previous exposure to *M. ovi*. With the exception of the 3 capture mortalities described above, all other animals were alive 2 weeks post capture based on GPS collar locations and telemetry.

In addition, 3 neonatal lambs were caught by hand and collared as part of the lamb survival study. On May 13, we caught the lamb (unknown sex) of Langley female S425 in the south fork of Tuttle Creek. On May 23 we caught the male lamb of Convict female S222 on a steep forested slope in McGee Canyon, and on May 25 we caught the female lamb of Convict female S423 in McGee Canyon.

Translocations

In the fall we translocated 9 rams to Laurel and Cathedral to increase genetic diversity and the potential for breeding. Four rams were moved from Wheeler to Laurel, and 5 rams were moved from the southern recovery unit to Cathedral (4 from Baxter and 1 from Sawmill). Five of these rams were previously uncollared (unknown heterozygosity), 2 had high heterozygosity (both with 0.647 from 17 variable loci), and 2 had moderate heterozygosity (0.529 and 0.588 from 17 variable loci).

Movement and Habitat Use

Post Translocation Movements of Laurel and Cathedral Rams

Laurel Creek Herd Unit:

Four adult rams (S451, S452, S351, and S352) were translocated from Wheeler to Laurel in October 2016. Two (S451 and S452) were released in the upper north fork of Coyote Creek, and the other 2 (S351 and S352) were released at the south fork of Laurel Creek in the Laurel Lakes Basin. In contrast to Cathedral (see below), there was no difference in post-translocation movements associated with these release sites; all 4 rams stayed within a 10 km radius of their

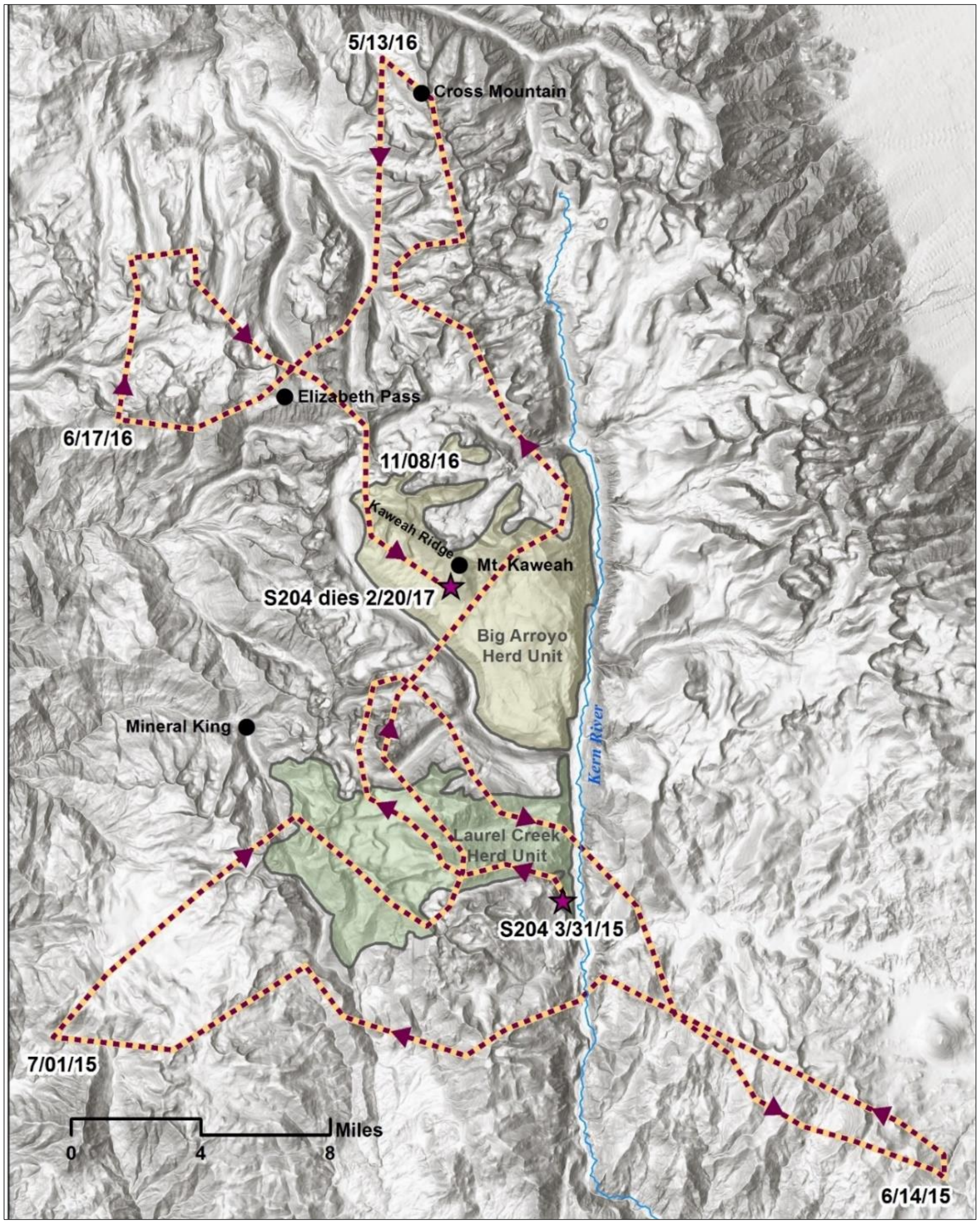


Figure 15. Movements of Sierra bighorn ram S204 from its translocation in to Laurel in March 2015, until its death in February 2017.

release sites and subsequently concentrated their use on the ridge dividing Coyote and Laurel Creek. Only S352 survived the winter. The other rams died in January (S451 and S452) and February (S351) at various locations: on the south-facing slopes of Coyote Creek, upslope of Little Kern River, and just south of Shotgun Pass. As these areas are difficult to access during winter, we were unable to determine cause of death for these mortalities. The extreme snow conditions of the big winter undoubtedly contributed to the high post-translocation mortality.

Ram S204 was translocated to Laurel from Sawmill in March 2015. In October 2015, S204 entered the Big Arroyo herd unit and traveled as far north as Cross Mountain, an area that does not have many recorded bighorn observations (Figure 15). He then spent the majority of the 2016 summer months near Elizabeth Pass just east of Lodgepole before moving to the Kaweahs (Figure 15). It is unknown if he interacted with other Big Arroyo animals, but it seems probable as he was in the general area they use. Ram S204 died in late February 2017 at the base of Mt. Kaweah. Due to the inaccessibility of this area in winter, his cause of death is unknown.

Cathedral Range Herd Unit:

Nine of ten ewes in Cathedral use separate ranges from the remaining Cathedral ram and the tenth ewe. Consequently, the ewes did not get bred in the fall of 2015 and produced no lambs in 2016. In November 2016, 5 adult rams were translocated to Cathedral from Sawmill (S456) and Baxter (S296, S297, S455, and S453). Rams were released at 2 locations, near Parsons Plateau and southwest of Mt. Lyell (Figure 16), to increase the potential for the newly introduced rams to locate resident ewes.

