HUMAN-WILDLIFE CONFLICTS AND BIGHORN RECOVERY

Bighorn Sheep Recovery, Collapse and Rescue on the Navajo Nation

NIKE J. GOODSON, *Stevens Wildlife Consulting, 15300 Horse Creek Road, Bozeman, MT, 59401, USA;* stevenswildlife@earthlink.net
DAVID R. STEVENS, *Stevens Wildlife Consulting, 15300 Horse Creek Road, Bozeman, MT, 59401, USA*
JEFFREY COLE, *Navajo Nation Department of Fish and Wildlife, Window Rock, AZ, 86515, USA*
JESSICA L. FORT, *Navajo Nation Department of Fish and Wildlife, Window Rock, AZ, 86515, USA*

ABSTRACT: In 1997 there were 31 desert bighorn sheep (*Ovis canadensis nelsoni*) in a single herd on the Navajo Nation. We identified cattle grazing and river-based recreation as limiting factors and reduced impacts of both during 1997 through 2000. During the next 13 years transplants initiated 2 new herds and the total population on the Navajo Nation increased to over 500 bighorn sheep. Lamb production and survival were consistently high from 2000 through 2013. In 2014 lamb survival declined precipitously in the Lower San Juan Canyon herd. In 2016 lamb survival declined steeply in the nearby Upper San Juan Canyon herd. Bighorn sheep tested positive for *Mycoplasma ovipneumonia*e (M. ovipneumoniae) in the Lower San Juan Canyon herd in 2015 and in all 3 herds on the Navajo Nation in 2018 and 2020. Poor lamb survival continued in both the Upper and Lower San Juan Canyon herds through 2021. During winter 2021-2022 we conducted a test and remove operation in the most severely impacted herd in the Lower San Juan Canyon. We also captured and tested ewes in the Upper San Juan Canyon. Surveys in fall of 2022 indicated increased lamb survival in both the Lower and Upper San Juan Canyon herds.

Biennial Symposium of the Northern Wild Sheep and Goat Council 24:41–52; 2024

KEYWORDS: desert bighorn sheep (*Ovis canadensis nelsoni*), lamb survival, *Mycoplasma ovipneumoniae*, Navajo Nation, San Juan Canyon herd, test and remove.

INTRODUCTION

From the beginning of field studies of bighorn sheep in North America populations have been subject to devastating declines separated by periods of population increase and range expansion (Smith 1954). Evidence indicates that *Mycoplasma ovipneumoniae* has been the dominant cause of declines in bighorn sheep populations in North America (Besser et al. 2012). The desert bighorn sheep herds on the Navajo Nation provide examples of healthy expanding herds where introduction of *M. ovipneumoniae* resulted in suddenly increased mortality of juveniles and long - term declines in recruitment. After over a decade of population increase, the initiation of 2 new herds on the Navajo Nation and an over 10-fold increase in the abundance of desert bighorn on the Navajo Nation, *M. ovipneumoniae* was introduced into one desert bighorn herd in the Lower San Juan Canyon. The infection was transmitted to the nearby Upper San Juan Canyon herd within 2 years. The population trajectory of both herds changed abruptly from increasing to declining. Lamb recruitment dropped to near zero and continued low. In the past wildlife management agencies responsible for bighorn sheep populations that were suffering long-term declines due to pneumonia had few options. Usually, bighorn sheep herds recovered without intervention; however, clearing *M. ovipneumoniae* from a herd can take decades and recovery is not assured (George et al. 2009). However, recently managers have been successful in clearing bighorn sheep herds of *M. ovipneumoniae* through capturing ewes, testing them for *M. ovipneumoniae* and removing those that test positive (Cassirer and Besser 2025). We attempted to arrest the decline in the Lower Canyon desert bighorn herd by capturing surviving ewes, testing them for *M. ovipneumoniae* and removing those that tested positive from the herd. We monitored fall lamb survival to determine success.

STUDY AREA

The study area was located in the San Juan River Canyon and Glen Canyon in southeastern Utah (Figure 1). The San Juan River formed the north boundary of the Navajo Nation within the ranges of the San Juan Canyon herds. In Glen Canyon the high water mark of Lake Powell was the Navajo Nation boundary. The Upper Canyon bighorn sheep range encompassed 113 km2 and included 30 km of the river canyon and a valley that extended about 4 kilometers south from the river. The Lower San Juan Canyon bighorn range was separated from the Upper Canyon by about 3 km of unsuitable terrain, a highway and the village of Mexican Hat. It encompassed 170 km^2 and included 55 km of river canyon. The Glen Canyon bighorn sheep range included 42 km of Lake Powell shoreline and encompassed 450 km2. Elevations ranged from 1128 m at Lake Powell to 1600 m on the rim above the Lower Canyon.

Bighorn sheep were native to both the San Juan River Canyon and to Glen Canyon. Populations in the Lower San Juan Canyon (below Mexican Hat) and in Glen Canyon were extirpated prior to 1970. The original native herd inhabited the San Juan River Canyon from Comb Ridge to the Mexican Hat Rock. At the initiation of our study in 1997 the bighorn sheep ranged nearly exclusively (with the exception of less than 10 observations of rams) on the Navajo Nation (south) side of the San Juan River. Later the Utah Department of Natural Resources transplanted bighorn sheep into locations north of the San Juan River and north of the San Juan Arm of Lake Powell on land managed by the Bureau of Land Management (BLM).

