2018-19 Annual Report
Sierra Nevada Bighorn Sheep Recovery Program

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Figure 1. Sierra bighorn ram in Yosemite National Park, from a motion triggered camera at McClure Saddle above Lyell canyon, December 28, 2018. This is the first time a Gibbs animal was documented in the Cathedral Range Herd Unit.

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Executive Summary

In 2018-19, there was large and long-lasting snowpack in the Sierra Nevada. We estimated that 72 Sierra bighorn females died, representing 25% of the population. Snow-caused mortality in the form of starvation and avalanche was the most common cause of death, causing 39% of collared female mortalities, while lion predation caused 12% of collared female mortalities this year. Despite these losses, no herd units were extirpated. Winter impacts were highly variable between herds, with little mortality in the Olancha herd but the largest proportional impacts in Bubbs, Big Arroyo, Warren, and Cathedral. The largest numeric losses were in Gibbs and Sawmill.

Bighorn movements documented this year demonstrated continued connectivity between herds as well as expansion within herd units. Specifically, individuals moved between the Baxter, Williamson, and Langley herds, as well as between Gibbs and Cathedral. At Convict, animals have begun using the north side of McGee Creek, and in the Big Arroyo, at least one individual crossed to the east side of the Kern River.

We documented a minimum of 37 lions in the eastern Sierra region, including 25 within the three count zones associated with Sierra bighorn. This is the greatest number of lions ever documented in these zones, although predation levels were not extreme this year. We define "extreme" predation levels as being above the 90th percentile or 11.4% within a single herd. Lions did kill a minimum of 13 Sierra bighorn across six herd units. Male lion L147 killed at least four of these animals and traveled through at least seven Sierra bighorn herds. Lion predation has persisted in the Langley herd, and its population continues to decline.

In 2018, a new climbing guidebook was published that focused on the Pine Creek region, which is an important lambing area for the Wheeler Ridge herd. Climbing use in Pine Creek has notably increased since 2010.

Introduction

Sierra Nevada bighorn sheep (*Ovis canadensis sierrae*) are a unique subspecies native to the Sierra Nevada in California (Wehausen and Ramey II 2000, Wehausen et al. 2005). They have distinctly wide splayed horns (Figure 1) and have been genetically isolated from other bighorn sheep subspecies for roughly 100-300,0000 years (Buchalski et al. 2016). Sierra bighorn have been a species of management interest since hunting regulations were put in place in 1878; they were placed on the federal endangered species list in 1999 after the population declined to approximately 100 individuals in 1995 (U.S. Fish and Wildlife Service 2007).

We monitor Sierra bighorn abundance, demography and habitat use to inform management decisions regarding translocation, predator management, and disease risk. We also monitor mountain lion abundance, demography, and habitat use because they are the main predator and largest known cause of mortality for Sierra bighorn. We work to reduce the potential for disease transmission between Sierra bighorn and domestic sheep, and we promote bighorn recovery through public outreach. This report summarizes the activities of the Sierra Nevada Bighorn Sheep Recovery Program from May 1, 2018 – April 30, 2019.

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'. We use '2018' to represent the animal year May 1, 2018 – April 30, 2019. The animal year begins with lambing season. 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

Following their listing under the Endangered Species Act in 1999, when the population was estimated to contain 95-129 individuals (Wehausen 1999), Sierra bighorn abundance increased to a high of 667 in 2016 (Greene et al. 2017). Although growth of individual herds has varied, the range-wide population has declined annually in the years since (Figure 2). During May 1, 2018 – April 30, 2019, we accounted for 556 Sierra bighorn including 254 females, 122 lambs, and 180 males (Table 1, Appendices A and B). The Recovery Plan (U.S. Fish and Wildlife Service 2007) specifies that minimum counts be used to evaluate progress toward recovery goals. However, minimum counts may underestimate population size because not every animal is observed every year. Additionally, these counts do not represent the impacts of winter because many herds are surveyed in the summer before winter mortality occurs. Identifying winter impacts requires a different analysis (see Winter Impact, Weather and Climate).

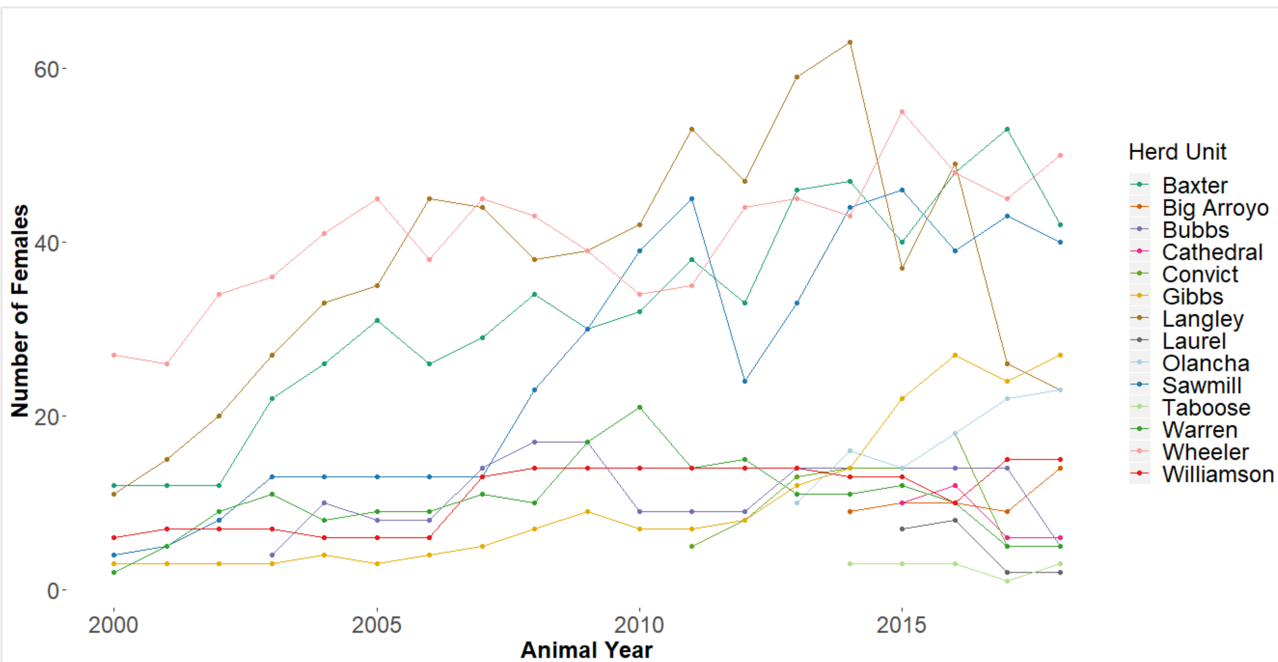


***Figure 2**. Estimated female Sierra bighorn within each herd since 1999. This includes reconstructed minimum counts and mark-resight estimates (CV<0.15). For herds not surveyed annually, the most recent count was used.*

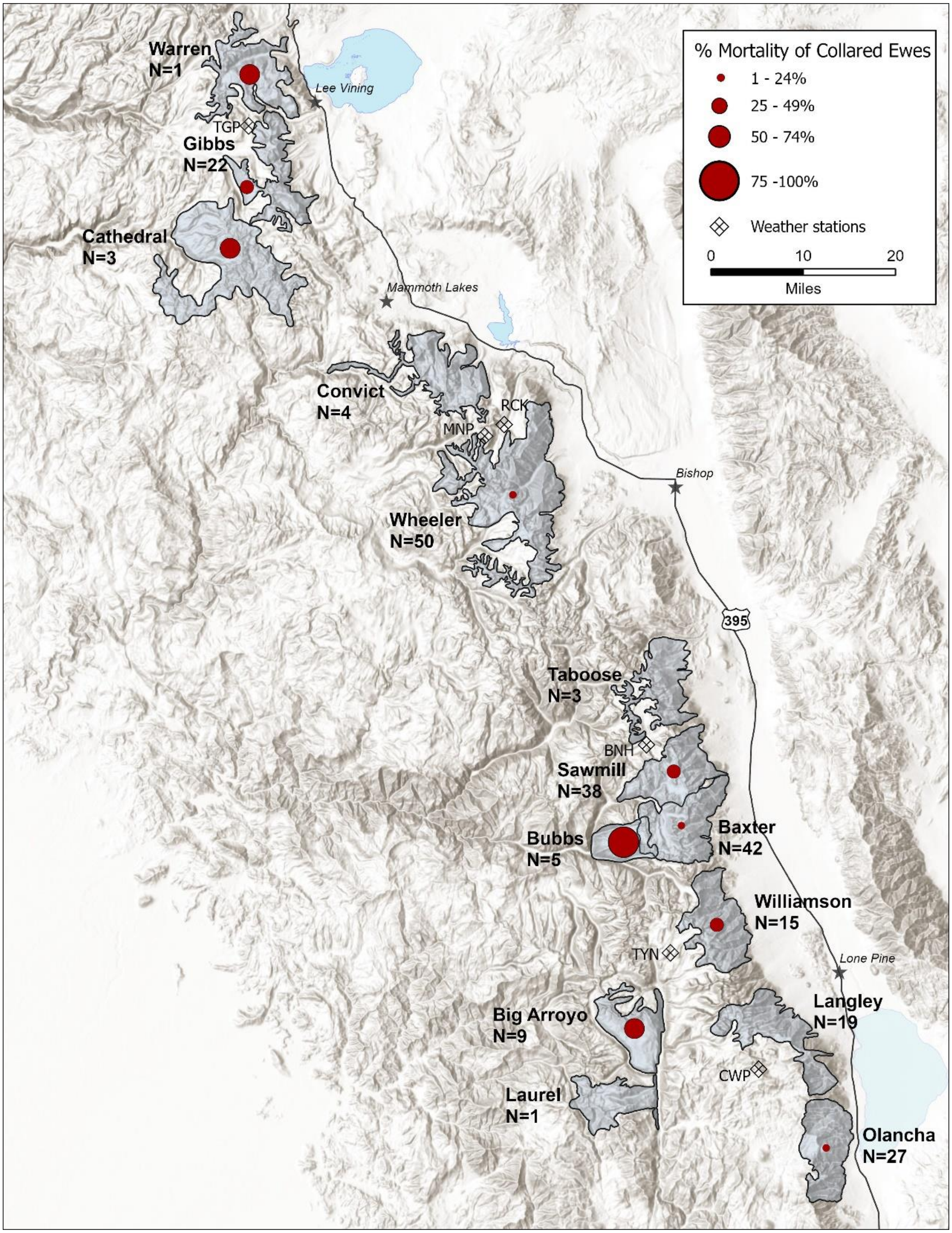


***Figure 3**. Herd units occupied by Sierra bighorn as of April 30, 2019. Also shown is the proportion of collared female mortality that occurred in each herd during 2018-19 and the remaining minimum count of females.*

Table 1. Reconstructed minimum counts (MC) of Sierra bighorn during May 1, 2018 – April 30, 2019. Lambs not identified by sex. Most surveys were conducted in summer 2018 and therefore do not include losses from the 2018-19 winter.

Herd	Female Adult	Female Yrlng	Female Total	Lambs	Male Adult	Male Yrlng	Male Total	MC Population	Notes
Olancha	20	2	22	11	10	2	12	45	3 yrlng females observed in spring, but overall total females highest in summer. Summer count shown. Censored 292.
Laurel	1	1	2	0	1	0	3	5	2 males of unknown age
Big Arroyo	12	2	14	4	4	5	9	27	2 more yrlngs counted than lambs seen in 2017
Langley	23	0	23	9	14	1	15	47	
Williamson (2017)	14	2	16	6	5	2	7	29	Includes female 166 who had not been seen for 2 years
Baxter[w]	35	7	42	15	34	5	39	96	Females from 3/1 count. Males from 3/19.
Sawmill	30	6	36	24	9	11	20	80	Counted one more adult male in winter but fewer total males. Summer count shown. Censored 203, 128, 254, 165, 255, 450.
Bubbs (2018)	4	1	5	4	2	1	3	12	
Taboose	2	1	3	1	5	1	6	10	Combined July and September opportunistic observations
Wheeler[w]	43	6	49	24	30	4	34	107	Censored 236, 409, presumed 510 dead
Convict	4	0	4	3	1	0	1	8	Females observed September
Cathedral	6	0	6	4	2	0	2	12	Does not include uncollared male caught on YNP camera at McClure Pass
Gibbs	20	7	27	16	16	9	25	68	Male observations from 6/26. Females from July observations. JW notes have 1 more lamb and 3 more adult females.
Warren	4	1	5	1	3	1	4	10	
Totals	**218**	**36**	**254**	**122**	**136**	**42**	**180**	**556**	

[w] Winter counts, other surveys conducted in summer

Sierra bighorn are currently distributed across 14 herd units: Warren, Gibbs, Cathedral, Convict, Wheeler, Taboose, Bubbs, Sawmill, Baxter, Williamson, Langley, Olancha, Big Arroyo, and Laurel, distributed among 4 Recovery Units (Figure 3). Downlisting criteria specifies numeric goals for each recovery unit: 50 in the North, Central, and Kern units, as well as 155 in the Southern unit (U.S. Fish and Wildlife Service 2007). Each recovery unit consists of 2-7 herd units (Figure 3). Currently only the Central recovery unit has enough females to meet its target (Figure 4). The 2018 distribution includes all 12 essential herd units identified in the Recovery Plan (Criteria B2, SNBS Recovery Plan 2007), and two non-essential herd units (Bubbs and Cathedral). However, persistence in six of these herds (Laurel, Bubbs, Taboose, Convict, Cathedral, and Warren) is tenuous because after the 2018-19 winter they were reduced to <5 females (Table 2).

