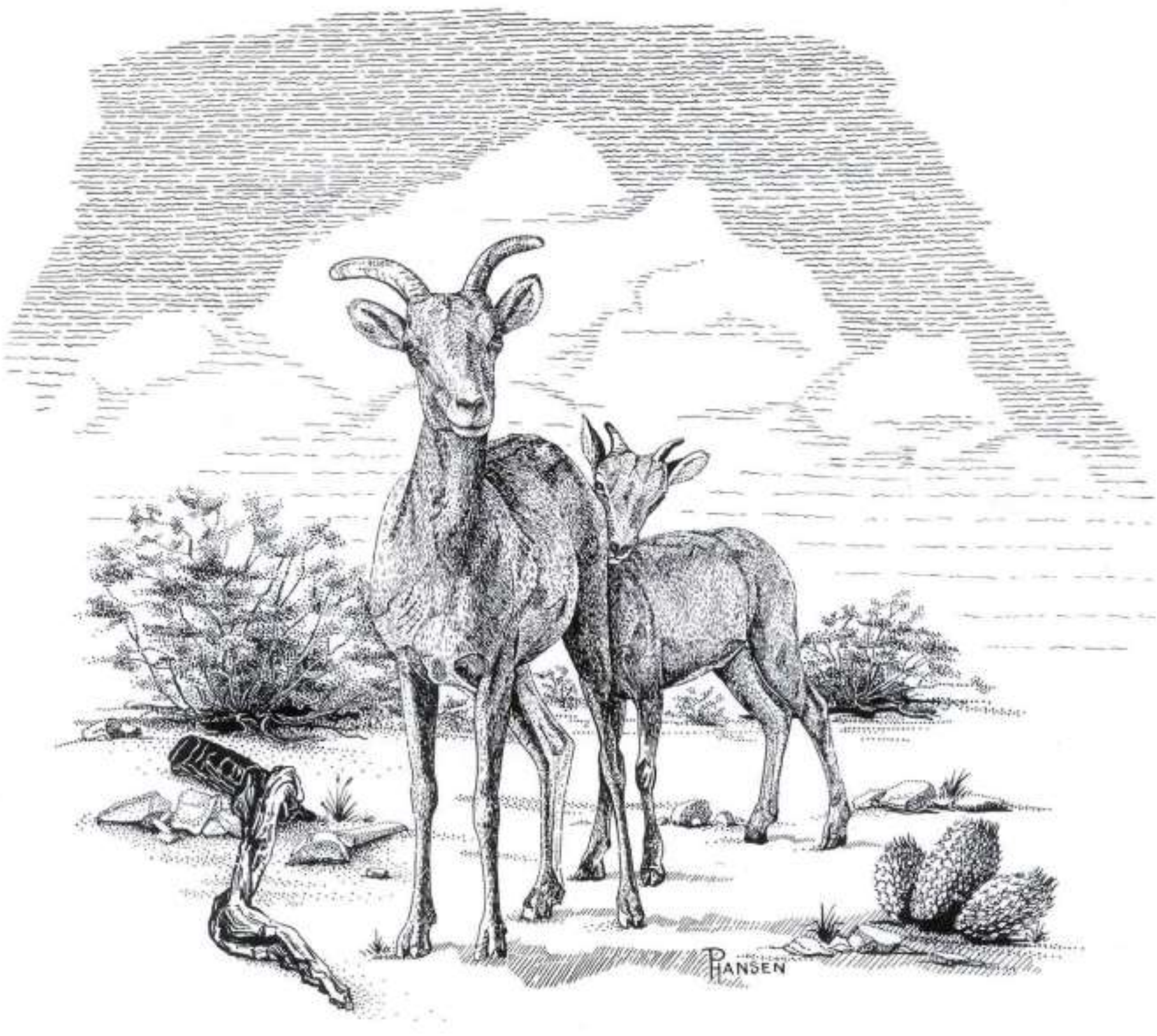
DESERT BIGHORN COUNCIL TRANSACTIONS



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Desert Bighorn Council Transactions
2017

A Compilation of Papers Presented at the
54th Meeting

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2017

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In Memoriam

Richard A. Weaver
1926 – 2017

Some Meaningful Words Regarding the Passing of Richard A. Weaver (1926-2017)

Upon the announcement of Dick Weaver's passing, many individuals whom he had known or worked with for as many as 5 decades provided individual tributes in recognition of his accomplishments and dedication to the conservation of desert bighorn sheep. To emphasize the value of Dick's friendship and knowledge to so many, and the esteem in which he was held, those tributes appear below. Following these short, albeit meaningful statements, are more detailed tributes from three of Dick's closest colleagues that were presented at the 54th meeting of the Desert Bighorn Council in St. George, Utah during April 2017.

Glenn Sudmeier, who worked closely with Dick for >40 years writes of the importance of Dick's relationship with the Society for the Conservation of Bighorn Sheep (SCBS), and the collaborative role both played by the California Department of Fish and Game (CDFW) and SCBS in advancing the conservation of those iconic animals. Rick Brigham, a wildlife biologist who retired from the Bureau of Land Management and worked closely with Dick for several decades, pays tribute to Dick's relationship with the Desert Bighorn Council, an affiliation that lasted 60 years. Upon Weaver's 1989 retirement from the California Department of Fish and Game, Steve Torres succeeded Dick as the statewide coordinator for bighorn sheep management, and he recounts many of Dick's contributions to that agency. Please read the many individual comments that were received immediately following Dick's passing. He was respected and admired by many, as noted in the passages below.

"As I sit here and … write a few [words] of my own there are tears in my eyes. Today Doris lost her love, and I lost my hero, and the bighorn lost the best friend they've ever had. Need I say more?"—*Glenn Sudmeier, Society for the Conservation of Bighorn Sheep*

"There are not many real biologists left anymore. It reminds me of my father-in-law's B-24 flight crew; there are only 2 remaining, including John, and they are the best of the best!! Dick was also among the best of the best!!"—*Bob Schaefer, California Department of Fish and Game*

"Tis a sad day indeed. I am sure it is also a sad day for the bighorn sheep of the world."—*Terri Stewart, California Department of Fish and Game*

"A very sad day."—*Bruce Garlinger, Eremico Biological Services*

"[Dick was] a symbol of a different time, a different Department, and plenty of good work. This upcoming DBC won't be the same."—*Regina Abella, California Department of Fish and Game*

"Good man. He lived a long and productive life."—*Valerius Geist, University of Calgary*

"I remember well he was of the common sense, we can DO wildlife management in the field and a paper/pencil guy … and luckily [he] got out before the computer age took over! I am certain the Desert is better off for Dick Weaver having been a part of its conservation and management through the years; and, certainly, wild sheep are as well."—*Eric Loft, California Department of Fish and Game*

"This is a very sad news, like losing another family member."—*Steve Torres, California Department of Fish and Game*

"[Dick] has been an incredible resource for bighorn sheep and many other wildlife species for quite some time and his legacy spans decades and states."—*Brian Wakeling, Nevada Department of Wildlife*

"… some of us always had a bit of jealousy that such a fine individual, who obviously gave so much and cared so deeply, was there to provide influence and guidance that increased the contributions … others provided. Our thoughts are with his family and all those lives he touched."*—Dan Yparraguirre, California Department of Fish and Game*

"I'm so sorry to hear of our friend's passing."—Andy Pauli, *California Department of Fish and Game*

"I'm sure I share with many of you the wonderful mentoring, guidance and inspiration Dick so generously offered us. Love the man and will miss him forever. Every time we see a bighorn he'll come to mind and he'll be with us out on the desert trails."*—Mark Jorgensen, California Department of Parks and Recreation*

"So sorry to hear of Dick's passing. I thank him for so much help during my career. Sheep have lost a true warrior on their behalf."*—Nancy Andrew, California Department of Fish and Game*

"A tribute to Dick is the same, wonderful experience of him that we all share... A passionate advocate for bighorn sheep and other desert life. A man with stories about every hill and old building we might pass while driving anywhere with him. A person who did it the hard way, wearing out his boots to learn the habits of sheep when there was no money to cover surveys and research. Someone who inspired all who knew him to work hard for the resource. He will be missed."*—Jeanne Scarmon, California Department of Fish and Game*

"Yes, this is sad news. But, not the end of an era. As long as there are bighorn sheep in California, Dick Weaver will be here."*—Charlie Jenner, DVM*

"Losing Dick really hurts. He and Marvin [Wood] are two very special people who held such a special place in our minds and hearts. I can't imagine a Sheep event without him. Bless him."*—Steve Hill, Society for the Conservation of Bighorn Sheep*

"A long and productive life indeed! I credit Dick as the catalyst who sparked my long-time interest in and research on mountain sheep."*—Rob Ramey, Wildlife Science International*

"Dick was among the five most influential men in my life — from both personal and professional perspectives."*—Vern Bleich, California Department of Fish and Game*

"End of an era."*—Dave Jessup, California Department of Fish and Game*

"Just got word… Dang."*—Bud Adams, California Department of Fish and Game*

"I'm old enough to feel the makings of a sob deep in my chest upon the news of his passing."— *Harley Shaw, Arizona Game and Fish Department*

"I submit that Weaver did not leave a few footprints [on the path of wildlife management]; instead, he established the path of wildlife management for desert bighorn sheep in the American southwest, a path that others will be following for many decades to come."— *Rick Brigham, Bureau of Land Management*

Thank you, Mr. Bighorn. Long may you run.

Vernon C. Bleich

A Tribute to Dick Weaver: Thank You, Mr. Bighorn, From the Society for the Conservation of Bighorn Sheep

As I look back over the years that Dick Weaver and the Society for the Conservation of Bighorn Sheep (SCBS) worked together the following comes to mind. Dick's association and relationship with SCBS began in 1968 when he accepted a new position with the California Department of Fish and Game (CDFG), as principal investigator into the status of bighorn sheep in the deserts of California. Dick's interest in and commitment to bighorn sheep conservation continued in an uninterrupted and productive way until his recent passing.

One of Dick's earliest contributions after accepting his new position was his insistence that extremely large culverts be installed beneath Interstate Highway 40 to encourage passage of bighorn sheep across what would become a barrier to movement following its construction. Further, he successfully argued for the installation of two wildlife water sources, one at the south end of the Bristol Mountains and one at the north end of the Marble Mountains, and the use of bighorn-friendly fencing, in those areas. These recommendations were among the earliest efforts to mitigate human impacts to bighorn sheep, impacts that would later become pervasive with the construction of additional interstate highways and other barriers in the deserts of the southwestern United States.

In 1970, as part of his ongoing work on bighorn sheep, Dick collaborated with SCBS to create the Volunteer Desert Water and Wildlife Survey. During the summer of that same year he organized in excess of two hundred SCBS volunteers to go into the desert and report on waterhole conditions and use by bighorn sheep at the numerous sites that he personally selected. From that initial effort was born the SCBS Area Captain Program and the periodic 4th of July waterhole counts, both of which continue today.

Dick Weaver's groundbreaking, and now legendary, work on bighorn sheep gave, and has continued to give, SCBS life, legitimate purpose, direction, and longevity. In 1984, Dick came to SCBS with an idea for a campaign he called "10,000 by 2000" or, in other words, 10,000 bighorn sheep in California by the year 2000. More than an actual goal, it was designed to be a talking point to reinvigorate supporters and keep the ball rolling in the direction of our mutual goals. And it worked; it raised awareness, money, and bighorn numbers.

In 1986 Dick addressed the California State Legislature in an attempt to reclassify desert bighorn sheep as a game animal in order to enhance funding and management opportunities. The legislature listened and Dick won, which eventually opened many other doors. In 1987, when the first Bighorn hunting season in 114 years was established, Dick came to SCBS with the idea of providing future bighorn sheep hunters with an award that would focus on the taking of the oldest rams, not necessarily the largest rams. Dick's idea was transformed into the "Patriarch Award" and, from the first season forward, it has been presented annually to the hunter harvesting the oldest ram.

During Dick's 43-years with CDFG he was a highly valued speaker at numerous SCBS Annual Membership meetings and a regular contributor of articles to the Society's original periodical, "The Sheepherder." From the end of Dick's professional career with CDFG through his transition into retirement there was no interruption or change in his interests and activities with SCBS and bighorn sheep. Shortly after his retirement, Dick accepted an offer to become the Society's first science adviser, a position he continued to hold until his passing.

Dick's generosity was immense, in that for many years he allowed himself and a week of his time to be auctioned off to the highest bidder for a "Wildlife Week" involving desert bighorn sheep, and he always donated the auction proceeds to SCBS. For a period of time, and before retirement took him out of California, he made himself available to the public by offering a service called "Desert Experiences" that included consulting, illustrated wildlife lectures, desert adventures, and photography excursions. Following his move to New Mexico, he attended every Society meeting possible, and he continued to provide numerous interesting articles for the "Sheep Sheet," the current SCBS periodical.

Throughout his years with CDFG and his retirement years, Dick remained a constant and tireless supporter of SCBS and one of his many "Weaverisms" addressed his motive well. "The only thing that makes government move is pressure from the private sector." The Society has, from time to time, done just that.

There are many other things Dick did on a personal level, and with many SCBS members. For example, I don't think there was a week that went by in more than forty years that Dick didn't call or drop me a line on something related to bighorn sheep, like an unusual sighting or a long forgotten green spot in some mountain range that just happened to come to mind. The topics were almost as numerous as his calls and notes. His constant contact among members kept us all going.

Yes, Mr. Bighorn has crossed the Great Divide. But, among us who remain, he has left a magnum of accomplishments and memories that all of us old Sheepers will graze on until our own eternities arrive.

Glenn W. Sudmeier, Society for the Conservation of Bighorn Sheep

In Remembrance of Dick Weaver

Everyone who has ever been to a DBC meeting will notice the absence of an important leader of this organization, Dick Weaver. At the last meeting he sat right up front. With one exception, Dick attended every meeting since the DBC was founded in 1957. Why did he miss the one meeting? Simple, because he had a boss who prohibited him from going. In a way, this represented the priorities of CDFG at the time, and desert bighorn sheep were not one of them. Dick Weaver's career and leadership changed that and, even in retirement, he continued to support this organization and encourage good work.

I'm honored to be delivering this tribute, and I will do my best to provide a statement that reflects the positive influences that he had on many people. Dick began his career in CDFG in 1948 and over the following 69 years, he never really quit. In addition to his work, Dick was a decorated wounded WWII veteran and a dedicated family man. He was 91 years old when he passed away.

Like many of you, I was fortunate to have Dick as a mentor and friend. Just as Dick inspired me, I've remained active in the DBC and bighorn sheep conservation even after moving to other jobs and responsibilities. I think it is fair to say I am a second or third generation mentee of Dick, since there were so many before me. Dick inspired numerous professionals and many equally passionate volunteers. These individuals were also mentors to me, and I try to be that with others. Thus, the second and third generations and beyond are part of Dick's legacy, all of whom will continue working on behalf of desert bighorn sheep.

At the 1996 DBC meeting in Holtville, California Dick began his keynote address with the following statement. He said, "One of the good things about getting old is that people think you are wise, and the girls think they are safe." Dick always had a way of getting one's attention, even if it was semi-inappropriate. He had a Yogi Berra quality with many quotable quotes that you will still hear. In their simplicity, though, there was also wisdom. We all know how he often said "Do what's best for bighorn sheep." In the management of desert bighorn sheep, Dick was a pioneer, an innovator, and a leader. He was an advocate for the desert as a special place; it was not a wasteland to neglect.

Pioneer and Innovator

In California, Dick is credited with establishing CDFG's bighorn sheep program. "Boots on the ground," as he would describe the effort. Dick was involved in some of the first surveys to inventory bighorn sheep populations in California and, in the late 1960s and early 1970s led the first comprehensive effort to evaluate bighorn sheep habitat and populations on a statewide basis. He published the results in a series of 14 detailed reports, and they remain an important reference even today. I once asked Dick if he minded if I referred to these early reports as historical. He responded, "Only if you don't mind being hit with my cane."

Dick participated in the development and success of the DBC, because he recognized that desert sheep management was bigger than just California. The DBC is one of the oldest wildlife conservation organizations in the U.S. that has held annual (now biennial) meetings and published the transactions of those meetings since its inception. Dick was a foundational participant and he saw the DBC as an important way to elevate bighorn sheep conservation.

Dick also recognized water resources as one of many important habitat components, and he initiated the first projects to improve water availability. He realized that his California state agency couldn't do it alone, so he supported using volunteers. He was instrumental in the establishment of the Society for the Conservation of Bighorn Sheep (SCBS). In 1986 Dick was co-author of the legislation that provided for the first bighorn sheep hunting in California in over 100 years.

Dick helped lead the first translocation of bighorn sheep in California in October 1971. Both he and Chuck Hansen drove a vehicle nonstop transporting 10 bighorn sheep (2 rams, eight ewes) from British Columbia to Lava Beds National Monument in northeastern California. Jim Blaisdell noted in his report to the DBC that they carried a permit that he completed that read "*United States Department of Agriculture Report of Animals, Poultry, or Eggs for Importation.* "*It listed the bighorn as follows: Number=10; Breed=bighorn sheep; purpose of importation=Well if all goes well, we'll be doing fine*!" This pioneered the way for many more future translocations to restore historical populations. Dick was involved with many of these.

If you go back and read the early DBC transactions, you can see that Dick's cohort of early wildlife managers used a holistic, multi-pronged approach that emphasized all the important elements of desert bighorn management: habitat, disease, restoration of historical populations, predation, competition from burros, and water restoration or development.

In addition to desert bighorn sheep, Dick also pioneered the earliest mountain lion assessments and research in California. Many don't know that Dick was the one who radio-collared the first mountain lion in California. He shared his story with two new CDFW employees who are now leading a statewide mountain lion project. This storytelling happened at a breakfast last December (2016) and once again, he connected history with the present.

Another example of Dick's innovation was his advocacy for the use of helicopters, which led to the first range-wide radio-collaring of bighorn sheep. Dick was a good friend of Don Landells of Landells Aviation in Desert Hot Springs, California and together they flew over many mountain ranges for surveys and habitat projects. Dick supported work with veterinarians to help look at the exposure and distribution of various diseases in bighorn sheep. He recognized the importance of good data and science and was a facilitator, supporter, and motivator.

Dick survived a tragic helicopter accident in October of 1986 in the Clark Mountains in which Don Landells and BLM wildlife biologist Jim Bicket were killed. This was a very difficult time, but the accident resulted in the adoption of important safety procedures that improved communication, flight following, and flight safety equipment.

Leader

I've been thinking about what it takes to be a mentor, because that's what Dick was. In remembering Dick, I came to realize that the best mentors don't realize they are mentors, because he certainly didn't! Humility, kindness, and a welcoming nature – these are all characteristics that greatly influence and inspire others. Dick put his ego aside to be open to "do what's best for bighorn sheep." He would often utter these words during challenging times or periods of passionate disagreement and this always seemed to simplify the decision. "Do what's best for bighorn sheep."

Everyone was Dick's friend. He was a wonderful human being and he leaves a permanent mark on behalf of desert bighorn sheep. He influenced both the profession and professionals. He was a leader and he was a "conservation conscience" for desert bighorn sheep. That's a big statement and if Dick were here to hear me say that, he would no doubt hit me with his cane.

In the very first published Desert Bighorn Council Transactions in 1957, Dick delivered the first report for the "Status of bighorn sheep in California." I will quote Dick's opening comments, because they made me smile and made me also realize how much attention Dick brought to desert bighorn sheep and their management. He said:

"I see we have very generously been given 30 minutes for the bighorn sheep in California. I can sum it up in about three. I feel a little inadequate, representing California here today, for I am only a peon in our Department of Fish and Game. Bob Cowell came along with me for moral support. He is a graduate of Peon University, also. But to get on with the bighorn sheep, there seems to be little interest in California's bighorns, outside our department, and inside of it, it has gotten to be a personal matter with many of us." This was 1957!

Dick was our connection to the past and to the present, much like a beloved family member. Parents, brothers, and sisters all share a unique history that bonds them together, and Dick was that bond with all of us in this profession, particularly those within this organization, the Desert Bighorn Council. The DBC lost an important leader, the last one who had roots in DBC's beginning. It is up to all of us to continue Dick Weaver's tireless advocacy for desert bighorn sheep.

Steve Torres – California Department of Fish and Wildlife

I would like to acknowledge the assistance of Dr. Vern Bleich in putting this tribute together.

Richard ‘Dick’ Arthur Weaver—Memories

One in a while, maybe once in a great while, you meet someone who changes your life, or makes your life a whole lot easier because they are a kindred soul. Dick Weaver was one of those people in my life; knowing him and what he knew and cared about, made my life as a federal wildlife biologist a whole lot easier for over three decades. I met Dick (and Doris) in 1971 when I attended my first Desert Bighorn Council meeting in Santa Fe, New Mexico. He welcomed me, and made me feel comfortable among a bunch of folks I did not know. I learned soon after that he was a founder of the Council in 1957. I watched, over the years, as he attended more DBC meetings than any other person, was Chair or member of the Council’s Technical Staff, was perennial chair of the DBC Awards Committee, and gave the status reports from Cal Fish and Game for decades.

Dick’s personality traits, his love and passion for bighorns and their surroundings, his awareness of what was going on around him, his ability to listen to others without interrupting them, his continual learning, his sharing and mentoring others with what he knew and experienced, and his recognition of others for their accomplishments, all made him the special man that he was. And he was a great story teller- a true raconteur—had it all in his mind. He was very likeable and got along with everybody, which helped him spread the word about the importance of desert bighorns in the grand scheme of things. And his knowledge, gained from years of wearing out boot leather in the mountain canyons of southern California stood him in great stead when dealing with non-government folks and his own higher-ups.

He was extremely knowledgeable about desert bighorns. He could hold his own with any group, not just biologists and scientists, but the hunters, and water builders, and folks who just cared for the bighorns and their habitat. After I retired, I invited Dick to my retirement country-Hells Canyon of the Snake River between Oregon, Idaho, and Washington about 10 years ago for annual Tri-State gathering of three state chapters of the Wild Sheep Foundation. He enjoyed the jet boat ride into some of the finest bighorn habitat anywhere to look for bighorns. And he impressed several of the local bighorn biologists, at the same time, just by being himself.

Most DBC members do not bring their spouses to the Council meetings. Dick brought Doris, who was head of the Ewes, for years. She, along with Ruth Kelly and Pat Hansen, were the mainstays. They sold jewelry, art, coffee cups, hats, and T-shirts, among other things, most all of which had the DBC logo on them. Almost everyone here has several items of DBC memorabilia.

So-what did Dick do for this Council? He kept it energized, and engaged with issues affecting bighorns throughout the American Southwest. He inspired others to get involved in their own states on their own issues. And what legacy has he left? Always answering the questions about bighorn management with "What is best for the bighorns?" His passion for desert bighorns and their habitat, his mentoring and counsel of bighorn biologists throughout the southwest, his recognition of biologists and administrators for their contributions to desert bighorn management, and the memories we all have of him as the great storyteller that he was.

George Welsh, an early Council member and now sadly several years gone, noted that "Every good wildlife biologist should leave a number of footprints on the path of wildlife management." I submit to you that Dick Weaver did not leave a few footprints—instead he *established* the path of management for desert bighorn sheep in the American Southwest that we all follow.

Rick Brigham

In Memoriam

Donald J. Armentrout
1943 – 2017

Don "Bear" Armentrout – 1943-2017.

Don passed away on August 3, 2017 in a hospital in Reno, Nevada, following a short illness. He was born in 1943 in Glendive, Montana. When he was 10, he and his family moved to Las Vegas, Nevada. He served in the United States Army (made 114 parachute jumps), then pursued a job in private industry before attending University of Nevada, Reno in the early 1970s, graduating with a degree in Wildlife Management. He started his 30 year career with the BLM in Elko, Nevada in 1976, and subsequently worked in the Winnemucca, NV district, followed by the California Desert District and ending at Susanville, California, where he retired in 2006.

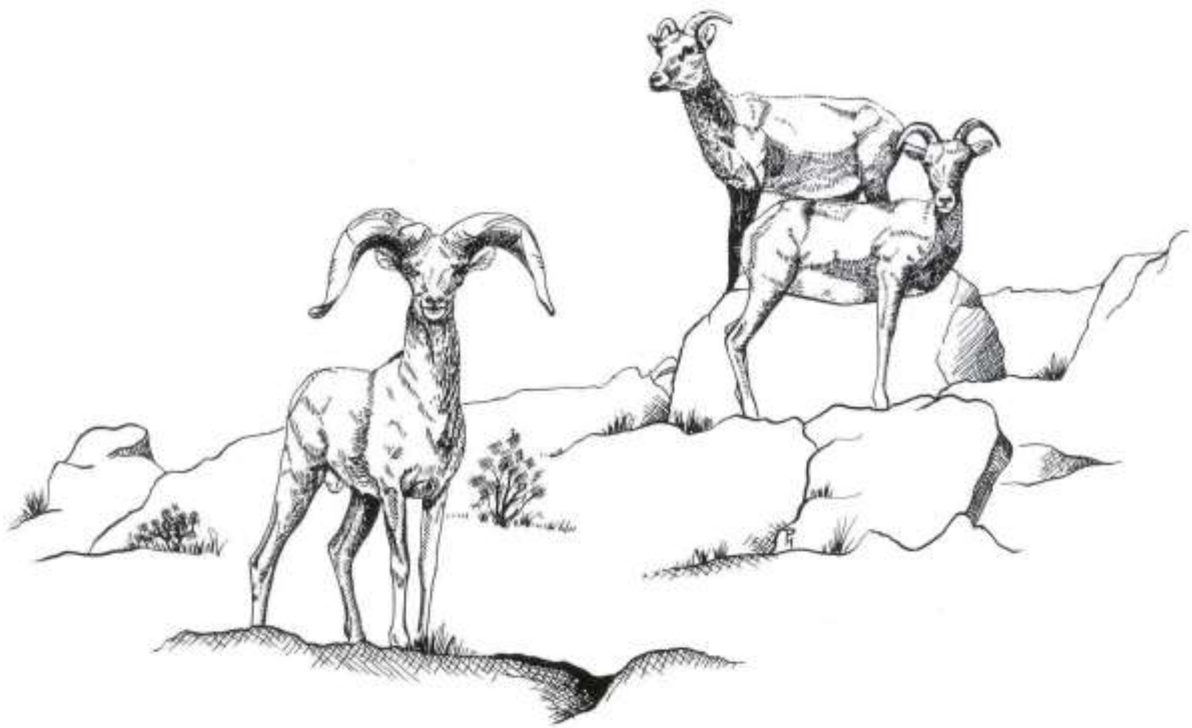
He was a hard-core, solid professional biologist and was active in both TWS-The Wildlife Society- and the Desert Bighorn Council. He was Nevada Chapter Representative to the Western Section of The Wildlife Society from 1978-1984 and 1995-96, served as President of the Western Section in 1985, and as Western Section Representative to the TWS National Board from 1986 to 1989. He joined the DBC in 1983; served as Council Secretary-Treasurer from 1984-1988, and as Historian from 2007 until his passing.

His first desert bighorn work included development of a BLM Habitat Management Plan for the Granite Mountains in the Winnemucca District to coordinate the aggressive bighorn reintroduction program by the Nevada Department of Wildlife. He also, along with Rick Brigham, developed a usable bighorn habitat assessment tool in 1988 (never published here, as it was deemed by the then-editor not to have been adequately field-tested). He was very busy in southern California. He enlisted colleagues from throughout southern California to enhance bighorn habitat, including water developments (using volunteer groups), provide protective measures on a landscape scale, and inventory waters using helicopters. In the mid-1990s he recognized major problems with the bighorn metapopulation using the Peninsular Ranges south of Palm Springs and Palm Desert, including a major reduction in numbers due to habitat encroachment by urban development and recreational users. He joined an interagency team and assembled volumes of information used toward development of a range-wide plan to bring the bighorns back. The plan was not accepted by the BLM but it did provide the basis for listing of the Peninsular bighorn in 1998 by the U.S. Fish and Wildlife Service. Bighorn numbers have climbed from a low of 300 to over 1,000. For this effort, and his duties as Secretary-Treasurer and Historian for the Council, Don was granted the Ram award in 2015. And for his contributions to the Western Section of the Wildlife Society, he was granted the James D. Yoakum Award in 2017.

Don was known for his keen knowledge, insight, persistence and political savvy. He was also known for being very well prepared to fight for those things in which he believed, and was not shy to tell others if he felt they were wrong or mistaken. He lived by the credo from Jack Ward Thomas- "The responsibility of a wildlife biologist is to tell the truth, only the truth, all the time." He will be missed.

Rick Brigham

Technical Reports



Status and Trend of Desert Bighorn Sheep in the North San Rafael Swell, Utah

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Abstract Dynamics of desert bighorn sheep (*Ovis canadensis nelsoni*) populations are determined by multiple, and often stochastic, factors. Successful management depends on understanding the mechanisms responsible for population growth or decline. We studied a population of desert bighorn sheep from January 2012 to January 2014 in the San Rafael Swell, Utah. Our objectives were to obtain a disease profile of the population, estimate survival of adults and neonates, determine causes of mortality, quantify population size and demographics, estimate production and identify lambing dates. Disease testing of 38 individuals (≈ 30% of population) revealed the presence of pneumonia-related pathogens including *Mycoplasma ovipneumoniae*, thought to be the primary agent associated with respiratory disease in bighorn sheep. We documented 19 mortalities attributed to a variety of causes including cougar (*Puma concolor*) predation (n = 10, 53%), bluetongue virus (n = 2, 11%), reproductive complications (n = 2, 11%), hunter harvest (n = 1, 5%), and unknown causes (n = 4, 21%). Annual survival of adult females was 0.73 (95% CI = 0.55 – 0.86) in 2012 and 0.73 (95% CI = 0.55 – 0.86) in 2013. Annual survival of adult males was 0.75 in 2012 (95% CI = 0.38 – 0.94) and 0.88 (95% CI = 0.50 – 0.98) in 2013. The population increased from an estimated 127 in 2012 to 139 in 2013 (λ = 1.09). November lamb to ewe ratios were 47:100 in 2012 and 31:100 in 2013 with a mean birthing date of 21 May in 2012 and 20 May in 2013. Despite confirmed presence of pneumonia-related pathogens, this population is currently increasing. We recommend management for spatial separation from domestic sheep (*Ovis aries*) and goats (*Capra aegagrus hircus*) and aggressive harvest of cougars to continue herd recovery and expansion.

Desert Bighorn Council Transactions 54:1–12

Key words bighorn sheep, cause-specific mortality, cougar predation, lambing date, *Ovis canadensis*, Utah

Desert bighorn sheep (*Ovis canadensis nelsoni*), although native to the North San Rafael Swell (NSR; Fig. 1), likely were extirpated following the last confirmed sighting in 1964 (Dalton and Spillett 1971). This herd was re-established in the 1970s and 1980s with 5 translocations totaling 57 animals from Canyonlands National Park, Coal Wash and San Juan, Utah (Utah Statewide Bighorn Management Plan 2013). An aerial survey in 2001 revealed that the herd had increased to an estimated 540 bighorns. However, subsequent surveys resulted in estimates of 250 in 2008 and 140 in 2011. Based on those surveys, the population had declined at a mean rate of

11% per year from 2001 to 2011 (λ = 0.89). November lamb to ewe ratios were lowest in 2007 and 2008 (23:100 and 22:100). Generally, lamb to ewe ratios < 25:100 in successive years is cause for concern (Douglas and Leslie 1999). Many factors affect neonatal survival, but low lamb survival commonly is associated with epizootic respiratory disease in bighorn populations (Cassirer and Sinclair 2007, Besser et al. 2008). Although disease was suspected in the NSR population, the exact causes for decline were not known.