After translocation, each ram moved in a different direction, and ultimately all died during the big winter. Rams S456 and S297 were released near Parsons Plateau, and initially moved north and west before they both headed east into the upper Lyell Fork of the Merced River (Figure 16). After a large winter storm at the beginning of January, S456, S295, and S297 reported on mortality. Ram S456 was found east of Hutchings Creek in a large avalanche path, which likely caused its death, while S297 was found with previously translocated ram S295 in the upper Lyell fork (Figure 16). The large quantity of pellets in a sheltered location suggested that S295 and S297 were in this location for some time, and likely died of malnutrition.

The 3 rams (S296, S453, and S455) released southwest of Mt. Lyell all made longer movements away from their release point. Ram S296 moved southeast outside of the Cathedral boundary to Iron Mountain, then crossed the San Joaquin drainage to Fish Creek, and stopped briefly at Red Slate Mountain before continuing to the south-facing slopes of Mt. Morgan (north) and joining bighorn in Convict (Figure 16). This 61 km movement occurred over 3 weeks and is one of the largest movements we have documented. Ultimately, S296 died of malnutrition on the north side of McGee Creek in late January. Ram S453 began with similar movements south, but then moved north into the Gibbs herd unit, first heading to Mt. Dana, and then moving south, passing Mt. Gibbs and Mt. Lewis, and over the Kuna Crest to the south face of Donohue Peak (Figure 16). At Donahue Peak he died in a large avalanche path during the same early January storm cycle as S456, S455, S297, and S295. Lastly, S455 moved from the north-facing slopes of the Lyell Fork of the Merced River, south to Timber Knob, and ultimately northeast, near Iron Mountain where he died from unknown cause in early January (Figure 16). While the 2 rams released near the Parsons Plateau had relatively small movements post translocation, the 3 rams released southwest of Mt. Lyell moved much greater distances.

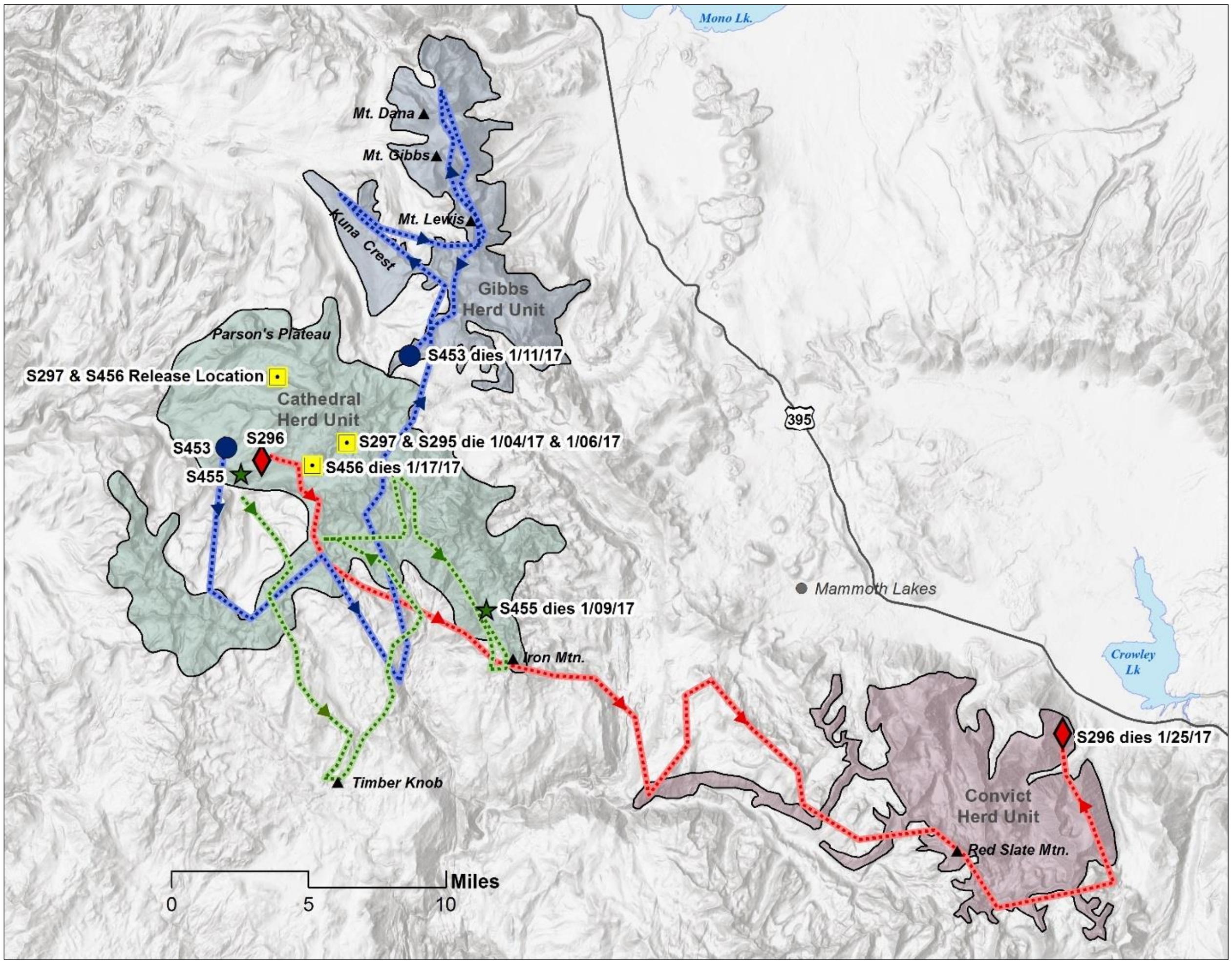


Figure 16. Post translocation movements from October 2016 – January 2017 of Sierra bighorn rams released in Cathedral.

Why did some Cathedral rams move so far away from their release site, while other Cathedral and Laurel rams stayed near their release site? Large post-translocation movements can limit our ability to manage for genetic diversity and maintain local population sizes. Integration into a new area can be a slow and complex process that involves spatial and social instabilities that lessen as the individual acquires information on resources and interacts with resident conspecifics (Scillitani et al. 2012). Established populations can facilitate integration and lessen the probability of dispersal (Scillitani et al. 2012).

In Italy, recently translocated male Alpine ibexes (*Capra ibex ibex*) reduced their home range sizes as they associated more with the resident population (Scillitani et al. 2012). The Laurel rams may have had smaller movements post-translocation because they were released closer to resident bighorn, although we are unable to confirm that translocated males mixed with residents. The narrow canyon landscape of Laurel Creek may have made it easier for newly translocated rams to find residents compared to the terrain near Mt. Lyell where there are many corridors for travel out of Cathedral. Proximity to resident females could explain why the 2 rams released at the Parsons Plateau moved smaller distances from their release location.

