DESERT BIGHORN COUNCIL TRANSACTIONS

Volume 58 2025

Desert Bighorn Council Transactions 2025

Papers Submitted Following the 58th Meeting Gold Canyon, Arizona

22–25 April 2025

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ISSN: 0418-7598 (print)
ISSN: 3068-305X (online)

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2025

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Editorial Insights From An Incoming Editor

Vernon C. Bleich

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Desert Bighorn Council Transactions 58:1–5

Last year I was recruited (some might say pursued) by the Desert Bighorn Council (Council) Technical Staff to assume editorship of the Desert Bighorn Council Transactions (Transactions) after a failure of responsibility resulted in a lapse of the publication of the 2023 issue. Albeit unfortunate, it validated the importance of Transactions for communicating science and management. Volume 57 (2023) has been completed and this issue (Volume 58) brings Transactions up to date.

I am very much a pragmatist, having spent my entire professional career with the California Department of Fish and Game (CDFG) and during which I gained an appreciation for the importance of applied and basic research. Since 1992 I have held adjunct or research professorships at eight universities, co-chaired 3 graduate committees (1 MS, 2 PhD), and served on the graduate committees of 17 additional students (9 MS, 8 PhD). During these opportunities, I built on my understanding of and appreciation for the importance of contributions from the academic community and applied research. Publication of results, observations, or ideas regardless of one's affiliation or job description is important to the advancement of knowledge and, especially, to the conservation challenges that many species of wildlife—including bighorn sheep (*Ovis canadensis*)—are facing.

If results are to be of value, the information should have meaningful implications from the standpoint of theory or application, and ideally for both. Results that do not originate from the correct scientific protocol, regardless of how well presented, cannot be fixed and should not appear in the professional literature. Conversely, poor writing or the ineffective presentation of science can be corrected, and part of the responsibility for doing so lies with the editor-in-chief (EIC) of any journal. Consulting editors and reviewers having special expertise in the subject matter bear the primary responsibility for evaluating the quality and presentation of the science. Layout editors or format editors possess technical skills and talent that some EICs, including me, depend on to produce a professional product that authors and readers will be satisfied with. The EIC, however, bears the ultimate responsibility for acceptance of a manuscript and for the final presentation and editorial details in the penultimate version of a journal submission.

During manuscript review the prospective contribution must be openly and honestly evaluated. Every member of the editorial team shares in the responsibility for ensuring the best quality product in a paper accepted for publication. Because the ultimate responsibility for acceptance of a manuscript rests with the EIC, he or she will occasionally override recommendations of the consulting editors, reviewers, or production staff. I served 6 years as EIC for *California Fish and Game*, a quarterly journal with worldwide circulation; prior to that, I had served as Associate Editor for 19 years. During that period, I learned that every decision has the potential to draw some criticism from one source or another. Although both assignments sometimes were stressful, I aways believed they were rewarding. In part, that is why I agreed to serve the Council as EIC for Transactions. As a previous EIC for *California Fish and Game* warned me, however, "There will never be a perfect issue, and not everyone—among them the authors, associate editors, reviewers, format editors, and even the previous editor(s)—will always be happy with your decisions." The sometimes difficult, albeit necessary, decisions made the job almost thankless at times but resulted in better contributions to science. The opportunity to return Transactions to a schedule of regular publication also has been rewarding, although it has been infinitely more challenging than I anticipated.

The EIC also has a responsibility to encourage submission of appropriate manuscripts. This philosophy revolves around maintaining high standards of criteria for acceptance, and involves encouraging authors to submit manuscripts they might not initially consider to be important enough to warrant publication in a professional journal yet may help provide a framework for future investigations. Nevertheless, peer review is the widely accepted standard for the unbiased evaluation of scientific work, and the process helps weed out unscientific, erroneous, or meaningless conclusions. Potential authors need to recognize that peer review helps assure reliable scientific results are published, and does not exist simply to undervalue your research.

Many papers published in Transactions have played prominent roles in our understanding of management or conservation, and in the advancement of knowledge about bighorn sheep (Krausman et al. 2023, Torres 2023, Torres et al. 2025). Manuscripts submitted for consideration as Technical Reports have been subjected to the peer-review process since the late 1970s (Krausman et al. 2023). Moreover, the value and importance of memorializing historical information accurately and in an easily retrievable format is becoming increasingly recognized (Diaz and Corti 2025), and Transactions have been a sound scientific publication since the founding of the Desert Bighorn Council (Krausman et al. 2023, Torres 2023, Torres et al. 2025). Although Transactions historically have included state status reports, notes, case reports. case histories, and commentaries (Krausman 1992), I have elected to include all of these in a single section that will appear in this and (hopefully) future volumes.

As noted recently by numerous scientists, the very foundations of our profession are based on experiences or observations made under field conditions, and the need to share or communicate those observations and other scientific findings widely and effectively has been emphasized (Leopold 1933, Hansen 1967). Nonetheless, the perceived relevance of such contributions increasingly is being ignored (Bleich and Oehler 2000, Bleich 2018, Berger et al. 2024, Torres et al. 2025), and with the result that, "Nothing will destroy the science and mission of conservation biology faster than a generation or two of biologists raised on dead facts and technology and lacking direct, personal experience with Nature" (Noss 1996:2).

The same caveat applies to the field of wildlife biology, perhaps because an increasing trend toward fascination with new technology often deemphasizes the importance of the query, "What ecological questions will be addressed and answered?" (Latham et al. 2015:144). An absence of critical forethought or planning all too often has occurred and resulted in advanced technology being employed simply because it was available, rather than necessary, to meet an objective (Nichols and Williams 2006, Hebblewhite and Haydon 2010). Moreover, simply assuming that use of advanced technology can be a substitute for rigorous fieldwork can be dangerous (Elbroch et al. 2017) and is a concern with which I and others have concurred for many years (Bleich 2018).

As conveyed by Maurice Hornocker (2023:91), "...remote sensing and all the gadgets and gizmos of the digital era have made the study of secretive species less challenging and the collection of quantitative data much easier. But the technology tends to focus solely on the specific target species, not the environmental forces that can and do alter behavior. The researcher's immersion into the target animal's environment, I maintain, leads to a better understanding of the animal and its world." Additionally, there is "... more and more evidence that some individuals would rather ... view information transmitted directly ... to a video display, than expend time and energy in a field setting..." (Bleich 2023:2). Moreover, an increasingly common strategy employed by researchers is to obtain data gathered years—or even decades—earlier by other investigators and "offer" to analyze it. Incredibly sophisticated software then is used by the investigator(s) to create innumerable models that potentially explain (1) what might have occurred back then; or (2) what might be occurring at the present time; or (3) what might occur in the future (make your choice) hundreds of kilometers from the comfort of their office (Bleich 2023:2), perhaps without ever encountering the species of interest or absent any familiarity with the area wherefrom the data were collected (Krausman 2021). These individuals frequently are referred to as "keyboard warriors" (Bleich 2023:2) or machine scientists (Guimera et al. 2020, Belikov et al. 2022).

The rampant rise in the availability and use of image processing, remote sensing, technological advances in data processing, and artificial intelligence (AI) will strongly influence the ways that science has been explored or pursued, how articles are developed for publication, how management is conducted, whether *a priori* hypotheses are considered, and how results are interpreted (Guimera et al. 2020; Krausman 2023; Conroy 2023a, 2023b, 2023c; Stokel-Walker 2023). I concur with Barnas and Fisher (2025) that ecological inferences derived from processed data will depend on a firm grasp of natural history and species-specific biology, but I anticipate a downward trending interest in that expectation. Through a renewed realization that many observations or conditions encountered under field conditions may be of tremendous value to future investigators, Transactions will continue to welcome scientific contributions that may not involve the latest technological advancements but still adequately address questions of interest. As long as the methods are sound, the system will continue to be of value; once methods are corrupted, the scientific method fails.

Confusing tools with solutions puts technology before biology, and can result in poorly thought-out questions (Hebblewhite and Haydon 2010), and reinventing programs that previously were highly successful can be especially problematic or even counter-productive to conserving bighorn sheep. "When wildlife biologists—whether experienced or newly minted—did not or do not grasp 'Ecology 101' pursuit of the bright, shiny object seems more likely. It is necessary to understand the culture of conservation and history of work accomplished to date in the location of interest because failure to do so exacerbates the tendency to 'ignore what has been done before' and ... rarely is there adequate consideration of the long-term research required to inform questions appropriate to conservation and management of large mammals" (Bleich 2018:544). Further, the current emphasis on sometimes questionable metrics, such as numbers of downloads, H-scores, citation scores, or impact factors likely will compel a lesser interest in basic understanding and more on the application of technology, albeit at the expense of many of the questions that require answers. Moreover, the upward trend in the use of AI will encourage movement away from science as it has been known and influence the ways that that science is pursued, research is conducted, articles are developed, results are perceived, and how management is conducted. All of these cause me great angst because, "The proliferation of AI tools in science risks introducing a phase of scientific enquiry [sic] in which we [will] produce more but [we will] understand less" (Messeri and Crockett 2024:49). Enough said.

