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Population Estimation, Survival Estimation and Range Delineation for the Georgetown Bighorn Sheep Herd: Final Report

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COVER PHOTOS

Top: Bighorn sheep from the Georgetown herd by Brett Crimmel
Bottom left to right: 1) Bighorn sheep licking road by Harry Rhulen; 2) Collared bighorn ram from Georgetown herd; 3) Group of bighorn near Empire, CO by Don McNair; 4) Bighorn sheep under the dropnet near Georgetown Colorado by Tom Nelson

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POPULATION ESTIMATION, SURVIVAL ESTIMATION AND RANGE DELINEATION FOR THE GEORGETOWN BIGHORN SHEEP HERD: FINAL REPORT

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EXECUTIVE SUMMARY

The Georgetown bighorn sheep herd, located within Data Analysis Unit RBS-3 and Game Management Unit S32, is one of the largest bighorn sheep herds in Colorado. It is also one of the most highly valued for the opportunities it provides for hunting and wildlife viewing and as a source for reintroductions throughout Colorado and other states. Colorado Parks and Wildlife (CPW) has been monitoring this herd through annual summer (late July/early August) and fall (late November/early December) coordinated ground surveys since 1988 and 1992, respectively. These surveys have provided valuable information on the herd including fall sex and age ratios, minimum population levels, and summer and fall minimal distributions. However, because of the opportunistic nature of these surveys, they do not provide all of the data desired by CPW to refine the management of the herd, to better understand its population dynamics and to mitigate the effects and reduce the threats associated with human activities within the range of the herd.

A study was, therefore, initiated in 2005 with the following objectives: 1) Estimate the size of the population with statistical confidence; 2) Estimate survival rates for adult ewes and rams; 3) Develop a population model for the herd; 4) Identify possible causes of declining recruitment; 5) Identify subherds; 6) Determine the range and distribution of the herd; 7) Identify key habitats such as lambing areas and migration corridors; 8) Determine the extent of interchange between subherds; 9) Determine the extent of interchange with other herds. In order to accomplish these objectives, adult ewes and rams were captured and fitted with radio collars. Resight surveys were conducted each July and December and mark-resight methods were used to estimate the size of the population. An optimized fit population model was developed (White and Lubow 2002). Each radio collar was regularly located in order to define herd distribution and movement patterns, identify subherds and estimate survival rates. All mortalities were located as quickly as possible and when possible carcasses were necropsied in order to determine cause of death. Biological samples were collected at the time of capture to develop a disease profile for the herd and to determine the pregnancy status of ewes. Ewes were monitored closely during lambing season in order to collect information on parturition (rates, locations and timing), and lamb mortality (timing and causes).

Seventy-seven individual bighorn (50 ewes and 27 rams) were collared during this study. A total of 5,422 VHF collar locations and 33,672 locations downloaded from the Globalstar and Lotek GPS collars were collected from these bighorn and used to define the range, distribution, movement patterns, and lambing areas of the herd. In addition, several subherds were identified within this DAU. Each subherd exhibits a seasonal shift between summer, lambing, and winter range with rams and ewes moving independently from each other. There is connectivity throughout the DAU, with adjacent subherds overlapping spatially and temporally indicating that transmission of pathogens and genetic materials between subherds is probable. The area of most restricted contact is Empire Junction. There is only one subherd of ewes that commonly crosses US highway 40 between Empire and Downieville (the Douglas Mountain subherd). Rams rarely cross this highway, with only a few instances of collared ram crossings recorded during this study.

None of the sheep collared in this study moved into the range of other herds. Four bighorn sheep were captured outside of S32 in S3 (1 ram), S4 (1 ram), S41 (1 ewe) and 1 ram 19 km north of the Georgetown herd outside of a GMU in order to determine if they moved into the range of the Georgetown herd. None of these bighorn sheep ever crossed into the Georgetown herd.

Mark-resight methods were used to estimate the adult ewe and adult ram populations each July from 2006 to 2009. The ewe population estimates for those years were 174 (SE = 15), 229 (SE = 31), 185 (SE = 20), 150 (SE = 19). The ram estimates were 194 (SE = 29), 216 (SE = 37), 157 (SE = 36), 171 (SE = 31). Within each year, the individual surveys varied widely in the number of bighorn observed, observed sex and age ratios, the individual sighting probabilities of marked sheep, and the proportion of marked animals observed on surveys. The mean proportion of the modeled populations observed during the summer and fall surveys was 0.40 and 0.56 respectively. The proportion of the herd observed during the fall surveys was higher than had been previously assumed. Based on the results of this study, the population estimate for this herd was revised upward.

From 2006 to 2009, the mean annual non-harvest survival rate of ewes was 91% and that of rams was 92%. The main source of mortality for ewes was vehicle collisions (46% of mortalities), followed by unknown causes (17%), harvest (13%), natural causes (8%), lions (8%), hardware disease (4%) and fence encounters (4%). The main source of mortality for rams was harvest (46% of mortalities) followed by vehicle collisions (23%), unknown causes (15%), wounding loss (8%) and lions (8%).

The adult survival rates and population estimates from this study were used along with other data to develop a population model for this herd that estimates both the July and December populations. The model runs from 1991 to present and indicates that the December population grew from approximately 300 animals in 1990 to nearly 500 by 2001 and then declined to approximately 300 animals by 2012. This is the midpoint of the population objective range for the herd and thought to be a sustainable number.

One of the objectives of this study was to determine the causes of low lamb recruitment into the Georgetown herd. We showed that 98% of the ewes were pregnant at the time of capture, and that at least 93% of ewes gave birth to live lambs. Neither of these, therefore, contributed to low lamb recruitment. Lamb mortality was high between May and the end of July each year. From 2006-2010, the mean lamb to ewe ratio was 0.34 during the summer surveys and 0.19 during the fall surveys. Lamb mortality was, therefore, high during the first 2 months of life and remained high through November. This high lamb mortality was the cause of low lamb recruitment into the herd. The main cause of lamb mortality was bronchopneumonia. Bronchopneumonia is implicated by the results of carcass necropsies, the timing of lamb mortality, and the frequent observations of live lambs showing signs of illness such as poor body condition, drooping ears, ataxia and failure to keep up with the herd. The Georgetown herd is exhibiting lamb recruitment patterns typical of a herd suffering the aftermath of a bronchopneumonia outbreak. However, unlike other outbreaks throughout the west, this low lamb recruitment was not preceded by an all-age die off.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

Funding for this project was provided by Colorado Auction Raffle Funds and the Rocky Mountain Bighorn Society. We thank the numerous Colorado Parks and Wildlife staff, field technicians, and volunteers who made this labor intensive study possible. Special thanks goes to J. George for her support, advice and field assistance; Area 1 staff R. DeWalt, N. Gallowich, H. Horton, T. Howard, J. Nicholson, T. Petersburg, T. Schmidt, D. Swanson; field technicians P. Aragon, K. Dickinson, J. Dolphin, B. Huff, A. Mangusso, T. Nelson, R. Riedner and A. Trujillo; L. Wolfe and M. Miller for help with capture and veterinary support; pilots D. Younkin and B. Smith for providing safe travels during aerial flights; and K. Eichhoff for GIS support. We are grateful to the many landowners and land managers who generously allowed access to their properties. The manuscript was greatly improved by reviews from M. Alldredge, J. Ivan and K. Knudsen. Funding for this project was provided by Colorado Auction Raffle Funds and the Rocky Mountain Bighorn Society. We thank the numerous Colorado Parks and Wildlife staff, field technicians, and volunteers who made this labor intensive study possible. Special thanks goes to J. George for her support, advice and field assistance; Area 1 staff R. DeWalt, N. Gallowich, H. Horton, T. Howard, J. Nicholson, T. Petersburg, T. Schmidt, D. Swanson; field technicians P. Aragon, K. Dickinson, J. Dolphin, B. Huff, A. Mangusso, T. Nelson, R. Riedner and A. Trujillo; L. Wolfe and M. Miller for help with capture and veterinary support; pilots D. Younkin and B. Smith for providing safe travels during aerial flights; and K. Eichhoff for GIS support. We are grateful to the many landowners and land managers who generously allowed access to their properties. The manuscript was greatly improved by reviews from M. Alldredge, J. Ivan and K. Knudsen.

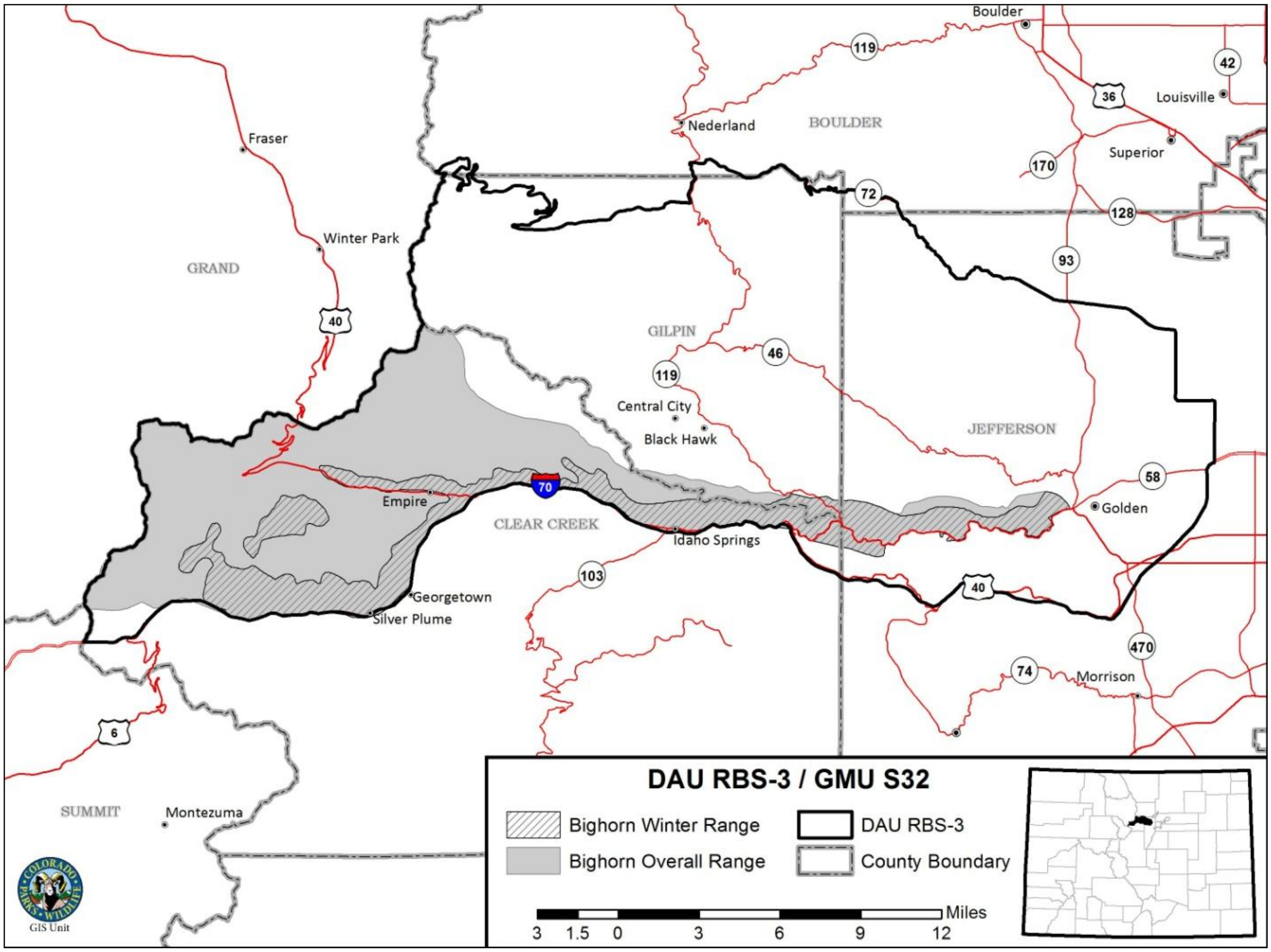

Figure 1. Distribution of bighorn sheep in the Georgetown herd.

INTRODUCTION

The Georgetown bighorn sheep herd, located within Data Analysis Unit RBS-3 and Game Management Unit S32, is one of the largest bighorn sheep herds in Colorado (Fig. 1). It is also one of the most highly valued for the opportunities it provides for hunting and wildlife viewing and as a source for reintroductions throughout Colorado and other states. Colorado Parks and Wildlife (CPW) has been monitoring this herd through annual summer and fall coordinated ground surveys since 1988 and 1992, respectively (Huwer 2010). These surveys have provided valuable information on the herd including fall sex and age ratios, minimum population levels, and summer and fall minimal distributions. However, because of the opportunistic nature of these surveys, they do not provide all of the data desired by CPW to refine the management of the herd, to better understand its population dynamics and to mitigate the effects and reduce the threats associated with human activities within the range of the herd. The desire for this additional information was heightened by concerns raised by the steady decrease in the lamb to ewe ratios during the annual fall surveys from 68: 100 in 2001 to 6: 100 in 2006.

A study was, therefore, initiated in 2005 with the following objectives: 1) Estimate the size of the population with statistical confidence; 2) Estimate survival rates for adult ewes and rams; 3) Develop a population model for the herd; 4) Identify possible causes of declining recruitment; 5) Identify subherds; 6) Determine the range and distribution of the herd; 7) Identify key habitats such as lambing areas and migration corridors; 8) Determine the extent of interchange between subherds; 9) Determine the extent of interchange with other herds. In order to accomplish these objectives, adult ewes and rams were captured and fitted with radio collars. Resight surveys were conducted each July and December and mark-resight methods were used to estimate the size of the population. An optimized fit population model was developed

(White and Lubow 2002). Each radio collar was regularly located in order to define herd distribution and movement patterns, identify subherds and estimate survival rates. All mortalities were located as quickly as possible and when possible carcasses were necropsied in order to determine cause of death. Biological samples were collected at the time of capture to develop a disease profile for the herd and to determine the pregnancy status of ewes. Ewes were monitored closely during lambing season in order to collect information on parturition (rates, locations and timing), and lamb mortality (timing and causes).

CAPTURE AND COLLARING

From December 2005 to April 2011, we conducted 99 bighorn captures on winter range via drop nets, chemical immobilization (i.e., darting), and helicopter netgunning. All three techniques were used in order to distribute the collars throughout the study area as required in mark-resight studies and in order to collect movement and use information from the entire range of the herd. During most of these captures, collar circumference and age was recorded and biological samples (blood, feces, pharyngeal swabs) were taken. These 99 captures consisted of 78 initial captures resulting in collar deployment, 9 recaptures to replace collars, 9 bighorn released without being collared and 3 mortalities.

Drop netting: On January 20, 2006, dropnets were used to capture bighorn sheep in Georgetown and Downieville (Fig. 2). In Georgetown, 21 bighorn sheep (12 ewes, 7 rams, and 2 lambs) were captured in a full dropnet. In addition to the data mentioned above, 10 of these bighorn were also weighed. Thirteen bighorn sheep (9 ewes, 4 rams) were released with collars and ear tags, 5 bighorn sheep (3 ewes, 2 lambs) were released without collars or ear tags because they were too young to collar. Two rams were given ear tags only. One young ram died during capture of a broken neck. This was probably the result of an impact with a large ram as the net fell. In Downieville, a quarter dropnet was used due to the restricted space available. Two ewes were radio collared; 2 lambs were too small to collar and were released. Eight additional potential drop net sites throughout the herd were baited from December 2005 through February 2006. None of these sites regularly attracted enough bighorn sheep to make them useful as dropnet sites.

Chemical immobilization: Forty-two bighorn sheep (31 ewes and 11 rams) were captured via chemical immobilization with A3080 (9 ewes, 5 rams), ketamine/metatomidine (14 ewes, 5 rams), or BAM

Figure 2. Bighorn sheep under the dropnet in Georgetown on January 6, 2006. Photo by: Tom Nelson.

(butorphanol, azaperone, and medetomidine) (8 ewes, 1 ram. Forty of these (31 ewes and 9 rams) were collared and ear tagged (Fig. 3). The other 2 rams died during capture. Both were immobilized using A3080. One ram died from a 5 foot fall incurred during induction that resulted in a punctured lung. The other ram died of malignant hyperthermia (overheating as a result of anesthesia). This is generally caused by specific anesthetics and may be brought on by underlying diseases that cause fever (such as bronchopneumonia). The necropsy in this case found pulmonary adhesions (previous bronchopneumonia), chronic active bronchopneumonia, lungworm, and emaciation. This was an older ram in poor body condition with active bronchopneumonia. The elevated body temperature associated with this bronchopneumonia in combination with the affects of the A3080 used to immobilize him caused him to overheat. This was an unusual case because the hyperthermia was associated with neither exertion nor high ambient temperatures and did not respond to therapy.

Figure 3. Capture via chemical immobilization. Photo by: Janet George.

Helicopter netgunning: Quicksilver Air was contracted to capture 31 bighorn sheep (16 ewes, 15 rams) via helicopter netgunning (Fig. 4). The bighorn sheep were captured, collared, ear tagged, sampled and released on site. They were not transported to an offsite processing area. No bighorn sheep died during helicopter netgunning.

Figure 4. Ram captured via helicopter netgunning, processed and released at the site of capture. Photo by: Quicksilver Air Inc.

Table 24 in Appendix 1 contains information on each of the 77 individual bighorn sheep (50 ewes and 27 rams) fitted with collars. A blue button ear tag was placed in the ear of each of these bighorn sheep (Fig. 5). Each ear tag was stamped with S-32 on the top and a number between 0 and 204 on the bottom. Each collar was fitted according to the Bighorn Sheep Capture and Translocation Guidelines (George et al. 2008). Three different types of radio collars were used; Lotek LMRT-4 (VHF collars), Lotek GPS 3300SL (store-on-board GPS collars), and Northstar Globalstar D-cell (GPS collars with satellite upload). A black on white alphanumeric mark was affixed to both sides of the VHF collars to enable individual identification of each collar as required by mark-resight methodology. Similarly, a black on yellow alphanumeric mark was affixed to one side of the Globalstar collars; no mark was placed on the other side in order to reduce interference with the collar modules. No marks were attached to the Lotek GPS collars. The VHF and Lotek GPS collars were equipped with mortality sensors. The Globalstar collars were not equipped with mortality sensors, but daily locations were monitored in order to determine if the animal was likely to have died. The VHF collars were equipped with a rot-off spacer made of canvas that was designed to allow the collar to drop off after 5 years on the bighorn sheep. As of December 2012, none of these collars had dropped off, even though 24 collars had been on for more than 5 years, including collars that had been on ewes or rams for 7 years. The Lotek GPS collars were equipped with a blow-off mechanism scheduled to release the collar either 52 (3 collars) or 60 (3 collars) weeks after deployment. The Globalstar collars were equipped with a blow-off device that was preprogrammed to release the collar on a specific date.

Figure 5. Bighorn ram collared near Georgetown, CO. Shown is the Lotek LMRT-4 VHS collar with alphanumeric mark attached and blue button ear tag used in this study.

At the time of their initial capture, 70 individuals were fitted with VHF collars, 4 with Lotek GPS collars and 3 with Globalstar collars. Of the bighorn sheep originally given VHF collars, 2 were recaptured in order to replace the VHF collar with Lotek GPS collars and 7 were recaptured to replace the VHF collar with a Globalstar collar. In selecting bighorn sheep to carry the Globalstar and Lotek GPS collars, an attempt was made to place at least one of these collars on a ewe from each subherd. Table 25 in Appendix 1 contains details of the recaptured bighorn sheep.

All of the bighorn sheep were captured within the boundaries of S32, except for 1 ram captured in S3 (fitted with a Lotek GPS collar), 1 ram captured in S4 (fitted with a VHF collar), 1 ewe captured in S41 (fitted with a Lotek GPS collar) (Fig. 6). These bighorn sheep were captured in GMUs adjacent to S32 in order to determine if there was any movement of bighorn into S32 from the surrounding areas. In addition to the 77 bighorns described above, 1 ram (known as the Granby Ram) was captured 19 km north of S32 outside of a bighorn GMU and fitted with a Globalstar collar. The Granby ram moved 650 km through Colorado and Wyoming, but never moved into the range of the

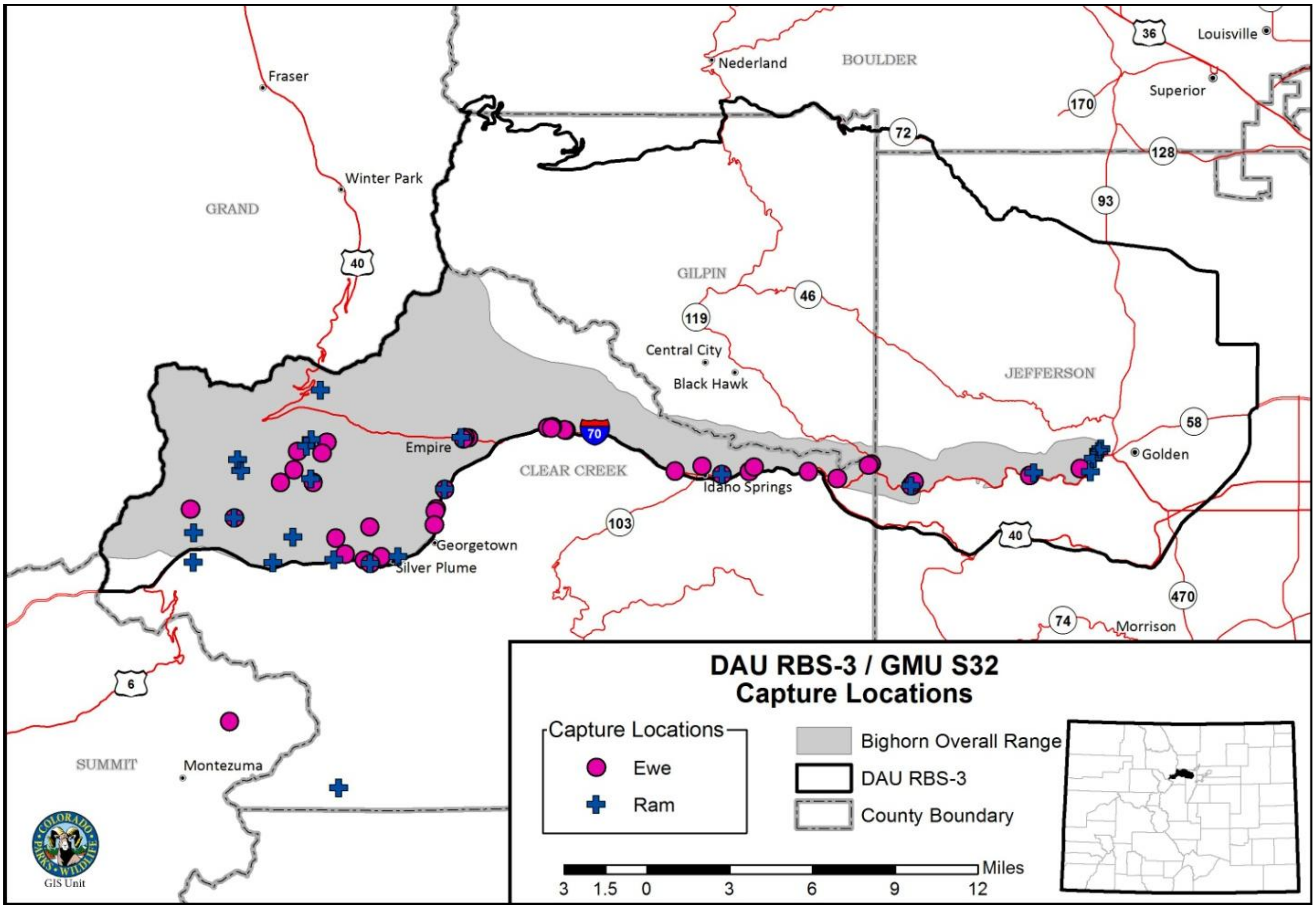

Figure 6. Capture locations of ewes and rams from the Georgetown herd during this study.

Georgetown herd. His locations are not included in this report as they are reported elsewhere (Huwer and Eichhoff 2015).

SURVEYS, SIGHTING PROBABILITY AND POPULATION ESTIMATION

Surveys have been conducted in late July or early August in the Georgetown herd since 1988. Beginning in 1992, fall surveys have also occurred in late November or early December (Huwer 2010). Each summer survey was conducted simultaneously either on foot or from trucks or off-highway vehicles. The winter survey consisted of 5-6 routes. These routes were designed to provide maximum coverage of the range of the herd. Routes have been modified and refined since 1988 to increase coverage of the bighorn range and in response to changes in bighorn distribution. The total combined length of all the summer survey routes was 298 km. Based on a viewshed analysis derived from a 30m digital elevation model with the Viewshed and Raster Calculator tools in the Spatial Analyst extension (ArcMap 10.1, Environmental Systems Research Institute, Inc., Redlands, CA), 87% (288 km^2) of the area classified as summer bighorn sheep range of the Georgetown herds was visible from the survey routes.

During these surveys, teams of observers (CPW staff and volunteers) used binoculars and spotting scopes to search for bighorn sheep along specified routes. Each team began at sunrise and continued until they had completed the route (3-12 hours later depending on the route). The observers recorded the following for each group of bighorn: number of bighorn, classification of each bighorn (full-curl ram, 7/8-curl ram, 3/4–curl ram, 5/8-curl ram, 1/2-curl ram, ewe, yearling ram, yearling ewe, lamb, or unclassified), number of marked ewes, number of marked rams, mark identifications, behavior, location and time of observation. If a group of bighorn were observed by 2 teams of observers, the duplicate sightings were removed. Summary statistics (i.e., total bighorn sheep counted, lamb to ewe ratio, and ram to ewe ratio) were then calculated.

From 2006-2009, mark-resight methods were used to estimate the size of the Georgetown population. This required additional surveys to be held each year for a total of 7, 7, 5 and 5, surveys in July 2006-2009, respectively and 4 and 3 surveys in December 2007 and 2008. Prior to the resight surveys each year, we confirmed that all marked bighorn were within the study areas and alive via ground and aerial radio-telemetry.

Tables 1 to 6 show the numbers of unduplicated bighorn sheep observed during resight surveys. Tables 7 to 12 show the lamb, ram, and yearling to ewe ratios and the proportions of ram and ewe collars observed during the resight surveys. The survey on July 9, 2006 was mostly weathered out, with adequate visibility on only 2 of the routes. This survey was therefore not included when calculating the individual collar sighting probability or means over all surveys. The number of bighorn sheep observed during the survey on July 2, 2007 was much lower than during the other surveys that year, with the ewe and lamb component of the population very low (only 3 ewes and 0 lambs were observed). We speculated that the ewe and lamb sightability this early in July may have been very low because they were still in small groups due to lambing activities. For this reason, the means over all the surveys in Tables 2 and 8 are shown with and without the July 2nd survey included.

Tables 13 and 14 show the collar sighting probability details of the resight surveys from 2006 to 2009. The data collected during the surveys on July 9, 2006 and July 2, 2007, while not included in the summary statistics in Tables 1, 2, 7 and 8, were included in Tables 13 and 14 and were used in estimating the size of the population. In addition to the data from the resight surveys summarized in Tables 3, 13 and 14, extra routes were run in July 2008 on the days between the surveys to increase the amount of data available for estimating the population. During these extra routes, 180 bighorn sheep and 24 additional collars were observed. Similarly, extra routes were run in December 2007 for an additional 21 bighorn sheep and 2 collars and in December 2008 for an additional 16 bighorn sheep and 2 collars.

Table 1. Number of unduplicated bighorn sheep observed during each of 7 resight surveys in July 2006, the totals and means over all surveys except that held on July 9, which was incomplete due to weather.

Survey Date	Ewe	Ram	Yearling	Lamb	Unclassified	Total	Marked Rams	Marked Ewes
7/1/2006	44	21	7	24	37	121	2	4
7/6/2006	51	35	10	20	12	128	4	12
7/9/2006	25	25	0	0	2	52	3	7
7/13/2006	67	105	15	10	10	207	5	13
7/21/2006	33	69	4	10	1	117	3	6
7/24/2006	70	100	11	17	8	206	8	15
7/26/2006	93	97	6	15	14	225	7	15
Total	383	452	53	96	84	1056	32	72
Mean excluding 7/9	60	71	9	16	14	167	5	11

Table 2. Number of unduplicated bighorn sheep observed during each of 7 resight surveys in July 2007, the totals and means over all surveys and the means excluding the survey held on July 2, which may have been held too early in the year.

Survey Date	Ewe	Ram	Yearling	Lamb	Unclassified	Total	Marked Rams	Marked Ewes
7/2/2007	3	67	0	0	21	91	6	0
7/6/2007	52	36	2	28	0	118	3	8
7/11/2007	59	96	3	28	1	164	7	5
7/13/2007	81	18	3	34	4	140	0	11
7/21/2007	40	89	1	19	2	145	9	8
7/23/2007	45	39	4	8	11	108	2	4
7/26/2007	71	87	6	33	11	208	8	12
Total	351	432	19	150	50	974	35	48
Mean	50	62	3	21	7	139	5	7
Mean excluding 7/2	58	61	3	25	5	147	5	8

Table 3. Number of unduplicated bighorn sheep observed during each of 5 resight surveys in July 2008 and the totals and means over all surveys.

Survey Date	Ewe	Ram	Yearling	Lamb	Unclassified	Total	Marked Rams	Marked Ewes
7/15/2008	63	23	6	34	39	165	4	19
7/17/2008	61	14	5	30	31	141	0	11
7/19/2008	50	69	5	8	0	132	2	10
7/25/2008	53	32	8	19	22	134	4	5
7/28/2008	74	60	9	17	1	161	6	9
Total	301	198	33	108	93	733	16	54
Mean	60	40	7	22	19	147	3	7

Table 4. Number of unduplicated bighorn sheep observed during each of 5 resight surveys in July 2009 and the totals and means over all surveys.

Survey Date	Ewe	Ram	Yearling	Lamb	Unclassified	Total	Marked Rams	Marked Ewes
7/13/2009	36	48	2	13	0	99	4	7
7/15/2009	43	24	1	20	19	107	3	11
7/17/2009	38	32	5	9	23	107	2	6
7/24/2009	63	53	4	28	1	149	4	13
7/28/2009	55	22	7	14	2	100	2	16
Total	235	179	19	84	45	562	15	53
Mean	47	36	4	17	9	112	3	11

Table 5. Number of unduplicated bighorn sheep observed during each of 4 resight surveys in November and December 2007 and the totals and means over all surveys.

Survey Date	Ewe	Ram	Yearling	Lamb	Unclassified	Total	Marked Rams	Marked Ewes
11/30/07	88	74	10	19	3	194	2	16
12/3/07	72	77	11	13	4	177	4	14
12/5/07	63	62	7	14	2	148	3	15
12/10/07	102	85	5	29	9	230	4	16
Total	325	298	33	75	18	749	13	61
Mean	81	75	8	19	5	187	3	15

Table 6. Number of unduplicated bighorn sheep observed during each of 4 resight surveys in November and December 2008 and the totals and means over all surveys.

Survey Date	Ewe	Ram	Yearling	Lamb	Unclassified	Total	Marked Rams	Marked Ewes
12/1/08	82	65	9	9	4	167	4	19
12/3/08	69	65	4	11	0	149	3	13
12/8/08	103	87	14	17	0	221	8	19
Total	254	217	27	37	4	537	15	51
Mean	85	72	9	12	1	179	5	17

Table 7. Lamb, ram, and yearling to ewe ratios, the proportions of ram and ewe collars observed during each of the resight surveys held in July 2006 and their means over all surveys except that held on July 9, which was incomplete due to weather.

Survey Date	Lamb: Ewe	Ram: Ewe	Yearling: Ewe	Proportion of Ram Collars Observed	Proportion of Ewe Collars Observed
7/1/2006	0.55	0.48	0.16	0.14	0.12
7/6/2006	0.39	0.69	0.20	0.29	0.36
7/9/2006	0.00	1.00	0.00	0.21	0.21
7/13/2006	0.15	1.57	0.22	0.36	0.39
7/21/2006	0.30	2.09	0.12	0.21	0.18
7/24/2006	0.24	1.43	0.16	0.57	0.45
7/26/2006	0.16	1.04	0.06	0.50	0.45
Mean excluding 7/9	0.27	1.19	0.15	0.35	0.33

Table 8. Lamb, ram, and yearling to ewe ratios and the proportions of ram and ewe collars observed during each of the resight surveys held in July 2007 and their means over all surveys and the means over all surveys except that held on July 2, which may have been held too early in the year.

Survey Date	Lamb: Ewe	Ram: Ewe	Yearling: Ewe	Proportion of Ram Collars Observed	Proportion of Ewe Collars Observed
7/2/2007	0.00	22.33	0.00	0.33	0.00
7/6/2007	0.54	0.69	0.04	0.17	0.24
7/11/2007	0.47	1.63	0.05	0.39	0.15
7/13/2007	0.42	0.22	0.04	0.00	0.33
7/21/2007	0.48	2.23	0.03	0.50	0.24
7/23/2007	0.18	0.87	0.09	0.11	0.12
7/26/2007	0.46	1.23	0.08	0.44	0.36
Mean of all	0.43	1.23	0.05	0.28	0.21
Mean excluding 7/2	0.43	1.05	0.05	0.27	0.24

Table 9. Lamb, ram, and yearling to ewe ratios and the proportions of ram and ewe collars observed during each of the resight surveys held in July 2008 and their means over all surveys.

Survey Date	Lamb: Ewe	Ram: Ewe	Yearling: Ewe	Proportion of Ram Collars Observed	Proportion of Ewe Collars Observed
7/15/2008	0.54	0.37	0.10	0.25	0.58
7/17/2008	0.49	0.23	0.08	0.00	0.33
7/19/2008	0.18	1.38	0.10	0.13	0.30
7/25/2008	0.16	0.60	0.15	0.25	0.15
7/28/2008	0.36	0.81	0.12	0.38	0.27
Mean	0.36	0.66	0.11	0.20	0.33

Table 10. Lamb, ram, and yearling to ewe ratios and the proportions of ram and ewe collars observed during each of the resight surveys held in July 2009 and their means over all surveys.

Survey Date	Lamb: Ewe	Ram: Ewe	Yearling: Ewe	Proportion of Ram Collars Observed	Proportion of Ewe Collars Observed
7/13/2009	0.36	1.33	0.06	0.27	0.21
7/15/2009	0.47	0.56	0.02	0.20	0.32
7/17/2009	0.24	0.84	0.13	0.13	0.18
7/24/2009	0.44	0.84	0.06	0.27	0.38
7/28/2009	0.25	0.40	0.13	0.13	0.47
Mean	0.36	0.76	0.08	0.20	0.31

Table 11. Lamb, ram, and yearling to ewe ratios and the proportions of ram and ewe collars observed during each of the resight surveys held in November and December 2007 and their means over all surveys.