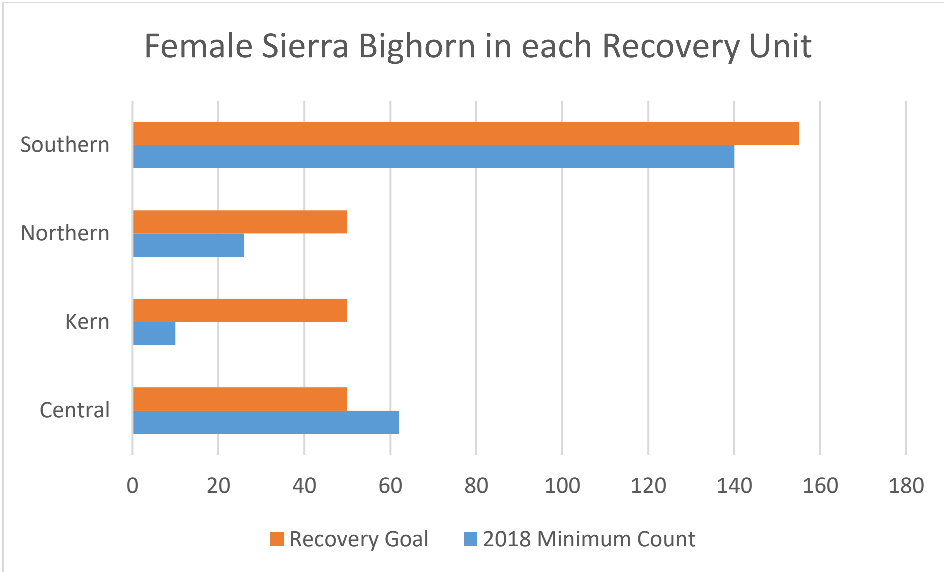


Figure 4. *Abundance and distribution of female Sierra bighorn across recovery units compared to downlisting recovery goals.*

We categorize our minimum counts as 'census', 'good', or 'poor' based on the proportion of females collared and proportion of collars seen as well as expert opinion (Appendix B). This year most surveys were either census or good quality (8/11), although Olancha, Baxter, and Wheeler were all poor. Baxter and Wheeler tend to have intermittent survey quality between years, and Olancha rarely has a good survey. This indicates that we may want to change the survey timing or survey routes to improve survey quality next year (Appendix A). If time allows, we may investigate the feasibility of a winter survey at Olancha and a summer survey at Baxter in the future. At Wheeler it seems that we frequently miss collared animals and may consider expanding our survey area in winter and spring to include some higher elevation areas such as Granite Park.

Table 2. Minimum counts of Sierra bighorn present in each herd as of April 30, 2019, based on reconstructed minimum counts and known mortalities and translocations that occurred after the count before year end. Lambs not identified by sex. In the notes, AF is adult female, YF is yearling female, AM is adult male, YM is yearling male, and UAS is an uncollared animal of unknown age or sex.

Herd	Female Adult	Female Yrlng	Female Total	Lambs	Male Adult	Male Yrlng	Male Total	Population Total	Notes
Olancha	18	2	20	11	10	1	11	42	Mortalities: 2 AF (271, 291), 1 YM (uncollared)
Laurel	1	1	2	0	1	0	3	5	No additions or subtractions documented
Big Arroyo	8	2	10	4	3	5	8	22	Mortalities: 4 AF (289, 496, 490, 285), 1 AM (495)
Langley	22	0	21	9	9	1	10	40	Mortalities: 1 AF (445), 1 F unknown age (uncollared), 5 AM (428, 4 uncollared)
Williamson (2017)	14	2	16	6	5	2	7	29	Not adjusted because not surveyed annually
Baxter[w]	35	7	42	15	34	5	39	96	No adjustments from survey in March 2019
Sawmill	26	6	32	24	4	11	15	70	Mortalities: 4 AF (457, 448, 460, 459), 5 AM (1 uncollared, 207, 361, 357, 393), 1 UAS
Bubbs (2018)	2	1	3	4	1	1	2	9	Mortalities: 2 AF (226, 317), 1 AM (198)
Taboose	2	1	3	1	5	1	6	10	No additions or subtractions documented
Wheeler[w]	39	6	45	24	29	4	33	102	Mortalities: 4 AF (506, 507, 418, 244), 1 AM (508)
Convict	4	0	4	3	1	0	1	8	No additions or subtractions documented
Cathedral	4	0	4	4	1	0	1	9	Mortalities: 2 AF (366, 375), 1 AM (488)
Gibbs	16	6	22	16	16	8	24	61	Mortalities: 4 AF (160, 250, 520, 334), 1 YF (518), 1 YM (501), 1 UAS (why total is 1 lower than sum)
Warren	3	1	4	1	1	1	2	6	Mortalities: 1 AF (523), 2 AM (524, 1 uncollared), 1 UAS
Totals	**194**	**35**	**228**	**122**	**120**	**40**	**162**	**509**	

[w] Winter counts, other surveys conducted in summer

Winter Impact, Weather and Climate

We estimate 25% of females, or roughly 72 individuals, died in the heavy snow winter of 2018-19 (Table 3 and Appendix B). Within the animal year, some herds are counted in the summer, before winter mortalities and other herds are counted during the winter, after some mortality has already occurred. Therefore, we cannot directly compare the population estimate from one animal year to the next to determine the impact from winter. Instead, we use two different methods: one based on the proportion of collared females per herd, and the other based on minimum counts (MC) before and after the winter (combining data from different animal years). Based on the collar ratio of females in each herd and the known collared female mortality, we calculated 62 females died (Table 3, column 9). Using minimum counts before and after winter, we calculated 82 females died (Table 3, column 13). Although both methods have some uncertainty, their similarity supports an estimate of roughly 72 female mortalities, or 25% of the 2018 year-end estimates (assuming a 50/50 sex ratio of lambs, Greene et al. 2017).

Table 3. Estimates of female Sierra bighorn mortality in the winter November 1, 2018 – April 30, 2019. Collar ratio estimates of mortality calculated as: [% collared female mortality]*[female MC pre-winter] summed across herds. Minimum Count (MC) estimates of mortality calculated as: [female MC post-winter]-([female MC pre-winter]+0.5*[lambs MC pre-winter]). Herds highlighted in red suffered larger losses, while those highlighted in orange suffered moderate losses.

Herd	# Collared Females in Nov. 2018	Female MC Pre-Winter	Lamb MC Pre-Winter	Season Year	Est % Females Collared	# Collared Female Mortality	% Collared Female Mortality	Est Total Female Mortality from Collar Ratios	Projected Adult and Yrlng Females	Female MC Post-Winter	Season Year	Est Total Female Mortality from MC
Olancha	13	23	11	summer 2018	0.57	2	0.15	4	29	27	summer 2019	2
Laurel	1	2	0	summer 2018	0.50	0	0.00	0	2	1	summer 2019	1
Big Arroyo	8	14	4	summer 2018	0.57	4	0.50	7	16	9	summer 2019	7
Langley	9	23	9	summer 2018	0.39	0	0.00	0	28	19	summer 2019	9
Williamson	3	15	6	summer 2018	0.20	1	0.33	5	15	15	spring 2019	5*
Baxter	17	45	22	spring 2018	0.38	2	0.12	5	56	42	spring 2019	14
Sawmill	13	36	24	summer 2016	0.36	4	0.31	11	48	38	summer 2019	10
Bubbs (2018)	2	5	4	summer 2018	0.40	2	1.00	5	5	5	summer 2018	5*
Taboose (2014)	2	3	1	summer 2014	0.67	0	0.00	0	3	3	summer 2019	0*
Wheeler	20	44	20	spring 2018	0.45	4	0.20	9	54	50	spring 2019	4
Convict	4	4	3	summer 2018	1.00	0	0.00	0	6	4	summer 2019	2
Cathedral	4	6	4	summer 2018	0.67	2	0.50	3	8	3	summer 2019	5
Gibbs	14	27	16	summer 2018	0.52	5	0.36	10	35	22	summer 2019	13
Warren	2	5	1	summer 2018	0.40	1	0.50	3	6	1	summer 2019	5
Totals	**112**	**252**	**125**			**27**	**0.24**	**62**	**309**	**239**		**82**

* For herds not counted annually, collar ratios were used to estimate losses

Big Arroyo, Cathedral, and Warren were the most sensitive to winter conditions with mortality estimates from 44-82%. Langley, Baxter, Sawmill, Wheeler, and Gibbs had a moderate sensitivity with mortality from 9-38%. Olancha was robust to the winter conditions with mortality rates from 5-15% (depending on the estimation method). The impact of the 2018-19 winter on Sierra bighorn survival was slightly less severe than 2016-17 when we estimated losing 30% of all yearling and adult females (~100).

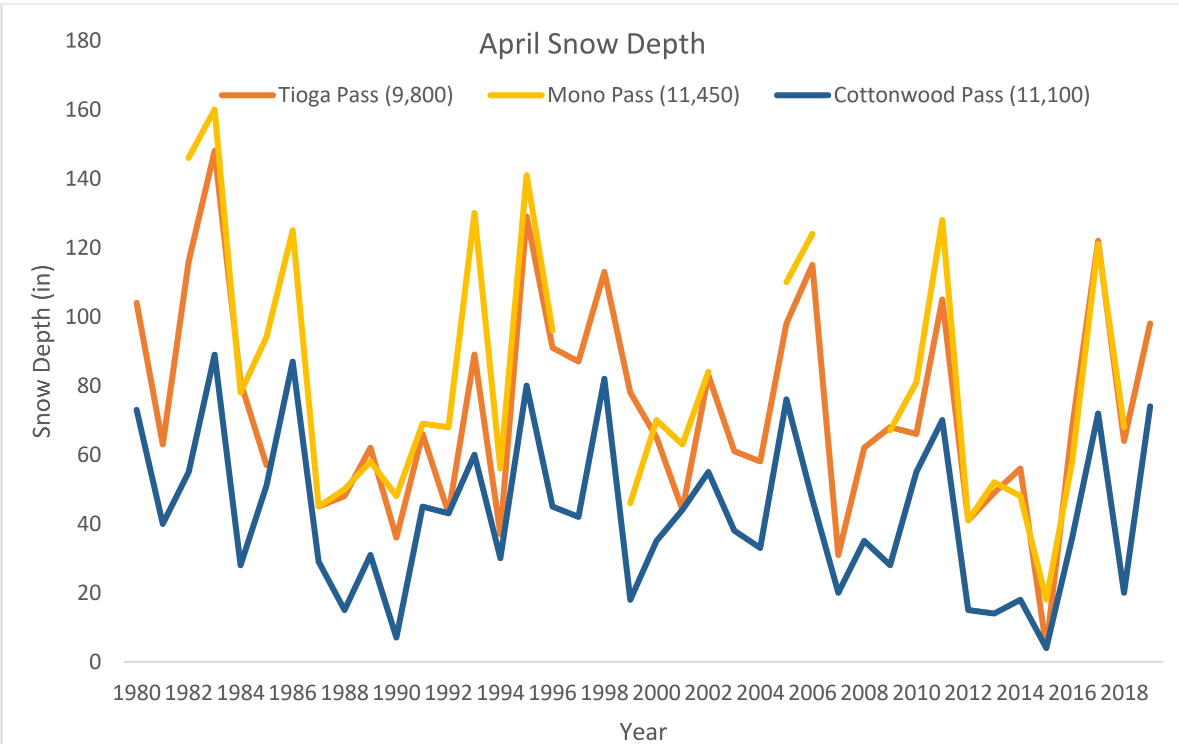


Figure 5. *April snow depth since 1980 at 3 high elevation sites in the Sierra Nevada within the historic range of Sierra bighorn. From north to south, Tioga Pass is within the NRU, Mono Pass is within the CRU, and Cottonwood Pass is within the SRU. Elevations given in feet. Data compiled from California Data Exchange Center Department of Water Resources (https://cdec.water.ca.gov/).*

The 2018-19 water year had above average snow and precipitation (https://water.ca.gov/News/News-Releases/2019/October-19/Water-Year-2020-Begins-with-Robust-Reservoir-Storage). There were more than 30 atmospheric rivers that made landfall in northern California. Atmospheric rivers are long, narrow regions in the atmosphere that transport water vapor outside of the tropics, typically in the form of rain and snow. On April 1, the state's snowpack was 175% of average (Figure 5). Compared to the most recent above average winter (2016-17), significant storms (>12" in 48 hours) occurred both earlier (November 22) and later this winter (May 17), which extended the temporal duration of the snowpack to be longer than other winters, even those with more overall snow (Figure 6).

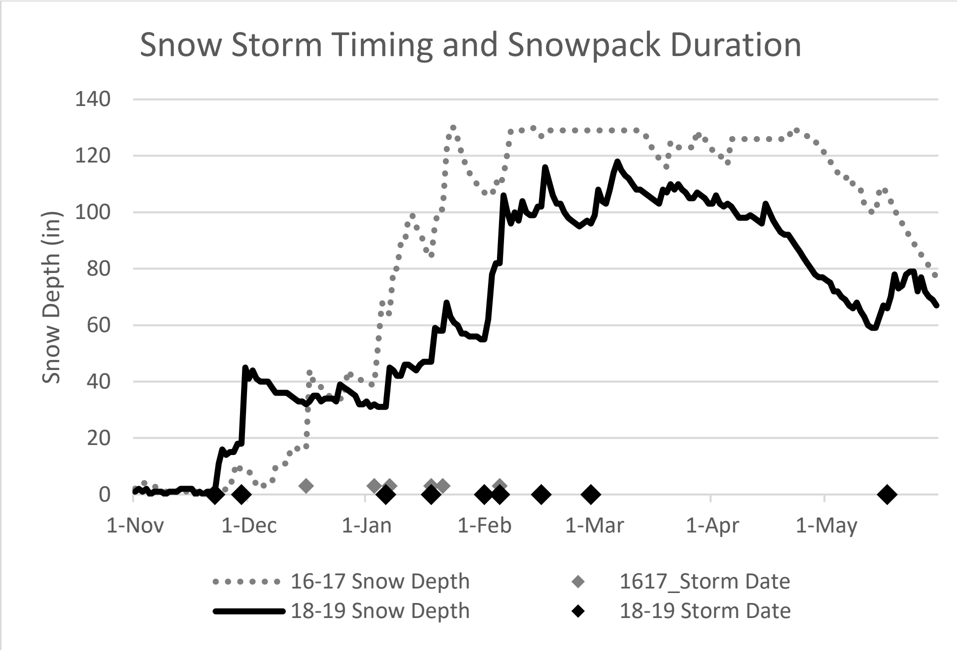


Figure 6. *Comparison of storm timing and snow depth between 2016-17 and 2018-19 at Volcanic Knob weather station above Edison Reservoir in the south fork of the San Joaquin drainage (http://cdec.water.ca.gov/index.html). Lines show cumulative snow depth. Points show the first date of a given storm with >12" of snow in 48 hours. Although there was less overall snow in 2018-19, the duration of the snowpack was similar in both years.*

Population Dynamics

In 2018 we estimated there were 254 females based on minimum counts. Because these annual range-wide estimates combine summer and winter survey data they are not the best way to evaluate specific winter impacts (see Table 3 for winter impacts), but they can elucidate longer term trends. Since 2000, females have generally increased until the declining trend of the last three years (Figure 7). These declines coincide with the wet winters of 2016-17 and 2018-19 when 30% (Greene et al. 2016) and 25% of females died, respectively. During these winters, the most common cause of death was starvation or avalanche (33%) followed by mountain lion predation (20%).