Over the years, Transactions have served managers, researchers and, most importantly, the conservation of bighorn sheep well. Additionally, the pervasive loss of institutional memory (i.e., generational amnesia; Fisher 2021), in our profession has been unfortunate. Publishing in Transactions will ensure the availability of meaningful and potentially important observations or results to future investigators, and will encourage others to do so, while simultaneously providing a respected outlet for more advanced approaches to problem solving. As EIC, I hope that wildlife managers and scientists involved with bighorn sheep will increase submissions to be considered for publication, with the result that Transactions will be increasingly recognized as a meaningful and important professional journal. A close working relationship between members of the Council's Publications Committee, Technical Staff, reviewers, and the EIC will improve the visibility and scientific value Transactions and increase interest in publishing therein, and are objectives that I will pursue.

ACKNOWLEDGMENTS

I thank R. T. Bowyer, J. R. Heffelfinger, P. R. Krausman, D. G. Stewart, and S. G. Torres for providing helpful comments that improved the manuscript. I also thank J. Berger, M. W. Oehler, D. R. Yparraguirre and F. W. Weckerly for prior discussions and sharing insights and opinions regarding the application of advanced technology to wildlife science. This is Professional Paper 170 from the Eastern Sierra Center for Applied Population Ecology.

REFERENCES

Anderson, J. G. 2017. Why ecology needs natural history. American Scientist 105:290–297.

Barnas, A. F., and J. T. Fisher. 2025. Will using artificial intelligence to review camera trap images reduce human connection to wildlife research? Wildlife Society Bulletin 49:e1588. <https://doi.org/10.1002/wsb.1588>

Belikov, A. V., A. Rzhetsky, and J. Evans. 2022. Prediction of robust scientific facts from literature. Nature Machine Intelligence 4(5):1–10. <https://10.1038/s42256-022-00474-8>.

Berger, J., V. C. Bleich, and R. T. Bowyer. 2024. Must we lose our biological connection to nature to endure changing times? Journal of Wildlife Management 88:e22639.

Bleich, V. C. 2018. Maintaining momentum for conservation: bighorn sheep as an example. Wildlife Society Bulletin 42: 540–546.

Bleich, V. C. 2023. Review of *Cougars on the cliff: one man's pioneer quest to understand the mythical mountain lion—a memoir*, by M. Hornocker. California Fish and Wildlife Journal 109(4). Available at: <https://journal.wildlife.ca.gov/2023/12/29/cougars-on-the-cliff-one-mans-pioneer-quest-to-understand-the-

mythical-mountain-lion-a-memoir/?utm_medi>.

Bleich, V. C., and M. W. Oehler. 2000. Wildlife education in the United States: thoughts from agency biologists. Wildlife Society Bulletin 28:542–545.

Conroy, G. 2023a. Scientists used ChatGPT to generate an entire paper from scratch — but is it any good? Nature 619:443–444.

Conroy, G. 2023b. Scientific sleuths spot dishonest ChatGPT use in papers. Nature News, 08 September 2023. Available at: https://www-nature-com.unr.idm.oclc.org/articles/d41586-023-02477-w

Conroy, G. 2023c. How ChatGPT and other AI tools could disrupt scientific publishing. Nature 622:234–236.

Diaz, N. I., and P. Corti. 2025. Ensuring the quality of historical data for wildlife conservation: a methodological framework. Perspectives in Ecology and Conservation 23:32–38.

Elbroch, L. M., B. Lowrey, and H. U. Wittmer. 2017. The importance of fieldwork over predictive modeling in quantifying predation events of carnivores marked with GPS technology. Journal of Mammalogy 99:223–232.

Fisher, R. 2021. The memory loss that harms the planet. British Broadcasting Corporation, London, United Kingdom. Available at <https://www.bbc.com/future/columns/wise-words>.

Guimera, R., I. Reichardt, A. Aguilar-Mogas, F. A. Massucci, M. Miranda, J. Pallares, and M. Sales-Pardo. 2020. A Bayesian machine scientist to aid in the solution of challenging scientific problems. Science Advances 6:eaav6971. <https://doi.org/10.1126/sciadv.aav6971>

Hansen, C. G. 1967. The future needs in desert bighorn research. Desert Bighorn Council Transactions 11:80–85.

Hebblewhite, M., and D. T. Haydon. 2010. Distinguishing technology from biology: a critical review of the use of GPS telemetry data in ecology. Philosophical Transactions of the Royal Society B Biological Sciences 365:2303–2312.

Hornocker, M. 2023. Cougars on the cliff: one man's pioneer quest to understand the mythical mountain lion—a memoir. Lyons Press, Essex, Connecticut, USA.

Krausman, P. R. 1992. The use of Desert Bighorn Council Transactions. Desert Bighorn Council Transactions 36:48.

Krausman, P. R. 2023. Managing artificial intelligence. Journal of Wildlife Management 87:e22492.

Krausman, P. R., B. F. Wakeling, and J. W. Cain III. 2023. The Desert Bighorn Council Transactions, society, and science. Desert Bighorn Council Transactions 57:19–24.

Latham, A. D. M., M. C. Latham, D. P. Anderson, J. Cruz, D. Herries, and M. Hebblewhite. 2015. The GPS craze: six questions to address before deciding to deploy GPS technology on wildlife. New Zealand Journal of Ecology 39:143–152.

Leopold, A. 1933. Game management. Charles Scribner's Sons, New York, New York, USA.

Messeri, L., and M. J. Crockett. 2024. Artificial intelligence and illusions of understanding in scientific research. Nature: 49–58.

Nichols, J. D., and B. K. Williams. 2006. Monitoring for conservation. Trends in Ecology and Evolution 21:668–673.

Noss, R. F. 1996. The naturalists are dying off. Conservation Biology 10:1–3.

Stokel-Walker, C. 2023. ChatGPT listed as author on research papers: many scientists disapprove. Nature 613:620–621.

Torres, S. G. 2023. The Desert Bighorn Council: a partner in the evolution of science and management. Desert Bighorn Council Transactions 57:12–18.

Torres, S. G., V. C. Bleich, and J. D. Wehausen. 2025. From field notes to policy: 65 years of science to management in the Desert Bighorn Council Transactions. Desert Bighorn Council Transactions 58:73–105.

Desert Bighorn Council Keynote Address—2025

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Desert Bighorn Council Transactions 58:6–10

As an avid reader, I have made an earnest effort to read as much as I can find time for, and of particular interest to me are what I would call "classics" in the wild sheep world. From Honess and Frost's 1942 bulletin *A Wyoming Bighorn Sheep Study* to Dwight Smith's 1954 *The Bighorn Sheep in Idaho*, I've read many accounts about Rocky Mountain bighorn sheep in the western U.S. and Canada. Having spent most of my career working with and managing bighorn sheep in the northern Rockies, I've tried to broaden my portfolio to include the desert bighorn sheep and northern thinhorn sheep literature, soaking up as much information and intel as I can from authors who know their subject matter so well.

Following my 30-year career with the Wyoming Game and Fish Department, and now having spent 15 years on the Conservation Staff of the Wild Sheep Foundation, and as I approach the half-century mark as a wildlife biologist and wild sheep conservationist, I sincerely appreciate the invitation and opportunity to address the Desert Bighorn Council at our 2025 Biennial Meeting. This year's conference theme, Management of Desert Bighorn Sheep in a Changing Landscape: Challenges and Opportunities, is focused on the contemporary issues of the day. I have learned much about desert bighorn sheep from many of you in the room today, and also from so many who aren't able to be with us today. I appreciate and acknowledge the guidance and perspectives of my desert bighorn sheep colleagues over these many decades.

In anticipation of this address, I scoured multiple sources of information about desert sheep management over the past century. Robert M. Anderson's excellent book, *Rimrock Man: The Early Life of W.B. Carson (1907–1946),* was a fascinating read for me, as Anderson relayed the stories and perspectives of Burch Carson, a true pioneering sheep biologist in west Texas. Combined with Carson's 1941 Bulletin No. 21 from the Texas Game, Fish, and Oyster Commission titled, *Man: The Greatest Enemy of Desert Bighorn Mountain Sheep*, these candid Trans-Pecos accounts identified some of the threats to desert sheep nearly a century ago. Carson felt that, before 1900, the primary cause of declining desert bighorn numbers was the influx of miners and railroad workers. Compare and contrast Carson's views and those of John Russo's 1956 observations of Arizona desert bighorn sheep with contemporary analyses on impacts to desert bighorn sheep from high-speed rail lines (e.g., Brightline West in the Mojave Desert), large ore-hauling trucks (e.g., the mine at Morenci, Arizona), and the risk of being killed on modern roads or highways.