Survey Date	Lamb: Ewe	Ram: Ewe	Yearling: Ewe	Proportion of Ram Collars Observed	Proportion of Ewe Collars Observed
11/30/07	0.22	0.84	0.11	0.12	0.48
12/3/07	0.18	1.07	0.15	0.24	0.42
12/5/07	0.22	0.98	0.11	0.18	0.45
12/10/07	0.28	0.83	0.05	0.24	0.48
Mean	0.23	0.92	0.10	0.19	0.46

Table 12. Lamb, ram, and yearling to ewe ratios and the proportions of ram and ewe collars observed during each of the resight surveys held in November and December 2008 and their means over all surveys.

Survey Date	Lamb: Ewe	Ram: Ewe	Yearling: Ewe	Proportion of Ram Collars Observed	Proportion of Ewe Collars Observed
12/1/08	0.11	0.79	0.09	0.24	0.58
12/3/08	0.16	0.94	0.06	0.18	0.39
12/8/08	0.17	0.84	0.14	0.47	0.58
Mean	0.15	0.85	0.10	0.29	0.52

Table 13. Ram collar sighting probability (number of surveys in which an individual is detected/total number of surveys) during resight surveys from 2006 to 2009.

Rams	July 2006	July 2007	July 2008	July 2009	Dec 2007	Dec 2008
Number of Surveys	7	7	5	5	4	3
Routes per Survey	11-14	13-16	13-15	13-15	5	5
Total Bighorn Sheep Observations	1056	974	733	562	770	551
Collars Deployed	14	18	16	15	17	14
Identified Collars	30	20	10	7	11	13
Unidentified Collars	2	15	6	8	2	2
Mean Individual Sighting Probability	0.31	0.17	0.13	0.09	0.16	0.31
Lowest Individual Sighting Probability	0	0	0	0	0	0
Highest Individual Sighting Probability	0.83	0.50	0.40	0.40	0.75	1.00
Collars seen 0 times	1	7	10	9	10	8
Collars seen 1 times	3	3	2	5	4	1
Collars seen 2 times	5	7	4	1	2	3
Collars seen 3 times	4	1	0	0	1	2
Collars seen 4 times	0	0	0	0	0	X
Collars seen 5 times	1	0	0	0	X	X

Table 14. Ewe collar sighting probability (number of surveys in which an individual is detected/total number of surveys) during resight survey for 2006 to 2009.

Ewes	July 2006	July 2007	July 2008	July 2009	Dec 2007	Dec 2008
Number of Surveys	7	7	5	5	4	3
Routes per Survey	11-14	13-16	13-15	13-15	5	5
Collars Deployed	35	33	33	34	33	32
Identified Collars	68	33	42	38	59	50
Unidentified Collars	4	15	12	15	2	1
Mean Individual Sighting Probability	0.28	0.17	0.26	0.22	0.45	0.52
Lowest Individual Sighting Probability	0	0	0	0	0	0
Highest Individual Sighting Probability	0.67	0.67	0.80	0.60	1.00	1.00
Collars seen 0 times	6	11	6	13	5	9
Collars seen 1 times	6	14	17	8	7	6
Collars seen 2 times	10	6	6	9	11	7
Collars seen 3 times	10	1	2	4	8	10
Collars seen 4 times	3	1	2	0	2	X
Collars seen 5 times	0	0	0	0	X	X

Figure 7 shows the mean proportion of collars available that were observed each year and the mean of the individual ewe and ram sighting probabilities (number of surveys in which an individual is detected/total number of surveys) from 2006-2009. The mean individual sighting probabilities are slightly lower than the proportion of collars observed due to the collars that were observed but unidentified. These collars are included in the proportion of collars observed, but not in the mean of the individual sighting probabilities.

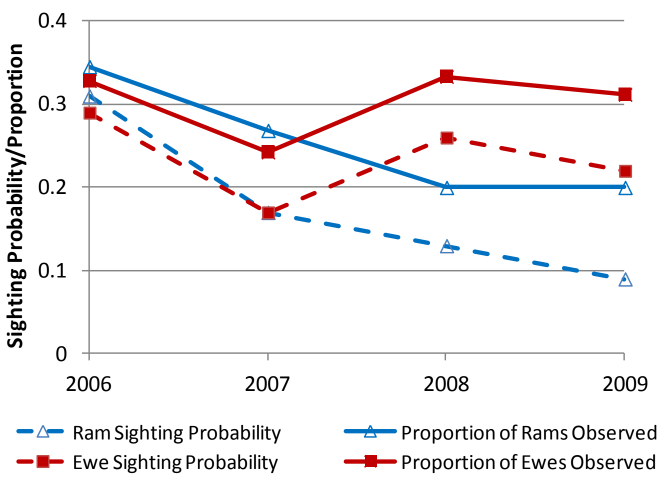

Figure 7. Mean individual sighting probability (number of surveys in which an individual is detected/total number of surveys) of collared ewes and rams and proportions of collared ewes and rams seen during coordinated ground resight surveys from 2006-2009.

From 2006 to 2009, 23 surveys were completed during July. The earliest survey was held on July 1 and the latest was held on July 28. We expected the number of ewes observed to increase during the month of July because during this time the Georgetown ewes transition from smaller groups in lambing habitat to larger groups in summer habitat. Smaller groups early in the month are more difficult to detect than larger groups later in the month. Figure 8 shows the relationship between the number of ewes observed on each survey and the survey date. This regression supports our expectation of increasing detection of ewes during July (slope = 1.1 with 95% CI = 0.15-2.00, R^2=0.21) with approximately 1.9 times more ewes detected at the end of July than at the beginning.

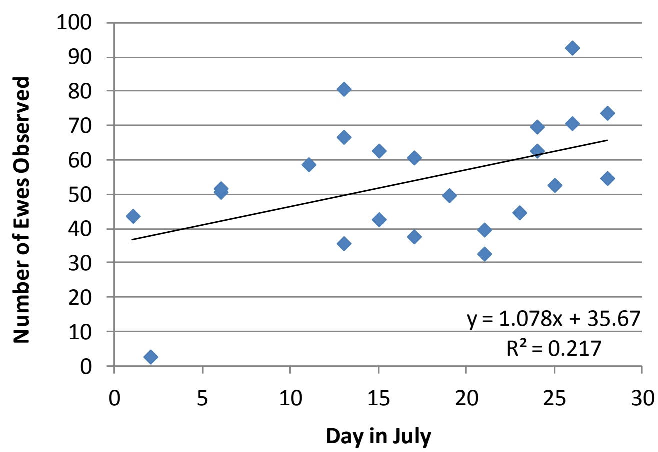

Figure 8. The number of ewes observed during each of the surveys from 2006 to 2009 regressed against the day of July on which the survey was conducted.

Very young lambs are easily missed on surveys due to their size and decreased activity level. As they age they are larger and more active and less likely to be missed during a survey. This should result in an increasing observed lamb to ewe ratio during the month of July. However, we actually expected to find a decreasing observed ratio due to high lamb mortality relative to ewe mortality during the month. We found evidence of this downward trend (slope = 0.9 with a 95% CI = -1.7 - -0.17, R^2 =0.25) (Fig. 9). This downward trend resulted in a 45% decrease in the lamb to ewe ratio during the month of July.

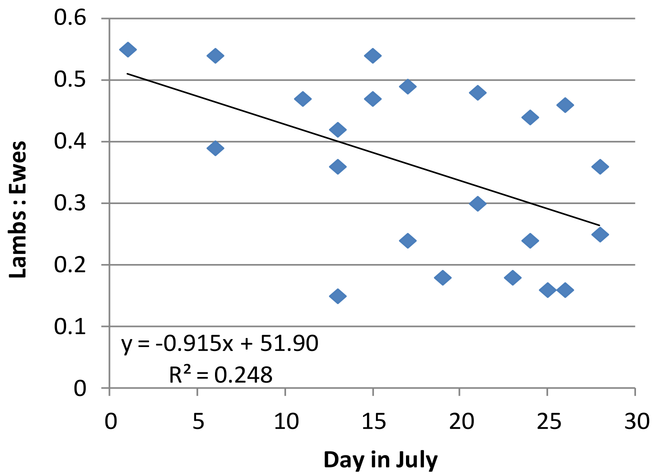

Figure 9. The lamb to ewe ratio observed during each of the July surveys from 2006 to 2009 regressed against the day of July on which the survey was conducted.

Mark-Resight Population Estimate

Following McClintock and White (2007), we used Bowden's estimator (Bowden and Kufeld 1995) implemented in NOREMARK software (White 1996) to generate a mark-resight estimate of the adult ewe and adult ram population each July from 2006 to 2009 along with 95% confidence intervals and percent confidence interval lengths (%CIL). We also calculated the proportion of the estimated ewe and ram populations that were collared during the resight surveys each year (Table 15).

One assumption of Bowden's estimator is that each animal has an equal chance of being selected for marking and that the marked animals are independent. This assumption can be approximated if the animals chosen to be marked are selected differently than those resighted (White and Shenk 2001). In this study, that was achieved by marking the animals on winter range and resighting them on summer range. Because minimal effort was required to estimate the December populations from the fall surveys, these estimates were calculated and shown in Table 15. However, it should be noted that because many of the animals were marked from the ground on winter range and resighted from the ground on winter range, the assumption of marks being independent of each other and of all sheep having an equal chance of being marked was likely violated.

Another assumption of Bowden's estimator is closure. Each year, we confirmed that the marked animals were alive and in the study area during the resight surveys through a combination of aerial and ground telemetry independent of the resight surveys.

Population Modeling

An optimized fit population model was developed to estimate the July and December (Fig. 10) populations from 1991 to 2010 (the time period for which there is sufficient data). This spreadsheet model is similar to those used to manage deer and elk populations in Colorado and incorporates the Bowden's estimates for the July ewe and ram populations, observed December age ratios, observed December sex ratios, observed adult ewe and ram survival rates, lamb survival rates, and removals (i.e., hunter harvest, translocations, and vehicle collision mortality) (White and Lubow 2002). The December Bowden population estimates were not used due to the violated assumptions of the estimator.

The July population estimates are higher than the December population estimates due to losses of bighorn sheep between July and December through hunter harvest, vehicle collisions, and other mortalities. Lambs account for the majority of the other mortalities between July and December.

Table 15. Ewe and ram Bowden population estimates with 95% confidence intervals and % confidence interval lengths (%CIL) for the Georgetown herd from 2006 to 2009 and the proportion of the ewe and ram population that were collared each year.

Year	Ewe	95% CI	% CIL	Ram	95% CI	% CIL	Prop Ewes Collared	Prop Rams Collared
July 2006	174	147–207	34	194	144–261	60	0.20	0.10
July 2007	229	175–300	55	216	154–303	69	0.14	0.07
July 2008	185	150–229	43	157	101–245	92	0.18	0.11
July 2009	150	118–192	49	171	112–264	89	0.23	0.13
Dec 2007	177	147–214	38	366	199–676	130	0.19	0.05
Dec 2008	159	125–202	48	171	94–311	127	0.20	0.08

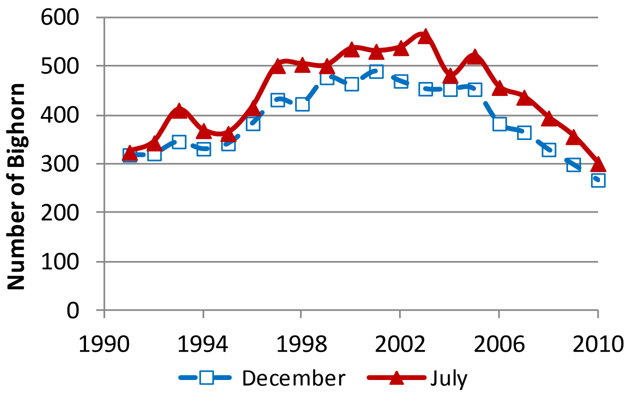

Figure 10. Modeled July and December population estimates for the Georgetown herd from 1991 to 2010.

Comparison of Survey Observations, Mark-Resight Population Estimate, and Modeled Population

The management of many bighorn sheep herds in Colorado is based primarily on the results of coordinated ground surveys (Colorado Division of Wildlife 2009). These surveys provide valuable information on sex and age ratios, minimum population size, and minimal distributions. However, due to the opportunistic nature of these surveys, they do not provide information on the proportion of the herd observed, without which we cannot derive statistically valid population estimates (Anderson 2001, Pierce et al. 2012). This was one reason for initiating a mark-resight study on the Georgetown herd.

Figures 11 and 12 compare the numbers of ewes and rams observed during the July surveys to the modeled ewe and ram population estimates and to the Bowden population estimates for ewes and rams. Figure 13 shows the proportion of the modeled July and December populations observed each year during the July and December surveys. These range from 0.28 to 0.61 with a mean of 0.40 for July and 0.34 to 0.82 with a mean of 0.56 in December. Even though 2-3 times more routes were run during each of the surveys in July than surveys in December and part of the winter range was inaccessible during surveys in December, the proportion of the herd seen was higher in December. This was due to the fact that, in December, sheep were concentrate on winter range that was easily accessible to survey and that ewes and rams are engaged in rutting behavior, which makes them more active and visible. In July the sheep are spread over a larger area and much less concentrated and accessible.

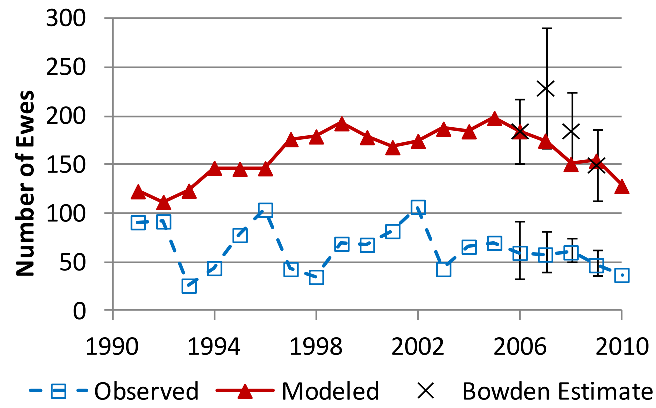

Figure 11. Number of bighorn ewes observed during the July survey from 1991-2010 (with means and ranges for years with multiple surveys); the modeled ewe population for the same time period and the Bowden population estimate with 95% confidence intervals for 2006 to 2009.

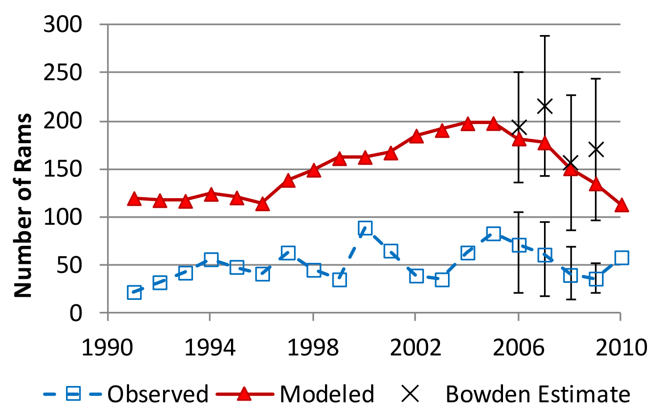

Figure 12. Number of bighorn rams observed during the July survey from 1991-2010 (with means and ranges for years with multiple surveys); the modeled ewe population for the same time period and the Bowden population estimate with 95% confidence intervals for 2006 to 2009.

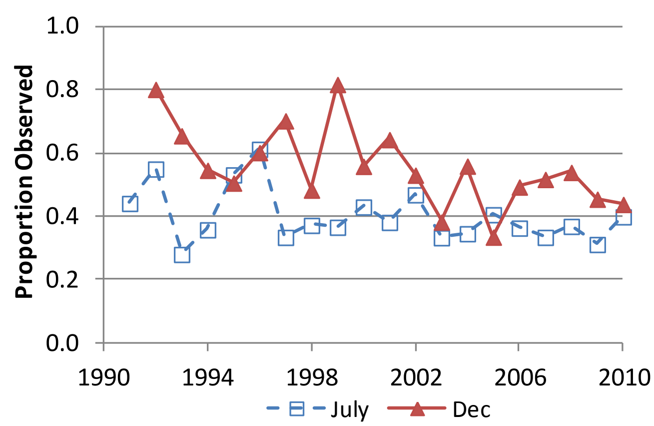

Figure 13. Proportion of the July and December modeled populations observed each year during the July and December surveys.

ADULT SURVIVAL AND MORTALITY

Annual survival rates were calculated for adult ewes, adult rams, and total adults for December 2005 to December 2009 using a Kaplan-Meier staggered entry design. Harvest mortality was considered additive to natural mortality and was incorporated as a separate parameter in the population model (White and Lubow 2002). To allow comparison of survival rates in Georgetown to other herds with different harvest pressures, we censored harvest mortalities when calculating survival rates (Table 16). During the years of this study this population was being managed downward through ewe and ram hunting. On average from 2006 to 2009, 4% of the adult ewe population and 11% of the adult ram population were removed via hunting each year. These hunting removals were considered primarily additive mortalities.

Table 16. Annual (December to December) survival rates for adult ewes, adult rams, and adults total for 2006 to 2009. Harvested animals were censored in order to allow comparison with herds that have differing hunting pressure.

	Survival (95% CI) No Harvest		
Year	**Adult Ewes**	**Adult Rams**	**Adult**
2006	97 (92-100)	94 (81-100)	96 (91-100)
2007	85 (73- 96)	100 (100-100)	90 (82- 97)
2008	86 (76- 98)	89 (74-100)	87 (79- 96)
2009	94 (87-100)	85 (65-100)	92 (85- 99)
Mean	91	92	91

Status of Collared Bighorn Sheep and Causes of Mortality

As of May 2011, 48% of the 50 ewes and 48% of the 27 rams collared had died and 36% of the ewes and 37% of the rams were still alive and wearing their collars. The rest of the collared bighorn sheep had been removed from the study, either because the collar had dropped off as designed, or because they were captured and removed from the herd (2 ewes were moved to the Cache La Poudre River herd).

The causes of mortality for the 37 collared bighorn sheep (24 ewes, 13 rams) that had died as of May 2011 are shown in Figures 14 and 15. Fourteen bighorn sheep (11 ewes, 3 rams) died following collisions with vehicles. Nine bighorn sheep (3 ewes and 6 rams) were harvested by hunters. Three bighorn sheep (2 ewes, 1 ram) were killed by lions. Two ewes died of natural causes (1 of these died of liver tumors). One ram was a wounding loss. One ewe died from hardware disease (infection subsequent to the ingestion of a piece of metal that punctured the reticulum). One ewe was euthanized after incurring injuries from entanglement in a fence. The cause of death for the remaining 4 ewes and 2 rams was unknown. Five of these were not found quickly enough to determine the cause of death. The complete carcass of the 6th bighorn sheep, a ram, was found in good body condition in bedded position on the alpine. This was definitely not a vehicle collision, old age, or predation.

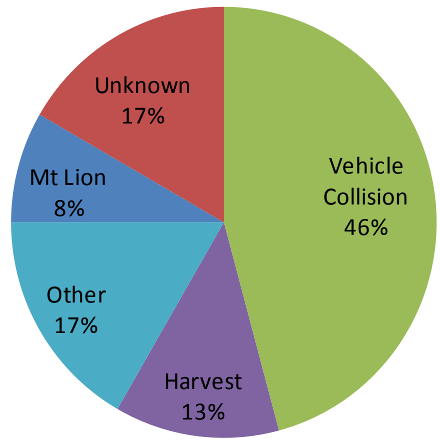

Figure 14. Causes of mortality for the 24 collared ewes that died between Dec 2005 and April 2011.

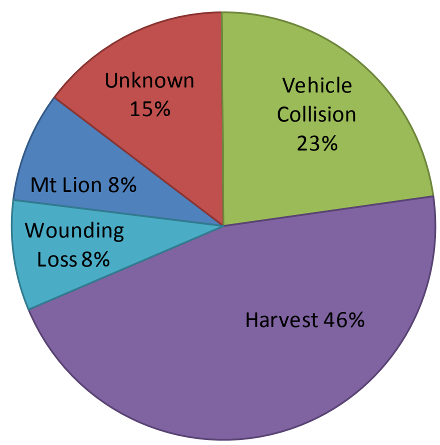

Figure 15. Causes of mortality for the 13 collared rams that died between Dec 2005 and April 2011.

Vehicle Caused Mortality

Bighorn sheep mortality resulting from collisions with vehicles is substantial in the Georgetown herd, although the exact number killed each year is unknown. Prior to 2006, records of bighorn killed in collisions with vehicles are sporadic. From 2006 to 2011, a concerted effort was made to record as much information as possible on each reported vehicle caused bighorn sheep mortality from this herd and to necropsy as many carcasses as possible. From 1991 through May 2011, 129 vehicle collision caused mortalities were recorded, with 63 of these recorded from January 2006 to May 2011. These represent the minimum number of bighorn sheep killed. Many of the bighorn sheep killed in vehicle collisions are never reported by the parties involved. Animals that die acutely and remain near the road are often found and reported by Colorado State Patrol, the Colorado Department of Transportation, CPW and by members of the public. Animals that are injured, but able to move more than a short distance from the road before dying from their injuries are usually not found or reported.

Radio collar information can be used to estimate the number of unreported bighorn sheep killed in vehicle collisions. From January 2006 to April 2011, 14 radio collared bighorn sheep were killed in vehicle collisions, 7 of these (i.e., 50%) were reported as vehicle killed. The other 7 were not reported and were found during regular telemetry searching. These were determined to have been killed in vehicle collisions through inspection of the carcasses. In other words, the radio collared bighorn sheep reported as vehicle killed accounted for only 50% of the radio collared bighorn sheep actually killed by vehicles.

The months during which most vehicle caused mortalities occur are April and November (Fig. 16). There are 4 circumstances in which bighorn sheep in this herd are most vulnerable to being killed in collisions with vehicles. First, bighorn sheep traditionally make seasonal movements down in elevation in the spring to take advantage of the spring green-up, which begins first at the lower elevations. Because major highways run through most of the low elevation areas used by this herd, bighorn sheep moving down in elevation to take advantage of the spring green-up are also vulnerable to vehicle collisions (Fig. 17). Second, bighorn sheep are drawn to all of the major roadways in the DAU in the winter by the minerals that are applied to the roads to reduce ice. Third, Highways 40, 6 and 119, and the Central City parkway all bisect traditional bighorn sheep movement corridors. Bighorn sheep following these traditional movement corridors across these roads are vulnerable to vehicle collisions. This is especially true during the breeding season (October – December). Fourth, bighorn that are sick and unable to keep up with the herd tend to move down in elevation rather than up. In this herd, as sheep move down in elevation, they are likely to encounter a major roadway and be vulnerable to being struck by a vehicle. Some vehicle caused mortality may, therefore, be compensatory for disease caused death. We cannot, however, evaluate this possibility with the data available. Specific geospatial information on areas where vehicles collide with bighorn sheep and suggestions for how to reduce vehicle collisions is included in Appendix 2.

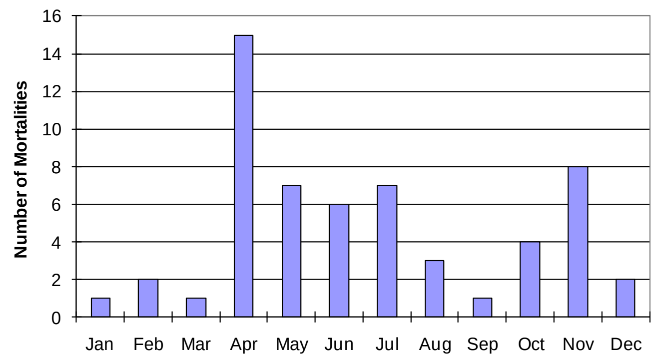

Figure 16. Timing of vehicle collision caused mortalities in the Georgetown bighorn sheep herd from 2006 to 2010.

Figure 17. Bighorn sheep feeding on shoulder of highway. V4 was killed in April 2009 in a collision with a vehicle. Photo by: Harry Rhulen.

RANGE DELINEATION AND BIGHORN SHEEP MOVEMENTS

Human use of and encroachment into the area inhabited by the Georgetown bighorn sheep herd is pervasive and ongoing. The 2 mechanisms through which human activities have the greatest potential to negatively impact the herd are loss and fragmentation of habitat and the introduction of livestock disease to the immunologically naïve bighorn sheep.

Managers often have opportunities to provide input on how to minimize the impacts of human activities on the herd. Examples include: designing roads to reduce the number of bighorn sheep killed in collisions with vehicles; routing trails and regulating their use to minimize impacts to crucial habitats such as lambing areas; identifying areas to protect in order to maintain migration corridors and connectivity throughout the herd; restricting the use of domestic sheep and goats for weed control and fire mitigation; advising landowners on how to reduce the probability that livestock diseases will be introduced into the bighorn sheep herd; etc. In order to inform mitigation efforts, detailed information on bighorn sheep distribution and movements is required. This study was, therefore, designed to:

1. Determine the range and distribution of the herd;
2. Identify key habitats and migration corridors;
3. Determine the extent of interchange between subherds;
4. Determine the extent of interchange with adjacent herds.

This information will also be useful in predicting how diseases introduced into the herd will spread through the herd or to adjacent herds and in designing effective management actions to prevent this spread.

Collar Locations

Collared bighorn sheep location information was recorded during captures, recaptures, surveys, opportunistic sightings, aerial and ground radio telemetry tracking, collar recovery, and Lotek GPS and Globalstar collar downloads. The capture and recapture locations are considered unbiased locations. Fifty-two of the bighorn were captured via helicopter netgunning and darting at location uninfluenced by the capturer. Fifteen sheep were baited to a site where they were captured under a dropnet. These locations are potentially biased; however, the dropnets were placed in areas frequented by bighorn and were locations frequented by the collared bighorn after capture.

From December 2005 to May 2011, we downloaded 33,672 locations from Lotek GPS and Globalstar collars and recorded 5,422 additional locations. Table 17 shows the distribution of all locations across the location methods. Some bighorn sheep used areas that were harder to access than others. The proportion of locations obtained by each location method is, therefore, not the same for each collar. Table 26 in Appendix 1 shows the number of locations obtained using each location method for each bighorn sheep, excluding locations downloaded from Lotek GPS and Globalstar collars.

Figures 18 and 19 show the distribution of these locations over the years of the study and months of the year respectively. In 2006, emphasis was placed on radio telemetry from the ground, and aerial telemetry was used only when necessary to locate bighorn sheep not found during ground telemetry surveys. Due to the inherent error associated with triangulating locations from the ground in bighorn sheep habitat resulting from VHF signal bounce, every attempt was made to get visual locations, with triangulation only used occasionally. Due to the topography and size of the area inhabited by collared bighorn, we could not thoroughly cover it using ground telemetry. When collared bighorn occupied certain areas inaccessible to the survey teams, they were not detected on our surveys. As a result, in October 2007, we shifted our emphasis from ground to aerial telemetry in order to reduce the bias associated with ground surveys.

Table 17. Number of recorded locations of collared bighorn sheep for each location method.

Location Method	Number of Locations
Aerial Telemetry	1,544
Triangulation	49
Capture	77
Surveys	440
Recapture	12
Recovery	37
Ground Telemetry	3,263
Downloads	33,672
Total	39,094

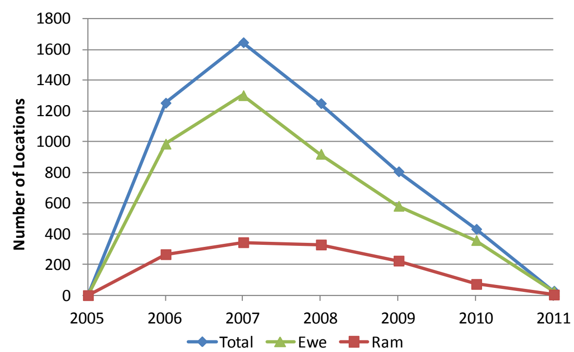

Figure 18. Number of locations of collared ewes and rams recorded each year from 2005 to 2011, excluding Lotek GPS and Globalstar collar downloads.

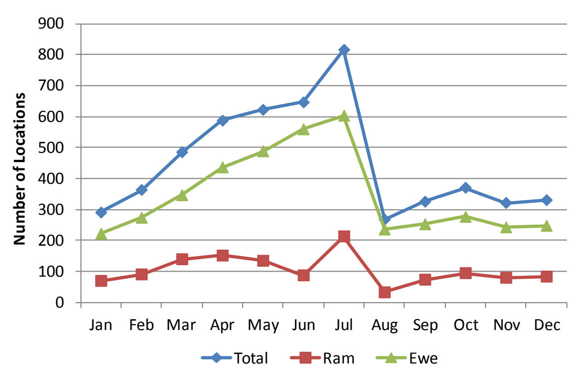

Figure 19. Monthly distribution of collared ewe and ram locations recorded from December 2005 to May 2011, excluding Lotek GPS and Globalstar collar downloads.

Table 18. Deployment details for each Lotek GPS and Globalstar (Global) collar.

Ear tag	Type	Class	Fix/ day	Subherd	First Location	Last Location	Wks On	# of Locations	Comments
19	GPS	Ram	6	Empire	2/5/09	2/4/10	52	2024	Dropped on schedule
23	GPS	Ewe	6	S41	1/23/08	3/10/09	59	2184	Dropped on schedule
25	GPS	Ewe	8	Engelmann	2/5/09	4/1/10	60	3146	Dropped on schedule
28	GPS	Ram	8	S3	1/23/08	11/30/08	45	2113	Broke off early
32	GPS	Ram	6	Engelmann	3/13/07	10/27/07	33	1320	Broke off early
64	GPS	Ewe	8	Empire	3/30/07	4/14/08	54	2961	Mortality
10	Global	Ram	6	Eastern	4/29/11	5/21/11	3	13	Stopped working, not recovered
11	Global	Ewe	6	Dumont	3/30/09	5/22/10	60	2471	Dropped early
22	Global	Ewe	6	Eastern	2/5/09	2/11/10	53	2160	Mortality
36	Global	Ewe	6	Western	2/5/09	2/5/09	0	0	Did not upload / drop
40	Global	Ewe	6	Engelmann	2/5/09	2/7/11	105	492	Did not drop
46	Global	Ewe	6	Engelmann	2/5/09	7/29/10	77	3207	Dropped early
47	Global	Ewe	6	Dumont	2/23/10	8/7/10	24	3089	Dropped on schedule
78	Global	Ewe	6	Western	2/5/09	8/7/10	78	3220	Dropped on schedule
79	Global	Ewe	6	Douglas Mt	3/24/09	8/7/10	72	2905	Dropped on schedule
100	Global	Ewe	6	Idaho Springs	2/5/09	3/31/10	60	2367	Dropped early

In addition to the ongoing radio telemetry surveys, ewes were monitored as closely as possible from April 15 to July 31 in an attempt to determine parturition rates and timing, lambing areas and lamb survival. Opportunistic sightings were accepted throughout the study from CPW staff as well as from the public.

Table 18 shows detail of each Lotek GPS and Globalstar collar. The 6 Lotek GPS collars were programmed to record their location every 6 hours (3 collars) or 8 hours (3 collars). Two of these collars, both on rams, broke off prior to the scheduled drop off date. The leather band on one of these wore through; the plastic housing on the other broke where it attached to the neck band with screws (possibly due to over tightening during deployment). One of the collared ewes died prior to the scheduled drop date. Three collars dropped off at the scheduled time. The 10 Globalstar collars were programmed to recorded 6 locations per day and transmit 1 of these locations. One Globalstar collar was recovered after the ewe's death. Three Globalstar collars dropped off earlier than programmed (1, 18, and 29 weeks early); 3 dropped off on schedule; 2 failed to drop off but uploaded daily locations as programmed. One Globalstar collar stopped uploading locations after deployed for 1 month and was never recovered. One Globalstar collar malfunctioned and never uploaded its location and also failed to drop off. A total of 33,672 locations were downloaded from the Lotek GPS and Globalstar collars. Three Globalstar collars are still in the field and it is hoped that they will still be retrieved and downloaded.

Subherds

Several overlapping subherds can be described within this DAU for both ewes and rams (Figs. 20 and 21). We assigned each individual bighorn to subherds based on seasonal movements and areas used. We then described how these subherds interacted with each other seasonally. This information has important implications for genetic exchange and disease transmission throughout the Georgetown herd.

The Eastern subherd occurs primarily from Golden to the junction of Highways 6 and 119 within a ½ mile north of Clear Creek (and parallel US Highway 6). They occasionally use the south side of Clear Creek between the junction of Highways 6 and 119 and Tunnel 2. Occasionally Eastern bighorn sheep move as far west as Idaho Springs. Figure 22 shows all of the locations collected from collared ewes belonging to this subherd (4 VHF collars and 1 Globalstar collar). Figure 23 shows all of the locations collected from collared rams belonging to this subherd (4 VHF collars and 1 Globalstar collar). The Globalstar collar only uploaded 13 locations and has not been recovered. One of these rams, #204, was captured as a 5-year old in March 2006. At the time of capture, it was discovered that he had a healed injury to his back leg, just above the hoof which allowed the hoof to flop and prevented him from bearing weight on this leg. He remained collared throughout the study (5 years) and the injury persisted the entire time. He remained with the ram band and his movement patterns did not differ from other rams in the area.

The Idaho Springs subherd occupies primarily the area within ½ mile north of Clear Creek (and parallel US Highway 6 and Interstate 70) from the junction of Highways 6 and 119 to Fall River Road. Figure 24 shows the locations of the collared ewes belonging to this subherd (3 VHF collars and 1 Globalstar collar). This map shows that ewes from this subherd rarely move west of Virginia Canyon in Idaho Springs, but occasionally move up to 6 miles east of their core range. Figure 25 shows the locations from 2 VHF ram collars from the Idaho Springs subherd. Ram #42 was captured as a 2-year-old and ranged much more widely (from Golden to Spring Gulch) than ram #88 that was captured as a 3-year-old and ranged from Tunnel 3 to Fall River Road.