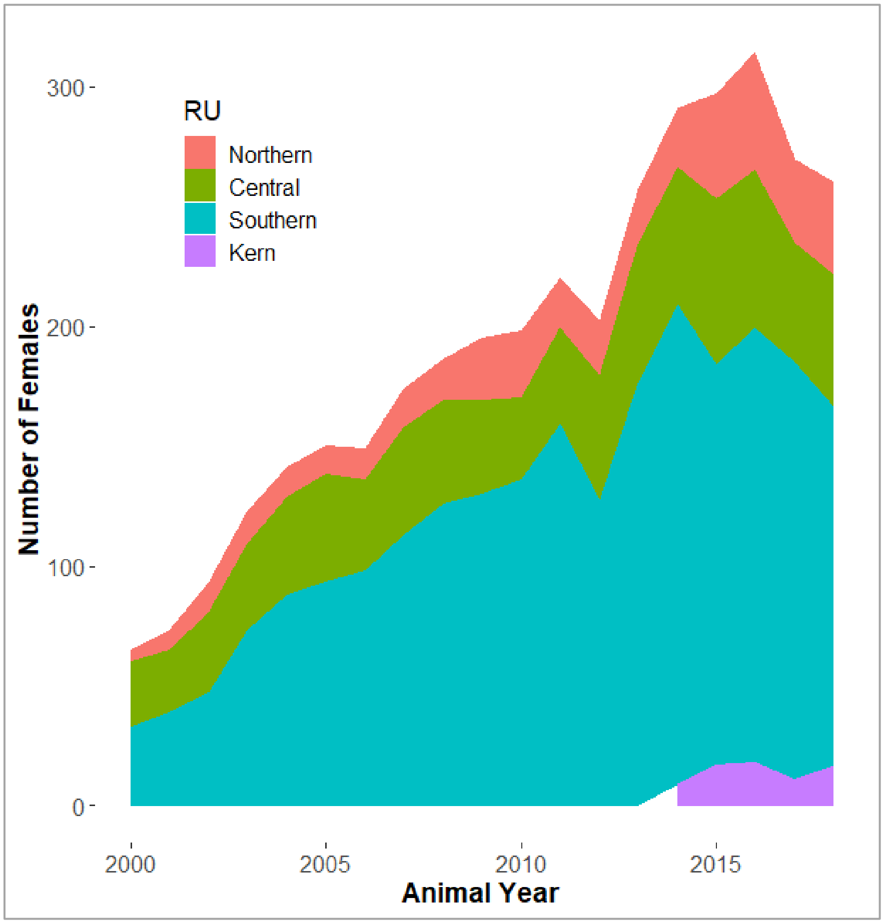


Figure 7. *Range-wide female Sierra bighorn population abundance since 1999. Range-wide numbers are calculated using annual herd values based on reconstructed minimum counts and Mark-Resight estimates as well as the most recent survey results for herds not surveyed annually. Herd counts combined across the animal year (May 1 – April 30). Because some herds are counted before winter in summer and others are counted during or after winter in the spring, the complete impacts of a given winter are not shown on this graph.*

Sierra bighorn populations tend to be driven by adult female survival (Johnson et al. 2010). As minimum counts do not provide confidence intervals and count quality is highly variable (Appendix B), we calculate vital rates based on collars and observed ratios, rather than specific counts (see Population Dynamics). We calculated Kaplan-Meier survival rates for collared females within each year (Appendix B). In 2018, range-wide adult female survival was 0.73 (SE = 0.06) with rates varying from 50% to 100% among herds (Figures 8-10). Population trends (Figure 7) and female collar survival rates (Figures 8-10) are not consistently synchronous across herds in time. In other words, one herd may be increasing while at the same time another herd, sometimes even its neighbor, is decreasing. This indicates population dynamics are determined by very localized conditions. However, this year, many herds experienced a synchronous decline in survival, indicating the large, range-wide impacts of the wet and long winter.

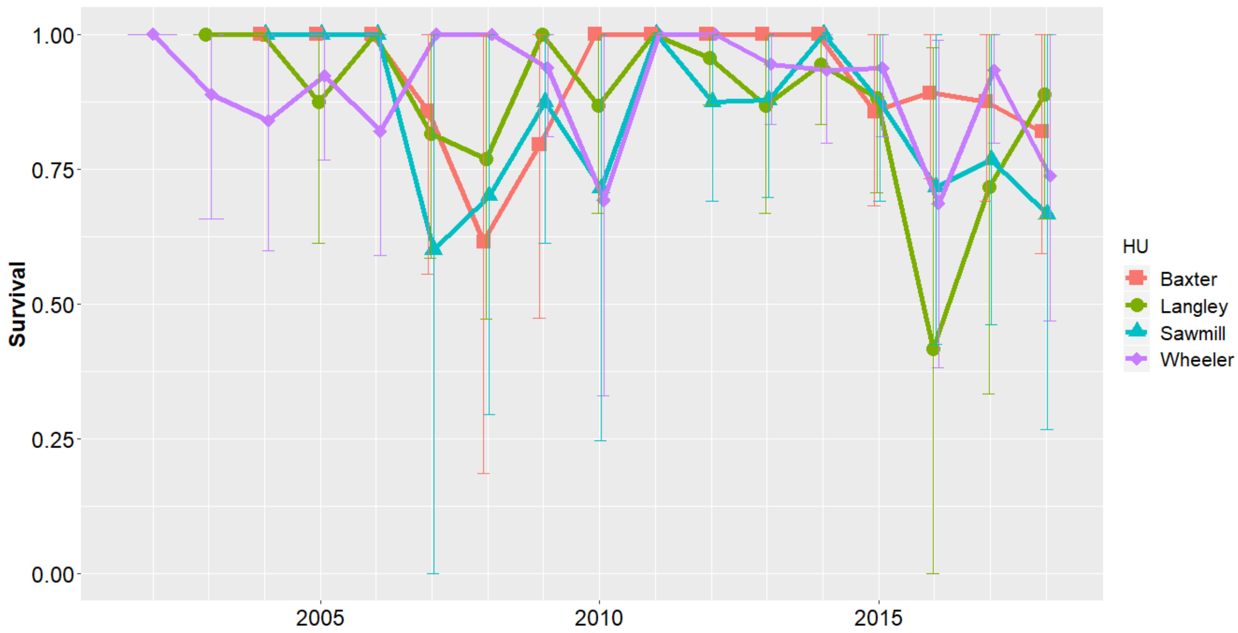


Figure 8. *Annual Kaplan-Meier survival for collared yearling and adult female Sierra bighorn with 95% confidence intervals (bounded at 0 and 1). These are herds that were used to provide source animals for recent translocations.*

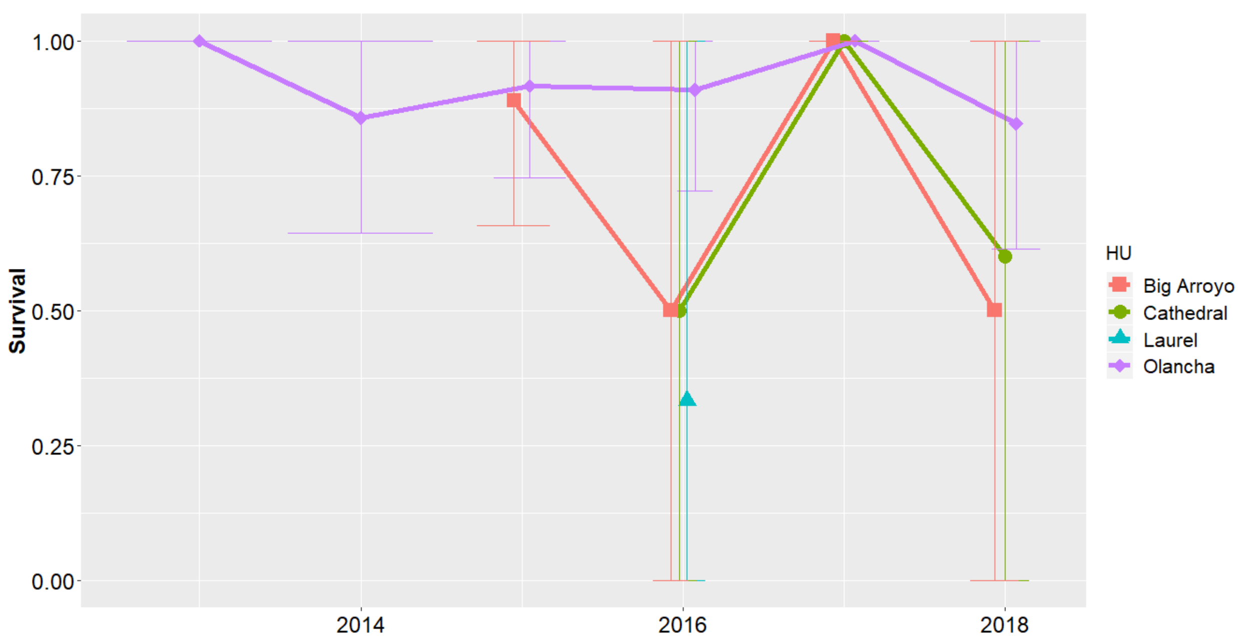


Figure 9. *Annual Kaplan-Meier survival for collared yearling and adult female Sierra bighorn with 95% confidence intervals (bounded at 0 and 1). These are newly re-established herds.*

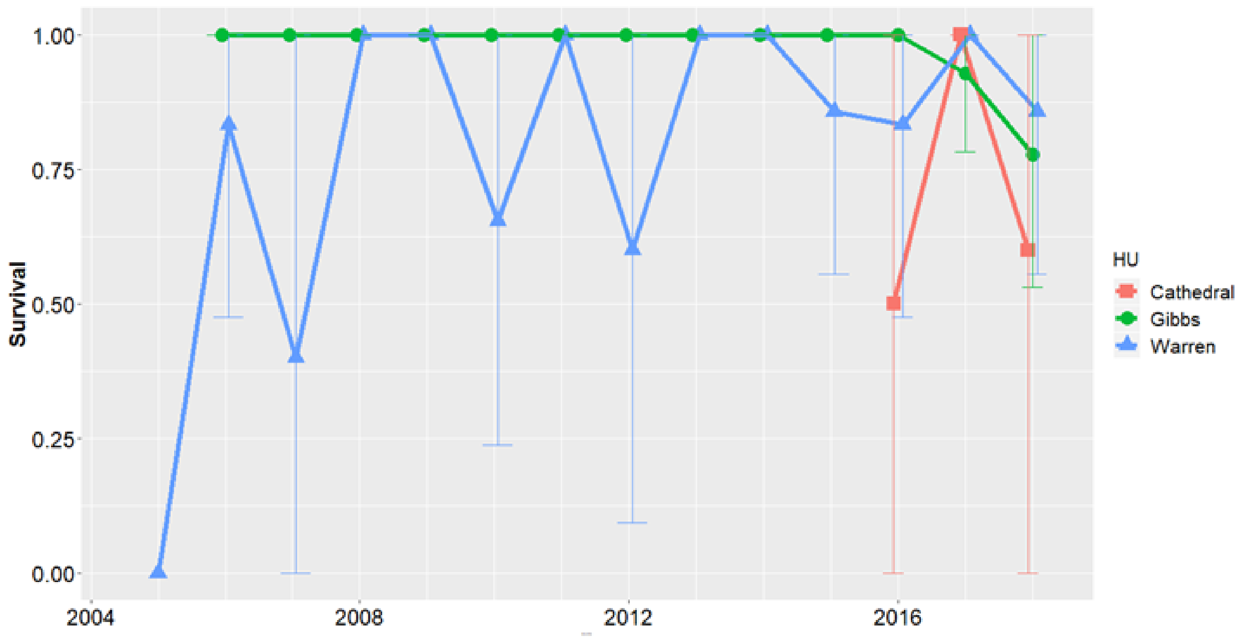


Figure 10. *Annual Kaplan-Meier survival for collared yearling and adult female Sierra bighorn with 95% confidence intervals (bounded at 0 and 1). These are herds within the northern recovery unit.*

Sierra bighorn tend to die in the winter and spring from either lion predation or conditions related to a large snowpack (Figure 11). Having a large snowpack may cause Sierra bighorn mortality in two ways: bighorn may be caught in avalanches or die from starvation. To evaluate the impact of large snowpacks, we combine these causes of mortality into a “snow” category. We have determined the cause of death for approximately 80% of collared female mortalities. During heavy snow winters (e.g., 2010-11, 2016-17) snow is typically the largest cause of mortality, and this year was no exception. Snow caused three times more mortality than lion predation this year across collared females (39 snow mortalities, 13 lion kills).

