S44 Basalt bighorn sheep distribution, movement, habitat selection, and adult mortality study: Final Report for Phase 1, 2015-2018

Julie Mao, Terrestrial Wildlife Biologist, Area 8

Matt Yamashita, District Wildlife Manager, Basalt
(now Area Wildlife Manager, Area 8)

Colorado Parks and Wildlife
0088 Wildlife Way
Glenwood Springs, CO 81601

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COLORADO
Parks and Wildlife
Department of Natural Resources

Introduction

The S44 Basalt bighorn sheep herd has been managed since 1972 as a source population for transplants to supplement or establish other bighorn populations both within Colorado and, historically, to other Western states. S44 has offered ram hunting opportunity in most years since 1982. Previous VHF collar data from 1987-1997 documented the sheep using areas along the Fryingpan River and Toner, Seven Castles, and Taylor Creeks (Byrne 1993; Byrne 1994; Byrne, *unpublished data*). Knowledge of this herd's current ecology using modern GPS collar technology will aid in effective management of the sheep, their habitat, and land-use planning decisions. Ultimately, successful management of the S44 herd has statewide implications, given this herd's role as both a source population and a hunted herd.

The objectives of this project were to:

1. Document seasonal home ranges, movement corridors, lambing grounds, and habitat selection using satellite-GPS collar data.
2. Conduct mark-resight population surveys as part of established coordinated ground counts to provide a more robust estimate of population size.
3. Monitor age and sex composition through visual observations of marked groups throughout the year.
4. Assess the disease status of captured adult bighorns.
5. Identify causes of adult mortality.

Methods

Captures

Sheep were baited at wintering areas in Toner Creek and Otto Creek and were captured using an anesthetic drug (BAM) delivered via ground darting or jab pole injection. Nasal and oral swabs and blood samples were taken, except in a few instances when handling time became too long. Each sheep was fitted with a Vectronic Vertex Survey collar and also a unique color combination of ear tags. The BAM was reversed with an injection of atipamizole. Total handling time per animal was usually <10-15 minutes. The collared sheep were released on-site.

Data Collection

The collars were programmed to take a GPS location every 13 hours. The VHF duty cycle was set to turn on at 08:00 (MST) and off at 17:00 (MST). The mortality sensor was set to 10 hours.

In addition to collecting locations through the GPS collars, we located the collared sheep via VHF tracking from the ground to make visual observations of their group size and composition. Groups without functioning collars were also opportunistically documented when seen while out VHF tracking the collared animals. We attempted to locate all of the collars per "round" of relocations before beginning a new round.

Each summer we also conducted a 1-day coordinated ground survey throughout the herd's summer range. Observers hiked or drove specific routes on the same day to survey for bighorn sheep. They recorded sheep group size and composition, identified any ear-tagged and/or radiocollared individuals, and noted time and direction of travel of the sheep group.

This project was originally planned for 4 years based on an expected collar battery life-expectancy, but the first collars began to fail as early as 2.3 years. Over half of the collars quit by 3 years. In addition, in early July 2018, a large human-caused wildfire, the Lake Christine fire, was started. Due to fire-fighting operations, road closures prevented access to significant portions of the bighorn herd's summer range for much of the season. Between the premature collar failures and the road closures, regular ground tracking of the collared animals effectively ended by June 2018 and no coordinated ground count was done in summer 2018.

The project was also originally intended to compare pre- vs post-treatment habitat use to assess the effects of habitat improvement projects on USFS lands in the lower portions of Seven Castles and Taylor Creeks. However, the habitat treatments that USFS had expected to occur in 2017 have been delayed. USFS now estimates that the treatments may happen in 2020 (USFS biologist Phil Nyland, *pers. comm.* 2019). Therefore, the bighorn sheep data collected in the 2015-2018 phase of this project represents pre-habitat treatment data ("Phase 1"). Post-habitat treatment ("Phase 2") data will depend on when the habitat treatments occur and whether future funding is available to deploy new collars on the sheep.

Data Analysis

GPS locations from January 2, 2015, through October 15, 2018, were included in the analysis. We defined each biological year as May 1st to April 30th. We also defined the following date ranges for four seasons:

1. Lambing: May 1 to June 15
2. Summer: June 16 to October 15
3. Rut: October 16 to December 15
4. Winter: December 16 to April 30

We parsed the GPS collar data into three herd segments based on the animals' sex and winter capture location: rams, Toner ewes, and Otto ewes . There were not enough rams captured at Otto Creek to separate the collared rams into herd segments for this analysis, so their data were grouped simply as the ram herd segment. To characterize seasonal homeranges, first we ran separate Brownian bridge movement models (kernelbb in R package adehabitatHR) datasets based on GPS collar datasets for each individual animal, biological year, and season. Datasets with <50 locations were not included in the Brownian bridge analyses. Then for each season, we averaged the resulting Brownian Bridge rasters among each herd segment. The mean rasters were converted to polygon contours representing 50, 75, 90, 95, 97.5, and 99% utilization distributions for each season.

We estimated population size through mark-resight analysis of the summer ground survey data using the Chapman estimator.

Results

Captures

Sixteen sheep in S44 were radiocollared over the span of this study (Table 1, Figure 1). We collared 4 ewes and 4 rams at the Toner bait site, and 7 ewes and 1 ram at the Otto Creek site. One of the Toner rams (Ram #5) died after only 2.5 months, so his collar data only contributed to a small portion of the winter data. Two other young rams were captured at Toner, sampled, and eartagged, but were not radiocollared.

Table 1. Captured animal identification, animal-collar association, dates of active GPS data collection, and disease screening lab results.