The Dumont subherd ranges primarily within ½ mile north of Clear Creek from the junction of Interstate 70 and US Highway 6 east of the Central City Parkway to the Junction of Interstate 70 and US Highway 40 at Empire Junction. These ewes occasionally move as far east as the junction of Highways 6 and 119 and move 2 miles up Mill Creek from Dumont. Figure 26 shows the locations of the 4 VHF collared ewes and 2 Globalstar collared ewes belonging to this subherd. Although 3 rams were captured within this area, none of them exhibited movement patterns that would associate them with this subherd; they were from the Empire, Georgetown and Idaho Springs subherds. It is unknown if there are rams that belong to this subherd.

The Empire subherd winters mostly at low elevation from Fall River Road to Empire and summers on the alpine along the Continental Divide from Berthoud Pass north to Mount Bancroft. Figure 27 shows the locations from 11 VHF ewe collars and from 1 Lotek GPS ewe collar from this subherd. Although most locations are north of US Highway 40, they occasionally move south onto Douglas Mountain. On July 25, 2006, 1 ewe from this subherd (#61) was located via aerial telemetry near Jasper Lake, 9 air miles north of the previously defined northern boundary of the range (James Peak). Two additional ewes (#44 and #38) were found near Rollins pass, 6.5 air miles north of this boundary. These ewes had been last located in the unit on June 1, July 13, and July 3 respectively and were all back in the unit by August 25. They were out of the unit for a maximum of 6 to 10 weeks. Ewe #61 died 9 months after this movement, so it is not known if she would have made this movement again in subsequent summers. Ewes #38 and #44 were still collared at the end of the study 5 years later. Neither of these ewes was ever found outside of the unit boundaries again. Figure 28 shows the locations from 2 VHF ram collars and 1 Lotek GPS ram collar belonging to this subherd. This shows that the rams do not move as far east as the ewes, but that they use the area west of US Highway 40 and East of the Continental divide near Stanley Mountain, whereas the ewes do not.

The Douglas Mountain subherd moves between Fall River Road and Silver Creek in Georgetown within ½ mile north of Clear Creek (I-70) with occasional movements as far west as Cloud Gulch. Figure 29 shows the locations of 6 VHF ewe collars and 1 Globalstar ewe collar from this subherd. Although 7 rams were captured within the core use area of this subherd, none of them exhibited movement patterns that would associate them with this subherd: 1 was from the Empire subherd, 1 from the Engelmann subherd, 4 from the Georgetown subherd, and 1 from the Western subherd. It is unknown if there are rams that belong to this subherd.

The Georgetown subherd primarily uses the area north and west of Clear Creek from the junction of I-70 and US Highway 40 at Empire Junction to Silver Plume Mountain, occasionally moving as far west as Mount Parnassus and as far east as Downieville. These bighorn sheep primarily use the low elevation areas near Clear Creek, however they occasionally move up to the alpine on Republican Mountain, Silver Plume Mountain and Bard Peak. Figure 30 shows locations from 8 VHF ewe collars from this subherd. On August 1 and 25 of 2006, 1 ewe (#60) was found west of the Eisenhower tunnel (1 mile west of the GMU boundary) with 13 other bighorn sheep. She had been located inside the unit on July 25. On October 1 she was harvested by a hunter inside the unit. Figure 31 shows the locations of 4 VHF ram collars from this subherd. Ram #63 was captured via chemical immobilization on January 1, 2006 in Downieville. The next time he was located, 3 weeks later, he was west of Empire junction. His movements were monitored through the 5-year study, and he was never again found east of Empire junction.

The Western subherd uses the area south of US Highway 40, north of I-70 and east of the Woods Mountain. They use both the low elevation areas along Clear Creek and the alpine areas from Republican Mountain, west to Bard Peak, north to Engelmann Peak and east along the ridge towards Lincoln Mountain. Figure 32 shows locations from 4 VHF ewe collars and 1 Globalstar ewe collar from this subherd. Figure 33 shows locations from 5 VHF ram collars from this subherd.

The Engelmann subherd uses the area from Silver Creek in Georgetown west to Herman Gulch and north to Engelmann ridge. They use both low elevation areas along Clear Creek and the alpine. Figure 34 shows the locations of 6 VHF ewe collars, 2 Globalstar ewe Collars and 1 Lotek GPS ewe collar. Figure 35 shows the locations of 5 VHF ram collars and 1 Lotek GPS ram collar.

There was 1 additional ram (#18) that has not been assigned to a subherd (Fig. 36). He was collared on Mount Bethel on February 5, 2009 and he was the only bighorn sheep observed in this location. He moved east to Browns Gulch and then north to Stanley Mountain where he was harvested 6 months after capture; only 9 locations were recorded in that time.

As mentioned above, there were only 4 sheep that were observed to move outside of the herd boundaries: 3 ewes from the Empire subherd and 1 ewe from the Georgetown subherd. Each of these movements occurred in July and August of 2006, and each ewe returned. The ewe from the Georgetown subherd was observed during this foray accompanied by 13 other bighorns. The ewes from the Empire subherd were not observed during their foray; however, it is probable that they were also accompanied by other bighorn.

Four bighorn sheep were captured outside of S32 in order to determine if they moved into the range of the Georgetown herd. Three of these were from the Mount Evans herd (RBS4): a VHF collar was placed on a ram (#20) in S4 (Fig. 37), a Lotek GPS collar was placed on a ewe (#23) in S41 (Fig. 38), and a Lotek GPS collar was placed on a ram (#28) in S3 (Fig. 39). The fourth bighorn was a lone ram captured near Granby, CO and outfitted with a Lotek GPS collar (Huwer and Eichhoff 2015). None of these bighorn sheep ever crossed into the Georgetown herd. The first 3 remained within the mapped range of Mount Evans herd. The "Granby Ram" moved over 650 km through the ranges of multiple sheep herds in Colorado and Wyoming.

There is connectivity throughout the DAU, with adjacent subherds overlapping spatially and temporally. The Eastern subherd interacts with the Idaho Springs subherd. The Idaho Springs subherd interacts with the Eastern, Dumont, Empire, and Douglas Mountain subherds. The Empire subherd interacts with the Idaho Springs, Dumont, Douglas Mountain subherds. The Georgetown subherd interacts with the Douglas Mountain, Engelmann and Western subherds. The Engelmann subherd interacts with the Douglas Mountain, Georgetown, and Western subherds. The Western subherd interacts with the Douglas Mountain, Engelmann and Georgetown subherds.

Seasonal Ranges

Each subherd exhibits a seasonal shift in range. Three seasons have been identified for ewes: summer, lambing and winter. Movements to and from these ranges are not concurrent between the subherds.

Table 19 shows the range(s) each ewe subherd used during each month of the year of this study. Figures 40 to 45 show the areas used by ewes during various seasons: December, January and February; March, April, and May; June; July and August; September and October; and November. Figures 46 to 51 show the same for ram subherds.

Table 19. Seasonal ranges used by each ewe subherd of the Georgetown bighorn sheep herd each month (W=winter, S=summer, L=lambing).

Subherd	Eastern	Idaho Springs	Dumont	Douglas Mt	Empire	Georgetown	Engelmann	Western
January	W	W	W	W	W	W	W	W
February	W	W	W	W	W	W	W	W
March	L	W/L	L	W/L	W/L	W	W	W
April	L	W/L	L	W/L	W/L	W	W/L	W
May	L	W/L	L	W/L	L	W	W/L	L
June	S/L	L	S/L	L	L	L	S/L	L
July	S	S	S/L	L	S/L	S	S/L	S/L
August	S	S	S	L	S/L	S	S	S
September	W	S	S	S	S	S	S	S
October	W	S	S	S	S/W	S	S	S
November	W	S/W	S/W	W	S/W	W	W	W
December	W	W	S/W	W	W	W	W	W

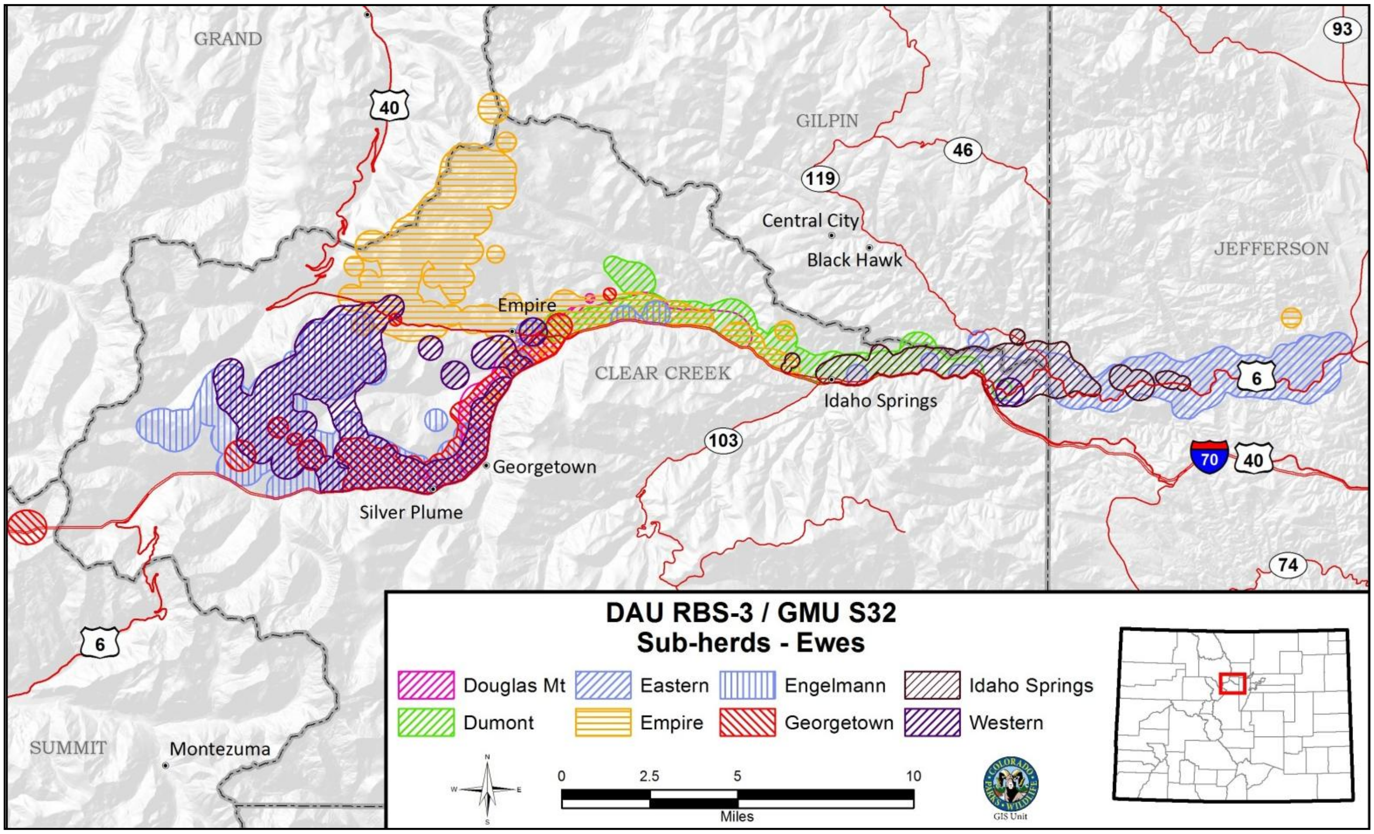

Figure 20. Ranges of Georgetown bighorn sheep ewe subherds.

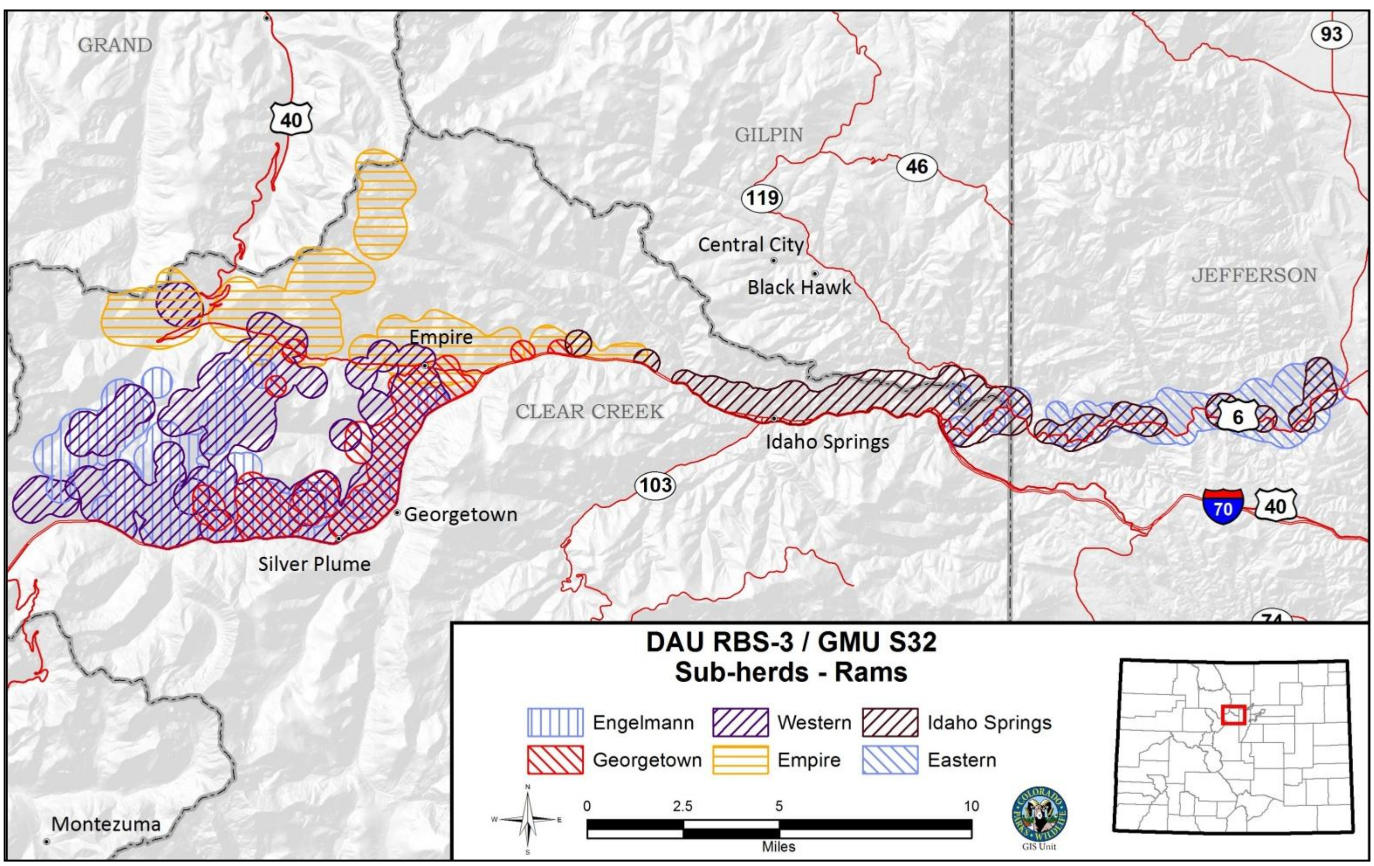

Figure 21. Ranges of Georgetown bighorn sheep ram subherds.

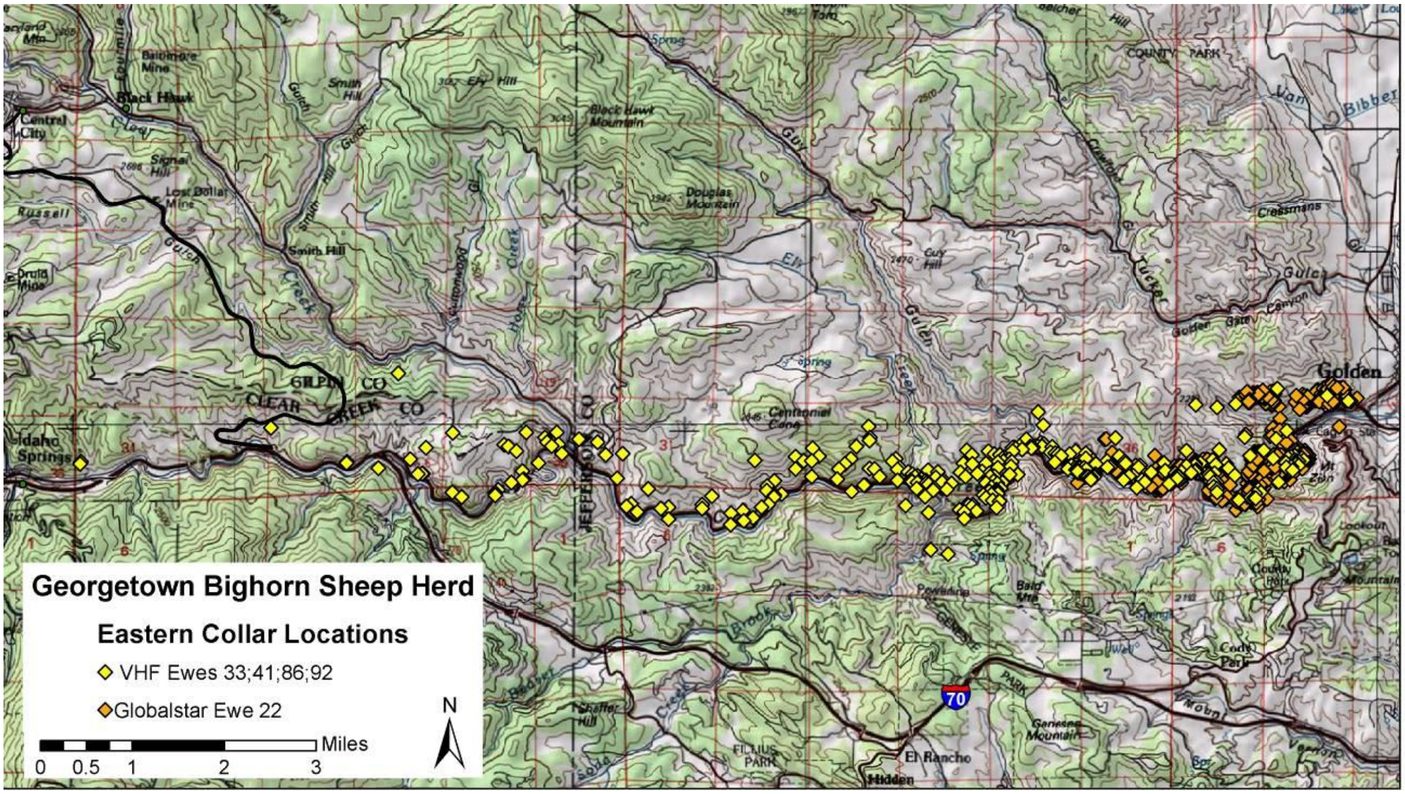

Figure 22. Collar locations of ewes from the Eastern subherd of the Georgetown bighorn sheep herd.

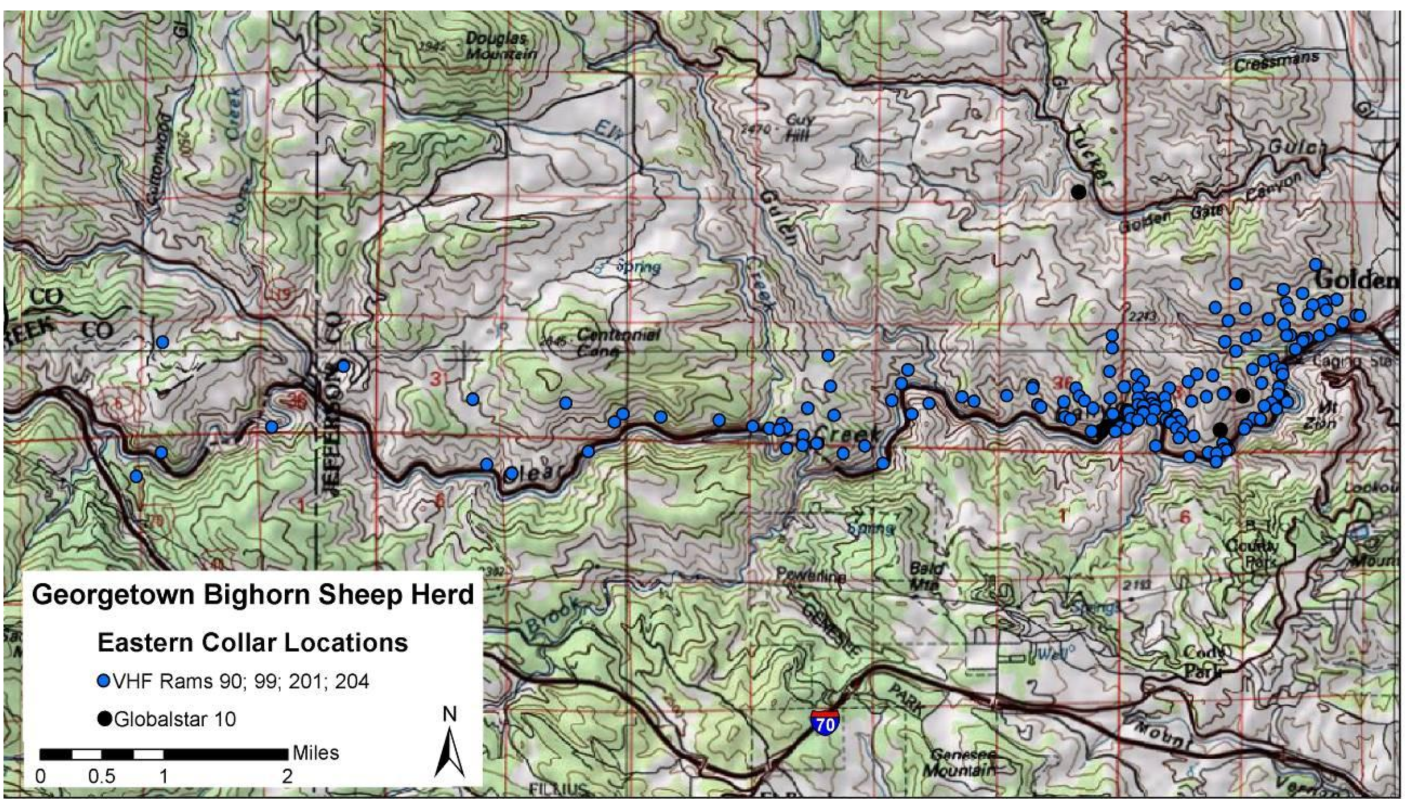

Figure 23. Collar locations of rams from the Eastern subherd of the Georgetown bighorn sheep herd.

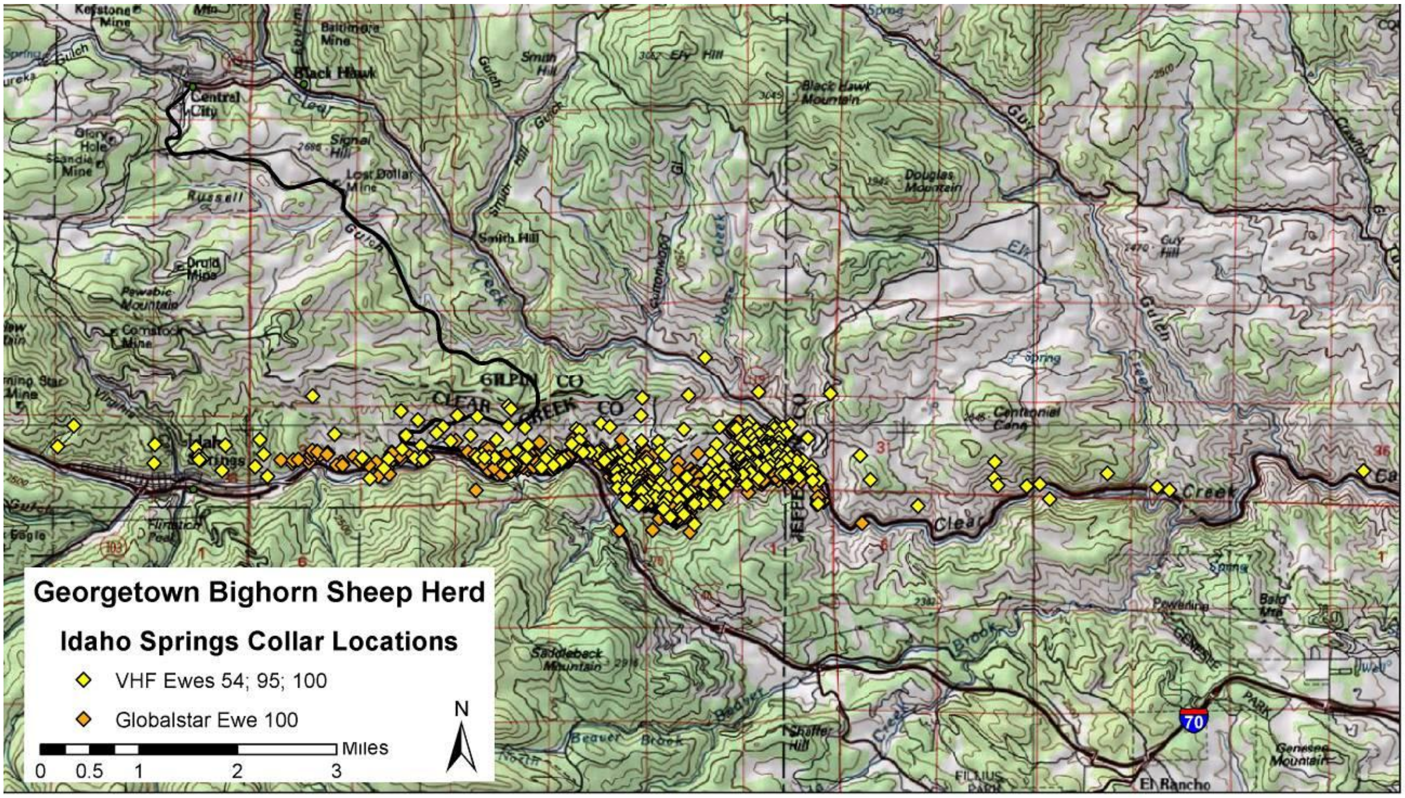

Figure 24. Collar locations of ewes from the Idaho Springs subherd of the Georgetown bighorn sheep herd.

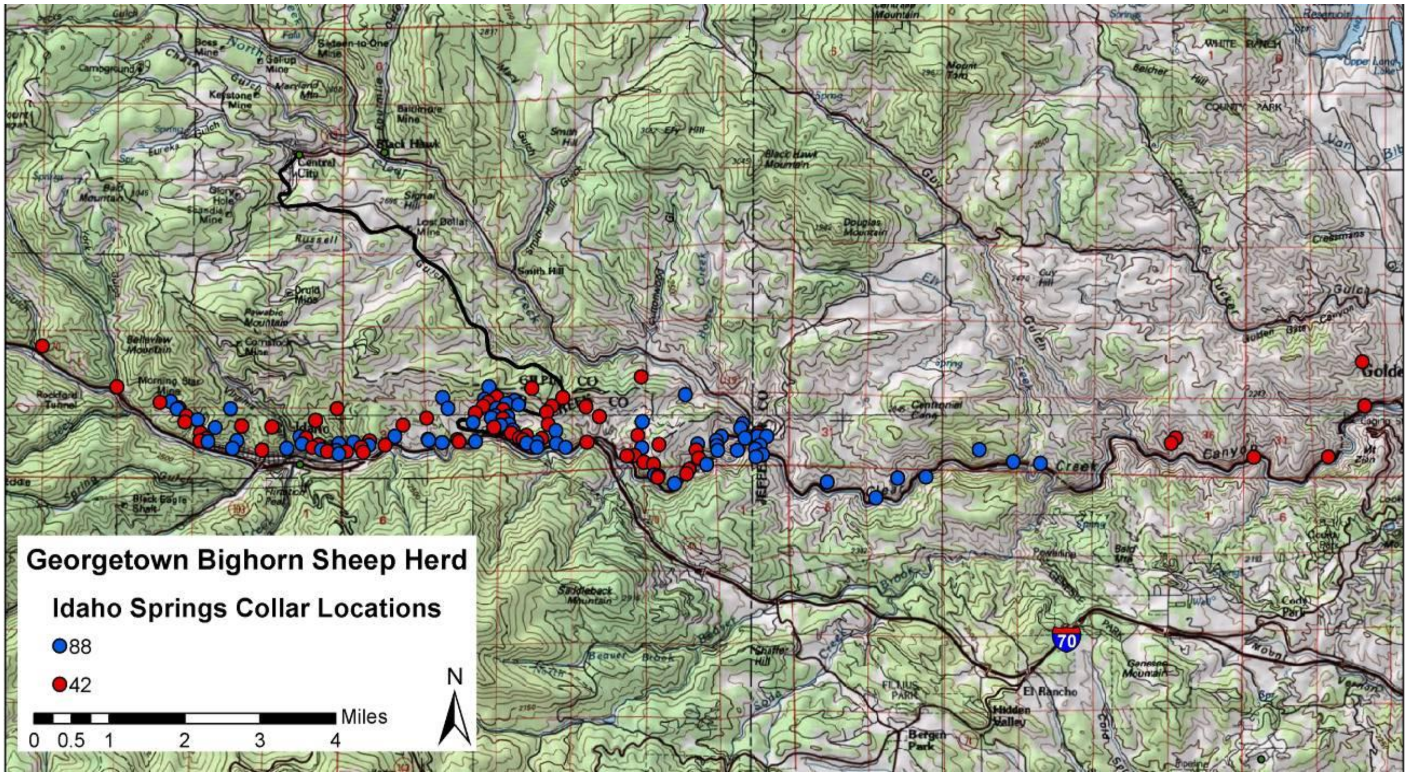

Figure 25. Collar locations of rams from the Idaho Springs subherd of the Georgetown bighorn sheep herd.

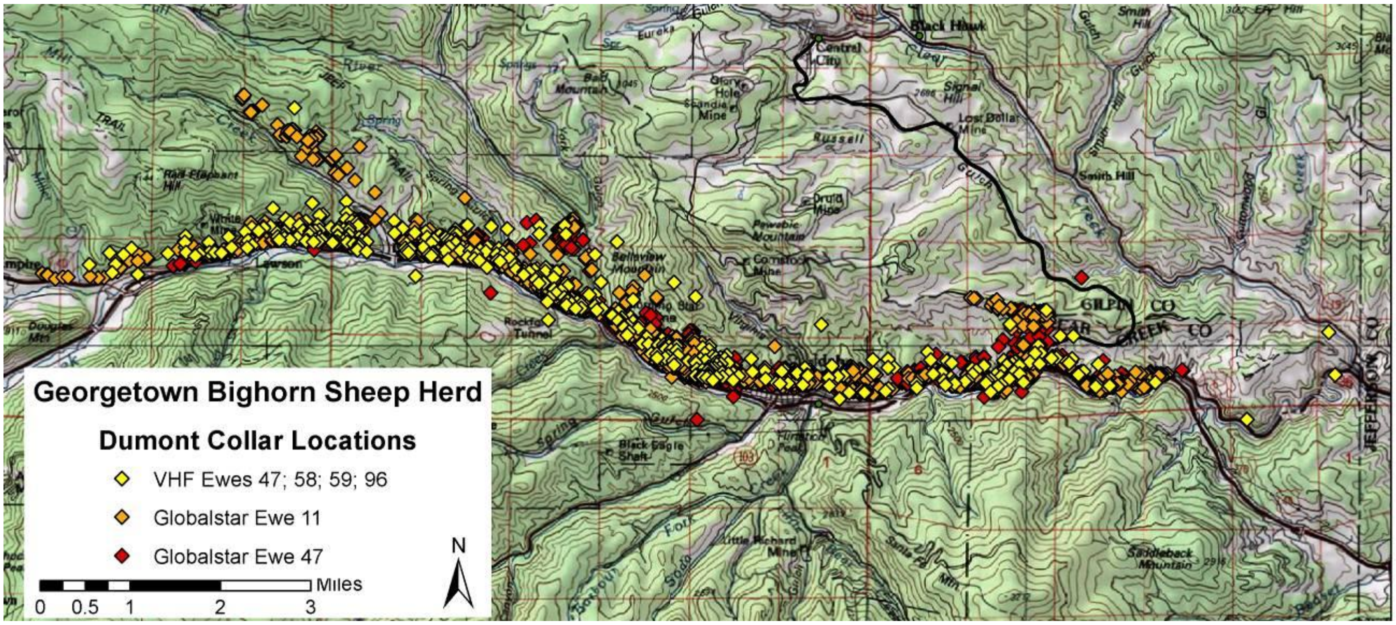

Figure 26. Collar locations of ewes from the Dumont subherd of the Georgetown bighorn sheep herd.

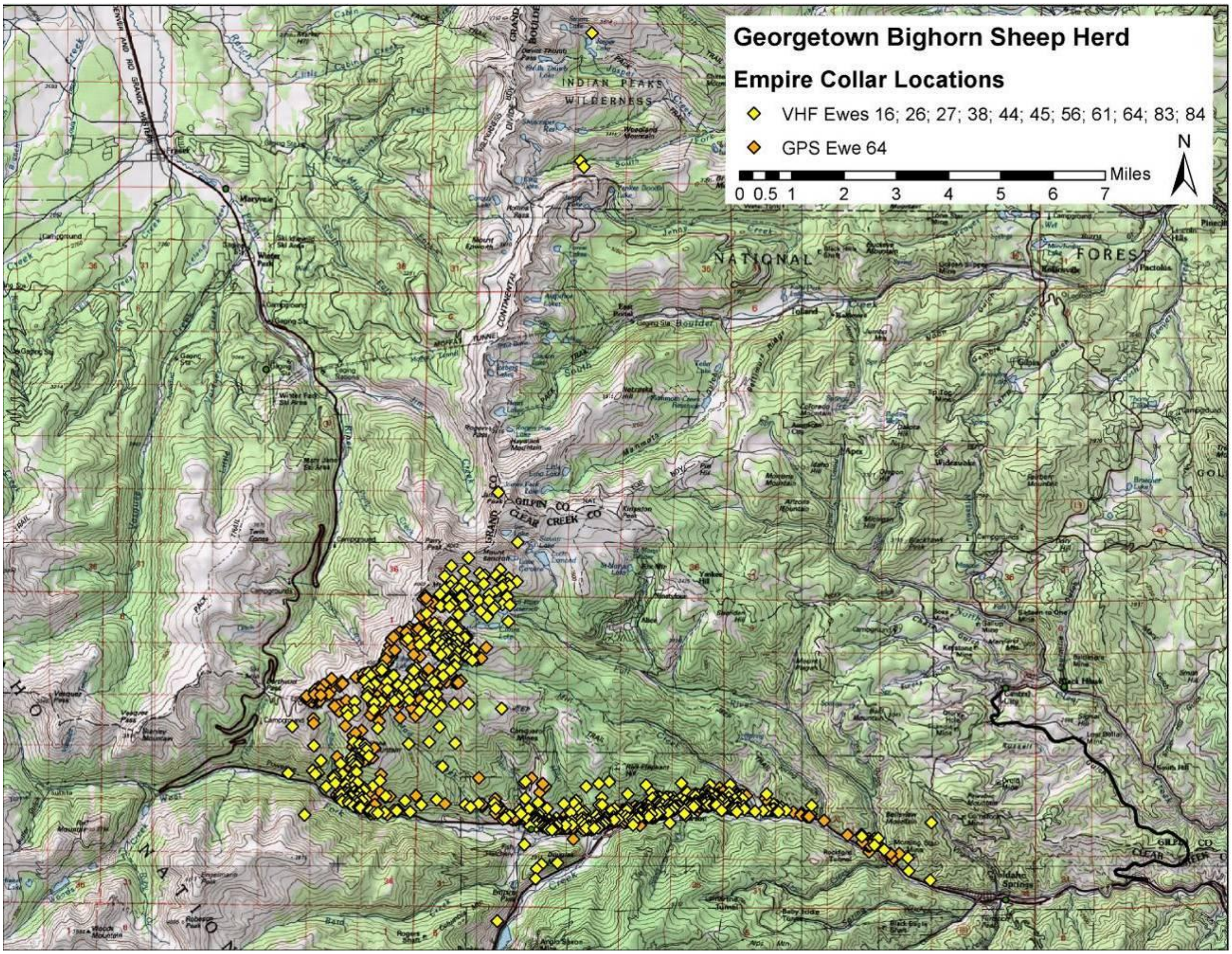

Figure 27. Collar locations of ewes from the Empire subherd of the Georgetown bighorn sheep herd.