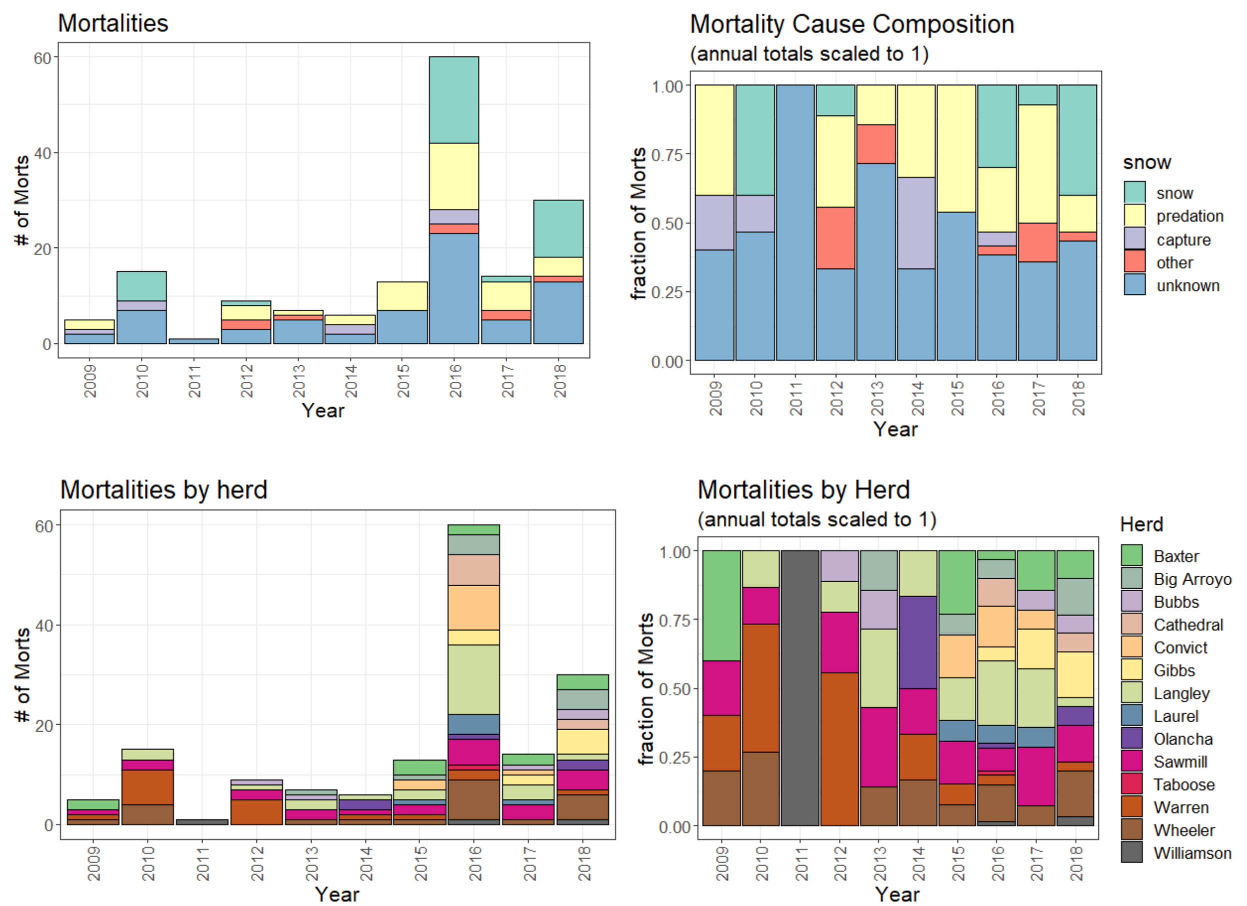


***Figure 11**. Collared female Sierra bighorn mortality 2009-2018 by cause of death and herd. The category snow includes death by avalanche and malnutrition during winter and spring. The number of mortalities (left) is influenced by the number of collared females at a given time which trends with the overall population size. The number of herds has increased with time. This does not include censored animals because their cause and date of death are unknown.*

Lion predation varies across herds in time. Some herds tend to have somewhat consistent low levels of lion predation, while any herd may temporarily experience a predation "episode" in which high levels of localized predation persists for several years (Gammons et al. 2021). It was initially thought the highest predation rates were limited to herds with the highest overlap with deer (the main prey for lions, Johnson et al. 2010), but recent high predation rates associated with population decline at Langley demonstrate that predation episodes may occur in any herd (42-47 % of Langley females were killed by lions during the winter of 2016-17, Gammons et al. 2021). Gammons et al. (2021) defined predation as "extreme" if it was above the 90^{th} percentile, which currently is 11.4%. In 2018, predation rates were not extreme, but may still be limiting or reducing Sierra bighorn population growth.

Bighorn mortalities are typically identified using collared bighorn clusters, collared lion clusters, or searches in areas with active lion use. This year we documented 57 total bighorn mortalities: 30 collared females, 13 collared males, and 14 uncollared bighorn mortalities. The majority of uncollared bighorn mortalities died from predation (N=8), with 3 from avalanche and 3 from unknown causes. However, having more collared lions means we are more likely to detect uncollared bighorn mortality caused by lion predation than by other causes.

Lamb Survival

During spring capture, the pregnancy rate for adult females was 100% (5/5) using ultrasonography. The range-wide observed lamb:ewe ratio was 61% ranging from 0-100% depending on the herd (Table 4). We estimate lamb survival using an observed age ratio approach (Table 4, White et al. 1996, Appendix B). For herds surveyed in summer this method evaluates lamb survival from ~3-18 months. For herds surveyed in winter to early spring (Baxter and Wheeler) this method evaluates survival from ~9-21 months. Lamb survival tends to be lower and more variable than adult survival. Lamb survival from 2018-19 ranged from 24-100% across herds (Table 4). We documented one uncollared female lamb mortality by lion in Williamson in winter (estimated February 2/28/19).

Table 4. Sierra Nevada bighorn sheep recruitment observed between May 1, 2018 and April 30, 2019. Ewe specifically refers to adult females (>1 year). Lamb survival estimates from observed ratios of lambs, yearlings, and adults from 2017 and 2018; survival is bounded at 0 and 1.

Herd	2018 AY Date	2018 lamb:ewe	2018 yrlng:ewe	Lamb Survival from ratios	LCL Lamb Survival	HCL Lamb Survival
Olancha	8/28-8/29	73%	27%	42%	15%	69%
Laurel	7/4	0%	100%	NA	NA	NA
Big Arroyo	8/6-8/8	36%	64%	39%	4%	74%
Langley	8/21-8/23	39%	4%	60%	22%	98%
Baxter[w]	3/1 and 3/19	47%	31%	55%	24%	85%
Sawmill	7/16-7/18	80%	53%	39%	20%	58%
Bubbs	9/26	100%	50%	NA	NA	NA
Taboose	7/26 and 9/5	50%	100%	NA	NA	NA
Wheeler[w]	1/30	63%	24%	24%	9%	39%
Convict	9/20	75%	0%	NA	NA	NA
Cathedral	9/19-9/20	67%	0%	NA	NA	NA
Gibbs	summer	75%	80%	69%	36%	100%
Warren	11/18	25%	50%	100%	0%	100%
Totals		**61%**	**37%**			

[w] Winter counts, other counts conducted in summer

Collaring and Translocating Efforts

Capturing Sierra bighorn provides the opportunity to determine body condition and pregnancy status, test for disease, measure genetic diversity, and deploy collars. Collared animals are critical for monitoring habitat use, migration, disease risk, vital rates, and for estimating herd size. As of May 1, 2019, there were 124 collared females, 48 with functional GPS collars, and 38 collared males, 13 with functional GPS collars. Based on minimum counts, we estimate 34% of females are collared range-wide. Power analysis indicates that we need to maintain radio 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 as well as newly established herds. We are slightly short of our collar goals at Wheeler (29%) and Big Arroyo (29%). In general, 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 disease risk from contact with domestic sheep, so we also try to maintain some collared males, particularly in herds near domestic sheep.

During October 21-26, 2018, we captured 37 bighorn from 7 herds (Gibbs, Warren, Sawmill, Taboose, Baxter, Convict, and Wheeler). Captured animals included 21 adult females, 7 yearling females, one female lamb, 7 adult males, and 2 yearling males. Capture-related injuries included a broken horn exposing the sinus and two lacerations requiring sutures. One recaptured animal was found with an open sore from her previous collar and was released without a GPS collar to facilitate healing.

During March 24-28, 2019, we re-captured four Sierra bighorn from two herds (Gibbs and Baxter). This included the animal with a broken horn injury from the previous fall capture; the injury had healed well, with a hard matrix of bone covering the sinus.

All captured animals were ferried into a central handling area for processing and then returned via helicopter to their capture location. Leading Edge Aviation conducted all captures using a net-gun fired from a helicopter. All captured animals were alive two weeks post capture, based on GPS collar locations. We did not detect *Mycoplasma ovipneumoniae* by PCR, and ELISA results from blood serum indicated no previous exposure.

Sierra Bighorn Movements

Southern Recovery Unit Connectivity

In general, movements between herds are uncommon. However, genetic analyses and movement data indicate some natural mixing between Baxter, Sawmill, and Williamson (Wehausen *pers. comm.* 2020, Few et al. 2011). In the last ten years, three GPS-collared individuals travelled from Baxter to Williamson (female S166 in 2010, Figure 12; female S167 in 2010, and male S454 in 2017, Few et al. 2011, Greene et al. 2018). On June 20, 2018, two-year-old male S454 moved from Williamson to Langley, traveling approximately 12 linear miles one way (Figure 12). Starting from Mt. Barnard, he proceeded to Mt. Young and then Mt. Langley. He then spent a month west of Mt. Hitchcock before making a second venture to Mt. Langley and then travelled back to Williamson on August 28 (Figure 12). It is unknown if S454 was traveling with other animals, but rams have previously been documented on Mt. Hitchcock. The only other known connection between Langley and Williamson occurred in the 1980's when two animals that had recently been translocated from Baxter and Sawmill to Langley moved to Williamson. These recent movements indicate that a large portion of the Southern Recovery Unit may be becoming a more connected metapopulation.

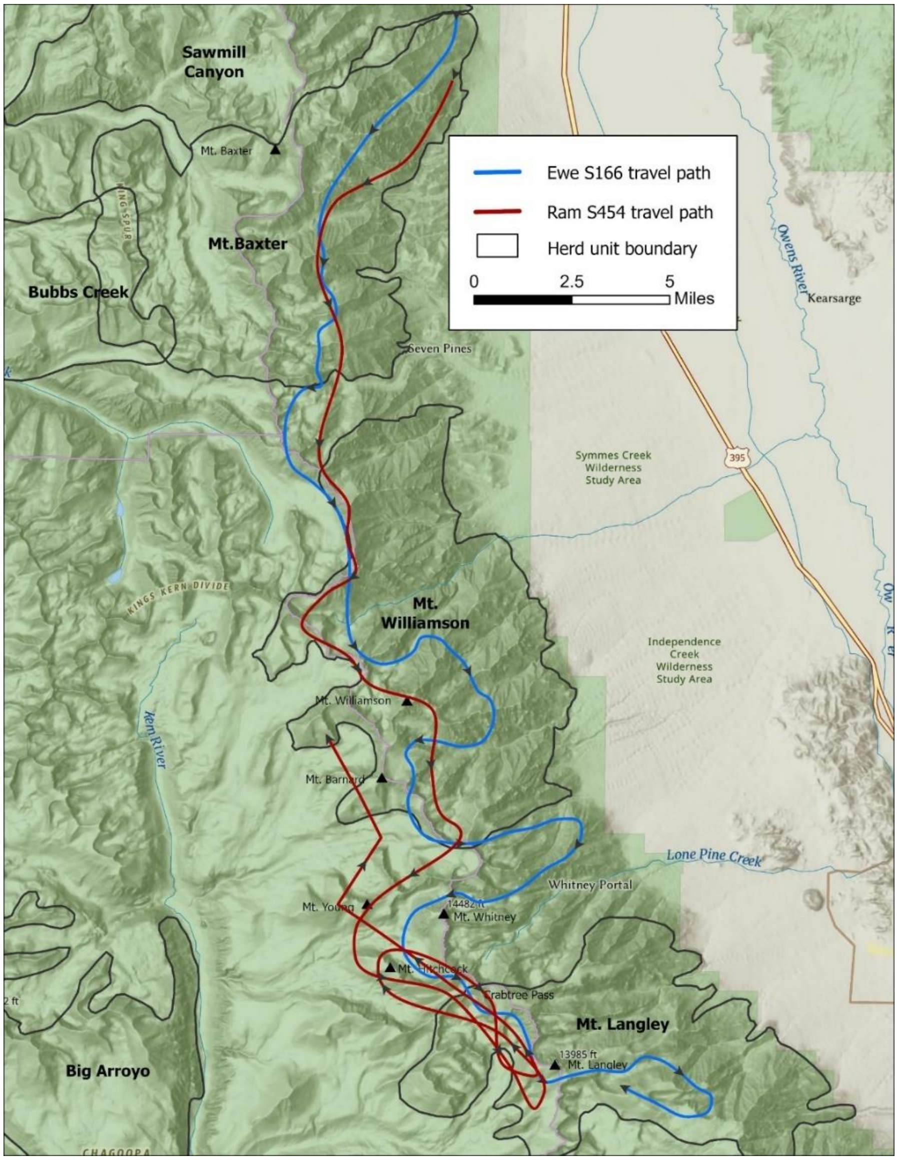


Figure 12. *Sierra bighorn movements across herds Sawmill, Baxter, Williamson, and Langley. Movements of Sierra bighorn male S454 from April 1, 2017 to October 8, 2018. Movements of Sierra bighorn female S166 from February 12, 2010 to July 9, 2010.*

Convict Expansion North

Sierra bighorn were first observed in Convict in August 2009; we believe they colonized from Wheeler (Stephenson et al. 2011). Convict bighorn primarily stayed south of McGee Creek, but recently they have expanded, crossing to the north side of McGee Creek. We first observed bighorn attempting to cross McGee Creek during the large storm cycles in the 2016-17 winter. During that winter, male S296, who had been translocated from Baxter to Cathedral in October but then quickly left Cathedral for Convict (Greene et al. 2017), successfully crossed McGee Creek on January 14, 2017. Shortly after he died of starvation on the north side of the creek. Female S424, her lamb, and a yearling male died in McGee Creek on January 24. They likely died of hypothermia while attempting to cross McGee Creek (Greene et al. 2017). It is unknown if any uncollared animals successfully crossed to the north side that year. However, on April 16, 2019, all known Convict sheep (four females, two lambs, and one male) were observed in a group on the north side of McGee Creek. These south-facing slopes tend to melt out early and may provide Convict animals with better spring habitat during snowy winters.