Animal database ID	Sex	Capture Location	Collar ID	Capture Date	GPS End Date	Collar Off Date	Reason for Collar Off or GPS End	Collar still active as of 10/8/19?	N locations as of 10/8/19	Approx N possible fixes	% Fix success	Left Color	Left Number	Right Color	Right Number	Age Estimate (1st capture)	Nasal Swab taken	Oral Swab taken	Blood taken	Mycoplasma serology	Mycoplasma PCR	M haemolytica leukotoxin	P multocida
1	M	Toner	17782	1/2/2015	4/23/2017	1/2/2018	Battery dead, replaced collar	No	1549	1554	100%	Yellow	12	Purple	11	5.5	Y	Y	N				
			17779	1/2/2018	11/16/2018		GPS transmissions stopped (battery dying or dead)	No	436	587	74%						Y	Y	Y	negative	negative	negative	negative
2	F	Toner	17779	1/2/2015	6/1/2017	6/2/2017	Mortality; unknown cause, possible bear predation	No	1619	1626	100%	Green	10	Blue	231	2.5	Y	Y	Y	Not detected			
3	F	Toner	17774	1/2/2015	9/25/2018		GPS transmissions stopped (battery dying or dead)	No	2366	2514	94%	Orange	188	Green	13	10.5	Y	Y	Y	Not detected			
4	F	Toner	17776	2/1/2015	9/25/2018		GPS transmissions stopped (battery dying or dead)	No	2334	2459	95%	Blue	391	Blue	392	8.5	Y	Y	Y	Not detected			
5	M	Toner	17781	2/1/2015	4/17/2015	4/19/2015	Mortality; unknown cause, collar unretrievable	No	131	138	95%	Purple	4	Blue	226	2.5	Y	Y	Partial	No blood			
6	F	Otto	17775	2/1/2015	11/11/2017		GPS transmissions stopped (battery dying or dead)	No	1536	1872	82%	Blue	229	Purple	15	8.5	Y	Y	Y	Not detected			
7	M	Otto	17780	2/1/2015	9/30/2016	10/1/2016	Mortality; harvested	No	1111	1121	99%	Green	6	Purple	2	3.5	Y	Y	Y	Not detected			
8	F	Otto	17773	2/10/2015	3/4/2015	3/5/2015	Mortality; lion predation	No	41	41	100%	Orange	186	Orange	187	8.5	Y	Y	Y	Not detected			
9	F	Otto	17778	2/10/2015	10/16/2017		GPS transmissions stopped (battery dying or dead)	No	1588	1807	88%	Yellow	20	Orange	191	1.5	Y	Y	Y	Not detected			
10	F	Otto	17777	3/8/2015	4/20/2015	4/21/2015	Mortality; probable lion predation	No	78	79	99%	Purple	20	Green	12	2.5	Y	Y	Y	Not detected			
11	F	Otto	17772	3/8/2015	2/3/2016	2/4/2016	Mortality; leg wound infection	No	563	613	92%	Purple	14	Orange	189	7.5	Y	Y	Y	Not detected			
12	F	Otto	17773	3/29/2015	3/20/2018	3/21/2018	Battery dead, replaced collar	No	1999	2007	100%	Red	8138	Red	8138	5.5	Y	Y	Y				
			30488	3/21/2018				Yes	753	1047	72%						Y	N	Y	Broke in centrifuge	negative	negative	negative
13	M	Toner	17777	1/14/2016	7/13/2019		GPS transmissions stopped (battery dying or dead)	No	1838	2356	78%	Purple	8	Blue	385	4.5	Y	Y	Y	Not detected			
14	F	Toner	17772	2/9/2016	9/6/2018		GPS transmissions stopped (battery dying or dead)	No	1525	1735	88%	Yellow	11	Yellow	18	6.5	Y	Y	Y	Not detected			
15	M	Toner	17780	3/1/2017	12/2/2017	12/3/2017	Mortality; culled, domestic sheep interaction	No	504	510	99%	Green	24	Blue	398	3.5	Y	Y	Y				
16	F	Otto	30486	4/11/2018				Yes	720	1008	71%	Purple	40	Yellow	21	4.5	Y	N	Y		negative	negative	negative
Short Ram	M	Toner	n/a	1/12/2017	n/a	n/a	n/a	n/a	n/a	n/a	n/a	none (fell out)		Purple	13	2.5	Y	Y	Y				
Slipperhoof	M	Toner	n/a	1/13/2017	n/a	n/a	n/a	n/a	n/a	n/a	n/a	none		Yellow	64	1.5	N	N	N				
			n/a	1/2/2018	n/a	n/a	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**						**Y**	**Y**	**Y**	Not detected	Mixed results	negative	negative

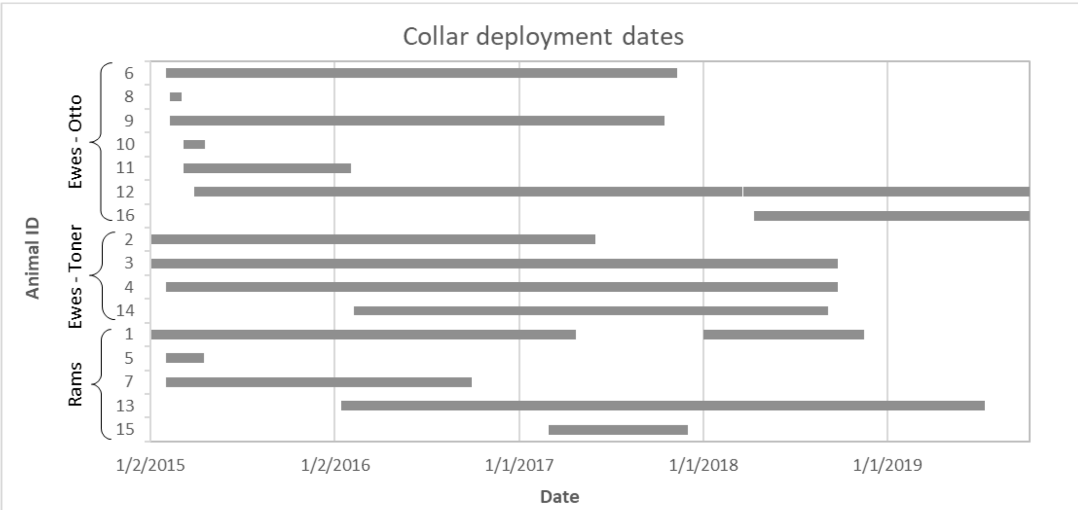

Figure 1. Dates of collar deployments per animal.

Collar performance

With the programmed GPS fix interval and VHF duty cycle, the collars were expected to last for 4 years. However, the average battery lifespan ended up being 3.1 years (range 2.3-3.7 years; N=10). Successful GPS fixes were obtained in approximately 90% of fix attempts (Table 1).

Objective 1: GPS collar spatial data analyses

The location data of the GPS-collared sheep enabled us to define the herd's seasonal distribution and movement patterns, and to identify important areas of habitat use such as lambing areas and migration corridors. There were two distinct subherds of ewes that occasionally overlapped spatially during late winter/spring and rut, but rarely overlapped temporally. At other times of the year, they were more often entirely separate. There were not enough collared rams from both capture sites to determine if there were distinct ram subherds, given that only 1 ram was captured from the wintering group at Otto Creek. However, rams captured at Toner Creek spent time in the late spring and early summer at Otto Creek, so there appears to be fluid group associations and movement among the rams.

Lambing in this herd begins in early May. The two subgroups of ewes used generally separate areas for lambing (Figure 2). Ewes in the Otto subherd lambed on Basalt Mountain, lower Toner Creek, and the lower cliffs between Seven Castles and Taylor Creek. The Toner ewes spent the lambing period in Toner, Seven Castles amphitheater, upper Taylor Creek, upper Downey Creek, and Red Table Mountain. During this time, the rams used areas that overlap winter range and also they began moving to mid-elevations in Seven Castles and Taylor Creeks (Figure 2).