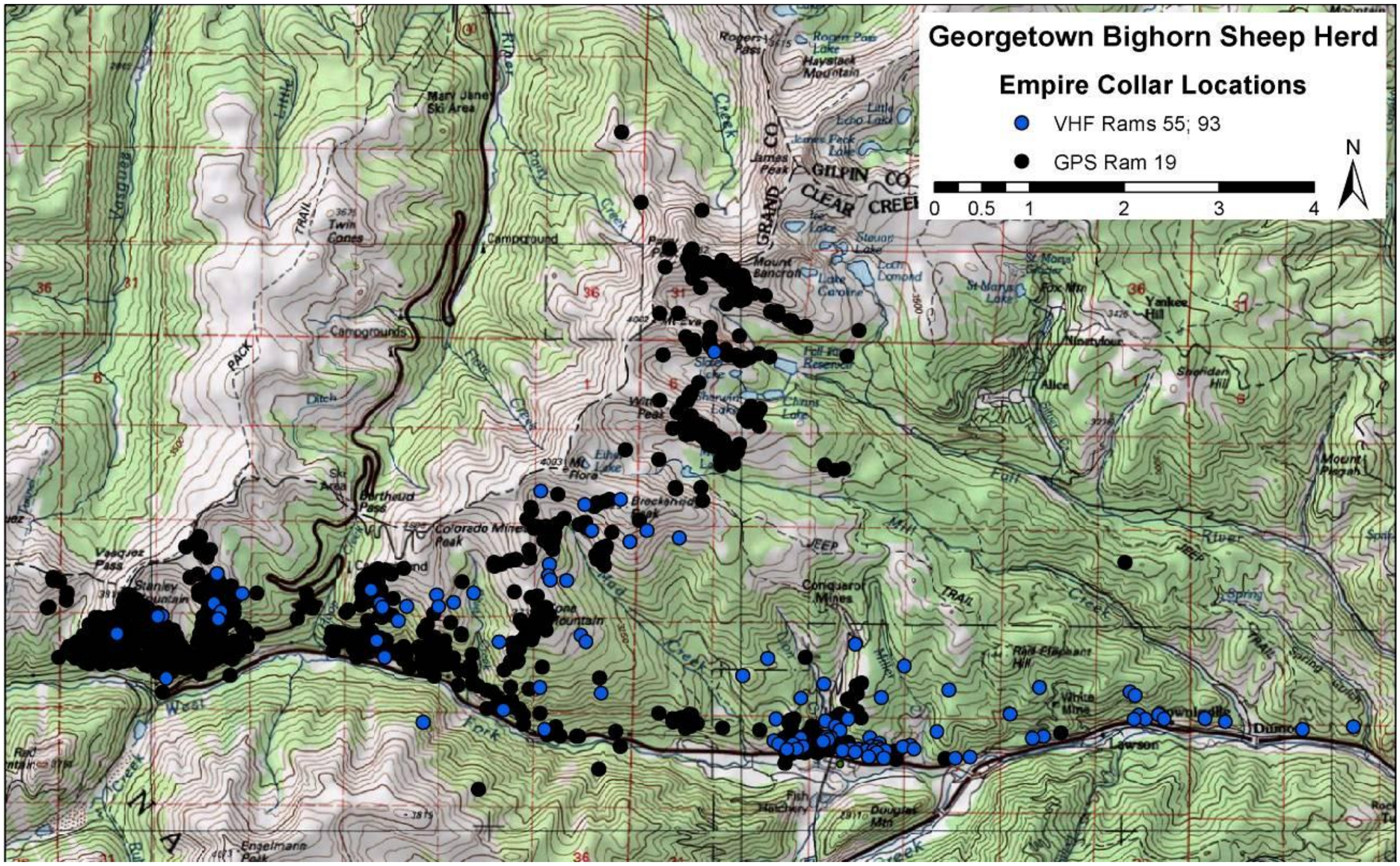

Figure 28. Collar locations of rams from the Empire subherd of the Georgetown bighorn sheep herd.

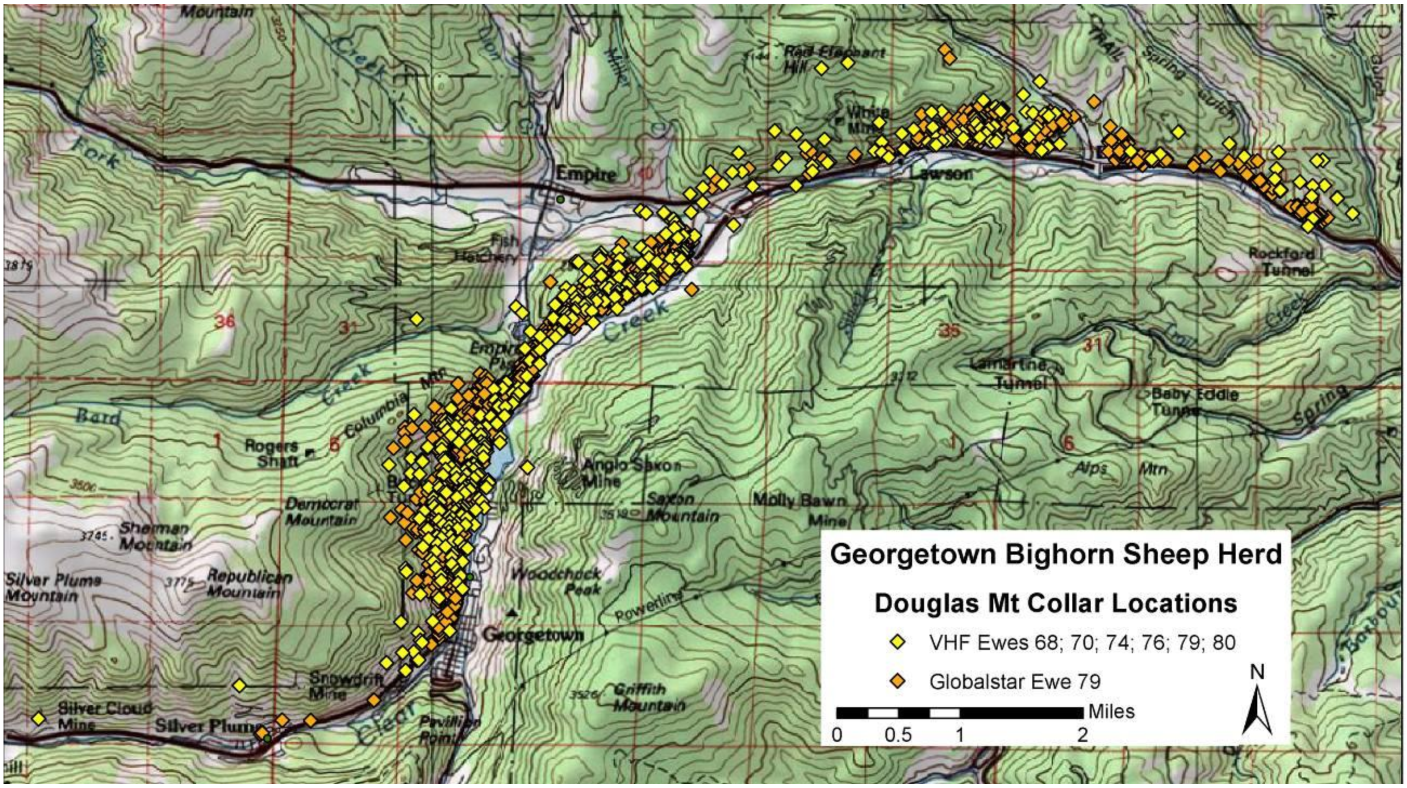

Figure 29. Collar locations of ewes from the Douglas Mountain subherd of the Georgetown bighorn sheep herd.

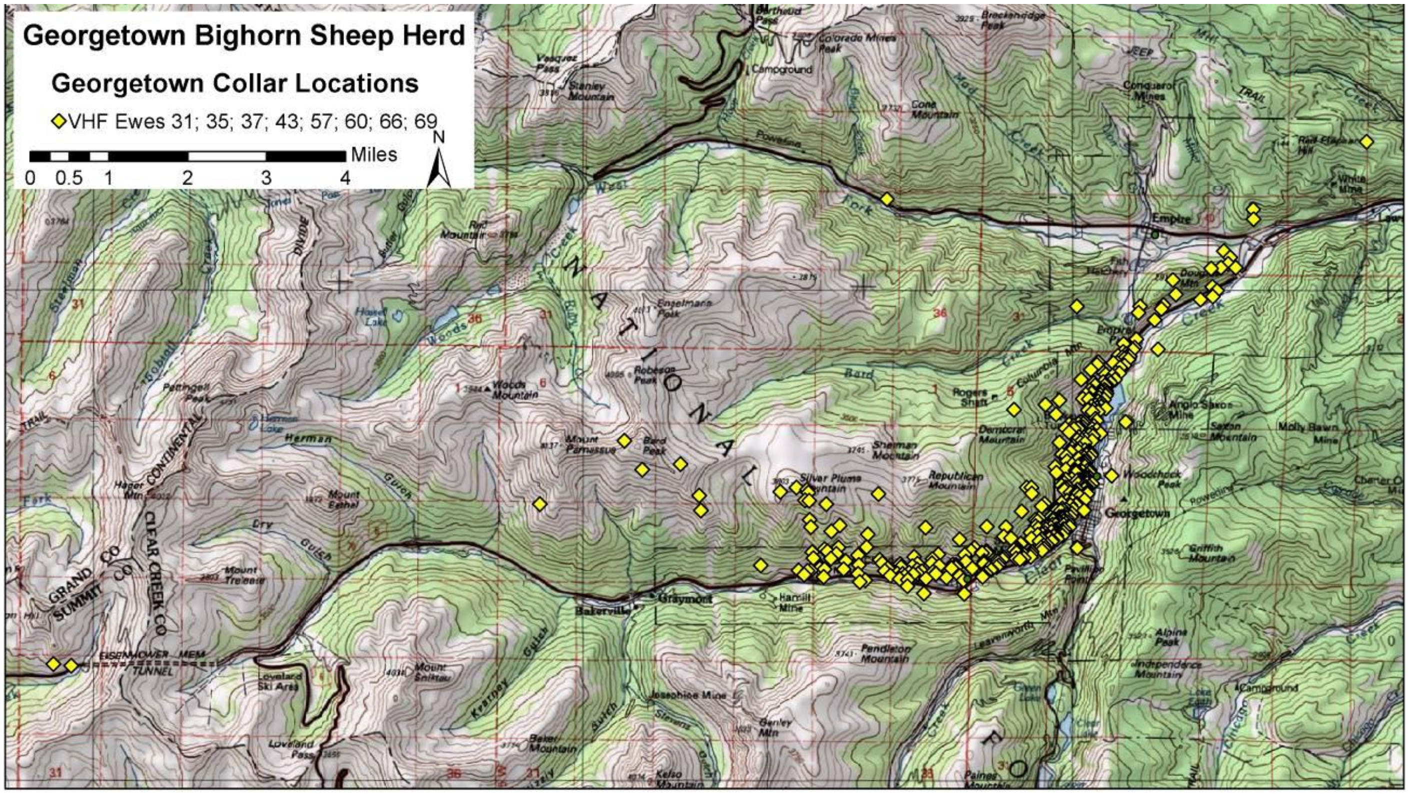

Figure 30. Collar locations of ewes from the Georgetown subherd of the Georgetown bighorn sheep herd.

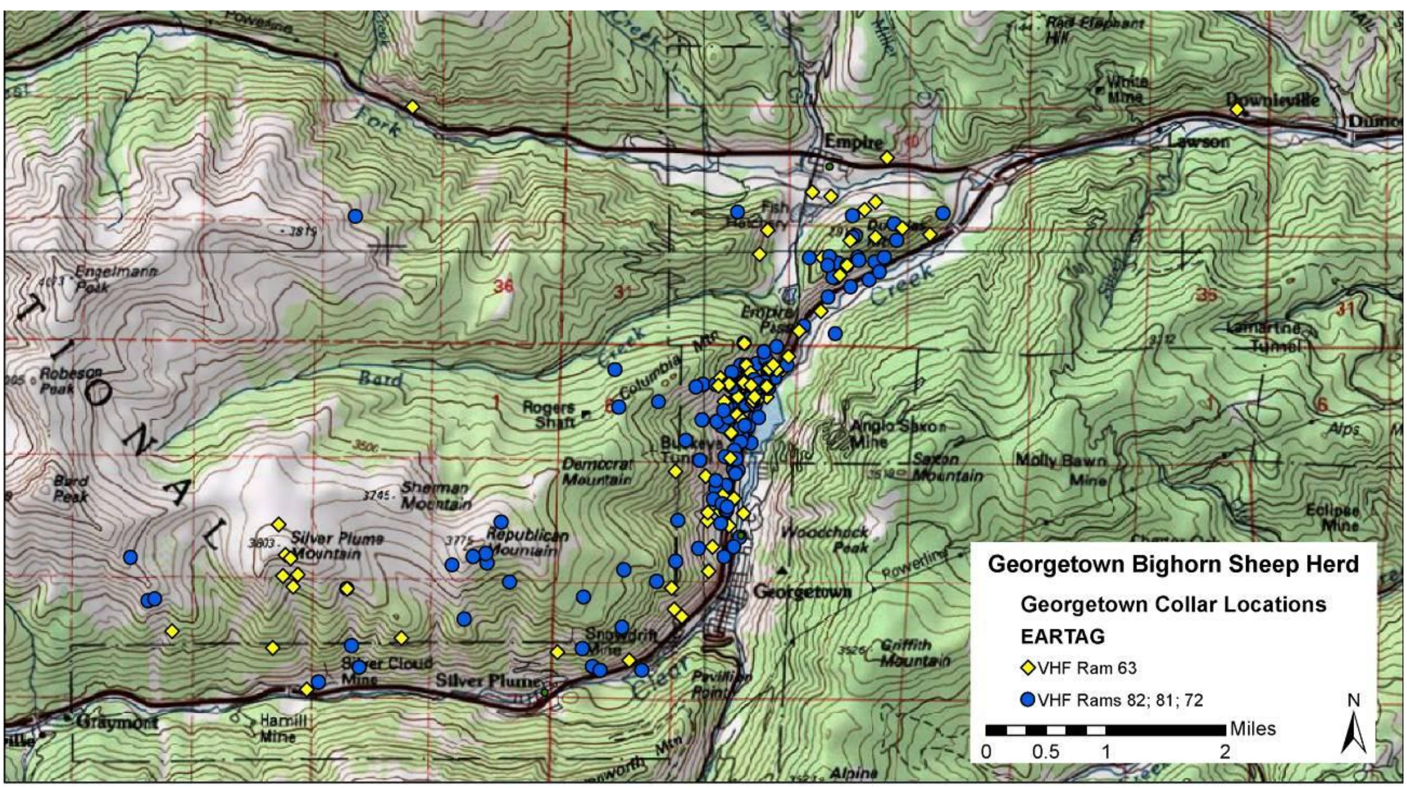

Figure 31. Collar locations of rams from the Georgetown subherd of the Georgetown bighorn sheep herd.

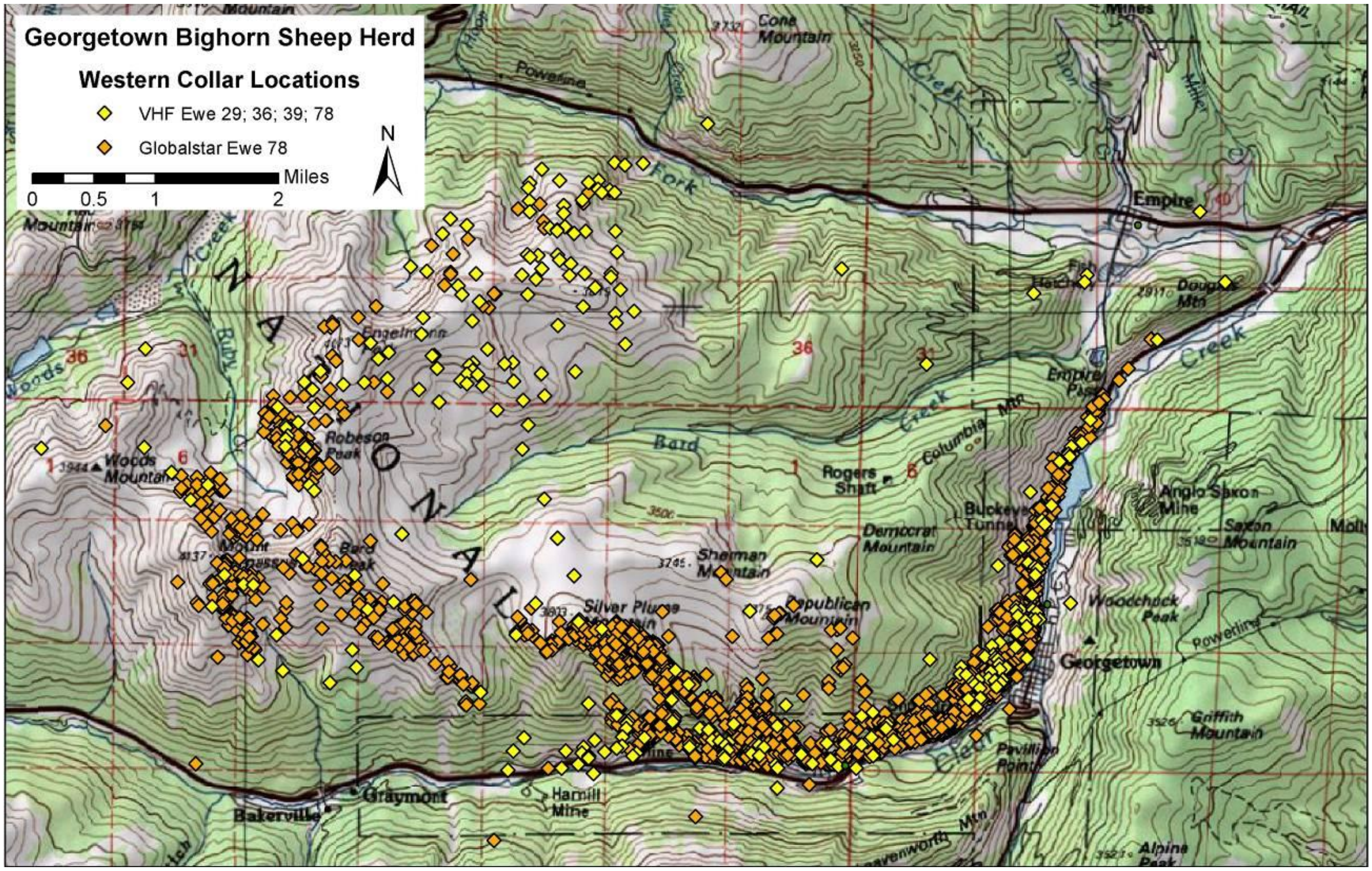

Figure 32. Collar locations of ewes from the Western subherd of the Georgetown bighorn sheep herd.

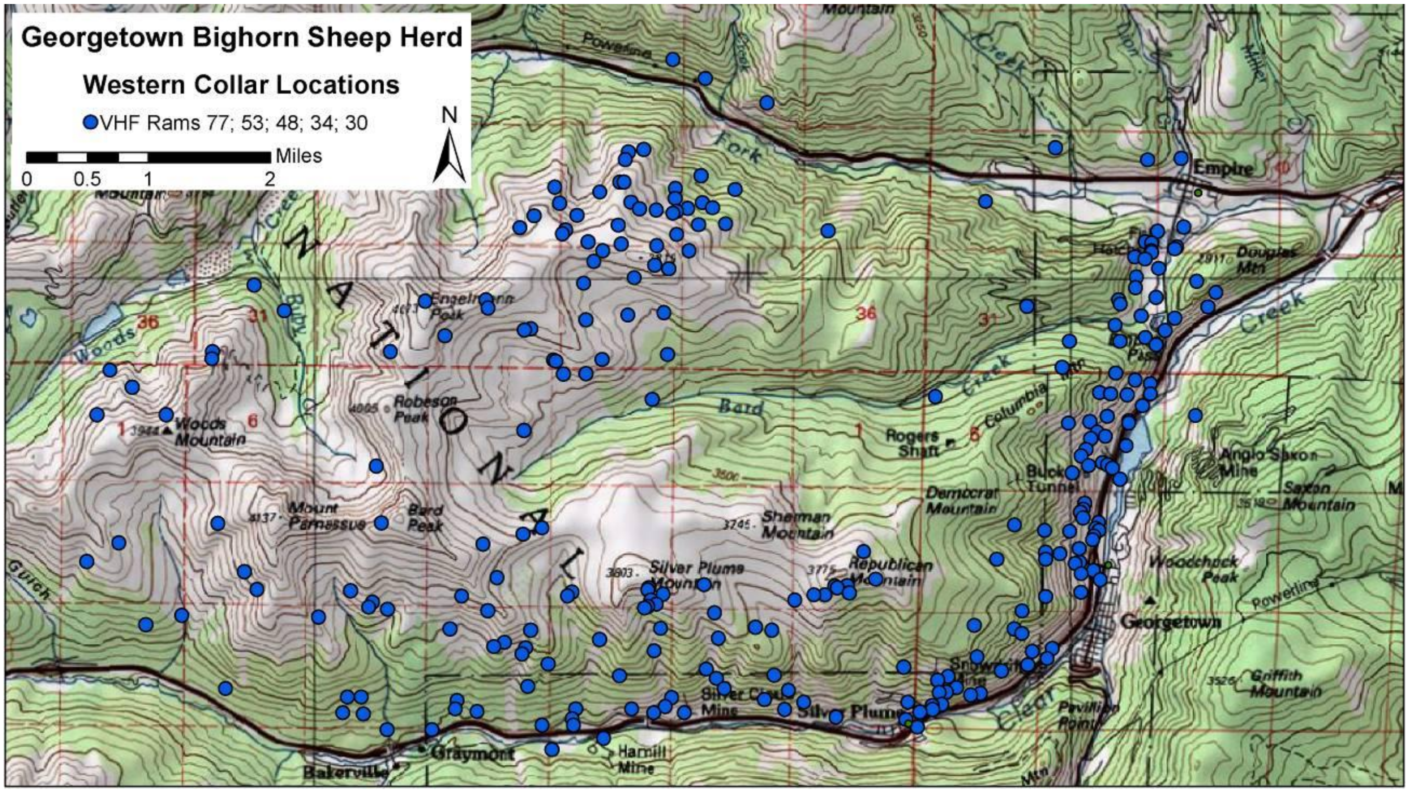

Figure 33. Collar locations of rams from the Western subherd of the Georgetown bighorn sheep herd.

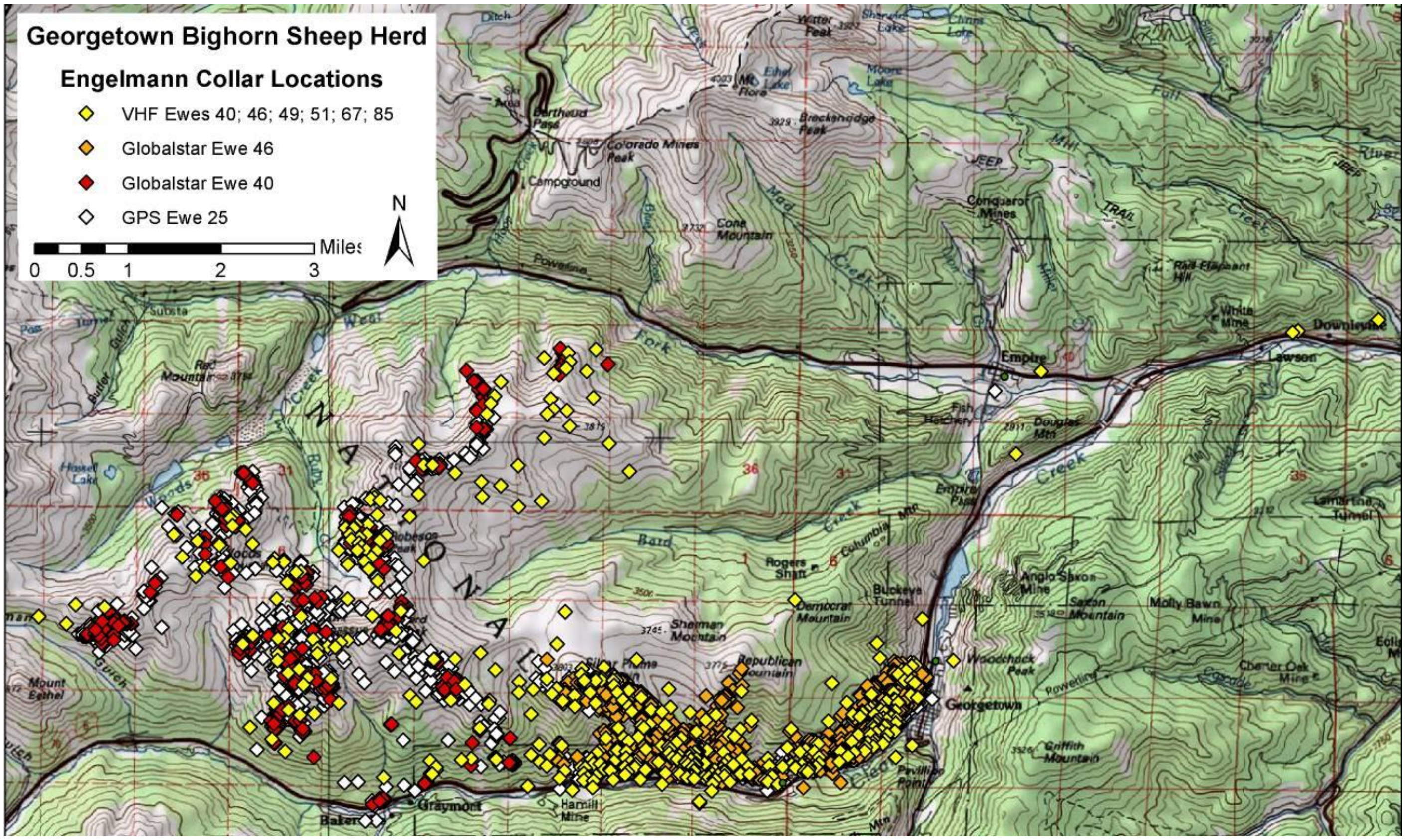

Figure 34. Collar locations of ewes from the Engelmann subherd of the Georgetown bighorn sheep herd.

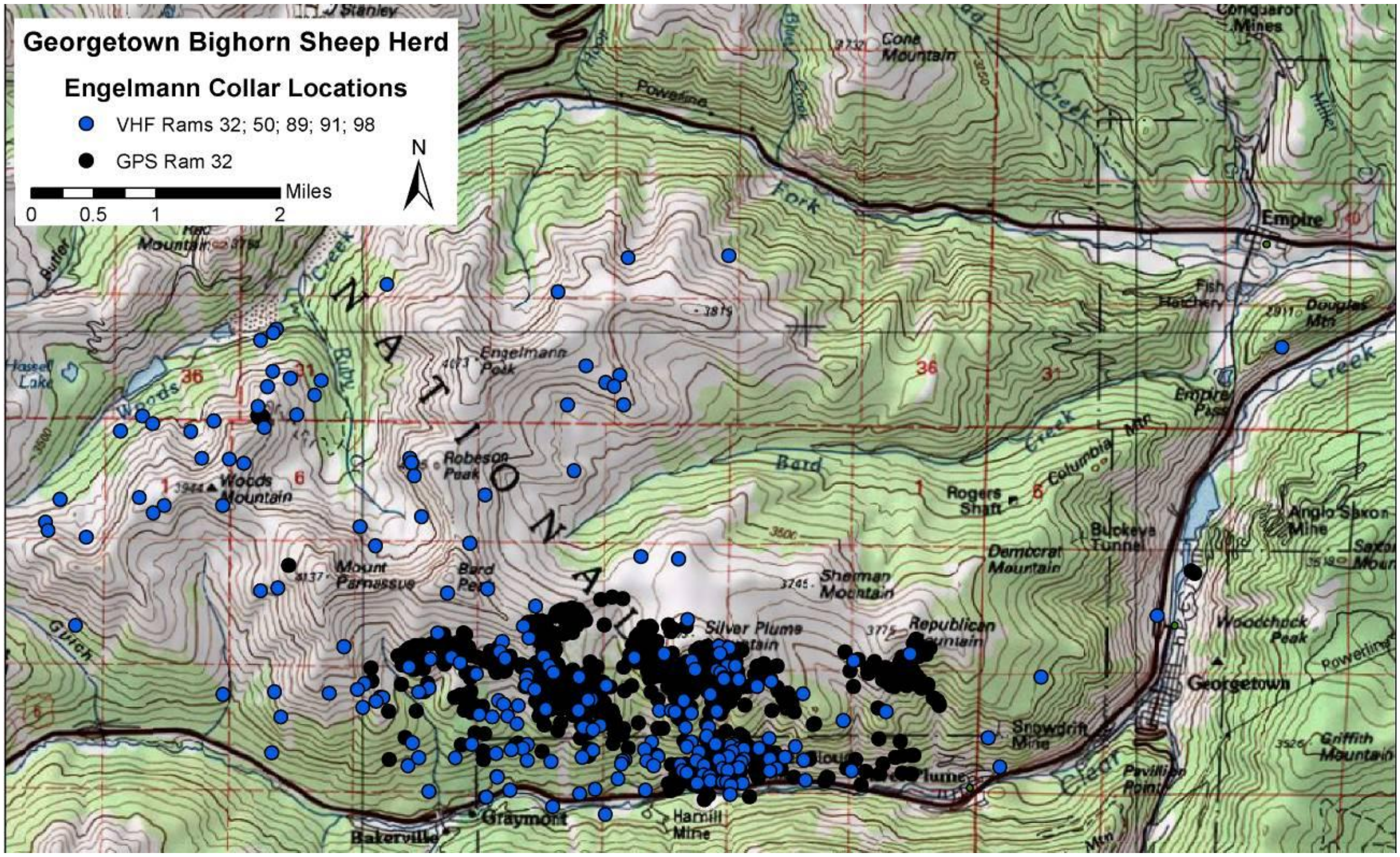

Figure 35. Collar locations of rams from the Engelmann subherd of the Georgetown bighorn sheep herd.

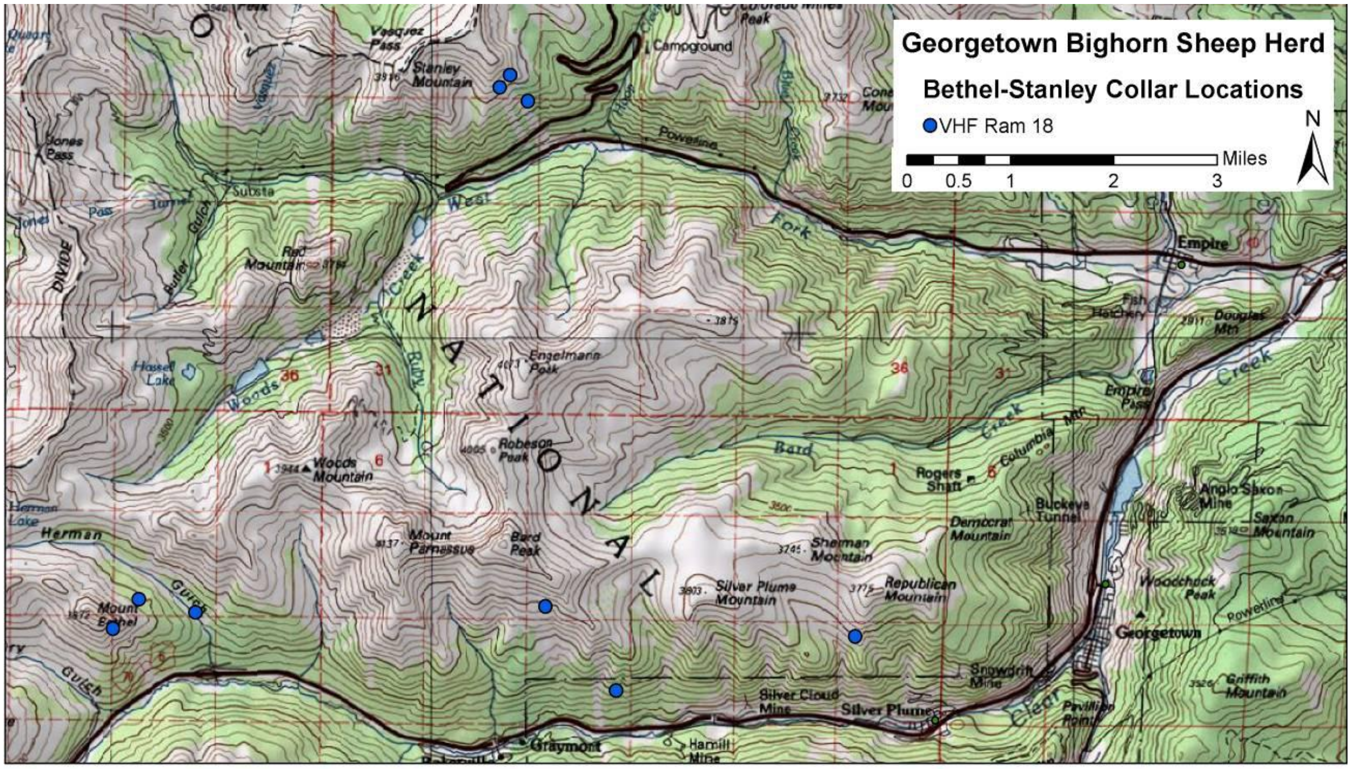

Figure 36. Collar locations of a ram that was captured on Mount Bethel and harvested on Stanley Mountain.