New Movement from Gibbs to Cathedral

Our newest herd, Cathedral, was reintroduced in 2015 and subsequently augmented with additional males in 2016 and 2017. Initially it was thought that while small, this herd would remain isolated from other herds in the Northern Recovery Unit, creating a refuge from disease transmission (Few et al. 2015). However, a connection between Cathedral and Gibbs was quickly established, which instead may help increase genetic diversity, and possibly recruitment, within Cathedral.

Initially males moved from Cathedral to Gibbs, and subsequently Gibbs males have visited Cathedral. Two of the males translocated in October 2017 quickly left Cathedral for Gibbs. Male S494 succumbed to an avalanche in January 2017; male S489 integrated into the Gibbs population in 2018. Since moving to Gibbs, S489 has not returned to Cathedral, but has ventured into areas between the two herds. During mating season in early November 2018, Gibbs male S487 moved 6 miles to Rogers Peak in Cathedral where he overlapped with Cathedral female S375 and Cathedral male S488 for about five days (~November 7-11, Figure 13). At this time, Cathedral male S488 was the only male in the Cathedral population. Cathedral male S488 and Gibbs male S487 intermittently traveled together in Cathedral and were together until male S487 moved back to Gibbs on December 11. Gibbs male S487 and an uncollared male were photographed together at McClure Pass at the top of Lyell Canyon between Gibbs and Cathedral on November 11 (McDonald *pers. comm*. 2018). On December 28, this same camera photographed an uncollared male (Figure 1, McDonald *pers. comm.* 2018). As there are no uncollared males in Cathedral, these observations are presumed to be of a Gibbs animal, or possibly two different animals. These movements indicate that Gibbs males may already be playing an important role in Cathedral recruitment and genetic diversity.

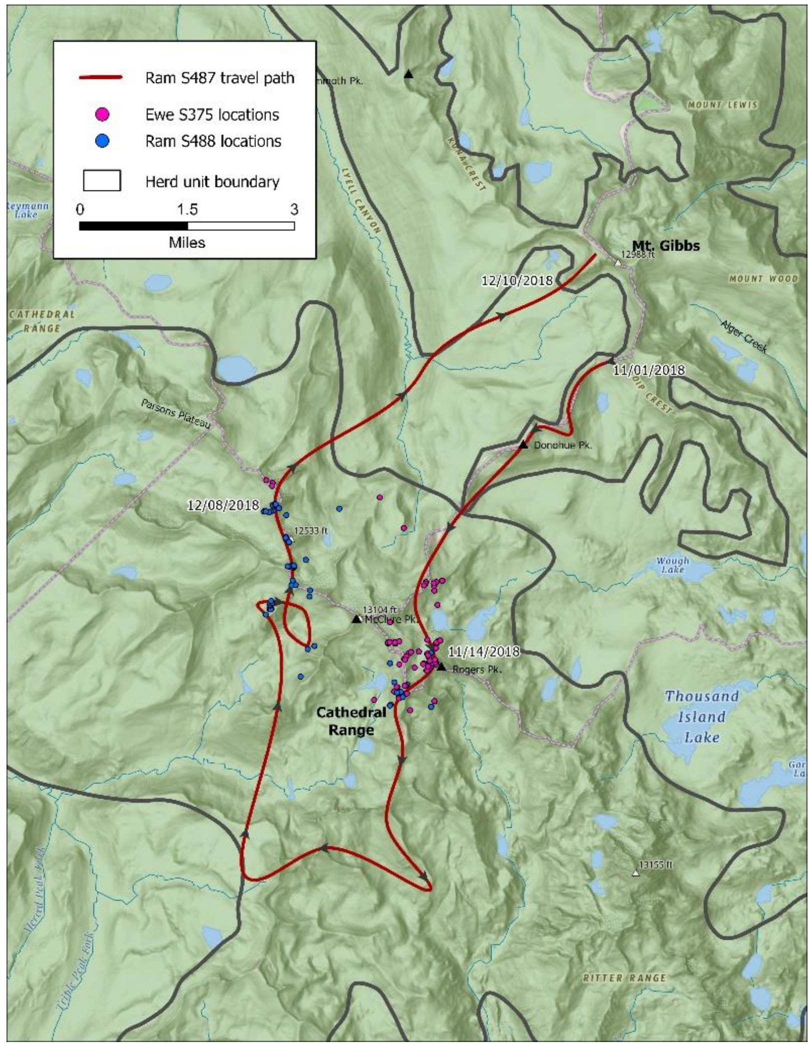


Figure 13. *Movements of Sierra bighorn male S487 from November 1, 2018 to December 10, 2018 as he moved between Gibbs and Cathedral, interacting with Cathedral female S375 and Cathedral male S488.*

Big Arroyo

Within the Kern Recovery Unit, males continue to move between the Big Arroyo and Laurel herd units. In June 2018, male S352 travelled west with resident Big Arroyo male S491. They separated in early July and on July 26, S352 moved back to Laurel. He remained in Laurel for the rest of summer and migrated back to Big Arroyo on November 26. He died near Funston Creek in late December 2019. Staff did not observe S352 during his most recent time in Laurel, so it is possible that he was accompanied by other Big Arroyo males. This connection between Laurel and Big Arroyo could be an important source of gene flow, as the only two other males seen in Laurel in 2018 are the offspring of resident Laurel females.

On December 23, female S496 crossed the Kern River to the east. This was the first time a Big Arroyo animal was known to have crossed the Kern River, although Laurel animals had previously crossed farther south. Female S496 remained on the east side and maintained an elevation of 7500 feet, primarily using west and south facing slopes. She died on February 23, and because snow made her inaccessible until July, no definitive cause of death was determined. Upon investigation, she was found partially buried amongst avalanche debris, suggesting avalanche may have been the cause of death. Since no visual observations were made of S496, it is unclear if she moved alone or with others to Guyot Creek. This novel movement may have been influenced by deep snow conditions, or alternatively, since S496 was recently translocated from Baxter in March 2018, her naïveté may simply have led her to explore areas previously not visited by the Big Arroyo herd.

Mountain Lion Monitoring and Management

Minimum Counts

We monitor trends in lion abundance annually by counting the minimum number of lions known to have been alive (hereafter, minimum count) within three count zones (Figure 14), using techniques following McBride et al. (2008). We also document lions within the eastern Sierra population that occur outside of these zones, but we do not attempt to count all of them, as we do within the zones. A count is estimated by summing the number of collared individuals, the number of unmarked mortalities, and the number of distinct unmarked individuals present that can be identified (Appendix B). In contrast to the 2017 annual report, we will not be inferring the presence of adult females that were missed in a given year. This change was made because several females dispersed in and out of the eastern Sierra lion population in recent years, indicating that we cannot assume females are philopatric in our population. In contrast to the

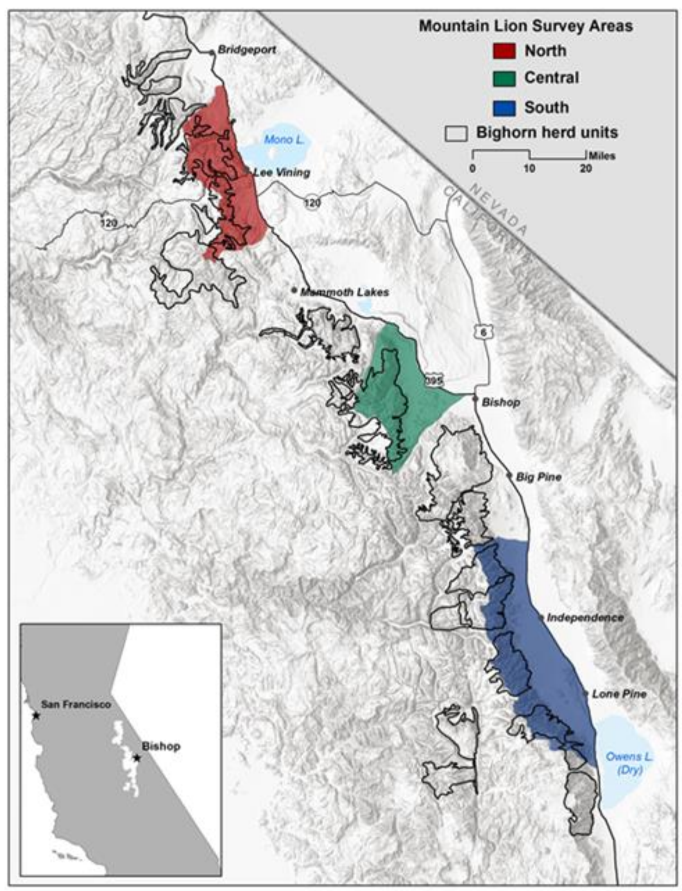


Figure 14. Mountain lion minimum count zones.

remainder of this section, in which years are reported as sheep-years (i.e., May 1-April 30), lion minimum count years are reported as July 1-June 30.

During 2018, we documented a minimum of 37 lions in the eastern Sierra lion population, 25 of which occurred within the three count zones (Figure 14) and 18 of which were collared. Unmarked lions were discerned from each other by mortalities (N = 5) and by categorizing physical evidence based on sex, time, and distance rules (N = 14). This was the greatest number of individual lions counted since the lion monitoring program for Sierra bighorn began, eclipsing the previous high of 19 documented in 2017 (Figure 15).

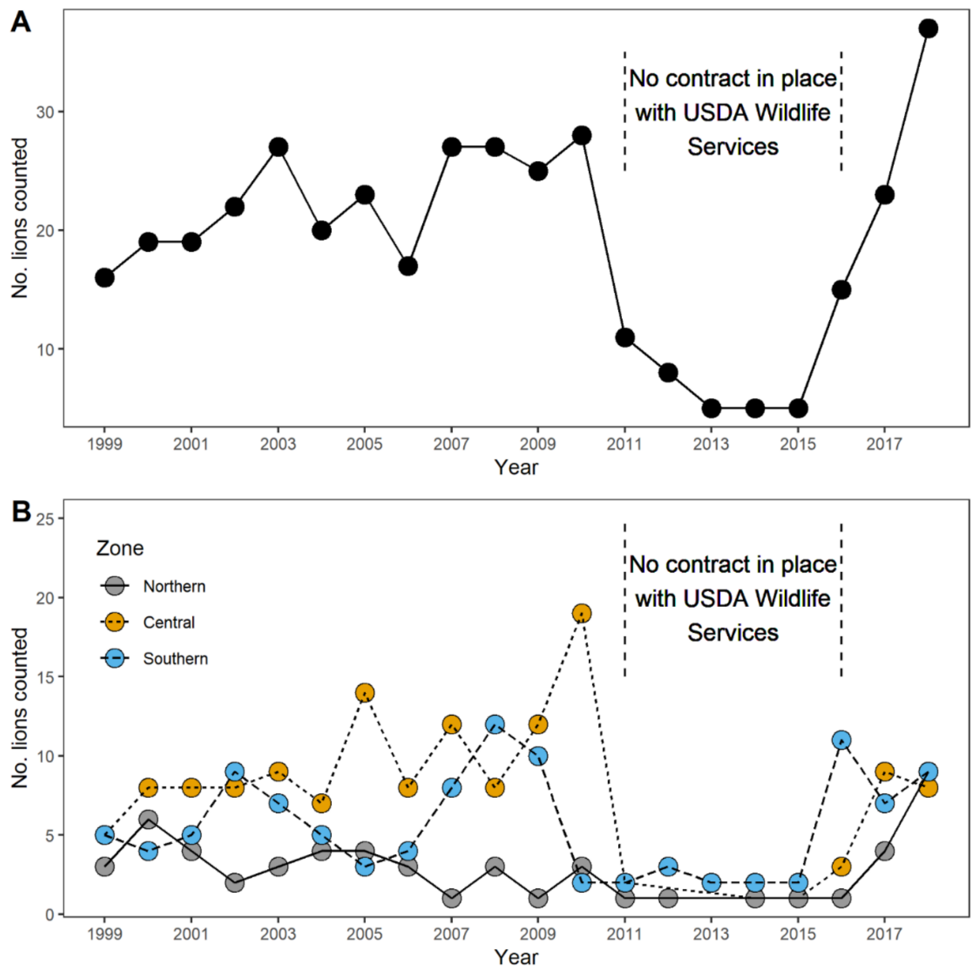


Figure 15. Minimum counts of lions throughout the eastern Sierra population (A) and within the 3 count zones (B), 1999-2018.

We detected a minimum of 9 lions in the North count zone (3 adult females, 2 adult males, and 4 subadults). This is the highest count ever for this zone, and this count is anticipated to be a census of the lions present, given repeated detections of the same individuals without the discovery of additional lions. We completed a similar census of lions in the South count zone, documenting 3 adult females, 1 adult male, and 5 subadults. Lion abundance within the South zone has returned to near the abundance observed during the predation episode at Baxter and Sawmill in 2008-2010 (Figure 15). As was the case in 2017, very few track surveys were conducted within the Central count zone in 2018; as a result the minimum count of 3 adult females, 1 adult male, and 5 subadults is almost certainly an underestimate.

Captures

We captured 10 individual lions on 10 occasions, including 7 females (6 adults and 1 subadult) and 3 males (all subadults, Appendix C). The number of lions captured in 2018 was similar to the average number of 10.1 lions captured per year during 1999-2017, excluding the years of 2012-2015, when no captures occurred. Two lions (L130 and L133, adult females) were recaptures, both previously captured in 2011. These lions were at least 12 and 10 years old, respectively, which is noteworthy because Gay and Best (1996) suggest that few lions live beyond 9 years. Since 1999, we have captured 114 individual lions on 179 occasions (Figure 16).