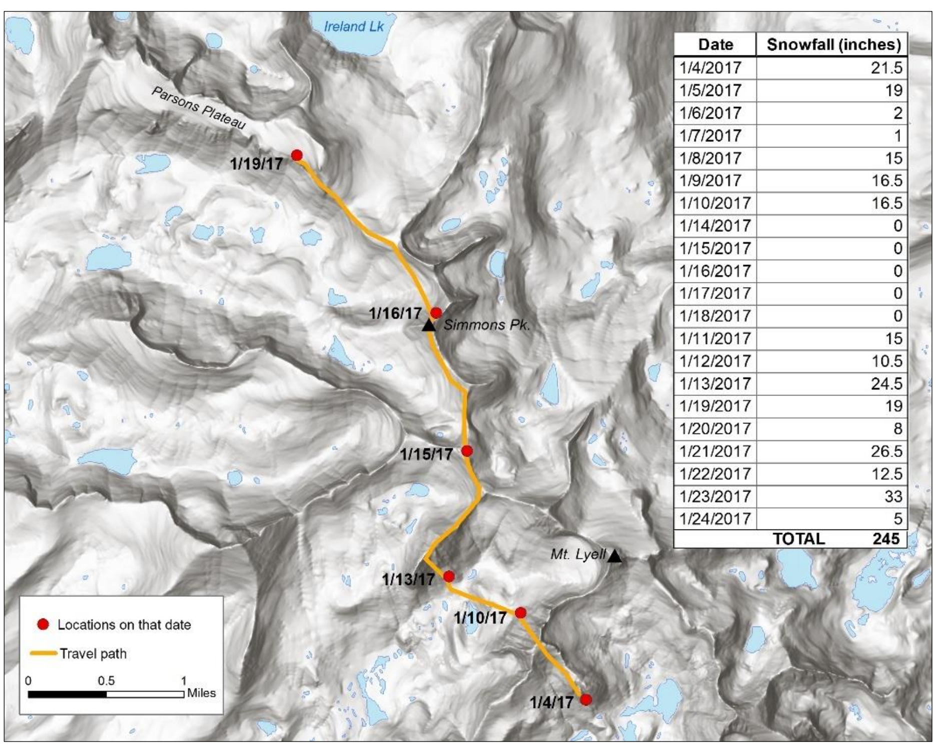
In 2015, when rams were first released into Laurel Creek and there were no resident animals, the rams dispersed large distances from their release site, demonstrating the potential importance of integration with resident animals. At the initial reintroduction of the Cathedral population in 2015, however, 3 adult rams were released near Washburn Lake alongside 10 females. The presence of the females at the release site may explain why these rams did not make large exploratory movements. Another possible factor contributing to different movements of translocated rams could be timing of translocation. The Cathedral area receives more snow than Laurel Creek, so a spring translocation to Cathedral may confine rams to their release location more so than in Laurel. All additional rams translocated to Cathedral have been in the fall and have made much larger movements compared to those moved in the spring. Age of ram may also determine the potential for rams to travel post-translocation. Mature rams may be more apt to move long distances than young rams. In the future we will consider moving young rams with ewe groups to reduce the likelihood of dispersal outside of the target herd.

Phenotypic plasticity to a high elevation winter range may also contribute to differences in post-translocation movements (Letty et al. 2007). For example, a ram accustomed to lower elevation winter range may be more likely to disperse and search for lower elevation winter habitat. While each animal will experience the stresses of translocation differently, understanding the factors influencing post-translocation movements will help improve the success of future translocations.

Winter Movements

Cathedral Range Ewes:

Bighorn sheep in the Cathedral herd spend summer and winter in the alpine, but the winter range is a small, wind-scoured subset of the area used in summer. When heavy snow started in January 2017, most of the ewes were still on summer range near Mt. Lyell several miles from their winter range on Parson's Plateau (Figure 17). Under less severe snow conditions, bighorn may travel between Mt. Lyell and Parson's Plateau in a day or two. During January 2017 travel took more than 2 weeks. Many of the days received more than a foot of snow at nearby Mammoth Mountain, with a total accumulation of 245 inches for January (Figure 17). Real-time GPS allowed us to monitor the movements of those ewes during their migration as we watched the snow accumulate in the mountains. Almost half of that winter's snow fell during a 3-week period in January and set a record for monthly snowfall at Mammoth Mountain. The ewes were traveling through very rugged terrain and in extreme avalanche conditions at elevations around 12,000 ft. Remarkably, all the ewes making the trek survived the migration; however, some succumbed later in the winter. The ability of those ewes to travel across such terrain under extreme weather illustrates how well adapted Sierra bighorn are to their alpine environment.



Date	Snowfall (inches)
1/4/2017	21.5
1/5/2017	19
1/6/2017	2
1/7/2017	1
1/8/2017	15
1/9/2017	16.5
1/10/2017	16.5
1/14/2017	0
1/15/2017	0
1/16/2017	0
1/17/2017	0
1/18/2017	0
1/11/2017	15
1/12/2017	10.5
1/13/2017	24.5
1/19/2017	19
1/20/2017	8
1/21/2017	26.5
1/22/2017	12.5
1/23/2017	33
1/24/2017	5
TOTAL	245

Figure 17. Movement of Sierra bighorn ewes during storms in the Cathedral Range herd in January 2017. Snowfall data is from nearby Mammoth Mountain snow study site.

Convict Creek:

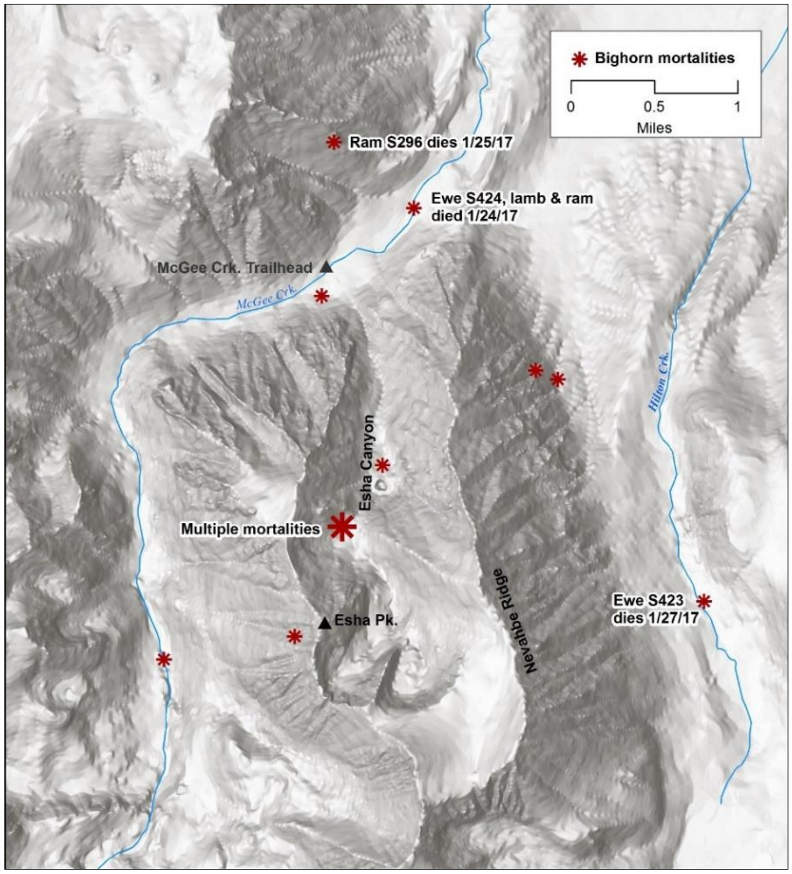


Figure 18. Winter mortalities of Sierra bighorn within the Convict Creek herd unit during the 2016-17 winter.