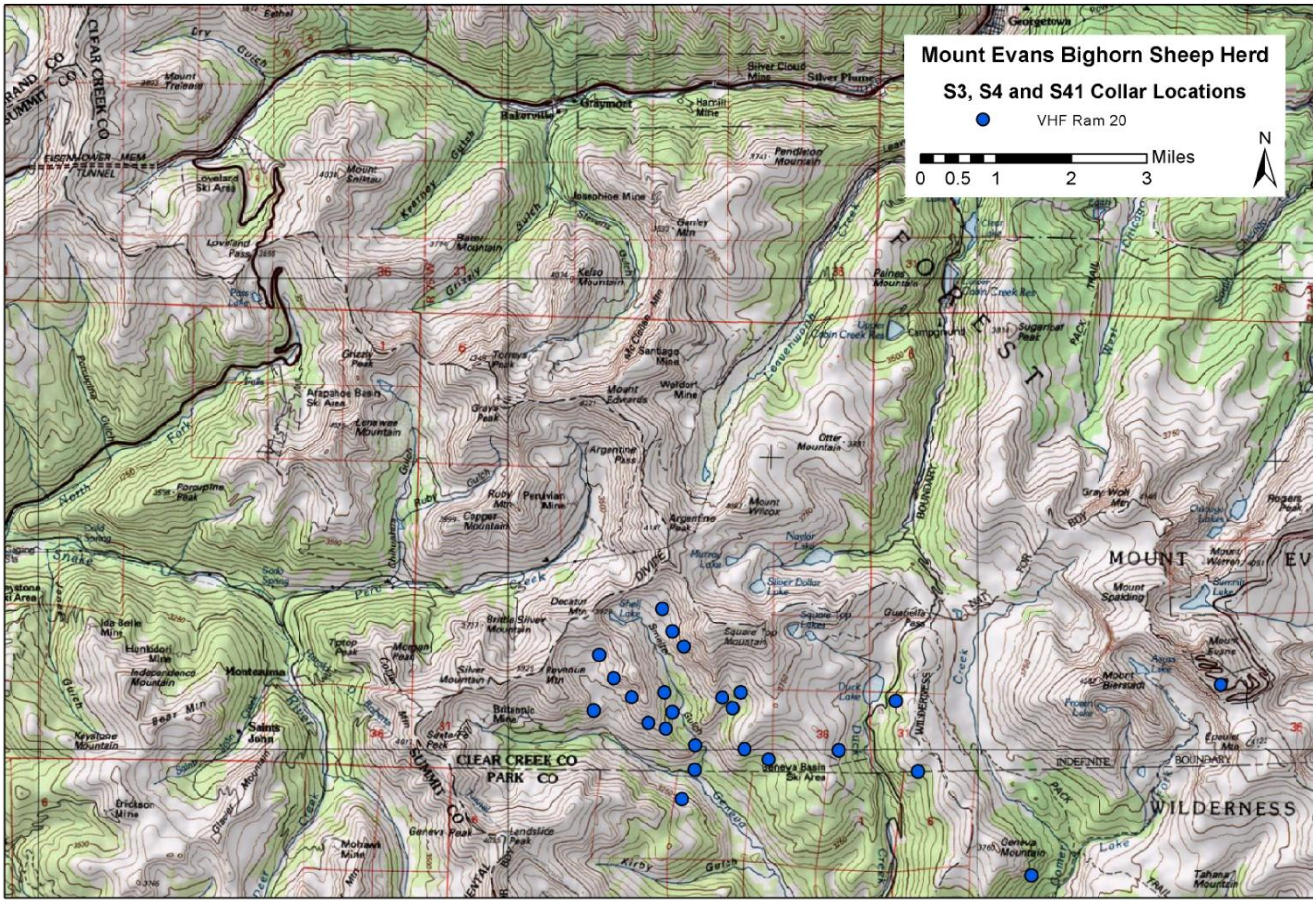

Figure 37. Collar locations of a ram from the Mount Evans data analysis unit.

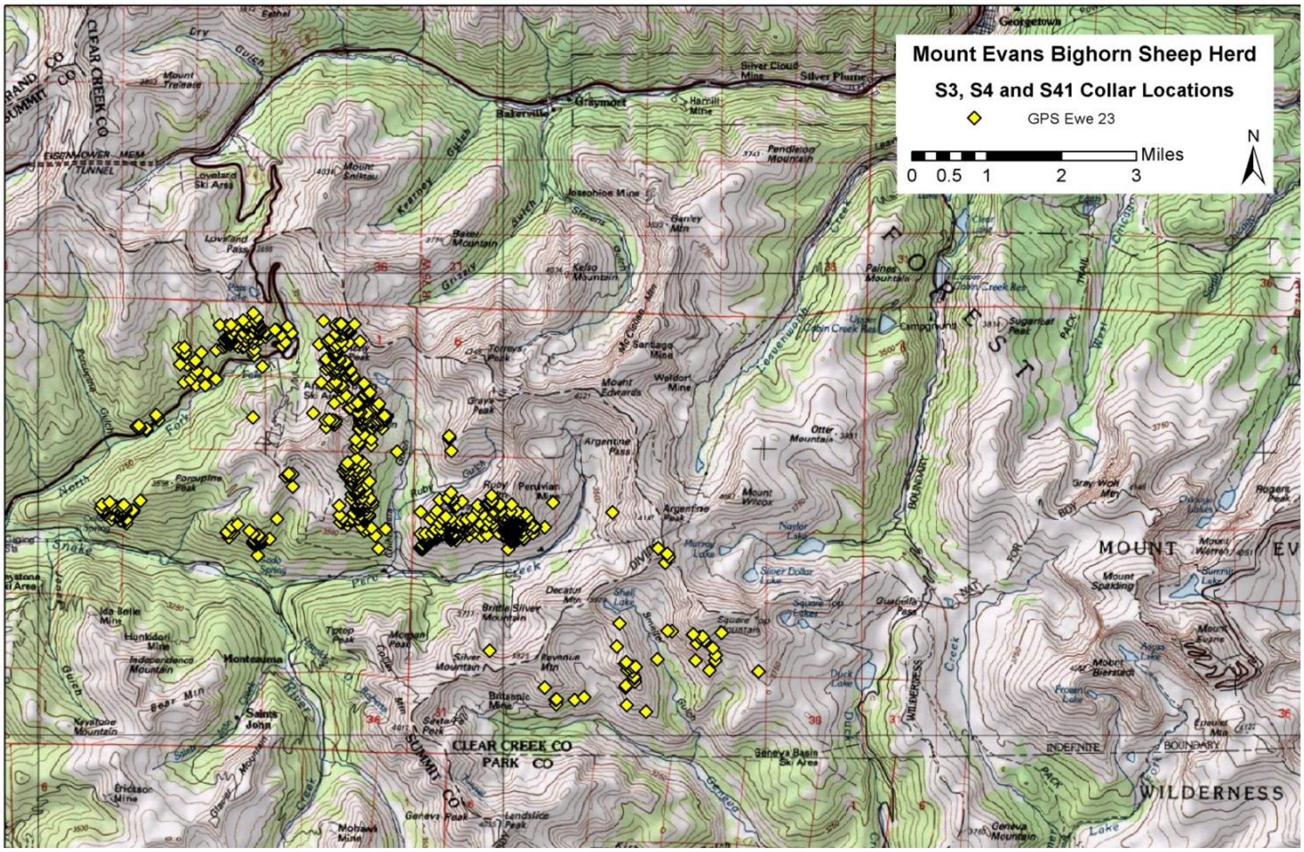

Figure 38. Collar locations of a ewe from the Mount Evans data analysis unit.

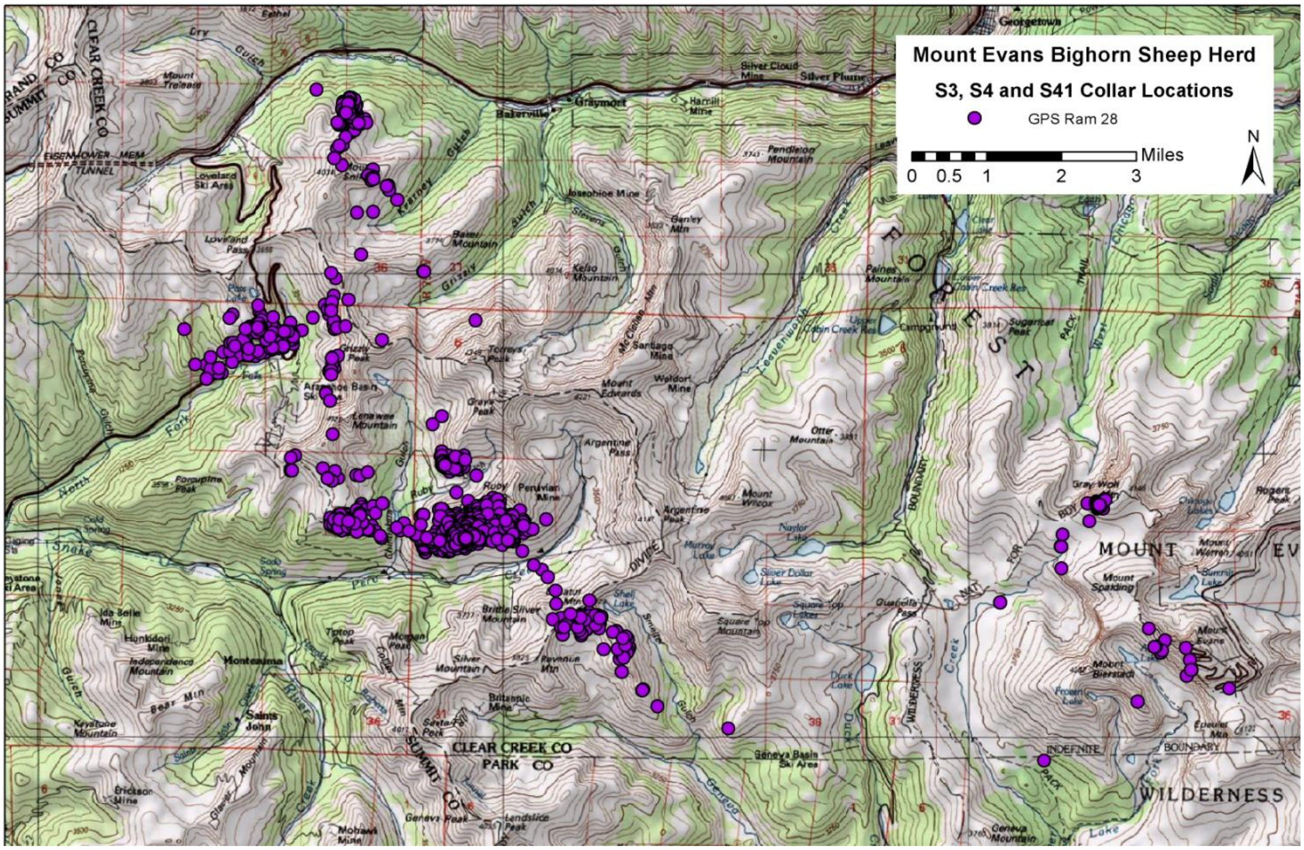

Figure 39. Collar locations of a ram from the Mount Evans data analysis unit.

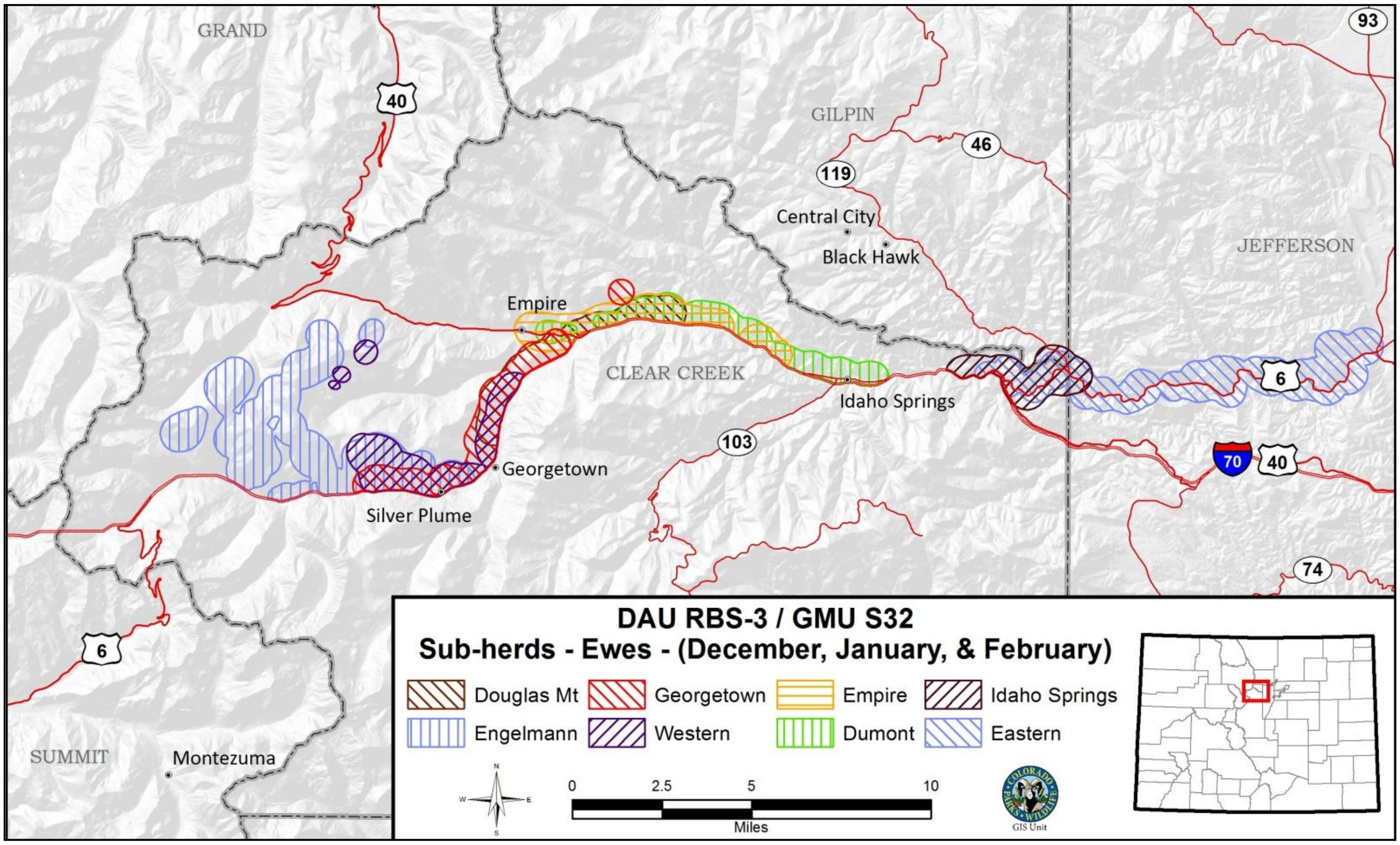

Figure 40. Ranges of the Georgetown bighorn sheep ewe subherds during December, January and February.

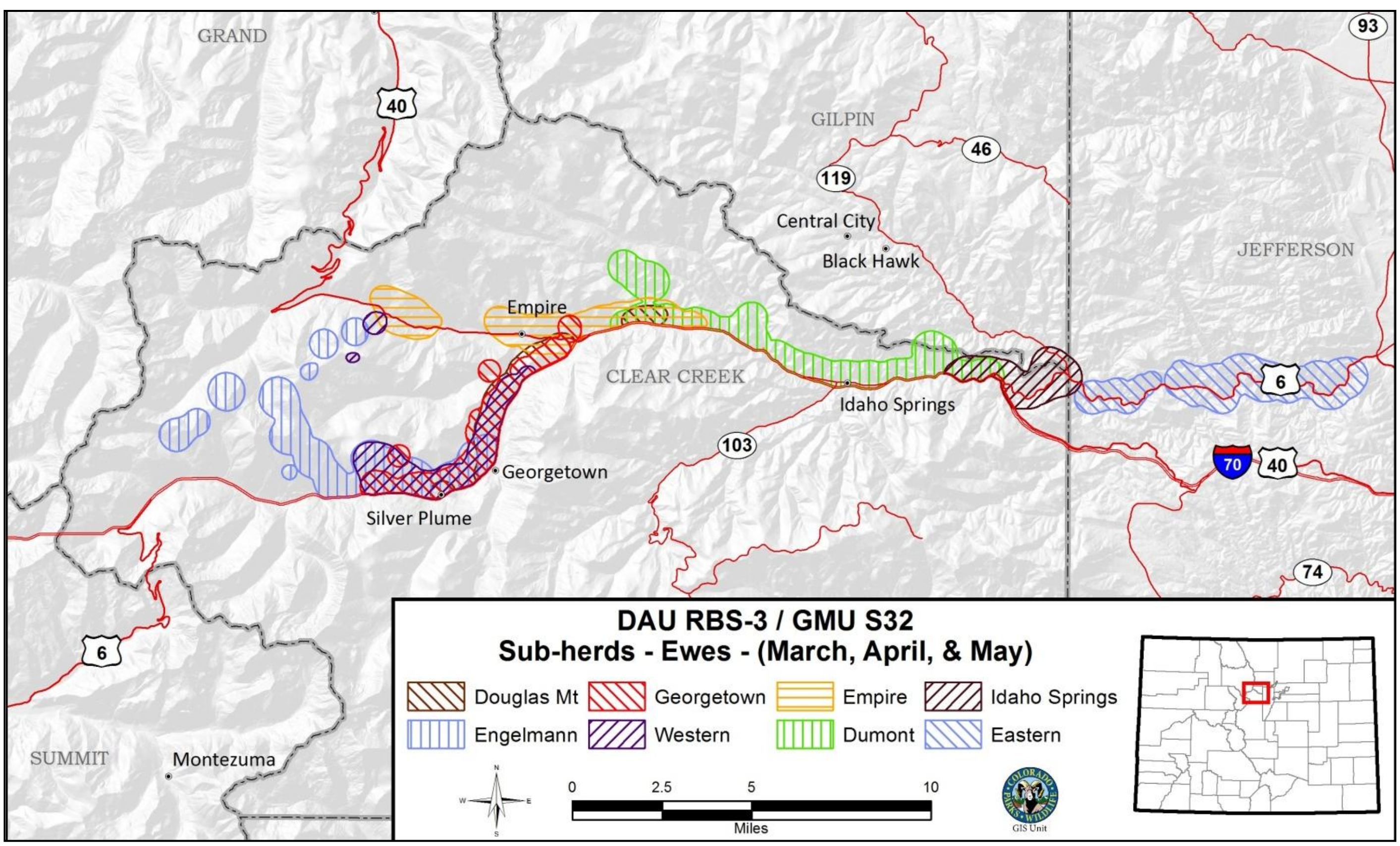

Figure 41. Ranges of the Georgetown bighorn sheep ewe subherds during March, April and May.

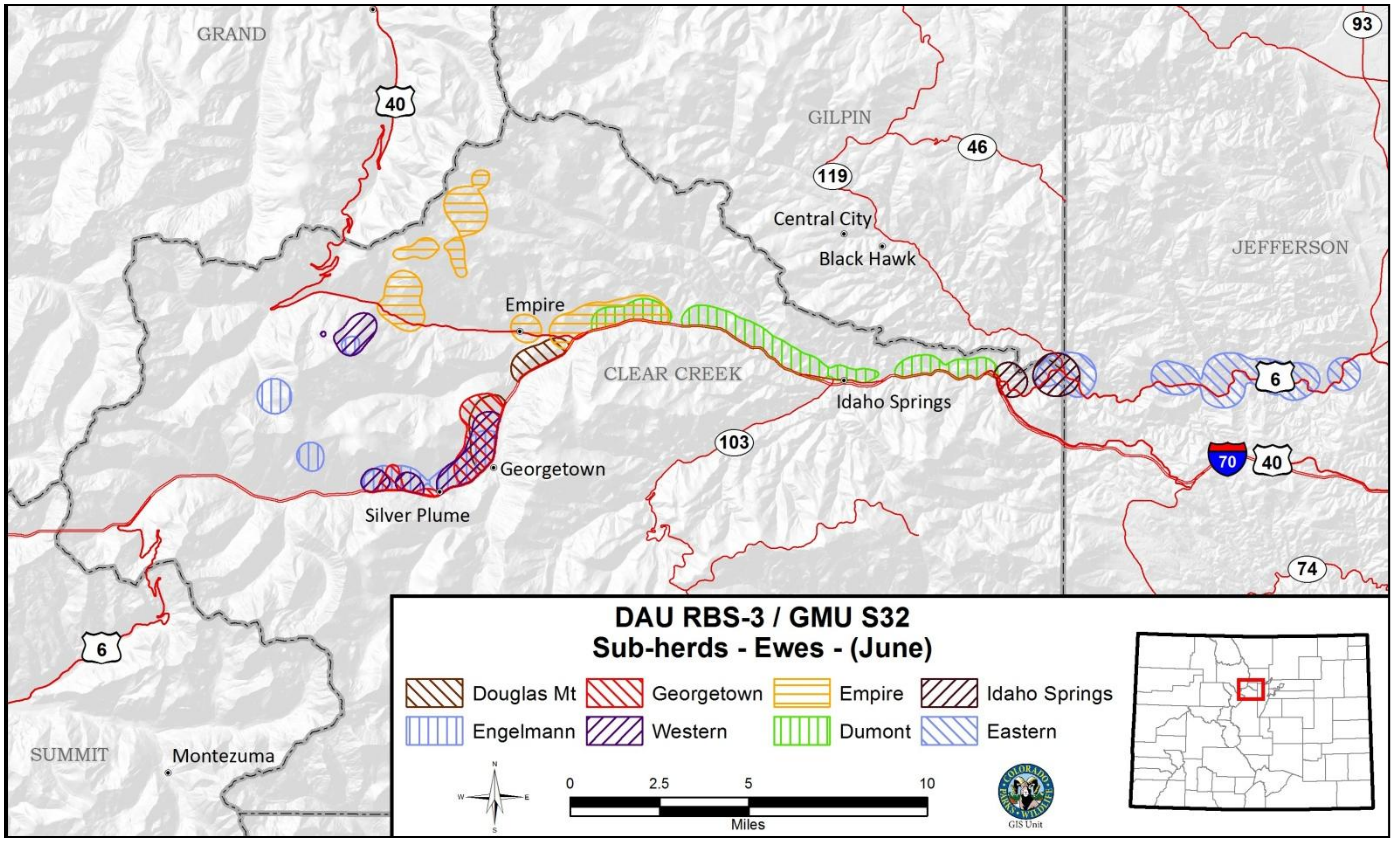

Figure 42. Ranges of the Georgetown bighorn sheep ewe subherds during June.

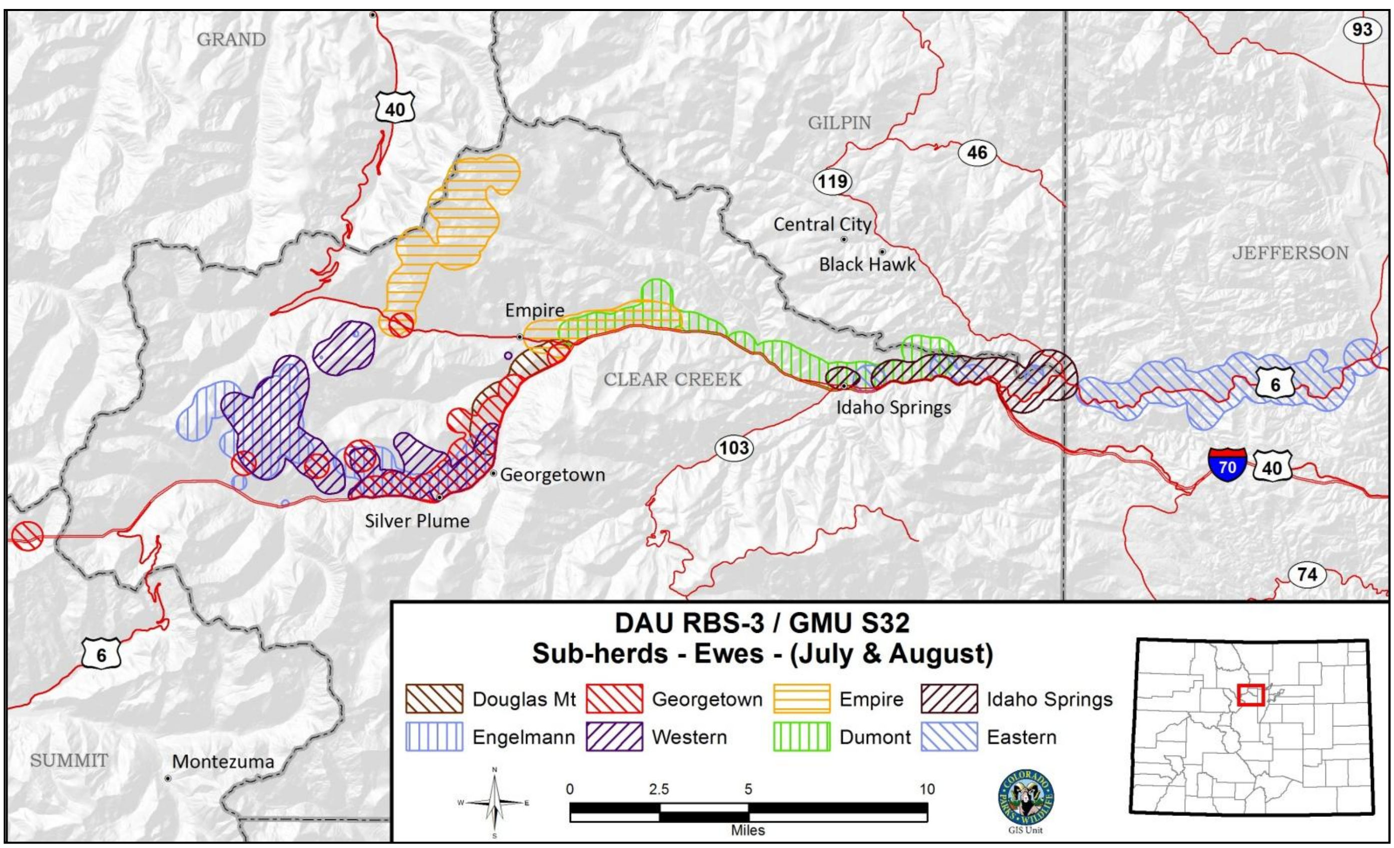

Figure 43. Ranges of the Georgetown bighorn sheep ewe subherds during July and August.

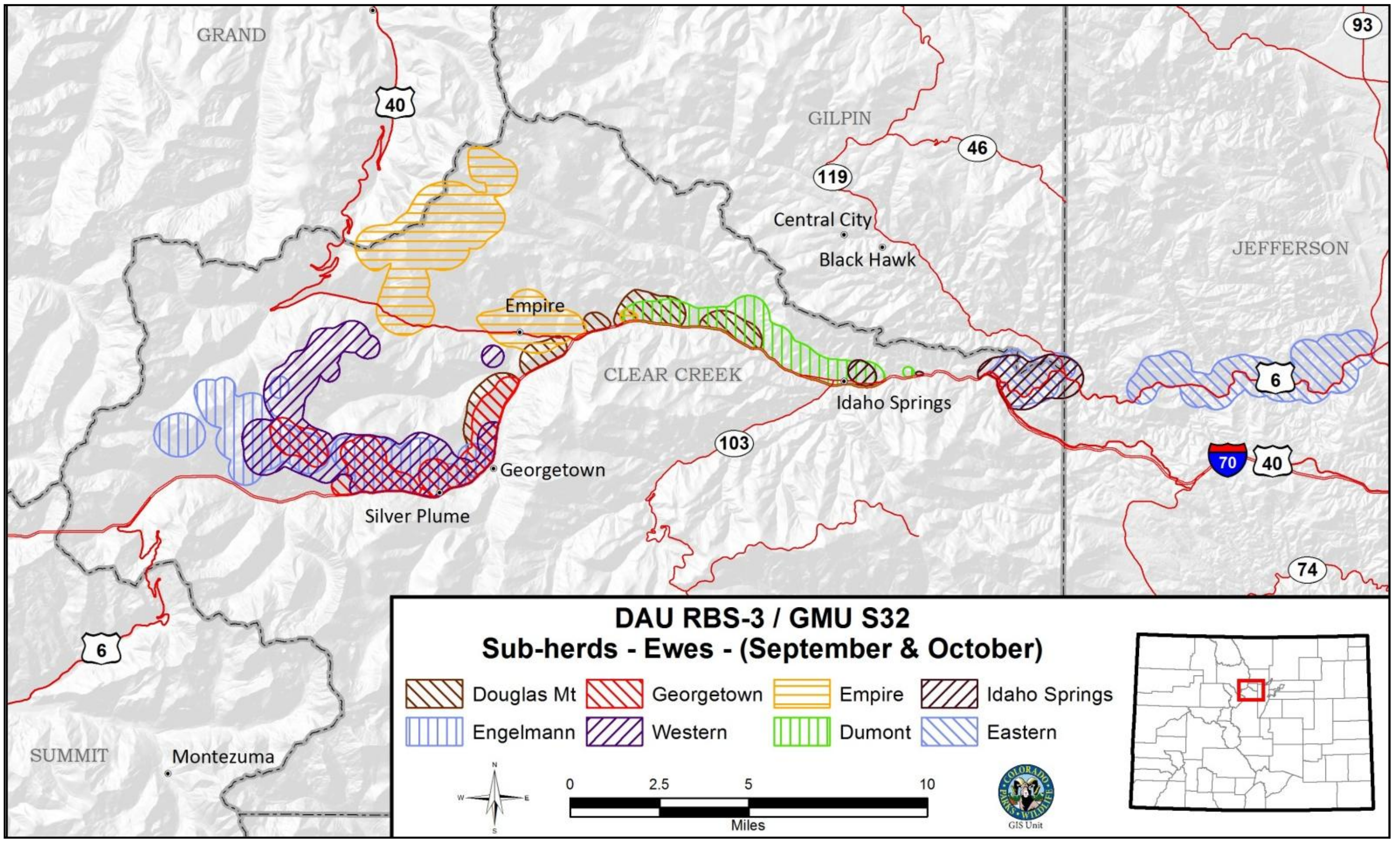

Figure 44. Ranges of the Georgetown bighorn sheep ewe subherds during September and October.

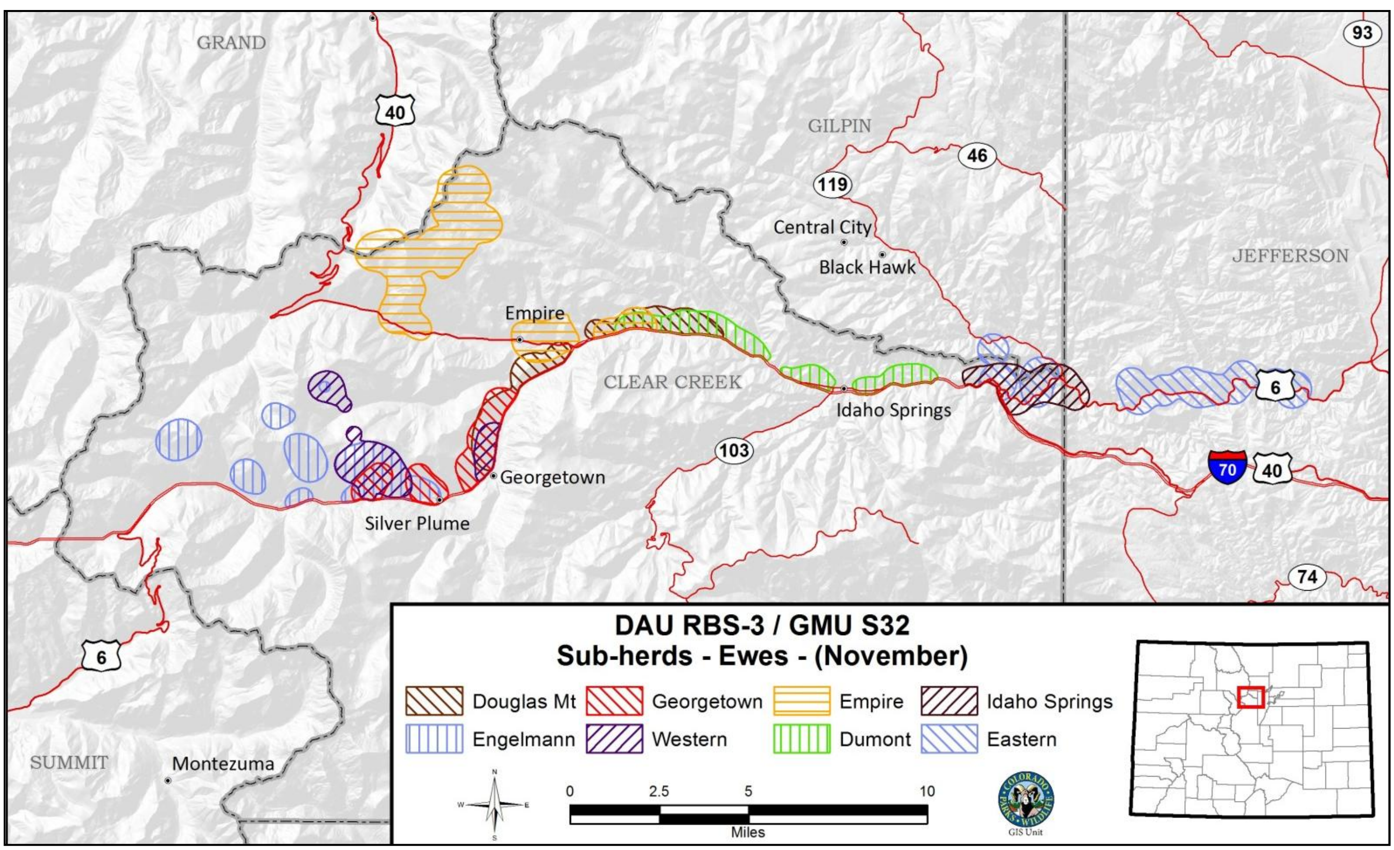

Figure 45. Ranges of the Georgetown bighorn sheep ewe subherds during November.