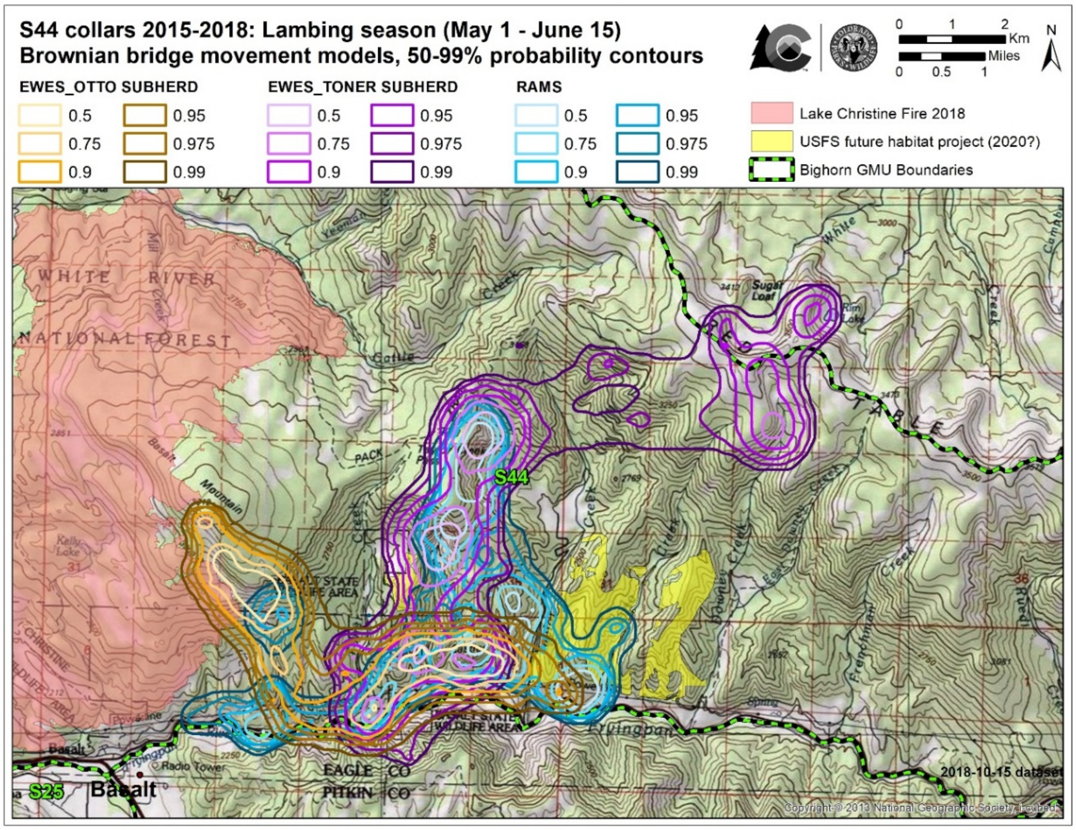

Figure 2. Lambing period homeranges of S44 subherds based on Brownian bridge movement models of GPS collar data from Jan 2015-Oct 2018.

In summer, the Otto ewes stayed at lower elevations that overlap much of their winter range, but the Toner ewes migrated via Seven Castles amphitheater and Taylor Creek Pass up to the Red Table (Figure 3). Occasionally the Toner ewes returned to mid-elevations in Seven Castles and Taylor Creek for short periods of a few days before traveling back to higher elevations on the Red Table.

The rams ranged from Basalt Mountain, upper Toner and Taylor Creeks, to the Red Table (Figure 3). The collared ram from Otto Creek spent summers on Basalt Mountain through Taylor Creek, compared to the 3 collared Toner rams which summered slightly higher in Toner Creek to Red Table Mountain.

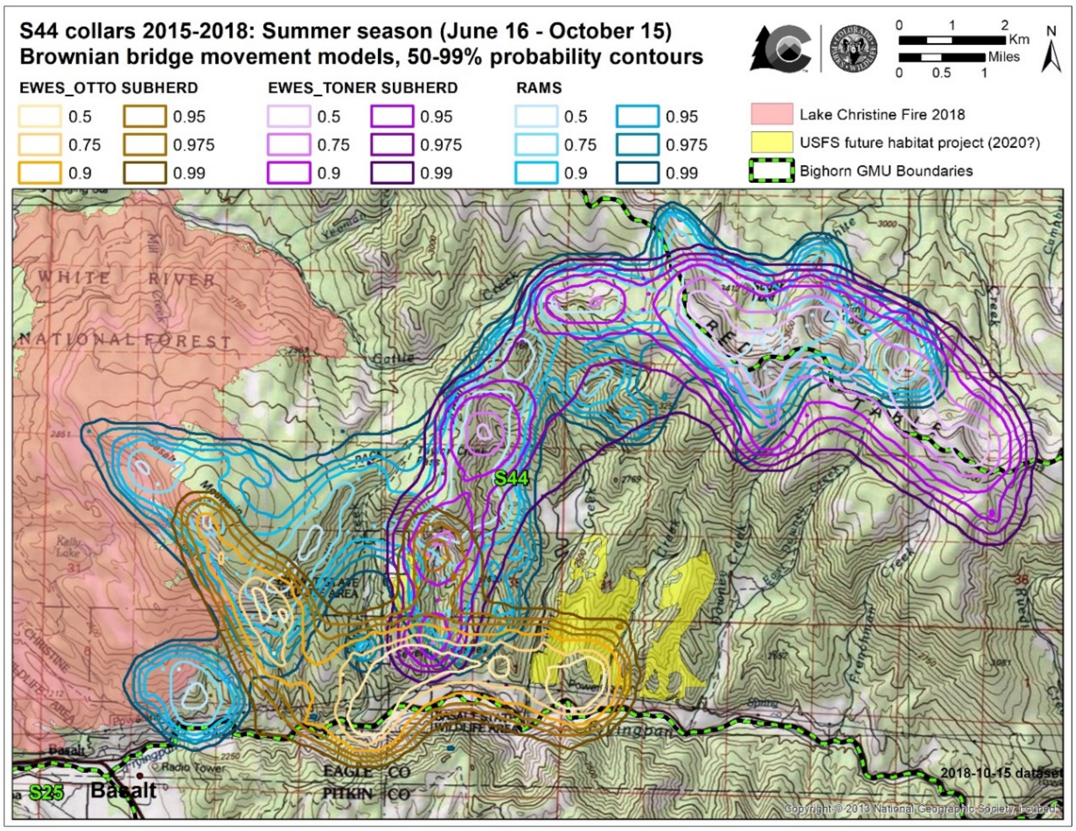

Figure 3. Summer homeranges of S44 subherds based on Brownian bridge movement models of GPS collar data from Jan 2015-Oct 2018.

The rams and Toner ewes that travelled up to Red Table Mountain spent time both inside and outside (immediately north) of the S44 unit boundary (Table 2). Because Ram #7 (captured at Otto Creek) never moved to the top of Red Table Mountain in the 2 summers that he was collared, we examined the summer distribution of ram locations in two ways: (a) including Ram #7, representing our current best approximation of the herd's overall distribution of rams, and (b) excluding Ram #7, representing a possible subherd of "Toner rams" (Table 2). All 4 of the collared Toner ewes had similar distribution and movement patterns, using both sides of Red Table Mountain, whereas none of the 7 collared Otto ewes travelled north onto the Red Table.

Including Ram #7's summer locations, the collared rams were inside of the S44 unit boundary about 2/3rd of the time and outside 1/3rd of the time. Excluding Ram #7, the "Toner" rams spent slightly more than half of the summer inside S44 and slightly under half to the north/outside of the unit. Similar distributions were seen in the hunting season subset (August 24 – Oct 15) of the entire summer season. Individual collared rams moved in and out of the unit within this date range, so they were partially, although not entirely, available for harvest during the hunting seasons.

The Toner ewes spent 3/4ths of the summer on the north-facing cliffs of Red Table Mountain outside of the unit and only 1/4th of the summer inside the unit. Narrowing the date range to the hunting season, the Toner ewes spent relatively more time inside the unit compared to the entire summer season.

Table 2. Percent of locations inside vs. outside of S44 unit boundary for the summer season and hunting season (subset of the latter half of summer). Locations outside of S44 were to the north of the unit boundary on the north face of Red Table Mountain.

Date Range	In/Out of S44	Collared rams (N = 4) including Ram #7		Collared rams (N = 3) excluding Ram #7		Collared Toner ewes (N = 4)	
		N locations	%	N locations	%	N locations	%
SUMMER (June 16-Oct 15)	Inside	1,095	64%	736	54%	611	25%
	Outside	620	36%	620	46%	1,847	75%
	Total	1,715		1,356		2,458	
HUNTING SEASON (Aug 24-Oct 15)	Inside	459	63%	310	53%	347	36%
	Outside	271	37%	271	47%	615	64%
	Total	730		581		962	

During the rut, the rams ranged widely throughout the overall herd range during this period (Figure 4). The ewes exhibited similar homeranges as during summer: the Otto ewes continue to remain at lower elevations, while the Toner ewes move between the Red Table and Toner Creek. The Toner ewes used the Red Table into early winter, presumably moving to lower elevations only when snow levels forced them out of the high elevations.