Dynamics of bighorn sheep populations are determined by multiple, and often stochastic, factors (Cassirer and Sinclair 2007). Successful management depends on understanding the mechanisms responsible for population growth or decline (Krebs 2002). Cougar (*Puma concolor*) predation (Wehausen 1996, Ross et al. 1997, Hayes et al. 2000, Kamler et al. 2002) and disease (Hobbs and Miller 1992, Singer et al. 2000) have been identified as the most common factors limiting native and reintroduced bighorn sheep populations. Cougar predation can have a pronounced impact when bighorn density is low (Bowyer et al. 2014) or when individual cougars become specialists at preying upon bighorn sheep (Ross et al. 1997, Ernest et al. 2002, Festa-Bianchet et al. 2006). Additionally, sympatric mule deer (*Odocoileus hemionus*) or livestock populations can facilitate high rates of cougar predation in small populations of bighorn sheep (Kamler et al. 2002, Rominger et al. 2004, Johnson et al. 2013). Bighorn populations that have experienced a disease-related die-off, when coupled with high rates of predation, may be especially vulnerable.

Disease, especially bacterial pneumonia, has been responsible for numerous declines in bighorn populations throughout North America (Cassirer and Sinclair 2007). Pneumonia outbreaks typically affect all age and sex cohorts and are usually followed by several years of poor lamb survival, dramatically reducing population growth (Spraker et al. 1984, Ryder et al. 1992, George et al. 2008). These events likely occur as a result of pathogen transfer from domestic sheep (*Ovis aries*) or goats (*Capra aegagrus hircus*), or exposed bighorn sheep through social contact (Singer et al. 2000, Monello et al. 2001, Cassirer and Sinclair 2007).

Routine monitoring of a mountain sheep population is critical for identifying and mitigating limiting factors (Douglas and Leslie 1999). Monitoring also provides baseline data to facilitate management decisions. The primary objectives of this study were to: 1) obtain a disease profile of the population, 2) determine bighorn survival through regular monitoring, 3) determine causes of death and factors limiting population growth, 4) quantify population size and demographics, and 5) quantify production, survival, and lambing dates of neonates.

STUDY AREA

The NSR is located in Emery County, Utah (Fig. 1, 38°58′N, 110°37′W). The area was characterized by steep canyons in the Wingate Sandstone Formation with broad mesa tops in Navajo and Entrada Sandstone Formations (Gilluly 1929). Desert bighorn sheep habitat in this area ranged in elevation from 1700-2100 m. Vegetation consisted of species typical of salt desert shrub environments. Common shrubs included blackbrush (*Coleogyne ramossisima*) and fourwing saltbush (*Atriplex canescens*) Pinyon pine (*Pinus edulis*) and juniper (*Juniperus* spp.) were the predominant tree species on mesa tops and on north-facing canyon slopes. The NSR was dry with annual precipitation averaging less than 20 cm per year. Daily high temperatures during the summer (June to September) averaged 31°C and often exceeded 35°C. Winters (November to February) were cold with daily

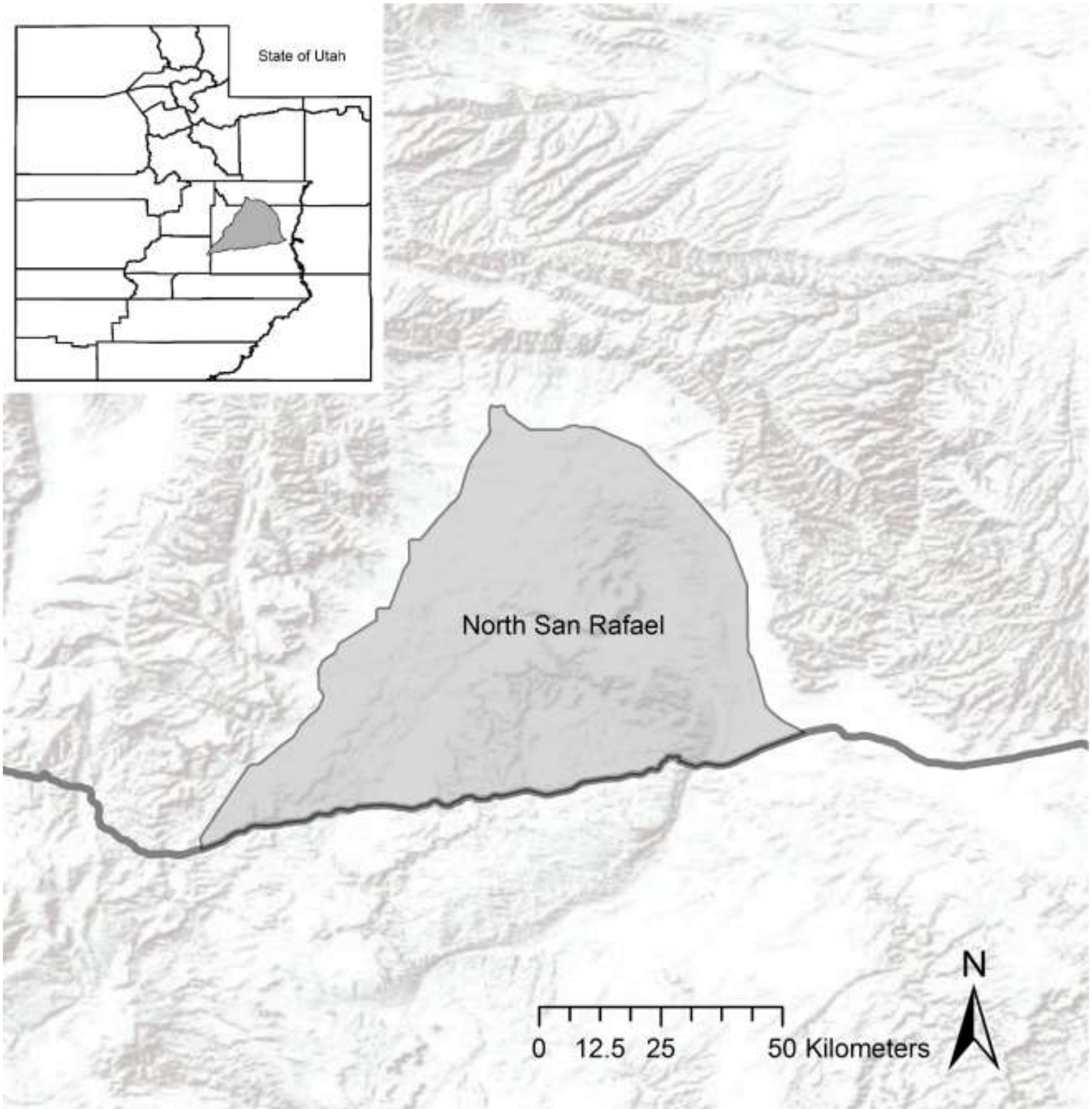

Figure 1. Location and map of desert bighorn sheep study area during 2012–2013 in North San Rafael Swell, Utah, USA.

low temperatures averaging -12° C. Native populations of pronghorn (*Antilocapra americana*) and mule deer inhabited the study area. Feral burros (*Equus asinus*) and domestic cattle (*Bos taurus*) also occupied portions of the NSR. Mammalian predators included mountain lions and coyotes (*Canis latrans*). The NSR study area was predominantly managed by the Bureau of Land Management (BLM). Recreation in the NSR included on and off-road travel, rock climbing, biking, hiking, camping, and hunting. Peak recreation occurred in spring with influxes of activity near Easter and Memorial Day (W. Paskett, UDWR biologist, personal communication).

METHODS

In January 2012, we captured 30 female and 8 male bighorn sheep by aerial net gunning (Barrett et al. 1982, Krausman et al. 1985, Webb et al. 2008). Efforts were made to sample widely across the NSR by distributing collars proportional to observations from aerial surveys 2 months earlier. Captured bighorn sheep were equipped with GPS collars equipped with a VHF transmitter, mortality sensor and a drop off mechanisms. We also fitted them with numbered ear tags identifiable through a spotting scope from distances up to 400 m. Captured bighorn sheep were tested for pathogens associated with pneumonia (*M. ovipneumoniae, Bibersteinia trehalosi, Pasteurella multocida, Mannheimia haemolytica*) using polymerase chain reaction (PCR), bacterial culture, and serology. Samples recovered from carcasses throughout the study were tested similarly with the addition of bluetongue and epizootic hemorrhagic disease testing by PCR. In January 2013, 10 additional bighorn sheep (8 females, 2 males) were captured and collared, bringing the total number of animals we monitored to 48.

We located and monitored the status of bighorn sheep weekly from the ground using radio telemetry, binoculars, and spotting scopes for 2 years, until collars dropped off in January 2014. We recorded the size and composition of all groups of bighorn sheep encountered. Yearlings were noted when identifiable. In addition to ground observations, monthly telemetry flights were conducted by fixed-wing aircraft to aid in locating animals. Upon detection of a mortality signal, bighorn carcasses were located and necropsied to determine cause of death. When feasible, bighorn carcasses were transported intact to the Utah State Veterinary Diagnostic Laboratory for necropsy. When physical extraction of the carcass was not possible, field necropsies were performed, and tissues of interest (liver, lungs) and the head were sent to the Utah State Veterinary Diagnostic Laboratory.

We determined mortalities caused by cougar predation from typical cougar kill-site characteristics. These include a dragline from kill site to cache site, mountain lion tracks at kill or cache site, mountain lion scat at cache site, canine puncture wounds in neck or face, canine punctures or claw slices in radio collar, rumen extracted and uneaten or buried, carcass partially or completely buried (i.e., rocks, sticks, grass, raked over carcass), broken neck (generally at cervical vertebrae 1, or more rarely 2), >10 cm of rostrum bones eaten, braincase cracked in female sheep (never males), humerus or femur cracked, mountain lion hair present at kill or cache site, mountain lion scrapes at or near cache site, hair plucked from carcass, and multiple cache sites (Rominger et al. 2004).

Helicopter flights were performed in the same area in November of 2012, 2013, and 2015 to estimate population size and quantify demographics. We calculated sightability estimators by the proportion of collared bighorns known to be present and observed during aerial surveys in years collars were deployed (2012, 2013) and used them to estimate overall population size. In 2015 we used the average sightability estimator from 2012 and 2013. Lambs, ewes, and rams were counted separately to quantify herd demographics; however, yearling ewes were not counted separately in aerial surveys as in ground surveys but included with adult ewes because of the difficulty of accurate identification from the air.

To estimate parturition dates we relocated collared and uncollared females to record birthdates from 25 April to 25 June during 2012 and 2013. We searched the NSR every 2 days (± 1.6 days [SD]) in 2012, and in 2013 (± 1.7 days). We recorded the behavior of females before, during, and after parturition, as well as first sighting, motor skills, size, and behavior of neonates (Festa-Bianchet 1988, Whiting et al. 2008, Whiting et al. 2011). To determine birthdates for neonates of uncollared females, we compared their young with neonates of estimated ages of collared females when all females congregated in nursery bands after parturition (Côté and Festa-Bianchet 2001, Whiting et al. 2008, Whiting et al. 2012). When ewe and lamb pairings were questionable, we waited until the lamb nursed in order to identify its mother (Festa-Bianchet 1988). We exercised care not to disturb females with young (Sikes et al. 2016).

We estimated birthdates of young, pooled them into sampling intervals and calculated corrected means (timing of births) and SDs (an index for synchrony of births) each year (Johnson et al. 2004, Whiting et al. 2011). This technique allowed robust calculations of unequal sampling intervals (bin sizes) in determining timing and synchrony of births (Johnson et al. 2004). Peak rut dates were calculated by backdating the approximate gestation period of bighorn sheep (179 days; Turner and Hansen 1980). We performed a known fate analysis (White and Burnham 1999) to determine annual survival rates of adults by sex.

RESULTS

Disease Testing

Bacterial strains associated with respiratory disease in bighorn sheep were present in the population. Thirty-one percent of bighorns sampled tested positive via PCR for *M. ovipneumoniae*. Hemolytic, or leukotoxin producing, *Mannheimia haemolytica* was also detected in several samples (n = 5, 14%). Non-hemolytic *Bibersteinia trehalosi* was also detected in the population (n = 22, 61%). *Pasteurella multocida*, another infectious agent frequently isolated from affected animals during pneumonia outbreaks, was also isolated from this population (n = 3, 8%). Bluetongue virus was not tested for at the time of capture but was isolated from 2 mortalities.

Survival

Annual survival of adult females was 0.73 (95% CI = 0.55 – 0.86) in 2012 and 0.73 (95% CI = 0.55 – 0.86) in 2013. Adult male survival was 0.75 in 2012 (95% CI = 0.38 – 0.94) and 0.88 (95% CI = 0.50 – 0.98) in 2013. Nineteen mortalities of collared individuals were documented over 2 years (Fig. 2). Ten mortalities (53%) were attributed to cougar predation. Two mortalities (11%) were attributed to bluetongue virus. Two mortalities (11%) were a result of reproductive complications. One bighorn ewe had a ruptured uterus, and 1 had dystocia (obstructed birthing). One mortality (5%) was a hunter harvested ram. Four mortalities (21%) had unknown causes, with predation excluded as a putative cause. One bighorn ewe had growths on the head and face, possibly sinus related that likely contributed to her mortality. Other mortalities of unmarked individuals encountered opportunistically included road kill (n = 2) and cougar predation (n = 2). We also recorded 2 capture-related mortalities.

Population Size and Sightability

Sightability was 80% (95% CI = 0.66 – 0.94) in 2012 (largely due to favorable weather conditions with fresh snow cover), and 68% (95% CI = 0.52 – 0.84) in 2013 (as a result of relatively poor conditions with patchy snow). In a flight conducted in 2011 before collars were deployed, we estimated a population size of 120. In 2012, we estimated a population size of 130 total bighorns using 80% sightability (λ = 1.17). In 2013, we counted 94 bighorns with 68% sightability for a population estimate of 140 (λ = 1.09). A flight count was not performed in 2014, but in 2015, after collars had dropped off, we counted 124 individuals. Using a mean sightability estimate from 2012 and 2013 ($\bar{x}$ = 74%) we estimated a population size of 170 (λ = 1.10). November lamb to ewe ratios were 47:100 in 2012, 31:100 in 2013, and 42:100 in 2015. Ram to ewe ratios were 36:100 in 2012, 53:100 in 2013, and 67:100 in 2015 (Table 1).

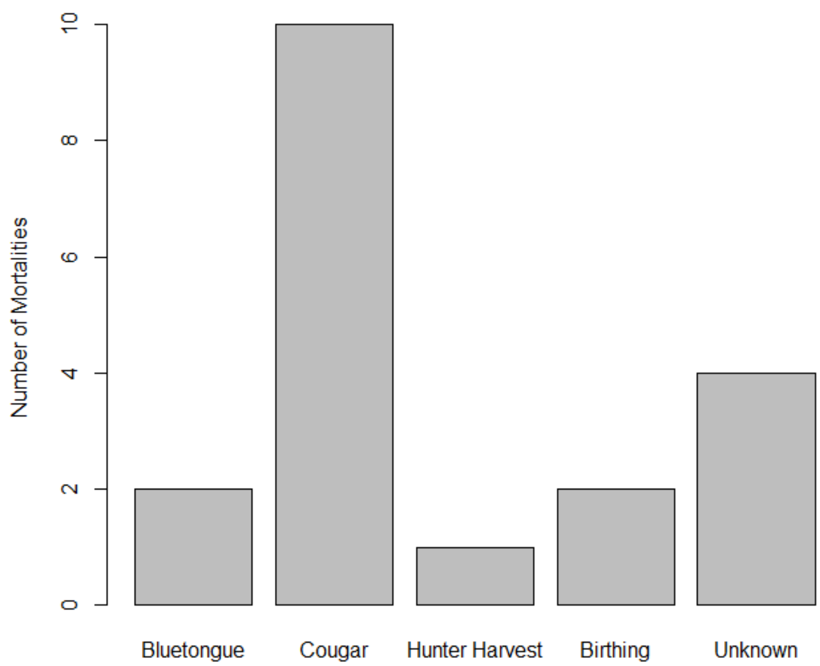

Figure 2. Cause specific mortality (*n* = 19) for collared desert bighorn sheep during 2012 – 2013, North San Rafael Swell, Utah, USA.

Table 1. Desert bighorn sheep aerial survey classification data, 2011 – 2015, North San Rafael Swell, Utah, USA.

Year	Lamb to Ewe	Ram to Ewe	Population Estimate	Lambda (λ)
2011	29:100	37:100	120	-
2012	47:100	36:100	130	1.09
2013	31:100	53:100	140	1.09
2014	-	-	-	-
2015	42:100	67:100	170	1.10

Production and Lambing Dates
A mean of 88 (± 3.6) adult females occupied the NSR during our study. Of the collared females sampled in 2012, 96% (22 of 23) were observed with a lamb. One was observed noticeably pregnant but was never observed with a lamb, which presumably died shortly after parturition. In 2013, 100% of collared ewes (12 of 12) were observed with lambs.

In 2012, we estimated birthdates for 29 young. Mean (± 2 *SD*s) birthdate for bighorn sheep in the NSR during that year was 21 May (± 19 days). In 2013, we estimated birthdates for 16 young and mean (± 2 *SD*s) birthdate for bighorn sheep that year was 20 May (± 21 days). Backdating the approximate gestation period of desert bighorn sheep of 179 days (Turner and Hansen 1980) puts the peak rut approximately 23 November.

DISCUSSION

Mycoplasma spp. have long been associated with bronchopneumonia related die-offs in bighorn sheep (Woolf et al. 1970; Miller et al. 2012). *M. ovipneumoniae*, specifically**,** is strongly associated with bronchopneumonia in bighorn sheep and is a candidate primary etiologic agent for this respiratory disease (Besser et al. 2008, 2012, 2013). It has also been implicated as a predisposing factor for a secondary fatal infection (Besser et al. 2008, Dassanayake et al. 2010). Typically, the introduction of *M. ovipneumoniae* to a bighorn sheep population results in polymicrobial bacterial pneumonia (Besser et al. 2008, 2012, 2013) and a subsequent die-off event. This polymicrobial pneumonia is thought to occur when *M. ovipneumoniae* binds to and degrades the cilia of the trachea and bronchi, resulting in disruption of the mucociliary escalator (Niang et al. 1998, Cassirer et al. 2018), preventing the bacteria from being cleared from the lower respiratory tract. The impaired host immune defenses then allow inhaled opportunistic pathogens to establish infections of lung tissues with often fatal results (Cassirer et al. 2018)

Thirty-one percent of bighorn sheep sampled were actively shedding the pathogen at the time of testing. Typically, exposed individuals that are shedding the pathogen facilitate the exposure of the pathogen to juveniles within the subpopulation or nursery group (Manlove et al. 2014), and disease-induced juvenile mortality imposes strong constraints on population growth (Manlove et al. 2016). However, lamb survival in the NSR was uncharacteristically high throughout the study for a population exposed to respiratory pathogens. Bighorns were observed coughing twice over the span of 2 years, and both of them were lambs, indicating that respiratory disease was still present and a future risk despite the high recruitment at the time.

While bronchopneumonia was not identified as a primary cause of death for any bighorn sheep in our study, it was identified as a secondary cause of death in 3 mortalities. In these cases, pneumonic symptoms were brought on by other infections identified as the primary cause of mortality (e.g., 2 bluetongue virus, 1 ruptured uterus). *M. ovipneumoniae* was isolated from one of those carcasses that were tested. Although respiratory disease was not identified as a primary cause of death, the presence of *M. ovipneumoniae* in the population along with the decline in population performance over time, indicates that the population most likely experienced a pneumonia related die-off with subsequent low lamb recruitment (Manlove et al. 2014, 2016).

Sporadic or continuous pneumonia episodes can persist in both adults and lambs in interconnected populations for many years, limiting population growth (Cassirer and Sinclair 2007). Therefore, even though pneumonia was not documented as a primary cause of death during our monitoring period, it may have been partially responsible for observed declines in recent years (2001 – 2011). Initial pneumonia related die-offs in bighorn sheep are typically followed by chronic infection in some surviving adults, but diminished lamb survival, resulting in aging populations of adults with limited recruitment (Cassirer and Sinclair 2007; Besser et al. 2008, 2012 2013; Plowright et al. 2013). Observations made of the NSR bighorn herd (2012 – 2013) especially the high lamb to ewe ratios indicating survival to recruitment support the notion of a population recovering from a pneumonia-mediated die-off.

Disease-induced mortality rates in bighorn sheep vary substantially by population (Manlove et al. 2016). Additionally, variation in mortality rates can be attributable to multiple processes including contact rates and social sub-structuring (Manlove et al. 2014), pathogen virulence, host susceptibility to pathogen establishment, and factors associated with each individual's unique mucosal immunity and carriage status (Manlove et al. 2016). Notwithstanding, vital rates of the NSR population, including lamb survival, are on the upward trend, indicating that the herd is potentially recovering from the effects of pneumonia for the time being.

Predation is a concern in the NSR bighorn population, as 53% of all adult mortalities were attributed to cougar kills (13% of the adult population annually). Because this herd experienced declines and diminished lamb survival following a probable pneumonia event, cougar predation could have been further limiting population growth due to a predator pit scenario. Cougar predation may also limit bighorn sheep in locations where predator populations are largely supported by sympatric prey populations (Hayes et al. 2000, Schaefer et al. 2000, Ernest et al. 2002), which, in this case, includes mule deer and domestic cattle. It has been hypothesized that declines in sympatric ungulate populations can increase predation on bighorn sheep as cougars switch to bighorns as an alternate prey source (Kamler et al. 2002, Rominger et al. 2004). Conversely, a relatively high density of mule deer and livestock occupying agricultural land surrounding the study area could be providing a stable food source for cougars, causing cougars to occupy the area and opportunistically prey upon bighorns (Johnson et al. 2013). Mule deer are present in the NSR and may be facilitating the persistence of cougars. However, because the health of bighorn sheep in this population is already compromised due to exposure to respiratory pathogens, predation losses by cougars may be compensatory to some degree (Cassirer and Sinclair 2007). As lamb recruitment is currently high, cougar predation is of lesser concern. However, if predation rates remain constant, future pneumonia events will again facilitate the likelihood of a predator pit scenario (Jokinen et al. 2008).

Regardless of whether predation events in the NSR are proximate or ultimate causes of mortality, predator control programs have been shown to limit the overall amount of bighorn mortality in small, vulnerable populations (Miller et al. 2012). Consequently, the UDWR has taken a pro-active stance to managing cougars within the NSR. The unit is classified as a harvest objective unit, allowing over-the-counter sales of cougar tags. The UDWR has also worked closely with USDA Wildlife Services and hunters to facilitate quick response time to cougar tracks or kills of bighorn sheep. During the course of the study (January 2012–January 2014) 8 cougars were removed from the unit.

The NSR reached an estimated population peak of over 500 individuals in 2001 and exhibited November lamb to ewe ratios of 36-60:100 from 1995 – 2005. Population declines were first observed in

2003, but causes are unclear, especially since lamb to ewe ratios remained very high until 2007. Low lamb recruitment began in 2007, but an acute die-off was never detected. Instead, it continued to gradually decline by ~11% annually. There was limited lamb recruitment and an ongoing population decline until 2012 when the lamb to ewe ratio increased from 29:100 in 2011 to 47:100 in 2012, and the population increased. Assuming there was no re-exposure to pneumonia related pathogens, the herd took 5-6 years to reverse the downward trend that presumably was the result of exposure to respiratory pathogens resulting in high lamb mortality. Time to full recovery is still unknown, and a return to previous population peak may never occur, but repeated exposure and persistence of pneumonia-related pathogens prolongs recovery (Manlove et al. 2016). This highlights the importance of maintaining spatial separation from domestic sheep and goats to maintain overall herd health.

MANAGEMENT IMPLICATIONS

Because the NSR has been exposed to pneumonia-related pathogens, specifically *M. ovipneumoniae*, traditional management options (such as augmenting the population) are limited. Instead, we recommend preventing re-infection as a primary management strategy. Bighorn sheep do not exhibit cross-strain immunity to *M. ovipneumoniae* (Cassirer et al. 2017), meaning the introduction of a new strain of *M. ovipneumoniae* can cause a new epizootic within the population. Maintaining spatial separation of bighorns and domestic sheep and goats are important to preventing repeated disease transmission. Soliciting cooperation by the public, and improving monitoring efforts and early detection strategies may also be key to preventing pneumonia outbreaks. Early detection strategies may include testing for disease and monitoring herd demographics more frequently.

GPS collar data revealed that the NSR population is somewhat fragmented into distinct subherds with limited interaction among them (Robinson 2017). Because these subherds rarely interact, isolated depopulation or test and cull management actions may be effective in limiting the spread of pneumonia from one group to another should a subherd be exposed in the future. However, rams move freely between groups across the population during rut (Robinson 2017), which would facilitate exposure in the late fall and early winter. If a disease or commingling event is detected, managers should act immediately to control the spread of disease.

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Resource Selection by Desert Bighorn Relative to Limestone Mines

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Abstract We investigated resource selection by desert bighorn sheep (*Ovis canadensis nelsoni*; 8F, 2M) from 2006 to 2009 using data from global positioning system (GPS) collars in an area modified by past and present mining activity. Active and inactive limestone mines overlapped approximately 12% of the range for the Cushenbury bighorn sheep population ($n \leq 40$) occupying the north slope of the San Bernardino Mountains, San Bernardino County, California, USA. We used a geographic information system (GIS) and remotely sensed imagery to characterize mining-related disturbance, vegetation, anthropogenic land transformations, and natural habitat within the range of these bighorn sheep. Modeling of a resource selection function (RSF) identified proximity to active mine areas, water sources, and revegetation sites as important determinants of habitat selection. Our results also indicated that bighorn sheep selected for steeper slopes, higher elevations, convex topography over a 150-m radius, terrain ruggedness over a 100-m radius, areas lacking recent wildfire, barren cover, shrub cover, quarry highwalls, and other mine disturbance areas. Avoidance of both mixed conifer-hardwood and bottoms of quarry pits also contributed to our best-fitting model. Our analyses demonstrated that bighorn sheep preferentially selected for areas of mine disturbance and associated anthropogenic features including steep quarry highwalls, water sources, and areas of revegetation, provision of which may mitigate for disturbance to natural habitats of bighorn sheep.

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Mountain sheep are recognized as ecological specialists that occupy habitats characterized by steep and rugged terrain proximate to suitable forage (McCann 1956, Geist 1971), and avoid areas of dense vegetation and limited visibility to minimize predation risk (Valdez and Krausman 1999). A combination of forage, visibility, proximity to escape terrain, and reliable water sources in arid regions (Leslie and Douglas 1979, Bleich et al. 1997, Singer et al. 2000, Oehler et al. 2005) defines a requisite ecological niche yielding a distribution of desert sheep that is limited to islands of mountainous habitat (Bleich et al. 1990). Anthropogenic land uses and development over the past century have created increasingly isolated bighorn

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populations, presenting additional risk to a species recognized to function as a metapopulation (Levins 1969, Bleich et al. 1996). Indeed, Epps et al. (2005) noted a 15% reduction in genetic diversity during a period of 40 years during which anthropogenic barriers (highways, canals, and urban development) had fragmented the historic range of these specialized ungulates. Further, modeling of potential disease outbreaks and climate-related stressors predicted a high risk of extinction in some California mountain ranges over a period of 60 years (Epps et al. 2004) in the absence of actions to mitigate or counteract those impacts.

Landscape modifications caused by mining activity may create habitat for wild sheep, but quantitative studies of mining-related impacts on wildlife populations, and mountain sheep in particular, remain rare (Bleich et al. 2009). Earlier investigations of habitat selection by bighorn sheep suggested that landscape transformations from mining promote occupancy by bighorn sheep after areas of low slope, dense vegetation, or both, were reshaped into habitat with greater relief and more open vegetation (Elliott and McKendrick 1984, MacCallum and Geist 1992, Bristow et al. 1996, Jansen et al. 2006). Medcraft and Clark (1986) quantified nutritional benefits for ungulates on reclaimed mine sites in Wyoming, and MacCallum (1988) reported that areas heavily used for foraging by bighorn sheep at a coal mine in Alberta were adjacent to mine highwalls—steep staircase-like escarpments common to surface mines. Subsequent research on the same population quantified positive population-level responses in the reclaimed mine areas (MacCallum 1992).

Activities related to mining influence how sheep forage or otherwise select habitat. Oehler et al. (2005) compared two populations of sheep in mined (treatment) and non-mined (control) areas near Death Valley, Inyo County, California with mine areas delineated by disturbed vegetation identified on aerial photos. Their results did not identify differences in habitat selection between populations, but foraging efficiency was lower for female sheep using the mine when compared to the control. Jansen et al. (2006) noted that animals generally exhibited similar behavior whether they were on desert islands at a mine in the Silver Bell Mountains, Arizona, or outside the mine; however, animals fed 6% less while inside the mine perimeter (Jansen et al. 2007). Jansen et al. (2006) observed that sheep groups were less alert and more socially interactive while on mine highwalls, which investigators attributed to a lack of vegetation yielding improved visibility and concomitant reduction in perceived risk of predation.

We sought to elucidate patterns of resource selection by bighorn sheep in a landscape influenced by mining, using data of high spatial and temporal resolution not available to earlier investigators. Results will be useful to natural resource managers and mining engineers in the development of adaptive management plans that enhance the quality of habitat available to bighorn sheep, and mitigate impacts related to industrial uses within the range of those ungulates.

STUDY AREA

Our study area was located on the north-facing slope of the San Bernardino Mountains, San Bernardino County, California, USA (34°20’N, 116°54’W). The climate is characterized as Desert Transition (Paysen et al. 1980) and elevations range from 1,300 to 2,400 m, with temperature and precipitation patterns intermediate between measuring stations north and south of the study area. Average mean daily temperature in Hesperia (30 km northwest of the study area; elevation 930 m) was 16.9°C with an average annual precipitation of 10.8 cm; average mean daily temperature at 2,058 m elevation in Big Bear Lake, 12 km south of the study area was 9.2°C, with average annual precipitation of 36.6 cm (National Oceanic and Atmospheric Administration 2017). Topography included desert washes, shallow rolling foothills, steep bedrock outcrops, and talus slopes; the study area was also transected by several major canyons. Vegetation communities transitioned from the creosote bush (*Larrea tridentata*) and blackbush (*Coleogyne ramoissima*) series at lower elevations to conifer woodlands comprised largely of pinyon pine (*Pinus monophylla*) and juniper (*Juniperus californica*) in the upper reaches of the range (Paysen et al. 1980). Several federally-listed plant taxa associated with carbonate soils were located within the study area. (Olson, 2003).