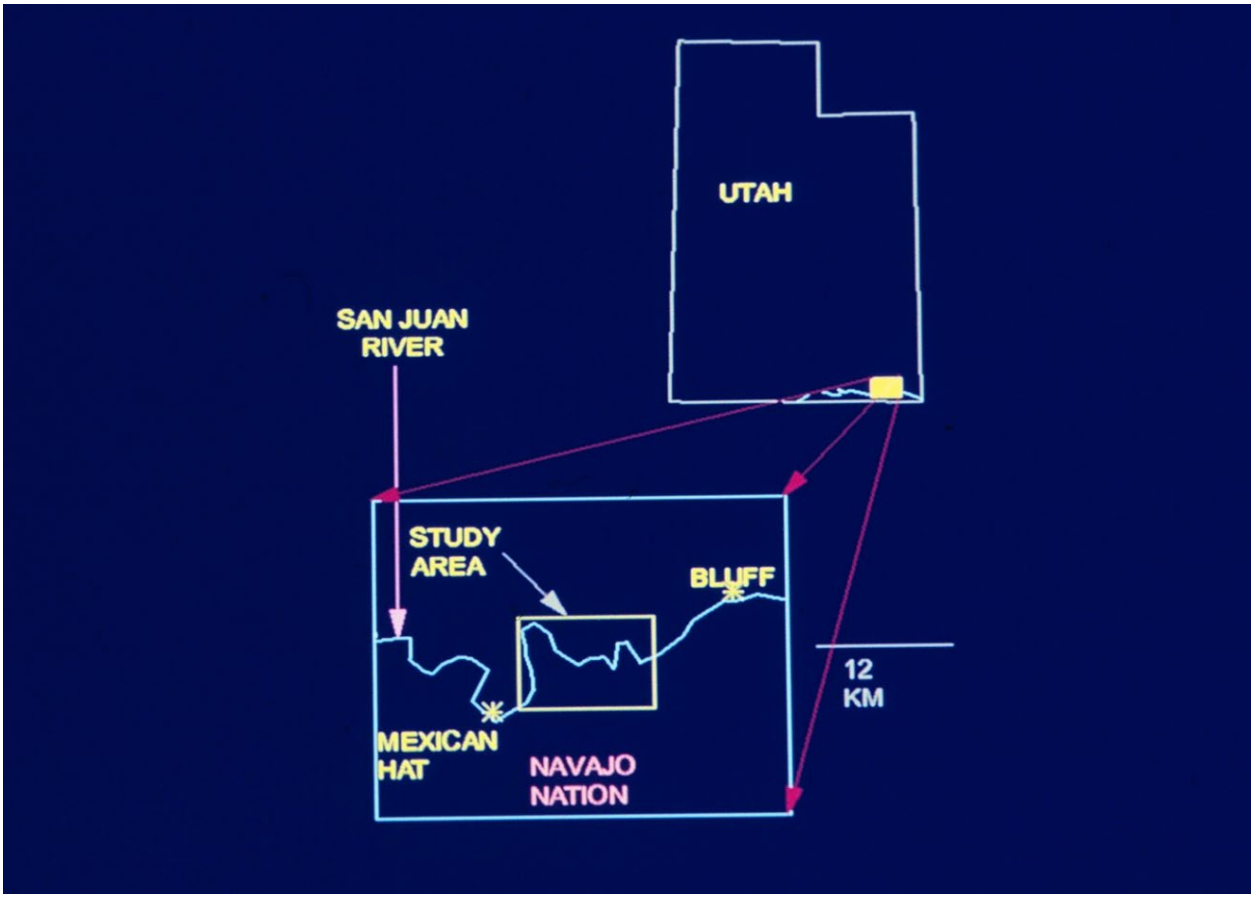

Figure 1. Location of the original, native herd in the Upper San Juan River Canyon in southeastern Utah.

Bighorn sheep were native to both the San Juan River Canyon and to Glen Canyon. Populations in the Lower San Juan Canyon (below Mexican Hat) and in Glen Canyon were extirpated prior to 1970. The original native herd inhabited the San Juan River Canyon from Comb Ridge to the Mexican Hat Rock. At the initiation of our study in 1997 the bighorn sheep ranged nearly exclusively (except for less than 10 observations of rams) on the Navajo Nation (south) side of the San Juan River. Later the Utah Department of Natural Resources transplanted bighorn sheep into locations north of the San Juan River and north of the San Juan Arm of Lake Powell on land managed by the Bureau of Land Management (BLM).

METHODS

At the initiation of the study in November 1996, 16 of 31 bighorn sheep in the Upper Canyon population were captured, ear tagged and fitted with VHF transmitters. Additional bighorn sheep in the Upper Canyon were collared and fitted with VHF transmitters in 1997, 2002, 2005, and 2011. In 2018 21 bighorn sheep were captured in the Upper Canyon. Nineteen were fitted with VHF and Iridium GPS transmitters and 2 with VHF only transmitters. Bighorn sheep carrying VHF transmitters were visually located on average once per week yearlong during 1997 and 1998. During 1999–2021, intensive fieldwork was conducted during spring (April through June) and for 2 months during fall (September through early December). We visually located radio collared bighorn sheep in the Upper Canyon herd or estimated their locations by triangulation 2–4 times per month during field periods 1999–2021. We programmed Iridium GPS units to return two locations per day 12 hours apart and to download location data twice per week. VHF and GPS collars were programmed to transmit a mortality signal if bighorn did not move for 6 hours.

We fitted 13 (11 ewes and 2 rams) of 24 bighorn sheep transplanted from the Upper San Juan Canyon herd to initiate the Lower Canyon in October 2003 with VHF transmitters. In 2010 20 bighorn sheep were transplanted to the Lower Canyon from the Upper Canyon in a supplemental transplant to expand herd range. We equipped 15 of these 20 sheep with VHF transmitters. In 2015 we captured 4 ewes and 1 ram equipped them with VHF transmitters and released them on the Lower Canyon range. We visually located or estimated by triangulation the locations of these bighorn sheep 1–2 times per month during field periods 2004-2021. In 2018 we captured 13 additional bighorn sheep and fit them with Iridium GPS transmitters and released them in the Lower Canyon.

In January 2008, 30 bighorn sheep were transplanted to Wetherill Canyon in Glen Canyon. We radio collared 20 of these transplants (17 ewes, 3 rams) with VHF transmitters. To expand their range, in 2015 we conducted a supplemental transplant of 14 bighorn sheep (12 of which, 10 ewes and 2 rams) were equipped with VHF and Iridium GPS transmitters into Mountain Sheep Canyon east of Wetherill Canyon. We located radio collared bighorn in Glen Canyon 1-2 times during spring field seasons and once during fall field seasons from 2008–2021.

For each visual observation, we recorded location, habitat use, movements, group size, sex-age composition, lactation status of ewes, association with a lamb for marked ewes, marked bighorn sheep present, and social behavior of marked and unmarked individuals. Interactions between bighorn sheep and domestic livestock, interactions between bighorn sheep and predators, and interactions between bighorn sheep and humans or humans with dogs were recorded. When we received a mortality signal, we attempted to locate the carcass and determine the cause of death. Causes of death were assigned based on observations of marked bighorn sheep prior to death and examination of the carcass and mortality site. When carcasses were found in good condition, we submitted the head and portions of the lungs to the Navajo Nation Veterinary Program for examination.

From 2010 on we collected nasal swabs and blood from all bighorn sheep captured and submitted them to the Washington Animal Disease Diagnostic Laboratory (WADDL) for PCR and Elisa testing for *M. ovipneumoniae*. We surveyed potential transplant areas on the Navajo Nation using fixed wing and helicopter aerial surveys, and boat-based surveys. Minimum population sizes were estimated by locating as many as possible of the bighorn ewes with active radio collars within a time span that precluded interchange among groups and counting them and their marked and unmarked associates. To this total we added the number of marked individuals known to be on the study area that were not observed. We estimated the number of adult rams based on the observed ratio between adult rams and ewes during the rut.