While the 2016-17 winter greatly reduced the bighorn population in Convict, it also provided an opportunity to observe winter mortalities and movements relative to large storms (Figure 18). In total, there were 16 recovered mortalities, including 5 uncollared bighorn, out of 34 sheep counted the previous summer. The causes of mortality were primarily from avalanche and malnutrition, although one investigation revealed 3 deaths from hypothermia (Figure 19). January and February produced the largest storms of the season, with the top 6 storms producing around 80 inches of snow (Figure 3). Eight bighorn with functional GPS collars died within 4 days of a winter storm that produced at least 12 inches of snow in the first 24 hours. Some bighorn appeared to limit their movements during these storms, while others made larger movements during or just after a storm. Seven mortalities were found in or near the vicinity of Esha Canyon, and 6 of these were found in a 100 m radius of one another on a ledge system near the base of Esha Peak (Figure 18). These 4 likely died within the storm cycle beginning January 22, and based on the remains, 1 additional uncollared ewe also died here (M142). The proximity of the animals to one another would typically indicate an avalanche-related death, however, the mortality investigation revealed that these animals likely died from malnutrition. This conclusion was based on the mortality location (not an avalanche path), the red color of the bone marrow, and the large quantity of pellets at the mortality site, which indicated that the animals had spent time at the site. Before January 22, these animals had been making normal movements. After January 22, the GPS collar locations clustered in a small area. Typically, a cluster indicates a mortality, but since evidence at the site indicates the animals were in a small area for several days, the precise time of death is not possible to determine.

In contrast to the reduced movement documented in Esha Canyon, 3 Convict animals ventured into novel habitat during late January storm cycles. Ram S296 was translocated to Cathedral in early November and arrived in Convict November 23 (Figure 16).

Figure 19. Brian Hatfield and Jon Weissman investigating the mortality of Sierra Nevada bighorn ram M122 that died from hypothermia after he was trapped by large steep snowbanks in McGee Creek in January 2017.

GPS collar locations indicate that this ram interacted with other Convict bighorn before travelling to the north side of McGee Creek January 15 (Figure 18). He is the first collared Sierra bighorn to use this terrain. It appears that ewe S424, her lamb, and a yearling ram also tried to cross to these south-facing slopes of McGee Canyon a week later but became trapped in McGee Creek by high snowbanks and died of hypothermia (Figure 19). In addition, VHF collared ewe S423 moved southeast from Nevahbe ridge, and was found dead at the bottom of the Hilton Creek drainage, an area not commonly used by bighorn. Her death was estimated to have occurred January 27 (Figure 18).

New Habitat Use and Range Expansion

Taboose Creek Herd Unit:

During the rut (October-January), ram movements increase as they search for available females (Geist 1971, Leslie and Douglas 1979, O'Brien et al. 2014). In Taboose, rams have been documented as far north as Coyote Flat during these autumn months (Few et al. 2015, Greene et al. 2016). During fall 2016, ram S355 travelled north to Mt. Jepson, and then worked his way back to Birch Mountain (Figure 20). Previously, ram S355's home range was between Mt. Pinchot and Birch Mountain. This movement demonstrates how rams can dramatically expand their range during the rut. After the large early January storm, S355 went on mortality on the south-facing slope of Tinemaha Peak above Red Mountain Creek. It was determined to be a probable avalanche-related mortality due to the presence of avalanche debris.

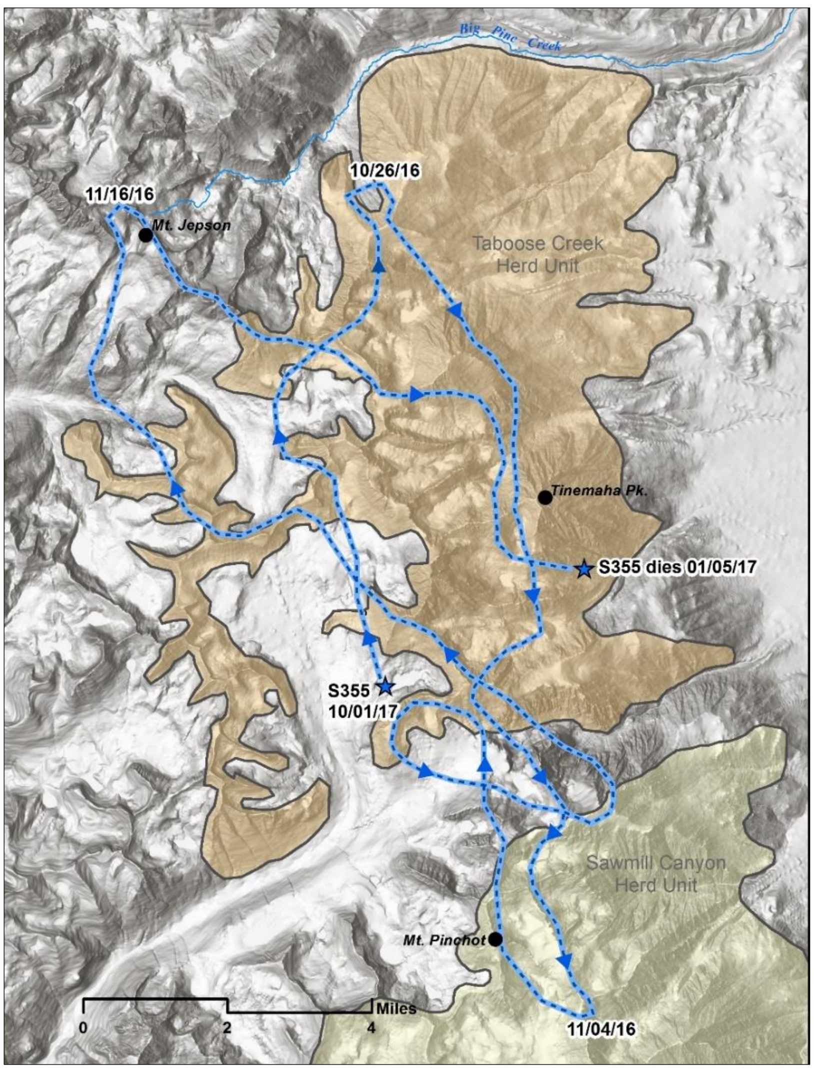


Figure 20. Large movements of Sierra bighorn ram (S355) from October 1, 2017 to his death on January 6, 2017

Predator Monitoring and Management

Mountain lion (*Puma concolor*) predation has varied during the course of the recovery effort but was comparatively minimal since 2010 until a substantial spike in predation in the 2016-17 winter. As of May 10, 2017, we documented 118 overwinter mortalities in 2016-2017, most caused by avalanche or malnutrition due to heavy snow levels, but in addition, mountain lions killed 25 of those bighorn. Specifically, 2-3 adult lions killed 18 bighorn (including 13 females) in Langley. This is the heaviest predation on a single herd that we have observed since the Recovery Program began in 1999. Prior to this winter, Langley was estimated to have 51 female bighorn and was one of only 4 herds large enough to provide source stock for translocations. This high level of predation at Langley caused a population decline that will delay implementing reintroductions essential for achieving recovery. Without management action, we thought it likely the Langley population would decline further. In addition, the Recovery Implementation Team requested removal of lions that killed bighorn.