METHODS

Capture, Telemetry, and Home Range

In 2006 and 2007 we captured bighorn sheep using a net-gun fired from a helicopter (Krausman et al. 1985) and fitted each with a store-on-board GPS collar (ATS Model G2110) programed to record locations at three-hour intervals during the day and once at midnight (6 locations/day). Each animal was also fitted with a secondary VHF-transmitter collar incorporating a tilt sensor (ATS Model M2510B; ATS, Isanti, MN, USA). We used Home Range Tools for ArcGIS (Rodgers et al. 2005) and ArcGIS 9.2 software (ESRI, Redlands, CA, USA) to calculate a 95% adaptive kernel composite home range from 1,709 aerial telemetry locations of 39 bighorn sheep (15 males, 24 females) collected from 1995 to 2010 combined with one randomly selected location per animal per week from GPS locations of 10 bighorn sheep (2 males, 8 females) collected during 2006 – 2009. We used a smoothing factor of 80% h_{ref} (Worton 1995, Kie 2013) to prevent fragmentation. We defined the Cushenbury study area as that composite home range and considered the area within that polygon as available habitat in modeling a resource selection function (RSF).

Characterization of Available Habitat

We developed a habitat model by characterizing both natural and anthropogenic landscape features within the study area using a geographic information system (GIS; ArcGIS 10.4; ESRI, Redlands, California, USA). We used vegetation classifications with 30-m resolution to characterize conifer, hardwood, mixed conifer-hardwood, shrub, and barren cover types (United States Forest Service 2010a). In addition to quantifying each cover type in isolation, we combined layers for conifer, hardwood and mixed conifer-hardwood into a single tree layer. To distinguish all vegetative cover from the barren cover type we combined the tree layer with the shrub cover type to create a composite tree-shrub layer.

We combined elevation data from a 1:24,000-scale, 10-m digital model for elevation (United States Geological Survey 2010) with proprietary aerial survey data provided by three limestone companies operating in the study area that characterized contemporary topography of mined areas. We calculated a ruggedness raster with the terrain diversity index of Nicholson et al. (1997) and generated a slope raster layer. We also evaluated convexity by comparing elevation of each 10-m grid cell with the average elevation within the evaluation radius that differentiated concave drainages less likely to be used by bighorn from convex ridgelines; those features could have an identical ruggedness value (Villepique et al. 2015). Positive convexity likely represents outcroppings or ridges providing enhanced visibility for bighorn sheep (Risenhoover and Bailey 1980, Valdez and Krausman 1999). Terrain ruggedness and convexity were calculated over radii of 15, 20, 30, 100 and

150 m to elucidate the scale at which bighorn sheep selected for rugged and convex terrain (Kie et al. 2002, Bowyer and Kie 2006, Villepique et al. 2015). We quantified hillshade as a proxy for moisture and vegetation type, with an aspect of 225° and a solar angle of 45°; southwestern slopes generated high hillshade values, whereas northeastern slopes produced low values (Nielsen et al. 2002).

To quantify free water availability we used a point layer of perennial water sources that included both natural and man-made sources (California Department of Fish and Wildlife, unpublished data). We obtained fire history polygons from an interagency database of wildfire perimeters (California Department of Forestry and Fire Protection 2016). We calculated years since wildfire for animal locations as the interval between the date of GPS locations and date of the most recent wildfire in the corresponding polygon of the fire history layer. We obtained information on roads (paved and unpaved), hiking trails, a state highway, and a railroad spur transecting the study area from a federal transportation database (United States Forest Service 2010b).

We manually digitized mine-related roads not reflected in this database into a unique layer. We digitized the total disturbance footprint of the three limestone mines using 1-m resolution imagery from the National Agricultural Imagery Program (NAIP) collected in 2009 (California Spatial Information Library 2010). We further classified this layer into features discernible from the elevation data provided by the mining companies: quarry highwalls, pit bottoms, and areas of the mine plant that were paved or occupied by buildings or industrial structures. A polygon layer representing areas revegetated during or prior to the study was provided by a contractor (JJ Restoration Service, Lucerne Valley, CA, USA) responsible for revegetation of the three limestone mines. We modeled mine-related features (Table 1) as both binary variables and as distance-to variables. We defined 34 candidate variables to characterize available habitat (Table 2).

Analysis of Sheep Locations

We tested for independence of animal locations using the program ASSOC1 (Weber et al. 2001) with the assumption that animals with simultaneous locations <200 m for >50% of the locations represented the same social group. We tested for bias against GPS fix acquisition (Frair et al. 2004) in areas where topography limited available sky (Cain et al. 2005) by comparing fix success rate and proportion of 3-D locations with four GPS collars that collected 6 locations/day on the same schedule as collars deployed on animals. We initially placed those collars on 1-m-high road barricades at mine locations (*n* = 2 pit-bottom, and *n* = 2 highwall) for 20 days, and then at 4 non-mine (control) locations on level ground for 50 days. To quantify resources available to bighorn sheep, we cast ten random locations for each animal location (Boyce 2006) in a design II arrangement that used those random locations as a proxy for habitat available within the composite home range (Thomas and Taylor 2006).

Model Development

Thirty-four candidate variables were evaluated for inclusion in an RSF using conditional logistic regression (PROC LOGISTIC; SAS Institute 2013) in a matched-case design (Manly et al. 2002, Boyce 2006, Long et al. 2009, Lendrum et al. 2012), with ten available random locations per animal location. The logistic model was fit for combined sexes and seasons and conditioned upon the individual animal. We retained candidate variables with absolute values of Pearson correlation <0.60 and screened for multicollinearity using linear

Table 1. Mine features delineated as candidate predictors for model of resource selection by bighorn sheep in the San Bernardino Mountains, California, USA, 2006 – 2009.

Variable	Feature	Description
DMF	Distance to mine footprint	Visible mine-related disturbance footprint (both active and inactive areas), including roads >10 m in width
DMFA	Distance to active mine areas	Areas of mining or mine-related activity in duration greater than 10% of the 32-month study period
DRDMIN	Distance to mine roads	Roads with access into study area controlled primarily by the mine operations
DVEG	Distance to mine revegetation	Documented mine revegetation efforts during or prior to the study period; does not include naturally re-established vegetation
HIWALL	Quarry highwalls	Terraces created by mining, comprised of stacked stair-stepped benches 10–24 m in height and 10–100 m in width
MINOTH	Other mine disturbance	All other visible mine disturbance including access roads >10 m in width, road berms, canyon fill and stockpile slopes
PITBOT	Quarry pit bottom	Level to near level quarry floor surfaces adjoining one or more quarry highwalls
PLANT	Plant site	Mine plant and administration areas (buildings, pavement, conveyors and pipelines; not considered available habitat in RSF)
REVEG	Revegetated mine sites	Areas with any documented revegetation activity during or prior to the study period

regression diagnostics in SAS 9.4 software (Allison 1999). Candidate models were generated from all possible combinations of uncorrelated predictor variables. For each combination, we generated candidate models using stepwise selection with criteria of $P <$ 0.25 to enter and $P < 0.30$ to remain (Hosmer and Lemeshow 2000, SAS Institute Inc. 2013). We calculated Akaike's Information Criterion adjusted for small sample size (AIC_c) and calculated Akaike weights for candidate models with $\Delta AIC_c \leq 4$, indicating substantial information-theoretic support (Burnham and Anderson 2002). We evaluated correlated predictor variables by comparing ΔAIC_c among models differing only in those correlated predictors.

We used *k*-fold cross validation with five partitions (Boyce et al. 2002, Anderson et al. 2005, Long et al. 2009) to evaluate predictive strength of the resource-selection functions by withholding a randomly selected 20% test-set of animal and available locations, and estimated model parameters with the remaining locations. For each of five iterations, we used the coefficients calculated from the training set to calculate RSF values for available locations in the test set, which we then ranked by RSF and assigned to one of ten equal-area bins (i.e., 10-percentile bins). We then used training-set coefficients to calculate values of RSF for animal (i.e., used) locations in the test set. We placed animal locations in the bins according to RSF value with number of locations summed for each bin. We regressed the tally of animal locations in each bin against the median value from random points, and used coefficients of determination, slope, and Spearman rank correlations, each averaged among the five-fold validation groups, as to assess the predictive success of each model (Boyce et al. 2002, Long et al. 2009).

RESULTS

We captured 10 bighorn sheep (8 F, 2 M) and

Table 2. Description of candidate variables used to model resource selection by the Cushenbury bighorn sheep population for 173,444 random locations, San Bernardino Mountains, California, USA, 2006 – 2009. Values reported for binary variables are counts. Correlated variables (|*r*| > 0.60) are indicated with an asterisk; correlates denoted by common letter in last column.

Variable	Description	Mean	SD	Min	Max	Correlates
Continuous and non-binary variables						
DMF*	Distance to mine footprint (km)	0.57	0.56	0	2.37	A, B, C
DMFA*	Distance to active mine areas (km)	0.8	0.68	0	2.86	B
DVEG*	Distance to revegetated mine areas (km)	1.02	0.62	0	2.75	C, D, E, F
DRDMIN*	Distance to mine roads (km)	0.48	0.53	0	2.29	A, D, G
DRDPUB	Distance to public roads (km)	0.95	0.69	0	3.15	
DH2O*	Distance to point water source (km)	0.89	0.54	0	2.62	G
DRR*	Distance to railroad (km)	2.88	1.31	0	5.68	F, H, I, J
DHWY*	Distance to highway (km)	4.05	2.31	0	8.01	J, K, L
ELEV*	Elevation (100 m intervals)	18.76	3.02	12.89	25.03	E, H, L
HLSHD	Hillshade (aspect 225°, azimuth 45°)	130.09	59.71	0	254	
SLOPE	Slope in degrees	26.36	11.33	0	69.08	
UTM_E*	UTM easting (km)	509.83	2.97	503.71	515.77	I, K
YRSFIRE	Years since most recent fire event	93.7	23.19	0	100	
Terrain ruggedness (over specified radius)						
RUG15*	15 m	0.16	0.17	-0.15	1.99	M, N
RUG20*	20 m	0.3	0.23	0	2.81	M, O
RUG30*	30 m	0.43	0.28	0	3.16	N, O
RUG100*	100 m	0.82	0.35	0.03	3.84	P
RUG150*	150 m	0.96	0.36	0.11	3.83	P
Convexity (over specified radius)						
CVX15	15 m	16.51×10^4	—	—	—	
CVX20*	20 m	16.15×10^4	—	—	—	Q
CVX30*	30 m	14.97×10^4	—	—	—	Q
CVX100*	100 m	10.78×10^4	—	—	—	R
CVX150*	150 m	10.00×10^4	—	—	—	R
Binary variables (frequency)						
BAR*	Barren cover (rock, soil, sand, snow)	3.13×10^4	—	—	—	S, T
CON*	Conifer cover	8.73×10^4	—	—	—	U, V
HDW	Hardwood cover	141	—	—	—	
MIX	Mixed conifer-hardwood cover	1.41×10^4	—	—	—	
SHB*	Shrub cover	5.03×10^4	—	—	—	V, W
TREE*	All tree cover types combined	10.15×10^4	—	—	—	U, W
TRESHB*	Tree and shrub cover types combined	15.18×10^4	—	—	—	S, X
HIWALL	Quarry highwalls	0.51×10^4	—	—	—	
MINOTH*	Other mine disturbance	1.39×10^4	—	—	—	T, X
PITBOT	Quarry pit bottoms	0.14×10^4	—	—	—	
REVEG	Revegetated Mine Areas	0.11×10^4	—	—	—	

retrieved 19,535 GPS locations collected from September 2006 to April 2009 during deployments ranging from 8 to 32 months. A composite home range of 33.9 km^2 was calculated and 4.0 km^2 of mine disturbance was delineated, comprising approximately 12% of the home range (Fig. 1). We analyzed data from nine animals (7F, 2M) after elimination of information from one female for a lack of independence.

Thirty percent of locations overlapped areas of mine disturbance; use of mines differed by month and greatest use occurred on the Mitsubishi Mine at the east end of the study area (Fig. 2). Fix success rates were not significantly different between test collars at mine locations (99.3 ± 0.2%; *SE*) and those at control locations (99.8 ± 0.2%); proportion of 3-D locations was lower (89.7 ± 4.1%), however, at mine locations compared to control locations (96.7 ± 1.8%). To avoid Type II error generated by the lower fix success rate (Frair et al. 2004, Cain et al. 2005, D'Eon and Delparte 2005, Ironside et al. 2017) in evaluating selection relative to mine highwalls and pit-bottoms, we retained all 2-D and 3-D GPS locations for RSF modelling.

We initially assessed candidate models that included measures of variables identified by Bleich et al. (2009) as important predictors of selection, including distance to a major road and distance to the railroad. Our measures of those seemingly spurious variables were each highly correlated with the variable UTM Easting (major road, Pearson's $r = 0.97$; railroad, $r = 0.74$; Table 3) and appeared to reflect the lower-elevation, eastern portion of the study area, that was transected by a railroad spur that sees low-speed rail traffic <5 times per week and a major road (Highway 18). To test our notion that those variables identified as predictive by Bleich et al. (2009) were not biologically meaningful but, instead, were proxies for characteristics of the east end of the home range, we compared models

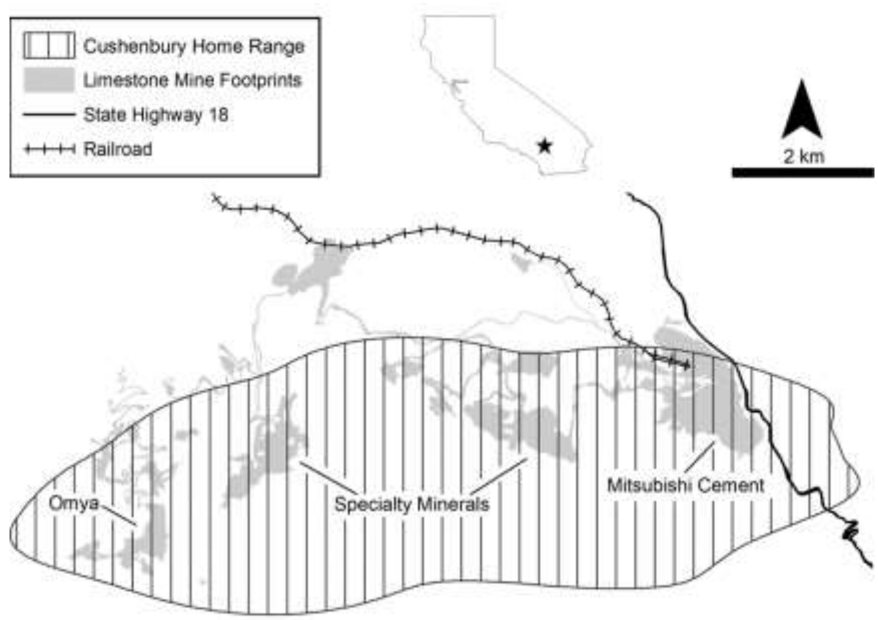

Figure 1. Study area (vertical hatching) defined by composite 95% adaptive kernel home range of desert bighorn sheep on the north slope of the San Bernardino Mountains, California, USA. Gray shading indicates footprint of three limestone mines operating in the study area.

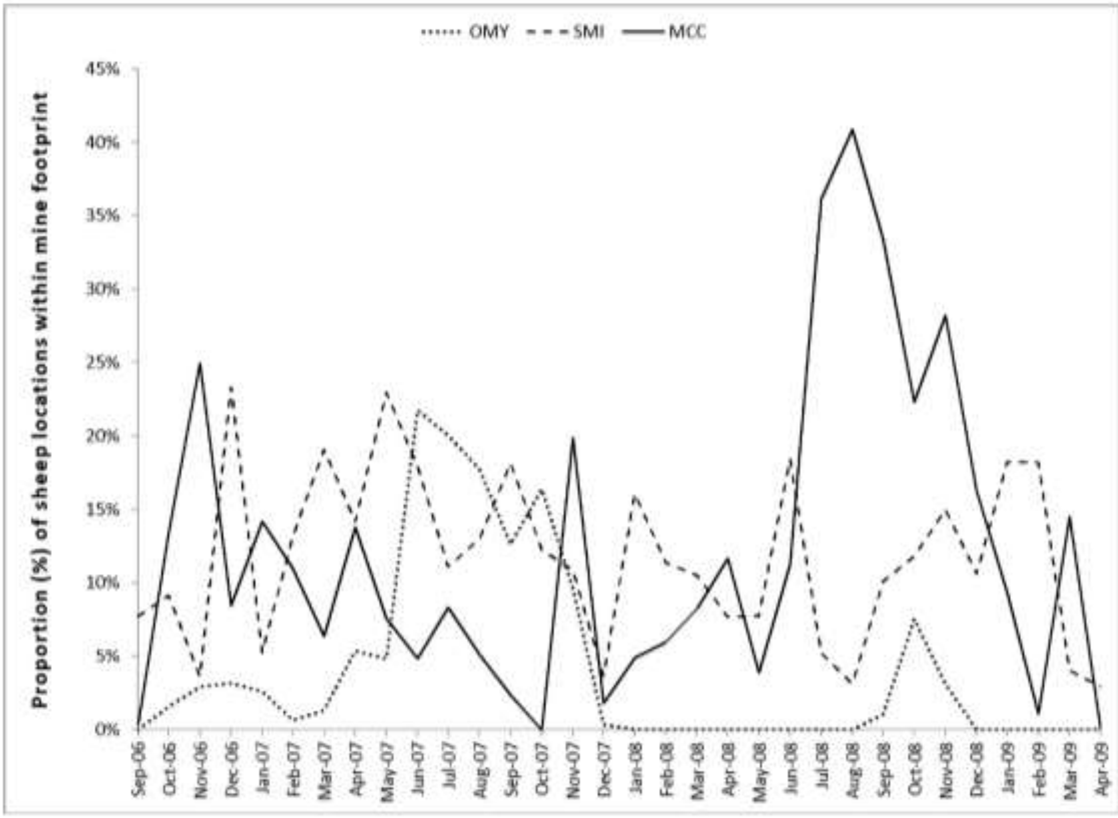

Figure 2. Monthly use of three limestone mines (Mitsubishi Cement Corporation [MCC] to the east, Specialty Minerals, Inc. [SMI] in the center, and Omya California [OMY]) by desert bighorn. San Bernardino County, California, USA.

substituting UTM Easting for the correlated distance-to variables of questionable biological relevance, and determined that UTM Easting generated a better model fit. We chose to treat UTM Easting and its correlates of distance to rail and distance to highway as extraneous variables and omitted them from further evaluation in an effort to identify characteristics selected by bighorn sheep in the eastern portion of the study area.

Fourteen variables were included in the most parsimonious model (Table 3, Fig. 3), whereas the next nearest model had little support (ΔAIC_c = 14.2); thus, we did not calculate Akaike weights or consider model averaging. The strongest predictors of habitat selection in our best model were proximity to active mines, selection for steep slopes, and proximity to water and revegetated areas. The next most influential predictors were elevation, convexity over a 150-m radius, and absence of recent wildfire. Other indicators in the best-fit model included selection for barren and shrub cover, highwalls, terrain ruggedness over a 100-m radius, and other mine disturbance. The model predicted avoidance of both mixed conifer-hardwood cover and the quarry pit bottoms. The combination of predictor variables in the RSF suggested higher-quality habitat for mountain sheep occurred on or near mined areas (Fig. 4). Results from k-fold validation yielded a positive slope with coefficient of determination (r^2) = 0.68 and Spearman rank correlation (r_s) = 0.78.

Table 3. Logistic regression coefficients estimated from resource selection function (RSF) for bighorn sheep proximate to active limestone mining operations in the San Bernardino Mountains, San Bernardino County, California, USA, 2006 – 2009.

			Odds Ratio – 95% CI			
Variable	Estimate	SE	Estimate	Lower	Upper	Mountain sheep select locations
BAR	0.4917	0.0354	1.64	1.53	1.75	In areas with barren cover
CVX150	0.3429	0.0178	1.41	1.36	1.46	With convex topography over a 150-m radius
DH2O	-0.5487	0.0211	0.58	0.55	0.60	Closer to point water sources
DMFA	-0.7595	0.0177	0.47	0.45	0.48	Closer to the active mining areas
DVEG	-0.5408	0.0224	0.58	0.56	0.61	Closer to revegetated mine areas
ELEV	0.1073	0.0046	1.11	1.10	1.12	At higher elevations
HIWALL	0.6018	0.0388	1.83	1.69	1.97	On quarry highwalls
MINOTH	0.1363	0.0348	1.15	1.07	1.23	Within other mine areas
MIX	-0.4905	0.0524	0.61	0.55	0.68	Outside mixed conifer-hardwood cover
PITBOT	-1.2078	0.1263	0.30	0.23	0.38	Outside quarry pit bottoms
RUG100	0.3358	0.0239	1.40	1.34	1.47	With rugged topography over a 100-m radius
SHB	0.3651	0.0211	1.44	1.38	1.50	In areas of shrub vegetation
SLOPE	0.0288	0.0008	1.03	1.03	1.03	With steeper slopes
YRSFIRE	0.0083	0.0005	1.01	1.01	1.01	Without recent wildfire

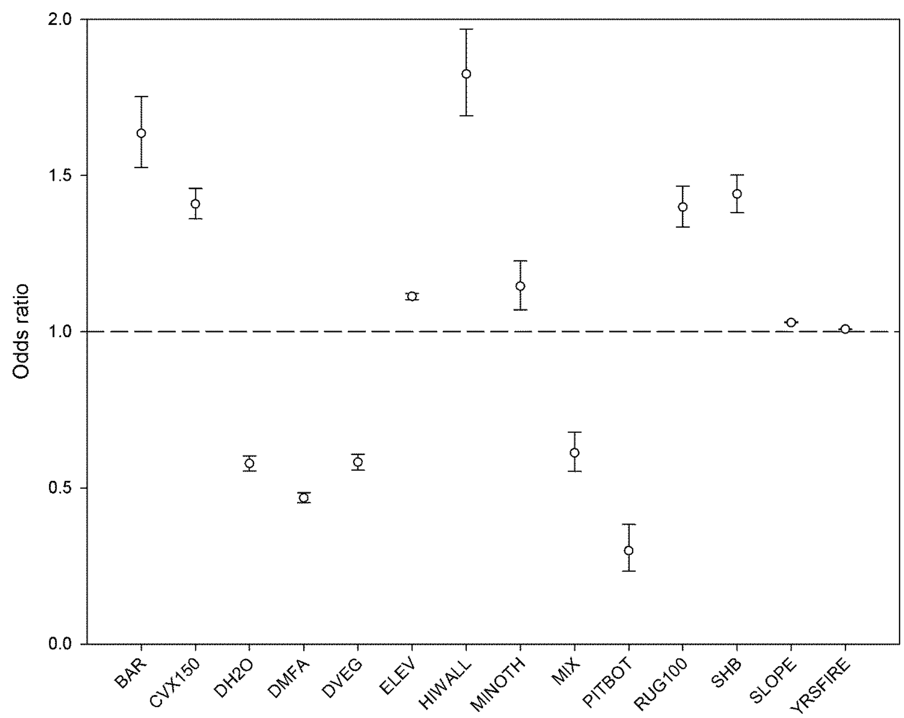

Figure 3. Odds ratios (mean and 95% CI) for predictor variables in the best fitting resource selection function (RSF) for Cushenbury bighorn sheep, San Bernardino Mountains, California, USA 2006 – 2009. Variables defined in Table 1-2.

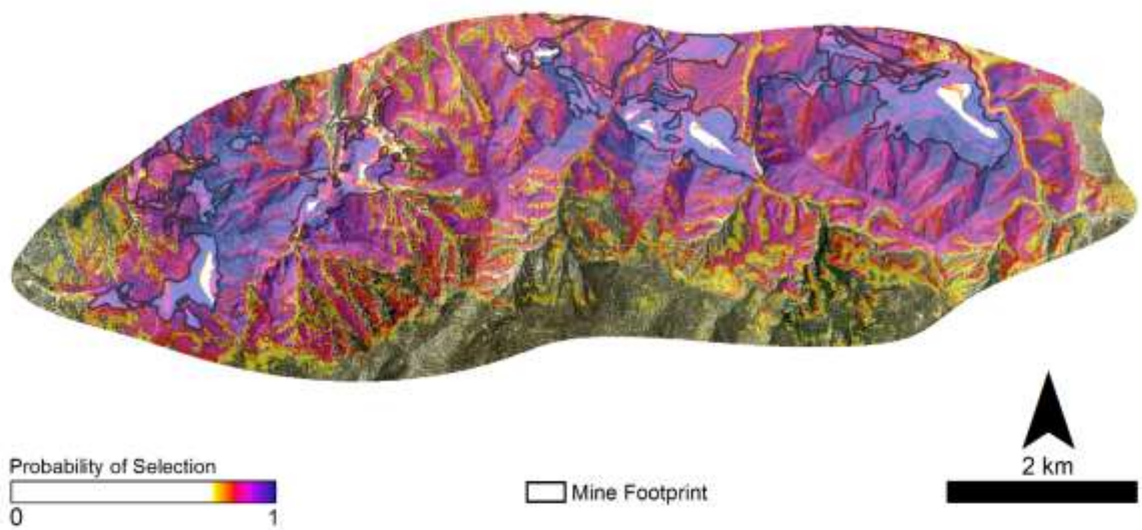

Figure 4. Resource selection function (RSF) for desert bighorn sheep (*Ovis canadensis nelsoni)* in an area of active limestone mines in the San Bernardino Mountains, San Bernardino County, California, USA, 2006 – 2009. The study area was defined using a 95% adaptive kernel composite home range. Darker colors represent higher probability of use by mountain sheep.

DISCUSSION

Comparisons to Earlier Results

Bleich et al. (2009) developed an RSF for the Cushenbury population using aerial telemetry data collected weekly from 1995 to 2003. The study area for that analysis encompassed 84 km^2 and was delineated using a composite minimum convex polygon for all telemetered study animals, with an additional buffer of 1 km (Bleich et al. 2009). Our study area was defined without a buffer because we sought to narrowly characterize 3rd order selection (Johnson 1980) within the home range to investigate how bighorn sheep use or avoid specific mine features, and resulted in our definition of a smaller area (33.9 km^2) as available habitat. Bleich et al. (2009) quantified a mine footprint of 3.3 km^2, whereas the mine footprint delineated in our analysis was 4.0 km^2. This increase was due to our use of high-resolution imagery to identify road-related disturbance greater than 10-m in width, talus slopes from historic mining, and other mine disturbance not reflected in the earlier analysis, rather than an actual increase in the extent of mine disturbance.

Our results indicated bighorn sheep were associated with areas closer to mines than were random points, consistent with the results of Bleich et al. (2009). Similarly, our analyses and those of Bleich et al. (2009) determined that mountain sheep avoided areas with recent wildfire and selected for higher elevations. Slope was also among the most influential determinants of resource selection in both investigations, consistent with other studies of mountain sheep in mined landscapes (MacCallum and Geist 1992, Oehler et al. 2005) and observations of desert bighorn in general (Valdez and Krausman 1999). In contrast to the analysis of Bleich et al. (2009), which documented avoidance of minor and major roads, we did not find any category of road to be an important determinant of habitat selection. Our results indicated selection for terrain ruggedness over a 100-m radius, consistent with selection for rugged terrain reported by others (McCann 1956, Geist 1971), whereas Bleich et al. (2009) unexpectedly found selection in the opposite direction, with animals selecting for lower terrain roughness. This divergent finding may result from different methods of quantifying terrain diversity; we used Nicholson's (1997) index, which included a measure of variation in aspect that was absent from the roughness index used by Bleich et al. (2009). Alternatively, conflicting results may be attributed to differences between VHF and GPS collars, which may be subject to different biases in addition to an order of magnitude lower accuracy in that older method. Bleich et al. (2009) assumed an average error in aerial locations of 177 m, an optimistic estimate because the nearby study area where that estimate originated (Nicholson et al. 1997) had substantially lower topographic relief than did the Cushenbury study area. GPS locations, by contrast, were expected to have 95% accuracy on the order of ≤15 m for 3-D fixes, but were 2–3 times larger for 2-D fixes (Frair et al. 2004, Cain et al. 2005, D'Eon and Delparte 2005).

Our results also diverged from those of Bleich et al. (2009) with respect to selection for proximity to water sources, a key habitat component for bighorn sheep (Bleich et al. 1997, Epps et al. 2004, but see Cain et al. 2008). Distance to water was among the most influential positive predictors in our analysis (odds ratio = 0.58, 0.55–0.60, 95% CI; Fig. 3), in contrast to the results of Bleich et al. (2009). This disparity likely derives from differing definitions of water between the two studies; the earlier analysis included features that were not reliable water sources. Bleich et al. (2009) characterized water as both points and as linear features by including intermittent streams; those ephemeral streams are dry in all but extreme precipitation events and are, therefore, unlikely to function as reliable water sources for bighorn sheep. The result of avoidance of water sources defined by Bleich et al. (2009), to include those streambeds can be understood in terms of avoidance of indirect risk of predation (Bleich 1999, Villepique et al. 2015); most of those drainages lie in steep canyons where topography and dense vegetation limit visibility, habitat characteristics that mountain sheep are expected to avoid (Risenhoover and Bailey 1980).

Bighorn sheep likely preferred the eastern end of the study area in the vicinity of the Mitsubishi Mine owing to a nexus of features that were among the strongest predictors in our RSF model: (1) escape terrain in the form of terraced quarry walls, (2) areas of revegetation on quarry benches where bighorn sheep regularly fed on new growth, and (3) consistent water at artificial sources. A similar convergence of habitat characteristics was noted on coal mines in Alberta, where benches of steep highwalls had been seeded and provided new growth of vegetation. Some of the highwalls described by MacCallum and Geist (1992) exposed natural seeps and were among the areas most heavily used by ewes escaping rams and by rams attending receptive females during the rut. Those investigators also noted some highwalls <100 m from mining activity were used for lambing by six ewes in one season, although most lambing occurred away from the mine.

Our results were concordant with work documenting avoidance of pit bottoms (Jansen et al. 2006) and avoidance of tree cover and dense vegetation (Bristow et al. 1996, Poole et al. 2016) by bighorn sheep in landscapes influenced by mining. We acknowledge potential bias against GPS collars collecting fixes in areas of tree cover and topographic limitation of available sky (Cain et al. 2005, Frair et al. 2010, Ironside et al. 2017) that may overestimate the magnitude of avoidance of quarry pit bottoms and mixed conifer-hardwood cover estimated in our RSF. We addressed that issue by including both 2-D and 3-D fixes in analysis based on our finding that pit bottoms reduced the proportion of 3-D GPS fixes but did not reduce overall fix rate. Such a reduction in proportion of 3-D fixes is well documented (Cain et al. 2005, Jiang et al. 2008) and may be explained by the requisite contact with ≥4 satellites for a 3-D fix. Mine pits in our study area featured steep slopes to the south (i.e., highwalls) that obstruct available sky, but available sky to the north was largely unobstructed by either topography or vegetation, allowing acquisition of 2-D fixes, but not always 3-D fixes. Our inclusion of 2-D locations served to minimize biases against detection of both pit bottoms and mixed conifer-hardwood cover.

Comparison between RSFs developed with VHF and GPS telemetry provided an example of how different results can be influenced by advancements in technology. Divergent findings also may be attributed to differences in the extent of habitat defined as available in the RSF model, definitions of variables, treatment of correlated variables, or inclusion of other variables that can mask factors of greater biological relevance in driving resource selection by wild sheep.