RESULTS

The original population in the Upper San Juan River Canyon in 1997 was 31 bighorn sheep. In 1997 cattle grazed virtually the entire river corridor through the bighorn range and the central area of the bighorn range. A gate to protect the bighorn range from poaching was vandalized and a ram was killed illegally. We observed bighorn displaced from the river corridor by boaters with dogs and boaters camping in areas critical to the bighorn for river access and lamb rearing. Our first recommendations were to construct barriers to protect most of the river corridor in the bighorn range from cattle grazing, negotiate an end to cattle grazing in the center of the bighorn range, repair gates to limit access and discourage poaching, eliminate dogs from accompanying boaters through the bighorn range and close overnight camping in critical areas used by bighorn for access to the river and lamb rearing (Goodson et al. 1999). Barriers were erected in the canyon to prevent cattle access to approximately 80% of the river corridor through bighorn range. An agreement was reached with Navajo grazing authorities to eliminate cattle grazing in the central area of the bighorn range. We were fortunate that there were no valid Navajo Nation grazing permits within the river corridor in the bighorn range. Two areas of the river corridor where we observed ewes with young lambs accessing the river to drink and which were used disproportionately by ewes rearing lambs were closed to overnight camping administratively by the Navajo Nation to protect the bighorn from disturbance (Goodson et al. 1999). The BLM managed recreation on the San Juan River and incorporated information on the closures in the information they provided to permit applicants. BLM river rangers met river runners at the launch sites to check permits and patrolled the river enforcing regulations. Based on our concerns the BLM eliminated dogs from accompanying boaters through the Upper Canyon bighorn range making the river and riparian vegetation more accessible for the bighorn. The Navajo Department of Fish and Wildlife facilitated repair and fortification of the 2 gates controlling access into the bighorn range.

The herd grew from a pre-lambing minimum of 31 in March to a fall estimate of 37 in 1997. In 1998 the herd grew to a minimum of 45, in 1999 to a minimum of 56, in 2000 to at least 61, in 2001 to minimum of 65, in 2003 to at least 85. Excellent mean annual survival of adult ewes during 1997-2001 (0.97, 90% CL 0.93, 1.00) was important to population growth. Mean annual survival of adult rams was lower 0.86 (90% CL 0.75, 0.97). Survival of lambs from birth through fall declined from 0.80, 90% CL 0.67, 0.93 (1997-1998) to 52%, 90% CL 0.40, 0.64 (2000, 2001) (Goodson et al. 2002). By 2002 the herd had grown to sufficient size to enable us to consider expanding bighorn sheep presence on the Navajo Nation through establishment of a second herd. We also recommended limited permit hunting of mature rams beginning in 2001.

In 2001 a single ram permit was sold by the Navajo Department of Fish and Wildlife through the Foundation for Wild Sheep. Over the next decade hunting was expanded to three tags for trophy rams through auctions and fourth permit was assigned through a lottery for tribal members.

Bighorn sheep transplants and movements

We began surveys in the San Juan Canyon below Mexican Hat (Lower San Juan Canyon) to assess its suitability as a transplant location in 2002. The Lower San Juan Canyon was a continuation of the Upper San Juan Canyon with similar vegetation and topography. The Lower Canyon was approximately twice the length of the Upper Canyon but had more limited side canyons. We found records of bighorn in the Goosenecks of the Lower Canyon from as recently as the mid-1960's (Wilson 1968) but no sign of current occupancy by bighorn sheep. Suitable bighorn sheep habitat in the Lower San Juan Canyon was separated by only 3 km of unsuitable terrain, a highway (US 163), and a small town, Mexican Hat, Utah from the Upper San Juan Canyon range.

In fall 2003 24 bighorn sheep were captured in the Upper Canyon and released in the Lower Canyon. The release site was 40 river miles (40 km straight line) from the range of the source herd in the Upper Canyon. Captured bighorn were trucked to the canyon rim and slung by helicopter about 1 km into the canyon. The new herd increased to a minimum count of 90 bighorn sheep in 2010. In December 2010 we transplanted 14 bighorn sheep from the Upper Canyon to the Lower Canyon to expand the new herd's range down canyon and reduce density in the Upper Canyon range. These bighorn were released 60 river miles and 50 straight line kilometers from the source herd range. Bighorn in the Lower Canyon were counted during 2-4 river trips each year. Our highest count of bighorn sheep from the river was 59 in 2008, 50 in 2010, 107 in 2011, and 137 in 2012. Weather conditions influenced counts with

higher counts achieved in hot, dry conditions when bighorn concentrated near the river. We estimated the Lower Canyon herd to include at least 150 bighorn sheep in 2013.

In 2005 we began the search for another release site. We conducted aerial and boat-based surveys of the San Juan Arm and south (Navajo) side of Lake Powell. We selected Wetherill Canyon as a transplant site due to its extensive habitat, distance from domestic sheep grazing and access to water. In January of 2008 we transplanted 30 bighorn sheep from the Upper San Juan Canyon to near the mouth of Wetherill Canyon in Glen Canyon. The release site was 120 km from the range of the source herd. We trucked the bighorn sheep in crates to the end of the closest road on the west side of Navajo Mountain. From there the bighorn were slung by helicopter about 20 km to the release site near the mouth of Wetherill Canyon.

In January 2015 we made a second transplant of bighorn sheep from the Upper San Juan Canyon herd to Glen Canyon. Fourteen bighorn sheep were released at the mouth of Mountain Sheep Canyon east of Wetherill Canyon to extend the range of the transplant herd and reduce density on the Upper San Juan Canyon herd range. From 1997 to 2013 desert bighorn sheep populations on the Navajo Nation grew from 31 bighorn in a single herd to over 500 bighorn sheep in three herds (Figure 2).