The Sierra Nevada Bighorn Sheep Recovery Plan (U.S. Fish and Wildlife Service 2007) recognizes mountain lions as a primary threat to bighorn and recommends management of lions as needed to address imminent threats. Fish and Game Code Section 4801 states that we may "remove or take any mountain lion, or authorize an appropriate local agency with public safety responsibility to remove or take any mountain lion, that is perceived to be an imminent threat to public health or safety or that is perceived by the department to be an imminent threat to the survival of any threatened, endangered, candidate, or fully protected sheep species." On April 6, 2017, we lethally removed 2 mountain lions in Langley. One was lion 143, a collared adult female that had immigrated from Nevada in September 2017, and the other was lion 142, an adult male. After these removals, 1 additional bighorn was killed by a lion on April 26, 2017. Prior to these 2 recent removals, we removed 22 mountain lions during 1999-2010 that were preying on Sierra bighorn and posed a threat to recovery; no lions were removed during 2011-2016.

Mountain lions are an integral part of the ecosystem of the Sierra Nevada and are a native predator of Sierra bighorn, although their primary prey are mule deer. Historically, bighorn population levels were high enough to withstand some level of predation by mountain lions. However, predator monitoring and management is necessary to reach recovery goals. Our mandate is to recover Sierra bighorn to conditions under which human intervention is no longer needed to ensure their long-term persistence.

From 1999-2011 we produced annual minimum counts of mountain lions in the southern recovery unit that are considered complete counts (Davis et al. 2012, Stephenson et al. 2010). During 2012-2015 mountain lion data was collected only incidentally, and counts from these years are likely incomplete. In 2016, focused effort on monitoring resumed to near 1999-2011 levels.

We used the protocol of McBride et al. (2008) in which gender, time, distance, and physical evidence were combined to determine the minimum number of individual lions present. Physical evidence was obtained from trail camera photos, lion kill/cache sites, data from GPS collared lions, and tracks observed during sign surveys. For track evidence specifically, unique individuals were distinguished where (1) the size of the track and stride length determined sex, (2) known events such as wind, rain, vehicle traffic, etc., determined track age, and (3) the proximity between individual track sets of known sex and age, combined with knowledge of the maximum sex-specific distance lions will travel during a 24 hour period determined whether an individual could be excluded from being double-counted.

In 2016 we found that mountain lion abundance had increased relative to previous years, including those for which complete counts were available, most notably with respect to adult females (Table 8). The number of adult females present in the southern recovery unit in 2016 (N=4) was the highest it had been since monitoring began in 1999.

Table 8. Minimum counts of mountain lions >10 months old and documented lion-killed bighorn in the southern recovery unit, 1999-2016.

Year[a]	Lions				Lion-killed bighorn
	Males	Females	Subadults	Total	
1999	1	2	2	5	1
2000	3	1	0	4	0
2001	2	1	2	5	0
2002	4	2	2	8	0
2003	3	1	1	5	0
2004	1	2	1	4	1
2005	1	2	0	3	1
2006	2	1	1	4	1
2007	3	3	2	8	7
2008	5	3	1	9	14
2009	1	3	4	8	5
2010	1	1	0	2	0
2011	1	1	0	2	1
2012[b]	2	1	0	3	2
2013[b]	1	1	0	2	2
2014[b]	1	1	0	2	3
2015[b]	1	1	0	2	8
2016	2	4	5	11	26

[a]Count years were July 1-June 30 (i.e., count year 1999 was July 1, 1999-June 30, 2000)
[b]The lion count during this year was likely incomplete

The number of adult female lions present in the southern recovery unit appears to be an important factor influencing the frequency of predation on bighorn. During 1999-2016, when the minimum count for adult female lions was 2 or less, the mean number of lion-killed bighorn annually was 1.4 (± 0.6 SE). When the minimum count for adult female lions was 3-4, the mean number of lion-killed bighorn annually was 13.0 (± 4.7 SE) (Figure 21). Thus a ~100 % increase in the number of resident female lions in the southern recovery unit was correlated with a ~800 % increase in the number of bighorn sheep killed by lions.

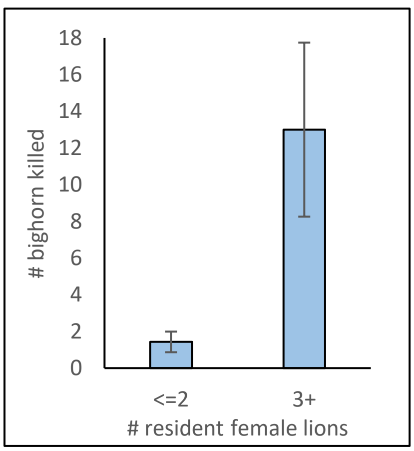


Figure 21. Mean number of Sierra bighorn killed by mountain lions (± SE) in relation to the number of resident female mountain lion minimum counts in the southern recovery unit, 1999-2016.

A similar relationship between the number of adult male lions present and lion-killed bighorn does not exist. We suspect that this is because males (1) generally have larger home ranges (Pierce and Bleich 2003), which would permit a potential wider diversity of prey and promote relatively less time spent within bighorn habitat, and (2) have kill rates that are relatively lower than females, whether they are accompanied by subadults or not (Knopff et al. 2010).

While monitoring effort resumed in 2016, a lack of resources available, particularly an absence of collaring effort, precluded the performance of a complete count in the southern recovery unit. We documented 11 unique lions (i.e., the most since monitoring began in 1999) (Table 9), and we obtained many photographs of unmarked lions that we could not distinguish between because we were unable to determine their sex.

Table 9. Unique mountain lions documented in the southern recovery unit (SRU), 2016. One lion used 3 recovery units; NRU and CRU are the northern and central recovery unit, respectively. NDOW is the Nevada Department of Wildlife.

Lion	Sex	Age	Reason Counted	Recovery Units Used	Notes
Unmarked	Male	Adult	Track data	SRU	
142	Male	Adult	Track data	SRU	Lethally removed
133	Female	Adult	Photographed	SRU	Had at least 2 subadults. Collar no longer present/functional.
Unmarked	Unknown	Subadult	Photographed	SRU	Offspring of 133
Unmarked	Unknown	Subadult	Photographed	SRU	Offspring of 133
143	Female	Adult	Collared	NRU, CRU, SRU	Lethally removed. Originally collared in Nevada by NDOW.
Unmarked	Female	Adult	Photographed	SRU	Had at least 3 subadults
Unmarked	unknown	Subadult	Photographed	SRU	Mother was unmarked
Unmarked	unknown	Subadult	Photographed	SRU	Mother was unmarked
Unmarked	unknown	Subadult	Photographed	SRU	Mother was unmarked
Unmarked	Female	Adult	Photographed	SRU	Was lactating but no documentation of offspring

Noteworthy Dispersal Event

Lion 143 was collared by the Nevada Department of Wildlife in July 2016 in the Wassuk Range of Nevada, northwest of Walker Lake. For 3 months she maintained a relatively stable home range in that vicinity but began a long-distance dispersal movement in late September (Figure 22). From then until December, she traveled ~300 km, generally continuously southward, punctuated only by brief stops after killing prey. She traveled as far south as Haiwee. In mid-December she began to establish what appeared to be a relatively stable home range that overlapped extensively with the Langley bighorn herd. During February and March 2017 she killed at least 4 bighorn before she was lethally removed on April 6, 2017.