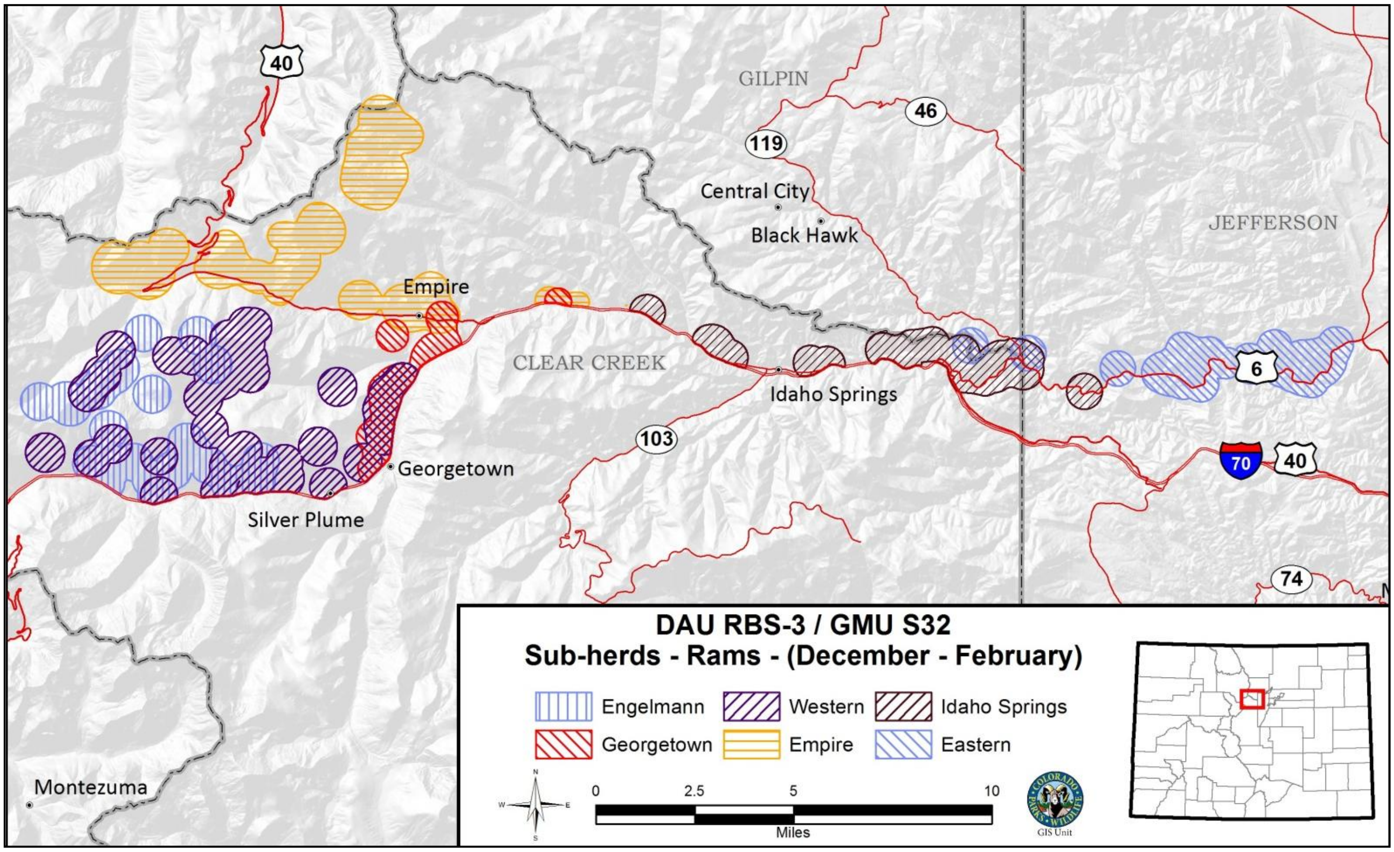

Figure 46. Ranges of the Georgetown bighorn sheep ram subherds during December, January and February.

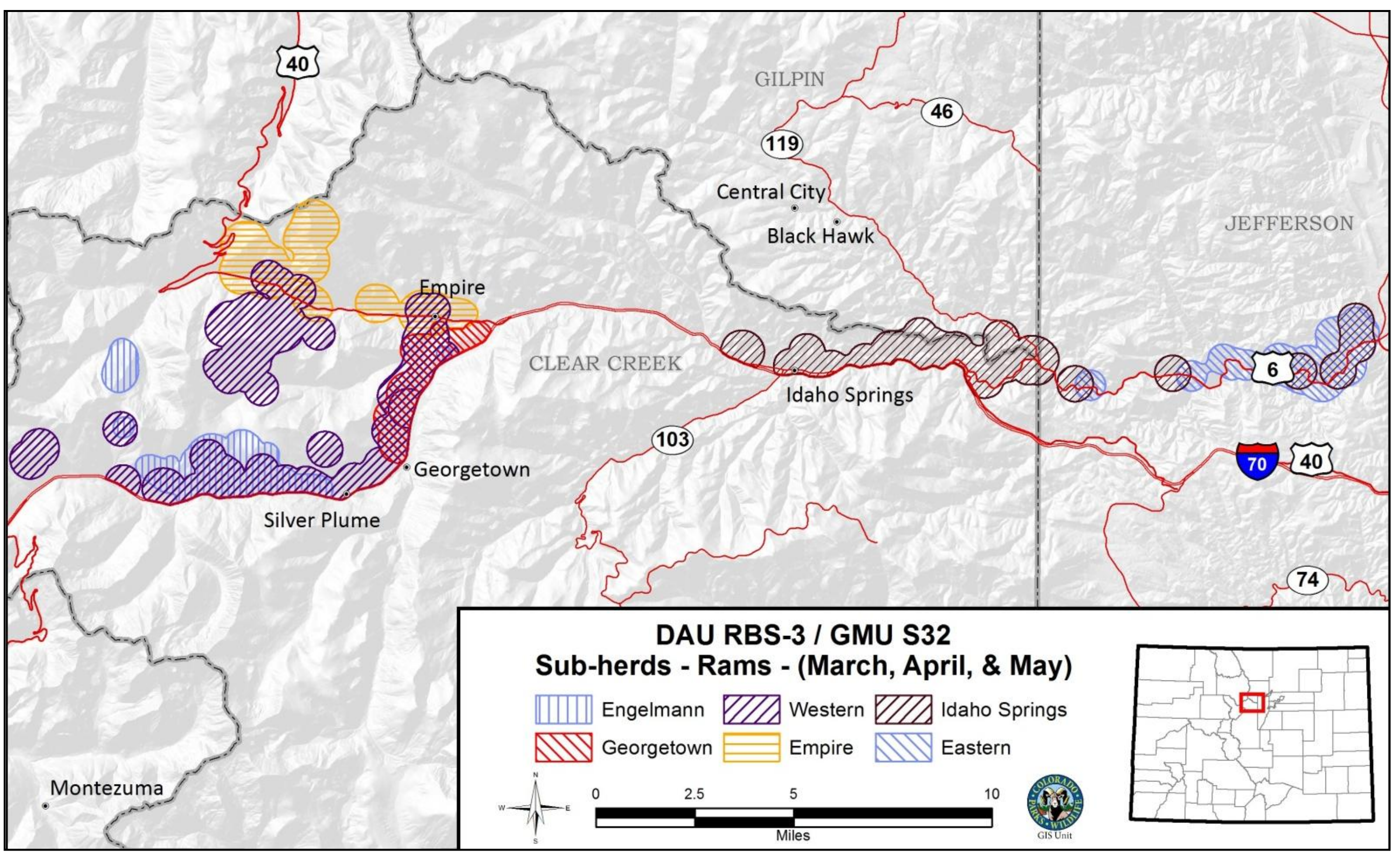

Figure 47. Ranges of the Georgetown bighorn sheep ram subherds during March, April and May.

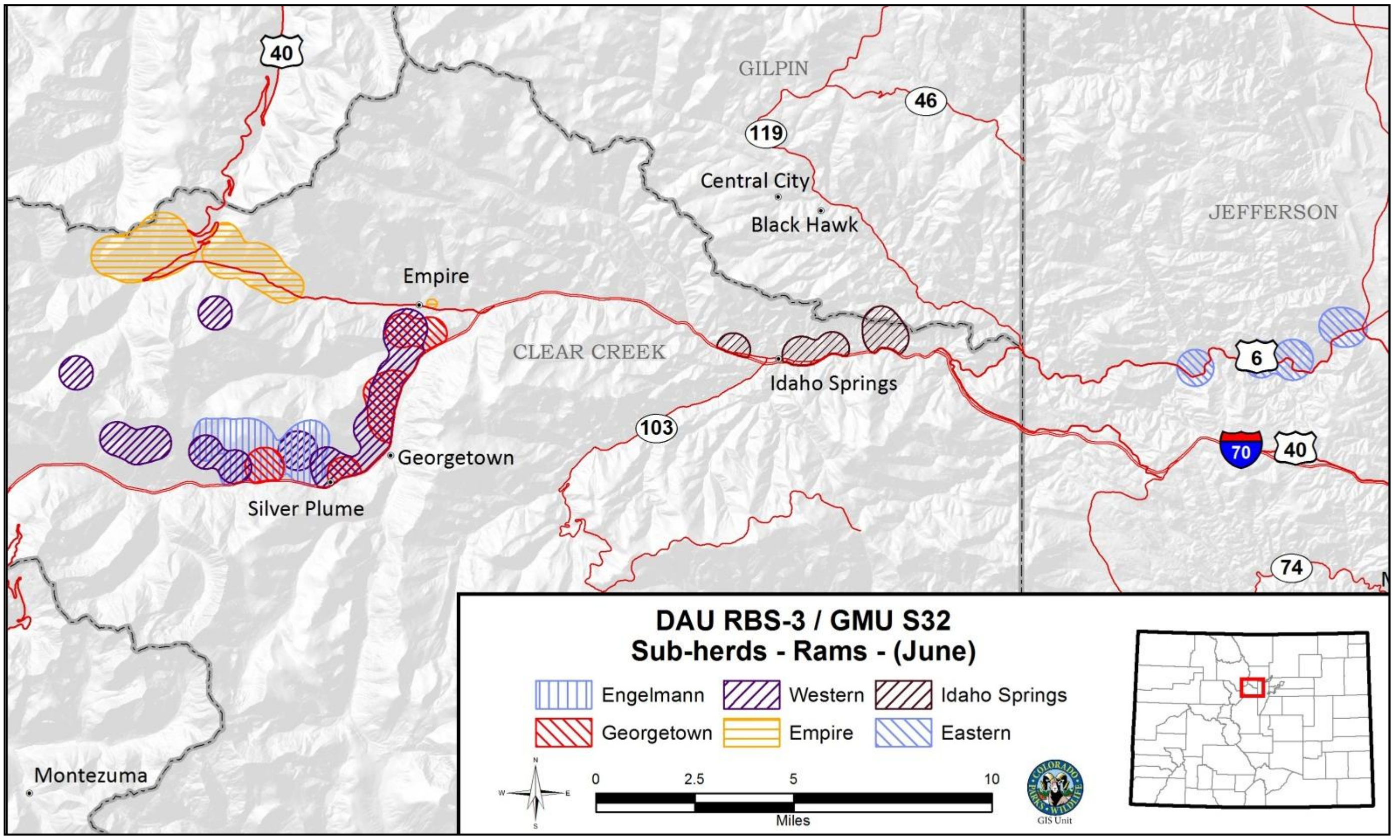

Figure 48. Ranges of the Georgetown bighorn sheep ram subherds during June.

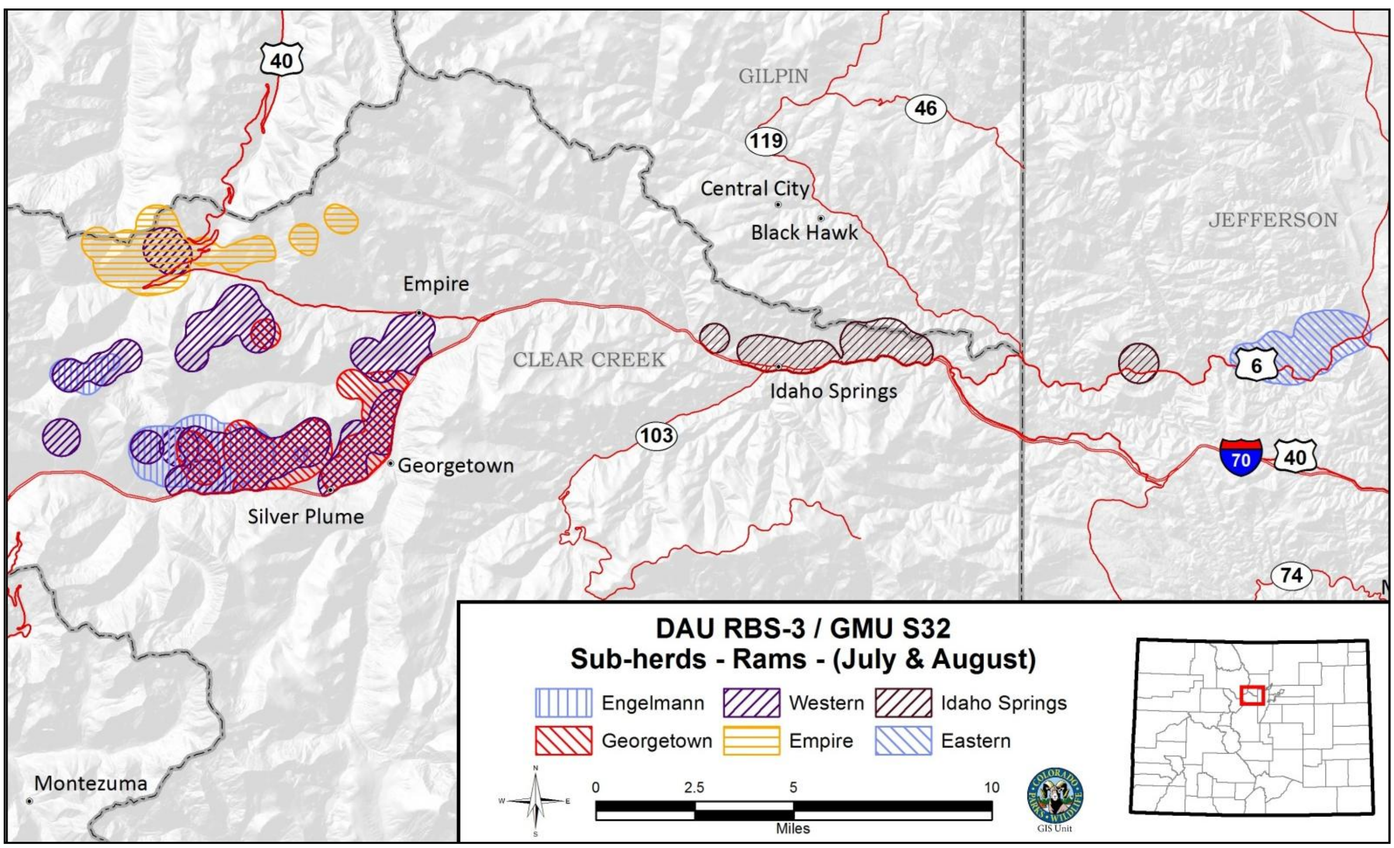

Figure 49. Ranges of the Georgetown bighorn sheep ram subherds during July and August

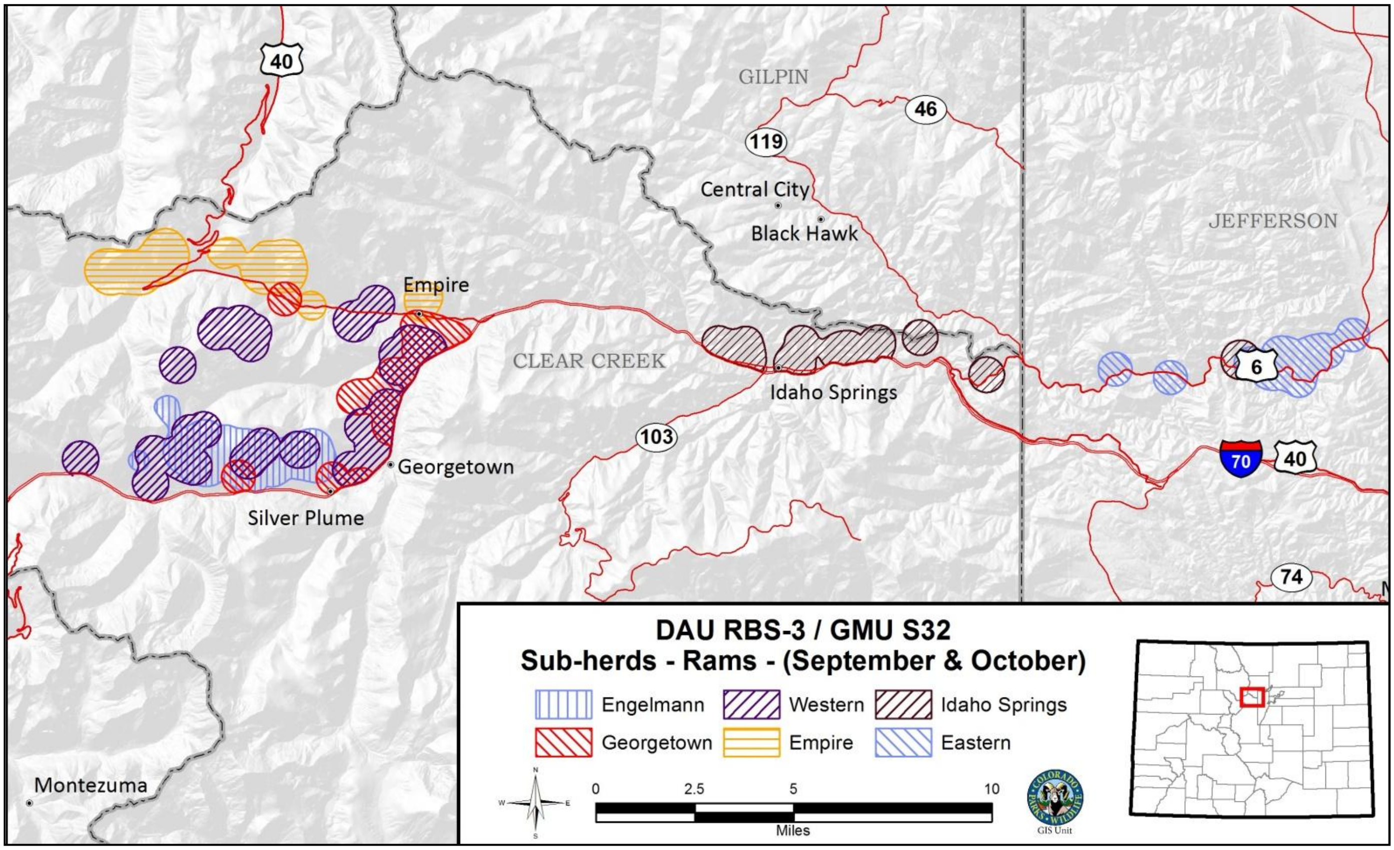

Figure 50. Ranges of the Georgetown bighorn sheep ram subherds during September and October.

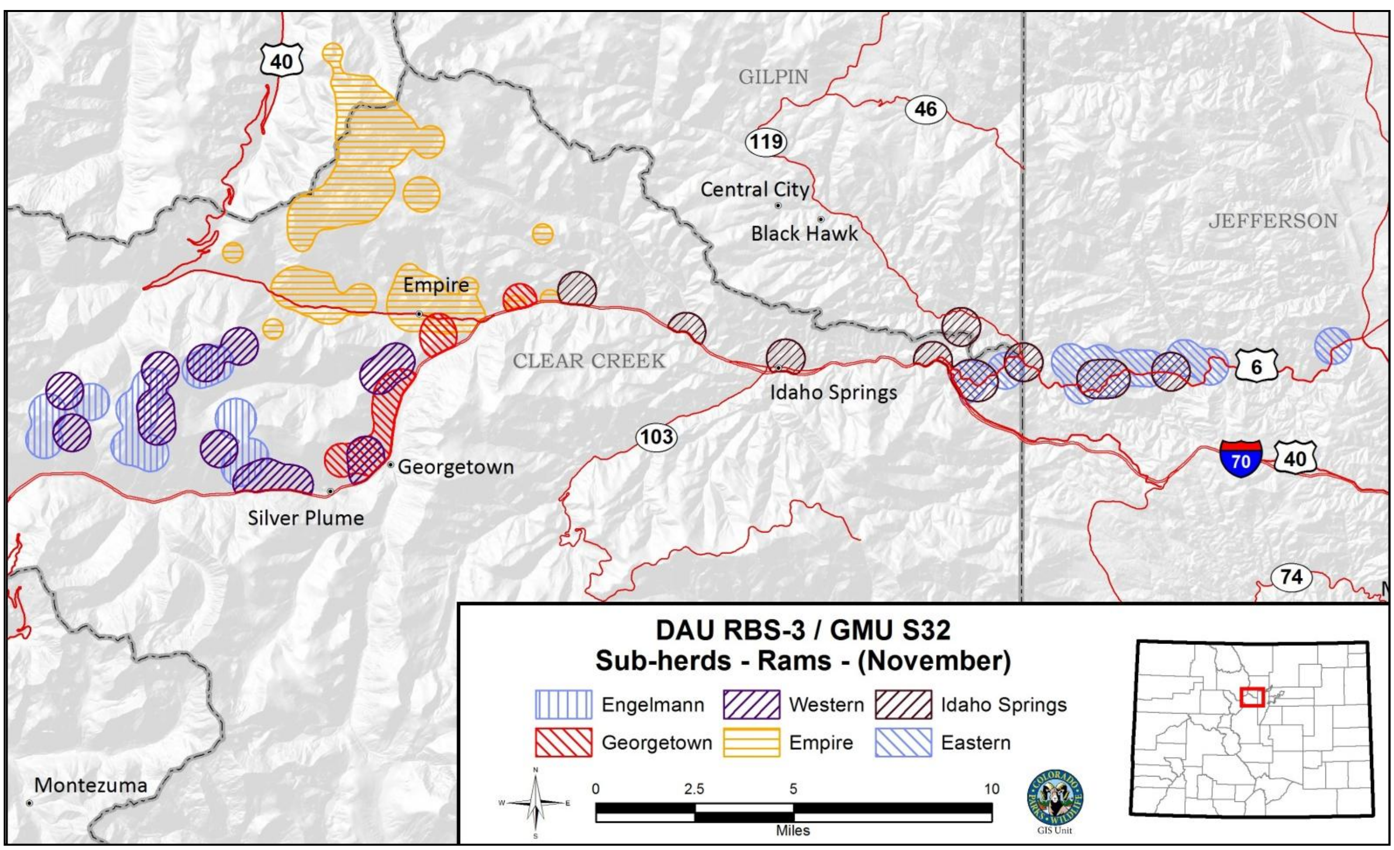

Figure 51. Ranges of the Georgetown bighorn sheep ram subherds during November.

Interactions with Domestic Sheep and Goats

There are no domestic grazing allotments within the range or proximity of this herd. There are, however, many domestic animals (e.g., sheep, goats, llamas, cattle) kept on private property within the range of the herd (i.e., hobby animals, companions for horses, 4-H animals, etc.) that could serve as sources for bighorn pathogens. Bighorn from the Georgetown herd are commonly found in towns and among residences, so interactions with these domestic animals are probable. In addition, there were at least 2 documented cases of feral goats in high bighorn density areas during this study. One of these goats was travelling with bighorn, the other was never observed interacting with bighorn; both were removed.

RECRUITMENT

One important parameter in assessing the overall health of a herd is the rate at which lambs are recruited into the herd. Recruitment in the Georgetown herd is monitored as the lamb to ewe ratio during annual coordinated ground surveys. One of the main impetuses for the initiation of the Georgetown collar study in 2005 was the steady decrease in lamb to ewe ratios observed during the fall coordinated ground surveys starting in 2001 (Fig. 52). A goal of the study was to gather information on the possible causes of this decline. The study was therefore designed to collect data on ewe pregnancy rates, lambing rates, lambing locations, timing of lamb mortality, and causes of lamb mortality.

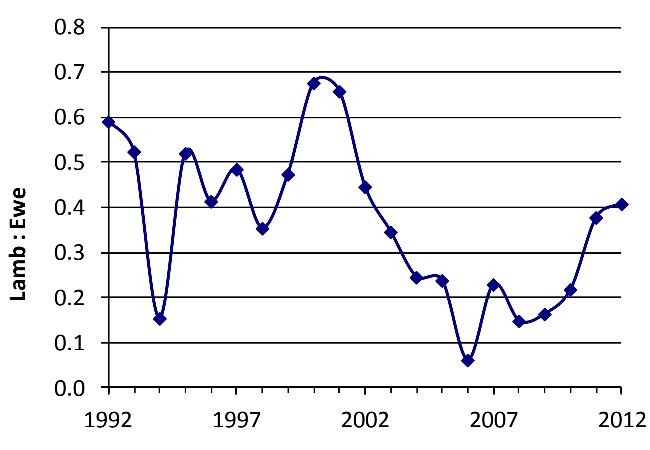

Figure 52. December lamb to ewe ratios for the Georgetown bighorn sheep herd from 1992 to 2012.

Pregnancy Rates

Ewe pregnancy rates were determined from blood samples collected from ewes captured in 2006 and 2007. Thirty-nine of the 41 ewes tested were pregnant at the time of capture. Although the blood test indicated that ewe #29 was not pregnant, she was seen nursing a lamb multiple times from May through October. The other ewe (#61) that tested as not pregnant at the time of capture was a 6-year-old in March 2006 and she was never seen with a lamb in 2006. Given that 98% of the ewes in 2006 and 2007 were pregnant at the time of capture, pregnancy rates were not considered a contributing factor of declining lamb recruitment. Pregnancy tests were not run on the ewes captured after 2007.

Parturition

From April 15 to July 31 2006, 2007 and 2008 collared ewes were monitored as closely as possible in an attempt to determine parturition rates, lambing areas and lamb survival. Table 20 shows the number of ewes from each subherd monitored during each lambing season. We attempted to locate each ewe 2 times per week during the lambing period. However, ewes that moved into inaccessible terrain were monitored much less frequently.

Table 20. Number of ewes from each subherd monitored during each lambing season from 2006-2009.

Subherd	2006	2007	2008	2009	Total
Eastern	4	4	3	4	15
Idaho Springs	3	3	3	3	12
Dumont	3	3	3	4	13
Douglas Mt	5	3	2	2	12
Georgetown	7	4	5	5	21
Western	1	4	4	4	13
Engelmann	4	6	6	6	22
Empire	8	7	7	6	28
Total	35	34	33	34	136

In 2006, each ewe was visually located between 2 and 16 times from May 1 and June 30, depending on their accessibility. The earliest a lamb was observed in the herd was in Clear Creek Canyon on May 1, with an uncollared ewe. The earliest a lamb was observed with a collared ewe was May 9 in the Eastern subherd. The last confirmed lamb born to a collared ewe was between June 12 and June 29. No new lambs were observed after June 29. In 2006, 30 of the 35 collared ewes were observed with a lamb at least once between May 9 and June 31. Twenty-eight of these were seen nursing, the other 2 were never seen nursing, but are believed to have had lambs due to behavior and association with lambs. Of the other 5 ewes, 1 was not pregnant at the time of capture, and 4 ewes either never lambed or lost their lambs before they were observed. Of the ewes never seen with a lamb, 2 moved to inaccessible terrain in which it was difficult to visually locate them. They were only located by air during the entire lambing season. The other 2 ewes were located 6 and 10 times between May 9 and July 31, but were never observed nursing a lamb.

Collared ewes were again closely monitored during the 2007 lambing season. The first lambs were seen with uncollared ewes on May 6 in Clear Creek Canyon (easternmost, lowest elevation portion of the herd). The first lamb with a collared ewe was observed on May 7 in the Eastern subherd. The last confirmed lamb born to a collared ewe was born between July 7 and July 17. No new lambs were observed after July 17. Thirty-two of the 34 ewes were seen nursing lambs. Ewes #45 and #58 were never observed with a lamb; they either never had lambs, or lost their lambs before they were observed. All 33 collared ewes were observed with a lamb in 2008. Twenty were observed nursing a lamb; the other 13 are believed to have a lamb based on association and behavior. The first lamb was observed on April 28 with a collared ewe just west of Downieville. The last new lamb to be observed was born sometime between June 27 and August 5 on the northern slope of Engelmann Mountain, just south of Blue Creek.

Determining lambing rates is labor intensive and, therefore, expensive. The intensive monitoring during the 2006-2008 seasons established high lambing rates in the Georgetown herd (i.e., 86%, 94% and 100%). Therefore, in 2009, ewes were not monitored as closely. As a result, only 20 of the 33 ewes were observed with lambs. Many of the others likely had lambs, but were never observed due to infrequent visual locations. The first lamb seen in 2009 was seen with an uncollared ewe on April 30. The first lamb of the year with a collared ewe was observed on May 14 just east of the Central City Parkway; the last was born sometime between June 20 and July 24 on Witter peak. Given the high proportion of the ewes observed each year with a lamb, parturition is not of concern for this herd.

Table 21 shows the range of dates for the initial lamb observation for each subherd. Table 22 shows the minimum, mean and maximum elevation of lambing locations for each of the subherds arranged from the lowest mean elevation to the highest mean elevations. The elevation of lambing sites are lowest in the eastern subherds and increase as you move west through the subherds, with the one exception being the Empire herd, which is centrally located but has the highest mean elevation of lambing sites.

Table 21. Range of dates that lambs were first observed with collared ewes from each subherd from 2006 to 2008.

Subherd	2006	2007	2008
Eastern	5/9-5/30	5/7-6/18	5/5-5/21
Idaho Springs	5/16-5/30	5/12-6/3	5/16-5/29
Dumont	5/10-6/13	5/16-5/19	5/16-5/22
Douglas Mt	5/15-6/1	5/14-5/23	5/4-6/9
Georgetown	5/15-6/29	5/22-5/23	5/22-6/16
Western	5/15-5/15	5/23-6/4	5/19-8/5
Engelmann	5/23-6/19	5/23-6/6	5/22-6/26
Empire	5/23-6/1	5/24-7/17	4/28-7/19
Total	5/9-6/29	5/7-7/17	5/4-8/5

Table 22. Minimum, mean and maximum elevations of lambing sites for each subherd of the Georgetown bighorn sheep herd.

Subherd	Minimum Elevation	Mean Elevation	Maximum Elevation
Eastern	6200	6467	6800
Idaho Springs	7100	7355	7800
Dumont	7400	8355	9600
Douglas Mt	8500	8850	9200
Georgetown	8500	9440	11000
Western	9000	9958	11200
Engelmann	9000	10040	12400
Empire	8400	10400	12400
Mean	8013	8858	10050

Lambing Habitat and Locations

Bighorn sheep escape terrain was defined as those areas with slopes greater than or equal to 60% (i.e., approximately 27 degrees). All areas within 300m of escape terrain were considered topographically suitable habitat. Areas within 500m of escape terrain were also included if escape terrain occurred on at least 2 sides. Areas that contained unsuitable vegetation (e.g., spruce fir containing areas) were removed from the topographically suitable area in order to estimate the amount of suitable bighorn habitat. Lambing habitat was defined as suitable habitat in patches of at least 2 ha in size with slopes $\geq$60% and southerly, easterly or westerly aspects (Fig. 53).

Lambing habitat is not limiting within any of the subherds. Lambing occurs throughout the occupied range of the Georgetown herd (Fig. 54). Through the monitoring of radio collared ewes during the lambing season, many previously unmapped lambing areas were identified throughout the herd.

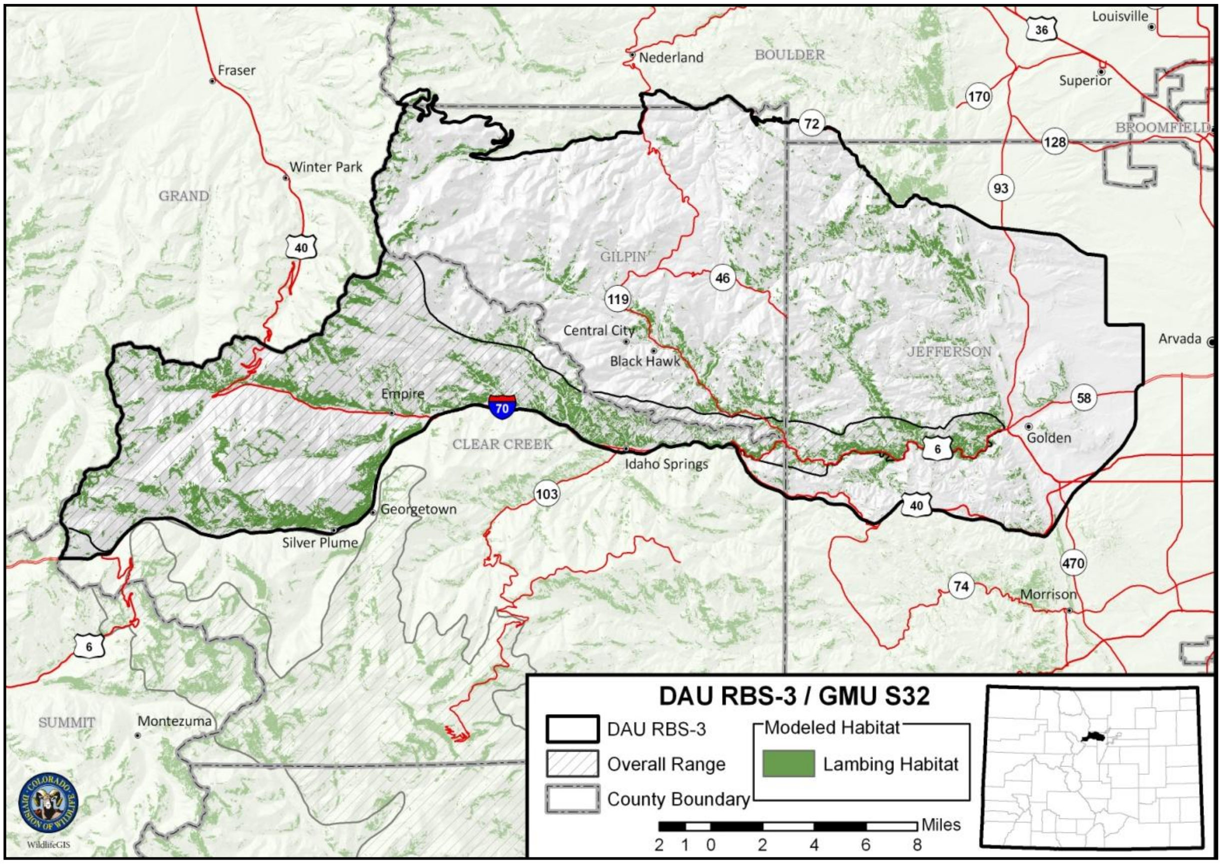

Figure 53. Modeled bighorn sheep lambing habitat and occupied range of the Georgetown bighorn sheep herd.