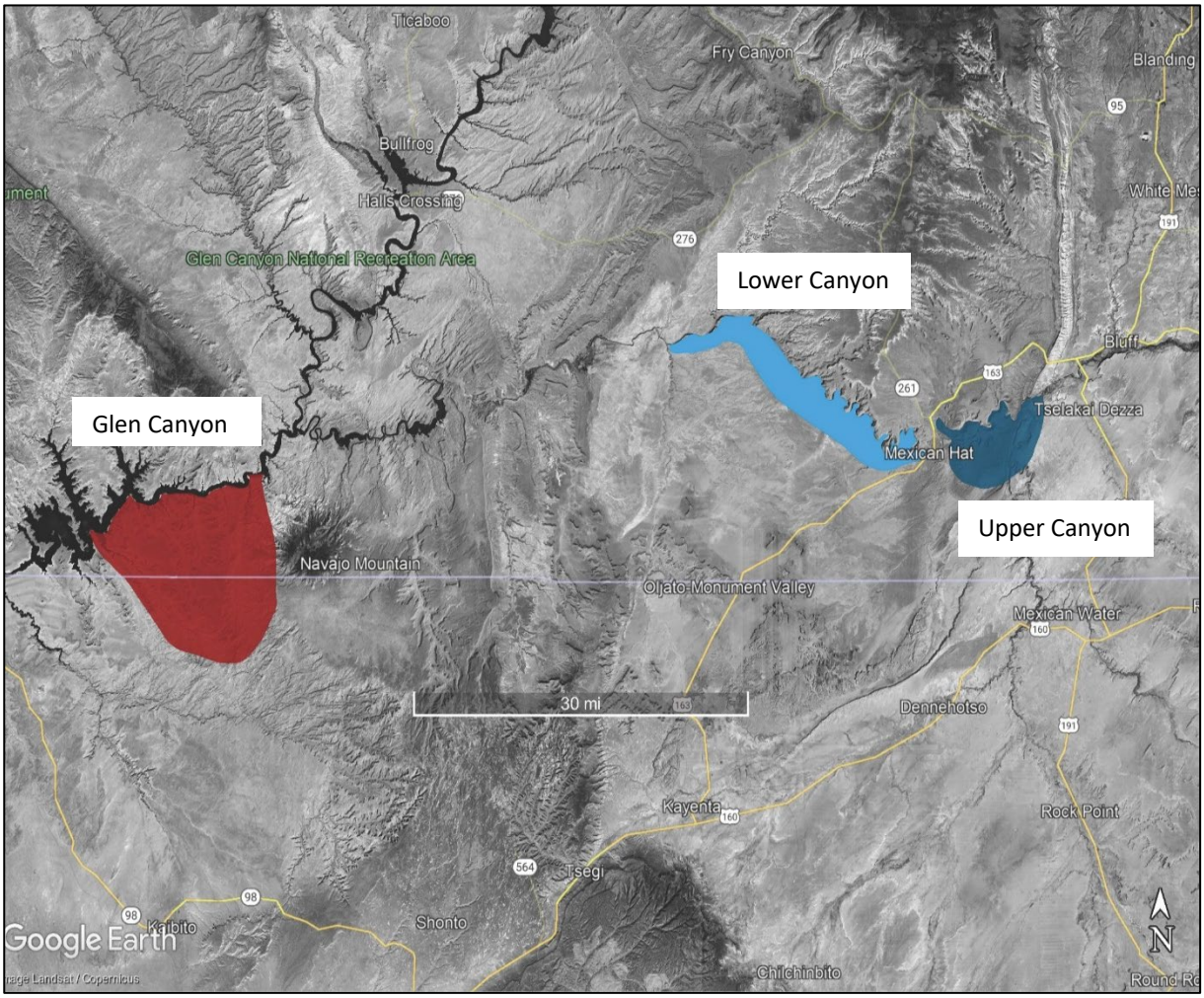

Figure 2. Locations of desert bighorn herds on the Navajo Nation.

In 2008 the Utah Department of Wildlife Resources (UDWR) released 30 bighorn sheep into John's Canyon across the San Juan River from the Lower Canyon herd. The initial release was followed by supplemental releases into John's Canyon in 2013 (16 bighorn sheep) and 2014 (6 bighorn sheep). In 2013 the UDWR released 49 bighorn at Nokai Dome on the San Juan Arm of Lake Powell about 50 km from the Glen Canyon herd and about 40 km from the Lower Canyon herd (pers. comm. Jace Taylor, UDWR, April 18, 2019) (Figure 3). The John's Canyon herd range was about 40–55 km south of ranges of the Red, White and Dark Canyon herds that had suffered die offs in the 1980s and had not recovered (pers. comm. Jace Taylor UDWR April 18, 2019) (Figure 3).

We radio tracked and observed bighorn rams crossing the San Juan River to the north (BLM) side and returning to the Navajo (south) side in both the Upper and Lower Canyon ranges. The UDWR (Annette Rouge pers. comm. April 17, 2015, pers. comm. Dustin Mitchell, UDWR, April 29, 2019) recorded radio collared rams moved from the transplanted herd in John's Canyon north to the range of the Red Canyon herd and returned to John's Canyon. GPS locations from bighorn sheep we released at Mountain Sheep Canyon in Glen Canyon showed at least two rams and two ewes crossed Lake Powell to the north shore at the Kaiparowitz plateau and returned to Mountain Sheep Canyon. At least 2 other radio collared rams travelled south to a domestic sheep flock on Navajo Canyon about 40 km from the area used regularly by radio collared ewes of the Glen Canyon herd. We also received a report of two rams crossing US highway 163 moving from the Upper to the Lower San Juan Canyon near Mexican Hat, Utah (pers. comm. Rick Boretti, BLM, October 2012) (Figure 4).

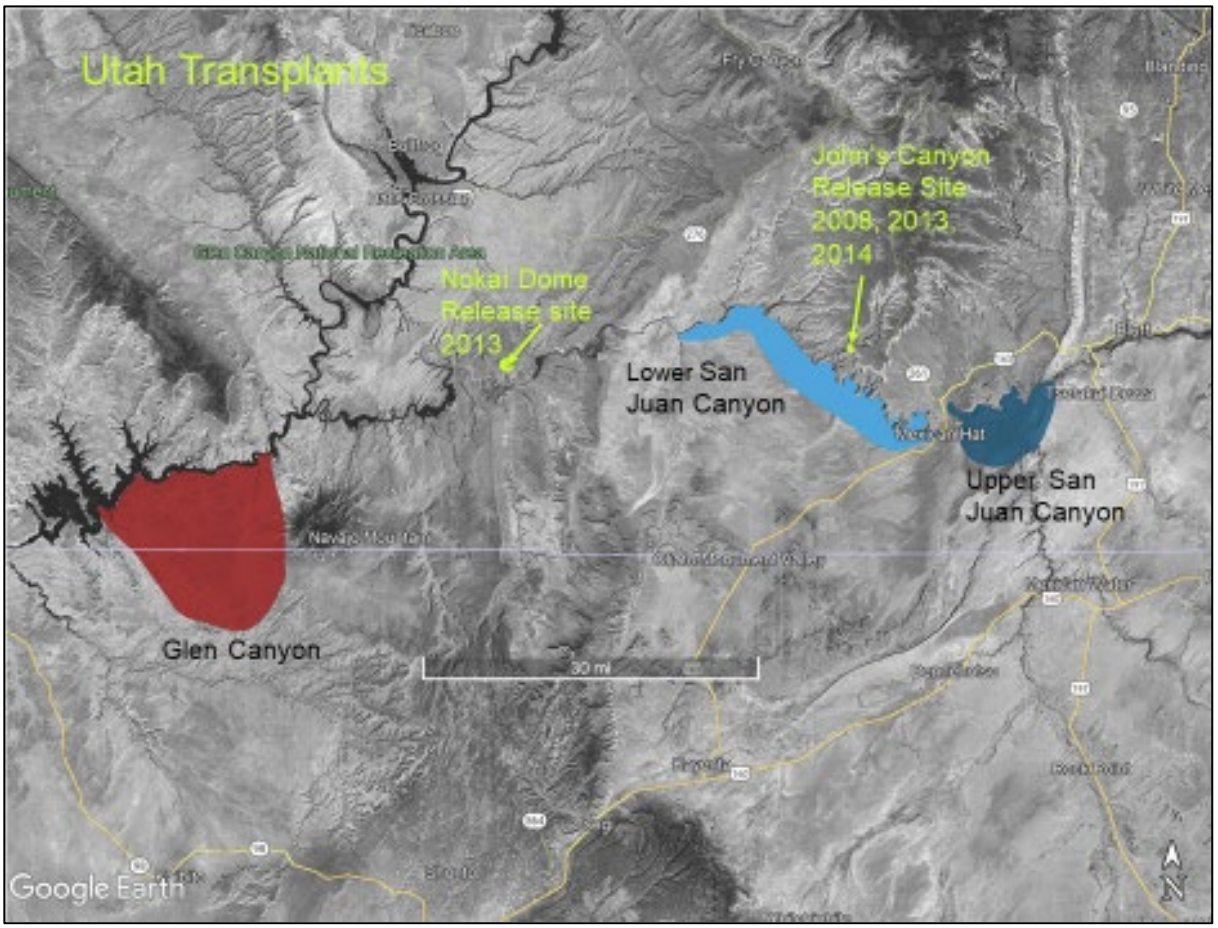

Figure 3. Utah Department of Wildlife Resources transplants of desert bighorn sheep near the Navajo Nation.