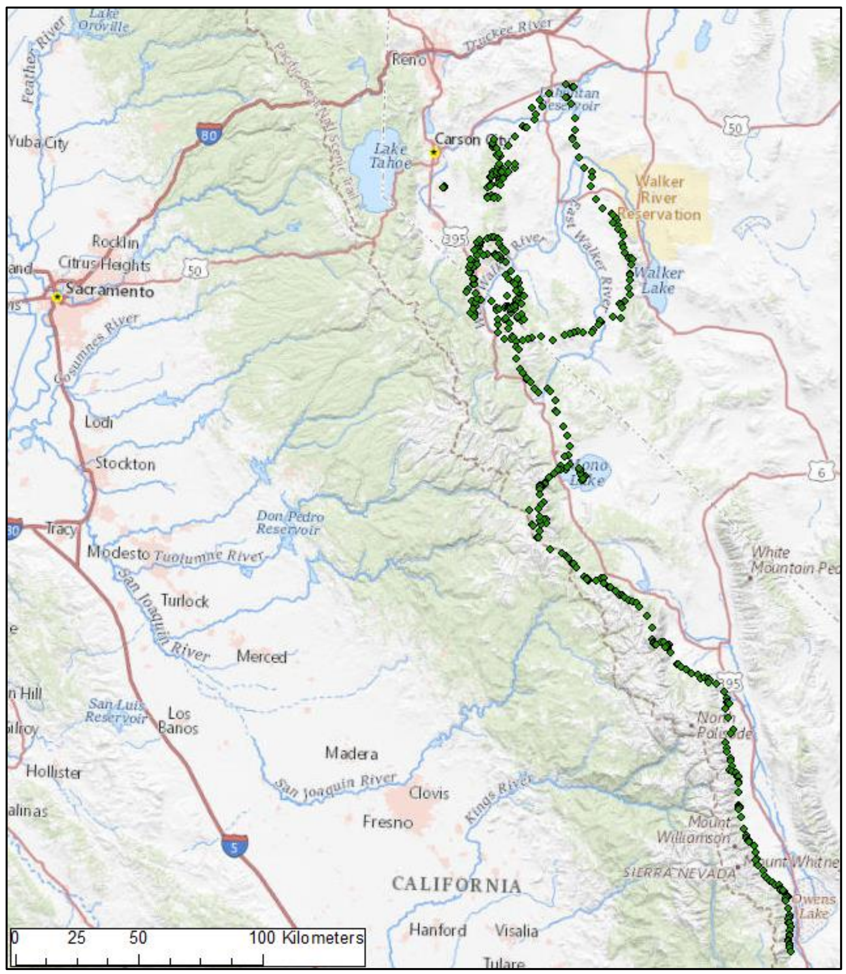


Figure 22. Long-range dispersal movement (~300 km) of Lion 143 during September-November 2017.

Disease Management

Grazing of domestic sheep on the Conway and Mattly Ranch properties owned by Mono County has posed a disease risk to Sierra bighorn for years, so much so that the Recovery Program discontinued augmentation of Warren after 2009. Domestic sheep numbering around 1,000 were annually grazed on the properties during June through November. Those domestic sheep were pastured at the base of bighorn habitat and within 1-3 miles of documented bighorn locations. In January 2017, the Mono County Board of Supervisors voted to discontinue leasing Conway and Mattly Ranches for domestic sheep production. The Recovery Plan recognizes that contact between bighorn and domestic sheep could lead to the loss of entire herds by transmission of respiratory pathogens to bighorn sheep. Consequently, implementation of measures to prevent contact between the two species is considered essential before the species may be downlisted. The discontinuation of grazing adjacent to bighorn habitat in Mono County will promote progress toward meeting recovery goals and facilitate further recovery actions for Warren.

Public Outreach

Sierra bighorn recovery depends on community support. The Recovery Program often partners with the Sierra Nevada Bighorn Sheep Foundation (SNBSF) to help inform and enthuse the public. This year public outreach included tabling at many local events such as: Endangered Species Day, Mule Days, United Methodist Women, Mono Lake Committee Chautauqua, Trout Fest, Kids Fishing Festival, Patio Talk Mono Basin Visitors Center, and ESIA Campfire Program. Also, we hosted three joint field trips in January, February, and April with approximately 68 participants total. In July, we hosted an interagency survey at Warren and Gibbs with participants from Yosemite National Park, SNBSF, and USFWS. In addition, Lacey Greene gave a presentation in July on Migration and Disease at the Mono Lake Committee and another in November at the Sequoia Kings National Park Science Symposium, "Approaching Recovery: Status Update for Sierra Bighorn".

Pine Creek Informational Kiosk

Recently there has been a dramatic increase in the recreational use of Pine Creek climbing areas, which are also used by Wheeler bighorn during lambing. We created and installed an informational kiosk to alert recreational users to the presence of endangered bighorn, provide information on the importance of the habitat in Pine Creek Canyon, and to promote best use practices to limit disturbance to wildlife (Figure 23). This project was a collaboration among

Figure 23. Collaborators putting in the Pine Creek Kiosk.

CDFW, the Access Fund, Inyo National Forest, SNBSF, Friends of the Inyo, artist Jane Kim, and the local climbing community.

The kiosk was installed on July 26, 2017 in Pine Creek Canyon in the Pratt's Crack parking area (37°22'54.65"/118°40'30.98"). The project was initiated by CDFW and the Inyo National Forest, with funding provided by the Access Fund. An agreement exists between CDFW and Friends of the Inyo for long-term maintenance of the kiosk. The SNBSF, Jane Kim, and the local climbing community contributed to the design and installation of the kiosk. This project was completed with a total input of 50 volunteer hours.

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Numerous personnel contributed to recovery efforts, data collection, and public outreach this year. Recovery Program staff include: Elsbeth Otto, Jackie Leary, Todd Calfee, Vicki Davis, Brian Hatfield, Dennis Jensen, and Jon Weissman. Additional CDFW staff include: Paige Prentice, Ashley Evans, Danielle Glass, Rick Ianniello, Jonathan Fusaro, Shannon Forshee, Jane McKeever, and Mike Morrison. SNBSF volunteers include: John D. Wehausen, Virginia Chadwick, Jora Fogg, and Julie Rolfe. In addition, helicopter pilot Jim Pope, fixed-wing pilot Geoff Pope, as well as CDFW warden pilots Michael Breiling and Gary Shales contributed to this effort. Additional collaborators include: Sarah Stock (Yosemite National Park), Erin Nordin (USFWS), Sherri Lisius (BLM), Sheena Girner (BLM), Carrie Schlick (USFS).

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Appendix A: Summaries of Population Monitoring Activities by Herd, May 2016-April 2017

Olancha Peak

Olancha was surveyed twice in the summer: first from June 21-June 24, 2016, and then from September 27-September 28, 2016. The highest count for all age classes occurred in September during which we accounted for 33 bighorn: 14 adult females, 4 yearling females, 6 lambs, 6 adult males, and 3 yearling males. This includes unseen but known collared animals. Most collared animals were seen except females S280 and S292, and males S259, S358 and S322. Female S279 was censored with an estimated dead date of September 2015, because she was last seen in June 2015 and first heard on mortality in September 2015. Since September 2015, she has intermittently been heard on live signal, but always in a similar location, a steep cliffy area of upper Olancha Creek, so we believe she is dead. During the survey, we recovered ram S197, who had died of possible predation. Our count included 2 more yearlings than we had counted as lambs in 2015, which demonstrates definitively that minimum counts at Olancha are missing individuals. We added 2 additional lambs to the 2015 minimum count to account for the additional yearlings. Following the survey, there was 1 additional Olancha mortality, ram S259 in February 2017. We only recovered the VHF collar and eartag on this individual and therefore were not able to determine cause of death. In general, summer seems to be a better season for surveying this herd because the terrain is more accessible and the bighorn more observable. Olancha bighorn tend to congregate around Olancha Peak but have also now been seen at the upper reaches of Cartago Canyon. As the herd continues to grow and expand, the survey area will likely expand to include upper Cartago. Outside of the two surveys, there were no additional observations at Olancha. At the end of the reporting period there was 1 fewer ram, with 64% of females and 37% of males wearing fVHF (functional Very High Frequency) collars. There were no fGPS (functional Global Positioning System) collars.