Selection for Mine Areas

Quarry highwalls located in areas of active and inactive mining, which accounted for only 3% of the study area, emerged as a predictor of resource selection, similar to results from previous investigations of mountain sheep in mined landscapes that show preferential use of highwalls for escape terrain, travel, and bedding areas (Elliott and McKendrick 1984, MacCallum 1988, Bristow et al 1996, Jansen et al. 2006). Mine equipment operators in our study area regularly observed bighorn sheep grazing on slopes and on road berms and using mine roads for travel at distances from 10 to 150 m from mining activity, consistent with reports that bighorn sheep tolerate predictable disturbance from steady or occasional road traffic (Graham 1980, Jansen et al. 2006, Bleich et al. 2009, Poole et al. 2016). Jansen et al. (2009) noted that ewe groups expanded use of newly mined areas upon resumption of copper mining. Furthermore, they noted both pregnant and post-parturient females selected for areas characterized by the highest activity within the mine (e.g., administration area, active ore extraction zones and haulage routes). Indeed, Wiedmann and Bleich (2014) emphasized that bighorn sheep adapt readily to sources of disturbance that are predictable, consistent, and benign—conditions that characterize the vast majority of disturbance in our study area.

Proximity to mine revegetation was among the most influential predictors in our model and is consistent with investigations of mountain sheep in northern environments showing preferences for revegetated areas (Elliot and McKendrick 1984, MacCallum and Geist 1992, Poole et al. 2016), as well as positive demographic responses to those reclaimed mine features (MacCallum 1992). Those northern populations occupied regions impacted by coal mining, which typically allows for concurrent reclamation of mined voids into grassland areas backfilled with spoils excavated from adjacent pits. In contrast, the limestone mines in our study area employed a benched, sidehill quarrying method (Nichols and Day, 2010) that involves sequential removal of material from steep mountain slopes. In some areas, operations will continue to excavate material extending well below existing topography. The resulting quarry pits are not backfilled because most material removed is sold for industrial uses; unmarketable rock is moved to large stockpiles that will be re-contoured with surrounding topography upon mine closure. While all stabilized slopes, roads, and horizontal surfaces of the final quarry walls are eventually revegetated, most reclamation work is generally not feasible until the final years of mine operation.

MANAGEMENT IMPLICATIONS

Bighorn sheep in our study area selected habitats on or near mines expected to produce limestone for at least another century. Understanding how wild sheep select habitat as the landscape changes will remain a management priority. Our results indicated a general tolerance of mine-related activities and selection of features created by mining that served the same function as natural habitat (e.g., provision of escape terrain and open foraging areas). Nevertheless, these physical features run the risk of creating ecological traps if their use by bighorn sheep results in poorer nutrition or otherwise leads to a decline in reproduction or survival (Bleich et al. 2009). The small sample of animals in our study precluded evaluation of potentially divergent strategies of resource selection by male and female bighorn sheep (Bleich et al 1997). Differential selection by sex relative to mine areas (Bristow et al. 1996, Jansen et al. 2006) can have important consequences such as the seasonal avoidance, by males, of previously occupied areas where mine expansion resulted in a reduction of forage (Jansen et al. 2009). Thus, we recommend future investigators evaluate survival, reproduction, and body condition in an effort to assess demographic responses to quantity and quality of forage provided by revegetation activities. Furthermore, future researchers should examine behavioral responses of bighorn sheep to mine activities including blasting and operating hours, both of which may differ in magnitude and extent with future mine expansions.

Revegetation sites within our study area were small (0.5–3 ha) relative to the total mine disturbance and, while our results indicated strong affinity for those areas, their effectiveness in replacing forage lost to mining activity awaits further investigation. To mitigate cumulative losses of carrying capacity for bighorn sheep resulting from future mine expansions, we recommend determination of seasonal diets and the quality of those diets, and that site-specific revegetation palettes be optimized to maximize the forage benefit for wild sheep while adhering to criteria specified in mine reclamation plans. Efforts by mines to augment existing and future revegetation sites with species identified from diet analyses may benefit bighorn sheep by providing high quality forage, thereby reducing the risk of mined landscapes becoming ecological traps. Further, any opportunities to revegetate additional sites concurrent with ongoing mine activity, as described by Anderson (2018), will lessen impacts of habitat loss. Moreover, enhanced forage availability resulting from concurrent revegetation efforts will be important if augmentations are implemented for this small, isolated population; sufficient forage to support additional mountain sheep must be available before translocations are considered.

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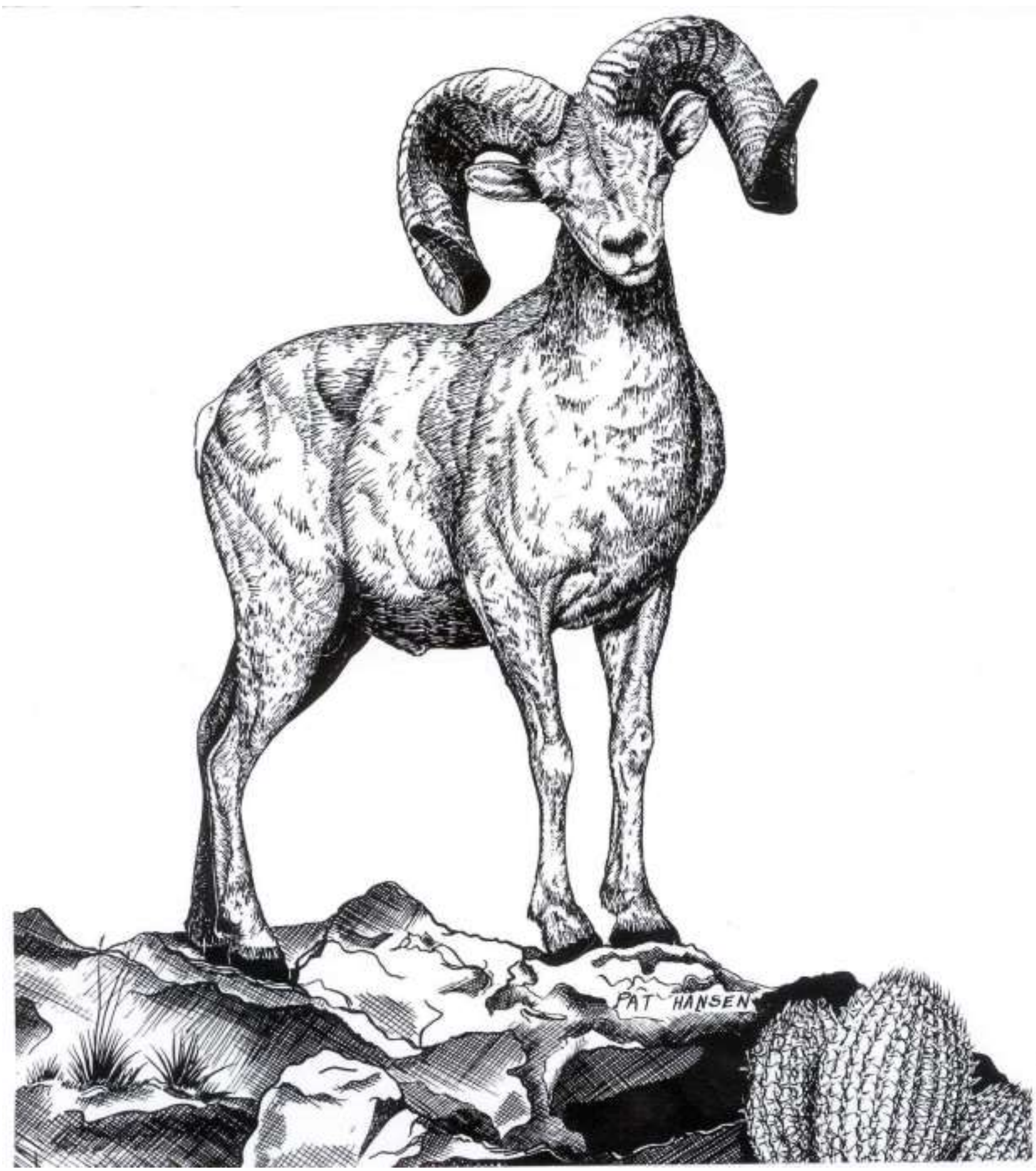

Leucism in Bighorn Sheep (*Ovis canadensis*), with Special Reference to the Eastern Mojave Desert, California and Nevada, USA

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Abstract Leucism is a genetic a condition in which there is partial loss of pigmentation and often presents as white, rather than normal, coloration of the pelage. Leucism has been reported frequently in bighorn sheep (*Ovis canadensis*) occurring in southeastern California and southwestern Nevada. In this paper I describe the distribution of leucistic bighorn sheep in that geographic area, describe the relative abundance of this white color morph in 2 populations of bighorn sheep in California over a period of 26 years, consider potential explanations for the widespread occurrence of leucistic individuals in southeastern California and southwestern Nevada, and speculate about the ramifications of shifts in climate for the distribution of the leucistic phenotype. Repeated founder effects, severe population bottlenecks, and source-sink dynamics are unlikely explanations for the widespread occurrence of the white color morph in that metapopulation, but none of these explanations can be excluded entirely. A decline in the frequency of occurrence of the white phenotype could, however, manifest in small populations because of stochastic events that result in elimination of the rare allele or if an unrealized, albeit detrimental, pleiotropic effect is associated with leucism. Nevertheless, in the absence of more likely explanations, the distribution of the white phenotype in the study area is explained most parsimoniously by the metapopulation structure of bighorn sheep in the study area, as evidenced by historical observations, radio telemetry studies, and recent genetic investigations.

Desert Bighorn Council Transactions 54:31–47

Key words abnormal coloration, bighorn sheep, connectivity, gene flow, leucism, Mojave Desert, *Ovis canadensis*

Leucistic individuals are deficient in pigmentation and are white in color but exhibit pigmented skin and eyes that are normally colored or blue (Abreu et al. 2013 for review; Fig. 1). Leucism is a double-recessive trait (Cruickshank and Robinson 1997); hence, normally colored parents have the potential to produce leucistic offspring, but the genetics of leucism should not be confused with the genetics of albinism (Searle 1968). Records of leucistic or otherwise white-colored bighorn sheep are especially prevalent from a small area of the Mojave Desert in southeastern California and southwestern Nevada (Bleich 2017). The regular observation of young and adult leucistic individuals of both sexes in the Clark Mountain Range, San Bernardino County, California and nearby ranges in California and Nevada suggests a higher than usual frequency of this white phenotype in that general area. Further, the regular occurrence of leucistic individuals in those ranges is consistent with the intermountain

Figure 1. A leucistic female bighorn sheep and 4 normally colored bighorn sheep (3F, 1M) in the Clark Mountain Range, San Bernardino County, California, 2006. Photo by T. Glenner, California Department of Fish and Game.

movements of bighorn sheep described previously (Monson 1964; Hansen 1965a, 1965b, 1965c, 1980; Jaeger 1994). Moreover, recent movements confirmed by radio telemetry (Nevada Division of Wildlife [NDOW], unpublished data) in the same general area suggest some gene flow among bighorn sheep occupying several mountain ranges in the Eastern Mojave Desert of California and Nevada, which is consistent with numerous reports of leucistic bighorn sheep in that region (Bleich 2017).

The purposes of this paper are to 1) provide details of the distribution of leucistic bighorn sheep in a specific geographic area of Nevada and California; 2) describe the relative abundance of this white color morph in two populations of bighorn sheep in California over 26 years; 3) evaluate potential explanations for the widespread occurrence of leucistic animals in that geographic area; and, 4) consider the ramifications of changes in habitat quality resulting from shifts in climate for the distribution of that leucistic phenotype.

STUDY AREA

Most reports of abnormally colored bighorn sheep have come from several mountain ranges in a small part of the Mojave Desert (37°05′N and 116°20′W × 35°45′N and 114°40′W; hereafter study area) in California and Nevada (Bleich 2017) within the Eastern Mojave Desert Subdivision of the Mojave Desert (Webb et al. 2009) and centered just east of the California-Nevada state line (Fig. 2). Within the study area, the Kingston, Mesquite, Nopah, Avawatz, and Clark Mountain ranges in California are inhabited by bighorn sheep on a permanent basis (Torres et al. 1994, Epps et al. 2003, Abella et al. 2011) and, except for the Avawatz and Nopah ranges, have been foci of long-term demographic investigations (Appendix A). In the Nevada portion of the study area, bighorn sheep inhabit the Spring Mountains and

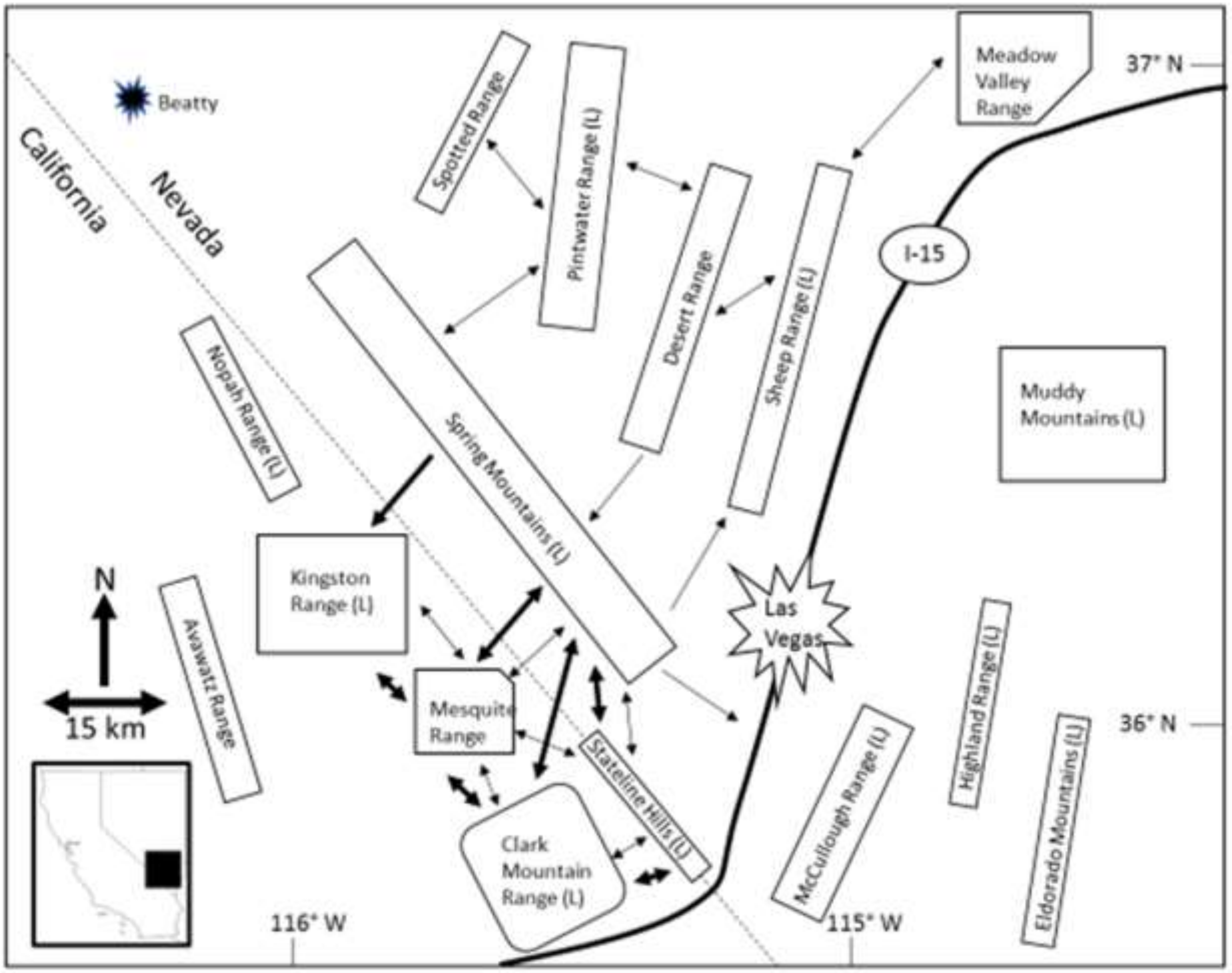

Figure 2. Schematic diagram of the study area in California and Nevada, showing mountain ranges among which movements of bighorn sheep have occurred, and in which leucistic (L) bighorn sheep have been observed (Bleich 2017). Thin arrows indicate directional intermountain movements reported by Monson (1964), Hansen (1965a, 1965b, 1965c, 1980), McQuivey (1975, 1978), or Jaeger (1994). Bold arrows indicate directional intermountain movements made by a 9-year old male from October 2014 to January 2017. A male lamb that was ear-tagged in the Nopah Range was recaptured 4 years later in the Clark Mountain Range, but the actual route of movement is not know.

Stateline Hills , Muddy and El Dorado mountains, and the Spotted, Pintwater, Desert, Sheep, Meadow Valley, McCullough and Highland ranges on a permanent basis (Cox and Cummings 2005) but demographic monitoring has been less intense than in California (NDOW 2016; Appendix A). The only substantial barrier to movements by bighorn sheep in the study area is Interstate Highway 15 (Fig. 2), a four-lane, high-speed, fenced roadway of the type that has been shown to retard gene flow between otherwise proximate populations (Epps et al. 2005; but, see Epps et al. 2018).

In California, the Kingston Range reaches an elevation of 2,236 m, and the Clark Mountain Range has a high point of 2,407 m. The Nopah, Avawatz, and Mesquite ranges are somewhat lower in elevation, with high points of 1,950 m, 1,876, and 1,640 m, respectively. The Spring Mountains reach the highest elevation (4,812 m) among the ranges in Nevada, followed by the Sheep (4,015 m), McCullough (2,837 m), Pintwater (2,830 m), Desert (2,546 m), Stateline Hills (2,275 m), Meadow Valley (2,332 m), Muddy (2,193), Eldorado (2,043 m), and Highland (2,004 m) ranges; only the Spotted Range (1,839) fails to reach 2,000 m at its highest point.

Climate across the study area is characterized by temperatures that peak in early summer and that reach their nadir in mid-winter and mean monthly maximum temperatures among the 7 weather stations in the study area are highly correlated ($0.993 \geq r \leq 0.999$, *CV* = 0.19%; V.C. Bleich, unpublished data). Mean monthly minimum temperatures also are highly correlated ($0.985 \geq r \leq 0.999$, *CV* = 0.37%; V.C. Bleich, unpublished data). At Mountain Pass, the highest-elevation weather station in the study area, the mean high temperature in July was 33.8°C, the mean low temperature in January was -1.4°C, and mean annual precipitation was 21.2 cm (WRCC 2007).

Elevation and landform each play important roles in determining precipitation and temperature in the Mojave Desert, both of which influence vegetation, and forage quality and availability. Precipitation increases semi-logarithmically with elevation up to 2,500 m, a point beyond which moisture content of the air determines rainfall amount (Jayko 2005). The western portion of the study area is characterized by a unimodal peak in precipitation, but a bimodal peak is typical east of longitude (Hereford et al. 2004). As a result, precipitation across the study area was much more variable ($0.194 \geq r \leq 0.924$; *CV* = 46.2%) than temperature.

From north to south there is a waning influence of vegetation typical of the Great Basin Desert and an increasing influence of the Mojave Desert with a transition at about 36°55′ N near Beatty, Nevada (MacMahon 1985:47). Thus, diversity of vegetation in the EMD is the result of mixing of vegetation representative of the Great Basin and Mojave deserts (MacMahon 1985, Hansen et al. 1999), an ecotone that is especially pronounced in the higher elevations of the Kingston, Spring, Sheep, and Clark Mountain ranges (Jaeger 1926, Munz 1935, Clokey 1951, Bradley 1964, Prigge 1975, Castagnoli et al. 1983).

Intermountain basins (<1,300 m) are characterized by desert scrub and desert riparian communities; pinyon (*Pinus* spp.)-juniper (*Juniperus* spp.) woodland and riparian cliff vegetation occur from 1,300 m to about 1,850 m, and vegetation above 1,850 m largely is coniferous forest (Bradley 1964); this generalized pattern exists across the study area (Weaver and Mensch 1970, Weaver and Hall 1972, Prigge 1975, Castagnoli et al. 1983). With the exception of the Mesquite Range, areas inhabited by bighorn sheep generally are well-watered by natural springs or tinajas, or because wildlife water developments have been installed specifically to help conserve bighorn sheep (Weaver and Hall 1972, Jaeger 1994, Bleich and Pauli 1990, NDOW 2015).

METHODS

Data Sources

I reviewed the results of waterhole counts, aerial surveys, and aerial events (i.e., other observations from aircraft) recorded from 1976 to 2009 in the Kingston, Clark Mountain, Nopah, and Mesquite ranges of California. I reviewed similar reports from the Avawatz Range because recent analyses by Epps et al. (2016) suggested occasional movements occur between what those authors identified as the Kingston-Clark and the Avawatz population clusters; moreover, the southern Piute word *avawatz* implies 'white sheep' (Werner 1951). I also reviewed estimates of population sizes and assessments of population trends for the Nevada mountain ranges, as reported by NDOW (2016).

I defined aerial surveys as annual demographic surveys conducted in a standardized manner (i.e., characterized by consistent survey intensities in well-defined survey polygons; Wehausen and Bleich 2007) by experienced observers and an experienced pilot, and that occurred from 1991 to 2009. In addition to the amount of actual survey time, observers recorded the location and information on the demographics of bighorn sheep seen and noted observations of anomalously colored individuals. Aerial events included the results of those aerial surveys augmented with information obtained during aerial captures, nonstandardized survey flights, and other overflights during which search time was recorded, and occurred from 1983 to 2009. Capture and collaring of live animals followed then-current guidelines (Ad Hoc Committee on Acceptable Field Methods in Mammalogy 1987) and animal capture and handling protocols from the California Department of Fish and Game (Jessup et al. 1986).

Statistical Analyses

I used data from aerial surveys and aerial events to calculate the rates at which bighorn sheep were encountered (animals/hr), the rates at which leucistic bighorn sheep were encountered (individuals/hr), and the proportions of leucistic animals on a mountain range by mountain range basis. I used the Kruskal-Wallis one-way analysis of variance (H; Siegel 1956) to test for differences among annual encounter rates of bighorn sheep, annual encounter rates of leucistic bighorn sheep, and proportions of white-colored individuals observed annually among mountain ranges; when results from <3 ranges were compared I used the Mann-Whitney U-test (Siegel 1956). I tested for trends in the rates at which leucistic bighorn sheep were encountered, trends in the proportion of white sheep encountered, and for evidence of a relationship between observation rates and proportion of leucistic individuals seen during aerial surveys with Spearman's rank correlation (ρ; Siegel 1956). I used the Z-test for proportions (Zar 1984) to test for differences between the proportions of leucistic male and female individuals and those of normally colored male and female bighorn sheep. Finally, I tested for overall trends in observation rates of adult animals observed during aerial surveys from the Kingston and Mesquite ranges combined, and from the Clark Mountain Range with Spearman's rank correlation.

RESULTS

White-colored bighorn sheep have been reported most often from several mountain ranges in the Eastern Mojave Desert of eastern California and southern Nevada; 11 of the 31 location records summarized by Bleich (2017) were within the study area (Fig. 2). Each of the white-colored bighorn sheep reported from the Kingston Range, Clark Mountain Range, or the Nopah Range had white pelage and dark-colored eyes, conditions that are consistent with leucism. Since 1983, leucistic bighorn sheep have been observed in the Clark Mountain Range during aerial events on 22 occasions, once (1 adult female) in the Kingston Range, and once (1 yearling male) in the Nopah Range. Leucistic bighorn sheep also have been reported frequently from the Stateline Hills and Spring Mountains (Fig. 1), but not from the Mesquite Range or the Avawatz Range (Bleich 2017). With the exceptions of 1988 and 1993, ≥ 1 leucistic individual has been observed in the Clark Mountain Range during each aerial event (Table 1). Multiple leucistic bighorn sheep observed during the same flight were confirmed to be different individuals. Leucistic individuals observed in different years may have been seen during previous flights but, alternatively, could have been different individuals.

From 1983 to 2009, observation rates of leucistic animals tallied during aerial events were greater in the Clark Mountain Range than in the Nopah, Kingston, or Mesquite ranges (H_3 = 32.010, P < 0.001); no difference existed in observation rates among the latter 3 mountain ranges (H_2 = 0.620, P = 0.733) during the same period (Table 2). The proportion of leucistic animals tallied during aerial events in those ranges during 1983 – 2009 also was greater in the Clark Mountain Range than in the Nopah, Kingston, or Mesquite ranges (H_3 = 34.580, P < 0.001), and the mean proportion of observations of leucistic animals in the Clark Mountain Range was 5× that in any other mountain range (Table 2). Again, no difference (H_2 = 0.620, P = 0.733) existed in the mean proportion of observations of leucistic animals seen in the Kingston, Mesquite, and Nopah ranges.

Table 1. Number of male and female leucistic bighorn sheep observed during aerial events or aerial surveys in the Clark Mountain Range, California, USA 1983 – 2009.

	Number of	
Year[a]	Females	Males
1983	2	1
1984	6	1
1986	3	1
1988	0	0
1990	2	0
1991	1	0
1992	1	1
1993	0	0
1994	1	0
1995	1	1
1996	2	0
1997	1	1
1998	1	1
1999	0	0
2000	1	1
2001	1	0
2002	0	1
2003	1	0
2004	1	0
2005	3	0
2006	2	0
2007	1	0
2008	1	0
2009	1	0

Table 2. Mean number of leucistic bighorn sheep seen per hour of flight time and mean proportion of leucistic bighorn sheep among total animals observed on each flight during aerial events or aerial surveys in the Clark Mountain, Mesquite, Kingston, and Nopah ranges, California, USA 1983 – 2009.

Data Source Location	Total Flights	Total Flight Time (hrs)	White Sheep Seen per Hour of Flight Time (Mean ± SD)	Proportion of White Sheep Among Total Animals Seen per Flight (Mean ± SD)
Aerial Events[a]				
Clark Mountain Range	22	81.49	1.188±3.042	0.061±0.055
Mesquite Range	16	28.19	0	0
Kingston Range	24	121.95	0.007±0.036	0.005±0.025
Nopah Range	4	15.67	0.062±0.108	0.013±0.022
Aerial Surveys[b]				
Clark Mountain Range	17	65.79	0.436±0.248	0.056±0.044
Mesquite Range	16	28.19	0	0
Kingston Range	20	105.15	0.009±0.040	0.0006±0.003
Nopah Range	0	—	—	—

When only the results of aerial surveys conducted from 1991 to 2009 and that employed consistent survey intensities in the Clark Mountain, Kingston, and Mesquite ranges were considered (standardized surveys did not occur in the Nopah Range), differences in mean observation rates (H_2 = 31.150, P < 0.001) and the mean proportion of leucistic animals tallied (H_2 = 31.150, P < 0.001) again occurred among mountain ranges (Table 2). Neither mean observation rates (U = 144, P = 0.803) nor mean proportion of leucistic individuals observed (U = 144, P = 0.803) differed between the Kingston and Mesquite ranges.

In the Clark Mountain Range, a highly significant relationship (ρ = 0.724, P < 0.001) existed between mean observation rate of leucistic individuals and the mean proportion of leucistic individuals among the total number of sheep observed annually. The proportions of observations of male (0.269) and female (0.731) leucistic bighorn sheep (n = 26) tallied during aerial surveys of the Clark Mountain Range did not differ from those of males (0.315) and females (0.685) of normal coloration (n = 485) tallied during aerial surveys from 1991 to 2009 (Z = -0.495, P = 0.617).

A general downward trend in observation rates of total adult animals seen during aerial surveys was evident (ρ = -0.357, P = 0.159, n = 17) in the Clark Mountain Range from 1991 to 2009, the year of the most recent aerial survey. Nevertheless, no relationship existed between rates at which leucistic animals were observed and year (ρ = -0.033, P = 0.882) in the Clark Mountain Range, and there was no relationship between year and the proportion of leucistic animals observed there annually (ρ = 0.027, P = 0.906). In the Kingston and Mesquite ranges combined (see Jaeger 1994), a highly significant downward trend in observation rates of total adult animals during aerial surveys occurred from 1991 to 2009 (ρ = -0.578, P = 0.015, n = 17).

DISCUSSION

The white-colored bighorn sheep observed in the Kingston Range, Clark Mountain Range, or the Nopah Range all were leucistic, as evidenced by their white coloration and dark eyes. The number of individual leucistic animals occurring in the Clark Mountain Range, however, cannot be confirmed given that only two such individuals have been captured and marked. Although the maximum number (6 females, 1 male) of leucistic individuals was seen in 1984, and four (3 females, 1 male) were seen in 1986, it cannot be determined which (if any) individual was observed during >1 aerial event. Further confounding this issue, observation rates of leucistic and normal bighorn sheep may vary because of differences in contrast with vegetation or substrate (Bleich et al. 2001), and prior exposure to helicopters can influence observation rates as a function of individual responses to those aircraft (Bleich et al. 1990b, 1994). Despite these sources of potential bias, ≥2 leucistic individuals have been seen in the Clark Mountain Range on 12 occasions from 1983 to 2009 (Table 1). Further, analyses indicated no temporal trend either in observation rates of leucistic individuals or in the proportion of leucistic individuals seen in the Clark Mountain Range, and there was a strong positive correlation between the observation rate for leucistic individuals and the proportion of leucistic individuals among the total number of sheep observed during annual aerial surveys. These results suggest there has been no detectable change either in observation rates or in the proportion of leucistic individuals observed in the Clark Mountain Range over nearly 30 years. A strong downward trend in observation rates in the combined Kingston and Mesquite ranges was evident, however, and suggests that population declined during the same period.

Leucistic bighorn sheep have been observed frequently in the Spring Mountain Range, Clark Co., Nevada (Bleich 2017). Hansen (1980) described two observations of white-colored bighorn sheep in the Spring Mountains, and regular seasonal movements from the Kingston Range and Clark Mountain Range to the State Line Hills and the Spring Mountains were confirmed by Jaeger (1994). Hansen (1965a) also reported a white-colored female in the Pintwater Range and noted there is interchange between that population and bighorn sheep occupying the Sheep Range to the east, and the Spring Mountains to the south. Monson (1964) summarized ≥11 intermountain movements in the study area and noted bighorn sheep that had been marked in the Desert Range were later observed in the Sheep Range. Additional movements among mountain ranges (Hansen 1965b, 1965c) suggested the potential for gene flow among bighorn sheep inhabiting the study area. Recent movements by a mature male bighorn sheep fitted with a Geographic Positioning System collar have substantiated similar movements (NDOW, unpublished data), and confirmed movement from the Spring Mountain Range directly to the Kingston Range (Fig. 2).

Assuming the same genetic variant, the seemingly regular occurrence of white-colored bighorn sheep in the Clark Mountain Range and proximate ranges suggests a higher-than-usual frequency of alleles responsible for the white phenotype. Previously described movements by bighorn sheep suggest at least some gene flow, or common ancestry, among bighorn sheep in those subpopulations. Metapopulation structure facilitates gene flow among bighorn sheep (Epps et al. 2007) and, when combined with numerous observations of white-colored individuals in most nearby mountain ranges (Bleich 2017), movements described above support the existence of a metapopulation (Schwartz et al. 1986; Bleich et al. 1990a, 1996).