According to Carson, by 1903 desert bighorn in the Trans-Pecos were practically eliminated, and sheep hunting seasons were closed. Further, Carson noted, "…bighorn sheep were further decimated when ranchers began stocking domestic sheep, which spread disease…", speculating in 1945 that "…there will be none if they are not fenced inside a large refuge, away from domestic sheep and their diseases…". This warning is often repeated, and unfortunately, often ignored today. In his 1960 Wildlife Monograph, *The Bighorn Sheep of the United States*, Helmut K. Buechner estimated 6,700–8,100 desert bighorn sheep remained in Arizona, New Mexico, Texas, Nevada, and California, for many of the reasons we'll get to shortly.

At the initial Desert Bighorn Council meeting held in Las Vegas in 1957, in what certainly today would not be appropriate, Desert Game Range Refuge Manager Winston E. Banko welcomed, "…all the bighorn men…" who gathered to share ideas and information, with the hope "that if all could take one good idea home with them, this would be a worthwhile meeting". An interesting observation is that nearly 70% of the attendees at the 1957 DBC meeting worked for federal agencies; contrast that with today's audience, where I'd guesstimate less than 10% of the attendees work for federal agencies, no doubt an indication of the fiscal uncertainty, travel restrictions, and prevailing political climate affecting many federal agencies and their employees.

In what can only be viewed as a *déjà vu* moment, presenters at the first DBC meeting identified restrictive fencing along the international boundary with Mexico as an impediment to desert bighorn sheep movements, along with competition for forage and other impacts resulting from feral horses, cattle, domestic goats, and deer. Nearly 75 years later, wild sheep managers have heightened and significant concerns with restrictive fencing along the border, while desert bighorn conservationists have advocated stridently for overpasses in Nevada, Arizona, and along the I-15 corridor in California), or for other means to mitigate impacts from high traffic volumes and to reduce vehicle-animal collisions. If "necessity is the mother of invention", one must recognize the technological advances (e.g., real-time GPS tracking collars, GIS mapping, CircuitScape and RSF analyses, movement simulation modeling) that have been developed and deployed to better quantify impacts to desert bighorn sheep.

While managed livestock grazing on many desert sheep public-land ranges is more closely regulated now than it was 75 years ago, overgrazing still occurs in places. Feral horse and burro numbers have exploded since passage of the Wild Free-Roaming Horses and Burros Act of 1971, and with substantial impacts on desert bighorn sheep and their habitats.

In the days of Compound 1080 and other widely used toxicants, predation was largely considered to be a minor influence on desert bighorn sheep numbers. Waterholes (presumably naturally occurring) were identified as potential bobcat or coyote predation "hotspots", while little mention was made of mountain lion predation on desert bighorns, but noted on mule deer. More recently, mountain lion predation on desert bighorn sheep has been identified as an important factor by Eric Rominger and others working in the southwestern United States and limiting desert bighorn sheep numbers and distribution in the southwest. As a result, implementation of strategic, targeted mountain lion control has yielded increases in desert bighorn sheep populations in several jurisdictions. Contrast the current social pushback and criticism of agency lion-control programs against what 75 years ago was quite likely very limited public criticism, few if any legal challenges, and a near absence of anti-hunting rhetoric.

It is unlikely that the DBC founders and participants in the 1957 inaugural DBC conference could have ever imagined what modern-day solar-energy arrays, massive wind-energy developments, spider-webbed transmission lines and communication networks, foothill subdivisions, and extensive suburban sprawl would look like. Nonetheless, those early desert bighorn managers certainly mentioned human encroachment and disturbance as factors impacting desert bighorn sheep populations and their habitats.

Presenters at the 1957 DBC inaugural conference, including Warren Kelly and Dick Weaver, also identified the withdrawal of public lands and access restrictions to military lands as impediments to desert bighorn surveys, data collection, and active management. While collaboration between state and federal desert bighorn management agencies and various branches of our military have improved in some jurisdictions and in some locations, there continue to be differences of opinion regarding access to and management of desert bighorn sheep and their habitat, as evidenced by the Desert National Wildlife Refuge. Prior to passage of the Wilderness Act of 1964 (and its subsequent addenda), restrictions on active desert bighorn sheep management in what would become designated wilderness areas rarely appeared on any manager's radar. In recent decades, however, it is my opinion—and that of many others—that selective application by some individuals and agencies of what I'd label as "purist wilderness" values, mores, and restrictions has hindered and adversely influenced desert bighorn sheep management.

The oft-cited Winston Churchill quote, "Those who do not learn history are doomed to repeat it" is certainly applicable to modern-day desert bighorn sheep management. I urge DBC attendees and desert bighorn stakeholders to read not only recent literature, but to spend time reading (or re-reading) some of the classic, natural history-oriented accounts of early challenges to the management and conservation of desert bighorn sheep. In my opinion, there are many valuable and still-applicable take-home messages left to us by our predecessors. Here are a few thoughts I'd like to share and leave with today's attendees, and subsequent readers of the DBC Transactions, and that I refer to as "Some Humble Recommendations to Address Challenges and Opportunities for Desert Bighorn Sheep."

1. Recognize, give credit, and learn from the mistakes, successes, and efforts of the desert bighorn sheep managers and researchers that came before us. Read, critique, and benefit from their (hopefully) published work(s), and carry forward some of their many "common-sense", field-based strategies and tactics to restore and enhance desert bighorn sheep populations and their ever-dwindling habitats.

2. Continue and improve inter-personal and inter-agency communications by wildlife scientists and managers focused on desert bighorn sheep. In my opinion, the originators of the Desert Bighorn Council more than 70 years ago clearly saw the benefits of information- and data-sharing and, frankly, recognized then, and now, that disagreements, difference of opinions, spirited debate, and critical evaluation of then-perceived evidence-based outcomes would all shape, hone, influence, and motivate creative desert bighorn sheep problem-solving, leading to better management outcomes.

3. Continue and amplify the need for scientifically based management of feral horses and burros in desert bighorn sheep range. With worsening chronic and acute drought conditions, increasing

anthropomorphic pressures and human footprint on fragile desert bighorn ranges, and the need (and opportunity) to "control the controllables", the feral horse and burro issue has gone far off the rails, straying far from the biologically based population objectives (i.e., Appropriate Management Level [AML]) identified more than 55 years ago. Congress created the current feral horse and burro problem, and Congress needs to candidly and promptly address this issue. As many Nevadans are pushing, "Get Back to the Act" is a sincere and much-needed mantra and direction that responsible politicians, horse-lovers, and resource managers must pursue. Even if the 1971 AML could be attained, there would still be acute land, water, and vegetation resource issues and decisions that unfortunately have been neglected for the past 55 years.

4. Recognition must be given to the "double-edged sword" that desert bighorn sheep connectivity wields, namely caution and critical evaluation of the trade-offs between important genetic exchange versus heightened transmission and sharing of respiratory pathogens, often with naïve "recipient" desert bighorn herds.

5. Defend and grow the "Conservation Permit" strategy employed by most desert bighorn sheep state wildlife agencies and tribal bighorn managers, which has been soundly supported and advanced by non-governmental desert bighorn conservation stakeholders over the past several decades. Recognize the inarguable and limited revenue streams to support desert bighorn sheep conservation from hunting license sales. There will *never* be enough hunting licenses issued to meet the ever-increasing costs of desert sheep management on western public, tribal, and military lands but hunters, as they have for decades, will continue to underwrite desert bighorn conservation through their generosity beyond the purchase of a hunting license.

6. State desert bighorn management agencies should, and must, work with federal land-management agencies and both "wilderness-watchdogs" and "wilderness-advocates" to heighten and acknowledge the need for management intervention, water development, habitat enhancement, and the ability to access and proactively manage desert bighorn sheep—including trapping and translocation operations where necessary and appropriate. There is a pressing, tangible, and urgent need to revisit and update the 2006 *Policies and Guidelines for Fish and Wildlife Management in National Forest and Bureau of Land Management Wilderness*, to which many current desert bighorn sheep managers likely have limited access, or may not be unaware of.

7. Continue and expand strategic water development(s) in desert sheep range, acknowledging the accrued benefits to other desert-dwelling wildlife (both vertebrate and invertebrate). As more and more agencies rely on non-governmental organizations and their volunteer manpower to fund, build, maintain, and monitor well-designed guzzler and pipeline projects, expand the use of satellite technology to monitor water levels remotely to better inform water-hauling methodologies and frequencies, and minimize impacts of stochastic catastrophic events (e.g., mudslides, flash floods), to help avoid the drying up of important seasonal water sources.

8. As desert bighorn sheep populations and habitat qualities or quantities wax and wane, elevate collaboration between and among desert sheep managers on translocating surplus animals from over-crowded habitats to bolster struggling desert bighorn herds, but again, while keeping a keen eye on the

ramifications of physically moving desert bighorn and their pathogens.