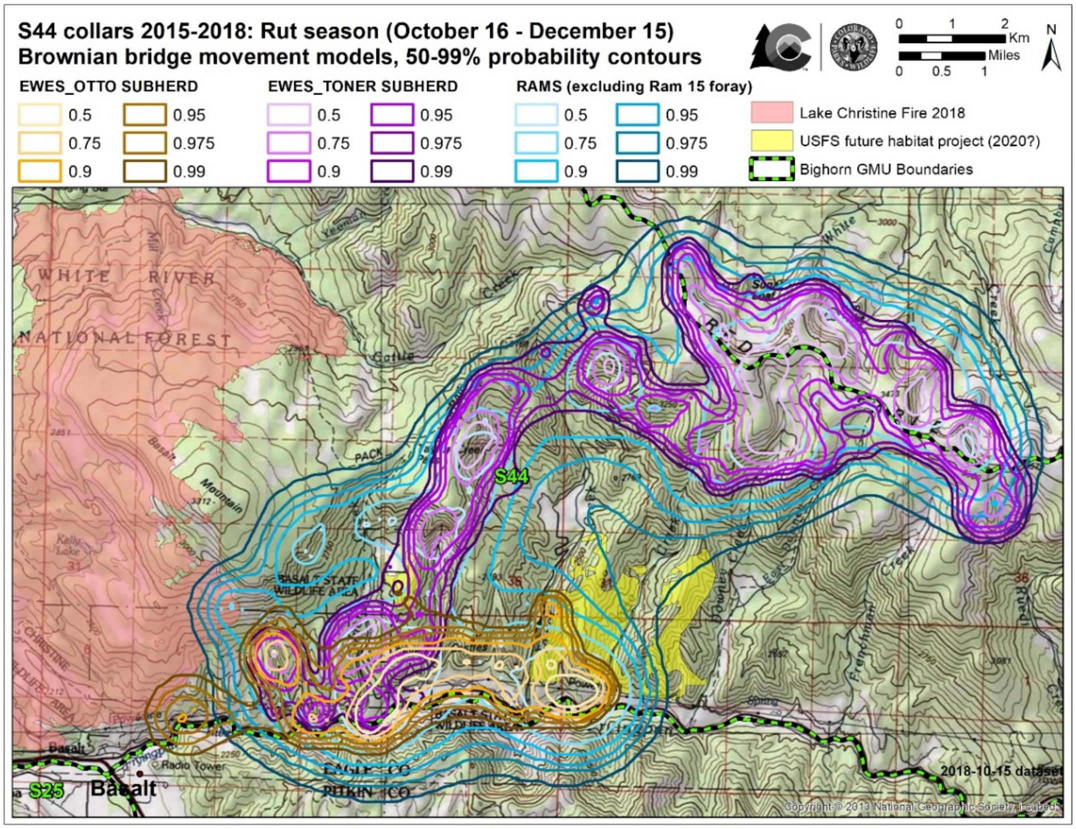

Figure 4. Rut homeranges of S44 subherds based on Brownian bridge movement models of GPS collar data from Jan 2015-Oct 2018. The ram homerange excludes the foray by Ram #15, which is shown in Figure 5.

Over the course of about 3 weeks in 2017, from November 10 to the beginning of December, one collared ram (#15) forayed widely outside the herd's usual homerange, travelling northeast of Wolcott, then back west to just outside of Carbondale (Figure 5). The straight-line distance between his furthest foray locations was 69 km (43 miles). It is unlikely that he encountered any domestic sheep near Wolcott because the domestic sheep had been shipped already (CPW Eagle-South District Wildlife Manager Craig Wescoatt, *pers. comm.*). However, upon reaching Carbondale, the ram found several hundred domestic ewes on private land and was observed near these domestic ewes for several days. Because of the high likelihood of contact with the domestics, CPW culled the ram to reduce the potential for disease transmission to other bighorn sheep. Although the samples taken from the ram showed no evidence of pneumonia and no significant pathogens, his foray behavior and the risk of continued contact with the domestic sheep made it imperative to cull him before he had a chance to return to the bighorn herd.

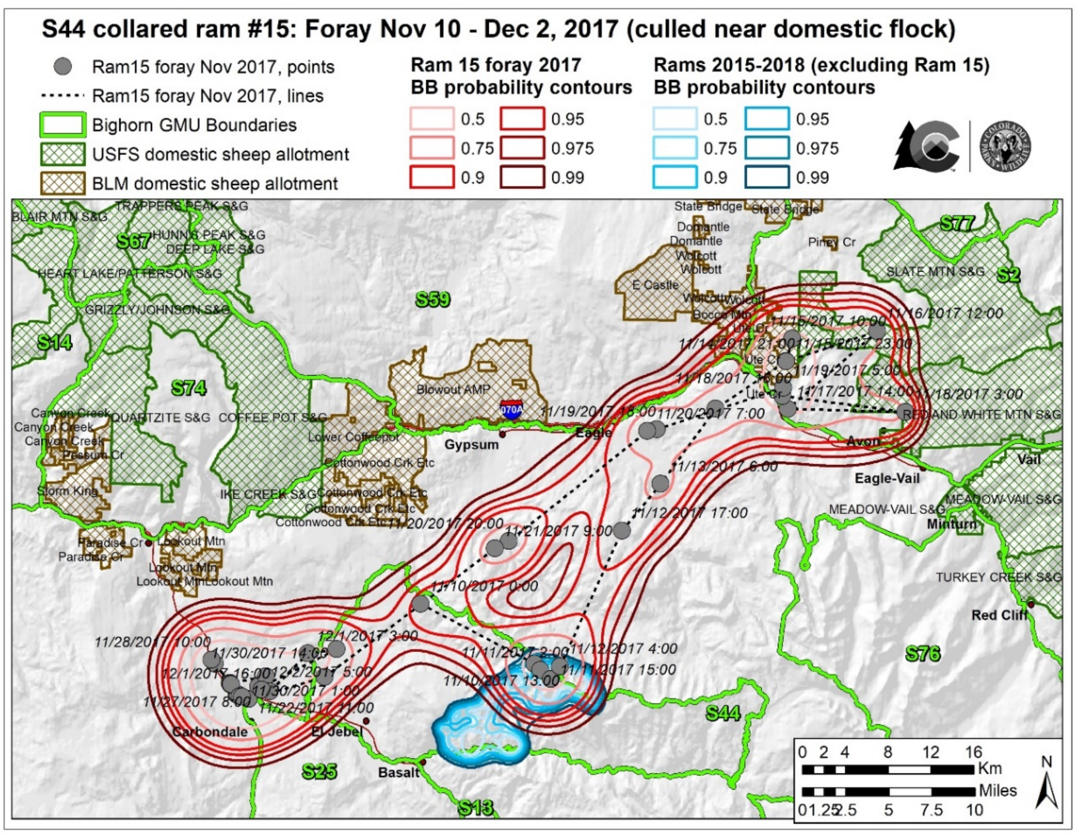

Figure 5. Foray by Ram #15 in November/December 2017. CPW culled the ram after he likely came into contact with several hundred domestic sheep on a private ranch. For spatial reference, the rut homerange of non-foraying rams is shown in blue.

During winter, all herd segments used the lower-elevation areas along the Fryingpan River from Basalt to Otto Creek, and mid-way up the side drainages flowing into the Fryingpan River from the north (Toner, Seven Castles, and Taylor Creeks) (Figure 6). The ewe subherds intermingled infrequently between the mouths of Toner and Seven Castles Creeks, but they more typically traveled separately. The collared rams mixed with each other throughout the winter.