Population bottlenecks or founder events can result in a chance increase in the frequency of rare alleles, including those associated with leucism (Laikre 1999), and an increase in the frequency of rare alleles can be indicative of an earlier population bottleneck (Stangl et al. 1995). Nonetheless, an extreme bottleneck could result in lowered fitness (Falconer 1981) and make persistence of the white phenotype less likely, or the rare allele could be lost as a result of the sampling effect of a strong bottleneck event without invoking the longer-term impacts of lowered fitness. Alternatively, a founder effect can occur when populations are established by few individuals and may reduce genetic variability or increase the frequency of rare alleles at some loci. Values of allelic richness (average number of alleles per locus) among bighorn sheep from the Kingston Range and Clark Mountain Range were, however, among the highest reported by Epps et al. (2006) for the 25 populations investigated. These results suggest that bottlenecks resulting in low genetic variability among bighorn sheep in those ranges are not likely to have occurred in recent years; no information on allelic richness currently is available for bighorn sheep in the Nopah Range.

In Nevada, exceptionally high values of genetic diversity were reported among bighorn sheep sampled in the Sheep Range and in the Desert Range (Wehausen and Jaeger 2016). Although not within the study area, a similar situation existed in the East Pahranagat Range (elevation 1,918 m), which lies immediately north of the Sheep Range. Values of genetic diversity in the Spotted Range and Pintwater Range were similar to, but slightly less, than values from proximate ranges further to the south (Muddy, Eldorado, McCullough, and Highland ranges; Jaeger and Wehausen 2012).

Contrary to California, the situation in Nevada is confounded by previous translocations of bighorn sheep. Animals had been moved directly from the Muddy Mountains to the Sheep Range, or indirectly from the Muddy Mountains to the Sheep Range via a secondary translocation from the Specter Range, and animals previously had been translocated from the River Mountains to the Spotted Range (Wehausen and Jaeger 2016). Nevertheless, values of genetic diversity suggest that bottlenecks resulting in low genetic variability among bighorn sheep inhabiting those ranges are not likely to have occurred in recent years. That the widespread occurrence of the white phenotype in southeastern California and adjacent southwestern Nevada described by Bleich (2017) is a result of one or more population bottlenecks or one or more founder events remains open to investigation. Given the regular migrations and other intermountain movements reported over the past 4 decades and recent investigations indicating substantial gene flow among these ranges, however, neither founder events nor bottlenecks readily explain the wide distribution of leucistic bighorn sheep in the study area.

An additional plausible explanation for the widespread occurrence of leucistic bighorn sheep described here involves source-sink dynamics, whereby populations occupying some mountain ranges serve as sources of emigrants to other mountain ranges that are recipients (i.e., population sinks; Pulliam 1988). Source populations occupy better habitat, have higher birth rates and survival rates when compared to sink populations, and serve as sources of emigrants to sink populations; sink populations generally occupy poor-quality habitat when compared with source populations, and cannot persist in the absence of immigration (Donovan et al. 1995).

Source-sink dynamics have clear implications for resource management and conservation (Holt 2011) but, with few exceptions, little is known about habitat quality or vital rates among the populations considered herein. It is likely however, that habitat generally is of higher quality in the Spring Mountains and Sheep Range of Nevada and in the Kingston and Clark Mountain ranges of California than in proximate lower-elevation ranges, as suggested by Wehausen and Jaeger (2016). The Sheep Range is large and is well-connected to neighboring ranges occupied by bighorn sheep (Wehausen and Jaeger 2016), as are the Spring Mountains and the Kingston and Clark Mountain ranges (Epps et al. 2016; Fig. 2). Habitat quality in these mountains appears to be primarily a function of climate conditions (as represented by elevation) combined with other factors (Epps et al. 2006), with high-elevation ranges supporting habitat that generally is of greater quality and—by my inference—are those most apt to support source populations.

There is inadequate information to invoke emigration from source populations as the means by which sink populations remain extant in the study area, but additional inferences can be made. For example, Weaver and Hall (1972) did not indicate bighorn sheep inhabited the Mesquite Mountains, and suggested bighorn sheep had declined in the Nopah Range, and those authors implied that both the Nopah Range and the Mesquite Range provided lower-quality habitat than the nearby Kingston and Clark Mountain ranges. Consistent with the observations of Weaver and Hall (1972), Jaeger (1994) determined that diet quality in the Mesquite Range was lower than that in the Kingston Range, but also demonstrated that the Mesquite Range was used extensively by bighorn sheep during parts of the year.

Female bighorn sheep occupied the high-elevation Kingston and Clark Mountain ranges during the hot season to take advantage of natural water sources and nutritious forage, and then moved to proximate low-elevation ranges (Mesquite Range and State Line Hills) during the cool season, and Jaeger (1994) concluded those movements represented a tradeoff between predation risk and the physiological demands for nutrients and water. Further, Weaver and Hall (1972) noted differences in forage availability between the Nopah Range and the Kingston Range.

The widespread distribution of the leucistic phenotype (Bleich 2017), combined with movements reported over many years (Monson 1964; Hansen 1965a, 1965b, 1965c, 1980), aerial telemetry investigations (Jaeger 1994, NDOW unpublished data), and genetic analyses (Epps et al. 2006, 2016; Jaeger and Wehausen 2012; Wehausen and Jaeger 2016) imply seasonal differences in habitat quality occur among these ranges. Nevertheless, the Clark Mountain Range probably has been occupied more consistently than some of the lower-elevation ranges that are more likely to be affected by drought or more arid periods and, thus, could serve as a stronghold for preserving genetic diversity (Epps et al. 2004, 2006), including the allele for leucism; the same would apply to the Kingston Range in California, and to the Sheep Range and Spring Mountains in Nevada.

Gene flow in desert bighorn sheep was inversely related to distance between mountain ranges (Epps et al. 2005, 2007), and genetic diversity was related to the amount of connectivity with other populations and to the maximum elevation of mountain ranges (Epps et al. 2006). Epps et al. (2004) also reported that populations in higher elevation ranges have lower extinction probabilities, and thus lower extinction frequencies, which also preserve genetic diversity. Greater levels of precipitation, lower temperatures, and more dependable availability of water were associated with higher elevations of the Mojave Desert in California (Epps et al. 2004), and that relationship likely holds across the Eastern Mojave Desert. The greater diversity among plant communities occurring at high elevations likely is the result of higher precipitation; increased precipitation and lower rates of evapotranspiration likely result in greater diversity of vegetation communities and an increase in forage quality (Wehausen and Jaeger 2016).

Because a source-sink population structure reflects local habitat condition and how it affects birth, death, and dispersal rates (Holt 2011), shifts in habitat quality have important implications for population persistence. In a warming climate, the higher elevation Kingston, Clark Mountain, and Sheep ranges, and the Spring Mountains, are those most apt to become refugia and to continue to support healthy populations of bighorn sheep (Epps et al. 2006, Wehausen and Jaeger 2016), but potentially with a change in the distribution of bighorn sheep or the proportion of leucistic individuals comprising local populations. For example, a warming climate in the Mojave Desert could reduce habitat quality (Epps et al. 2004, 2006), thereby resulting in lowered carrying capacity and smaller populations (Bowyer et al. 2014). In another potentiality, the extirpation of bighorn sheep from some lower-elevation mountain ranges (Epps et al. 2004, 2006) could occur as those ranges become less habitable because of increasing variability in climate (IPCC 2001), with the result that the geographic distribution of the white phenotype is altered.

Three separate lines of inference, among which are visual observations dating from the 1950s, telemetry data from the 1990s and 2000s, and results of recent genetic investigations all point to widespread connectivity among populations of within the study area. Such evidence can be compelling, but the power of such evidence can be limited by differences in the metrics or processes considered (Epps and Keyghobadi 2015). For example, movement and gene flow are distinct processes—with the latter requiring reproduction (Lowe and Allendorf 2010)—but evidence of genetic connectivity among populations considered here is strong given the widespread distribution of the white phenotype.

Interstate Highway 15 lies between populations lying east of that potential barrier to movement but from which leucistic bighorn sheep have been reported and separates them from mountain ranges inhabited by leucistic animals west of that highway (Fig. 2). Although I could locate no evidence of recent movements of bighorn sheep between ranges separated by the interstate highway, Epps and Keyghobadi (2015) noted that future researchers have an opportunity to take advantage of time-lags in genetic structure to establish baselines for connectivity conservation, as well as to consider and estimate time lags and investigate where the disconnect between pre- and post-fragmentation connectivity is greatest.

MANAGEMENT IMPLICATIONS

Given the impacts to habitat quality for bighorn sheep associated with a warming environment and projected population-level responses (Epps et al. 2004), the distribution, population dynamics, and probability of persistence of bighorn sheep in these mountain ranges could change substantially because of elevational differences and resultant disruptions to connectivity (Epps et al. 2006). Thus, future challenges to population persistence imposed by a shifting climate, disease, predation, or other yet unidentified factors (e.g., Clark et al. 2011) have the potential to impact the frequency of occurrence of the white phenotype in these mostly small or declining populations (Appendix A). Downward trends in population size portend an uncertain future for these populations, especially given recent impacts of respiratory disease (NDOW 2016).

If mobile animals, such as bighorn sheep, can readily traverse habitat of lower quality, large fractions of the landscape may offer little resistance to movements (Keeley et al. 2017). Such movements provide greater opportunities for connectivity and the conservation of genetic diversity and, ultimately, for population persistence given the several high-elevation mountain ranges in the study area and the advantages they confer (Epps et al. 2006). Clearly, maintenance of connectivity should be the primary management objective, not only in the study area, but throughout the distribution of bighorn sheep in North America. That objective is complicated by respiratory disease in some populations, and connectivity likely is best viewed as a double-edged sword (Simberloff and Cox 1987). Nevertheless, "We still have the raw materials [to ensure the persistence of bighorn sheep]; what is needed is a commitment to protect and manage them properly" (Bleich et al. 1990a).

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APPENDIX A. SELECTED BIGHORN SHEEP POPULATIONS AND TRENDS IN THE EASTERN MOJAVE DESERT, CALIFORNIA AND NEVADA

Population estimates in California were obtained from the literature and trends were inferred from those data for the Nopah and Avawatz ranges. The negative trends in the Kingston and Mesquite ranges, and in the Clark Mountain Range, were calculated from data obtained during aerial surveys conducted from 1990 to 2009 (Table 1). Population sizes and trends for Nevada mountain ranges are based on the results of population models and are current (NDOW 2016).

	Population Estimates by Year					
Location	1993[a]	1994[b]	2003[c]	2010[d]	2015[e]	Population Trend
California						
Nopah Range	51–100		51–100	51–100		Static[a c d]
Kingston + Mesquite	101–150	75 ♀♀	51–100	51–100		$\rho = -0.578$, $P = 0.015$[f]
Clark Mountain	101–150	60 ♀♀	25–50	25–50		$\rho = -0.357$, $P = 0.159$[f]
Avawatz	25–50		51–100	51–100		Static[a c d]
Nevada						
Spotted Range					120	Up[e]
Spring Mountains					150	Down[e]
Pintwater					220	Up[e]
Desert + Sheep					280	Static[e]
Meadow Valley					150	Static[e]
Muddy (+ Black)					950	Healthy[e]
Eldorado					130	Down[e]
McCullough + Highland					170	Down[e]

[a] Torres et al. (1994)
[b] Jaeger (1994)
[c] Epps et al. 2003)
[d] Abella et al. (2011)
[e] NDOW (2016)
[f] Spearman's rho (this paper)

State Status Reports

Status of Bighorn Sheep in Arizona, 2017

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Desert Bighorn Council Transactions 54:49–52

Populations

Estimates of Arizona's desert bighorn sheep (*Ovis canadensis mexicana* and *O. c. nelsoni*) populations have remained relatively stable over the past 2 years statewide. Ram:100 ewes:lamb ratios averaged 53:100:20 in 2016 (n = 1,488). Based on survey data, Arizona currently has an estimated population of 5,000–5,500 desert bighorn sheep

The desert bighorn sheep population in the Kofa Mountains (Units 45A, 45B, and 45C) in southwestern Arizona is doing well but has not quite fully recovered and is at about 650 animals (the population had been at about 800 in 2000). The Black Mountain population (Units 15A, 15B, 15C, and 15D) in northwestern Arizona experienced a disease outbreak which resulted in a 53% decrease in the number of bighorn sheep observed on the survey in 2016. Even though Unit 15D is somewhat isolated from the rest of the Black Mountains by AZ Highway 68, the disease crossed the highway and impacted that portion of the population as well. We documented bighorn sheep carcasses of both sexes and coughing sheep in all Black Mountain units. Annual population monitoring will continue for the next few years.

Rocky Mountain bighorn sheep (*O. c. candensis*) continue to prosper in Arizona. This population is estimated at about 1,200 animals. Ram:100 ewes:lamb ratios averaged 50:100:38 in 2016 (n = 284). For both Rocky Mountain and desert bighorn sheep, Arizona surveys about one third of the population annually, although some areas of specific concern or recent translocations have been surveyed annually.

Research

The research project examining bighorn sheep habitat use and the factors that put a bighorn sheep at risk of mortality in 2 desert mountain ranges is nearly complete with final report due in early 2019.

Habitat

The Department works with private organizations (primarily ADBSS and the Wild Sheep Foundation) and federal agencies to achieve habitat improvements for bighorn sheep. Many of these projects are solicited each year through the Department's Habitat Partnership Committees and are funded with Special Big Game License-Tag funds generated through the sale of 3 bighorn sheep tags.

In 2016, the Department and ADBSS coordinated on projects for over $300,000. Projects included building or maintaining water sources, habitat, sheep surveys, and translocations.

Harvest

Bighorn sheep permits remain the most sought after hunting permits in Arizona. In

2016, 16,314 individuals applied for the 105 available permits.

During the 2016 season, 103 hunters participated, harvesting 101 rams in 630 days of hunting. Hunt success was 98%. The age of harvested rams ranged from 3 to 13 ($\bar{x}$ = 8), and horns had green scores ranging from 134 5/8 to 190 4/8 ($\bar{x}$ = 163 B&C).

Continuing a long history, the Arizona Game and Fish Commission awarded the Special Big Game License Tags for bighorn sheep (2 tags per year) to ADBSS in 2016, with a third tag to the Arizona Big Game Super Raffle (AZBGSR). Each year, ADBSS has traditionally auctioned 1 tag at the Wild Sheep Foundation Annual Convention and auctions the second at their fundraising banquet. The third is raffled through AZBGSR. In 2016, $740,150 was raised with these permits, 100% of which comes back to the Arizona Game and Fish Department to fund conservation and management of bighorn sheep in Arizona.

Translocations

Arizona relocated 75 bighorn sheep through 2 desert bighorn sheep and 1 Rocky Mountain bighorn sheep translocations in 2016. Fifty-one desert bighorn sheep (in a ratio of about 1 young male:3 females) were captured using established Department helicopter capture and handling protocols. The bighorn sheep were released in Santa Catalina Mountains in Unit 33, in an effort to re-establish bighorn sheep population in that area. This was the fourth and final release into Santa Catalina Mountains. During the second desert bighorn sheep translocation, 31 bighorn sheep were captured in Unit 37A (Silver Bell Mountains); 20 were released in Redfield Canyon in Unit 32 and 11 were released into Aravaipa Canyon in Units 31 and 32. For Rocky Mountain bighorn sheep, 24 bighorn were captured opportunistically during 2 attempts in May and June 2017; all were released on the South Fork of the Little Colorado River and Black River areas in Unit 1. This brings the total translocated bighorn sheep in Arizona to 2,320.

<u>Santa Catalina Mountains Project</u>

The Arizona Game and Fish Department conducted aerial surveys for bighorn sheep in the Catalina Mountains on September 28–29, 2016. Thirty-seven bighorn sheep were observed during the survey flights (11 rams, 22 ewes, 4 yearlings, 0 lambs). Ground observations were collected concurrently with the survey flights. Within 1 of the 5 survey blocks, a ground observer detected 3 lambs and 12 ewes. Minimum recruitment for this herd was 25 lambs per 100 ewes, which is lower than the 44 lambs per 100 ewes observed in early summer 2015 (differing observation periods a likely factor).

Observations of 19 of 34 collared bighorn sheep during the survey resulted in a 56% observation rate. We used a mark-recapture model to estimate abundance of bighorn sheep in the Catalina Mountains. The marked animals were all animals with working radio collars that were present within the survey area during the survey. Animals were recaptured by observing them during the survey flights. The idea behind mark-recapture models is that the proportion of animals with marks observed during the flight should reflect the proportion of animals with marks in the population. This insight can be used to estimate abundance even if the survey does not observe all animals in the population. The key assumptions are that 1) the population is closed (i.e., it does not change size during the surveys), 2) marks (i.e., collars) are not lost or overlooked during the survey, and 3) marked animals are not more or less likely to be observed than unmarked animals. We believe all assumptions were met during this survey.

We used program MARK to implement the mark-recapture model and estimated abundance and the 95% confidence interval.

We fit 3 models to the data. Model 1 estimated different detection probabilities during the marking phase (collared bighorn sheep within the survey area and available for observation) and the recapture phase (collared bighorn sheep observed during the survey). Models 2 and 3 build on Model 1 by allowing detection probabilities to differ between rams and other bighorn sheep (ewes, yearlings, and lambs). Model 2 estimated a different detection probability for rams and other bighorn sheep but assumed this detection difference was the same during the marking and recapture phases. Model 3 also estimated a different detection probability for rams and other bighorn sheep, but did not assume that this detection difference was the same during the marking and recapture phases. We used Akaike's Information Criterion (AIC) to select the simplest of the 3 models that adequately fit the data.

All models produced nearly identical abundance estimates, but AIC scores indicated Model 1, with different detection probabilities during the marking phase and the recapture phase, was the most supported. According to the top model, our best estimate of abundance was 66 animals (58 to 88; 95% confidence interval).

The Arizona Game and Fish Department completed 3 translocations of 30 bighorn sheep each into the Catalina Mountains over 3 years (2013 – 2015) in an effort to re-establish this population. Based on the lower than hoped for population estimate, the Department is moving forward with a fourth translocation this year. Up to 20 bighorn sheep will be captured in the Plomosa Mountains on November 21, 2016 and released in the Catalina Mountains the following day.

Black Mountains Detailed Update

During the October 2015 bighorn sheep surveys in the Black Mountains of Units 15B West, 15C, and 15D, we detected a possible disease event. Dramatically fewer bighorn sheep were observed in Units 15C North and 15C South and a smaller decline in Unit 15B West; however, Unit 15D observations were at a record high. During the survey, 5 dead and 1 sick bighorn sheep were documented in Unit 15C North and 4 dead bighorn sheep in Unit 15B West. Earlier in the year (summer/fall timeframe), several dead bighorn sheep were picked up along the Colorado River; 1 ewe was tested and confirmed to have pneumonia. Since the survey, 3 more dead bighorn have been reported. The carcass count is now 8 in Unit 15C North and 4 in Unit 15B West. Coughing bighorn sheep were observed on survey and have been reported by hunters in the area.

In early November, the Department captured and translocated 40 bighorn sheep out of Unit 15D into Kanab Creek in Unit 12A/13A. The majority of bighorn captured for this translocation effort were taken out of the southern and central portions of Unit 15D. Capture crews saw no evidence of sick bighorn sheep during this effort. However, in December we received a report of a coughing, ear tagged bighorn sheep in Kanab Creek; this ear tagged bighorn may have been from the recent release. Regional personnel will monitor this bighorn sheep population as appropriate.

Since we had a helicopter on site for this capture, we decided to capture and sample a few bighorn in Unit 15C to confirm disease presence. Three bighorn sheep were captured in Unit 15C North and blood samples taken; these presence of pneumonia (*Mycoplasma ovipneumoniae* and *Pasteurella* spp.) was confirmed in the population. All bighorn observed during this capture in Unit 15C exhibited coughing and runny noses.

The spread of this disease into Unit 15D is a significant concern, as Unit 15D is currently the largest and densest bighorn sheep population in the State and is the source for northern Arizona translocations. The

Region started the process with ADOT to repair holes in the right-of-way fence along AZ Highway 68 (the dividing line between Units 15C South and 15D) and were investigating the possibility of fencing the 3 underpasses to prevent bighorn sheep from moving from Units 15C South to 15D. Unfortunately, bighorn sheep hunters reported coughing bighorn sheep in 15D near Thumb Butte just south of AZ Highway 68, indicating the disease may have already spread into this area. Two rams taken from this spot had large accumulations of mucus in their nasal passages, a symptom typical of pneumonia. We collected nasal swabs from all bighorn harvested in the Black Mountains, and results confirmed the presence of *Mycoplasma*.

Region 3 completed a spot survey of Unit 15D on December 9, 2015 looking for sick bighorn sheep. The initial focus was in the most northern portion of Unit 15D North; 3 bands of coughing bighorn sheep were observed. One ewe from each band (3 total) was culled from the herds and necropsied. The lungs of all 3 ewes were consistent with pneumonia. Anne Justice-Allen determined that is was not necessary to cull any more bighorn from this area, as the 3 already culled provided solid evidence of pneumonia in this portion of the population.

The survey crew then moved into the central and southern portions of Unit 15D. A few coughing bighorn were observed around Mount Nutt and Battleship, which are core areas of bighorn sheep in the unit. No animals were culled.

The survey crew did not locate any bighorn sheep carcasses during this attempt. All bighorn observed appeared in good body condition. It appears we are seeing the beginning stage of this disease event; the disease appears to be working its way into all of Unit 15D.

Strain typing of the *Mycoplasma* has been conducted to aid in determining the most likely source. The *Mycoplasma* strain has been confirmed as the Mohave strain which is the cause of recent die-offs in southern California and Nevada. This is the first time this strain has been documented in Arizona; identifying specific strains will help us to track and determine the origin of these diseases and will help guide future management actions.

At this point, the Department will continue to monitor bighorn sheep in the Black Mountains (Units 15B West, 15C North, 15C South, and 15D). We will track reports of sick bighorn and attempt to collect samples from all dead bighorn sheep in this area. The number of bighorn sheep observed on the population survey in 2016 was 53% lower than 2015. This population will be surveyed again in 2017.

Colorado Desert Bighorn Sheep Status Report, 2017

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Desert Bighorn Council Transactions 54:53–55

Population status

The overall trend of Colorado's bighorn sheep herds have remained stable to slightly increasing over the last 2 years. Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*), the predominant bighorn in Colorado, has decreased slightly from an estimated post-hunt population of 6,895 in 2015 to 6,810 in 2016. Over the last couple of years, Colorado's desert bighorn (*Ovis canadensis nelsoni*) populations have been stable to increasing with post-hunt population estimates for all herds totaling 520 in 2015 and 540 in 2016 (Fig. 1). Colorado's desert bighorn population is made up of 3 different populations: the Black Ridge herd (Game Management Unit [GMU] S-56) near Grand Junction, the Uncompahgre/Dominguez herd (GMU S-62 on the northeast corner of the Uncompahgre Plateau), and the Dolores River herd (GMUs S-63 and S-64) along the Dolores River from Dove Creek down to Bedrock. The Black Ridge herd has remained stable at 200 bighorns. The Uncompahgre herd is stable to increasing at 165. The Dolores River population (comprising the Upper and Middle Dolores herds) has been stable to slightly increasing to a post-hunt population estimate of 175 in 2016.

Harvest status

Conservative hunter harvest is taking place in all of the Colorado desert bighorn herds. The Black Ridge herd (S-56) currently has 4 ram licenses, with license allocation at 2% of the population and a 3-year average hunter success rate of 100%. The 3-year average growth rings measured from the harvested rams in S-56 is 5.9, which has been slightly decreasing in recent years. Four ram licenses are allocated for harvest in the Uncompahgre bighorn herd (S-62) at 2.5% of the population, with a 3-year average hunter success rate of 92%. The average rams harvested in S-62 have 5.5 growth rings measured on a 3-year average. The Dolores River population has the most conservative license allocation at 4 ram licenses per year at 1.4% of the population estimate. The 3-year harvest success rate is 80% with the 3-year average growth rings measured from harvested rams being 6.0. Licenses are now allocated to GMUs S-63 and S-64 separately starting in 2016. Most licenses are allocated to Colorado residents with 1 license being allocated to non-residents that floats between the units each year.

Collaborative projects

Numerous projects have been initiated to study Rocky Mountain and desert bighorn sheep between the Colorado Parks and Wildlife (CPW), U.S. Forest Service (USFS), Bureau of Land Management (BLM), and/or Rocky Mountain Bighorn Society (RMBS) in the past. In 2009, the USFS Rocky Mountain Region, BLM Colorado State Office, Colorado Division of Wildlife (now CPW),

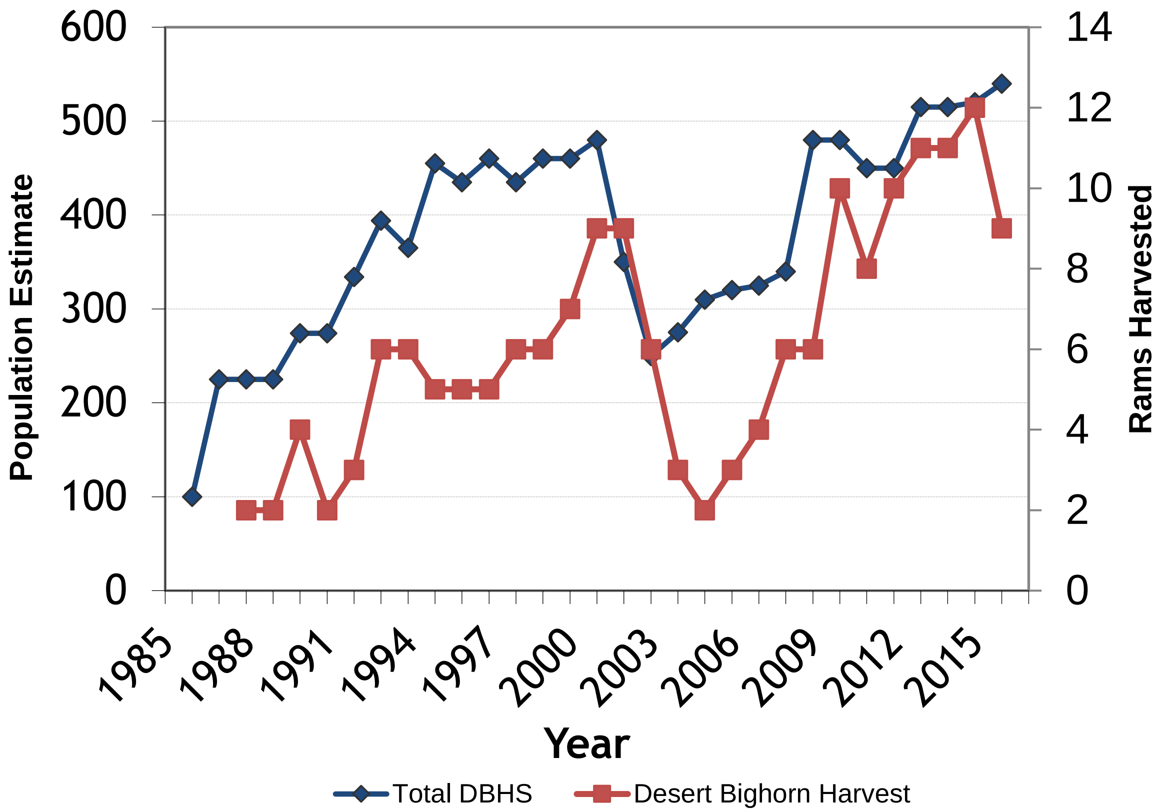

Figure 1. Desert bighorn sheep population estimate and ram license numbers from 1985 to 2016.

Colorado Department of Agriculture, and the Colorado Woolgrowers Association developed and signed a Memorandum of Understanding (MOU) for Management of Domestic Sheep and Bighorn Sheep (USDA-FS 2009). The purpose of the MOU was "to provide general guidance for the cooperation in reducing contact between domestic and bighorn sheep in order to minimize potential interspecies disease transmission and to ensure healthy bighorn sheep populations while sustaining an economically viable domestic sheep industry in Colorado". The MOU was again renewed in 2014 (USDA-FS 2014). The MOU has been beneficial in bringing all parties to the table to discuss bighorn and domestic sheep management in areas of overlap or at least in close proximity around the state. In the fall of 2016, a statewide Bighorn Sheep Working Group was launched to promote discussion and cooperation between numerous stakeholders interested in bighorn sheep and domestic sheep management across Colorado.

In 2012, the BLM and CPW initiated a project to evaluate habitat use of desert bighorns in proximity to domestic sheep grazing allotments within the Dominguez-Escalante National Conservation Area (DENCA). The Uncompahgre (S-62) desert bighorn sheep population resides primarily within the DENCA. There are 4 active winter domestic sheep grazing allotments within the DENCA, as well as 4 additional winter allotments adjacent to the DENCA. To better understand bighorn sheep habitat use and movements, we deployed satellite GPS collars on 23 bighorns (13 rams and 10 ewes) with 6 more rams to be collared this year.

Data collected to date was used to develop a desert bighorn habitat suitability layer and qualify core herd home range maps that were incorporated into a risk of contact analysis (USDI-BLM 2017) assessing the potential for interaction between desert bighorn sheep and domestic sheep allotments. The analysis was used to develop and determine what management actions should be implemented to minimize contact between domestic sheep and bighorn sheep when domestic sheep allotment plans are to be renewed. Now that the DENCA Resource Management Plan is final, the BLM will schedule allotment plan renewals in the future.

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Status of Bighorn Sheep in Nevada, 2016 – 2017

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Desert Bighorn Council Transactions 54:56–63

Herd Distribution and Populations

There are approximately 75 desert bighorn, 25 California, and 7 Rocky Mountain bighorn herds in Nevada. The origin of the desert bighorn herds are 30 remnant, 30 reintroduced, and 15 pioneering herds (Fig. 1). The reintroduction of herds to historically occupied habitat involved construction of over 150 water developments and 137 translocation events involving 2,111 animals.

Desert bighorn population herd size ranges from 20 to 700 with an average herd of 240 (yearling and older animals). The 2017 statewide population estimate for desert bighorn surpassed 10,000 for the first time in recorded history (Fig. 2). Estimates for each herd are generated from deterministic spreadsheet models that reconstructs population dynamics based on known production/recruitment, known harvested ram ages, and estimated adult survival. It is estimated that the lowest point in Nevada's bighorn population was 2,000–3,000 in 1960. Based on historical accounts and archeological/paleontological evidence of bighorn sheep, biological judgment of areas that had adequate bighorn habitat and a conservative density value for bighorn sheep, Nevada's bighorn population in 1860 exceeded 30,000. It was first acknowledged in the *2001 Nevada Bighorn Sheep Management Plan* that the entire state of Nevada, the heart of Great Basin, was a single but diverse metapopulation of desert bighorn sheep (Ramey 1993, Ramey 2000, Wehausen and Ramey 2000). The plan also recognized decades of successful transplants of Rocky Mountain and California bighorn sheep and the need to continue to manage these herds in concert with the expanding distribution of desert bighorn.