Laurel Creek

We did not perform a systematic survey of Laurel in 2016. Instead, by combining opportunistic observations from August 16-September 12, we obtained the following minimum count: 6 adult females, 1 yearling female, 3 lambs, 1 adult male, and 3 yearling males. This includes all collared animals known to be alive and in the area. This is the first minimum count of the Laurel herd, because only 1 collared female was observed in the summer of 2015 after translocation. The Laurel herd began with a translocation in March 2015 of 7 pregnant females (including one yearling) and 4 adult males. One female (S380) died in October 2015 of unknown causes, and the rest of the translocated females were observed in the summer of 2016. Three of the four rams initially translocated left the area within the first year: S311 died on the east side of the crest in Hogback Creek in November 2015, S364 traveled to Olancha and died in January 2016, and S322 immigrated to Olancha in November 2015. In November 2016, 4 rams (S351, S352, S451, S452) were translocated into Laurel from Wheeler. Two were recaptured and targeted specifically for their high heterozygosity, and two were previously uncollared. Laurel suffered large losses during the big winter including 57% of known collared females; 2 from avalanche (S376, S378), and 2 from unknown causes (S379, S381). Cause of death was difficult to determine because mortalities from January – March could not be investigated until the area became accessible in June. Four collared rams died during the winter of unknown cause (S451, S452, S204, S351), including 3 of the November 2016 translocations. At the end of the reporting period we can account for 2 adult females, 1 yearling female, 3 lambs, 1 adult male, and 3 yearling males. All adult animals have fVHF and fGPS collars.

Big Arroyo

There was no systematic survey of Big Arroyo, but various observations from June-August were combined to come up with a minimum count of 9 adult females, 1 yearling female, 5 lambs, 4 adult males, and 3 yearling males. All but one collared female was seen (S289). None of the known collared males were observed by program staff. However, in June a hiker reported a group of 3 bighorn above Emerald Lake near Alta peak, which was in the area ram S204 had been but far west and outside of the Big Arroyo designated herd unit. This observation was not confirmed. No animals were captured in or translocated to Big Arroyo. During the big winter, 50% of collared females died (S283, S290, S284, S286), as well as 3 males (S193, S200, S202). Three animals died from malnutrition and the cause of death was not determined for the others. Cause specific mortality investigations could not be performed until the summer because access to Big Arroyo was restricted by snow and high run off. At the end of the reporting period, we can account for 6 adult females, 1 yearling female, 5 lambs, 1 adult ram, and 3 yearling rams. After accounting for known mortalities, we estimate that 89% of females are marked, 78% with fVHF collars, and 11% with fGPS collars. For males 75% are marked with fVHF and none have fGPS collars.

Mt. Langley

We surveyed Langley from September 5-8, 2016. The reconstructed minimum count was 43 adult females, 6 yearling females, 16 lambs, 16 adult males, 7 yearling males, and 1 yearling of unknown sex. Most collared animals were seen (81%; 13/16). At the very beginning of the animal year, on May 13, 2016, one neonatal lamb (sex undetermined S434) was hand-captured. This lamb was associated with S425 who had been implanted with a vaginal implant transmitter in the previous spring. The lamb died November 5 from unknown causes. We were not able to investigate or even recover the lamb collar due to big winter conditions. During fall we captured 6 month old lambs: 3 females (S444, S445, S446) and 2 males (S443, S447). On March 24, 2017, we captured 1 ewe (S470) who died of lung damage, likely capture-related, on April 10. We documented a total of 27 mortalities in Mt. Langley: 17 collared and 10 uncollared: 17 female, 5 male, and 5 unknown sex. Of these mortalities, 19 were killed by mountain lion. In addition, 1 animal died from spring capture, and 7 from unknown causes (4 clearly not predation). Female S221 was censored as of May 1, 2016 because she had not been observed for two years; she would have been 8 years old. Unexpectedly, one of the mountain lion kills was collared female S81, whom we had assumed died in 2014 because she had not been observed since October 9, 2014. In response to high levels of mountain lion predation, two mountain lions (1 male, 1 female) were removed from the Mt. Langley winter range in April 2017. At the end of the year, after accounting for the known mortalities, we estimate 18% of females are marked (N=7: 4 with fGPS, 2 with fVHF), and 21% of males are marked, all 4 with fGPS collars.

Mt. Williamson

Due to its small size and survey difficulty, Williamson is not surveyed annually. On August 3, 2016 a group of 12 bighorn were observed on the east plateau of Trojan Peak. Combining this observation with collars not seen resulted in a minimum count for of 10 adult females, 1 yearling female, 4 lambs, and 3 adult males. As the rams are likely an underestimate, we will continue to use the 2014 minimum count of 8 adult rams and 2 yearling rams. We documented 3 mortalities: 2 mountain lion kills (uncollared ram and ram S113) and 1 by unknown cause (female S270). There were no capture activities in Williamson. At the end of the reporting period, we estimate 36% of females are marked with fVHF collars, but none have fGPS collars. Only 13% of rams are marked with fVHF collars and none with fGPS collars. All of the VHF collars in Williamson will be 5 years old in animal year 2017. Additional VHF and GPS collars should be added to Williamson before we lose all functional collars, at which point monitoring and capturing will become more difficult.

Mt. Baxter

Our best survey of Baxter occurred on January 17, 2017 in which we documented 42 adult females, 6 yearling females, 20 lambs, 34 adult males, and 6 yearling males. This included 9 collared animals not seen (7 of which were female). In October we captured 2 adult females (S438, S439), 1 female lamb (S437), 4 adult males including 2 recaptures (S453, S455, S296, S297), and 2 male lambs (S440, S454). All 4 adult rams were translocated to the Cathedral Range, a recently re-introduced population in which all rams had died. We surveyed Baxter again in the summer but, as is typically the case with this herd, the winter count was higher for all age and sex classes. In general, Baxter did not suffer from high mortality rates during the big winter, most likely due to the fact that most of the population uses a low elevation winter range. However, there were some mortalities: 2 adult females were killed by mountain lion (S301, S306), 1 adult male died from malnutrition (S300), and 1 adult male died of unknown cause (S363). In the spring we captured 6 adult females including 1 recapture (S438, S462, S463, S464, S465, S214) to maintain our capacity to detect changes in the population. At the end of the year, we estimate 50% of females are marked (N=24), 31% with fVHF collars (N=15) and 21% with fGPS collars (N=10). Although the ram count is likely an underestimate, at most we have 25% of males marked (N=10), 10% with fVHF collars (N=4), and 5% with fGPS collars (N=2).