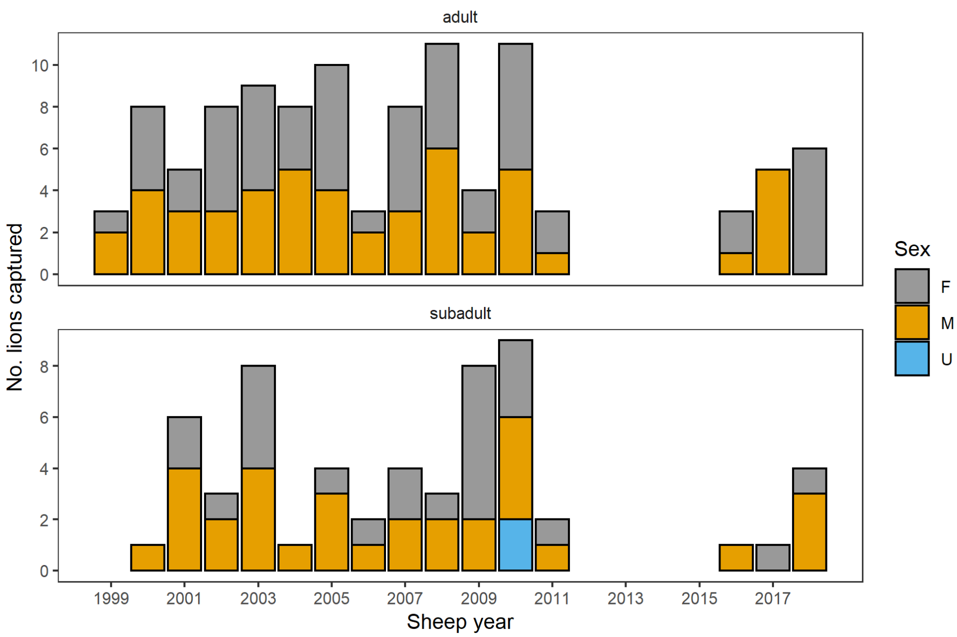
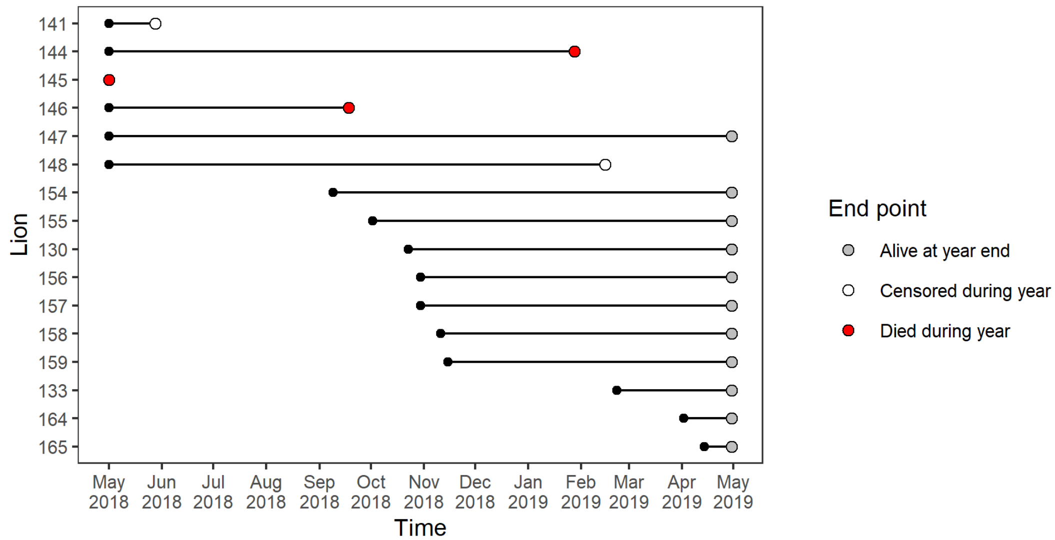


Figure 16*. Age and sex distribution of 114 lions captured in the eastern Sierra Nevada, 1999-2018. If individuals were captured >1 time in a year, only the initial capture was included.*

Lion Survival and Mortality

Including the 10 lions we captured and collared this year and 6 lions captured during previous years, we monitored a total 16 individual lions via GPS or VHF collars during 2018 (Figure 17). The estimated annual survival rate of adult female lions and adult male lions this year was 1.0 and 0.5 (± 0.50 SE), respectively (Figure 18). Annual survival rates were only calculated when ≥4 individuals were collared within a year. Adult female survival was higher than the average estimated survival rate of 0.83 (± 0.16) during 1999-2017, and adult male survival was lower than the average estimated survival rate of 0.68 (± 0.30) over the same time period. However, because there is high variance around survival estimates in any given year due to small samples sizes, caution is warranted in interpreting the degree to which survival changes from year to year. In order to evaluate changes in survival rates over time, it may be more appropriate to consider several years of data together as a period of interest for comparison (e.g., average survival during 1999-2005 vs. average survival during 2006-2011) and/or group males and females together for analysis.

Figure 17. *Beginning (small black circles) and ending (large colored circles) dates of lions radio-monitored (n=16) during 2018.*



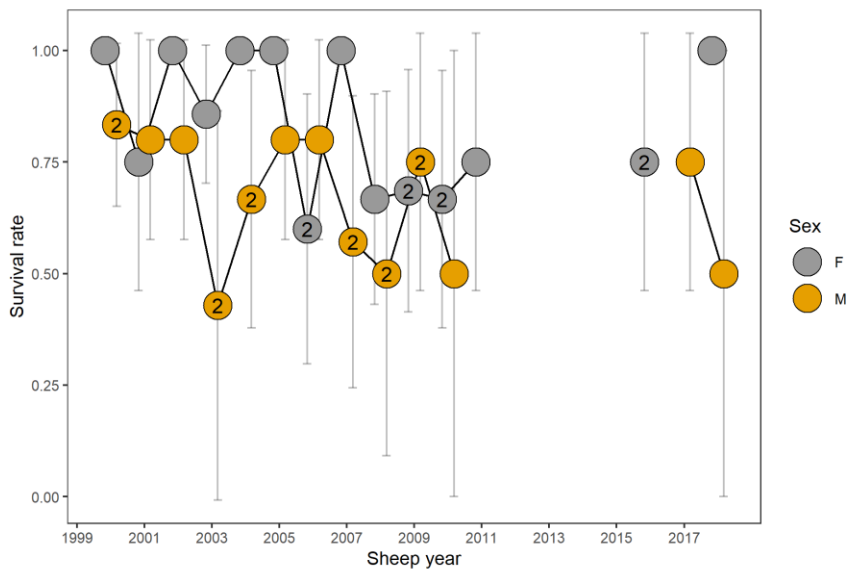


Figure 18*. Estimated annual Kaplan-Meier survival rates (± SE) for adult mountain lions (≥24 months) in the eastern Sierra Nevada, 2000-2018. Numbers within circles indicate the number of collared individuals removed for Sierra bighorn protection in that year. Years for each sex in which <4 individuals were monitored are excluded.*

Nonetheless, high survival for adult females has been relatively common within the eastern Sierra lion population, with survival rates of 1.0 occurring in 5 of 13 previous years, and low adult female survival (<0.75) generally only occurring in association with efforts to protect Sierra bighorn from predation (Figure 18). Average adult female lion survival in the eastern Sierra is similar to that in other lion populations outside of California, both hunted and un-hunted (see Table S6 in Clark et al. 2014), as well as highly urbanized areas within California (Benson et al. 2020). This suggests that adult female survival may be relatively invariant to geography, hunting exposure, and habitat fragmentation, although Vickers et al. (2015) documented a notable exception in the highly fragmented Santa Ana mountains of California, where adult female survival was low (0.56). Adult male lion survival is more variable throughout their distribution, potentially as a result of differences in hunting exposure (Clark et al. 2014), as they are often selectively harvested (Logan and Runge 2021), and because of their larger home ranges, which may increase their exposure to other anthropogenic sources of mortality such as vehicle collisions and depredation. The survival estimate for eastern Sierra lions is in the midrange of estimates from other populations (0.12-1.0, Clark et al. 2014).

We documented 10 lion mortalities during 2018, including 3 females (2 adults and 1 subadult), 5 males (all adults) and 2 subadults of unknown sex (Table 5). No lions were lethally removed to protect Sierra bighorn; the last year in which that occurred was 2016. The causes of death for collared lions were intra-specific killing (N = 2) and vehicle collision (N = 1) (Table 5). Since 1999, excluding capture-related mortalities (N = 6), we have documented 88 lion mortalities, including 53 collared and 35 uncollared individuals. The dominant causes of mortality have been human-related (Figure 19), which is typical for most lion populations, whether they are hunted (Hornocker 1970, Logan et al. 1986, Clark et al. 2014, Logan and Runge 2021) or not (Taylor et al. 2002, Schwab and Zandbergen 2011, Vickers et al. 2015, Benson et al. 2020).

Table 5. Documented lion mortalities in the eastern Sierra Nevada 2018 (N=10).

Lion	Sex	Age	Date	Zone[a]	Location	Cause	Collared[b]
145	M	adult	5/1/2018	North	Walker River	Intra-specific killing	Collared
152	U	subadult	5/4/2018		Crowley Summit (Hwy 395)	Vehicle collision	Uncollared
151	M	adult	6/21/2018		Lone Pine (Hwy 395)	Vehicle collision	Uncollared
153	F	subadult	9/8/2018		Crooked Meadows	Depredation	Uncollared
146	F	adult	9/18/2018	Central	Pearsonville (Hwy 395)	Vehicle collision	Collared
160	F	adult	12/29/2018		Big Pine (Hwy 395)	Vehicle collision	Uncollared
161	U	subadult	12/30/2018		Big Pine (Hwy 395)	Vehicle collision	Uncollared
144	M	adult	1/28/2019	North	Mono Lake	Intra-specific killing	Collared
163	M	adult	2/22/2019		Big Pine	Vehicle collision	Uncollared
162	M	adult	3/22/2019		Crowley Lake	Depredation	Uncollared

[a] Refers to the primary count zone in which the lion resided or spent the most time near (collared individuals only)
[b] Indicates if animal had a functioning collar at the time of death

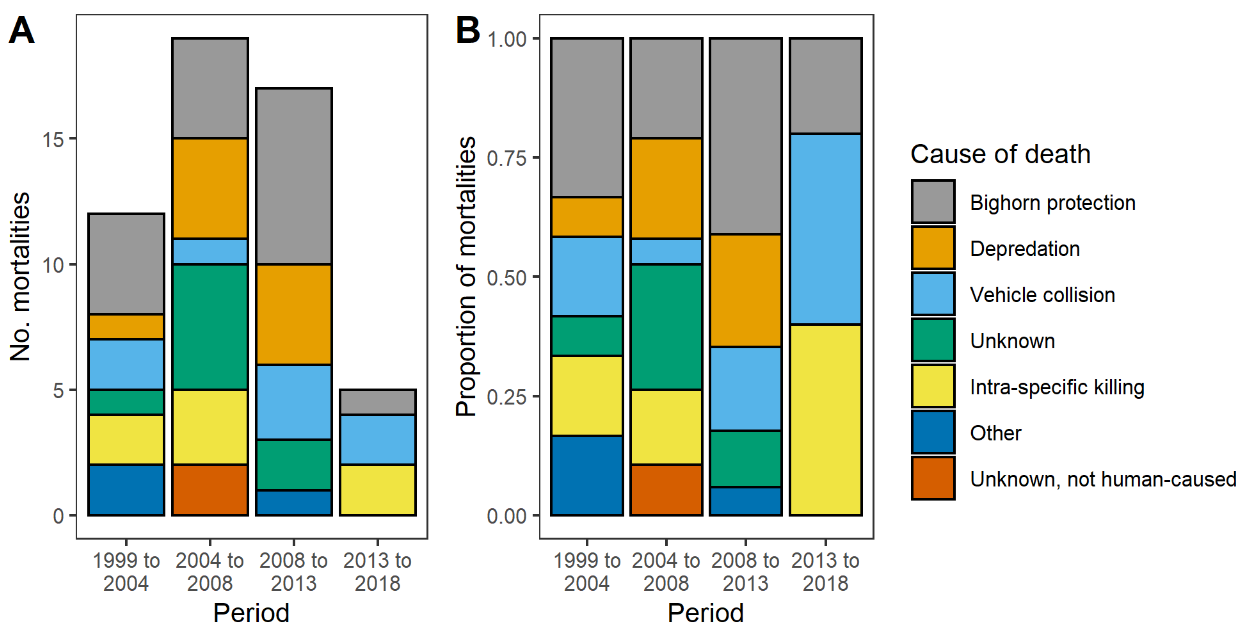


Figure 19. *Numbers (A) and proportions (B) of deaths by cause for collared lions (N=53) in the eastern Sierra Nevada, 1999-2018.*

Reproduction

We documented 12 adult females and detected at least 1 offspring with 11 of them (Appendix C). The mean number of offspring detected was 1.4 per adult female (range = 1-2), however this should not be interpreted as a mean litter size because subadults were of varying ages and some may have died prior to observation.

Predator-Prey Interactions

We documented a minimum of 13 Sierra bighorn killed by lions this year (8 adult ewes, 7 adult rams, and 1 yearling ewe; Figure 20), compared to a long-term average of 9 per year (range = 1-32). The long-term average is influenced by the number of collared lions (which has been increasing in recent years) and the number of Sierra bighorn in the population, as well as the number of collared Sierra bighorn. Lion-killed Sierra bighorn are more likely to be detected when more lions and more sheep are being monitored through GPS or VHF collars. In addition, the impact of these mortalities on the Sierra bighorn population must be interpreted cautiously because as the bighorn population grows, the proportional impact of predation decreases.