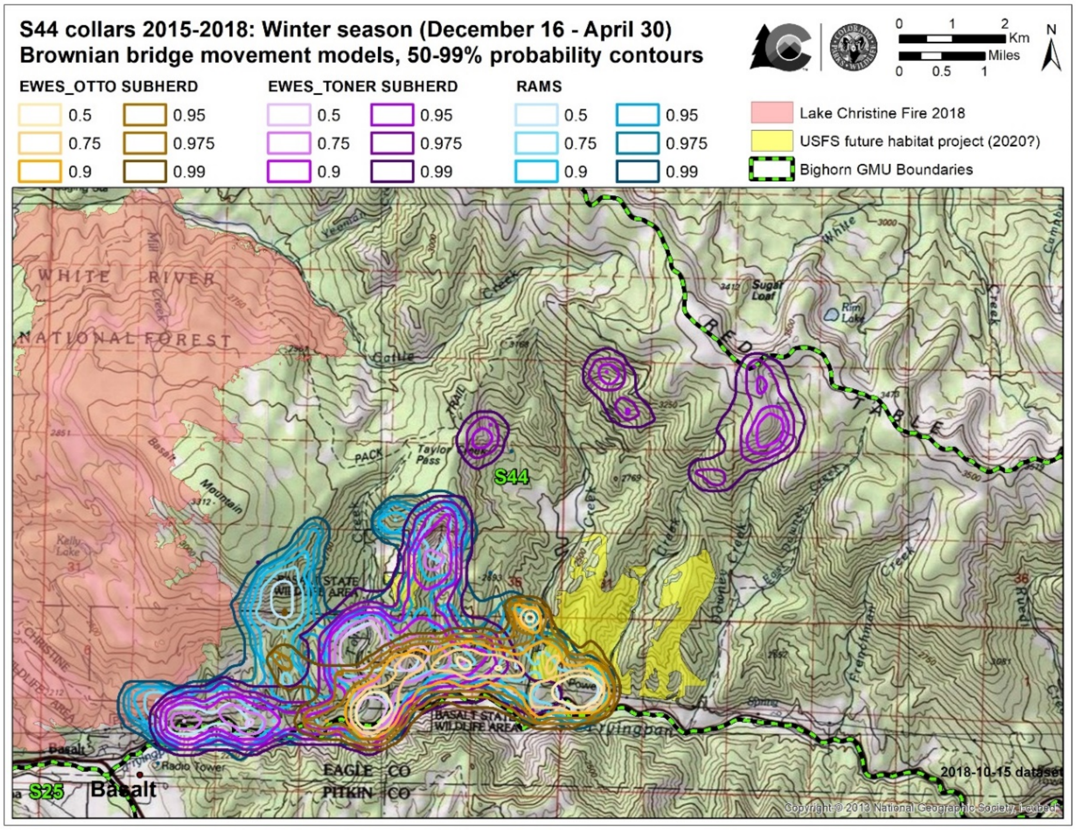

Figure 6. Winter homeranges of S44 subherds based on Brownian bridge movement models of GPS collar data from Jan 2015-Oct 2018.

Seasonal homeranges of the migratory Toner subherd of ewes were approximately twice the size of the non-migratory Otto subherd of ewes (Table 3). The rams' seasonal homeranges were comparable in size to the Toner ewes' homeranges in summer and winter, but were markedly larger than either of the ewe groups' homeranges during rut (Table 3). The estimated area of Ram #15's foray in 2017 was 12 times larger than the typical homerange area of the non-foraying rams (Table 3).

Table 3. Area (square kilometers) of homeranges based on the 99% probability Brownian bridge movement models by herd segment and season.

Herd segment	Lambing	Summer	Rut	Winter
Ewes-Otto	17	25	16	10
Ewes-Toner	28	46	38	20
Rams	20	59	97*	23
Ram #15 foray (2017)			1,189	

* = Excludes Ram 15's foray during the 2017 rut

Objective 2: Mark-resight population survey

Mark-resight population estimates from 2015-2017 suggest a stable to slightly increasing population, currently estimated at 76 sheep (95% CI 56-104 sheep) (Table 4). There is marginal evidence of a statistically significant increase from 2015 to 2016, but not for 2016 to 2017. In summer 2018, because of USFS road closures due to the Lake Christine fire prohibiting access onto Red Table Mountain, we did not conduct a 2018 coordinated ground survey and were unable to generate a mark-resight estimate.

Table 4. Summer (pre-hunt) population estimates based on mark-resight analysis using the Chapman estimator.

Year	Known Marked and Alive	Marked sheep seen	Unmarked sheep seen	Total sheep seen (raw count)	Mark-Resight Population Estimate	SE	*Log-normal 95% CI*	
							LCL	UCL
2015	9	5	26	31	**52**	11	34	80
2016	10	8	47	55	**67**	8	53	86
2017	8	6	53	59	**76**	12	56	104

Objective 3: Age & sex composition

Through ground tracking of the radiocollared sheep, we obtained counts and age-sex classifications of the groups associated with the collared sheep throughout the year. From March 2015 through October 2018, we completed 40 rounds of relocations, which took between 1-24 days per round.

Count and classification data from ground tracking vary in reliability each round, depending on whether all of the collared sheep were found (suggesting an accurate representation of the herd) or whether there was either over-counting (e.g., if a round took too many days to complete and groups mixed, such that some individuals were double-counted) or under-counting (e.g., if some collars were not found, such as when sheep on the Red Table are inaccessible due to road conditions in early summer and late fall). In the figures below, “biased” rounds, in which ratios and counts may be over- or under-estimated, are depicted as hollow symbols; rounds in which ratios and counts are thought to be more representative are shown as solid symbols.

The first lambs each year were seen between May 7th and 16th and were likely born up to a week prior. However, because access onto the Red Table is often blocked by snow until late June/early July, the first complete rounds of telemetry relocations of all of the collars in summer were not usually achieved until July[a]. Observations of lamb ratios during May and June were more likely than at other times of the year to be either incomplete or biased (Figure 7). Therefore, neonatal lamb ratios during the lambing period were based primarily on the more accessible Otto Creek subherd of ewes and we do not know whether that subherd is representative of the Toner subherd. Nevertheless, based on the minimal data available, the

[a] We also attempted fixed-wing telemetry in 2015 to observe the sheep on the Red Table, but were not able to see the sheep in the talus and cliffs from the airplane.

observed lamb ratios increased over the course of the lambing season, as expected if lambing occurs over a timespan of multiple weeks. Observed lamb ratios[b] averaged 36 lambs:100 ewes during mid-summer and 26 lambs:100 ewes in the winter[c] (Figure 7).