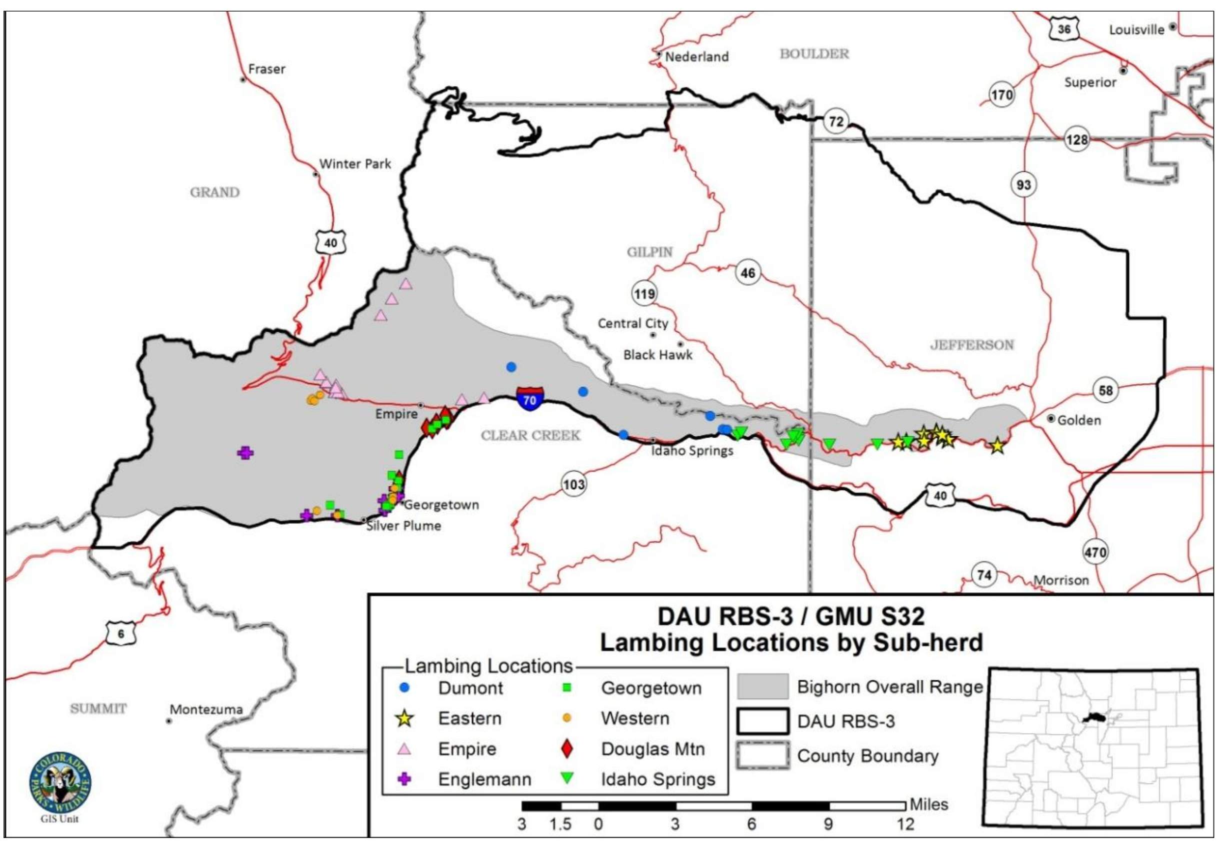

Figure 54. Lambing locations of collared ewes, showing the subherd to which the collared ewe belonged.

Lamb Mortality

Lamb mortality was not measured directly. However, there were 2 indicators of the timing and extent of lamb mortality during this study: 1) the lambing rate compared to the lamb to ewe ratio during the summer and fall surveys each year; 2) the number of collared ewes with and without a lamb throughout the lambing season each year.

In 2006, approximately 86% of the collared ewes were observed with a lamb. During the resight surveys in July, the mean observed lamb to ewe ratio was 0.27. This indicates that lamb mortality during the first 1 – 3 months was high. The observed lamb to ewe ratio during the December survey was 0.06, indicating that high lamb mortality continued from July to December. This was the lowest December lamb to ewe ratio observed during the 20 year history of the survey (Fig. 52). Similarly, in 2007, 94% of the collared ewes were observed with a lamb, the mean observed lamb to ewe ratio in July was 0.43, and the lamb to ewe ratio during the December survey was 0.23. This trend continued in 2008 with all of the collared ewes thought to have lambed, a mean observed July lamb to ewe ratio of 0.36 and a December observed lamb to ewe ratio of 0.15. Collared ewes were not monitored as closely during the lambing seasons of 2009 and 2010 as they were from 2006-2008, so it is unknown what percent of them lambed. However, given the high percentages of lambs born in previous years, it is assumed that lambing rates were high in these years also. The lamb to ewe ratios during the summer (i.e., 0.36 in 2009 and 0.30 in 2010) and fall surveys (i.e., 0.17 in 2009 and 0.22 in 2010) indicate that lamb mortality during these years was once again high from birth through December. Figure 55 shows these trends in lambs per 100 ewes for each year of the study.

An attempt was made from 2006 to 2008 to closely monitor collared ewes during May, June and July in order to determine when they gave birth and how long the lamb survived. Figures 56, 57 and 58 show the number of ewes with a lamb, the number of ewes without a lamb and the number of ewes whose lamb status was unknown from May 1 to July 31 of 2006, 2007 and 2008, respectively. The number of ewes without a lamb decreased in May as ewes gave birth and then increased in June and July as the lambs died. More effort (approximately 50% more technician-hours) was expended in this effort in 2007 than in 2006 and 2008. This resulted in a lower number of ewes whose lamb association was unknown. The timing of lamb births and mortality was consistent over the 3 years (Figs. 59 and 60). The timing of lamb mortality shown in these figures is consistent with lamb mortality resulting from disease as they are weaned and, therefore, no longer supported by their mother's immune systems.

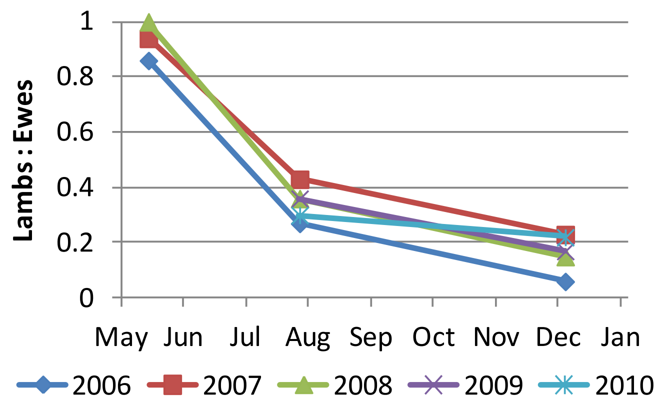

Figure 55. Lambs per ewe from May to December from 2006 to 2010. The data points in May represent the percentage of collared ewes observed with a lamb each year. The data from July and December are the lambs per ewes observed during resight surveys.

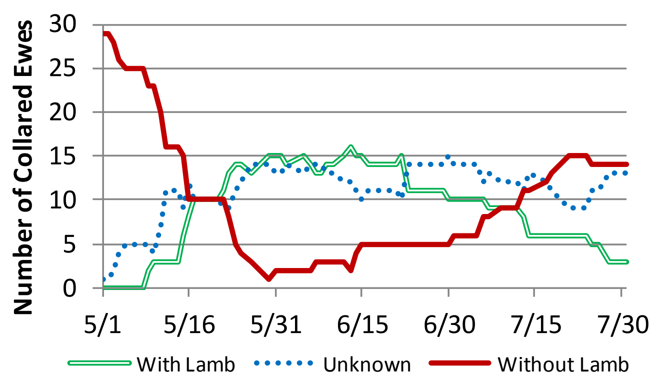

Figure **56.** Number of collared ewes with and without a lamb each day from May 1 to July 31 2006.

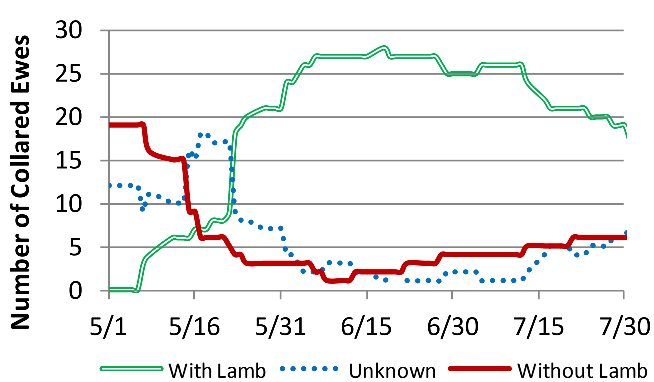

Figure 57. Number of collared ewes with and without a lamb each day from May 1 to July 31 2007.

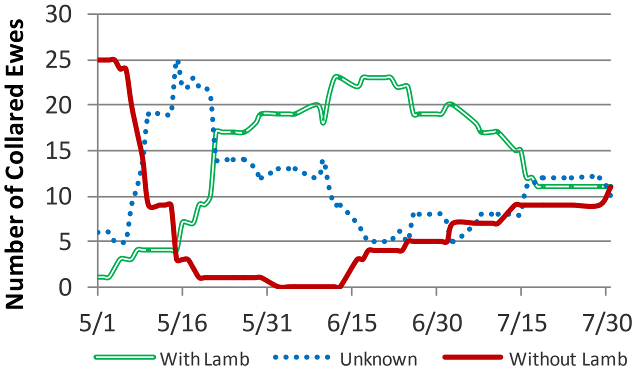

Figure 58. Number of collared ewes with and without a lamb each day from May 1 to July 31 2006.

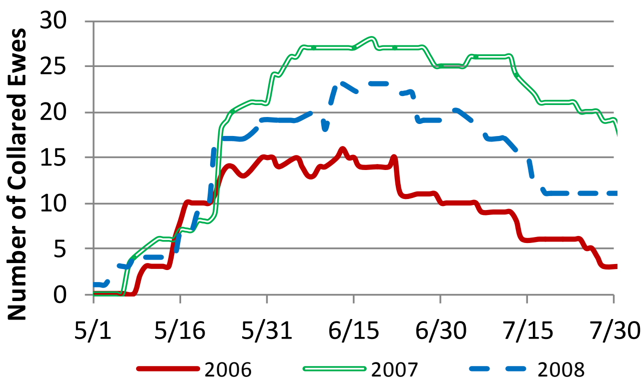

Figure 59. Number of collared ewes with a lamb each day from May 1 to July 31 2006, 2007 and 2008.

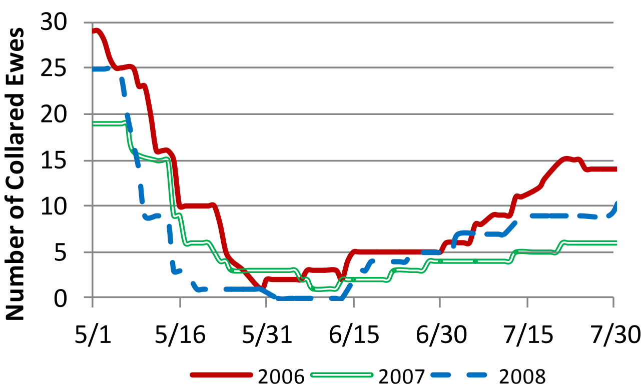

Figure 60. Number of collared ewes without a lamb each day from May 1 to July 31 2006, 2007 and 2008.

Causes of Lamb Mortality

We attempted to recover as many lamb carcasses as possible to determine the cause of death. From 2006-2010 we recovered 20 carcasses, 16 of these were transported to the CPW Wildlife Health Lab for necropsy (Table 23).

Table 23. Mortality causes of lambs recovered from 2006-2010.

Cause of Mortality	2006	2007	2008	2009	2010	Sum
Bronchopneumonia	2	4		2	1	9
Malnutrition/ Bronchopneumonia	1					1
Trauma		1			2	3
Chronic Poor Doer			1			1
Predation			1	1		2
Not necropsied		3	1			4
Total Recovered	3	8	3	3	3	20

During the summer of 2006, 3 lamb carcasses were recovered. None of these are thought to have been from collared ewes. The first was recovered within 2 days of death on July 8, 2006 and was in good condition. Necropsy results indicated that the cause of death was acute bronchopneumonia. The second lamb was recovered on July 18, 2006, several days after death. Due to the degraded state of the carcass, the necropsy was unable to determine a cause of death. It did, however, rule out malnutrition, vehicle collision and predation. Histology results indicated that bronchopneumonia was the probable cause of death. The third lamb was recovered on July 21, 2006, approximately 2 days after death. Malnutrition was the leading cause of death for this lamb; however, inspection of the lungs indicated that bronchopneumonia was a contributing factor in its death. A collared ewe (#59) in the area had been seen nursing 2 lambs 1 month earlier (Fig. 61). It is possible that this lamb had lost its mother and that #59 was nursing it, but that the lamb was not receiving enough nutrition to survive.

Figure 61. A collared ewe nursing 2 lambs. Photo by: Brendan Huff.

Eight lamb carcasses were recovered in 2007. One lamb, collected on May 11, was estimated to be 1-2 weeks old and died of trauma, probably caused by a fall. He was otherwise in good body condition with no indication of bronchopneumonia. This was, however, probably due to his young age. Four lamb carcasses, collected on July 26, July 30, August 1, and December 10, were transported to the CPW Wildlife Health Lab for necropsy, and all found to have died of bronchopneumonia. Three additional lambs were collected (on August 3, 21 and 24), but not necropsied. The carcasses from 3 lambs born in 2008 were recovered. One lamb had been observed in a residential yard in Silver Plume continuously for several days when dogs killed it on December 4. No necropsy was conducted due to the incomplete nature of the carcass. One lamb was found alive and ataxic in the middle of Highway 6 on February 2 and moved off the road. It was found dead on the shoulder of the road a few hours later and taken to the CPW Wildlife Health Lab for necropsy. Necropsy determined that this lamb had suffered no trauma, did not have bronchopneumonia, and was not depredated; it was classified as a chronic poor doer. Another nearly 1 year old lamb was found being eaten by a bobcat on the shoulder of I-70 on April 22, 2009. It was also transported to the CPW Wildlife Health Lab for necropsy. The ultimate cause of death was predation by the bobcat; however, the lamb was in very poor body condition making it easy prey.

The carcasses of 3 lambs born in 2009 were recovered. One lamb was found alive, alone, and ataxic on June 12 by Clear Creek County animal control. During the previous few years, several lambs had been reported in this state. Each of these lambs was left and monitored for a few days before it died. We decided to take this June 12th lamb to the CPW Wildlife Health Lab for treatment and observation. However, it died while being loaded into the truck and was taken for necropsy. Necropsy determined the cause of death to be bronchopneumonia. On July 17, another lamb was found in the CDOT shed near the Central City parkway. It had been staying in and around the shed for about a week. We treated her with Draxxin (an antibiotic) and moved her up the hill. She then moved to the business next door where she stayed for several days until reported. On July 22, she was collected, treated with Draxxin and Dormectin and released near a group of lambs and ewes near Georgetown. This lamb had to be put down the next day. The carcass was sent for necropsy, which revealed severe bronchopneumonia. On April 16, 2010, a nearly 1-year-old lamb that had died after a collision with a vehicle was collected.

The carcasses of 3 lambs born in 2010 were collected. On June 16, 2010, a lamb was found dead in the median of Interstate 70. It had been struck by a vehicle; no signs of bronchopneumonia were found during necropsy. On July 4, a radio collared ewe's (Y3) lamb was found dead and submitted for necropsy. The cause of death was trauma. On July 20, 2010, the lamb of radio collared ewe #76 was found ataxic and lying in the creek. She was euthanized and submitted for necropsy. She had been observed during the previous week looking unhealthy (i.e., droopy ears, unable to stand). Necropsy determined the cause of death to be bronchopneumonia.

Another lamb was reported as sick and alone in Georgetown on February 2, 2011. She was easily captured (by cornering her and restraining her by hand) due to her weak state and was transported to the CPW Wildlife Health Lab for treatment and observation. She was tested, treated and survived several years in captivity.

In addition to these recovered carcasses, many lambs were observed during this study to be in poor body condition. Additional lambs were observed alone at low elevations. It is thought that these lambs were sick and unable to keep up with the herd.

CONCLUSIONS

Seventy-seven individual bighorn (50 ewes and 27 rams) were collared during this study. A total of 5,422 VHF collar locations and 33,672 locations downloaded from the Globalstar and Lotek GPS collars were collected from these bighorn and used to define the range, distribution, movement patterns, and lambing areas of the herd. In addition, several subherds were identified within this DAU. Each subherd exhibits a seasonal shift between summer, lambing, and winter range with rams and ewes moving independently from each other. There is connectivity throughout the DAU, with adjacent subherds overlapping spatially and temporally indicating that transmission of pathogens and genetic materials between subherds is probable. The area of most restricted contact is Empire Junction. There is only one subherd of ewes that commonly crosses US Highway 40 between Empire and Downieville (the Douglas Mountain subherd). Rams rarely cross this highway, with only a few instances of collared ram crossings recorded during this study.

None of the sheep collared in this study moved into the range of other herds. Four bighorn sheep were captured outside of S32 in S3 (1 ram), S4 (1 ram), S41 (1 ewe) and 1 ram 19 km north of the Georgetown herd outside of a GMU in order to determine if they moved into the range of the Georgetown herd. None of these bighorn sheep ever crossed into the Georgetown herd.

Mark-resight methods were used to estimate the adult ewe and adult ram populations each July from 2006 to 2009. The ewe population estimates for those years were 174 (SE = 15), 229 (SE = 31), 185 (SE = 20), 150 (SE = 19). The ram estimates were 194 (SE = 29), 216 (SE = 37), 157 (SE = 36), 171 (SE = 31). Within each year, the individual surveys varied widely in the number of bighorn observed, observed sex and age ratios, the individual sighting probabilities of marked sheep, and the proportion of marked animals observed on surveys. The mean proportion of the modeled populations observed during the July and December surveys was 0.40 and 0.56 respectively. The proportion of the herd observed during the December surveys was higher than had been previously assumed. Based on the results of this study, the population estimate for this herd was revised upward. The population estimate prior to this study was above the objective and the population was being managed to bring the population down to objective through ewe and ram hunting. Based on the results of this study, the number of ewe licenses was increased.

The number of ewes observed on coordinated ground surveys increased during the month of July as ewes groups increased in size. The lamb to ewe ratio decreased during the month of July because lamb mortality rates were higher than ewe mortality rates.

From 2006 to 2009, the mean annual non-harvest survival rate of ewes was 91% and of rams was 92%. The main source of mortality for ewes was vehicle collisions (46% of mortalities), followed by unknown causes (17%), harvest (13%), natural causes (8%), lions (8%), hardware disease (4%) and fence encounters (4%). The main source of mortality for rams was harvest (46% of mortalities) followed by vehicle collisions (23%), unknown causes (15%), wounding loss (8%) and lions (8%).

The adult survival rates and population estimates from this study were used along with other data to develop a population model for this herd that estimates both the July and December populations. The July population estimates from the model for the years 2006 to 2009 were 458, 438, 395, and 357. The December population estimates from the model are lower than the July estimates due to removals by hunting and mortalities. The model runs from 1991 to present and indicates that the December population grew from approximately 300 animals in 1990 to nearly 500 by 2001 and then declined to approximately 300 animals by 2012. This is the midpoint of the population objective range for the herd and thought to be a sustainable number.

One of the objectives of this study was to determine the causes of low lamb recruitment into the Georgetown herd. We showed that 98% of the ewes were pregnant at the time of capture, and that at least 93% of ewes gave birth to live lambs. Neither of these, therefore, contributed to low lamb recruitment. Lamb mortality was high between May and the end of July each year. From 2006-2010, the mean lamb to ewe ratio was 34 during the summer surveys and 19 during the fall surveys. Lamb mortality was, therefore, high during the first 2 months of life and remained high through November. This high lamb mortality was the cause of low lamb recruitment into the herd. The main cause of lamb mortality was bronchopneumonia. Bronchopneumonia is implicated by the results of carcass necropsies, the timing of lamb mortality, and the frequent observations of live lambs showing signs of illness such as poor body condition, drooping ears, ataxia and failure to keep up with the herd. The Georgetown herd is exhibiting lamb recruitment patterns typical of a herd suffering the aftermath of a bronchopneumonia outbreak. However, unlike other outbreaks throughout the west, this low lamb recruitment was not preceded by an all-age die off. Given the number of people that recreate within the range of the herd and the number of sheep enthusiasts who watch this herd, the probability of an all-age die-off going unnoticed is very small. Although there are no grazing allotments near this herd, there are potential sources for bighorn pathogens throughout the range of the Georgetown herd in the form of hobby domestic animals kept by residents.

MANAGEMENT RECOMMENDATIONS

Annual surveys of the herd should continue in order to expand on the long term monitoring data set of the herd and to increase the chances of identifying changes in population parameters that could indicate changes to herd health and performance and the associated needs for management changes.

Summer surveys provide information on summer distribution of the herd. Otherwise, fall surveys are preferred over summer surveys for several reasons. Firstly, fall surveys occur during the rut and thus provide more reliable ram to ewe ratios. Secondly, lamb mortality rates are high during the first few months of life. Lamb to ewe ratios are high immediately following lambing and decrease as lambs die. Lamb mortality rates remain moderate through the summer surveys but stabilize by the fall surveys. Lamb to ewe ratios are therefore much higher during the summer surveys than during the fall surveys. The fall lamb to ewe ratios are a much more consistent indicator of lamb recruitment than the summer surveys. Thirdly, during the summer survey the bighorn are spread out over a larger geographic area. During the fall survey they are concentrated on winter range. A much greater proportion of the population is, therefore, observed during the fall survey than during the summer survey. This is true even though the fall survey requires only a third of the routes (and labor) of the summer survey. Lastly, viewing distances during the fall survey, when bighorn are concentrated on easily accessible winter range, are shorter than during the summer survey, when the bighorn are spread out over their less accessible summer range. This results in more accurate classifications and collar identification as evidenced by the much larger number of unidentified collars on summer surveys than on fall surveys. When summer surveys are used, it is important that they be conducted on approximately the same date each year given the changes in sighting probability and lamb to ewe ratios with time. It is also important that summer surveys occur after ewe groups have reconsolidated following lambing, because a smaller proportion of the herd will be observed in surveys conducted while ewes are still in small groups following lambing.

The management of many bighorn sheep herds in Colorado is based primarily on the results of coordinated ground surveys (Colorado Division of Wildlife 2009). In most of these herds, no information on bighorn sightability is available, but managers must apply a reasonable upward adjustment to the minimum counts to estimate the size of the population. The size of the upward adjustment required depends on survey methods and characteristics of the herd and its habitat. The Georgetown herd occupies an area characteristic of other bighorn habitat in Colorado. This study provides sighting probabilities, proportions of collars observed and proportions of modeled population observed during ground based surveys. These results, along with those of similar studies, can be used to inform the size of the upward adjustments applied to minimum counts obtained through ground counts in other herds (Neal 1990, George et al. 1996, McClintock and White 2007, Huwer et al. 2015).

During both the summer and fall surveys, the proportion of the herd, the ram: ewe and the lamb: ewe observed on a specific day is variable, depending on environmental conditions and sheep distribution on the day of the survey. In cases where management is based primarily on the results of coordinated counts without reliable estimates of bighorn sighting probability, annual variation in these parameters can be reduced by conducting multiple surveys per season.

Bronchopneumonia is affecting this herd. Efforts to identify ways to reduce the impact of this disease on populations should continue including the pursuit of a vaccine and effective treatments. Efforts should continue to reduce the probability of contact between domestic sheep and goats and bighorn. This includes working with residents to properly fence their livestock and to inform authorities when possible contact between domestics and bighorn has occurred. CPW should continue to work with land management agencies and residents to avoid using domestics for weed and fire mitigation within the range of the bighorn herd.

Vehicle collisions cause a high percentage of the annual bighorn mortality. Efforts should be made to identify possible strategies to reduce vehicle caused bighorn mortalities. Possible approaches in areas where bighorn cross roads include constructing wildlife overpasses, encouraging bighorns to cross at the safest possible locations (e.g., via fencing), and altering driver behavior (e.g., via signs, slowing vehicles or warning systems which are activated when wildlife are on the road). Bighorns are also killed in vehicle collisions in areas where they are attracted to the shoulders of roads but do not cross. Possible mitigation in these areas include using different de-icing substances on the roads, modifying roadside vegetation, discouraging bighorn from approaching roadways, erecting barriers in certain locations, and altering driver behavior. Several specific areas where multiple bighorn have been killed in collisions with vehicles have been identified in Appendix 2 along with possible mitigation efforts at each site. When possible, CPW should work with CDOT to reduce the probability of bighorn-vehicle collisions in these areas.

Clear Creek County owns approximately 1600 acres north of Interstate 70 between Fall River Road and the Town of Empire. This area is commonly known as the "Sheep Keep" and is managed for the benefit of bighorn sheep. The property is utilized by the Georgetown bighorn sheep herd as overall range, winter range, winter concentration area, production area and movement corridor. It is of vital importance in maintaining connectivity between the eastern and western portions of the herd. This area is highly fragmented by private property. CPW has been working with Clear Creek County to identify management strategies for this property that will maximize the benefit of this area to bighorn sheep. This cooperative relationship should be continued and expanded where possible. In addition to the "Sheep Keep," there are several restricted movement corridors that are vital to maintaining connectivity within the herd. CPW should pursue acquisition of or conservation easements on properties within these movement corridors to ensure genetic diversity throughout the herd and to protect traditional bighorn sheep movement patterns.

LITERATURE CITED

Anderson, D. R. 2001. The need to get the basics right in wildlife field studies. Wildlife Society Bulletin. 29:1294-1297.

Bowden, D.C. and R.C. Kufeld. 1995. Generalized mark-resight population size estimation applied to Colorado moose. Journal of Wildlife Management 59: 840–851.

Colorado Division of Wildlife. 2009. Colorado bighorn sheep management plan: 2009-2019. Special Report 81. Colorado Division of Wildlife, Fort Collins, CO. 88pp.

George, J. L., M. W. Miller, G. C. White, and J. Vayhinger. 1996. Comparison of mark-resight population size estimators for bighorn sheep in alpine and timbered habitats. Biennial Symposium of the North American Wild Sheep and Goat Council 10:20-25.

George, J.L., L.L. Wolfe, M.W. Miller. 2008. Bighorn sheep capture and translocation guidelines. Colorado Division of Wildlife. Denver, CO. 49 pp.

Huwer, S.L. 2010. Bighorn sheep management plan: Data analysis unit RBS-3, Georgetown Herd. Colorado Division of Wildlife. Denver, CO. 46 pp.

Huwer, S.L. and K. Eichhoff. 2015. Long-distance movement of the Granby Ram through Colorado and Wyoming. Biennial Symposium of the North American Wild Sheep and Goat Council. In press.

Huwer, S.L., J.R. Stiver, B.P. Dreher, J.L. George. 2015. Sighting probability and survival in two Colorado bighorn sheep herds. Biennial Symposium of the North American Wild Sheep and Goat Council. In press.

McClintock, B. T., and G. C. White. 2007. Bighorn sheep abundance following a suspected pneumonia epidemic in Rocky Mountain National Park. Journal of Wildlife Management 71:183–189.

Neal, A.K. 1990. Evaluation of mark-resight population estimates using simulations and field data from mountain sheep. M. S. Thesis, Colorado State University, Fort Collins, Colorado.

Neal, A.K., G.C. White, R.B. Gill, D.F. Reed, and J.H. Olterman. 1993. Evaluation of mark-resight model assumptions for estimating mountain sheep numbers. Journal of Wildlife Management 57: 436–450.

Pierce, B. L., R. R. Lopez, and N. J. Silvy. 2012. Estimating animal abundance. Pages 284-310 in N. J. Silvy, editor. The wildlife techniques manual: research, volume 1. Johns Hopkins University Press, Baltimore, MD, USA.

White, G.C. 1996. NOREMARK: population estimation from mark-resighting surveys. Wildlife Society Bulletin 24: 50–52.

White, G.C. and K.P. Burnham. 1999. Program MARK: survival estimation from populations of marked individuals. Bird Study 46: 120–139.

White, G. C., and B. C. Lubow. 2002. Fitting population models to multiple sources of observed data. Journal of Wildlife Management 66:300-309.

White, G. C., and T. M. Shenk. 2001. Population estimation with radio-marked animals. Pages 329–350 in J. Millspaugh and J. M. Marzluff, editors. Radio tracking and animal populations. Academic Press, San Diego, California, USA.

APPENDIX 1: INDIVIDUAL BIGHORN CAPTURE AND LOCATION DATA

Table 24. Initial capture information for each bighorn sheep collared including the date of the last location and the number of months each bighorn sheep wore a collar. The following were used for chemical immobilization: MK (ketamine and metatomidine, A3080 (thiafentanil), and BAM (butorphanol, azaperone, and medetomidine). Collars that were still on at the end of the study are indicated by >5/31/2011 in the "Last Location" column.