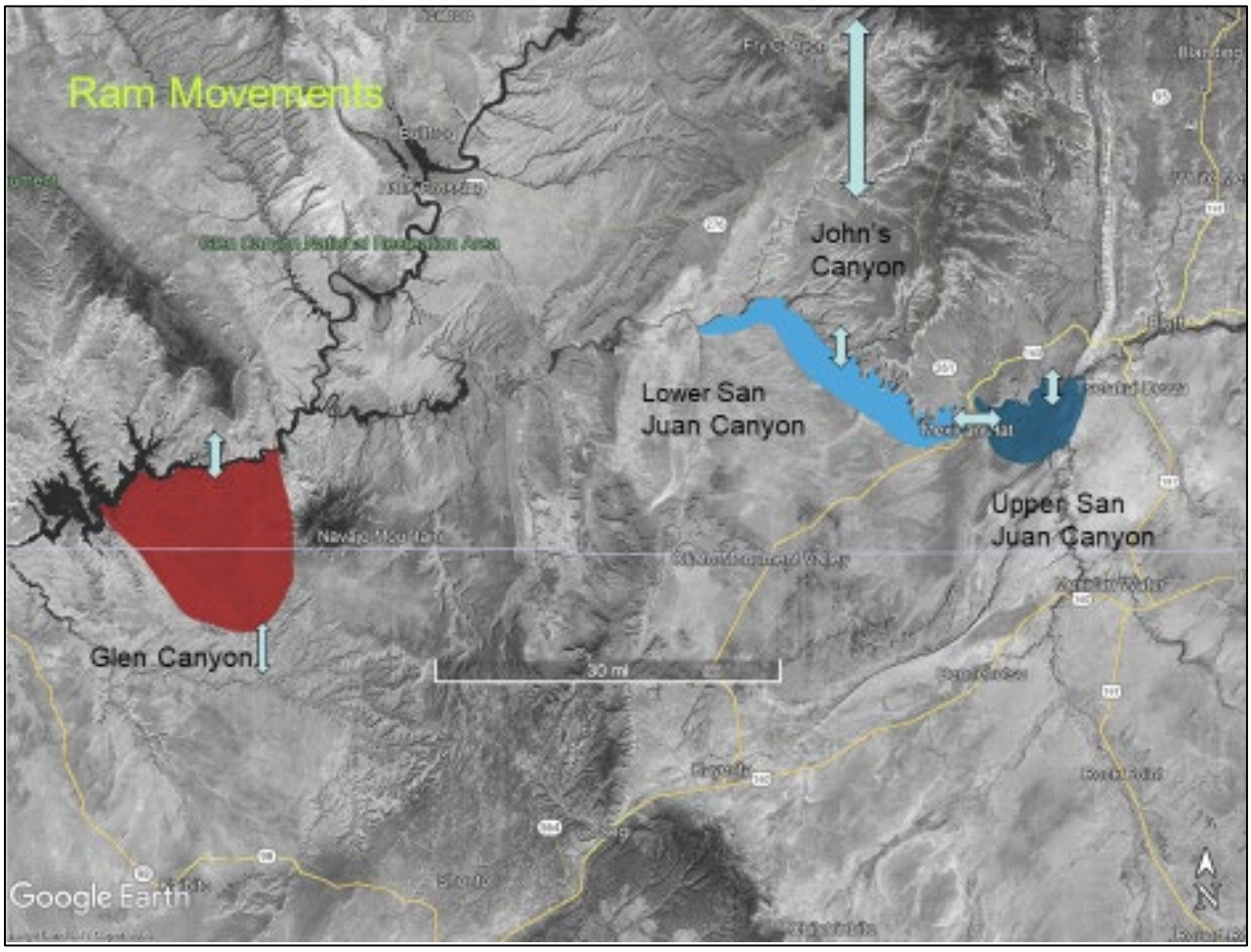

Figure 4. Ram forays outside core ranges 2000–2014.

Population declines and disease testing

In the Lower Canyon lamb:ewe ratios in October ranged from 0.7 to 1.0 during 2004-2013. In October 2014 we observed 20 ewes and 0 lambs. In the Upper Canyon fall lamb:ewe ratios were consistently over 50 percent from 1997 through 2015. Typical ratios were observed in December 2014 (0.78) and December 2015 (0.62). In 2016 we observed 29 ewes in December and 4 lambs (lamb:ewe ratio 0.24). In December 2017 we observed 38 ewes and no lambs. In the Glen Canyon the lamb:ewe ratio in October before Movi infection (2015–2017) averaged 0.62. After infection (2019–2020) the average fall lamb:ewe ratio declined to 0.39.

All bighorn sheep captured in the Upper Canyon in 2010 (N=20) tested negative for *M. ovipneumoniae*.

After the decline in lamb survival observed in 2014 we captured 5 bighorn in the Lower Canyon and tested them for *M. ovipneumoniae*. All 5 were positive for Movi by both Elisa and PCR indicating exposure and active infections. In 2015 we captured and tested 16 bighorn sheep from the Upper Canyon and all were negative for Movi on PCR and Elisa. In 2018 M. ovipneumoniae was detected using PCR in all three herds (Upper Canyon N=18, Lower Canyon N=13, Glen Canyon N=8). The proportion of bighorn testing positive were Lower Canyon (0.92), Glen Canyon (0.38) and Upper Canyon (0.20). In 2020 bighorn captured in all three herds tested positive for Movi using PCR (Lower Canyon, N=10, 50% detected, Upper Canyon, N= 29, 28% detected, Glen Canyon, N=50, 6% detected (Figure 5).