9. Recognizing the opposing views of many, strategically enact large carnivore control efforts to benefit desert bighorn sheep, particularly in advance of desert bighorn translocations or population augmentation efforts. Also, please recognize that predator control will likely (and thankfully) never return to the wide-scale application of toxicants on the landscape. Prophylactic predator control to benefit desert bighorn sheep needs to be spatially-targeted, time-limited, and followed up with appropriate and rigorous evaluation of tangible benefits, economic costs, and biological realities.

10. Recognize and proactively implement programs and strategies to address and reduce the biological impacts of exotic ungulates (e.g., aoudad) on desert bighorn sheep habitat and populations. Realizing the complex land-ownership patterns and differential access for aoudad management in some jurisdictions (e.g., Texas), proactively develop and implement protocols to respond to dispersal and unplanned establishment of aoudad in arid, more public-land states (e.g., Nevada, Arizona) where desert bighorn habitat is already experiencing biotic and abiotic pressures.

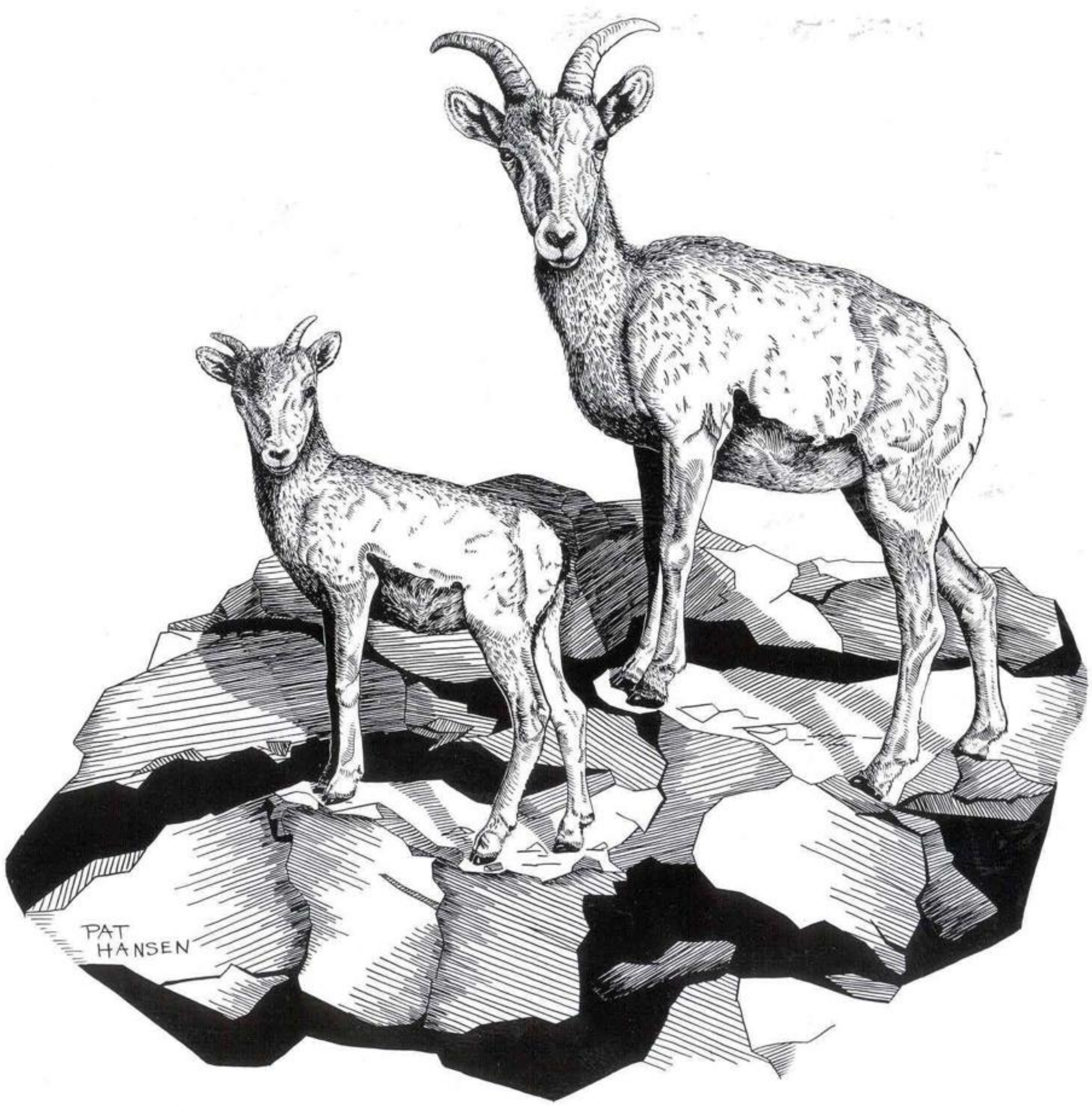
11. Ramp up federal land-management agency regulations and protocols to limit—or ideally, to decrease—the risk of contact between domestic sheep or domestic goats with desert bighorn sheep. Recognizing the political heat that temporal and spatial separation generates, continue to recognize and educate various publics regarding the importance of effective separation in aiding long-term desert bighorn sheep population persistence on western landscapes. Unintended consequences from accidental contact between pathogen-bearing domestic animals (e.g., pack goats) may still adversely affect desert bighorn herd health and viability.

In closing, I appreciate the opportunity to address the 2025 Desert Bighorn Council, to share some of my perspectives and observations gleaned over the past nearly 50 years of my professional career. My sincere thanks to not only the organizers of the Desert Bighorn Council more than 70 years ago, but to all of those who have kept the Desert Bighorn Council functioning and highly relevant for those 7 decades. Keep going!

I'll end with two of my favorite quotations of all time and in my opinion touch the center of this year's DBC meeting theme. As Jack Ward Thomas, the first wildlife biologist ever to sit as Chief of the U.S. Forest Service said in a message to The Wildlife Society, "…do not look around for someone else to lead…look at yourselves…for better or for worse, we're it…and it is our opportunity, and our obligation, to lead the way…". Whether you are ready or not, it is up to the folks in this room, and our desert bighorn colleagues that could not be present today, to embrace this challenge and continue to lead the way for desert bighorn sheep conservation.

And lastly, as famed anthropologist and naturalist Margaret Mead profoundly stated, "Never doubt that a small group of thoughtful committed citizens can change the world; indeed, it is the only thing that ever has." Thank you for what you have done, and will no doubt continue to do, to benefit desert bighorn sheep conservation in the West!

Technical Reports



Comparison of Two Sampling Protocols for *Mycoplasma ovipneumoniae* in Hunter-harvested Desert Bighorn Sheep

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Desert Bighorn Council Transactions 58:12–15

ABSTRACT In Arizona, bacterial pneumonia associated with *Mycoplasma ovipneumoniae* has caused population declines in desert bighorn sheep (*Ovis canadensis nelsoni, O. c. mexicana*), prompting routine disease surveillance during capture operations. Owing to the limited and irregular intervals of captures, the authors initiated the collection of nasal swabs from hunter-harvested rams at mandatory hunter check-ins by the Arizona Game and Fish Department starting in 2020 to enhance monitoring coverage and frequency. This study compared detection rates and agreement of *M. ovipneumoniae* between bilateral deep nasal swabs collected by the hunters at harvest and by biologists at check-in during the 2023 and 2024 hunting seasons. Paired hunter-biologist samples from 32 individual bighorn sheep were analyzed in 2023, and 68 were analyzed in 2024, revealing moderate agreement between methods, with hunter-collected samples showing slightly higher detection rates than those collected at check-in.

KEY WORDS Arizona, desert bighorn sheep, hunter, hunter-harvest, *Mycoplasma ovipneumoniae, Ovis canadensis*

Bighorn sheep (*Ovis canadensis*; BHS) are an iconic North American species that faced substantial population declines in the late 19th century. These declines have been attributed to unregulated hunting, livestock competition, and disease (Brewer et al. 2014). Since the 1960s, conservation efforts have primarily focused on translocating BHS from stable populations in efforts to augment or re-establish herds in historical habitat (Krausman and Bleich 2013, Whiting et al. 2023). Arizona is home to the Rocky Mountain bighorn sheep (*O. c. canadensis*) and two subspecies of desert bighorn sheep: Nelson's (*O. c. nelsoni*) in the northern region and Mexican (*O. c. mexicana*) in the central and southern regions of the state. Through sustained efforts in translocation and population augmentation over several decades, Arizona has successfully increased bighorn populations to unprecedented levels across their native habitats, following near-extirpation events similar to those experienced in other western states during the early twentieth century. Since 1955, the Arizona Game and Fish

Department (AZGFD) has captured and released approximately 1,400 desert bighorn sheep. Although desert bighorn populations exhibit fluctuations, there has been an overall increase in numbers. The statewide population now exceeds 5,600, and with substantial growth observed in the Kofa Mountains, where the estimated population increased from 404 in 2012 to 941 in the 2021 based on aerial survey results.