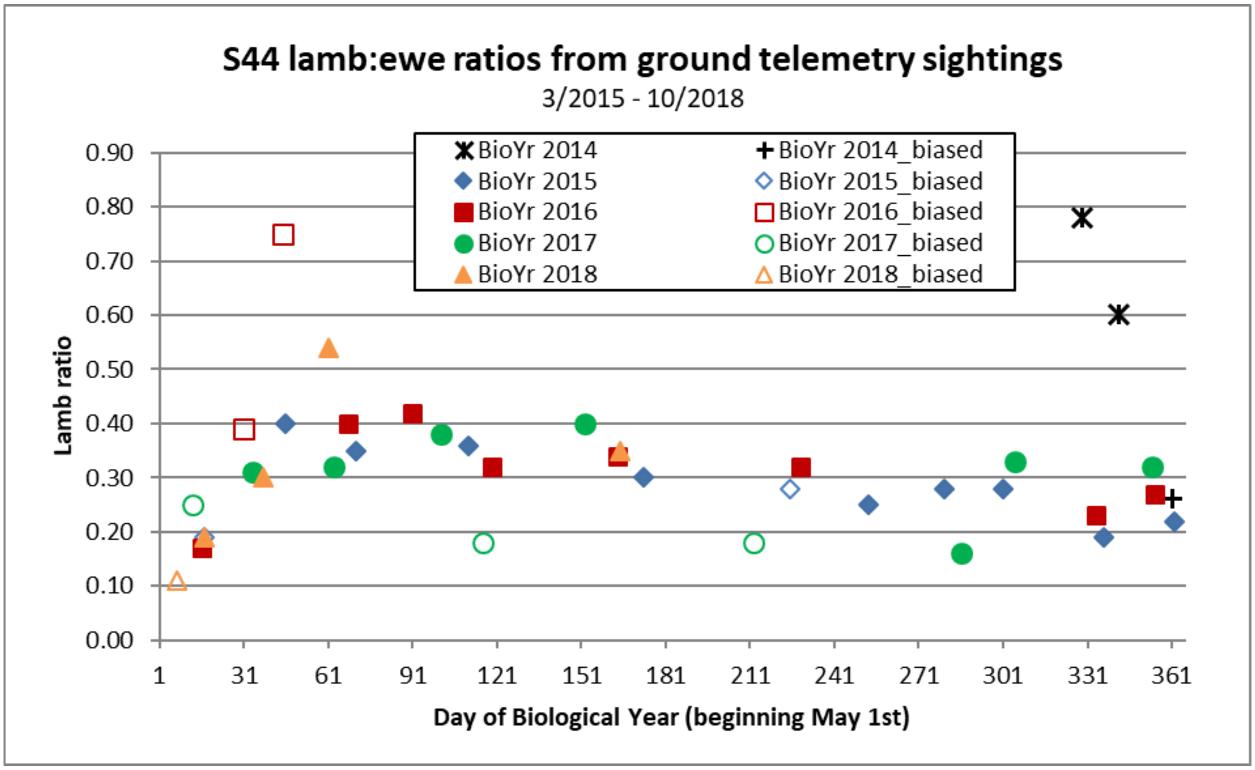

Figure 7. Lamb:ewe ratios determined from ground telemetry sightings of radiocollared groups and opportunistic sightings of non-collared groups.

[b] Excluding values from telemetry rounds in which ratios were believed to be “biased.”
[c] Excluding 2014 winter values, which appear to be outliers.

Observed ram:ewe ratios ranged widely from 39:100 to 133:100 (excluding "biased" values; Figure 8). There was an apparent trend of declining ram ratios through the summer, bottoming out in mid-October; however, this is likely an artifact of (a) having insufficient rams collared to adequately represent the ram herd segment; (b) rams and ewes being spatially separate during the summer months; and (c) intentional avoidance of tracking the collared rams during the hunting season to avoid interfering with or influencing hunters. Ram:ewe ratios during rut and winter, when the sheep are more concentrated and the rams and ewes are more frequently grouped together, are likely to be more accurate than those observed during summer. During winter, the observed ram:ewe ratio averaged 87:100 and ranged between 60:100 to 133:100 (Figure 8).

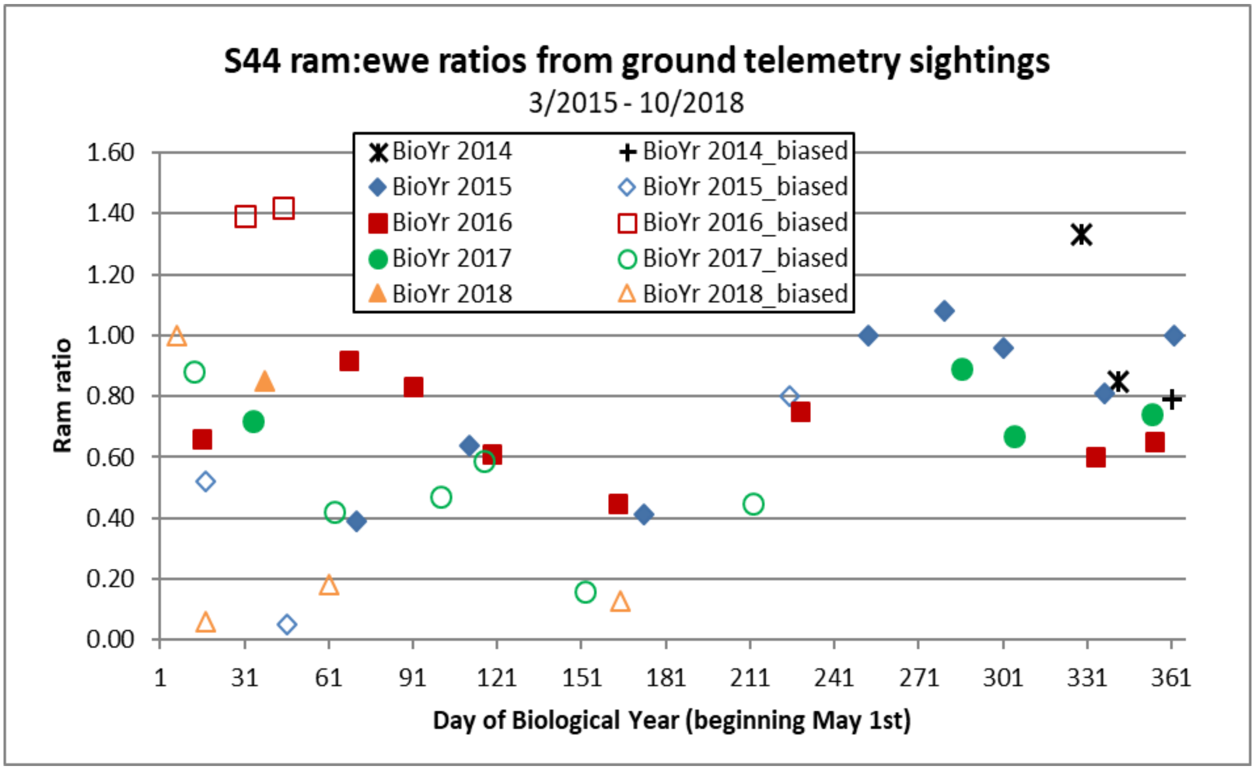

Figure 8. Ram:ewe ratios determined from ground telemetry sightings of radiocollared groups and opportunistic sightings of non-collared groups.

The minimum counts of total sheep seen during ground telemetry in biological year 2015 averaged 50 sheep (95% CI 45-55 sheep); in biological year 2016 it averaged 57 sheep (95% CI 54-61 sheep); and in biological year 2017 it also averaged 57 sheep (95% CI 46-69 sheep), excluding the counts from the "biased" relocation rounds (Figure 9). These minimum counts are similar in trend to the population estimates from the summer coordinated ground counts (Table 4), with an increase from 2015 to 2016 and no difference between 2016 and 2017.

In 2018, the total counts from telemetry were not reliable because (a) more collar batteries were beginning to fail, leading to some groups not being found each round of telemetry relocations, and (b) the Lake Christine fire limited the road access to Red Table Mountain where many of the sheep spend summer.