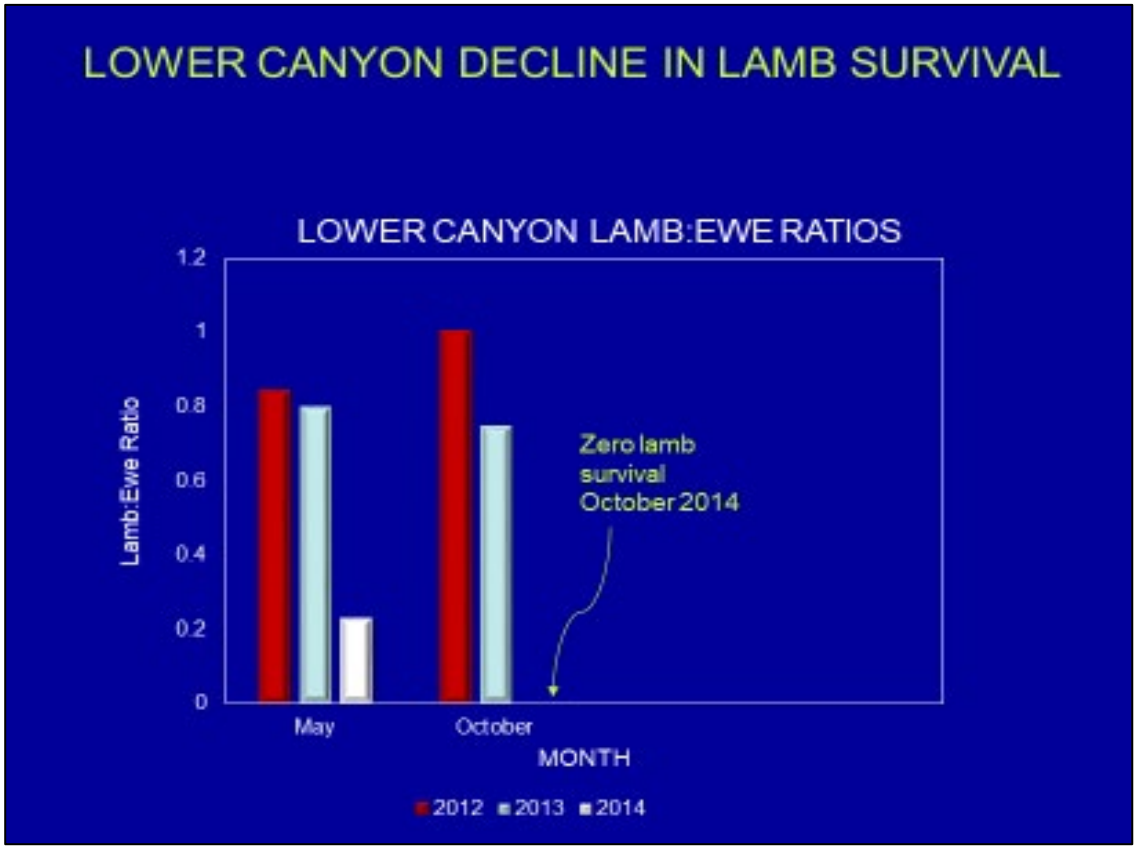

Figure 5. Lower Canyon spring and fall lamb:ewe ratios 2012–2014.

In the Lower Canyon population estimates declined from 174 in 2012 (minimum count 137) to 46 (minimum count 33) in 2020. In the Upper Canyon population estimates declined from 320 (minimum count 189) in 2016 to 100 (minimum count 63) in 2020. We estimated the Glen Canyon herd remained stable at about 300 bighorn sheep from 2017-2020 based on stable minimum counts in Wetherill and Mountain Sheep Canyons (2015, 93; 2016, 88; 2018, 74; 2019 95; 2020, 91) and lamb recruitment (fall lamb:ewe ratios 2015, 0.64; 2016, 0.67; 2017, 0.54; 2019, 0.52; 2020, 0.26).

Strain-typing, based on 4 loci, was conducted by WADDL on samples provided in 2018 and 2020. Strain 1 was shared between the Upper and Lower San Juan Canyon and Nokai Dome (a Utah transplant herd across the San Juan Arm of Lake Powell and over 30 km distant from both the Lower Canyon and Glen Canyon herds). This confirmed that at least one strain (Strain 1) was transmitted from the Lower to the Upper Canyon and indicated the same strain crossed the San Juan River. Strain 2 was identified in Glen Canyon and was shared with the Kaiparowits herd on the other side of Lake Powell indicating that this strain crossed Lake Powell. Strains 3 and 4 were identified in the Lower and Upper Canyon herds and did not match any other strains. Earlier trees provided by WADDL based on the same data using IGS found a match between the Lower Canyon and John's Canyon herds and indicated Strain 4 in the Upper San Juan Canyon was identical with Strain 1 shared with the Nokai Dome and the Lower Canyon herds (Figure 6).