Ear Tag	Class	Subherd	Collar Type	Collar Mark	Age (yr)	Collar Circ (in)	Disease Samples	Capture Date	Capture Location	Capture Method	Last Location
10	Ram	Eastern	Globalstar				yes	4/28/2011	Tunnel 1 West	Dart (BAM)	5/21/2011
11	Ewe	Dumont	Globalstar	J8	7		yes	3/30/2009	Dumont-Excel	Dart (BAM)	5/22/2010
16	Ewe	Empire	VHF	T0	5	20	yes	3/27/2008	Empire	Dart (BAM)	5/29/2008
18	Ram		VHF	L	8		yes	2/5/2009	Bethel Mt	Helicopter	8/24/2009
19	Ram	Empire	GPS	I0	8		yes	2/5/2009	Cone Mountain	Helicopter	2/4/2010
20	Ram	S4	VHF	Z1	4	19.5	yes	3/11/2008	Smelter Basin	Helicopter	10/20/2010
22	Ewe	Eastern	Globalstar	H8			yes	2/5/2009	Tunnel 1	Helicopter	2/11/2010
23	Ewe	S41	GPS		4		yes	3/11/2008	Peru Creek	Helicopter	3/10/2009
25	Ewe	Engelmann	GPS	V8	6		yes	2/5/2009	Mt Machebeof	Helicopter	4/1/2010
26	Ewe	Empire	VHF	T	6+	19	yes	4/1/2008	Dumont	Dart (BAM)	4/18/2009
27	Ewe	Empire	VHF	V0	5	18	yes	3/27/2008	Empire	Dart (BAM)	>5/31/2011
28	Ram	S3	GPS		3		yes	3/11/2008	Sniktau	Helicopter	11/30/2008
29	Ewe	Western	VHF	H0	4	17	yes	3/13/2007	Engelmann	Helicopter	>5/31/2011
30	Ram	Western	VHF	Z7	4	20.5	yes	3/13/2007	Engelmann	Helicopter	10/20/2010
31	Ewe	Georgetown	VHF	C1	5	19	yes	3/27/2008	Silver Plume	Dart (BAM)	>5/31/2011
32	Ram	Engelmann	VHF	Z1	4	19.5	yes	5/11/2006	Silver Plume E.	Dart (MK)	10/27/2007
33	Ewe	Eastern	VHF	C4	3	16	yes	1/9/2006	Huntsman Gulch	Dart (MK)	>5/31/2011
34	Ram	Western	VHF	L4	3	18.5	yes	2/17/2006	Bakerville	Dart (A3080)	4/28/2009
35	Ewe	Georgetown	VHF	C7	7+	16	yes	12/22/2005	Georgetown	Dart (MK)	>5/31/2011
36	Ewe	Western	VHF	T1	4	18	yes	3/13/2007	Engelmann	Helicopter	>5/31/2011
37	Ewe	Georgetown	VHF	T	10	15.5	yes	1/13/2006	Jackpine Mine	Dart (MK)	4/9/2007
38	Ewe	Empire	VHF	X4	7	18	yes	1/23/2006	Downieville	Dart (A3080)	>5/31/2011
39	Ewe	Western	VHF	F1	6	18	yes	3/13/2007	Engelmann	Helicopter	4/9/2011
40	Ewe	Engelmann	VHF	F4	6	16	yes	1/13/2006	Bakerville	Dart (MK)	>5/31/2011
41	Ewe	Eastern	VHF	J7	7	15.5	yes	1/9/2006	Huntsman Gulch	Dart (MK)	1/8/2010
42	Ram	Idaho Springs	VHF	A4	2	19.5	yes	2/16/2006	Frei East	Dart (MK)	11/4/2009

Ear Tag	Class	Subherd	Collar Type	Collar Mark	Age (yr)	Collar Circ (in)	Disease Samples	Capture Date	Capture Location	Capture Method	Last Location
43	Ewe	Georgetown	VHF	H0	10+	16	yes	1/13/2006	Jackpine Mine	Dart (MK)	5/19/2006
44	Ewe	Empire	VHF	H	4	16.5	yes	1/23/2006	Downieville	Dart (A3080)	>5/31/2011
45	Ewe	Empire	VHF	V4	6	17	yes	1/20/2006	Downieville	Dropnet	4/13/2011
46	Ewe	Engelmann	VHF	V1	8+	17	yes	3/3/2006	Cloud Gulch	Dart (MK)	7/29/2010
47	Ewe	Dumont	VHF	X7	6+	19	yes	4/1/2008	Twin Tunnels	Dart (BAM)	8/7/2010
48	Ram	Western	VHF	Z0	4	21.5	yes	3/13/2007	Bard Creek	Helicopter	8/19/2009
49	Ewe	Engelmann	VHF	J	4	18	yes	3/13/2007	Engelmann	Helicopter	9/28/2010
50	Ram	Engelmann	VHF	Z4	4	20.5	yes	3/13/2007	Ruby Creek	Helicopter	10/20/2010
51	Ewe	Engelmann	VHF	H1	3	19	yes	3/13/2007	SE Woods Mt	Helicopter	11/22/2008
53	Ram	Western	VHF	A	3	21.5	yes	3/13/2007	Engelmann	Helicopter	7/22/2010
54	Ewe	Idaho Springs	VHF	V7	4	15	yes	2/1/2006	Tunnel 4	Dart (MK)	>5/31/2011
55	Ram	Empire	VHF	T7	8	19.5	yes	1/23/2006	Downieville	Dart (A3080)	5/4/2011
56	Ewe	Empire	VHF	V	7	15	yes	3/17/2006	Empire	Dart (MK)	>5/31/2011
57	Ewe	Georgetown	VHF	C1	5	15.5	yes	3/28/2006	Georgetown	Dart (A3080)	4/25/2007
58	Ewe	Dumont	VHF	J0	4	16	yes	3/6/2006	Twin Tunnels	Dart (MK)	>5/31/2011
59	Ewe	Dumont	VHF	J2	7	17	yes	3/23/2006	Argo Mine	Dart (A3080)	8/27/2010
60	Ewe	Georgetown	VHF	H1	4	17	yes	3/28/2006	Silver Plume	Dart (A3080)	8/25/2006
61	Ewe	Empire	VHF	J4	6	16.5	yes	3/28/2006	Empire	Dart (A3080)	5/9/2007
63	Ram	Georgetown	VHF	Z2	7	19.5	yes	1/23/2006	Downieville	Dart (MK)	>5/31/2011
64	Ewe	Empire	VHF	C0	3	17	yes	3/21/2006	Downieville	Dart (A3080)	4/14/2008
66	Ewe	Georgetown	VHF	F7	4	16	yes	1/20/2006	Georgetown	Dropnet	>5/31/2011
67	Ewe	Engelmann	VHF	X2	5	16	yes	2/1/2006	Jackpine Mine	Dart (MK)	>5/31/2011
68	Ewe	Douglas Mt	VHF	X0	7	16.5	yes	1/20/2006	Georgetown	Dropnet	3/19/2011
69	Ewe	Georgetown	VHF	F	4	15.5	yes	1/20/2006	Georgetown	Dropnet	9/17/2009
70	Ewe	Douglas Mt	VHF	V0	4	15	yes	1/20/2006	Georgetown	Dropnet	4/2/2007
72	Ram	Georgetown	VHF	L2	4	19.5	yes	1/20/2006	Georgetown	Dropnet	8/26/2007
74	Ewe	Douglas Mt	VHF	X7	3	16	yes	1/20/2006	Georgetown	Dropnet	4/2/2007
76	Ewe	Douglas Mt	VHF	X	6+	16		1/20/2006	Georgetown	Dropnet	>5/31/2011
77	Ram	Western	VHF	L0	7+	19.5	yes	1/20/2006	Georgetown	Dropnet	5/4/2011
78	Ewe	Western	VHF	H2	5	16	yes	1/20/2006	Georgetown	Dropnet	8/7/2010
79	Ewe	Douglas Mt	VHF	F0		16		1/20/2006	Georgetown	Dropnet	8/7/2010

Ear Tag	Class	Subherd	Collar Type	Collar Mark	Age (yr)	Collar Circ (in)	Disease Samples	Capture Date	Capture Location	Capture Method	Last Location
80	Ewe	Douglas Mt	VHF	T0	3	16		1/20/2006	Georgetown	Dropnet	7/26/2007
81	Ram	Georgetown	VHF	L	5	18.5		1/20/2006	Georgetown	Dropnet	9/15/2006
82	Ram	Georgetown	VHF	A2	2	19.5	yes	1/20/2006	Georgetown	Dropnet	10/20/2010
83	Ewe	Empire	VHF	F2	7	17	yes	1/23/2006	Downieville	Dart (A3080)	2/15/2008
84	Ewe	Empire	VHF	C2	4	16	yes	1/20/2006	Downieville	Dropnet	>5/31/2011
85	Ewe	Engelmann	VHF	C	7	18	yes	3/23/2006	Silver Plume	Dart (A3080)	>5/31/2011
86	Ewe	Eastern	VHF	V2			No	3/9/2006	Mayhem Gulch	Helicopter	6/2/2008
88	Ram	Idaho Springs	VHF	X1	3	20.5	yes	3/30/2006	Argo Mine	Dart (A3080)	9/1/2009
89	Ram	Engelmann	VHF	A7	3	20.5	yes	3/13/2007	S Bard Peak	Helicopter	10/20/2010
90	Ram	Eastern	VHF	L7	3	21.5	yes	3/9/2006	Mayhem Gulch	Helicopter	4/24/2008
91	Ram	Engelmann	VHF	L1	4	20.5	yes	3/31/2006	Nowhere Bridge	Dart (MK)	9/25/2008
92	Ewe	Eastern	VHF	H4	8+	17	yes	3/6/2006	Mayhem Gulch	Dart (MK)	1/8/2010
93	Ram	Empire	VHF	A0	3		yes	2/27/2006	Empire	Dart (MK)	2/27/2006
95	Ewe	Idaho Springs	VHF	J1	4	16	yes	3/9/2006	Tunnel 4	Helicopter	8/2/2010
96	Ewe	Dumont	VHF	H7	4	16	YES	2/22/2006	Idaho Springs	Dart (MK)	5/19/2008
98	Ram	Engelmann	VHF	T4	4	21.5	yes	3/13/2007	SE Woods Mt	Helicopter	8/30/2010
99	Ram	Eastern	VHF	A1	7	21.5	yes	3/9/2006	Mt Galbraith	Helicopter	1/3/2008
100	Ewe	Idaho Springs	VHF	T2	6	16	yes	3/9/2006	Tunnel 4	Helicopter	3/31/2010
201	Ram	Eastern	VHF	Z0		22.5	No	3/9/2006	Mt Galbraith	Helicopter	5/31/2006
204	Ram	Eastern	VHF	Z	5	22.5	yes	3/9/2006	Mt Galbraith	Helicopter	3/31/2011

Table 25. Recapture information for each bighorn sheep that was recaptured to replace the original collar.

Ear Tag	New Collar Type	New Mark	Old Mark	Subherd	Recapture Date	Recapture Location	UTMN	UTME	Method
32	GPS	Z1	Z1	Engelmann	3/13/2007	Ruby Creek	428956	4399371	Helicopter
36	Globalstar	L8	T1	Western	2/5/2009	Engelmann	433183	4398703	Helicopter
40	Globalstar	T8	F4	Engelmann	2/5/2009	Robeson Mt	431286	4398685	Helicopter
46	Globalstar	F8	V1	Engelmann	2/5/2009	Silver Plume Mt	434497	4395453	Helicopter
47	Globalstar	X8	X7	Dumont	2/23/2009	ID Springs	454296	4399358	Dart(BAM)
59	VHF	P5	J2	Dumont					
64	GPS	C0	C0	Empire	3/30/2007	Downieville	447132	4401956	Dart(MK)
78	Globalstar	C8	H2	Western	2/5/2009	Republican Mt	436492	4396088	Helicopter
79	Globalstar	A8	F0	Douglas Mt	3/24/2009	Georgetown	440252	4396211	Dart(BAM)
100	Globalstar	Z8	T2	Eastern	2/5/2009	Kermit's	462052	4399322	Helicopter

Table 26. Number of each type of location, excluding locations downloaded from Lotek GPS and Globalstar collars, for each collared bighorn sheep.

Ear Tag	Initial Capt	Ground Visual	Aerial	Survey	Triang-ulation	Harvest	Recapture	Recovery	Total	Months Collared	Location /Month
10	1								1	1	1.0
11	1	17	1	3					22	14	1.6
16	1	3	2					1	7	2	3.5
18	1	2	5			1			9	7	1.3
19	1	4	7	2				1	15	12	1.3
20	1		23						24	31	0.8
22	1	3		3					7	12	0.6
23	1		12						13	12	1.1
25	1	7	3					1	12	14	0.9
26	1	15	12	3				1	32	13	2.5
27	1	21	23	4					49	38	1.3
28	1		11					1	13	9	1.4
29	1	26	39	2	1				69	51	1.4
30	1	10	38	4	1				54	43	1.3
31	1	28	19	5					53	38	1.4
32	1	7	14	1			1	1	25	18	1.4
33	1	91	34	10	2				138	65	2.1
34	1	17	31	2	1			1	53	38	1.4
35	1	88	29	15					133	65	2.0
36	1	30	24	2	1		1		59	51	1.2
37	1	17	5	1	1			1	26	15	1.7
38	1	104	33	11					149	64	2.3
39	1	30	35	2	2			1	71	49	1.4
40	1	20	33	1			1		56	65	0.9
41	1	74	3	11			1		90	48	1.9
42	1	46	26	9	2			1	85	45	1.9
43	1	10						1	12	4	3.0
44	1	91	33	9	1				135	64	2.1
45	1	84	33	14	2			1	135	63	2.1
46	1	53	25	7	2		1		89	53	1.7
47	1	53	6	9			1		70	28	2.5

Ear Tag	Initial Capt	Ground Visual	Aerial	Survey	Triang-ulation	Harvest	Recapture	Recovery	Total	Months Collared	Location /Month
48	1	10	28					1	40	29	1.4
49	1	36	36	2				1	76	43	1.8
50	1	21	33	1	1				57	43	1.3
51	1	30	16	1		1			49	20	2.5
53	1	8	30	1				1	41	40	1.0
54	1	98	29	13	1				142	64	2.2
55	1	45	32	10	3				91	63	1.4
56	1	90	30	8					129	62	2.1
57	1	35	3	1	1			1	42	13	3.2
58	1	125	29	15	2				172	63	2.7
59	1	113	27	10					151	53	2.8
60	1	9	2	1					13	5	2.6
61	1	15	6		1			1	24	13	1.8
63	1	39	33	11	2				86	57	1.5
64	1	46	9	6			1	1	64	25	2.6
66	1	95	28	14					138	64	2.2
67	1	67	34	8	1				111	64	1.7
68	1	82	34	13				1	131	62	2.1
69	1	98	22	11	1			1	134	44	3.0
70	1	29	3	3				1	37	14	2.6
72	1	21	8	4	1	1			36	19	1.9
74	1	35	2	3				1	42	14	3.0
76	1	106	32	12	1				152	64	2.4
77	1	41	37	9	1				89	63	1.4
78	1	80	18	11	1		1		112	55	2.0
79	1	101	23	15			2		142	55	2.6
80	1	55	4	5				1	66	18	3.7
81	1	14	1	2		1			19	8	2.4
82	1	59	33	10					103	57	1.8
83	1	49	13	7	1			1	72	25	2.9
84	1	97	29	9	1				137	64	2.1
85	1	46	40	6	1				94	62	1.5
86	1	69	12	4				1	87	27	3.2
88	1	29	29	8	4			1	72	41	1.8
89	1	16	35		1				53	43	1.2
90	1	31	13	6					51	26	2.0
91	1	19	25	3	2			1	51	30	1.7
92	1	63	30	10			1		105	46	2.3
93	1								1	0	
95	1	94	28	15				1	139	53	2.6
96	1	71	8	8	1			1	90	27	3.3
98	1	11	35	1	1			1	50	42	1.2
99	1	14	10	5	1			1	32	22	1.5
100	1	68	16	16			1	1	103	49	2.1
201	1	2						1	4	3	1.3
204	1	30	40	12	3				86	61	1.4
Total	77	3263	1544	440	49	4	12	33	5422	2846	1.9

APPENDIX 2: REDUCING VEHICLE CAUSED MORTALITY IN THE GEORGETOWN BIGHORN SHEEP HERD

Bighorn sheep mortality resulting from collisions with vehicles is substantial in the Georgetown herd, although the exact number killed each year is unknown (see Vehicle Caused Mortality section). Bighorn sheep are killed on the major roads throughout the DAU (Table 27). Prior to 2006, records of bighorn killed in collisions with vehicles are sporadic. From 2006 to May 2011, a concerted effort was made to record as much information as possible on each reported vehicle caused bighorn sheep mortality from this herd and to necropsy as many carcasses as possible. These reported mortalities are thought to represent 50% of the actual mortalities, as many go unreported.

Table 27. Number of vehicle caused mortalities reported and confirmed on each major road in S32 from 1991 to May 2011 and from 2006 to May 2011.

Road	1991 - May 2011	2006- May 2011
Interstate 70	68	35
Highway 6	31	19
Highway 40	17	6
Highway 119	12	1
Central City Parkway	4	2
Unknown	3	
Other	2	
Total	135	63

Figures 62 and 63 show the approximate location of each recorded vehicle caused mortality from the Georgetown bighorn sheep herd. The numbers around certain locations indicate the number of bighorn sheep killed at locations where multiple mortalities have occurred. In most cases specific locations were not recorded, instead a general description was given (e.g., I-70 mm 231). As the map shows, vehicle caused mortalities occur throughout the range of the herd and are fairly dispersed. This map does, however, identify a few areas where multiple mortalities have occurred and where it may be possible to reduce mortalities through mitigation efforts.

MORTALITY LOCATIONS

Table 28 lists the locations where there were at least 6 mortalities recorded from 1991to 2011. These are listed in descending order of the number of mortalities from 2006 to 2011.

Table 28. Locations of multiple bighorn sheep/vehicle collisions and the number of bighorn sheep mortalities 1991-May 2011 and 2006 - May 2011.

Location	1991 - May 2011	2006 - May 2011
I-70 US 40 WB Onramp	10	6
US 40 Empire Junction	13	5
Highway 6 mile marker 260	7	5
Highway 6 mile marker 258	6	5
I-70 Twin Tunnels	9	4
I-70 Dumont Exit	5	3
I-70 E of Twin Tunnels	4	3
I-70 Bakerville	4	2
I-70 W of Twin Tunnels	5	1
Highway 119 mile marker 0.5	11	0

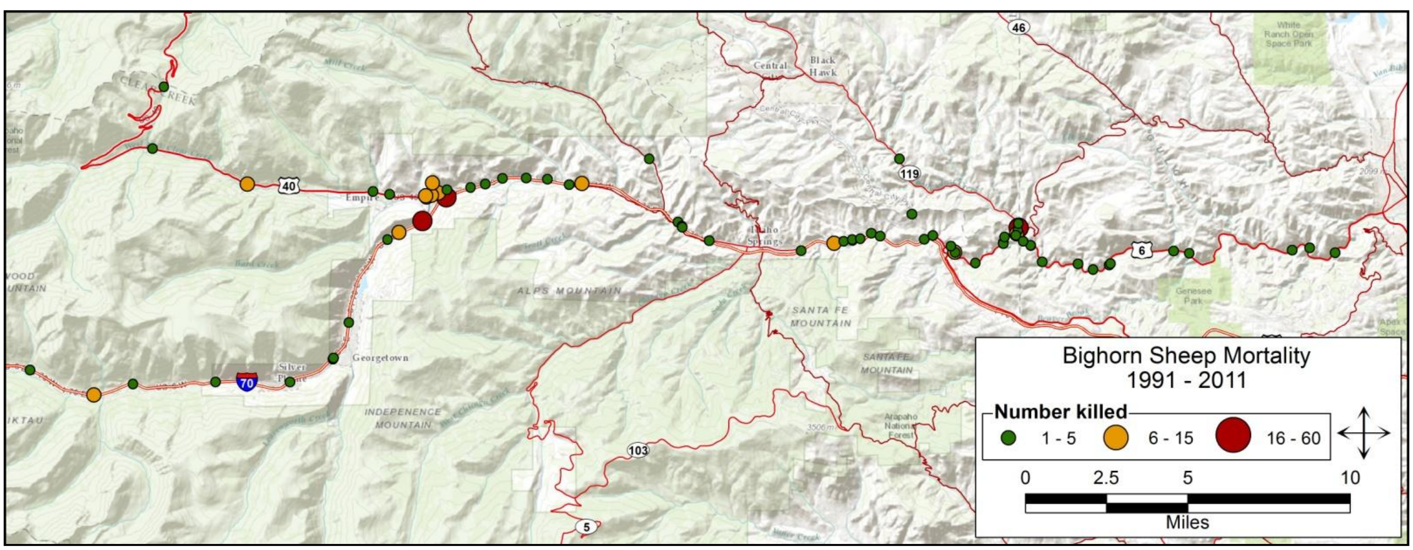

Figure 62. Locations of vehicle caused bighorn sheep mortalities from 1991 to 2010. The numbers indicate the number of bighorn sheep killed at each location where more than 1 bighorn was killed.

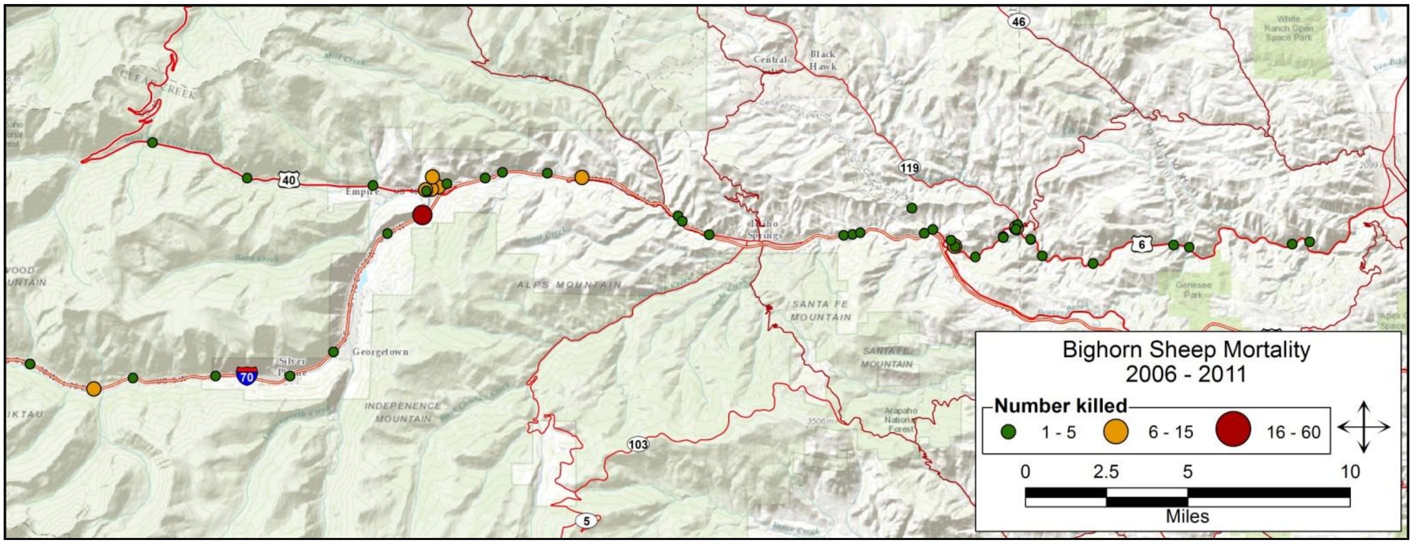

Figure 63. Locations of vehicle caused bighorn sheep mortalities from 2006 to 2010. The numbers indicate the number of bighorn sheep killed at each location where multiple sheep were killed.

REDUCING BHS VEHICLE COLLISIONS

The potential for mitigation efforts to reduce the number of vehicle collisions at each of these hotspots is site specific as are the possible mitigation strategies. There have been a number of reports on mitigation strategies for reducing wildlife vehicle collisions and the effectiveness of these strategies (Huijser, et. al, 2006, 2008, 2009, 2009). This section contains an assessment of the potential mitigation strategies for the locations listed in Table 28 where at least 3 bighorn sheep were recorded from 2006 to May 2011.

US Highway 40 Entrance Ramp onto Westbound Interstate 70

Figure 64. Aerial view of the US Highway 40 entrance ramp onto westbound Interstate 70. The orange circle indicates the area where bighorn sheep are stuck by vehicles.

Figure 64 shows the ramp from US Highway 40 onto westbound Interstate 70 between Empire and Georgetown. The orange circle indicates the area where bighorn sheep are killed in collisions with vehicles. This is the highest priority because more bighorn were killed at this location than any other from 1991-2011 (10) and from 2006-2011 (6). From 2006-2011, 4 collared ewes, 1 yearling ewe, and 1 adult ram were killed at this location. These mortalities occurred in March (1), April (2), May (4), July (1), August (1), and November (1). The majority of the bighorn sheep were probably hit by cars on this ramp as they try to cross the ramp to access vegetation between the ramp and I-70. They may also be hit standing on the shoulder licking salt or eating vegetation. Drivers may not notice bighorn sheep in time to avoid collisions because the drivers are: A) moving through a blind corner; and B) gaining speed while looking back at traffic on I-70 in preparation for merging (Fig. 65).

Figure 65. Bighorn sheep ewe killed in a collision with a vehicle at the bottom of the US Highway 40 entrance ramp onto westbound Interstate 70 on April 2, 2007. Photo by: Dawson Swanson.

Possible mitigation efforts at this location include:

1. Encourage bighorn sheep to cross at top of ramp where vehicles are traveling more slowly, drivers are looking ahead and there is no blind corner. Possible ways to achieve this are:
   a. Install wildlife deterrent system at bottom of ramp,
   b. Install guardrails at the bottom of the ramp.
2. Discourage bighorn sheep from crossing the ramp by making vegetation unpalatable to them in April and May.
3. Make bighorn sheep on shoulder/road more visible by:
   a. Installing lighting on the ramp. Currently there is lighting just west of the end of the ramp, so extending the lighting up the ramp may help illuminate bighorn sheep in low light situations. No information is currently available on the time of day that bighorn sheep are struck at this location. This would only be effective if bighorn sheep are being hit during low light times.
4. Alerting drivers to the possibility of bighorn sheep being on road by:
   a. Installing bighorn sheep crossing signs,
   b. Installing enhanced crossing signs, for example, "Caution: Bighorn Sheep on Ramp Next 100 Yards". This could be further enhanced with flags or flashing lights during critical times of the year (Fig. 66),
   c. Installing bighorn sheep detection and warning system similar to that used on Highway 6 in Golden. If a bighorn sheep is detected on the shoulder via a camera a lightboard tells motorists there are bighorn sheep on the highway.

Figure 66. Example of a sign used to alert drivers of the possible presence of bighorn sheep near the road.

5. Queue drivers on the ramp (install stop light) in order to slow cars down and encourage drivers to look ahead, this may only be necessary at peak bighorn sheep/vehicle collision times of year (April and May).
6. Slowing vehicles on the ramp until they are around the blind corner. This could be achieved by extending the entry ramp to the west.

US Highway 40 at Empire Junction

Figure 67. Aerial view of US Highway 40 at Empire Junction. The orange circle indicates the area where bighorn sheep are stuck by vehicles.

Figure 67 shows US Highway 40 at Empire Junction, just east of Empire. The orange circle indicates the area where bighorn sheep are killed in collisions with vehicles. There were 13 bighorn sheep recovered here from 1991-2011. From 2006-2011, 3 collared ewes and 2 uncollared ewes were killed at this location. These mortalities occurred in April (3), August (1), and December (1). The majority of the bighorn sheep are hit as they try to cross US 40. They are also hit standing on the shoulder licking salt or eating vegetation. Drivers may not see bighorn sheep in time to avoid collisions because of a blind corner (especially westbound), and do not see the bighorn sheep until it is too late. This bighorn sheep crossing is important to maintain because it is the only place where bighorn sheep cross US 40, thus the only link between the eastern and western portions of the herd.

Possible mitigation efforts at this location include:

1. Discourage bighorn sheep presence on shoulder by:
   a. Removing vegetation on the north side of the road,
   b. Making vegetation unpalatable by planting undesirable plants or treating current plants.
2. Changing bighorn sheep crossing behavior by building an overpass or underpass.
3. Making bighorn sheep on shoulder/road more visible by removing objects on side of road that obscure bighorn sheep (trees, large boulders, etc).
4. Alerting drivers to the possibility of bighorn sheep

being on road by:

a. Installing bighorn sheep crossing signs
b. Installing enhanced crossing signs, for example, “Caution: Bighorn Sheep on Ramp Next 100 Yards” (Fig. 66),
c. Installing bighorn sheep detection and warning system similar to that used on Highway 6 in Golden. If a bighorn sheep is detected on the shoulder via a camera a lightboard tells motorists there are bighorn sheep on the highway.
d. Reducing the speed limit in this area. The speed limit is 55 miles per hour through this section and 45 miles per hour just to the west. Extending the 45 mph zone through this section would give drivers more time to avoid collisions with bighorn sheep.

Highway 6 in Clear Creek Canyon at Mile Marker 260

Figure 68. Aerial view of US Highway 6 in Clear Creek Canyon near the junction with Colorado Highway 119. The orange circle indicates the area where bighorn sheep are stuck by vehicles.

Figure 68 shows the junction of Highways 6 and 119 approximately 10 miles west of Golden. The orange circle indicates the area where bighorn sheep are killed in collisions with vehicles. From 2006 through May 2011, 2 ewes and 3 rams were killed and recovered from this location. These mortalities occurred in April (1), June (1), August (1), October (1), November (1). The bighorn sheep killed at this location were trying to cross the road between 2 sections of their range. As the dates of mortalities indicate the bighorn sheep use both sides of the road for much of the year. At this location the bighorn sheep use the road as a bridge to cross the river. Due to the bridge configuration the bighorn sheep descend onto the roadway and then travel 75 yards along the road before they can ascend the other side; roughly indicated by the yellow line in the Figure 69. In addition, bighorn sheep movement onto and off of the roadway may be slowed due to guardrails, jersey barriers and difficult-to-negotiate substrate that they either have to negotiate or avoid. This increases the amount of time bighorn sheep spend on the roadway when they cross. Moreover, westbound drivers at this location are traveling through a blind corner, and eastbound drivers are possibly distracted by a lightboard, and multiple informational signs

Figure 69. Aerial view of US Highway 6 in Clear Creek Canyon at mile marker 260 near the junction with Colorado Highway 119. The yellow line indicates the approximate path used by bighorn sheep crossing the road.

Possible mitigation efforts at this location include:

1. Building an overpass or underpass.
2. Making bighorn sheep on shoulder/road more visible by:
   a. Installing lighting to make bighorn sheep more visible. No information is currently available as to the time of day that bighorn sheep are struck at this location. This would only be effective if bighorn sheep are being hit during low light times.
   b. Removing distracting signs on eastbound side that draw driver’s attention away from bighorn sheep. At the eastern end of the bighorn sheep crossing (indicated by yellow line in Fig. 69), there is currently a lightboard, ski area sign, casino information sign, stoplight ahead sign, Clear Creek sign, etc. These should be moved to a different area so that they do not distract driver’s attention from bighorn sheep on the road.
3. Alerting east- and westbound drivers to the possibility of bighorn sheep being on road by:
   a. Installing bighorn sheep crossing signs,
   b. Installing enhanced crossing signs, for example, “Caution: Bighorn Sheep on Ramp Next 100 Yards” (Fig. 66),
   c. Installing bighorn sheep detection and warning system similar to that used on Highway 6 in Golden. If a bighorn sheep is detected on the

shoulder via a camera a lightboard tells motorists there are bighorn sheep on the highway.

4. Making changes to the roadway to reduce the distance that bighorn sheep travel along road or to ease their movement onto and off of the roadway. If allowed by roadway safety standards, this could include changing guardrails and changing the Jersey barrier at the eastern end of the bighorn sheep crossing to make it more easily navigated.

Highway 6 at Mile Marker 258

Figure 70. Aerial view of US Highway 6 at mile marker 258. The orange circle indicates the area where bighorn sheep are stuck by vehicles.

Figure 70 shows the area approximately 1 mile east of the US Highway 6 / Interstate 70 junction (approximately 12 miles west of Golden). The orange circle indicates the area where bighorn sheep are killed in collisions with vehicles. From 2006 through May 2011, 3 ewes, 1 yearling ewe, and 1 lamb were killed and recovered from this location. These mortalities occurred in June (4) and July (2). The bighorn sheep killed at this location were probably foraging on the north shoulder rather than trying to cross the road. Drivers may not see bighorn sheep in time to avoid collisions because they are moving through a blind corner with rocks very close to the shoulder obscuring their view. Drivers are not able to see bighorn sheep on road until it is too late to avoid hitting them.

Possible mitigation efforts at this location include:

1. Discouraging bighorn sheep from being on the road by:
   a. Removing vegetation on shoulder
   b. Making vegetation less attractive
   c. Installing wildlife deterrent system
2. Removing any objects from the north side of the road that obscure driver's view. There is some vegetation that could be removed to improve visibility. However, most of the offending material in this location is rock, which would be expensive to remove.
3. Alerting drivers to the possibility of bighorn sheep being on road by:
   a. Installing bighorn sheep crossing signs
   b. Installing enhanced crossing signs, for example, "Caution: Bighorn Sheep on Ramp Next 100 Yards." This could be further enhanced with flags or flashing lights during June and July (Fig. 66),
   c. Installing bighorn sheep detection and warning system similar to that used on Highway 6 in Golden. If a bighorn sheep is detected on the shoulder via a camera a lightboard tells motorists there are bighorn sheep on the highway.

Interstate 70 Dumont Exit

Figure 71. Aerial view of the Interstate 70 Dumont exit. The orange circle indicates the area where bighorn sheep are stuck by vehicles.

Figure 71 shows the Dumont exit ramp from westbound Interstate 70 east of Dumont. The orange circle indicates the area where bighorn sheep are killed in collisions with vehicles. From 2006-2011, 1 yearling ewe, and 2 rams were killed at this location. These mortalities occurred in May (1) and November (2). The bighorn sheep killed at this location were either foraging on the north shoulder or trying to cross the road to get to the vegetation between the ramp and I-70. Drivers may not be able to see bighorn sheep in time to avoid a collision because of the high rates of speed of cars exiting I-70 and due to the vegetation close to the shoulder on the north side of the ramp.

Possible mitigation efforts at this location include:

1. Discourage bighorn sheep presence on eastern end of the ramp, where cars moving the fastest, by encouraging them to cross towards the western end of the ramp by:
   a. Removing vegetation from the easternmost point of the area between the ramp and I-70 and replacing it with a substrate the bighorn sheep

do not like to walk on. This may encourage bighorn sheep to cross the ramp further west.
   b. Making vegetation between the eastern end of the ramp and I-70 unattractive by treating current plants,
   c. Making vegetation between the eastern end of the ramp and I-70 unpalatable by planting undesirable plants,
   d. Installing guardrails on the east end of the ramp,
   e. Installing wildlife deterrent system on the eastern end of the ramp.
2. Making bighorn sheep on shoulder/road more visible by:
   a. Installing lighting to make bighorn sheep more visible. Presently there is lighting just east of the end of the ramp, so extending the lighting up the ramp may help illuminate bighorn sheep in low light situations. No information is currently available as to the time of day that bighorn sheep are struck at this location. This would only be effective if bighorn sheep are being hit during low light times.
   b. Removing clump of trees/shrubs on the north side of the ramp.
3. Alerting drivers to the possibility of bighorn sheep being on ramp by:
   a. Installing bighorn sheep crossing signs
   b. Installing enhanced bighorn sheep crossing signs

I-70 East of Twin Tunnels

Figure 72. Aerial view of Interstate 70 East of the Twin Tunnels near Idaho Springs where bighorn sheep are stuck by vehicles.

Figure 72 shows the area approximately 1 mile east Idaho Springs, just east of the twin tunnels. From 2006 through May 2011, 1 ewe, 1 ram, and 1 unknown sex bighorn sheep were killed and recovered from this location. These mortalities occurred in May (1), June (1) and July (1). The bighorn sheep killed at this location were probably foraging on the north shoulder rather than trying to cross the road. Drivers may not see bighorn sheep in time to avoid collisions because they are moving through a blind corner with rocks very close to the shoulder obscuring their view. Drivers are not able to see bighorn sheep on road until it is too late to avoid hitting them.

Possible mitigation efforts at this location include:

1. Discouraging bighorn sheep from being on the road by:
   a. Removing vegetation on shoulder
   b. Making vegetation less attractive
   c. Installing wildlife deterrent system
2. Removing any objects from the north side of the road that obscure driver's view. There is some vegetation that could be removed to improve visibility. However, most of the offending material in this location is rock, which would be expensive to remove unless incorporated into other road projects.
3. Alerting drivers to the possibility of bighorn sheep being on road by:
   a. Installing bighorn sheep crossing signs
   b. Installing enhanced crossing signs, for example, "Caution: Bighorn Sheep on Ramp Next 100 Yards" (Fig. 66),
   c. Installing bighorn sheep detection and warning system similar to that used on Highway 6 in Golden. If a bighorn sheep is detected on the shoulder via a camera a lightboard tells motorists there are bighorn sheep on the highway.

LITERATURE CITED

Huijser, M.P., P.T. McGowen, W. Camel, A. Hardy, P. Wright, A.P. Clevenger, L. Salsman and T. Wilson. 2006. Animal vehicle crash mitigation using advanced technology. Phase I: Review, design and implementation. SPR 3(076). FHWA-OR-TPF-07-01, Western Transportation Institute – Montana State University, Bozeman, USA. Available from the Internet: http://www.oregon.gov/ODOT/TD/TP_RES/ResearchReports.shtml

Huijser, M.P., T.D. Holland, A.V. Kociolek, A.M. Barkdoll and J.D. Schwalm. 2009. Animal– vehicle crash mitigation using advanced technology. Phase II: System effectiveness and system acceptance. FHWA-OR-TPF-09-14, Western Transportation Institute – Montana State University, Bozeman, USA.

Huijser, M.P., T.D. Holland, M. Blank, M. C. Greenwood, P. T. McGowen, B. Hubbard & S.

Wang. 2009. The comparison of animal detection systems in a test-bed: a quantitative comparison of system reliability and experiences with operation and maintenance: final report. Western Transportation Institute – Montana State University, Bozeman, USA. 123 pp.

Huijser, M.P., P. McGowen, A. P. Clevenger, and R. Ament. 2008. Wildlife-vehicle collision reduction study: best practices manual. Western Transportation Institute – Montana State University, Bozeman, USA. pp 174. Available from the Internet: http://www.fhwa.dot.gov/environment/hconnect/wvc/index.htm

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