Many threats persist, however, among which are drought, predation, habitat loss, and multibacterial respiratory disease (Brewer et al. 2014). *Mycoplasma ovipneumoniae* (Movi) has been identified as one of the principal pathogens causing pneumonia in BHS. *Mycoplasma ovipneumoniae* can lead to high mortality rates, create Movi carrier animals, and severely reduce lamb recruitment for multiple years, thereby posing risks for smaller BHS populations (Cassirer et al. 2018). In Arizona, desert bighorn sheep populations have been notably affected by Movi. For example, an all age mortality event occurred in the Black Mountains of northwestern Arizona in 2015, resulting in a 53% decline of individual BHS observed during surveys.

The AZGFD initiated active Movi surveillance during capture events in 2009. Mortalities of BHS also were investigated and tested for Movi. These surveillance efforts had several limitations. Capture events require substantial resources. Risks are involved when capturing and handling animals for both staff and BHS. The BHS populations also must meet specific criteria for them to be selected, such as geographic location, disease status, and population quality. These factors result in infrequent and irregular intervals of specific populations being selected, which leads to limited and biased surveillance.

During live captures, blood, bilateral deep nasal swabs, and oropharyngeal swabs were collected. The nasal and oropharyngeal swabs were immediately placed in cryovials containing tryptic soy broth (TSB) with 20% glycerol. Blood samples were refrigerated, and the swabs were either refrigerated or frozen prior to diagnostic testing at the Washington Animal Disease Diagnostic Laboratory. These samples were tested for Movi cELISA, Movi real-time polymerase chain reaction (PCR), and aerobic bacterial culture.

The authors planned to expand the surveillance methodology by including hunter-harvested animals. The goal was to incorporate populations that were not part of the Department captures and to increase the frequency of monitoring. In Arizona, a mandatory check-in at the AZGFD headquarters or at a regional office is required following the successful harvest of any BHS. Hunters are required to bring the head, including the horns of the harvested animal, to the check-in station. The purpose of the mandatory check-in is to gather hunting and biological data to aid future management, as well as placement of a metal pin to show that this animal was harvested legally. This process is completed by a Department staff member, often a biologist. Successful hunters have up to 3 days after the end of the hunt to complete the check-in process.

Beginning in 2020, the authors instituted nasal swab collections for Movi PCR by Department staff during the mandatory check-in. Post-mortem BHS could be maintained under highly variable ambient conditions and time frames by the time of sample collection. For example, we have received both refrigerated heads with soft tissues attached within 48 hours of harvest, and frozen heads with soft tissues completely removed more than two weeks after harvest. We were interested in evaluating whether the samples collected during mandatory check-in under various conditions would be comparable to freshly sampled nasal swabs at the time of harvest.

METHODS

For 2023 and 2024, hunters with BHS tags were mailed a sampling kit with instructions. The kit included a polyester swab, a cryovial containing tryptic soy broth (TSB) with 20% glycerol, and a small envelope for the cryovial. Hunters were instructed to use the swab to perform deep nasal swabs bilaterally of freshly harvested BHS. The swab was to be placed into the TSB vial immediately, and the vial kept on ice and then frozen as soon as possible. Hunters were asked to bring the vial containing the swab with them to the mandatory check-in.

During the check-in, Department staff took an additional swab using the same method; vials were labeled to indicate Department versus Hunter collection. The TSB vials were kept frozen until submitted to the Washington Animal Disease Diagnostic Laboratory (WADDL) for Movi polymerase chain reaction (PCR). At WADDL, 16S Movi PCR was performed on all samples submitted, and cycle threshold (CT) values ≤36 were considered detected. If Movi was detected, strain typing was subsequently performed.

We compared the results of Movi detection between department- and hunter-sample sources for the years 2023 and 2024. The relationships were calculated using Cohen's Kappa and interpreted according to Cruz and Koch (2004).

RESULTS

For 2023, there were a total of 152 BHS harvested. Total samples tested were 112, including 62 staff-collection samples and 50 hunter-collection samples. Within these, we tested 32 pairs (i.e., the same animal with both hunter and staff collections). Among the 32 pairs, 24 pairs were in agreement, with 4 positive from both methods of collection, and 20 negative from both collections. Five of the pairs were positive from staff collection but negative from hunter collection; 3 were positive from hunter collection, but negative from staff collection. The total number of Movi detections was 7 in hunter collections and 9 in staff collections within the paired samples. This resulted in a Kappa value of 0.337 (i.e., fair agreement; Cruz and Koch 2024).

For 2024, there was a total of 152 BHS harvested. Total samples tested were 158, including 81 staff samples and 77 hunter samples. A total of 68 pairs was tested. Among these, hunter detection was 13 and staff detection was 8. Sixty-one pairs were in agreement, with 7 positive from both hunter- and staff-collections, and 54 negative from both types of collection. One of the pairs was positive from the staff collection but negative from hunter collection; 6 were positive from hunter collection, but negative from department collection (Kappa=0.61), suggesting substantial agreement (Cruz and Koch 2004).

Combining paired samples from 2023 and 2024 yielded moderate agreement (Kappa=0.503) between the two methods. Hunter collections showed a higher detection rate at 20% compared to 17% of the staff samples, but a lower percentage of indeterminate samples (5%) compared to staff samples (7%). In addition to Movi detections, two new Movi strains, BHS-0024 and BHS-132, were identified among the hunter-collected samples.

DISCUSSION

Hunter participation was very good for this study, with approximately 63% of the hunters returning the swabs. For 2023, the envelopes were not pre-labeled in the kits. Therefore, we received some partially or incorrectly labeled envelopes and cryovials. In 2024, hunters were provided with pre-labeled kits with the hunter's name and hunt number, which improved the process when sorting samples and minimized the chance of labeling errors.

The results demonstrated that hunter- and staff-collected samples both could be useful for detecting Movi, with slightly superior results (i.e., higher detection rate, lower percentage of indeterminate samples) among hunter-collected samples. The authors successfully expanded our surveillance efforts for Movi by using the hunter-harvested BHS. These samples broadened the distribution of geographic locations and included populations of BHS not previously sampled, and we were able to include BHS from game management units with previously unknown status during both years. Increasing access to populations and geographic locations with lesser-known status aids in the (early) detection of Movi. Further, in addition to new populations and geographic locations, we detected two new strains of Movi through this method. This was a significant finding and could increase our understanding of local disease ecology and improve management actions.

Based on these results, we recommended the Arizona Game and Fish Department continues its effort in raising awareness of Movi among hunters by emphasizing the importance of Movi surveillance, and providing pre-labeled sampling kits to the hunters by mail or during workshops. Department staff will only collect swabs during check-ins if the hunters do not provide their swabs. We also recommend testing be performed on selected samples based on population history and geographic location, or if the hunters report evidence of respiratory distress or had observed interactions between BHS and domestic sheep or goats.

REFERENCES

Brewer C. E., V. C. Bleich, J. A. Foster, T. Hosch-Hebdon, D. E. McWhirter, E. M. Rominger, M. W. Wagner, and B. P. Wiedmann. 2014. Bighorn sheep: conservation challenges and management strategies for the 21st Century. Wild Sheep Working Group, Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming, USA.

Cassirer E. F., K. R. Manlove, E. S. Almberg, P. L. Kamath, M. Cox, P. Wolff, A. Roug, J. Shannon, R. Robinson, R. B. Harris, B. J. Gonzales, R. K. Plowright, P. J. Hudson, P. C. Cross, A. Dobson, and T. E. Besser. 2018. Pneumonia in bighorn sheep: risk and resilience. Journal of Wildlife Management 82:32–45.

Cruz, R. F., and S. B. Koch. 2004. Issues of validity and reliability in the use of movement observations and scales. Pages 45–68 *in* R. F. Cruz and C. F. Borrell, editors. Dance/movement therapists in action: a working guide to research options. Charles C. Thomas Publisher, Limited, Springfield, Illinois, USA.

Justice-Allen A. E., E. Butler, J. Pebworth, A. Munig, P. Wolff, and T. E. Besser. 2016. Investigation of pneumonia mortalities in a *Mycoplasma*-positive desert bighorn sheep population and detection of a different strain of *Mycoplasma ovipneumoniae*. Northern Wild Sheep Goat Council Proceedings 20:9–13.

Krausman, P. R., and V. C. Bleich. 2013. Conservation and management of ungulates in North America. International Journal of Environmental Studies 70:372–382.

Whiting, J. C., V. C. Bleich, R. T. Bowyer, and C. W. Epps. 2023. Restoration of bighorn sheep: history, successes, and remaining conservation issues. Frontiers in Ecology and Evolution 11:1083350.