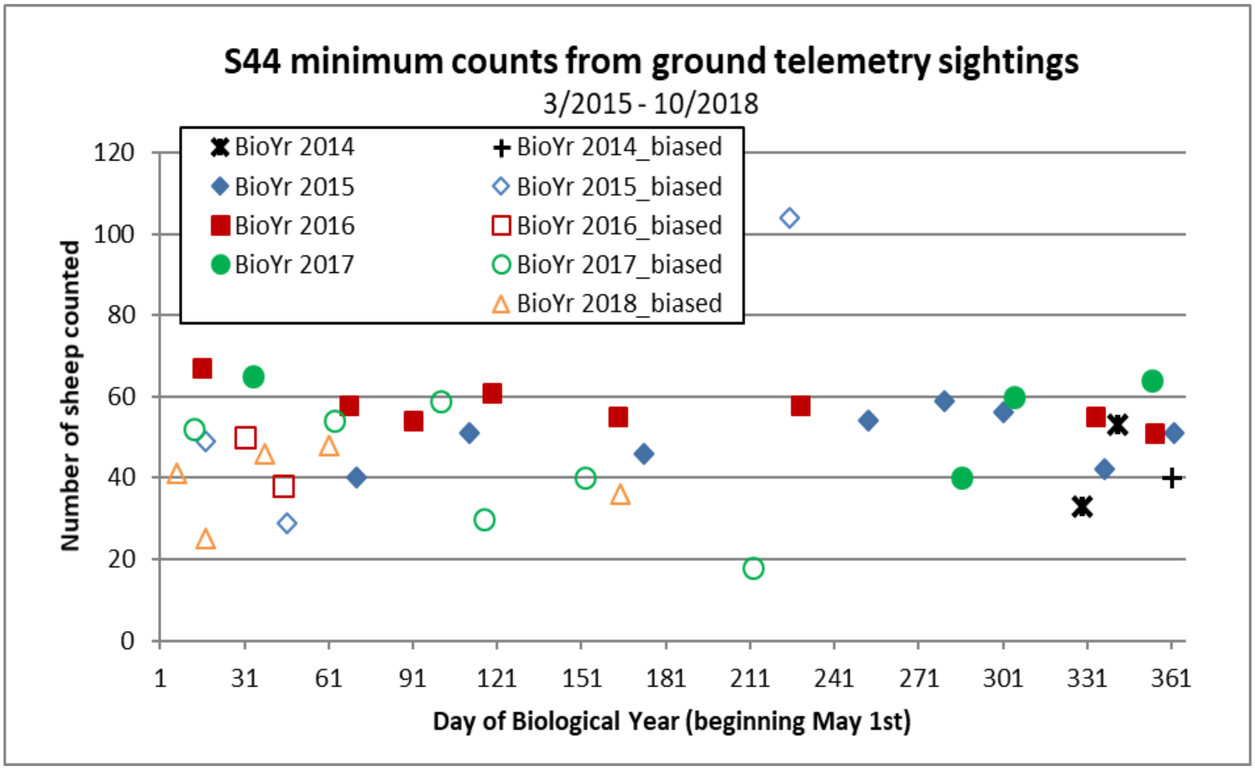

Figure 9. Minimum herd counts determined from ground telemetry sightings of radiocollared groups and opportunistic sightings of non-collared groups.

Objective 4: Disease testing of captured bighorn sheep

Serology tests for *Mycoplasma ovipneumoniae* (*M. ovi*) did not detect active or past infection in any of the blood-sampled sheep (N=13). Polymerase chain reaction (PCR) tests to detect active infection by *M. ovi, Mannheimia haemolytica*, and *Pasteurella multocida* were negative for the 4 sheep captured in early 2018, with the exception of one ram whose *M. ovi* PCR results were mixed (Table 1). (Note: Also see additional disease results from dead sheep in the "*Mortalities*" section below.)

Objective 5: Mortalities and opportunistic disease testing of dead bighorn sheep

Among the 16 sheep (11 ewes, 5 rams) collared, 6 died (4 ewes, 2 rams) over the course of the monitoring period of January 2015 to October 2018 (Table 5). Two ewe mortalities were attributed to lion kills, one ewe mortality was a possible bear predation, one ram was harvested, another ewe died of a septic infection due to a leg wound, and aram died due to unknown causes. An additional ram was culled following contact with domestic sheep.

Monthly survival rate of adult sheep based on the collars was 0.98 (95% CI 0.96-0.99) and annual survival rate was 0.81 (95% CI 0.65-0.91). There was no statistically significant difference in survival between sexes or subherds. However, the sample size is considered small for a survival analysis. Additional collared animals would provide better inference on any differences in survival rates among various segments of the population.

Skulls and tissue samples from 4 of the collared sheep mortalities and 5 other opportunistically collected carcasses were sent to the Wildlife Health Lab for disease testing. *M. ovi* was not detected in any of the 9 samples, but *Pasteurellaceae* leukotoxin was detected in 5 animals and *P. multocida* was detected in one ewe. Two adult ewes out of 9 sheep skulls examined also had sinus tumors.

Table 5. Mortalities of S44 radiocollared sheep and other opportunistically collected dead sheep, 2015-2019.

Animal ID	Wildlife Health Lab ID	Sex	Capture site	Years collared	Mortality date	Age (years) at death	Cause of death	Lab necropsy disease results					
								Sinus tumor	*M. ovi* PCR (sinus lining)	*Pasteurellacea* lukotoxin A PCR		*Pasteurella multocida* (sinus lining)	
										Lung	Sinus lining	PCR	LAMP
Radiocollared sheep mortalities:													
8	15 1403	F	Otto	0.1	3/5/15	9	Predation (mtn lion)	+	—	n/a	+	—	n/a
5		M	Toner	0.2	4/18/15	3	Unknown	n/a	n/a	n/a	n/a		n/a
10	15 1405	F	Otto	0.1	4/20/15	3	Predation (mtn lion)	—	—	n/a	—	—	n/a
11	16 724	F	Otto	0.9	2/3/16	8	Leg wound, septic infection	+	—	n/a	—	+	n/a
7		M	Otto	1.7	10/1/16	5	Hunter-harvested	n/a	n/a	n/a	n/a	n/a	n/a
2		F	Toner	2.4	5/30/17	5	Possible predation (bear)	n/a	n/a	n/a	n/a	n/a	n/a
15	18 189	M	Toner	0.8	12/2/17	4	Culled	—	—	—	+		—
Opportunistically collected mortalities:													
n/a	15 1404	F	n/a	n/a	4/20/15	lamb	Predation (mtn lion)	—	—	n/a	+	—	n/a
n/a	16 722	M	n/a	n/a	3/3/16	7	Roadkill	—	—	n/a	—	—	n/a
n/a	19 864	F	n/a	n/a	1/23/17	lamb	Roadkill	—	—	n/a	+	n/a	—
n/a	18 246	M	n/a	n/a	1/30/18	1	Predation (mtn lion)	—	—	n/a	—	n/a	n/a
n/a	19 865	M	n/a	n/a	10/2/19	2	Leg wound	—	—	n/a	+	n/a	—

Key: + = detected; — = not detected; n/a = not tested.

Conclusions

Seasonal homerange and movement patterns derived from the GPS collar data provide information that will be useful for the effective conservation and management of the S44 herd and land-use planning decisions. Based on the collar data, we identified 2 separate subherds of ewes, one elevationally migratory and one non-migratory. For the rams, there is weak evidence of differences in homerange patterns between the rams collared at Toner compared to the one ram from Otto Creek. However, a larger sample size of collared rams, particularly from Otto Creek, would be needed in the future to confirm or refute whether there are indeed separate ram subherds.