Sawmill Canyon

Our best survey of Sawmill was in the summer from September 13-15, 2016. We accounted for 36 adult females, 3 yearling females, 16 lambs, 16 adult males, and 4 yearling males. There were 6 collared females not seen and 18 collared males not seen. We focus on surveying known female habitat and therefore do not see as many males, likely significantly undercounting them. In October we captured 7 animals: 3 adult females including 1 recapture (S448, S449, S205), 1 female lamb (S450), 2 male lambs (S441, S442), and 1 adult male (S456). S456 was translocated to Cathedral. In March, we captured 6 females, including 1 lamb (S461), 1 recapture (S323), and 4 new adults (S457, S458, S459, S460). We documented 15 mortalities including 5 collared females, 8 collared males, and 2 uncollared lambs of unknown sex. The majority of mortalities were by unknown causes (4 collared males, 1 collared female, and 2 uncollared lambs), 3 were from mountain lion predation (2 females, 1 male), 3 were from avalanche (1 female, 2 males), and 1 from malnutrition (male). We estimate 49% of females are marked (N=21), 40% with fVHF collars (N=17), and 21% with fGPS collars (N=9). Although a low minimum count is biasing this we estimate up to 77% of males are marked (N=11), 50% with fVHF collars (N=11), and 9% with fGPS collars (N=2).

Bubbs Creek

No observations were made in Bubbs Creek; no mortalities were detected. The last count of Bubbs Creek was from a helicopter in 2013: 10 adult females, 1 yearling female, 9 lambs, 5 adult rams, 1 yearling male, and 1 unknown aged female for a total of 27 animals. Based on this minimum count, we estimate 31% of females are marked (N=4), 23% with fVHF (N=3). We estimate 60% of males are marked (N=3), all with fVHF. There are no fGPS collars in the herd.

Taboose Creek

There was no comprehensive survey of Taboose during the reporting period. Based on 2014 observations, the minimum count for Taboose is 2 adult females, 1 yearling female, 15 adult males, and 2 yearling males for a total of 17 animals. We detected 8 mortalities in Taboose: 6 from avalanche, including 3 collared adult males (S355, S338, S431), a collared adult female (S411) and 2 uncollared animals, 1 male and 1 female. In addition, 1 adult collared male (S354) died of unknown cause and 1 uncollared male, first found by a skier, died from malnutrition. At the end of the period, with a population estimate based on spring observations of 1 female and 4 males after the big winter mortality, we estimate all females (N=1) have fGPS and fVHF collars and 50% of males (N=2) are collared with fVHF collars and 25% with fGPS collars (N=1).

Wheeler Ridge

We had our best Wheeler winter count on February 14, 2017 in which we accounted for 45 adult females, 3 yearling females, 17 lambs, 36 adult males, and 3 yearling males for a total of 104 animals. This count includes 4 female and 5 male collared animals not seen. On November 1, we captured 4 adult males (S451, S452, S351, S352) and translocated them to Laurel. In the spring we captured 5 adult females (S421, S466, S467, S468, S469). We had 2 collared female mortalities related to this capture (S467 and S469). In addition, an uncollared female died within a few days of capture, but it is unknown if this mortality was related to capture. In the spring 1 male neonatal lamb was hand captured (S471) and died from rock fall the following day. We also censored lamb ram S294 that dropped its lamb collar and has no identifying marks (e.g. ear tags), and adult female S388 because she had not been seen for two years. In addition to the mortalities and censors listed above, we documented 14 other mortalities: 6 collared adult females (S17, S248, S386, S413, S419, S420), 3 adult males (S152, S347, 1 uncollared), 2 yearling males (S389, 1 uncollared), and 3 uncollared lambs 1 male, 1 female, 1 unknown sex). Of these 14 mortalities, 5 died from predation by mountain lion, 1 from predation by bobcat (yearling male), 1 from malnutrition, 2 from physical injury, and 5 of unknown causes. At the end of the period, we estimate 47% of females are marked (N=22), 27% with fVHF (N=13) and 10% with fGPS collars (N=5). In addition, up to 28% of rams are marked (N=11); 18% with fVHF (N=7) and 8% with fGPS (N=3) collars.

Convict Creek

Out best minimum count came from an opportunistic observation on July 13, 2016 of 13 adult females, 5 yearling females, 8 lambs, 12 adult males, and 2 yearling males for a total of 40 animals. This count includes 1 collared female not seen (S175). In the spring we hand captured 1 male (S435) and 1 female (S436) neonatal lamb. We documented 14 mortalities including 8 collared adult females (S222, S336, S397, S398, S402, S422, S423, S424), 2 collared adult males (S335, S401), an uncollared adult male, 1 female lamb (S436), and 1 uncollared male lamb. Five animals died in 4 separate avalanche events; 4 died from malnutrition; 3 died from hypothermia and were found in McGee Creek, and 1 from unknown causes. Additionally, in January, male S296 that had been translocated from Baxter to Cathedral in November died just north of McGee Creek from malnutrition. At the end of the period we estimate 40% of females are marked (N=4), 20% with fVHF (N=2), and 18% of males are marked (N=2), 9% with fVHF (N=1). There are no fGPS collars in Convict.

Cathedral Range

We were able to census Cathedral on July 12, 2016 and found 10 adult females and 2 female yearlings. In addition, there was 1 collared adult ram (S295) that was not seen, for a total of 11 animals. In November, we translocated 5 rams into Cathedral (S296, S297, S453, S455 from Baxter, and S456 from Sawmill). Three of the translocated rams left the Cathedral area immediately after translocation. During the big winter all 6 rams died – 3 from malnutrition, 1 from avalanche, and 2 from unknown (but not predation) causes. In addition, we documented 6 collared female mortalities: 1 from malnutrition (S344) and the rest from unknown causes (S368, S370, S371, S372, S373). At the end of the period, Cathedral had 4 adult females, 2 with VHF collars (no GPS) and 2 yearling females; there were no males alive in Cathedral.

Mt. Gibbs

Our best count occurred from observations in July and August accounting for 22 adult females, 5 yearling females, 10 lambs, 14 adult males, and 5 yearling males, for a total of 57 animals. All collared animals were seen. We documented 6 mortalities, 3 adult females (S218, S253, S219) and 3 adult males (S215, S186, S161). Two died from avalanche, 1 from malnutrition, and 3 from unknown (but not predation) causes. There were no animals captured in Gibbs, so we ended the period with 55% of females marked (N=12), 41% with fVHF (N=9), and 5% with fGPS collars (N=2). We estimate 11% of males are marked with fVHF (N=2) and none with fGPS collars.

Mt. Warren

During August we accounted for 9 adult females, 1 yearling female, 5 lambs, 8 adult rams, and 2 yearling rams for a total of 25 animals. All collared animals were seen during the survey. There were 4 collared animal mortalities, 3 adult males (S239, S331, S328) and 1 adult female (S330). Two animals died from malnutrition (S330, S331); one male was killed by a mountain lion, and another male died from unknown causes (but not predation). All 4 mortalities occurred in March or early April. At the end of the survey period, there was only 1 female marked with a non-functioning VHF collar (S89; 13%) and no collared males.

Supplemental Material

Appendix B. Collar Details by Herd and Function

available upon request