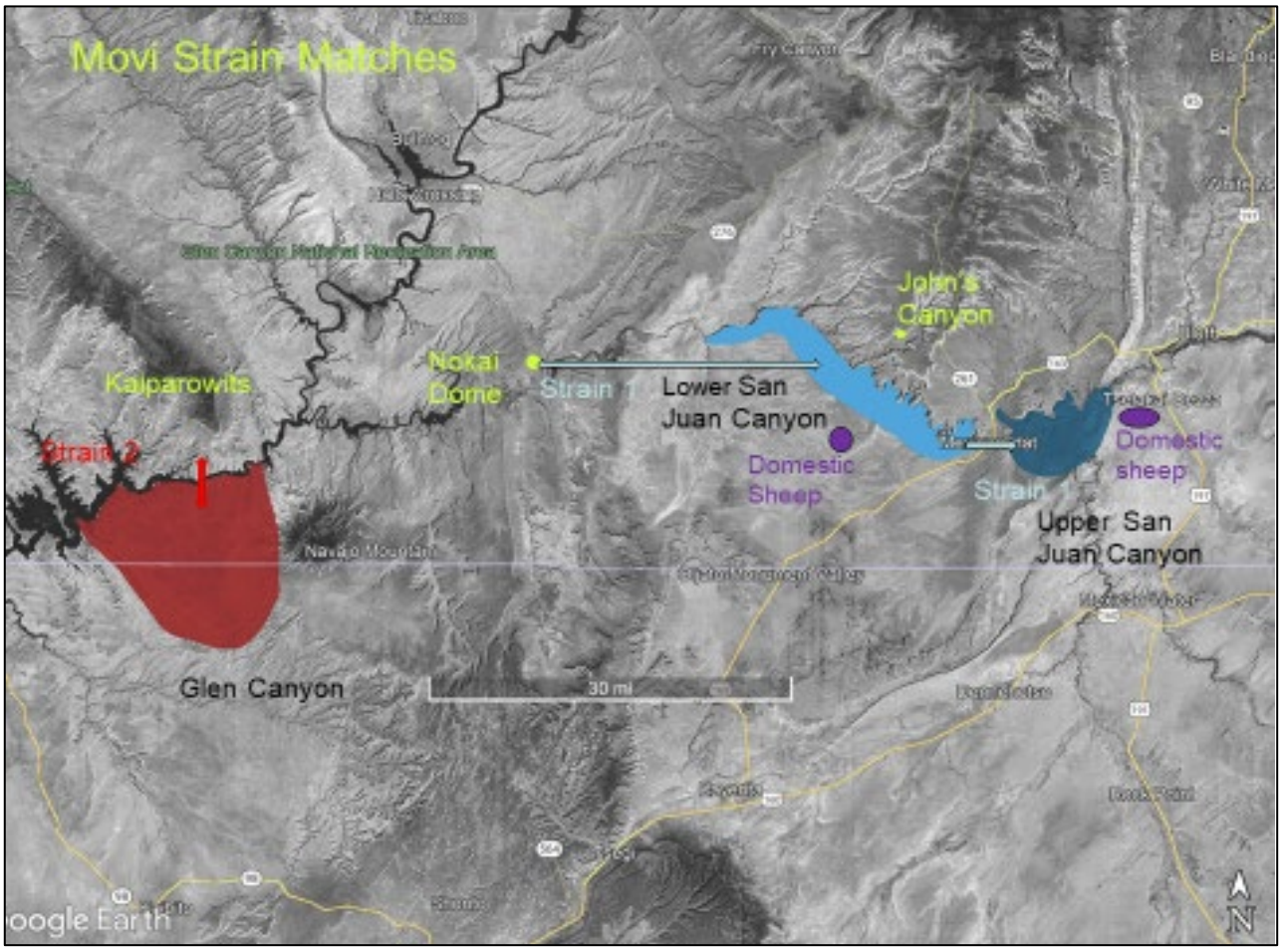

Figure 6. Strain matches among bighorn sheep herds on the Navajo Nation and nearby bighorn sheep herds in Utah.

Local domestic sheep flocks were tested for *M. ovipneumoniae* in 2012 (all domestic sheep in 3 flocks containing 14, 24, and 50 sheep, respectively). Over half (54%) of the domestic sheep were positive for *M. ovipneumoniae* using PCR. Samples from domestic sheep were strain tested by WADDL in 2021 and no matches were found between strains identified in bighorn sheep tested in 2018 or 2020 and strains identified in local domestic sheep flocks.

Navajo domestic sheep flocks are typically grazed near homesteads. Flocks often include goats and sheep and are usually accompanied by dogs. Navajo sheep ranchers usually pen their flocks at night. These precautions are needed to protect flocks from feral dogs which are common on the Navajo Nation and coyotes. They may also serve to reduce the risk of close contact between bighorn sheep and domestic sheep. We also received one unverified report that bighorn rams observed close to Navajo domestic sheep were shot because of a Navajo belief that the bighorn ram would transmit disease to their flock.

A domestic sheep flock grazed within 1.5 km of the Upper Canyon bighorn range from 1997-2021. No domestic sheep flocks grazed within 4 km of the Lower Canyon herd range from 2002–2021. However, strain testing and timing of lamb mortality indicate that the Lower Canyon was infected with *M. ovipneumoniae* before the Upper Canyon and transmitted at least one strain to the Upper San Juan Canyon herd. All captured Upper Canyon bighorn (N=16) tested negative for *M. ovipneumoniae* in 2015, after Lower Canyon ewes lost their entire 2014 lamb crop and all 5 bighorn captured in the Lower Canyon in 2015 tested positive for *M. ovipneumoniae*.

In 2021–2022 we conducted a capture, test and remove operation to clear the Lower Canyon herd of *M. ovipneumoniae*. Three helicopter capture operations were required to capture all surviving ewes in the Lower San Juan Canyon. Bighorn hid under ledges after the first hour of capture and capture

success declined. A total of 13 bighorn ewes were captured, 8 ewes tested positive for *M. ovipneumoniae* and 5 ewes tested negative. All ewes testing positive were removed from the population during a fourth helicopter operation.

In October 2022 for the first time since 2013 ewes in the Lower Canyon raised healthy lambs. The 5 surviving ewes were observed with 3 lambs in October, a lamb:ewe ratio of 0.60. Ewes in the Upper Canyon (N=20) were captured and tested for *M. ovipneumoniae*, (5 positive, 25%), however, none was removed. In December of 2022 we observed 5 healthy lambs and a total of 23 ewes in the Upper Canyon. The fall lamb:ewe ratio in the Upper Canyon (0.22) was the highest observed since 2016.

DISCUSSION

Chronic or acute pneumonia in bighorn sheep related to infection with *M. ovipneumoniae* has been implicated in many bighorn sheep declines and die-offs. It has caused increased adult mortality and severe and persistent declines in lamb survival (Besser et al 2012). Infections of M. ovipneumoniae typically cause all-age die-offs followed by low lamb survival. This pattern is caused by differential immune competency in adult and juvenile bighorn sheep. Adult bighorn sheep have stronger immune systems than lambs. Some ewes that survive the initial die-off clear the infection. Other ewes survive but are not able to clear the infection and continue to shed bacteria. It is these carrier ewes that maintain the disease in the population. Lambs receive passive immunity from their mothers through suckling. However this protection is short lived. Lambs typically develop pneumonia between 2 weeks and 2 months of age and most succumb before they reach 3 months of age. Persistent pneumonia in lambs had caused long term declines in bighorn sheep populations and led to extirpation of some herds (Besser et al. 2012, Besser et. al. 2021). Infection with *M. ovipneumoniae* was associated with near zero lamb survival in the Lower San Juan Canyon herd from 2014 through 2021 and with poor lamb survival in the Upper San Juan Canyon herd from 2016–2021.

The likely sources of *M. ovipneumoniae* infection in the Lower Canyon were bighorn sheep that the UDWR transplanted across the river from the Lower Canyon into John's Canyon in 2008. At least 2 rams from the John's Canyon herd moved north and contacted bighorn of the Red Canyon herd (Annette Roug, UDWR, pers. comm. April 17, 2015; pers. comm. Dustin Mitchell, UDWR, April 29, 2019). The Red Canyon herd and nearby White Canyon and Dark Canyon herds underwent pneumonia die-offs in the 1980's and 1990's following an introduction of domestic sheep into the range of the Dark Canyon herd. None of these herds have recovered. They remain at a population level less than half of pre-die-off abundance (pers. comm. Jace Taylor, UDWR, April 18, 2019, personal communication Dustin Mitchell, UDWR, April 29, 2019). Bighorn rams crossed the San Juan River in the Lower Canyon and move between the Lower and Upper Canyons. It is likely that rams moving across the river infected the Lower Canyon herd in 2013-2014. In 2015-2016 1 or more rams likely moved from the Lower Canyon to the Upper Canyon infecting the Upper Canyon herd with *M. ovipneumoniae*. Strain matches confirmed that the Lower Canyon and Upper Canyon herds share at least one strain of *M. ovipneumoniae* and that the same strain is present across the San Juan River in Utah bighorn sheep herds. The John's Canyon and Nokai Dome herds in Utah that share Movi strains with the Navajo San Juan Canyon herds have experienced low lamb survival similar to the Lower and Upper San Juan Canyon herds (personal communication Jace Taylor, UDWR, April 18, 2019).

Infection with *M. ovipneumoniae* was confirmed in the Glen Canyon herd in 2018. Strain testing indicated that bighorn sheep from Glen Canyon crossed Lake Powell and were infected by bighorn sheep on the Kaiparowitz plateau that use the opposite shore of Lake Powell. Movements of GPS equipped bighorn confirmed that both ewes and rams crossed Lake Powell near the mouth of Mountain Sheep Canyon where Lake Powell is at least 0.8 km wide and returned to Mountain Sheep Canyon. Thus Glen Canyon bighorn were infected with a different strain of *M. ovipneumoniae* that our data indicated had less severe impacts on survival of lambs and adults.