We documented lambing areas on Basalt Mountain, Seven Castles, Taylor Creek, and Red Table Mountain. We also identified migratory movement corridors between winter and summer ranges: (a) for the Toner subherd of ewes and the rams, from Toner and Taylor Creeks to upper Downey Creek and Red Table Mountain, and (b) for the Otto subherd of ewes, along the cliffs and fields north of the Fryingpan River between Otto Creek and Basalt Mountain. Compared to VHF-collared bighorn locations from the late 1980s and 1990s (Byrne 1993, Byrne 1994, Byrne, *unpublished data*), the herd has apparently expanded spatially, with sheep now using areas further north on Red Table Mountain and eastward in Hoovers Bend and Otto Creek. In addition, we documented the relative amount of time that collared bighorns summering on Red Table Mountain spent inside vs. outside of the S44 unit boundaries.

One of the original objectives of this study was to compare habitat selection by bighorn sheep before vs. after habitat treatments within the timespan of this project. However, the planned USFS habitat treatments have been delayed, possibly until 2020. Also, unexpectedly, the large-scale Lake Christine wildfire in summer 2018 burned areas on the western edge of documented bighorn sheep use areas. Therefore, the collar data from 2015-2018 represents a pre-habitat treatment and pre-wildfire period (“phase 1”) that can be compared in the future to collar data that we hope to collect via deployment of a new set of collars in winter 2020-2021 (“phase 2”). Habitat selection analyses will be delayed until a pre- vs. post-treatment comparison can be done.

Age and sex composition estimates from ground VHF tracking of the collared groups were most useful for mid-summer and winter for lamb:ewe ratio, and rut and winter for ram:ewe ratio. At other times of the year, the animals were less accessible or observable, either because of limited road access during lambing/early summer and early winter periods, or in order to not disrupt or influence hunters during the hunting seasons in late summer. As a result, neonatal lamb:ewe ratios during the lambing period were challenging to obtain and possibly inaccurate. Likewise, ram:ewe ratios were apparently lowest in summer, but rams and ewes are mostly separate during that season, so the ratios could have been skewed lower if ram groups were underrepresented in the collared animal sample or if ram groups were less visible than ewe groups. Furthermore, each round of telemetry relocations sometimes took too long to be able to discern short-term changes in ratios within a season. Nevertheless, visual observations of the collared animals enabled us to document behavior and habitat associations, obtain accurate age and sex ratios in certain seasons, and to monitor animal health (e.g., look for signs of coughing or physical injury).

From a respiratory disease standpoint, S44 is moderately healthy, with no *M. ovi* detected. However, *Pasteurellaceae* leukotoxins and sinus tumors caused by an infectious virus have been detected in dead S44 bighorns. When *M. ovi* is not present, *Pasteurellaceae* and sinus tumors may not cause the dramatic all-age die-offs that have occurred in other bighorn herds. However, sinus tumor may make sheep more susceptible to bacterial respiratory infection on a slower timeframe (Fox et al. 2015). CPW's Veterinary Pathologist Karen Fox has cautioned that "*the presence of sinus tumors and potentially pathogenic bacteria in the herd suggests that these animals may not be ideal candidates for transplanting to other herds*" (Fox 2015). If transplanted S44 sheep acquire *M. ovi* from other bighorns or from domestic sheep at their new location or if they carry the sinus tumor virus and *Pasteurellaceae* bacteria to their new site, the transplant could end up as a failed effort.

Mark-resight population estimates from 2015-2017 suggest a stable-to-slightly increasing population. Possible reasons for a population trend that is not growing more quickly include a higher than optimal ram:ewe ratio, moderate lamb:ewe ratio, disease factors, and predation by mountain lions on adult bighorns. The winter ram:ewe ratio of 87:100 is typical of conservatively hunted bighorn sheep herds, but a herd does not need to have a high ram:ewe ratio to sustain reproduction. In mule deer, high buck ratios have been correlated with low fawn ratios and it is hypothesized that the bucks compete with does and fawns for space and forage (Bergman et al. 2011). Similar intra-species competition between rams and ewes and their lambs could be occurring in S44 in wintertime, when the whole herd congregates on limited winter range. The winter lamb ratio of 26:100 is considered within a "healthy" range from a disease perspective (WAFWA 2015), but might be only just enough recruitment to offset annual adult bighorn mortality and not quite enough to produce faster population growth. Population growth of this herd may also be dampened by a combination of sinus tumor/*Pasteurellaceae* infection and lion predation having a limiting effect on adult bighorn survival. Pregnancy rates of ewes and survival rates of neonatal lambs are also unknown parameters that affect the population growth rate.

In the second phase of this project, pending future funding, we plan to deploy a new set of GPS collars on rams and ewes to collect post-habitat-treatment and post-wildfire data on bighorn habitat selection, movements, and distribution. A larger sample size of collared rams from both trap locations will allow us to further clarify whether or not distinct subherds of rams exist. Pregnancy rates can be determined from blood samples collected from ewes captured in mid- to late winter and would be easy and cost-effective to accomplish. Neonatal lamb survival would be a more intensive and expensive effort and may be beyond current management needs.

Determinations of whether S44 should continue to be used as a transplant source herd and whether the current S44 unit boundary reflects appropriate harvest management goals are beyond the scope of this project, but the biological data from this study should be factored into in future management decisions on those topics.

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Budget expenditures

Project expenses are shown in Table 6.

Table 6. Expenditures for the S44 collar project as of October 2019.

Amounts spent as of 10/25/2019	RMBS	A&R	CPW	TOTAL
Vertex collars, cotton spacers, alphanumeric label on belting, shipping	$ -	$ 8,942.47	$ -	$ 8,942.47
Gloabalstar for 1st 12 months * 11 collars (Vectronic invoice 5717-20141015)	$ 2,178.41	$ -	$ -	$ 2,178.41
Globalstar for 2nd 12 months * 10 collars (Vectronic invoice 7798-20160421)	$ 1,560.20			$ 1,560.20
Globalstar for 3rd 12 months*10 collars (Vectronic invoice 9300-20170418)	$ 1,272.20			$ 1,272.20
Jabstick package deal deluxe (with 20 needles, syringe, carrying case) + shipping	$ 897.97	$ -	$ -	$ 897.97
Customs - fedex	$ -	$ 44.62	$ -	$ 44.62
Apple pulp	$ 100.00			$ 100.00
Feed pellets	$ 643.70			$ 643.70
Weed-free hay, 15 bails @$12ea	$ 180.00			$ 180.00
CSI receiver (split between A&R and CPW/NWTerr budgets)		$ 273.22	$ 435.78	$ 709.00
H antenna		$ 300.00		$ 300.00
Omni antenna		$ 78.00		$ 78.00
Shipping for antennas		$ 10.69		$ 10.69
Drugs			$ 708.00	$ 708.00
Apply funds to S13/S25 project for 2016-2017 Iridium fees for 4 remaining active collars (Vectronic invoice 7798-20160421)	$ 140.70			$ 140.70
Apply funds to S13/S25 project to cover 2017-2018 Iridium fees for 2 remaining active S25 collars (Vectronic invoice 9300-20170418)	$ 395.04			$ 395.04
3 new Vertex collars to replace non-functioning collars. Vectronic invoice 669-20180213.	$ 2,247.00			$ 2,247.00
Globalstar for 4th 12 mo*8 collars. Vectronic invoice 10688-20180418.	$ 1,189.04			$ 1,189.04
TOTAL SPENT TO DATE	$ 10,804.26	$ 9,649.00	$ 1,143.78	$ 21,597.04
Remainder	$ 1,432.74	$ -		$ 1,432.74

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