Over 5,700 desert bighorn sheep were classified during helicopter surveys in August through October 2016 (Fig. 3). The 5-year moving average lamb:100 ewe ratio from 1992 through 2011 was between 38 and 43 but the last 5-year average was only 32. Certainly drought conditions from 2012–2015 affected lamb survival, but one could also speculate that the rising populations and increasing densities may be playing a role in the lamb recruitment decline. The ram ratios have been highly variable from year to year and likely biased low as to be expected (inconsistent and low sightability) with mature rams typically segregated from the larger ewe/lamb groups in smaller bachelor groups during the surveys conducted 1–2 months post-breeding. The long-term average ram ratio was 60 rams:100 ewes through 2011, with the last 5-year average slightly declining to 57.

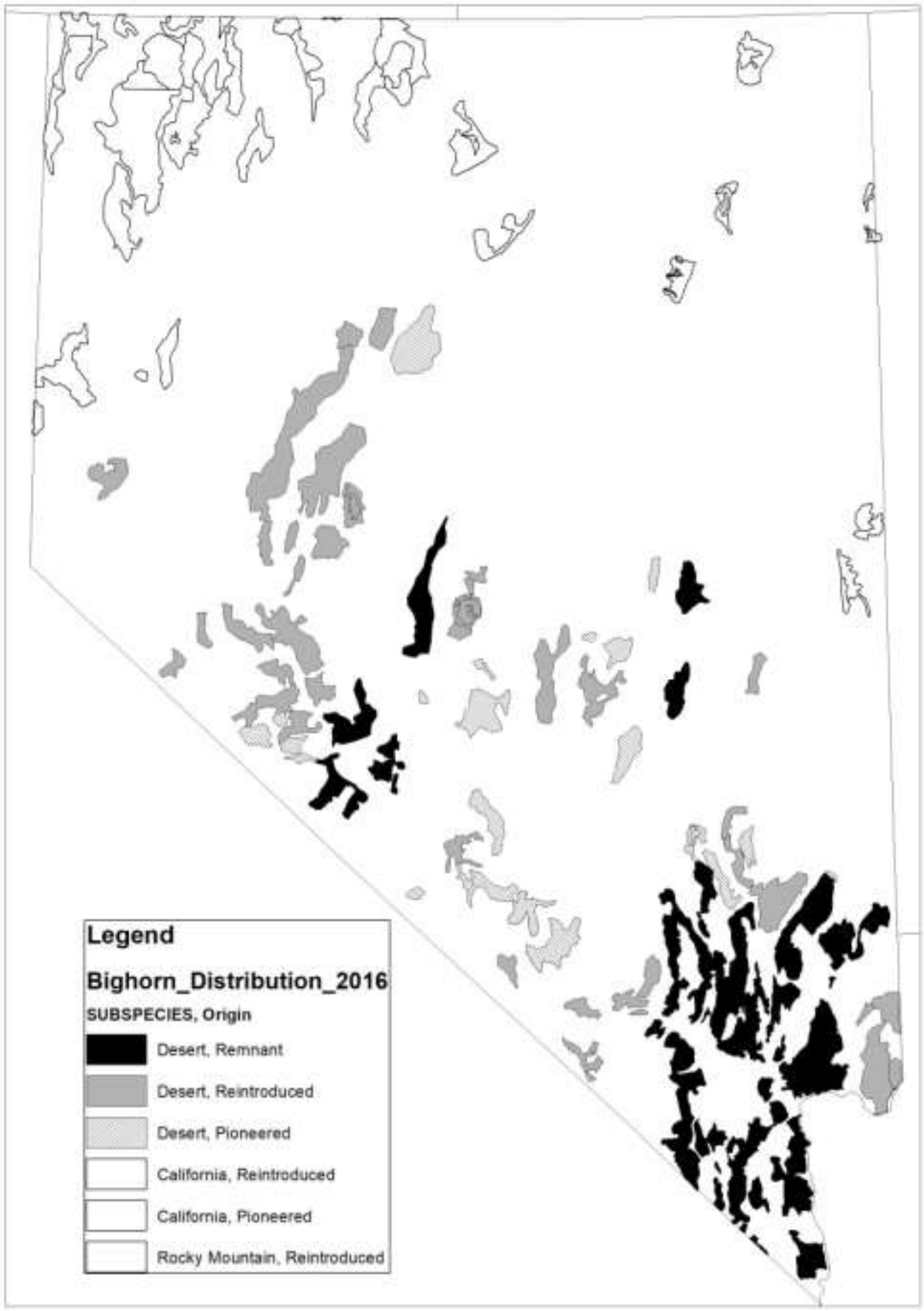

Figure 1. Occupied bighorn sheep habitat in Nevada by subspecies and origin in 2016 (remnant, reintroduced, or pioneered).

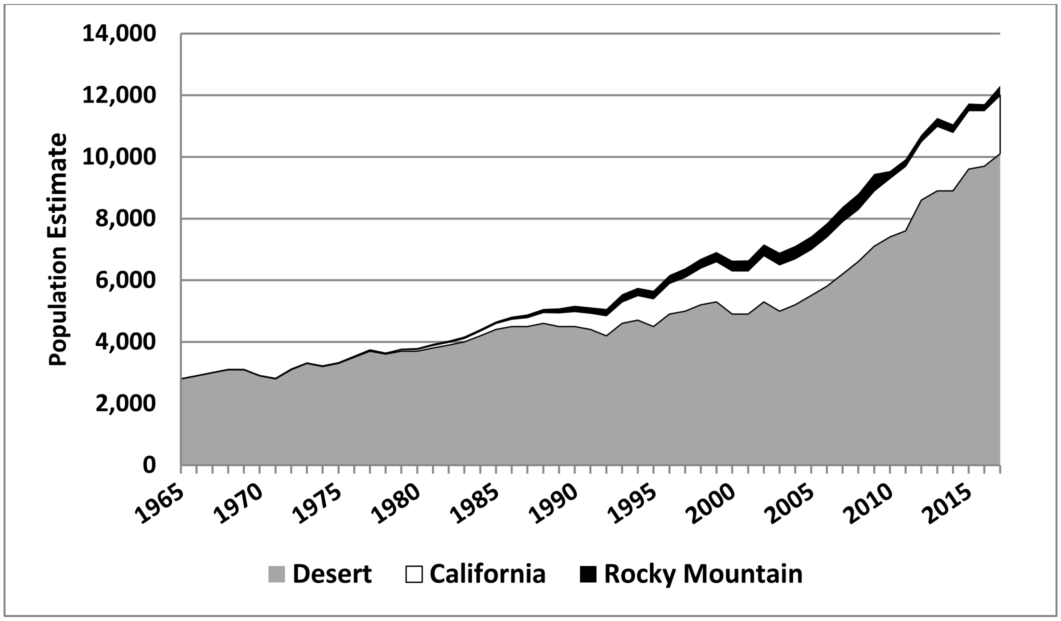

Figure 2. Nevada bighorn sheep population estimates by subspecies, 1965 – 2017.

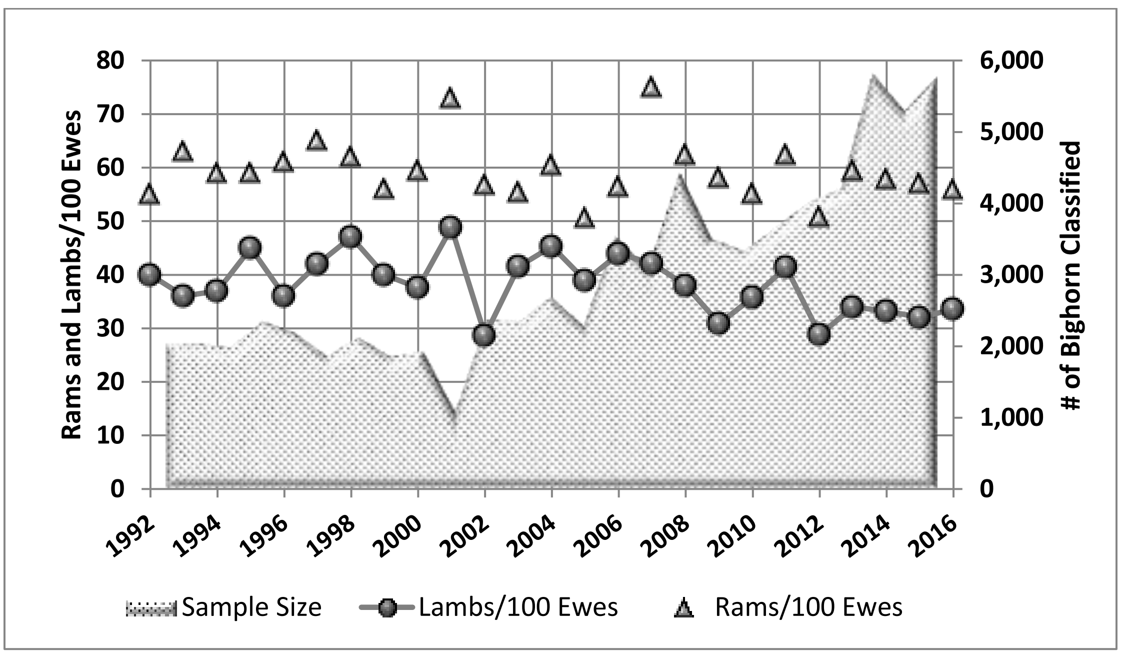

Figure 3. Desert bighorn helicopter survey results, Nevada, 1992 – 2016

Harvest

A total of 311 desert bighorn tags were available to residents and nonresidents (90:10 split) through a restricted draw process. A total of 8,073 residents and 8,202 nonresidents applied for 280 and 31 tags, respectively. An additional 2 auction tags and 3 special raffle/draw tags were also issued in 2016. Hunter success has increased to 90% over the last 14 years compared to 81% for the prior decade. Since the first year of the any ram regulation in 1996, the average age of harvested rams has been 6.3 years. The 2016 average age of harvested rams was 6.5. The *Nevada Bighorn Sheep Management Plan* calls for a statewide ram harvest age objective of 6.0. Since 2010 there has been 1 or more rams harvested that exceed 180 B&C score. Nevada's annual desert bighorn ram harvest totals since the first legal hunting season in 1952 to the present is a classic exponential growth curve all the while maintaining strong age structure in the harvest and quality hunting experiences (Fig. 4). The fruits of the past bighorn restoration labors continue to result in an increase in ram tags available from reintroduced herds. In 2016, 50% of the statewide desert bighorn ram tags were from reintroduced and pioneering herds.

Disease Surveillance and Herd Responses

Nevada continues to document pneumonia events and compromised lamb survival years after the initial event in herds of all bighorn subspecies. To better understand the geographic extent and suite of pneumonia-causing pathogens involved, the likely transmission pathways, and to help identify at-risk herds, and herds that are clean for translocation source stock, Nevada Department of Wildlife (NDOW) began an aggressive disease surveillance program in 2011. Through 2016, over 550 desert bighorn sheep in over 50 different herds have been captured and sampled in addition to numerous necropsies performed, and samples collected from hunter harvested rams and ewes to build a baseline database of pathogen profiles and herd health metrics. Figure 5 displays which herds have been exposed to

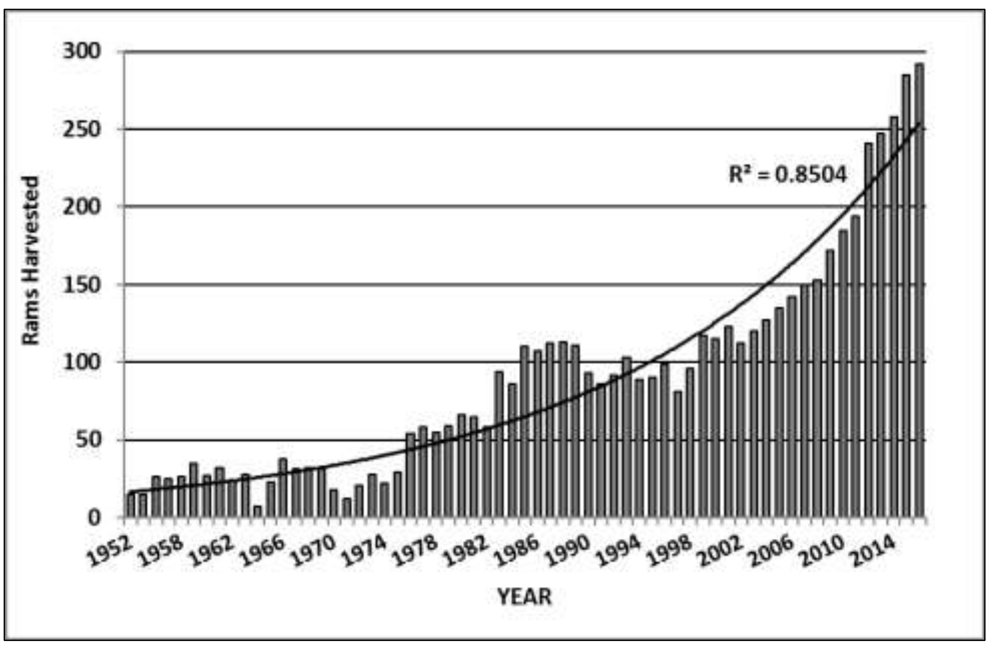

Figure 4. Desert bighorn ram harvest from the first legal hunting season in 1952 through 2016 in Nevada.

Mycoplasma ovipneumoniae (*M. ovi*), the primary pathogen of concern (Besser et al. 2008, Besser et al. 2013, Cassirer et al. 2017). We found a strong association of *M. ovi* positive herds experiencing major disease and die-offs but the persistent poor lamb survival was variable among herds. In addition to identifying which herds were exposed to *M. ovi*, we attempted to determine the *M. ovi* strain type in each herd. Much of the exposure and specific strain type distribution was logically defined by contiguous bighorn habitat involving metapopulations. But there are still other situations that defy logic like a clean herd completely surrounded by *M. ovi* positive herds with relatively no barriers to bighorn dispersal and likely pathogen transmission.

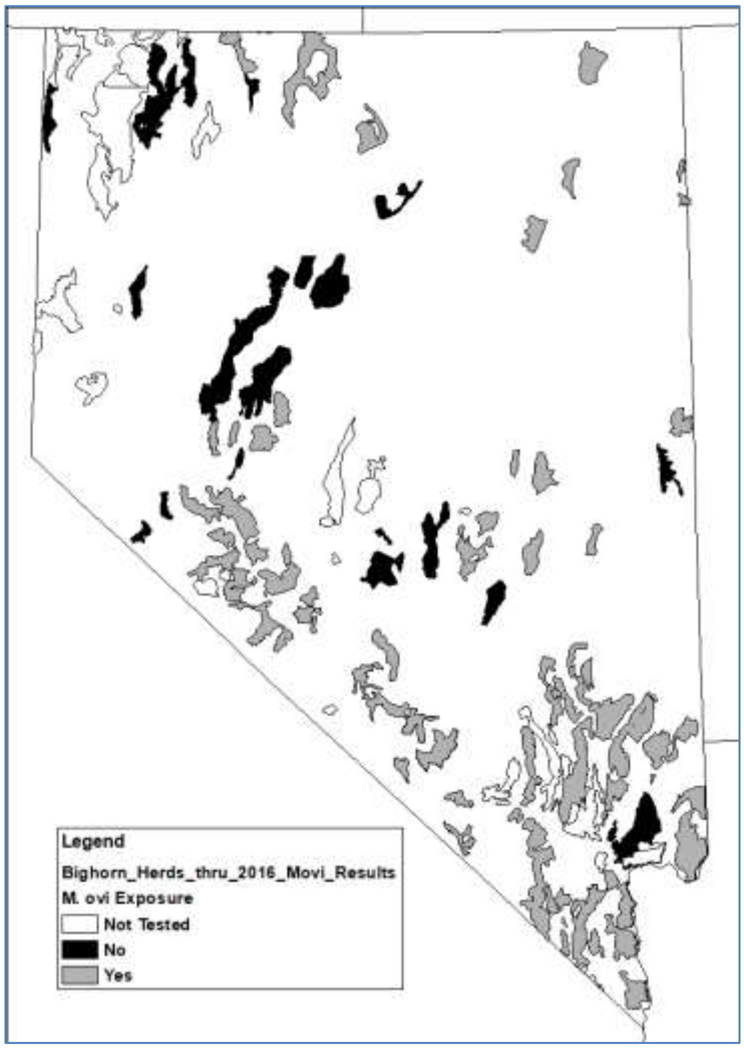

Figure 5. Display of which herds have tested positive for *Mycoplasma ovipneumoniae* (*M. ovi*) (gray), herds sampled but *M. ovi* was not detected (black), and herds not yet sampled (white) as part of statewide disease surveillance program, 2011 – 2016.

Figure 6 depicts the estimated boundary of a bighorn metapopulation involved in a disease event and associated pathogen transmission in Nevada, California, and Arizona. Beginning in 2010, a small number of animals tested positive for *M. ovi* in the River Mountains on the north end of this regional metapopulation. The results were not fully appreciated at the time with no obvious adult or lamb mortality documented. In fall 2013, 4 desert bighorn sheep herds (38 animals from the McCullough, Eldorado, River, and Spring Mountains) were targeted for disease investigation after reports of coughing sheep and unusual mortalities in spring and summer 2013. Two animals showing clinical signs of disease were lethally harvested for more extensive testing and both had pneumonia consistent with *Mycoplasma* infection on microscopic examination. Concurrently a pneumonia outbreak was documented in a number of Mojave Preserve herds just south of the border in California.

Through sampling by all 3 states and DNA testing of the isolated *Mycoplasma* bacteria, the Southern Nevada strain was detected in all Nevada herds and in the Black Mountains of Arizona. A different, more virulent strain called the Mojave strain was detected in several of the Mojave Preserve herds in California and also in the Spring Mountains in Nevada. During 2015 surveillance efforts in Nevada and Arizona it was confirmed that the Mojave strain had replaced the Southern Nevada strain in all herds sampled. Pathogen transmission was likely spread by dispersing bighorn sheep as depicted in Figure 6 by 1 example of a GPS-collared mature ram that made annual movements between 3 mountain ranges in Nevada and California.

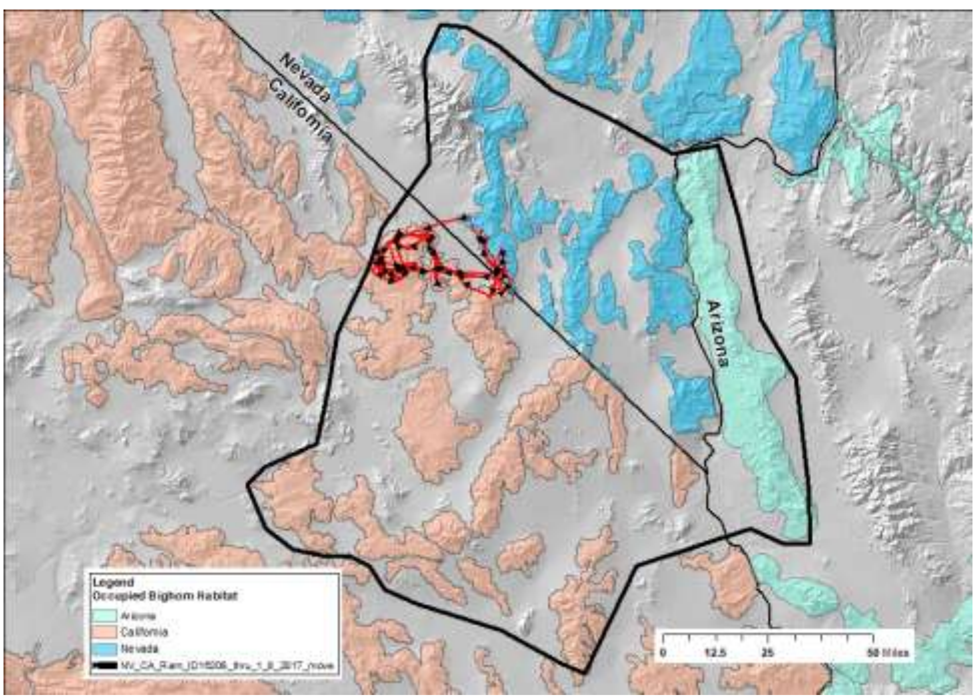

Figure 6. Regional depiction of likely bighorn sheep metapopulation (black polygon) across Nevada, California, and Arizona. Polylines with arrows depict the movement of a mature ram with a GPS collar from 2014 – 2016.

Figure 7 shows the 2014 – 2016 average lamb ratios as a herd response metric in relation to *M. ovi* exposure status. Most of the herds in the bottom portion of the graph are located within the regional metapopulation exposed to the Mojave strain of *M. ovi*. Their lamb ratios were 10 and lower for those years. Herds on the upper half of the graph, though still exposed to *M. ovi* have average to above average lamb ratios, with varied number of years since their initial exposure to *M. ovi*. Work continues on trying to isolate the covariates and conditions related to varying responses of herds exposed to *M. ovi*, both in terms of the initial disease event and the potential for prolonged years of high lamb mortality.

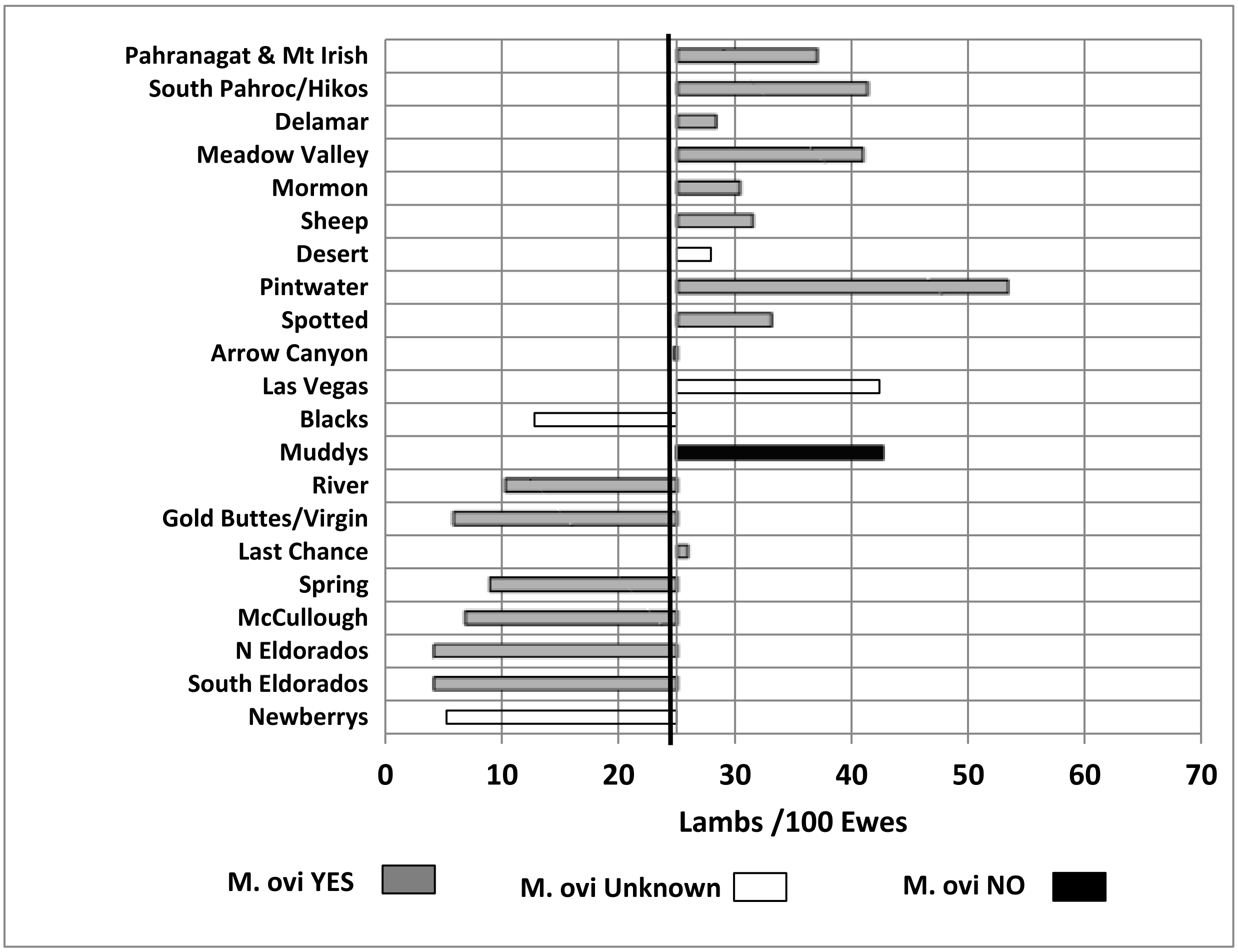

Figure 7. Southern Nevada bighorn herd lamb ratios vs. *Mycoplasma ovipneumoniae* (*M. ovi*) exposure, 2014 – 2016. The vertical line at 25 lambs:100 ewes is considered minimum recruitment for maintaining stable population. Herd status to *M. ovi* exposure is depicted by the color of the bar. The end of the horizontal bars going left and right of the vertical line are the lamb ratio values for a given herd.

Future Management Considerations

NDOW will continue to conduct ewe hunts in select herds to manage their population in relation to limiting habitat components such as summer water availability and also to reduce dispersal and the associated threat of disease transmission. Though the present picture of quality ram hunts and harvest in the eyes of our sportsmen is as good as ever, hunt management changes and outreach must be instituted to reduce ram hunting opportunities and educate the public about the lack of young ram recruitment into the mature age segment of several herds. Some of these herds are highly sought after hunt units because of past trends of trophy quality rams. These changes will no doubt be an opportunity to catch the attention of more sportsmen and not only educate them about the impacts of disease transmission and pneumonia events, but to build a stronger advocacy group to help NDOW and other western states in seeking positive public land management decisions and persuading private landowners to help in securing greater separation between domestic sheep/goat flocks and adjacent wild sheep herds. NDOW will continue to evaluate all the past data collected on pathogen profiles, *M. ovi* strain types, herd responses, and possible predictor variables to better understand why certain herds respond differently to pathogen exposure. Efforts will be proposed, discussed, and possibly instituted for passive and targeted testing and culling of animals determined or suspected to be carriers/shedders of virulent pathogens in herds that have persistently poor lamb recruitment.

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Status of Desert Bighorn Sheep in New Mexico, 2015 – 2016

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Desert Bighorn Council Transaction 54:64–66

Synopsis

The statewide population of desert bighorn in New Mexico increased in 2015 and 2016. At the end of 2016, the statewide population was estimated at 1,125 (range = 1045–1205). The statewide estimate encompasses sheep from 6 wild populations constituting 4 known metapopulations. Hunting opportunities for desert bighorn rams have correspondingly increased by 38%. Current objectives include continuing to increase the statewide population of desert bighorn and promoting growth among individual populations beyond minimum thresholds (100 total desert bighorn and 50 ewes). This will be accomplished through translocations, including restoration of desert bighorn into unoccupied habitat, and the continued application of mountain lion removal in desert bighorn ranges.

Fra Cristobal-Caballo Mountains (435–485)

The Fra Cristobal (FC) and Caballo (CA) mountains desert bighorn populations combine for the largest metapopulation in New Mexico. The Fra Cristobal herd, estimated at 290-320 sheep, also represents the highest density of desert bighorn in New Mexico (~3 bighorn/km^2). This population resides entirely on the Armendaris Ranch owned by Turner Enterprises, and as such, is jointly managed. In 2017, sheep from the Fras Cristobal Mountains will be translocated to the Ladron population. The Fra Cristobal remain the only wild source for translocations in New Mexico, and this upcoming effort will be the third augmentation supported by this population. At the end of 2016, there were 34 individuals with functioning radiocollars in the Fra Cristobal Mountains. There are no functioning radiocollars in the Caballo population which is estimated at 145–165 desert bighorn. Fall 2016 lamb:ewe ratios in the FC and CA populations were 62:100 and 55:100 respectively.

Bootheel (350–405)

The Bootheel metapopulation includes desert bighorn in the Big and Little Hatchets (225–265), and Peloncillo Mountains (125–140). Spring 2016 lamb:ewe ratios were among the highest ever observed with 73:100 in the Peloncillos, 52:100 in the Little Hatchets and 37:100 in the Big Hatchets. The Peloncillos received an augmentation of 11 sheep (4 ewes, 7 rams) from Red Rock in October 2016.

San Andres Mountains (180–220)

NMDGF manages the San Andres population in conjunction with the White Sands Missile Range and United States Fish and Wildlife Service. Because no surveys occurred in 2013 or 2014, partners decided to perform aerial surveys in the San Andres in both 2015 and 2016. Survey efforts for this desert bighorn population are substantial, requiring two helicopters over two days to thoroughly cover the estimated range (733 km^2). These surveys resulted in an estimate of 180–220 bighorn with a fall 2016 lamb:ewe ratio of 31:100.

Ladron Mountains (80–95)

Considered New Mexico's smallest desert bighorn population, it is also the only population estimated below the minimum objective. GPS radiocollars were deployed here during the October 2016 capture (n = 8). The Ladron herd be augmented with an additional translocation in 2017.

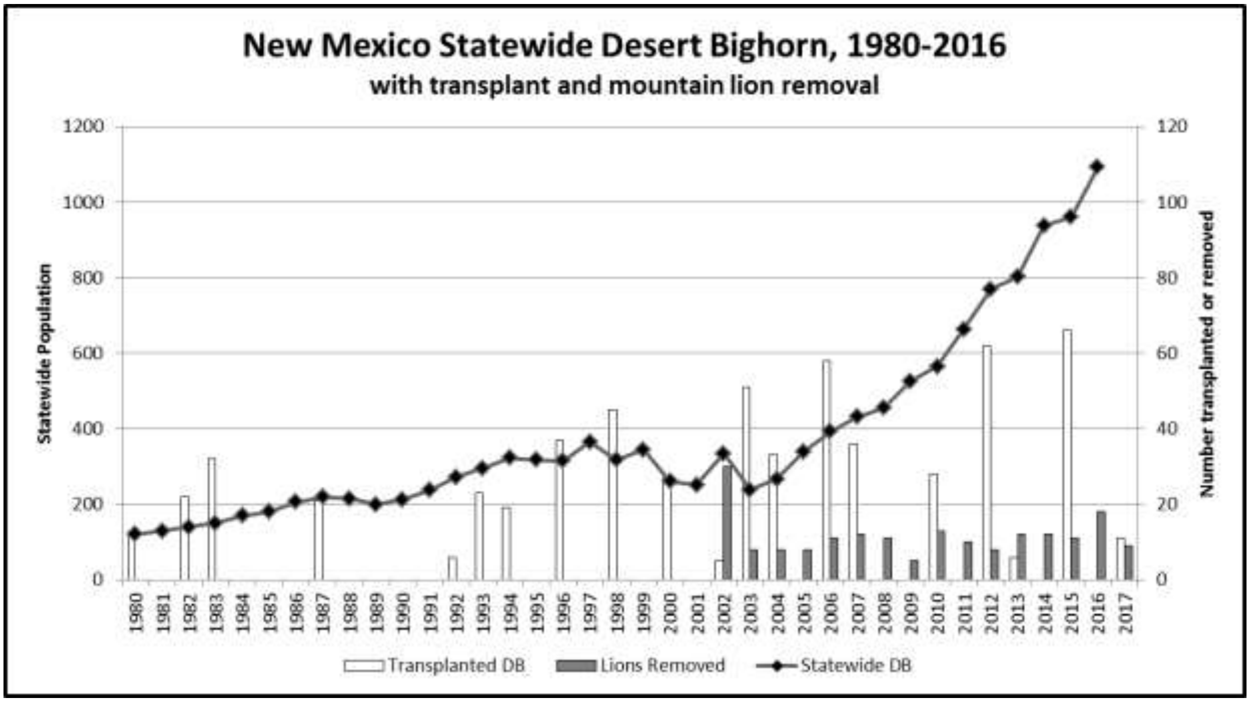

Figure 1. New Mexico statewide desert bighorn population trend from 1980 – 2017. Transplanted desert bighorn sheep and mountain lion removals are also shown.