Parturient Bighorn Sheep: Variability in Selection of Resources Among Source and Translocated Populations

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Desert Bighorn Council Transactions 58:16–39

ABSTRACT Animals translocated to new habitats often face substantial challenges in adjusting to their new environments. Adaptation to the physical characteristics and climatic conditions of their original habitat may not align with the demands of the new location, necessitating varying degrees of ecological and physiological adjustment. Failure of translocated individuals to adapt to new areas can undermine the success of repopulation efforts leading to high mortality or failure to thrive, and raising ethical concerns among the public. In 2020, 30 bighorn sheep (25 females, 5 males) were successfully translocated to North Dakota. To investigate conditions of successful translocations, we quantified selection of resources relative to timing of parturition by adult female Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) in a source population in Montana (*n*=7), and animals from that population that were translocated to North Dakota (*n*=68) during 2020–2023. We hypothesized that selection of resources, in both areas, would be affected by topography and biomass of herbaceous vegetation. Further, because females adjust selection of resources relative to timing of parturition, we tested the hypotheses that in the last month prior to parturition, adult females, in both study areas, select for areas with high biomass of herbaceous vegetation. We also hypothesized that during the month following peak parturition females in both study areas would select areas that facilitate safety of young over nutritional needs of mothers. We used resource selection functions to investigate differences in selection of resources prior to and following parturition in each of the study areas, and compared those results between the source population in Montana and that in North Dakota from 2020 to 2023. In support of our hypothesis, adult females in Montana and in North Dakota selected for similar resources by using steep, rugged slopes with access to high biomass of herbaceous vegetation prior to parturition, but shifted away from those areas following parturition, when most females were provisioning dependent young. Our results are consistent with the prevailing notion that similarities between habitats at source locations and release sites may improve the success of bighorn sheep translocations.

KEYWORDS bighorn sheep, *Ovis canadensis*, resource selection, translocation, pre-parturition, post-parturition

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Bighorn sheep (*Ovis canadensis*) declined throughout western America, Canada, and Mexico during the era of European colonization because of introduced diseases, habitat loss or modification, and overharvest (Lula et al. 2020, Whiting et al. 2023). In efforts to restore the species to its historic range, wildlife agencies began translocating bighorn sheep from extant populations to areas where they had been extirpated in the early 20th century (Donovan et al. 2020). Unfortunately, many translocations resulted in low recruitment or limited range expansion, and some were unsuccessful (Whiting et al. 2023). Some investigators have implicated a failure to consider local adaptations to environmental conditions (e.g., ecotype) as a factor limiting success of translocations, but research examining region-specific environmental factors has been limited (Wiedmann and Sargeant 2014, Bleich et al. 2018).

Historical records of translocations of bighorn sheep suggest limited methodological continuity among states (Jahner et al. 2019, Barbosa et al. 2021, Whiting et al. 2023). Early efforts were hindered by a multitude of factors including, locations of domestic sheep herds, landownership, and uncertainties regarding the taxonomic classification of bighorn sheep (Ramey 1993, Brewer et al. 2014, Bleich et al. 2018). The desire to preserve genetic lines was sometimes outweighed by the convenience of using readily available stock (Whiting et al. 2023). Consequently, some translocations were of the suitable putative subspecies and others were not. The result was the incongruous distribution of subspecies to habitats that were more suitable for another subspecies. The translocation of desert bighorn sheep (*O. c. nelsoni*) from the River Mountains in southern Nevada to the Stillwater Range in northern Nevada, where the habitat may have been more suitable for Rocky Mountain bighorn sheep (*O. c. canadensis*) (Berger 1990, Wiedmann and Sargeant 2014, Jahner et al. 2019) is such an example. Similarly, California bighorn sheep (formerly *O. c. californiana*) were translocated throughout the western United States from low-elevation areas to some high-elevation mountain ranges, or to badland habitats (Wiedmann and Sargeant 2014, Jahner et al. 2019, Barbosa et al. 2021). Many conservation practitioners have since transitioned to a translocation model that prioritizes the matching of ecotypes with appropriate habitats (Bleich et al. 2018). In the context of bighorn sheep, an ecotype is a subpopulation of animals that have expressed behavioral or phenotypic adaptations to specific environmental conditions (Turesson 1922, Wiedmann and Sargeant 2014).

Timing of parturition is influenced by local phenological patterns and forage quality (Rubin et al. 2000). An existing challenge, when translocating bighorn sheep, is a mismatch in the timing of seasonal forage production in their new environment and parturition, which may have deleterious effects on lamb survival, body condition, and adult fitness (Whiting et al. 2011). Recently translocated females may experience reduced fitness resulting from asynchronous timing of parturition with plant productivity and forage quality as the population adapts (or fails to adapt) to its new environment (Whiting et al. 2011). Nonetheless, bighorn sheep in translocated populations have been shown to shift both timing and synchrony of parturition to align with environmental conditions at release sites (Whiting et al. 2011). Bighorn sheep that are naïve to new areas, may be more vulnerable to predation as well as malnutrition until they are familiar with locations of forage and escape terrain from predators (Conner et al. 2018, Whiting et al. 2023). Such a scenario may have occurred following the early translocations of the California bighorn sheep ecotype from British Columbia, Canada, to western North

Dakota, where the population struggled to adapt to the environmental characteristics of the Little Missouri River watershed (Wiedmann et al. 2024).

Although little information exists on factors influencing translocation outcomes, habitat mismatch is likely an influential factor in the long-term success or failure of recently translocated populations. Further, a review of historical translocations suggests that environmental and ecotypic differences in translocation stock are rarely considered by agencies when translocating bighorn sheep (Whiting et al. 2023). The success of the reintroductions in North Dakota and mixed results of translocations in Nevada add to a growing body of evidence that translocated individuals may better adapt to their environment if they come from source populations inhabiting conditions that closely resemble the target environment (Bleich et al. 2018, Whiting et al. 2023, Lutz and Bleich 2026).

Few studies have simultaneously compared habitat selection of source and release populations, however; the recent translocations of bighorn sheep from Montana to North Dakota provided a unique opportunity to explore this relationship. Therefore, we compared selection of resources by bighorn sheep at Rocky Boys Reservation in Montana (source population) with that by bighorn sheep translocated to North Dakota. We hypothesized that adult females in Montana and North Dakota would exhibit similar shifts in selection of resources prior to and following parturition and that selection would be affected by topography and biomass of herbaceous vegetation. Therefore, we hypothesized that prior to parturition adult females would select for high biomass of vegetation to provide nutritional support for mothers. We predicted that females prior to parturition would select areas with greater herbaceous biomass, but potentially greater predation risk. Following parturition, we hypothesized that adult females would shift selection of resources to areas associated with increased safety for dependent young. We predicted that following parturition adult females would select areas with rugged terrain and steep slopes that facilitate survival of young over nutritional needs of mothers.

STUDY AREAS

In 2006, biologists from the North Dakota Game and Fish Department (NDGF) began augmenting the struggling populations of California bighorn sheep in the Little Missouri National Grassland with the Rocky Mountain ecotype obtained from the Missouri River Breaks in north-central Montana (Bleich et al. 2018). The Rocky Mountain ecotype is thought to be well-adapted to western North Dakota because it occupies an environment with topography, climate, and vegetation and at similar latitude to western North Dakota. The addition of 39 (8 Male, 31 female) individuals from the Missouri River Breaks, Montana, led to increased recruitment and population abundance throughout much of the Little Missouri National Grassland (Wiedmann and Sargent 2014, Bleich et al. 2018). In 2020, the Three Affiliated Tribes Fish and Wildlife Division collaborated with NDGF to translocate and reintroduce 30 (25 female, 5 male) Rocky Mountain bighorn sheep from Rocky Boy's Reservation in Montana to Fort Berthold Reservation in western North Dakota. Those reintroduced bighorn sheep have demonstrated strong population growth following translocation (Wiedmann et al. 2024).

Our study areas included Rocky Boy's Reservation in northern Montana (444 km^2), the Little Missouri National Grassland (4,160 km^2), and Fort Berthold Reservation (3,990 km^2) in western North Dakota, and surrounding public and private lands (Figure

1). Little Missouri National Grasslands and Fort Berthold Reservation both are in the watershed of the Little Missouri River (Figure 1). Bighorn sheep in North Dakota primarily occupied steep, rugged terrain proximate to the Little Missouri River, which spans lands managed by the Bureau of Land Management (BLM, 5%), United States Forest Service (USFS, 50%), National Park Service (NPS, 10%), Three Affiliated Tribes (5%), state land (5%), and private land (25%) (Wiedmann and Sargeant 2014, Wiedmann et al. 2024).