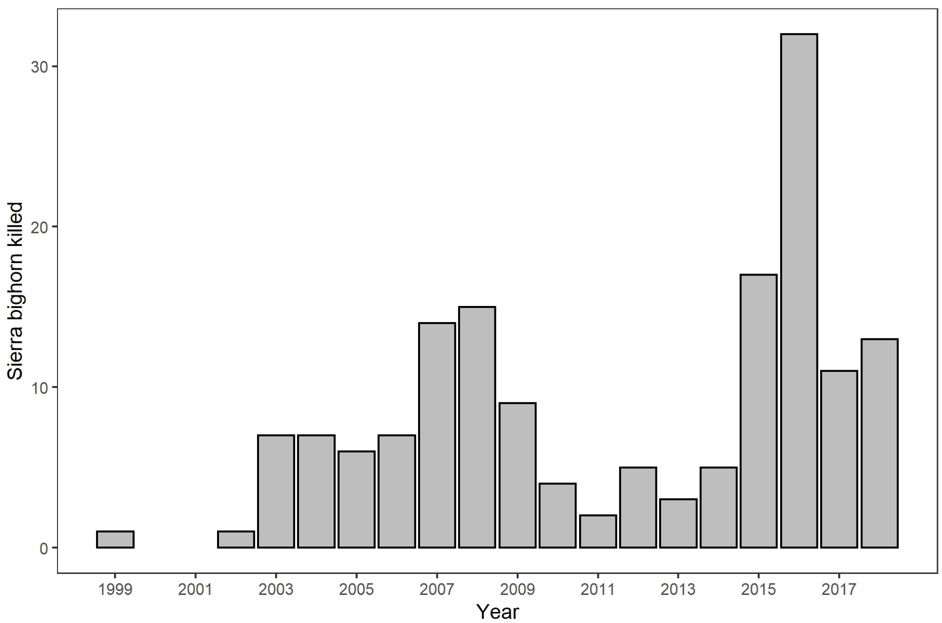


Figure 20. *Minimum number of Sierra bighorn killed by lions 1999-2018. These include mortalities detected from collared Sierra bighorn, lion GPS clusters, and opportunistic observations. Results are not standardized and are likely influenced by the number of lions and the number of Sierra bighorn, as well as the amount of each that are monitored with GPS or VHF collars.*

Other factors that influence the impact on Sierra bighorn populations are the distribution of mortalities, the age and sex of bighorn predated upon, and the status of the herds in which they occur. We detected lion-killed Sierra bighorn in the Langley (n = 4), Wheeler (n = 4), Sawmill (n = 2), Gibbs (n = 1), Williamson (n = 1), and Olancha (n = 1) herds. Male L147 killed at least 4 of these sheep; Male L148 killed 1 of them, and the responsible lion could not be identified for the remainder. Given the small sizes of these herds (mean = 28.9 ewes, range 16-49), and the declining or flat trends in population growth in recent years (with the exception of Wheeler), it is unlikely much of this predation is compensatory. Lion predation of ewes within herds previously used as translocation sources is concerning because these ewes or their offspring could potentially have contributed to restocking Sierra bighorn in other herds (Gammons et al. 2021). At least 2 ewes were killed by lions in the Sawmill and Langley herds, and these former source herds remain below the threshold abundance of 40 ewes (Few et al. 2015) to be considered source herds at this time. Given the declining trend in abundance of the Langley herd, which began in 2016 in association with an extremely high predation rate, the persistence of lion-caused mortality of adult ewes is particularly concerning.

Noteworthy Lion Movements

Male lion L147 was captured on March 5, 2018 as a subadult at the mouth of Lubkin Creek within the Langley herd unit. In July, L147 traveled south into the Olancha herd unit and later traveled to the south edge of the Williamson herd unit, returning to Langley between each foray (Figure 21). On August 16, L147 began a two-week exploration covering approximately 60 miles. L147 started traveling northwest, then crossed the Kern River near Junction Meadow before moving north to Kings Canyon. He then proceeded east up Bubbs Creek, near the Bubbs herd unit, then returned south at the end of the month. In September, L147 traveled south along the Kern River approximately 50 miles to little Kern Lake, traveling through both the Big Arroyo and Laurel Creek herd units. In October and November L147 traveled at least 200 miles, revisiting several areas, while also exploring side drainages of the Kern more extensively. He returned to winter range at Langley on December 20. Throughout 2018, L147 travelled through eight Sierra bighorn herds, more than half of the occupied herd units (Figure 21). These included Laurel, Big Arroyo, Olancha, Langley, Williamson, Baxter, and Sawmill. During his time in Sierra bighorn habitat, he killed at least 4 bighorn, 3 males and 1 female.

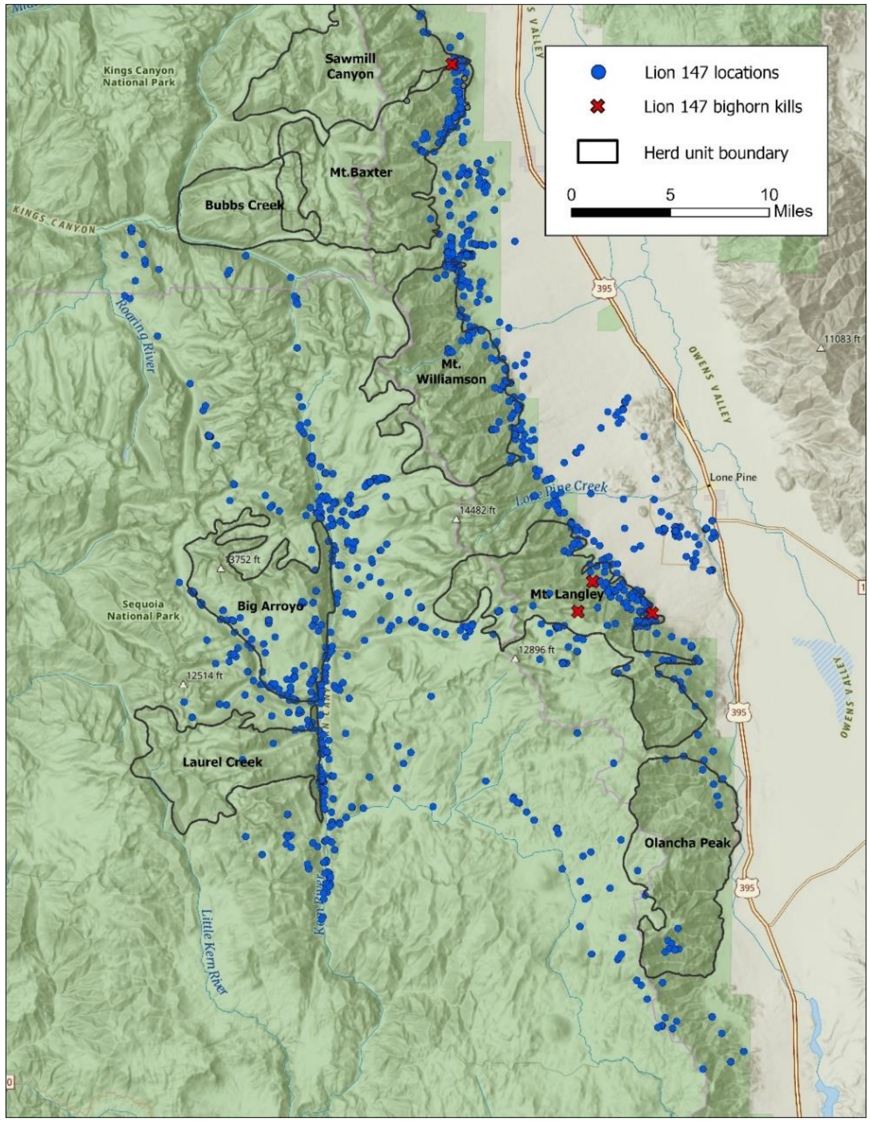


Figure 21. Movements of male lion L147 from May 1, 2018 to April 30, 2019 as he moved across 7 Sierra bighorn herds and killed 4 Sierra bighorn.

Public Outreach

In September 2018, the Sierra Nevada Bighorn Sheep Foundation held an event at the Mono Basin Visitor Center called *Close-up with Sierra Bighorn* to celebrate the new signage for the bighorn exhibit (Figure 22). With the help of the Sierra Nevada Bighorn Sheep Foundation, CDFW hosted three fieldtrips in February, March, and April, each with approximately 30 participants. All trips yielded so much interest we had to turn people away in order to keep groups to a manageable size.

***Figure 22**. Sierra Nevada Bighorn Sheep Foundation members Jora Fogg and Ginnie Chadwick describe bighorn natural history to visitors at the Close-up with Sierra Bighorn event at the Mono Basin Visitor Center in September 2018.*

Pine Creek Recreation Monitoring

The goal of the Pine Creek Recreation study is to track recreational use and monitor Sierra bighorn to detect changes in habitat use and lambing success that may result from recreational use (Sturgill 2018). In general, climbers tend to visit Pine Creek in the spring and fall when temperatures are pleasant and most snow in the area has melted (Figure 23). May tends to be the most popular month for recreational use in Pine Creek and is also the peak month for lambing.

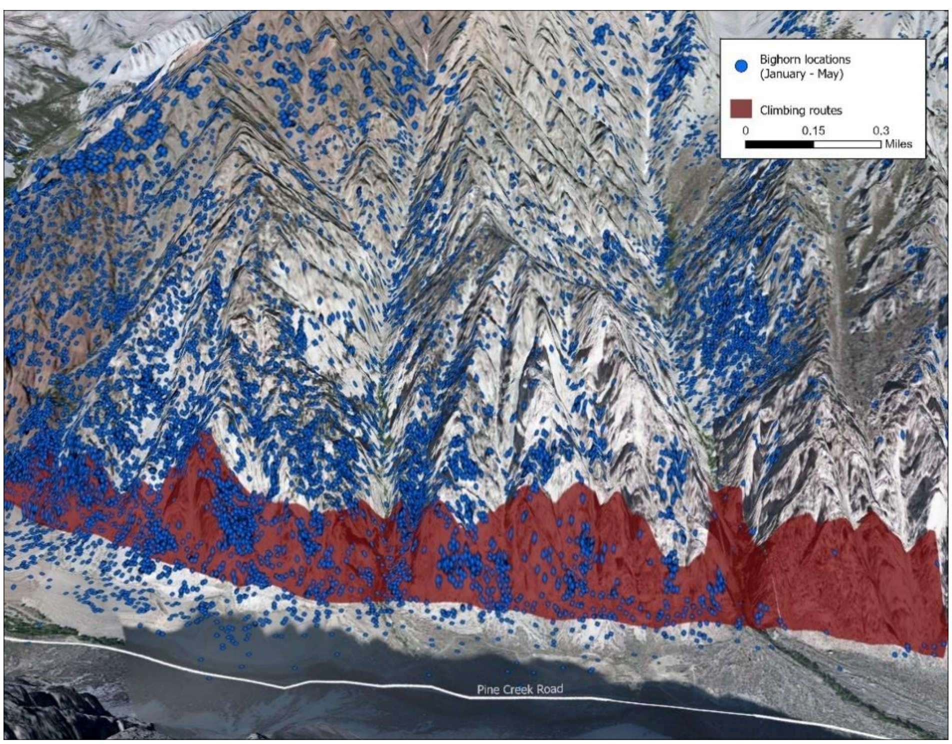


***Figure 23**. Climbing areas in Pine Creek Canyon and Sierra bighorn locations.*

Three trail counters show that overall use has increased, although it varies by trail and year (Figure 24). Recreational use is expected to continue to increase; in 2018 a Pine Creek climbing guidebook was published, and popular climbing websites like Mountain Project are continually adding new climbing routes in the area. We plan to conduct a comprehensive quantitative analysis of Sierra bighorn habitat use and lambing status in relation to recreational use.

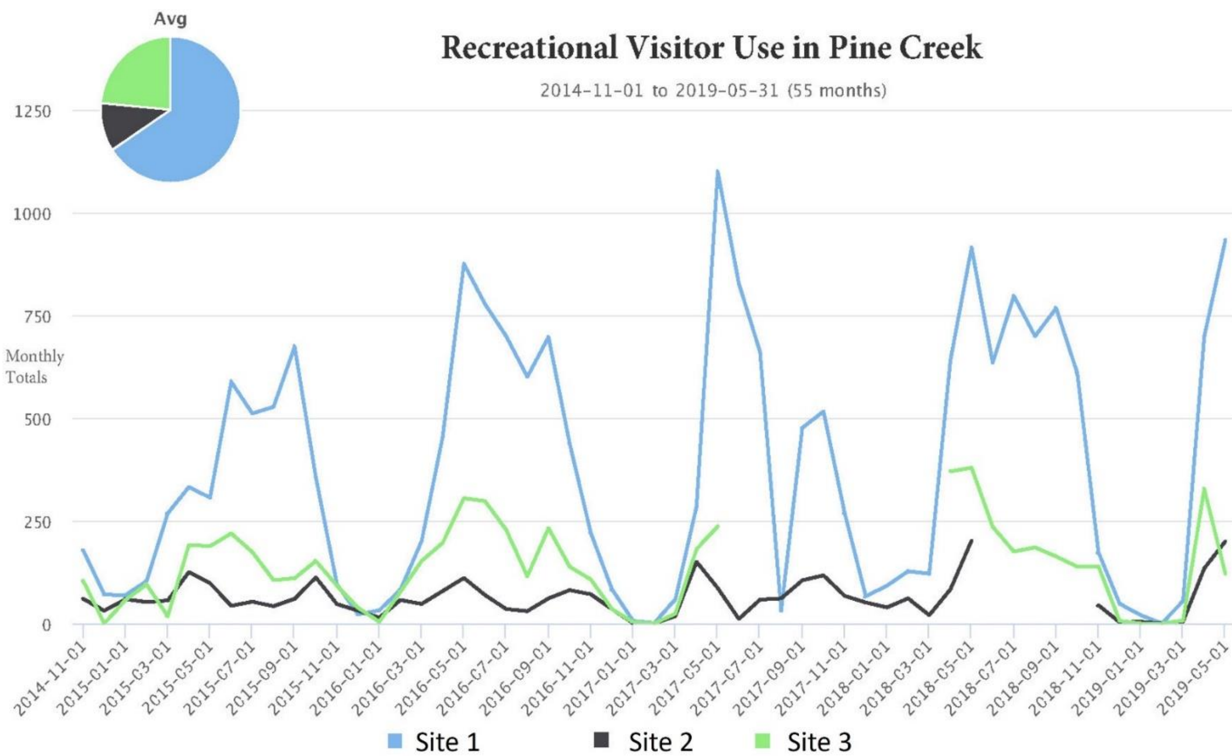


__Figure 24.__ Recreational use in Pine Creek Canyon determined by trail counters in 3 high-use sites.

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Appendix A. Herd Unit Summaries

Olancha

Olancha was surveyed during August 28-29, 2018. Only 54% of known collared females were observed (7/13) and 50% of known collared males were observed (2/4). The reconstructed minimum count was 21 adult females, 2 yearling females, 11 lambs, 10 adult rams, and 2 yearling rams. Similar to 2016 and 2017, this is likely not a census and Olancha should be considered for mark-resight analysis. Throughout the winter many Olancha sheep were observed repeatedly in Falls Creek and Olancha Canyon. Female S291 was killed by a mountain lion on February 5. There were no captures or translocations in Olancha. This is by far the most successful of our recently translocated herds, as adult survival during snowy winters has remained consistently high. Based on the minimum count, 48% of females (N=11) are collared, 17% (N=4) with functional GPS (fGPS); four rams are collared, two with fGPS.