Mountain Lion Control

The mountain lion is the primary predator of desert bighorn sheep in New Mexico, and prior to implementation of a control program, the annual desert bighorn mortality rate from lion predation was 0.16. Removing mountain lions in desert bighorn range was essential to desert bighorn delisting from state-endangered status, and remains an effective management tool in their continued recovery. In the past two years 36 lions were removed, for an average of 3.6 lions removed per year among actively controlled ranges. Lion removals occur in all desert populations except the San Andres, and removals in the Fra Cristobal Mountains target offending lions that have preyed on either 3 adult ewes or 5 bighorn sheep of any age and sex class. Thirty percent of the lions removed were caught in the Ladron Mountains.

Red Rock Captive Facility

The Red Rock facility is maintained by 2 part-time contractors who are responsible for: monitoring the captive desert bighorn population, facility maintenance, and removal of mountain lions within and around the enclosure. Red Rock remains a key source for desert sheep translocations in New Mexico. In 2016, 11 sheep were captured at Red Rock and translocated to the Peloncillo Mountains. Sheep were released north of Granite Gap, an area where rams are consistently seen but few ewes had been observed. Three lions were removed in or near the enclosure in 2015 and 1 in 2016. Of the 9 known adult mortalities over these two years, 3 were attributed to lion predation. Based on the annual walking census, known mortalities, and removals during the fall capture, the 2016 population estimate for Red Rock was ~ 60 bighorn.

Research

October 2016 marked the launch of a study aimed at improving abundance estimates. The project was initiated in the Fra Cristobal Mountains, and commenced with the capture and placement of GPS collars on 30 individuals. Population estimates will be modeled based on sightability and double-observer data collected during a series of helicopter surveys.

Hunting

Total annual licenses for desert bighorn rams in 2015 and 2016 totaled 29 and 30, respectively. Enhancement licenses continue to raise significant funds for bighorn sheep management in New Mexico (Table 1). One auction and one raffle license per subspecies are awarded each year. Harvest rates remain high as does trophy quality. In 2015 and 2016, over 44% of harvested rams had green scores above minimum Boone & Crockett criteria.

Table 1. Proceeds from enhancement authorizations and scores from rams hunted on auction, raffle, and public (top score only) licenses. A * indicates official B&C scores.

	2013	2014	2015	2016
Auction	$324,000	$396,000	$200,000	$177,500
Raffle (Desert+Rocky)	$83,008	$64,819	$143,560	$126,200
Auction Score	170 4/8	182 1/8*	DNH	170 5/8
Raffle Score	195 3/8*	187 3/8*	182 2/8	186 6/8*
Public Score	181 1/8	181 3/8	176 0/8*	182 0/8

Status of Desert Bighorn Sheep in Texas, 2015 – 2017

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Desert Bighorn Council Transactions 54:67–70

Populations

The Texas bighorn population had been on the rise since 2002, but in 2008 it began to level off (Fig. 1). Annual aerial surveys were conducted in August of 2015 and 2016. During the 2015 survey, 1,070 bighorn were observed with a lamb:ewe ratio (lambs per 100 ewes) of 39%. In 2016, 1,207 bighorn were observed with a 42% lamb:ewe ratio for 2016. There are an estimated 1,500 desert bighorn sheep statewide.

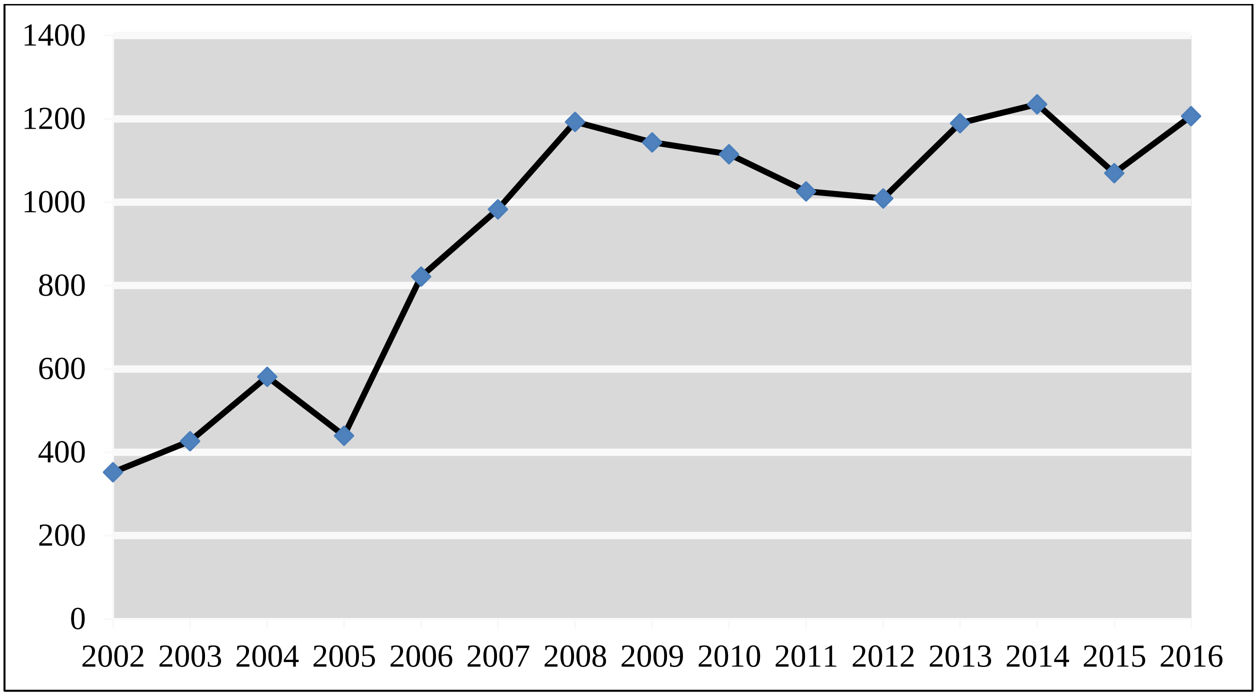


Figure 1. Statewide desert bighorn survey results for Texas. 2002 – 2016.

Harvest

There were a total of 30 permits issued for the reporting period (2015 – 2017). In the 2015 – 2016 hunting season, 18 permits were issued, which included 3 public and 15 private landowner permits. The 2015 – 2016 hunt season resulted in a 100% success rate. For the 2016 – 2017 season, 12 permits were issued. Out of the 12 permits, 9 were issued to private landowners. The remaining 3 were public permits. The 2016 – 2017 hunt season also resulted in a 100% success rate.

Water Development

Four new water guzzlers were constructed in strategic locations which will benefit bighorns as well as other wildlife. Two were constructed on public land and 2 on mountain ranges within private property. This added a potential 10,000 total gallons of water for those 4 guzzlers across the landscape. In addition to the 4 new guzzlers, and in collaboration with the Mule Deer Foundation (MDF), 2 new guzzlers were constructed on the fringes of bighorn habitat. The MDF also helped with repairs on 10 existing guzzlers within bighorn ranges.

Restoration

Translocations from December 2010 through January 2015 restored desert bighorn into the Bofecillos Mountains, 9 Point Mesa, Capote Peak, Black Gap and Big Bend. The bighorns translocated to these areas appear to be doing well, gradually expanding their range and recolonizing habitat adjoining the release site core areas. This expansion has resulted in increased sightings by both the public and private landowners. Some of those sightings were over 20 miles from the actual release sites. Monitoring for all three recently established desert bighorn herds has shifted from frequent telemetry monitoring to yearly monitoring during aerial bighorn surveys.

Research

In total, 229 bighorns (77 M, 52 F) have been fitted with radio telemetry collars to facilitate post-release monitoring. The collaring of these bighorns has also served as research for 3 M.S. projects and 1 Ph.D. project. One of the M.S. projects included investigating the survival and habitat utilization of translocated desert bighorn sheep to 9 Point Mesa. The second M.S. project investigated the movements and survival of translocated bighorns from two distinct herds. The third M.S. project is investigating bighorn-aoudad interactions. And finally, the Ph.D. project is investigating the spatial, temporal, and demographic characteristics of desert bighorn sheep in Texas.

Results from these projects show that the bighorns from the Big Bend Ranch State Park study use an area of almost 1.5 million acres, which includes mountain ranges on both the Texas and Mexico side of the border. Additionally, travel corridors between Texas and Mexico seem to have been identified.

These projects are still ongoing and final results are not available at this time.

Disease Monitoring

While there have been no noticeable disease outbreak in the Texas bighorn herds, disease monitoring continues to be an important component of the management and restoration of desert bighorn sheep in Texas.

As part of TPWD's Desert Bighorn Program efforts to enhance our disease surveillance and monitoring program, as well as to contribute towards WAFWA-WSWG Disease Management Venture (DMV), a tissue sampling capture was conducted in the Sierra Diablo, Beach and Baylor mountains in November 2016. Fifty-one bighorn (8 M, 27 F, 16 L) were captured from those 3 mountain ranges. All animals captured were transported to processing stations where various tissue samples were collected. Upon completion, the bighorns were placed in holding trailers and then transported back as close the mountain as reasonably possible where they were released on-site (Table 1).

The samples, which have routinely been collected from bighorns on all previous captures, included blood, hair, fecal, and ear/nasal swabs. In addition to these samples, a tonsil swab was also collected from each bighorn. The tonsil swab will be added to the tissue sampling list and become standard procedure on all future captures.

All samples were submitted to the Texas Veterinarian Medical Diagnostic Lab (TVMDL). Some of the samples were also sent to the Washington Animal Disease Diagnostic Lab (WADDL). The WADDL results had not been finalized at time of print. However, we have received the final TVMDL report.

The following are the results from the TVMDL Final Report:

- Pregnancy – 90% of adult ewes were pregnant.
- Ear Swabs – only 2 sheep had ear ticks.
- Blood – EHD = 20% positive.
- Blue tongue = 18% positive.
- Note –Data reported at the January 2017 TBS BOD meeting in Dallas were incorrect. The positive and negative results for EHD and Blue Tongue were mistakenly swapped. The results at the BOD meeting were reported as 80% and 82% positive, respectively, which was incorrect.
- Fecal – 25% of animals had intestinal parasites including, *Trichostrongyle* type *ova*, *Trichuris*, *Nematodirus*, *Eimeria* and *Moniezia*. These parasites are typically detected in wildlife populations, and in this instance, were not found in extremely heavy loads.
- Tonsil swabs (Fig. 2)

Table 1. Capture summary for 2016 desert bighorn sheep tissue sampling.

Capture Location	Rams	Ewes	Lambs	Total
Sierra Diablo	4	18	8	30
Beach Mountains	4	3	3	10
Baylor Mountains	0	6	5	11
Totals	8	27	16	51

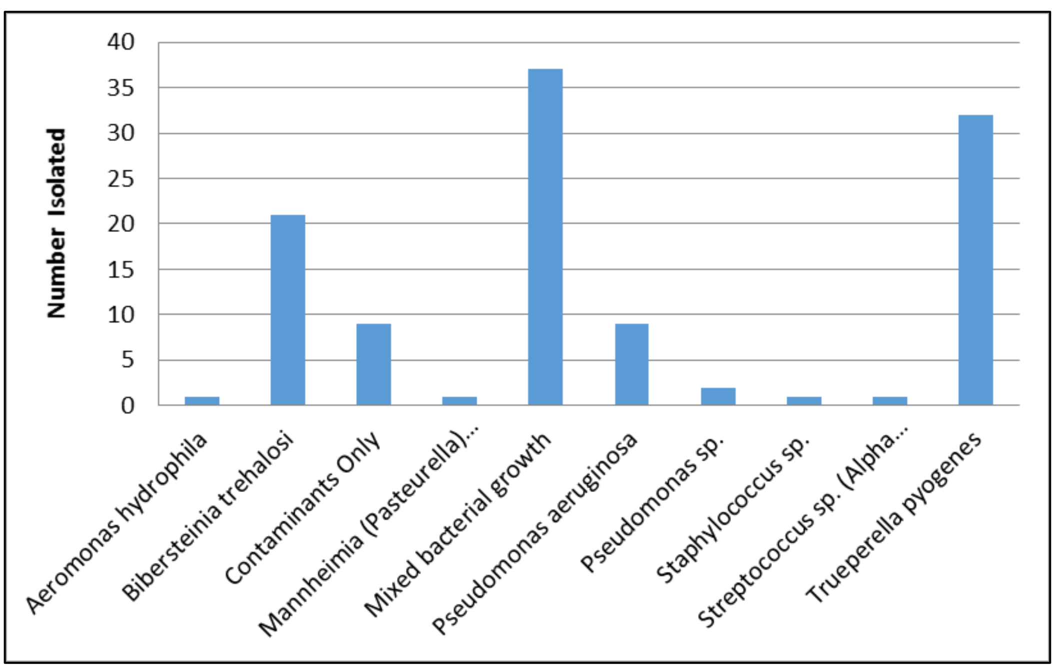
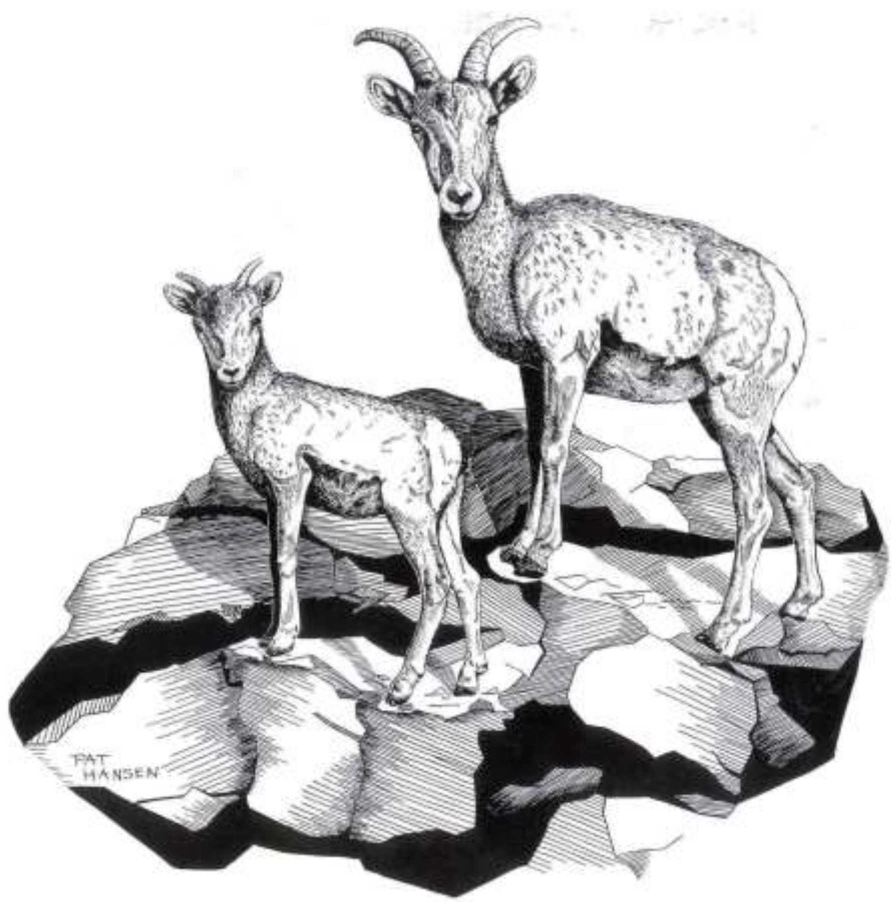


Figure 1. Bacteria identified from tonsil swabs collected on desert bighorn sheep in 2016.

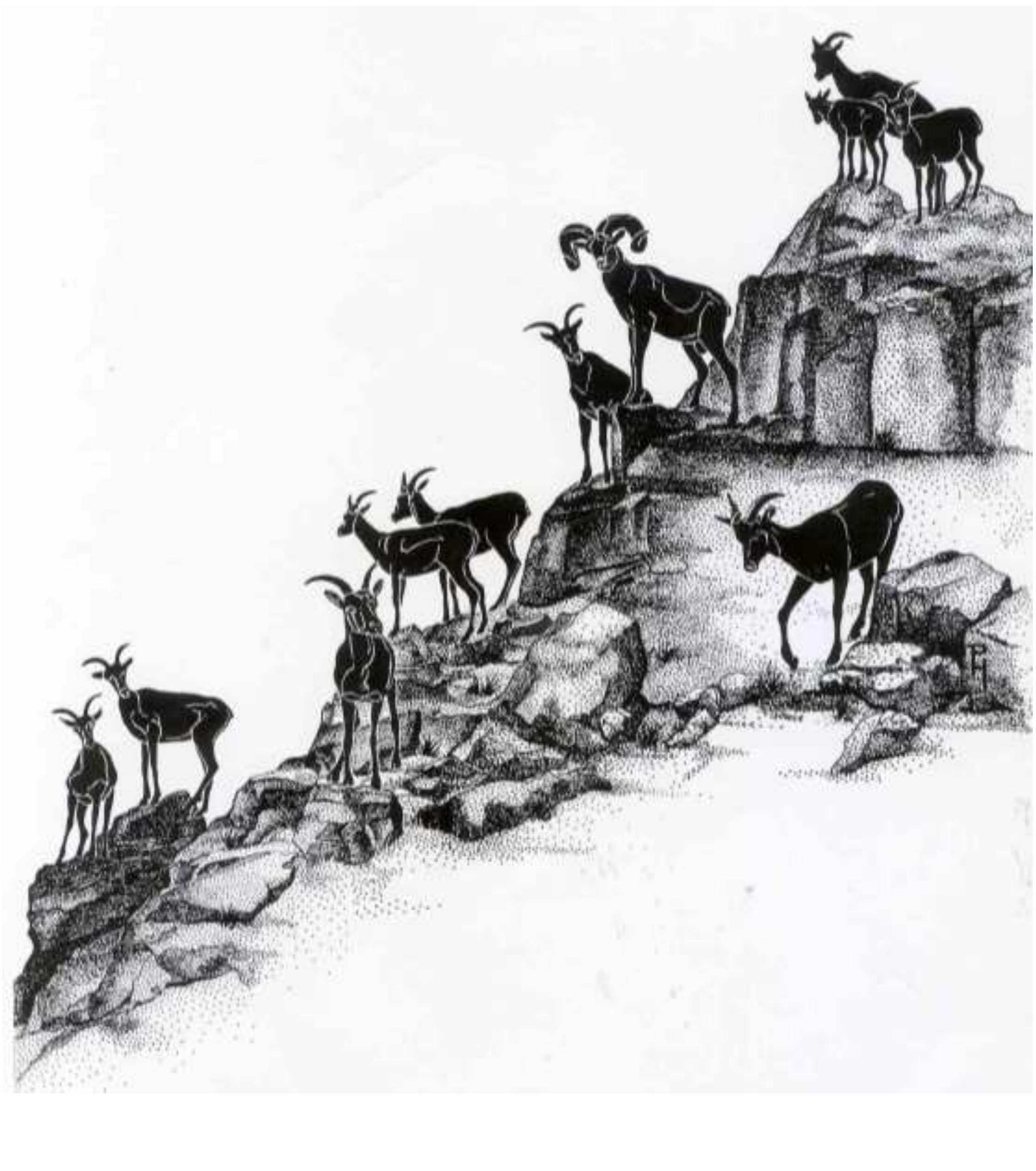
Closing

Overall the desert bighorn populations in Texas are doing well and holding steady. As populations grow and surplus animals are available, TPWD intends to continue to restore desert bighorn to historic mountain ranges which are currently uninhabited. Additionally, population augmentations will continue when deemed appropriate.

TPWD will continue to work and collaborate with conservation partners, hunters and outdoor enthusiasts, dedicated private landowners and committed individuals to ensure that the restoration, management and research of desert bighorn sheep in Texas keeps moving forward. Cooperation, support and partnerships will always to be a vital part of the restoration effort and critical to the success of the program.



Abstracts of Presented Papers



Abstracts of Presented Papers and Posters

EFFECT OF SCALE ON ESTIMATION OF RESOURCE SELECTION BY BIGHORN SHEEP IN AN AREA OF ACTIVE MINING: GPS VS. VHF TELEMETRY

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We investigated resource selection by desert bighorn sheep (*Ovis canadensis nelsoni*) from 2006 to 2009, using high-resolution data from global positioning system (GPS) collars fitted to 10 bighorn sheep (8 females, 2 males), in an area modified by past and present mining activity. Active and inactive limestone mining operations overlapped approximately 30% of the home range for the Cushenbury herd, a group of 12-40 desert bighorn sheep located along the north slope of the San Bernardino Mountains in Southern California. A geographic information system (GIS) and remotely sensed imagery were used to characterize and quantify mining-related disturbance present during the study, and to quantify vegetation and topography of anthropogenic and natural habitat within the range. We estimated a resource selection function from topographic metrics, vegetation cover, measures of mine-related disturbance, highways, recreational roads and trails, fire history, and proximity to water sources. We compare our analysis with an earlier estimation of resource selection that used location data from aerial location of very high frequency (VHF) collars. Preliminary results suggest that differences in spatial and temporal resolution between location methods can yield opposite results, such as the result of positive selection for proximity to water sources when GPS data were analyzed, versus a negative selection for those same water sources in results based on VHF telemetry data. We present results of our analysis and a discussion of potential causes for concordant and divergent results between methods.

AN OVERVIEW OF *MYCOPLASMA OVIPNEUMONIAE* AND BIGHORN SHEEP PNEUMONIA IN SOUTHERN NEVADA, UTAH, AND CALIFORNIA

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Pneumonia is a population-limiting disease in bighorn sheep, although impacts vary widely among populations and over time. We summarized data on pneumonia epidemics in bighorn sheep collected west-wide by the WAFWA Wild Sheep Working group and compiled information on shedding, exposure, and genotypes (strains) of the pneumonia-associated bacterium *Mycoplasma ovipneumoniae* (Movi) in selected desert sheep populations in Nevada, Utah, and California. Median population decline was 21% (range 14 – 83%) in 9 pneumonia "outbreaks" in desert sheep recorded between 1980 and 2015, lower than the median of 48% (range 15 – 100%) in 64 pneumonia outbreaks documented in northern (Rocky Mountain/California) populations during the same time period. Median post-outbreak carriage prevalence (PCR detection) of Movi in 40 infected bighorn sheep populations was 22% and did not differ between northern and desert subspecies. Median antibody prevalence (cELISA) was higher (76%) in 20 previously exposed northern sheep populations than in 22 exposed desert sheep populations (57%, $\chi_1^2 = 9$, p=0.002). We used multi-locus sequencing to genotype approximately 100 Movi samples obtained from desert sheep populations during and after pneumonia outbreaks. Movi has shown host specificity in domestic sheep and goats and the majority of strains detected in bighorn sheep were of the domestic sheep genotype. A single strain was typically identified within a population during and following pneumonia epidemics. However, strains usually varied widely among populations,

likely as a consequence of independent spillover events. We discuss implications for population monitoring, management, and restoration.

RESOURCE SELECTION IN FEMALE DESERT BIGHORN SHEEP: TRADEOFFS ASSOCIATED WITH REPRODUCTION

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Selection of resources that effect the development of a fetus to increase probability of survival for neonates is essential for maintaining viable populations in large ungulates. Therefore, biologists need to understand how species select resources across gestation to increase their ability to manage recruitment. Desert bighorn sheep (*Ovis canadensis nelsoni*) populations have dwindled across their range over the last several decades and translocations have been a key management strategy for recolonizing areas. When selecting translocation sites, it is essential that biologists select areas with habitat types that positively influence recruitment. In an effort to increase our understanding of resource selection by sheep during gestation and following parturition, the Nevada Department of Wildlife and University of Nevada, Reno captured and collared 30 adult, female sheep on Lone Mountain (Tonopah, NV), of which 15 were translocated to the Garfield Hills range (Luning, NV). In addition to receiving collars, all individuals were given vaginal implant transmitters to provide parturition timing information and assist with neonate captures. Following captures, we monitored parturition events, adult resource selection, and neonate survival in both study areas. We used mixed effects logistic regression to identify habitat selection prior to parturition and following parturition events. In addition, we analyzed the difference in resource selection between individuals with a surviving neonate and individuals without a neonate. Our preliminary analyses show alterations to habitat selection at different stages of gestation and a shift from risk averse to risk prone resource selection following the death of a neonate.

ASSESSMENT OF URBAN VISITOR USE AND RECREATION ON DESERT BIGHORN SHEEP IN THE PUSCH RIDGE WILDERNESS

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From 2013-2016 the Arizona Game and Fish Department released a total of 110 desert bighorn sheep (*Ovis canadensis mexicana*) in the Pusch Ridge Wilderness area (PRW), Arizona. Bighorn were released in an effort to re-establish a former endemic population that was extirpated in the mid to late 1990's after experiencing rapid population decline. Reasons for the decline are likely multifactorial, however, urbanization and an increase in backcountry recreation are often cited as likely contributing factors. Many prey species may exhibit antipredator responses in the presence of humans and domestic canines. These responses may lead in turn, to behavioral modification and spatiotemporal avoidance strategies that can be costly at both the individual and population level. The PRW borders the city of Tucson on the south and the town of Oro Valley to the west. The proximity of the PRW to these urban areas makes it a popular destination for recreationists. Our study site was dissected by six primary Forest Service (FS) trails and multiple non-designated or "wildcat" trails. Human use of the PRW was quantified across the study site using real time observer field counts and modeled use metrics derived from motion activated trail cameras located on each designated FS trail (N=15). Bighorn behavioral observations were conducted at multiple spatial scales across the study site and related to human use metrics in a generalized linear model (GLM) to further examine the interactions and potential responses of bighorn sheep to backcountry recreationists. The results of this study are forthcoming and will be presented at the meeting.

ENVIRONMENTAL ADAPTATION IN DESERT BIGHORN SHEEP THROUGHOUT THEIR NORTH AMERICAN RANGE

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Desert bighorn sheep are a broadly distributed North American species occupying a diversity of desert habitats with significant variation in climate factors, yet little is known regarding local adaptation in this species. New landscape genomics techniques utilizing both single nucleotide polymorphism (SNP) genotyping and multivariate statistical analyses now allow for insight regarding local adaptation in wild populations under varying environmental and selective pressure. We present a preliminary study using partial redundancy analysis (RDA) to identify correlations between 8,806 SNP loci and a suite of environmental variables in 35 populations of desert bighorn sheep (274 total individuals) distributed throughout much of its North American range. Our results indicate that between 10.8 and 54.4% of adaptive genomic variation can be accounted for by environmental factors. Forward step-wise model selection indicates significant factors associated with adaptive divergence include elevation, precipitation during the driest month, and multiple metrics on temperature; partial RDA conditioned on neutral genetic variation resulting from isolation-by-distance, ANOVA $P = 0.002$. In addition, permutation tests revealed 51 loci under divergent selection that represent outliers (0.5%) along the first RDA axis, suggesting these candidate loci may have disproportionately large effects on local adaptation. Our results suggest environmental factors are strong drivers of adaptive genomic divergence in this taxon, and provide a foundation to investigate how desert bighorn sheep might respond to global environmental change.

DESERT BIGHORN GUZZLER USE AND WATER CONSUMPTION AT TWO SITES FROM 2012 – 2016

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Long-term observations of artificial water development (guzzlers) use and water consumption by desert bighorn sheep in desert landscapes are lacking. Such information could prove useful for land and wildlife managers in assessing the capacity, design and proper spacing of guzzlers. Bighorn use and water consumption were observed between 2012 and 2016 at two guzzlers, Kelso Peak and Kerr, in the Kelso/Old Dad Mountains of Mojave National Preserve, San Bernardino County, California. Climate data was compiled from nearby (Elev. 962 ft. Baker, CA Approximately 20 miles from sites) National Weather Service station and, beginning in 2015, limited onsite temperature and precipitation sensors. Observations of Bighorn at guzzlers were obtained by use of remote cameras while water consumption was recorded by remote sensor monitoring of water levels in storage tanks courtesy of the Society for the Conservation of Bighorn Sheep. Manual monitoring of water levels was also done. Climate data exhibited hotter than normal temperatures through all observed years and below normal precipitation except during the Spring of 2016, which was above normal. Remote cameras recorded over 26,500 camera hours of observations of which bighorn were observed in about 5 percent. Diel use, frequency and duration were similar across years. Water consumption

averaged 13 and 31 gallons per day from May through September for Kelso and Kerr, respectively, and was minimal the rest of the year. As expected, preliminary analysis exhibited increased water consumption and use by bighorn with warmer temperatures and greater time since last rain event.

CAMERA-DERIVED LAMB SURVIVAL ESTIMATES FOR PNEUMONIA-INFECTED HERDS IN THE MOJAVE DESERT

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Since the 2013 pneumonia outbreak and subsequent die-off at Old Dad Peak (Kelso Mountains, California), pneumonia-infected sheep have been observed throughout the Mojave Desert in California. *Mycoplasma ovipneumoniae* (*M. ovi*) has been documented in all infected herds, and lamb survival appears to be suffering the greatest impact. From 2014 to 2016, we estimated yearly lamb survival by tracking lambs with collared ewes to 5 months of age, using remote cameras at point-source water features during the lambing season in 9 infected populations. Lamb survival varied across years and ranges, but was consistently low at Old Dad Peak, while showing marked increases in 3 other ranges over the 3-year period. Our results suggest that other factors, in addition to disease, influence infected herds in this system. We propose to determine whether lamb to ewe ratios are correlated with these estimates and model lamb survival to further test for the effects of other variables such as forage quality and nutrition, genetic diversity and structure, and infection rates. Ultimately, identifying factors that exacerbate impacts of pneumonia in bighorn sheep herds in the Mojave Desert will help us to better understand the dynamics of respiratory disease in this system and inform management of these populations.