Recent publications have documented successful efforts to recover bighorn herds infected with M. ovipneumoniae (Garwood et al. 2020, Besser et al. 2021, Cassirer and Besser 2025, Weyand et al. 2025). In the past wildlife management agencies responsible for bighorn sheep populations that were suffering long-term declines due to pneumonia had few options to deal with the situation. Usually bighorn sheep herds recover without intervention; however, clearing *M. ovipneumoniae* from a herd can take decades and

recovery is not assured (George 2009). Use of improved disease testing has provided better information on the course of the disease and suggested alternative management. Results of research on *M. ovipneumoniae* epidemiology in the Hells Canyon metapopulation of Rocky Mountain bighorn sheep suggested testing of bighorn sheep to identify carrier ewes could be useful in management (Cassirer et al. 2020). Two types of tests are commonly used: blood tests that determined antibodies (Elisa) in blood that indicate prior exposure to the disease and PCR tests on nasal swabs that indicate bighorn that are shedding bacteria in their nasal passages. The PCR test permits identification of bighorn sheep that continue to shed bacteria maintaining Movi in the population and causing persistent lamb mortality (Cassirer et al. 2020).

Weyand et al. (2018, 2025) presented results from experiments in which bighorn ewes that tested positive for *M. ovipneumoniae* on PCR were removed from groups of captive bighorn ewes and from free-ranging herds. Lambs survived in pens with no carrier ewes and in free-ranging herds where carrier ewes were removed. All lambs died in pens including carrier and non-carrier ewes. It was not necessary to cull rams. Rams join ewes during the rut when lambs are about 6 months old and lamb immune systems have matured so that most survive a *M. ovipneumoniae* challenge. Removal of carrier ewes succeeded in increasing lamb survival in penned studies and in free-ranging bighorn sheep herds in Hells Canyon, Montana and South Dakota (Cassirer et al. 2017, Garwood et al. 2020, Besser et al. 2021, Cassirer and Besser 2025, Weyand et al. 2025). Lamb survival rebounded in the Lower Canyon herd following removal of ewes that tested positive for *M. ovipneumoniae* providing preliminary evidence for population recovery.

MANAGEMENT IMPLICATIONS

When transplanting into or near ranges occupied by other bighorn sheep consider transplanting only ewes. Our first transplant to Glen Canyon in 2008 was into unoccupied bighorn range and none of the transplanted bighorn with radio collars moved large distances or swam Lake Powell.

We recommend multiple years of capture and testing to determine whether ewes carry *M. ovipneumoniae* consistently and removing only ewes that test positive at least twice for *M. ovipneumoniae* in 2 different years. Capturing testing and removing in one year may result in removing ewes that are not consistent carriers. We received different result for 2 nasal swabs collected from the same ewe during a single capture. We recommend testing 2 nasal swabs per ewe for *M. ovipneumoniae* using PCR, considering only ewes that test positive on both swabs as positive for *M. ovipneumoniae*, and removing only ewes that test positive on both swabs for at least 2 years. An objective of capturing 60–80 percent of ewes each year and capturing and testing over several years would provide more reliable results and result in fewer ewes removed. Monitor fall lamb survival to determine success. A fall lamb:ewe ratio of greater than 50 percent would indicate a recovering herd.

We recommend intensive field monitoring on bighorn sheep ranges with high levels of recreation and/or livestock use to determine conflicts and develop mitigation strategies. In our study field monitoring determined areas where erection of barriers would eliminate cattle from extensive areas of river canyon and identified areas critical to bighorn for access to water and riparian vegetation.

REFERENCES

Besser, T. E., M. Highland, K. Baker, E. F. Cassirer, N. J. Anderson, and J. M. Ramsey. 2012. Causes of pneumonia epizootics among bighorn sheep, western United States. Emerging Infectious Diseases, 18(3), 406-414.

Besser, T. E., E. F. Cassirer, A Lisk, D. Nelson, K. R. Manlove, P. C. Cross and J. T. Hogg. 2021. Natural history of a bighorn sheep pneumonia epizootic: source of infection, course of disease, and pathogen clearance. Ecology and Evolution 11:14366-82.

Cassirer, E.F., K. R. Manlove, E. S. Amberg, P. Kamath, M. Cox, P. Wolff, A. Roug, J. Shannon, R. Robinson, R. B. Harris, R. K. Plowright, P.J. Hudson, P. C. Cross, A. Dobson, and T. E. Besser. 2017. Pneumonia in bighorn sheep: Risk, reservoirs, and resilience. Journal of Wildlife Management 82:43-35.

Cassirer, E. F. and T.E. Besser. 2025. Outcomes of selective removals of for control of pneumonia in a bighorn sheep metapopulation. Ecology and Evolution 15: 70869-83.

Garwood, T. J., C. P. Lehman, D. P. Walsh, E. F. Cassirer, T. E. Besser, J. A. Jenks. 2020. Removal of chronic

Mycoplasma ovipneumoniae carrier ewes eliminates pneumonia in a bighorn sheep population. Ecology and Evolution 10:3179-3573.

George, J. L., R Kahn, M. W. Miller and B Watkins, Eds. 2009. Colorado Bighorn Sheep Management Plan 2009-2019. Special Report 81. Colorado Division of Wildlife.

Goodson, N.J., D.R. Stevens, 1999. Effects of river-based recreation and livestock grazing on desert bighorn sheep on the Navajo Nation. Transactions *of* North American Wild Sheep Conference 2: 123-132.

Goodson, N. J., D. R. Stevens, 2002. Survival rates and causes of mortality in a desert bighorn sheep population on the Navajo Nation. Transactions *of* Desert Bighorn Council 46:18-24.

Smith, D. R. 1954. The bighorn sheep in Idaho. Wildlife Bulletin No. 1. Idaho Department of Fish and Game, Boise, ID.

Weyand, L. K., E. F. Cassirer, and T. E. Besser. 2018. Fatal pneumonia in bighorn sheep lambs: the critical role of *Mycoplasma ovipneumoniae* carrier ewes. Proceedings *of* Biennial Symposium Northern Wild Sheep and Goat Council 21:113.

Weyand, L. K., B. L. Felts, E. F. Cassirer, J. A. Jenks, D. P. Walsh, T. E. Besser. 2025. Fatal interactions: Pneumonia in bighorn lambs following experimental exposure to carriers of Mycoplasma ovipneumoniae. Journal of Clinical Microbiology. 2025 2:1328-34 *https://doi.org/10.1128/jcm.01328-24*.

Wilson, L. O. 1968. Distribution and ecology of the desert bighorn sheep in southeastern Utah. M.S. Thesis. Utah State University. *https://doi.org/10.26076/a4b7-40a5*