Bighorn sheep within the Montana study area occupied the mountainous terrain of the western Bears Paw Mountains, with grassland prairies at 800 m rising to the peak of Baldy Mountain at 2,108 m (Figure 1). The climate is similar to central Montana, with long, semi-arid and snowy winters extending from November through April. Summers are punctuated by occasional summer rainstorms, ranging from 27.5 to 51.2 cm annually. Autumn rains transition to snow in November, which ranges from 55 to 254 cm annually (climateengine.org). High elevation grasslands dotted with patches of green ash (*Fraxinus pennsylvanica*) and sagebrush (*Artemisia spp.*) occur near 1,000 m, and slope steeply down to narrow riparian floodplains with intermittent stands of aspen (*Populus tremuloides*). Riparian corridors with minimal slopes also contain patches of Rocky Mountain juniper (*Juniperus scopulorum*), silver buffaloberry (*Shepherdia argentea*), and snowberry (*Symphoricarpos occidentalis*). Except for narrow riparian valleys, steep slopes are sparsely vegetated. Shadscale (*Atriplex confertifolia*), rubber rabbitbrush (*Ericameria nauseosa*), and little bluestem (*Schizachyrium scoparium*) occupy patches of silt and bentonite clay between rocks, boulders, and erodible soils (Feist 1997, Jensen 1988).

In North Dakota, topography within the Little Missouri River watershed, which includes both Fort Berthold Reservation and Little Missouri National Grasslands, consists largely of riparian flatlands sloping steeply up to prairie grassland mesas at elevations of about 1,000 m. Long, cold winters (November – January) with temperatures in January ranging from -8 to -15° C during the years 2020–2024 (climateengine.org). Short, semi-arid summers (June – August) with mean temperatures ranging from 19° to 23° C in July, during the years of our study (2020–2024; climateengine.org). During winter, most precipitation fell as snow, ranging from 130 to 416 cm annually during the years of our study; Desert Research Institute and University of Idaho 2024). Precipitation during the warm season (May – October) as rain is bimodal, occurring during May and June, and again in September and October, ranging from 28.6 to 48.3 cm annually (climateengine.org).

Vegetation composition of both study areas is similar and is typical of the northern Great Plains. The growing season for annual forbs and grasses begins after snowmelt in March and April, followed by perennial forbs and grasses in April and May (Montana Natural Heritage Program 2017, Jensen 2020). Prairie grasslands contain a mix of annual and perennial grasses, sedges (*Carex spp.*), and forbs such as western wheatgrass (*Agropyron smithii*), needle and thread (*Stipa comata*), and prairie coneflower (*Echinacea angustifolia*). Vegetation on steep (15–40%), north-facing slopes consists largely of little bluestem, prairie sandreed (*Calamovilfa longifolia*), and Rocky Mountain juniper. South-facing slopes often support sagebrush, shadscale, and rubber rabbitbrush. Sandy, riparian floodplains contain green ash, Rocky Mountain juniper, and silver buffaloberry (Montana Natural Heritage Program 2017, Jensen 2020).

Both study areas are host to a suite of predators that were capable of killing bighorn sheep, including mountain lions (*Puma* *concolor*), coyotes (*Canis latrans*), bobcats (*Lynx rufus*), and golden eagles (*Aquila chrysaetos*) (Jensen 2020, Bleich et al. 2018, Wakeling et al. 2026). No effort was made to manipulate predator populations during this study.

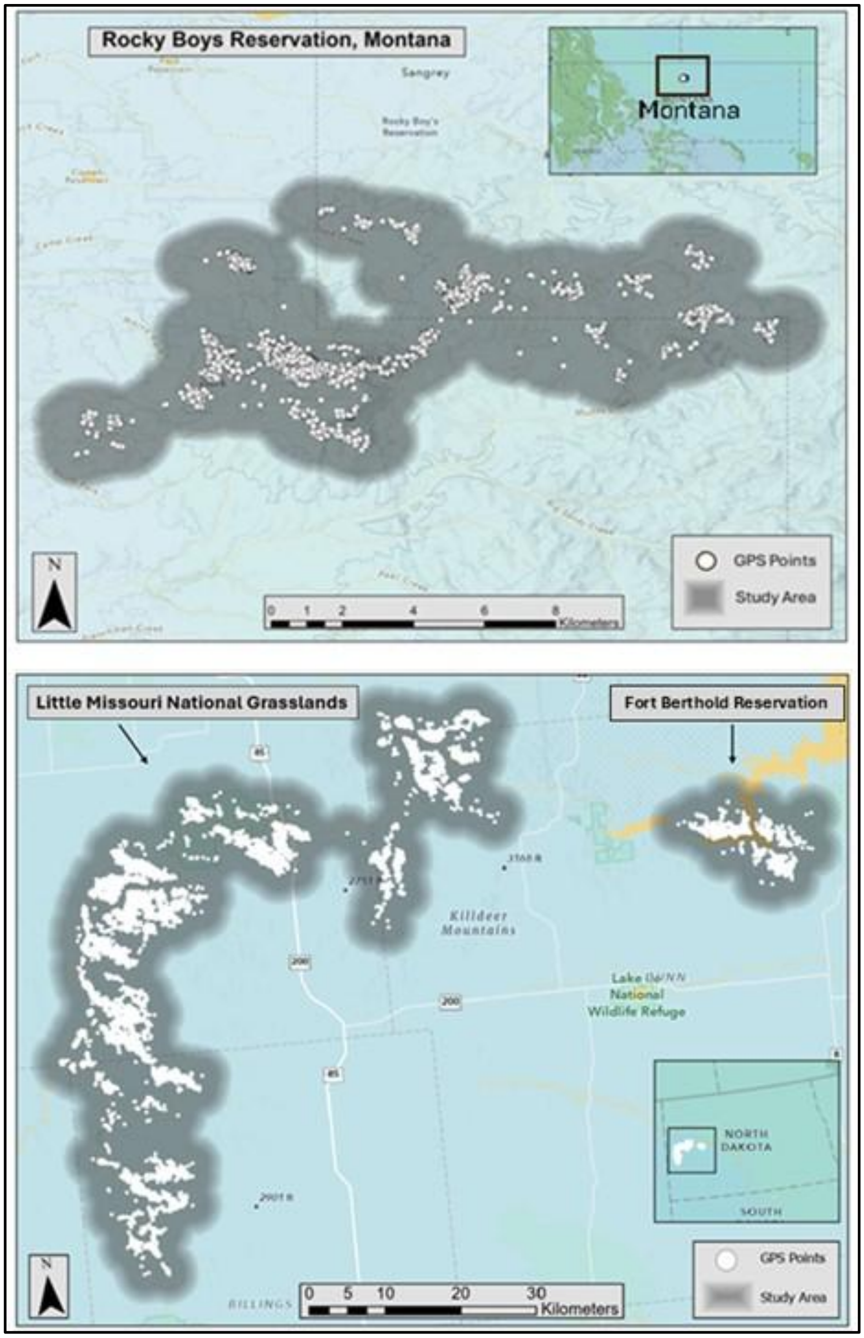

FIGURE 1. Rocky Boy's Reservation, Montana, (source population), Little Missouri National Grasslands, and Fort Berthold Reservation, North Dakota, USA (translocated population), where we evaluated selection of resources by adult female Rocky Mountain bighorn sheep (*O. c. canadensis)* 2020–2023. The study area boundary was delineated using a 99% kernel density estimate with a 1-km buffer generated from GPS locations of 7 adult bighorn sheep in Montana and 68 adult bighorn sheep in North Dakota.

METHODS

Study Populations

For this study, we used data provided to us from NDGF, which were generated from adult female bighorn sheep in the translocated population in North Dakota from Fort Berthold Reservation (*n*=25) and from Little Missouri National Grasslands (*n*=43), and adult females (n=7) from the source population in Montana (Figure 1). We only used data from adult females in our analyses. Iridium GPS collars (Telonics Inc., Mesa, Arizona, USA) at both study areas were applied to adult females, and were programmed to record a single daily location at 0600 Mountain Standard Time. We removed locations with a Horizontal Dilution of Precision (HDOP) > 9.9 to reduce location error (D'eon and Delparte 2005). Twenty-eight collars did not generate an HDOP or other horizontal error measurement and we were unable to determine positional error for these collars. We then visually examined locations in ArcGIS Pro (ArcGIS 10.8, Environmental Systems Research Institute [ESRI], Redlands, California, USA) and eliminated obvious spatial outliers and points generated while personnel were handling collars.