MOJAVE DISEASE PROJECT: INVESTIGATING INTERACTION OF RESPIRATORY DISEASE AND BIGHORN SHEEP FROM GENES TO INDIVIDUALS TO POPULATIONS

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Four years after the outbreak of respiratory disease in desert bighorn sheep populations in and near Mojave National Preserve, collaborative research on the long-term consequences of that outbreak continues. We are investigating how disease, in particular *Mycoplasma ovipneumoniae* (*M. ovi*), environment, and bighorn sheep genes interact to

influence individual and population-level outcomes. Specifically, we are examining how immune response, immune phenotype, and expression of immune system genes vary spatially and by *M. ovi* infection status, whether neutral and adaptive genetic variation influence disease outcomes or correlate with immune phenotype, and implications of neutral genetic structure for understanding the spread of disease within the Mojave and between the Mojave and Peninsular bighorn sheep populations. Also, in collaboration with California Department of Fish and Wildlife and the National Park Service, we have monitored movements and survival of more than 160 adult bighorn sheep, and estimated patterns of lamb survival across populations and years using remote cameras and observations. We present a brief summary of findings from these ongoing projects, including spatial variation in immune function and phenotype detected between and within Peninsular and Mojave populations, correlations between immune phenotype and population connectivity, evidence for long-term genetic separation between Mojave and Peninsular populations, demographic patterns within the Mojave, correlation between genetic structure and recently-observed intermountain movements by bighorn sheep, and implications for potential spread of various strains of *M. ovi* within the region.

EVALUATION OF DESERT BIGHORN SHEEP MOVEMENT ALONG INTERSTATE-15; VIRGIN RIVER GORGE

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Following extirpation of desert bighorn sheep (DBS) in the Virgin River Gorge (VRG) in northwestern Arizona, attempts to reestablish a viable DBS population have been underway since the late 1970's. During the extirpation period, Arizona Department of Transportation (ADOT) built Interstate-15 (I-15) through the VRG, and is now reconstructing I-15. Little is known about the effects of I-15 on local DBS movements and mortality. As I-15 is upgraded, it is important to understand of effects of I-15 on DBS to determine options for DBS-vehicle collision and habitat fragmentation mitigation. To gain his understanding, AGFD and ADOT outfitted DBS with Global Positioning System (GPS) collars, placed cameras under I-15 bridges, and analyzed DBS-vehicle collision rates. Results indicated that 18 GPS collared DBS crossed I-15 383 times with a passage rate of 0.36 crossings/approaches. Collared DBS crossings occurred primarily along a roadway section that includes five bridges. Cameras documented 136 DBS crossings all between May and November. Unexpectedly, we documented high incidence of GPS collared DBS at a ridged section lacking bridges. The only confirmed DBS-vehicle collisions also occurred at this same location. We conclude that DBS-vehicle collisions within the VRG are rare due to 1) high traffic volumes and median barrier and 2) the presence of VRG bridges where DBS can cross under I-15. Although DBS crossed I-15 at a frequency for adequate genetic interchange, our data suggest that construction of a wildlife overpass near MP 20.0-20.5 would both enhance connectivity and reduce potential collisions for DBS in the VRG.

POTENTIAL FORAGING DECISIONS BY DESERT BIGHORN SHEEP TO BALANCE WATER AND NUTRIENT INTAKE

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Deserts have unpredictable precipitation patterns, and wildlife managers often provide supplemental water to help desert ungulates endure hot, dry periods. When surface water is unavailable, preformed water in forage provides the main source of water, and ungulates must make resourceful foraging decisions to meet their requirements. We compared two desert bighorn sheep (*Ovis canadensis mexicana*) populations in Arizona: a population with supplemental water removed during treatment, and a control population. We examined whether sheep altered their seasonal diets without supplemental water. We calculated water and nutrient intake and metabolic water production from dry matter intake and forage moisture and nitrogen content, to determine whether sheep could meet their water and nutrient requirements solely from forage. Diets of sheep were higher in protein (all seasons) and moisture (autumn and winter) during treatment compared to pretreatment period. During treatment, sheep diet composition was similar between the treatment and control populations, suggesting that water removal did not influence sheep diets. We estimated that under drought conditions, without any surface water available, female and male sheep would be unable to meet their daily water requirements in all seasons, except winter, when reproductive females had a nitrogen deficit. We determined that sheep could achieve water and nutrient balances in all seasons by shifting their total diet proportions by 8–55% from lower to higher moisture and nitrogen forage species. We elucidate how seasonal forage quality and foraging decisions by desert ungulates allow them to cope with their arid environment.

GENETIC DIVERSITY AMONG NATIVE AND NONNATIVE BIGHORN SHEEP POPULATIONS IN ARIZONA

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Translocation is an important management tool that has been used for nearly 60 years to restore and augment populations of bighorn sheep in Arizona. To evaluate the impact of these actions on genetic variation, we characterized statewide genetic structure and diversity using microsatellite and mitochondrial (mtDNA) data in 15 native and nonnative (putatively reintroduced or supplemented) Arizona bighorn sheep populations sampled between 2005-

2012. Nonnative populations showed no reduction in genetic diversity, with allelic richness and heterozygosity estimates equivalent to, in some cases greater than, their source populations. The Silver Bell Mountains population had comparatively low indices of genetic diversity (A_R = 1.84, H_E = 0.25, H_O = 0.27), but showed the greatest genetic similarity to the Sheep and Mohawk Mountains populations, indicating potential translocation opportunities if warranted. Differences in mtDNA sequences between nonnative populations in northern Arizona and their source population in the Black Mountains suggest either bighorn sheep persisted there prior to translocation, or gene flow occurred from the unsampled Grand Canyon population. Bayesian clustering on genetic similarity and genetic divergence estimates (F_{ST}) corroborated previous work differentiating two desert lineages consistent with *O.c. nelsoni* and *O.c. mexicana*, and the Rocky Mountain subspecies, *O.c. canadensis*. Evidence of desert bighorn introgression into the Rocky Mountain population in southeastern AZ suggests desert bighorn sheep may have occupied this region at the time of translocation. This statewide investigation reveals important insights into the genetic outcomes of translocations and natural dispersal events and maintenance of genetic diversity among nonnative populations of Arizona bighorn sheep.

AN ANALYSIS OF FACTORS INFLUENCING MORTALITY AND HABITAT SELECTION IN TWO DESERT BIGHORN SHEEP (*OVIS CANADENSIS MEXICANA*) POPULATIONS IN ARIZONA

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Mountain lions (*Puma concolor*) and bighorn sheep (*Ovis canadensis*) are native species sharing a long history in the Southwest and, in current times, are commonly the focus of management and research efforts. Numerous previous studies have reported on bighorn sheep, mountain lions, and their interspecific relationships, including the influence of predation on bighorn sheep populations and bighorn sheep habitat selection strategies. However, questions still remain regarding which factors influence risk of predation for bighorn sheep and how they select habitat to reduce this risk. Currently, the Research Branch of the Arizona Game and Fish Department is conducting a 4-year study with the purpose of a) understanding factors that influence bighorn sheep risk of lion predation and b) documenting bighorn sheep habitat selection in relation to presumed predator avoidance strategies. We are tracking 104 GPS-collared bighorn sheep in two Arizona populations, including one recently reintroduced population, and recording data on bighorn sheep group size/composition and cause-specific mortality. Additionally, we are recording measurements on environmental factors including topographic features, vegetation, and horizontal visibility. We will use a proportional-hazards analysis framework to examine which factors put bighorn sheep at increased risk of mortality. We will use a habitat selection framework to a) document if and how selection changes with time after translocation/reintroduction, and b) to examine whether bighorn sheep select habitat consistent with presumed predator avoidance strategies. We anticipate this research will inform the Department's ongoing bighorn sheep and mountain lion management actions, including decisions related to fire, recreation, predators, and translocation strategies.

REESTABLISHING DESERT BIGHORN SHEEP (*OVIS CANADENSIS MEXICANA*), SUSTAINABLE CONSERVATION AND INFECTIOUS DISEASE MANAGEMENT

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The Arizona Game and Fish Department (AGFD) translocates bighorn sheep to reestablish locally extinct populations. One population in the Santa Catalina Mountains once numbered >200 animals, but died out in the late 1990s. Between 2013-2016, AGFD reintroduced desert bighorn sheep to the Santa Catalina Mountains with 3 translocations of roughly 30 bighorn sheep each and 1 of 20 bighorn sheep, from 3 populations in Arizona. Source populations were selected based primarily on their recent population trends, though current disease status and relative habitat conditions were

known. The 2013 (*n* = 31), 2015 (*n* = 30), and 2016 (*n* = 20) translocations came from *M. ovipneumoniae*-positive populations. The 2014 translocation was sourced from a *M. ovipneumoniae*-positive population (n = 16) and a *M. ovipneumoniae*-negative population (*n* = 14). Adult bighorn sheep in the first 3 translocations were equipped with GPS collars, and mortalities were investigated within 48 hours. From the 2013 release, one bighorn sheep died from acute capture myopathy, 16 died from predation, all within 6 months of release, and 2, at 11and 18 months after translocation, died from undetermined causes. Nine months after the 2014 release, 6 bighorn sheep, with no prior exposure to *M. ovipneumoniae*, succumbed to acute bacterial pneumonia with a strain matched to the positive source population. Five bighorn sheep died from predation in 2014, between 6 and 18 months after release. There have been 11 mortalities from the 2015 translocation: 7 predations, 1 trauma, 2 pneumonias, and 1 undetermined. Translocation planning should assess the probable impact of factors such as disease status for both the source and receiving populations, exposure to predators, and habitat conditions in order to achieve species conservation goals.

EVALUATING THE ROLE OF HARVEST ON HORN SIZE OF MOUNTAIN SHEEP

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Harvest-induced evolution can have severe implications for the management and persistence of populations across the world; yet, the true effects of harvest remain highly debated. Even at limited temporal and spatial scales, population level responses to harvest can occur across taxa, and include reduced weapon size, reduced growth rate and early sexual maturation, among others. Nevertheless, in most populations, the threshold of harvest severity that prompts evolutionary change is unclear. Mountain sheep (*Ovis canadensis* and *Ovis dalli*) possess impressive weapons that are highly desirable to hunters. Previous research has noted variable temporal trajectories in horn size, which have been attributed to harvest pressure. Harvest can affect patterns of horn size in two distinct ways. First, intensive harvest can result in demographic changes, where declines in mean horn size result from a high proportion of young animals being harvested through time. Alternatively, selection for fast-growing males may result in declines in horn size of a population despite no change in age structure. We synthesized harvest records of mountain sheep throughout their range and assessed changes to age structure and horn size among 266 herds over 40 years. After accounting for age, temporal trends in horn size were not explained by demography alone in 61 herds, but instead may be associated with selective pressures or environmental conditions. Nonetheless, 77% of mountain sheep herds (*n*=205) exhibited no temporal shift in age-specific horn size, indicating most harvest strategies for mountain sheep in North America have not resulted in changes in horn size.

MANAGEMENT AND CONSERVATION OF BIGHORN SHEEP WITH CROSS-BORDER HOME RANGE BETWEEN BAJA CALIFORNIA AND CALIFORNIA

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The bighorn sheep, *Ovis canadensis*, is a very popular and charismatic species in Baja California, even being the mascot of the Autonomous University of the State, but recently, it has suffered a series of problems, which include the loss of its habitat, the introduction of species to its home range that compete for food and resources, and are illegally hunted. The Government of the State of Baja California is planning in its State Strategy for the bighorn sheep to be used as a sustainable resource, and reach a better sense of care for its population. With the first geo-data collection for bighorn sheep in Baja California, and the use of various techniques of telemetry as part of the studies of the Bighorn sheep in the Autonomous University of Baja California, and the San Diego Zoo Institute of Conservation Research, home range areas and routes for 10 bighorn sheep with Satellite GPS collars in the north of Sierra Juárez from December 2013 to May 2014 were obtained. Rams had an average of 1.52 km for daily route and a home range area of 26.396 km^2, and some of them had a cross-border home range. As the bighorns uses resources from both the United States and Mexico, a governance effort between both countries can help preserve the bighorn sheep in this area of the Peninsular Range.

THE STATUS AND TREND OF DESERT BIGHORN SHEEP IN THE NORTH SAN RAFAEL SWELL

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The North San Rafael (NSR) population of desert bighorn sheep was once one of the largest populations in Utah, reaching an estimated 543 individuals in 2001. Since that time the NSR herd declined by a mean 11% annually until 2011. While disease was a suspected contributor, exact causes of decline were not known. Objectives of this study were to locate collared females weekly to determine survival, determine cause specific mortality, and quantify population size, demographics, production, and survival of neonates. In January 2012, we fitted 38 bighorns (30 ewes, eight rams) with GPS/VHF collars and collared an additional 10 bighorns (eight ewes, 2 rams) in January 2013 and tested all for pathogens associated with disease. In 2012, 31% of bighorns tested positive in PCR for *Mycoplasma ovipneumoniae*. In 2013, 30% tested positive. We documented 19 mortalities of collared sheep over two years. Ten mortalities (53%) were attributed to cougar predation. Two mortalities (11%) were attributed to bluetongue virus. Two mortalities (11%) were a result of reproductive complications (ruptured uterus, dystocia). One mortality (5%) was a hunter harvested ram. Four mortalities (21%) had unknown causes, with predation excluded as a putative cause. Despite individuals testing positive for pathogens associated with pneumonia, no mortalities were attributed to disease as the primary cause of death. Lamb:ewe ratios were 47:100 in 2012 and 31:100 in 2012. Adult male survival was 75% in 2012 and 89% in 2013. Adult female survival was 73% and 73%. Other key findings included sightability estimates of 80% and 68% in 2012 and 2013, respectively.

A STOCHASTIC BIGHORN SHEEP CAPTURE MORTALITY EVENT COMPARED TO A LONG-TERM CAPTURE MORTALITY DATA SET

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In October 2016, New Mexico Department of Game and Fish captured 76 bighorn sheep (*Ovis canadensis*) using the helicopter net-gun technique. There were 3 direct mortalities during the capture and 4 additional mortalities the first week post-capture, attributed to idiopathic capture myopathy. These high capture mortality (4.0%) and post-capture mortality rates (5.5%) are compared with a long-term data set (1997-2016) of 672 additional helicopter net-gun captures with 11 capture mortalities (1.5%) and 2 post-capture mortalities (0.3%). Additionally, capture mortality rates for 493 bighorn sheep captured using 4 alternative methods were 1) drop-net 1.5% (n=393), 2) chemical immobilization 13.1% (n=61), 3) corral trap 0% (n=7), and 4) hand-capture of neonates 3% (n=32). Total capture mortality for 1,249 bighorn sheep captured between 1997 and 2016 was 2.8%. Prior to the most recent capture event the total capture mortality was 2.4%. Prior to the most recent capture event, total mortality, excluding chemical immobilization, was 1.7%. This 19 year data set will provide baseline capture related mortality values for state wildlife management agencies tasked with capturing bighorn sheep.

BIGHORN SHEEP POPULATION HEALTH IN UTAH

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The Utah Division of Wildlife Resources has been conducting systematic surveillance of the Utah bighorn sheep populations since 2012. As of March 2017, approximately 80% of the bighorn sheep populations have been tested. Exposure to respiratory pathogens is widespread and only a few populations are still considered free of respiratory disease. We present the results from these surveillance efforts, and examine the test results in light of available population performance data.

BIGHORN SHEEP SINUS TUMORS, AN UPDATE

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In 2009, bighorn sheep sinus tumors were discovered within a herd of seven Rocky Mountain bighorn ewes in Colorado, USA that were culled due to a history of at least 10 years of failed lamb recruitment. Since discovery, at least 43 cases of sinus tumors have been identified in at least 12 free ranging bighorn herds in Colorado including Rocky Mountain and desert bighorn herds. Additional cases have been identified in California, Nebraska, Nevada, and Wyoming. The disease has been shown to be infectious experimentally and likely has moved across the landscape through natural and artificial movements of bighorn sheep. While sinus tumors alone do not appear to affect adult survival or lamb recruitment, sinus tumors in combination with other typical respiratory pathogens have been consistently identified in Colorado bighorn herds that are struggling with poor lamb recruitment. Sinus tumors may contribute to transmission of other respiratory pathogens through enhanced shedding.

Abstracts of Presented Posters

POTENTIAL CHANGES TO DESERT NATIONAL WILDLIFE REFUGE FROM PROPOSED NEVADA TEST AND TRAINING RANGE WITHDRAWAL EXPANSION

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The Desert National Wildlife Refuge (DNWR) in southern Nevada encompasses one of the largest blocks of intact habitat for desert bighorn sheep (*Ovis canadensis nelsoni*). In 1936, Executive Order 7373 established DNWR and expressly provided for conservation of desert sheep. The Nevada Test and Training Range (NTTR) overlays 846,000 acres of the western portion of the 1.6 million-acre DNWR. The National Defense Authorization Act of 2000 extended the withdrawal for the NTTR. This authorization will expire in November 2021. On August 25, 2016, the U.S. Air Force issued a Notice of Intent to prepare a Legislative Environmental Impact Statement (LEIS) for the NTTR. Alternatives include: (1) keeping existing land withdrawal and management as is (Status Quo); (2) extend withdrawal area by changing primary jurisdiction of lands to provide Air Force with increased access for military activities; (3) Alternative 1 or 2 and expand withdrawal area by including up to 275,926 additional acres, via two sub-alternatives on the DNWR; (4) establish a time period of withdrawal renewal as either 20 years, 50 years, or as an indefinite military withdrawal; and (5) No Action alternative which includes returning NTTR lands to the public domain, through the Department of the Interior. Alternatives 2 and 3 have potential negative impacts to bighorn sheep and their habitats on DNWR's public land portion. These potential impacts would occur in the Spotted, Pintwater, Desert, East Desert, and northwest Sheep ranges. At this time, analysis of existing data and species studies are being completed for upcoming Draft LEIS.

AN EVALUATION OF PRESCRIBED FIRE ON DESERT BIGHORN SHEEP HABITAT USE IN THE GALIURO MOUNTAINS OF SOUTHEASTERN ARIZONA

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The Galiuro Mountain Ecosystem contains a fire adapted plant community with an historic fire return interval of three to eight years. Long-term intensive grazing and fire suppression have disrupted this fire regime resulting in encroachment of woody vegetation into historically open habitats. In 2016, the United States Forest Service began implementing the Galiuro FireScape, an eight-year plan to return the natural fire regime to 137,000 acres in the Galiuro Mountains using prescribed fire. In 2015, the Arizona Game and Fish Department began a multiyear effort to enhance the two desert bighorn sheep (*Ovis canadensis*) populations located in the northern and southern reaches of the Galiuro Mountain Ecosystem in Aravaipa Canyon and Redfield Canyon, respectively. That fall, in preparation for a planned translocation, five Aravaipa Canyon and three Redfield Canyon bighorns were captured, tested for transmissible disease, fitted with GPS transmitters, and released. In November of 2016, 31 desert bighorn sheep were translocated to this range. Eleven sheep, including three fitted with GPS transmitters, were released into Aravaipa Canyon; 20 sheep, seven with GPS transmitters, were released into Redfield Canyon. The treatment with prescribed fire of the first of four burn units containing occupied and unoccupied desert bighorn sheep habitat is scheduled for 2019. This timeframe allows for the accumulation of GPS data identifying home range and habitat use. Unused desert

bighorn sheep habitat and a potential corridor between the two existing desert bighorn sheep populations will be identified for treatment with prescribed fire during the implementation of the Galiuro Firescape Project. The accumulation of pre and post-treatment data will facilitate the evaluation of prescribed fire as a tool to influence habitat use in the Galiuro Mountain Ecosystem by desert bighorn sheep.

COMPARISON OF TWO BACTERIAL TRANSPORT MEDIA FOR CULTURE OF TONSILAR SWABS FROM BIGHORN SHEEP (*OVIS CANADENSIS*) AND MOUNTAIN GOATS (*OREAMNOS AMERICANUS*)

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Monitoring of respiratory pathogens in bighorn sheep and mountain goat herds serves the purpose of evaluating population health, and comparing pathogen distribution between populations. In live animals, bacterial cultures for *Pasteurellaceae* are usually done from tonsillar or oropharyngeal swabs that are placed in a bacteriologic transport media (BTM). BTM require refrigeration after sample collection, and must be received by the laboratory within 48-72 hours. Practically, this means that samples need to be shipped on Monday – Thursday, which can be challenging when working in remote areas. Bacterial cryopreservation media (BCM) may provide increased flexibility in the timing of shipping, since once frozen bacterial viability may be better preserved over time. For this reason, BCM have been increasingly used for transport of tonsillar or oropharyngeal swabs from bighorn sheep and mountain goats. However, BCM have not been systematically evaluated for survival and recovery of bacteria in comparison to BTM. Duplicate tonsilar swabs were collected from 77 bighorn sheep and 19 mountain goats from 5 populations in Utah between October 2015 and January 2016. Swabs were refrigerated in agar-based BTM or frozen in TSB/glycerol BCM prior to bacteriologic culture. On a herd level, the cryogenic media yielded comparable or superior bacterial growth, but the agreement between the two media was poor on an individual animal level. Based on these results, both BTM and BCM are suitable transport systems for swab samples, with BCM providing increased flexibility for capture scheduling and specimen shipment to the laboratory. The results should not be compared between individual animals, but are comparable on a herd level.

INSTRUCTIONS FOR CONTRIBUTIONS TO THE
DESERT BIGHORN COUNCIL TRANSACTIONS

GENERAL POLICY: Original papers relating to desert bighorn sheep ecology and management are published in the *Desert Bighorn Council Transactions*. All papers presented at the Council's meetings are eligible for publication. There are 3 types of papers published in the *Transactions*: technical papers; state reports; and opinions, comments, and case histories or notes. Technical papers are peer reviewed. State reports are edited for syntax and style. Opinions, comments, and case histories and notes provide for philosophical presentations and the presentation of ideas and concepts. These papers are also peer reviewed. Additional papers may be published when reviewed and approved by the Editorial Board. Papers must be submitted to the Editor within 1 year of the Council's annual meeting to be considered for the current edition of the *Transactions*.

SUBMISSION AND COPY: Electronic submissions as word processing (e.g., word) files are preferable. However, if for some reason authors are unable to submit electronically, please use good quality white paper 215 × 280 mm (8.5 × 11 inches), or size A4. Double space throughout, with 3-cm margins. Do not hyphenate at the right margin. Type the name and complete address of the person who is to receive editorial correspondence in the top left corner of page 1. On succeeding pages, type the senior author's last name in the top left corner and the page number in the top right corner. The author's name and affiliation at the time the study was performed follows the title. Present address, if different, should be indicated in a footnote on the first page. Keep 1 copy. Submit 4 good copies.

STYLE: Proceed from a clear statement of purpose through introduction, study area, methods, results, and discussion. Sequence of contents: title, authors, abstract, key words, introduction, study area, methods, results, discussion, literature cited, tables, and figures. Follow the CBE Style Manual Committee 1994. The former guidelines for the *Wildlife Society Bulletin* are the preferred style and are available from the editor on request. See a recent volume of the *Desert Bighorn Council Transactions* for examples.

TITLE: The title should be concise, descriptive, and ≤10 words. Use vernacular names of organisms.

FOOTNOTES: Use only for author's address if there are multiple addresses for authors and in tables.

ACKNOWLEDGEMENTS: Include acknowledgements at the end of the paper, before Literature Cited, as a titled paragraph.

SCIENTIFIC NAMES: Vernacular names of plants and animals should be accompanied by the appropriate scientific names (in parentheses) the first time each is mentioned.

ABSTRACT: An abstract of about 1–2 typed lines per typed page of text should accompany all articles. The abstract should be an informative digest of significant content. It should be able to stand alone as a brief statement of problems examined, the most important findings, and their use.

KEY WORDS: Place key words below the abstract. Supply 6–12 key words for indexing: vernacular and scientific names of principal organisms, geographic area, phenomena and entities studied, and methods.

References: Authors are responsible for accuracy and completeness and must use the style in **Guidelines for Authors and Reviewers of *Wildlife Society Bulletin* manuscripts**. Avoid unnecessary references. Order multiple references consecutively by date. Show page numbers for quotations, paraphrases, and for citations in books or bulletins unless reference is to the entire publication. Cite unpublished reports only if essential. Include source, paging, type of reproduction, and place for unpublished reports are filed parenthetically in the text.

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Illustrations: Illustrations and drawings must be submitted as an electronic file suitable for no larger than 215 x 280 mm (8.5 x 11 inches) final layout. Make all letters and numbers large enough to be ≥1.5 mm tall when reduced. Lettering size and style when reduced should be the same in all figures. Submit prints of good contrast either as high resolution image files (e.g., jpeg, tif) or as a hard copy on glossy paper. Type captions on a separate page in paragraph form. On the back of each illustration, lightly write the senior author's name, figure number, and "Top."

Submission and Proof: All papers will be reviewed for acceptability by the Editorial Board and 2 outside reviewers. Submit papers to James W. Cain at jwcain@nmsu.edu. If hard copies must be submitted, they should be mailed to James W. Cain, New Mexico Cooperative Fish and Wildlife Research Unit, P.O. Box 30003, MSC 4901, Las Cruces, NM 88003, USA. When papers are returned to authors for revision, please return revised manuscripts within the time allotted. Galley proofs should be returned within 72 hours.

Transmittal Letter: When the manuscript is submitted, send a letter to the Editor, stating the intent to submit the manuscript exclusively for publication in *The Transactions*. Explain any similarities between information in the manuscript and that in any other publications or concurrent manuscripts by the same author(s), and furnish a copy of such manuscripts or publications.

DESERT BIGHORN COUNCIL MEETINGS 1957–2017

Year	Location	Chairperson	Secretary	Treasurer	Transactions Editor
1957	Las Vegas, NV	M. Clair Albous			
1958	Yuma, AZ	Gale Monson & Warren Kelly			
1959	Death Valley, CA	M. Clair Albous	Fred Jones	Fred Jones	
1960	Las Cruces, NM	Warren Kelly	Fred Jones	Fred Jones	
1961	Hermosillo, MX	Jon Akker	Ralph Welles		Ralph Welles
1962	Grand Canyon, AZ	James Blaisdell	Charles Hansen & L. Fountein	Charles Hansen	Charles Hansen
1963	Las Vegas, NV	Al Jonez	Charles Hansen	Charles Hansen	Jim Yoakum
1964	Mexicali, MX	Rudulfo Corzo	Charles Hansen	Charles Hansen	Charles Hansen & D. Smith
1965	Redlands, CA	John Goodman	John Russo	John Russo	Jim Yoakum
1966	Silver City, NM	Cecil Kennedy	John Russo	John Russo	Jim Yoakum
1967	Kingman, AZ	Claude Lard	John Russo	John Russo	Jim Yoakum
1968	Las Vegas, NV	Ray Brechbill	John Russo	John Russo	Jim Yoakum
1969	Monticello, UT	R. & B. Welles	W. G. Bradley	W. G. Bradley	Jim Yoakum
1970	Bighop, CA	William Graf	W. G. Bradley	W. G. Bradley	Jim Yoakum
1971	Santa Fe, NM	Richard Weaver	Tillie Barling	Tillie Barling	Jim Yoakum
1972	Tucson, AZ	George Welsh	Doris Weaver	Doris Weaver	Charles Hansen
1973	Hawthorne, NV	Warren Kelly	Doris Weaver	Doris Weaver	Juan Spillet
1974	Moab, UT	Carl Mahon	Lanny Wilson	Lanny Wilson	Juan Spillet
1975	Indio, CA	Bonnar Blong	Lanny Wilson	Lanny Wilson	Charles Hansen
1976	Bahia Kino, MX	Mario Luis Cossio	Peter Sanchez	Peter Sanchez	Charles Hansen
1977	Las Cruces, NM	Jerry Gates	Peter Sanchez	Peter Sanchez	Charles Hansen
1978	Kingman, AZ	Kelly Neal	Peter Sanchez	Peter Sanchez	Charles Hansen
1979	Boulder City, NV	Bob McQuivey	Peter Sanchez	Peter Sanchez	Charles Hansen
1980	St. George, UT	Carl Mahon	Peter Sanchez	Peter Sanchez	Charles Hansen
1981	Kerrville, TX	Jack Kilpatric	Peter Sanchez	Peter Sanchez	Charles Hansen
1982	Borrego Sprs., CA	Mark Jorgensen	Rick Brigham	Rick Brigham	Charles Hansen
1983	Silver City, NM	Andrew Sandoval	Rick Brigham	Rick Brigham	Charles Hansen
1984	Bullhead City, AZ	Jim deVos, Jr.	Rick Brigham	Rick Brigham	Charles Hansen
1985	Las Vegas, NV	David R. Pulliam, Jr.	Rick Brigham	Rick Brigham	Charles Hansen
1986	Page, AZ	Jim Guymon	Bill Dunn	Bill Dunn	Paul Krausman
1987	Van Horn, TX	Jack Kilpatric	Bill Dunn	Bill Dunn	Paul Krausman
1988	Needles, CA	Vernon Bleich	Don Armentrout	Don Armentrout	Paul Krausman
1989	Grand Junction, CO	Jerry Wolfe	Don Armentrout	Don Armentrout	Paul Krausman
1990	Hermosillo, MX	Raul Valdez	Don Armentrout	Don Armentrout	Paul Krausman
1991	Las Cruces, NM	Bill Montoya	Don Armentrout	Don Armentrout	Paul Krausman
1992	Bullhead City, AZ	Jim deVos, Jr.	Stan Cunningham	Stan Cunningham	Paul Krausman
1993	Mesquite, NV	Kathy Longshore	Charles Douglas	Charles Douglas	Walter Boyce
1994	Moab, UT	Jim Guymon	Charles Douglas	Charles Douglas	Walter Boyce
1995	Alpine, TX	Doug Humphries	Charles Douglas	Charles Douglas	Ray Boyd

DESERT BIGHORN COUNCIL MEETINGS 1957–2017

Year	Location	Chairperson	Secretary	Treasurer	Transactions Editor
1996	Holtville, CA	Andy Pauli	Charles Douglas	Charles Douglas	Ray Boyd
1997	Grand Junction, CO	Dale Reed & Van Graham	Steve Torres	Charles Douglas	Raymond Lee
1998	Las Cruces, NM	Eric Rominger & Dave Holdermann	Darren Divine	Charles Douglas	Raymond Lee
1999	Reno, NV	Rick Brigham & Kevin Hurley	Darren Divine	Charles Douglas	Allan Thomas & Harriet Thomas
2000	Bullhead City, AZ	Ray Lee & Jim deVos	Darren Divine	Charles Douglas	Jon Hanna
2001	Hermosillo, Sonora, Mexico	Carlos Castillo & Jim deVos	Darren Divine	Charles Douglas	Jon Hanna
2002	Palm Springs, CA	Mark Jorgenson	Darren Divine	Charles Douglas	Jon Hanna
2003	St. George, UT	Jim Karpowitz	Darren Divine	Darren Divine	Brian Wakeling
2005	Alpine, TX	Clay Brewer	Esther Rubin	Stacey Ostermann	Brian Wakeling
2007	Las Vegas, NV	Ross Haley	Esther Rubin	Stacey Ostermann-Kelm	Brian Wakeling
2009	Grand Junction, CO	Scott Wait	Esther Rubin	Kathleen Longshore	Brian Wakeling
2011	Laughlin, NV	Brian Wakeling	Esther Rubin	Kathleen Longshore	Brian Wakeling
2013	Las Cruces, NM	Eric Rominger & Patrick Morrow	Esther Rubin	Kathleen Longshore	Brian Wakeling
2015	Borrego Springs, CA	Ben Gonzales & Regina Abella	Amber Munig	Kathleen Longshore	James W. Cain
2017	St. George, UT	Rusty Robinson & Justin Shannon	Amber Munig	Kathleen Longshore	James W. Cain