Laurel

On July 4, the only remaining collared female in Laurel (S382) was observed with a yearling female and two unknown aged males on the ridge between Laurel and Rattlesnake drainages. This observation combined with a single known collared male (S352) not seen, bring the reconstructed population estimate to 1 adult female, 1 yearling female (50% collared) and 3 males (33% collared). No captures or known mortalities occurred in this herd this year. As this group has not established a consistent area of use, it will likely become more difficult to find these animals as their GPS collars stop functioning. Female S382 GPS collar stopped updating in November 2018, but male S352 is still working intermittently. At the end of the animal year, there was one female with fVHF and one male with fVHF and fGPS.

Big Arroyo

We observed bighorn in the Big Arroyo Herd Unit June 25-26, July 6, and August 6-8. Across these visits, all collared females were observed and all but one collared male (S491) was observed. A group of three females and one lamb was briefly observed near the summit of Red Spur. One individual (S499) was able to be identified. Based on GPS collar locations it is likely the other individuals were S496 and S497; these three females were translocated together in the spring of 2018. There were more rams seen this year than the previous year and there were more yearlings seen than in the previous year, indicating 2017 was not a census. The reconstructed total was 12 adult females, 2 yearling females, 4 lambs, 4 adult rams, and 5 yearling rams. As all collared females were observed, it is probable this is a census of the Big Arroyo herd. During the winter, 4 adult collared females died. The cause of death was not able to be determined for any because we could not investigate them until the following summer, due to inaccessibility. One adult collared male died in February of starvation. At the end of the animal year, 29% of females were marked (N=4), 14% with fGPS (N=2). In addition two males have fGPS collars.

Langley

The best Langley survey occurred during August 21-23. The reconstructed minimum count was 23 adult females, 0 yearling females, 9 lambs, 15 adult males, and 1 yearling male. All collared females were observed. Only one male collar was observed (25%) out of four. Predation persists at Langley; three lion kill mortalities were detected between December and March: two uncollared male bighorn mortalities were detected from lion L147 clusters, and one female bighorn mortality was encountered opportunistically. In addition, a collared ram died in upper Guyot Creek from old age, and an uncollared male encountered opportunistically while investigating L147 clusters was determined to have died of unknown cause. We estimate 35% of females are marked (N=8), 30% (N=7) with fGPS. There are 4 males with collars, but none have fGPS.

Williamson

No systematic survey was conducted at Williamson, although there were a few opportunistic observations. On May 3, 5 adult females, 2 males, and one yearling of unknown sex were observed in George Creek. The following February, a group of three males were seen at the mouth of Bairs Canyon. That February two mortalities were detected: staff opportunistically encountered a female lamb killed by a lion in Shepherd Creek and a collared adult female was killed by avalanche. At the end of the animal year, there were two collared females, one with fGPS and two collared males, one with fGPS.

Baxter

Baxter was surveyed four times: February 19, March 1, March 12, and March 19. The highest minimum count of total females (N=41) occurred on March 1st with 35 adult females and 7 yearling females as well as 15 lambs. The highest minimum count of males (N=40) occurred March 19 with 35 adult males and 5 yearling males. These minimum counts include known collared animals not seen (5 females, 3 males). The highest Mark-Resight estimate came from the March 1 survey at 53 females (40-71). Based on the lowest CV, the best Mark-Resight estimate came from combining all observations, resulting in 40 total females (35-45). These efforts all included the use of telemetry.

During the March 19 survey a group of mixed Baxter and Sawmill animals was observed on the north side of Sawmill Creek. This was a group of 6 adult females (including Baxter S465, S307, S439), 1 yearling female, 12 lambs (including Sawmill female S511), 1 adult male, and 2 yearling males. As we were unable to differentiate Sawmill and Baxter animals in this mixed group, we only included the known Baxter collars in the Baxter minimum count. Sawmill Canyon is the dividing line between the Baxter and Sawmill herds, but animals clearly cross the boundary and mix. Collar data indicate infrequent but consistent movement across the canyon. Because Sawmill and Baxter are typically surveyed in different seasons, the data cannot easily be combined into a joint count. This mixing is one good reason to survey Sawmill and Baxter in the same season so that the counts can be combined and mixed groups counted. At the end of the animal year, 37% of females were marked (N=15), 5 with fGPS. There were 6 collared males, but only one with fGPS.

Sawmill

During a July survey at Sawmill, we accounted for 30 adult females, 6 yearling females, 24 lambs, 9 adult males, and 11 yearling males. All collared females were seen. Our reconstructed count included 6 collared adult males and 1 collared yearling male not seen. We also conducted a survey in March on winter range, but all age classes were higher during the summer count, except for adult males in which one more was detected (N=10) in winter. In October, we captured 6 females, including one lamb and one yearling. During the winter and early spring, we documented 6 mortalities: two lion kills in Sawmill Canyon (one male, one female), two of unknown cause (one male, one female), one female died from avalanche, and female S460 died from physical injury. S460 was found intact with lesions associated with her collar and sternum. In addition, she had swollen nodules in her neck and her olecranon process was swollen indicating some sort of systemic infection, although lab results were unable to confirm. At the end of the animal year, 32% of females were marked (N=13), four with fGPS. There are five collared males, but none have fGPS.

Bubbs

Bubbs animals were observed in June, July, and September. In September we accounted for 11 animals: 4 adult females, 1 yearling female, 4 lambs, 2 adult males, and 1 yearling male. This included two collared females that were seen and one collared male that was not seen. In addition, a hiker photographed an uncollared adult ram west of the large Gardiner Lake. Although this count is rather low compared to a high count in 2013 of 14 females, we are considering 5 the new post big winter population estimate at Bubbs. Bubbs does not get surveyed annually, but the counts for the last 18 years have ranged from 4-17 females. This spring both collared females died: one of starvation and one from unknown cause, but not predation. The animal year ended with one male collared with fVHF.

Taboose

During July and September there were two opportunistic observations at Taboose that resulted in a minimum count of two adult females, 1 yearling female, 1 lamb, 5 adult males, and 1 yearling male. Most of these animals were observed on July 26th, at which time many pellet samples were collected to compare ground observations with pellet-derived group composition. This group also included ram S258 who has been identified as a Sawmill ram and was therefore not included in this count. Taboose is not surveyed annually, but this will be the new population estimate for Taboose, which had previously varied between 1 and 3 females. In October, one female was captured and collared (S512). At the end of the year, there were two collared females in Taboose, one with a fGPS. No males were collared, although sometimes known Sawmill rams are in the region.

Wheeler

Wheeler was surveyed January 30, 2019 and documented 44 adult females, 6 yearling females, 24 lambs, 30 adult males, and 4 yearling males. This included 7 collared females not seen and 6 collared males not seen. We documented 8 mortalities: 4 from lion (female S507, males S416 and S508, and one uncollared male), 3 from avalanche (females S510 and S244 and one uncollared male), and one from unknown causes (female S506). In October we captured 13 animals including a recaptured female (S242) and male (S405), and 11 new captures: 3 female yearlings, 4 adult females, and 4 adult males. At the end of the animal year, 28% of females were collared (N=14), four with fGPS. In addition, eight males are collared, four with fGPS.

Convict

Based on a single opportunistic observation in September, the minimum count for Convict is 4 adult females, 3 lambs, and 2 males; one collared male was not seen, and an additional adult male was collared in October. In October, we captured 2 females (S525, S526) and one male (S527). As of May 1, we estimated 75% of Convict females are collared (N=3), one with fGPS. There are two collared rams but neither have fGPS.

Gibbs

Our best minimum count from Gibbs came from a series of observations in July and August: 20 adult females, 7 yearling females, 16 lambs, 16 adult males, and 9 yearling males. Seven Gibbs animals were captured in the fall (6 females including one recapture of an adult female (S160), one yearling female, and one yearling male). Two of these adult females were recaptured in the spring. One of the recaptures (S500) had suffered the loss of her entire left horn during the fall capture but appeared to have healed well when recaptured in the spring. Just before the spring capture we documented five mortalities: two females were killed by avalanche (S334, S250), an adult and a yearling female died of starvation (S518, S520), and the remains of an uncollared, unknown sex animal were found for which the cause of death could not be determined. After spring capture there was another collared female mortality (S160) from mountain lion at lower elevation (8600ft) above Walker Lake. This is the second mountain lion mortality at Gibbs. Both occurred at lower elevations outside of the main areas used by this herd. However, if a lion did spend time hunting in Gibbs meadow the bighorn losses could be large. Cameras placed near McClure Pass by YNP documented the movement of an uncollared Gibbs ram into the Cathedral area. We estimate 37% of females are marked (N=10), five with fGPS. In addition, three rams are collared, one with fGPS.

Cathedral

In September, we censused Cathedral: 6 adult females, 4 lambs, and 1 male. In addition, one collared ram from Gibbs made it into the Cathedral area, based on a YNP fox camera placed at McClure pass. During the winter there were 3 collared animal mortalities: a male and female died from starvation, and a female died of unknown cause. At the end of the period there were 2 collared females (50%), but neither had fGPS.

Warren

Our best count from Warren came from an opportunistic observation in November: 4 adult females, 1 yearling female, 1 lamb, 3 adult males, and 1 yearling male. All collared animals were seen. In October, we captured 2 females and 1 male. This was the first successful capture since fall 2014. During the winter, we documented 4 mortalities: 3 from avalanche (collared male S524, uncollared male, and unknown) and 1 from starvation (female S523). By the end of the animal year there was only one collared female with fGPS.

Appendix B. Methods

Female Over-Winter Mortality

We used two methods to estimate over-winter female mortalities (Table 3) 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 both of these methods have their limitations. Relying only on the ratio of collar female mortalities assumes that uncollared animals die at the same rate as collared females. This is generally thought to be true, but random mortalities might alter this within a given herd year. 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 and 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 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 any type of observation; censor date is one month after the last observation (visual, telemetry, or GPS collar update). 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's count. Even with reconstructions, minimum counts tend to underestimate true abundance, particularly as herds get above 20 individuals, and 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.

Range-wide abundance represents our best estimate of female population size post winter and is compiled from herd unit survey data. However, 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 are 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). The total count of females in summer surveys does include the impact of winter on all age classes. For this reason, more complex vital rate analyses based on count data require separating the data based on survey timing, or, alternatively, range-wide analyses can focus on data not associated with counting efforts, such as collar survival (e.g., Conner et al. 2018).

We generally estimate that there are 2 males for every 3 females that we count based on past counts in the Sierra Nevada (Wehausen 1980) and various studies on bighorn sheep (e.g., Valdez and Krausman 1999). 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). However, this year our ram counts came up with higher numbers than our ratio, so we used the count values.

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 radio-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.

Mountain Lion Minimum Count Estimation

Annual lion 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 radio-collared Sierra bighorn mortalities as well as through 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 or dragged roads 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.

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 there is little danger of overestimating abundance, the true abundance can be 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).

The primary reasons that, despite being the best method available, minimum counts are potentially problematic are that (1) it is unknown what proportion of unmarked individuals present have been accounted for, and (2) the ability to account for unmarked individuals is dependent on survey effort. For example, if a given area actually has 5 adult females present, one might determine with a small amount of survey effort that 2 of them exist. The true abundance in that case would be 60% greater than the minimum count, which may lead to inappropriate management recommendations. However, with additional survey effort, the remaining 3 could be accounted for, and the minimum count would equal the true abundance. In either case, one does not actually know what the true abundance is—the amount of survey effort required to count all individuals present is unknown. Thus, 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 radio-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.

Appendix C. Lion Supplementary Data

Table C1. Lions captured in the eastern Sierra Nevada during 2018 (N=10). Zone refers to the primary count zone in which the lion resided or spent the most time near.

Lion	Sex	Age	Date	Zone	Location	Method	Recapture
154	M	subadult	9/9/2018	North	Crooked Meadows	hounds	No
155	F	subadult	10/2/2018	North	Log Cabin Mine	cage trap	No
130	F	adult	10/23/2018	North	Glass Mountain	hounds	Yes
156	M	subadult	10/30/2018	North	Wilson Creek	cage trap	No
157	F	adult	10/30/2018	North	Wilson Creek	cage trap	No
158	F	adult	11/11/2018	North	Bald Mountain	hounds	No
159	F	adult	11/15/2018	North	Hot Creek	cage trap	No
133	F	adult	2/22/2019	South	Goodale Creek	cage trap	Yes
164	F	adult	4/2/2019	South	McMurray Meadows	hounds	No
165	M	subadult	4/14/2019	South	North Bairs Creek	hounds	No

Table C2. Adult female lions and minimum numbers of offspring detected in the eastern Sierra Nevada during 2018.

Lion	Offspring
unmarked lion “Wells mother”	1
unmarked lion “Swall mother”	2
unmarked lion “June mother	2
unmarked lion “155 mother”	1
130	2
157	1
158	1
159	2
160	1
167	2
168	1