To account for the known trade-off between nutritional needs of adult females and safety of dependent young following parturition (Blum et al. 2023), and to better understand how bighorn sheep respond to changes in vegetation biomass throughout the growing season, we focused on the spring growing season (early March–mid-June). Pregnancy of adult females and recruitment of young by individuals were not recorded in this population, but prior to parturition adult females exhibit relative risk-prone behavior using habitats that may be in greater risk of predation (Blum et al. 2023). Following parturition, females with dependent young may shift to a more risk-averse strategy that favors safety of young over nutritional requirements of the mother (Blum et al. 2023). In North Dakota, neonates have been observed from about 8 April (ordinal day 98) to mid-September, but peak birthing occurs during May (Wiedmann et al. 2024). Therefore, we selected the average peak-parturition time (early May; ordinal day 128) for bighorn sheep in North Dakota as described by Wiedmann et al. (2024). Using this date as our signpost, we chose a time period representing females in the final trimester of pregnancy and prior to when parturition would occur (ordinal days 65–96) (Figure 2). That time period reflected our best estimate of when pregnant females were still engaging in "risk-prone" behavior and most females were likely pregnant; we refer to this interval as the pre-parturition period (Figure 2). Additionally, we chose a time interval following the peak of parturition to represent a time period when most females would be provisioning dependent young (ordinal days 129–160); we refer to this interval as post-parturition. Those dates were used in developing models for North Dakota and Montana (Figure 2). Our analyses were conservative because there was the potential that not all females provisioned young throughout the post-parturition period. If females were not pregnant, gave birth to stillborn young, or if mortality of young occurred, how they selected resources during the interval following the peak of parturition may have reflected acquisition of resources for the individual rather than to protect vulnerable young; this likely would result in greater variation among individuals during that time period.

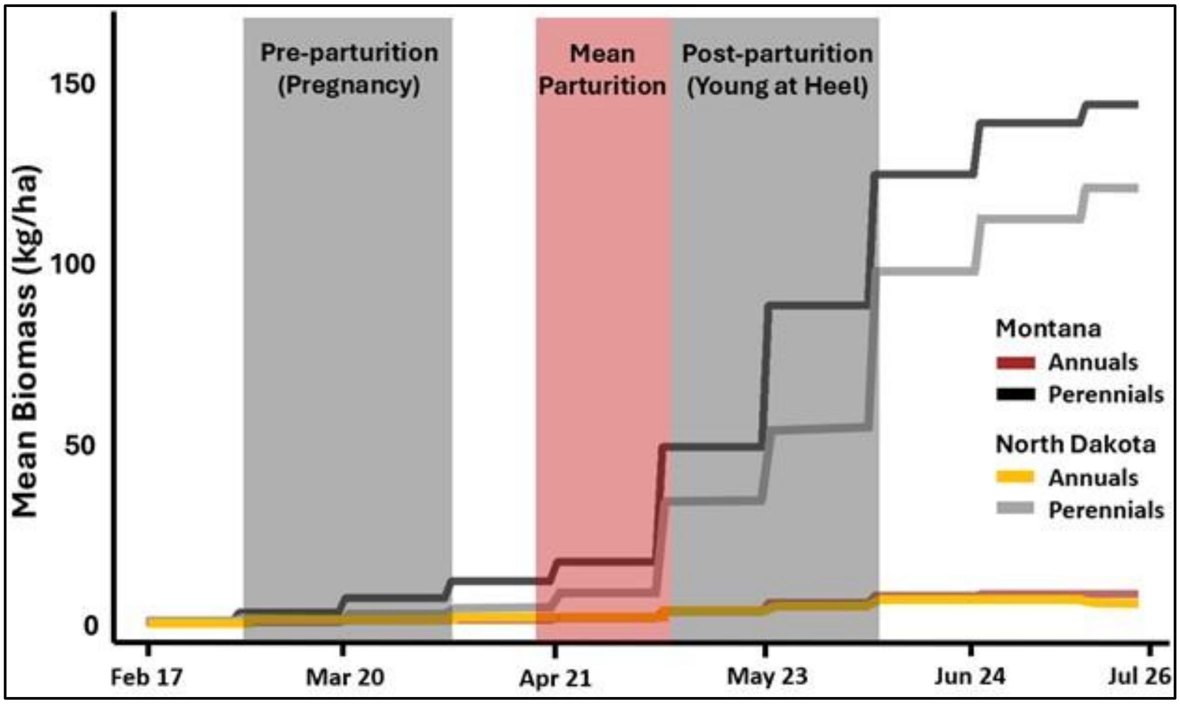

FIGURE 2. Biomass of herbaceous vegetation (kg/ha) relative to date and timing of our analyses for female Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) in western North Dakota and central Montana, USA, 2020–2023. Time periods for modeling selection of resources were pre-parturition season (ordinal days 65–96) and post-parturition season (ordinal days 129–160), denoted with gray shading. Note that the pink shading denotes the estimated timing of mean annual parturition timing as determined by Wiedmann et al. (2024). Biomass of perennial forbs and grasses in Montana are represented by the black line and annual forbs and grasses by the red line. Biomass of perennial forbs and grasses in North Dakota are represented by the yellow line and annual forbs and grasses by the gray line.

Selection of Resources

All of the radio locations were generated from collars that only collected a single location per day at 0600 MST; therefore, our results reflect selection of resources during early morning. We used resource selection functions (RSF) in a used versus available framework at the third order scale of selection (Johnson 1980, Manly et al. 2002). To characterize availability of resources, we generated utilization distributions (UDs) for each individual using a 99% kernel density estimate (KDE) based on locations collected during the spring, using R Statistical Software (Signer et al. 2019, R Core Team 2026, Wickham et al. 2023). We used random locations within the utilization distribution of each individual to quantify available resources (Fieberg et al. 2021). We identified the appropriate ratio of used-to-available locations by generating one available point per used point and increasing the ratio until model coefficients stabilized (Northrup et al. 2013, Osterhout et al. 2024). Further, we generated available locations within each utilization distribution at a 1:20 ratio for North Dakota and a 1:100 ratio for Montana to characterize availability of resources (Signer et al. 2019).

We extracted slope (º), elevation (m), and aspect (º) from a 30-m resolution digital elevation model (DEM) and transformed aspect to Cartesian coordinates (0–2 radians) using sine (east-west) and cosine (north-south) (Table 1; Stewart et al. 2002, Zar 2010, U.S. Geological Survey 2024). We computed a localized version of the vector ruggedness measure (VRM) to represent an index of ruggedness of terrain with the Topography Toolbox for ArcPro using a 3x3 neighborhood (Dilts et al. 2023, Dilts 2025; Blum et al. 2023; ESRI, Redlands, California, USA). The localized version of the vector ruggedness measure removes confounding influences of folded topography, ridgelines and drainages, which tend to inflate values in the original VRM (Dilts et al. 2023). We initially included elevation in our analysis, but later excluded it after we determined that ruggedness, slope, and aspect were likely to represent direct factors influencing selection of resources whereas elevation is more of a proxy for a collection of site-specific factors that influence selection of resources. We downloaded vegetation layers at 30-m resolution from the Rangeland Analysis Platform (RAP; U.S. Department of Agriculture 2024), which included aboveground biomass productivity over 2, 16-day periods for perennial forbs and grasses and annual forbs and grasses. We created a time-varying covariate that corresponded with the 16-day mean biomass estimates for annual and perennial forbs and grasses at each location obtained from the RAP (Allred et al. 2021, U.S. Department of Agriculture 2024). We extracted the values of each raster layer at each GPS location (used and available) for the applicable time-varying covariate. Additionally, we included annual time-varying estimates of cover for shrubs and trees (Allred et al. 2021, U.S. Department of Agriculture 2024]). All vegetation and topography layers were projected to NAD 83 Zone 13N and aligned using the Align Rasters Toolbox for ArcGIS Pro (ArcGIS 10.8, Environmental Systems Research Institute, Redlands, California, USA; Dilts 2023). Prior to analyses, we standardized all continuous variables to represent standard deviations from the mean (Zar 2010). We computed pairwise Pearson correlation coefficients for all covariates (Zar 2010), and none exceeded our predetermined correlation threshold (0.7; Arnold 2010). In addition, our variance inflation factor (VIF) analysis indicated no issues with multicollinearity (all VIF values <2), and we retained all covariates for analysis (Arnold 2010, Zar 2010).

TABLE 1. Descriptions of covariates used in modeling selection of resources for female Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) in north-central Montana (MT) and western North Dakota (ND), USA, 2020–2023.

Model	Predictor	Units	Description
MT, ND	Slope	Degrees	Slope steepness, generated from 30-m digital elevation model (DEM)
MT, ND	Ruggedness	NA	Vector Ruggedness Metric (VRML), unitless measure of terrain
MT, ND	North-South aspect	Radians	Measure of aspect with cosine transformation, generated from 30-m DEM
MT, ND	East-West aspect	Radians	Measure of aspect with sine transformation, generated from 30-m DEM
MT, ND	Perennial forbs and grasses (PFG)	kg/ha	Mean biomass of 30 m cell, from 2, 16-day biomass productivity estimates obtained from Rangeland Analysis Platform
MT, ND	Annual forbs and grasses (AFG)	kg/ha	Mean biomass of 30 m cell, from 2, 16-day biomass productivity estimates obtained from Rangeland Analysis Platform
MT, ND	Tree cover	%	Mean percent cover of 30-m cell, obtaine from Rangeland Analysis Platform

We used generalized linear mixed-effects models (GLMM) to assess habitat use intensity as a function of covariates. Following standard resource selection function (RSF) modeling procedures, we used a binomial error distribution with a logit-link function (Gillies et al. 2006; Bolker et al. 2009; Long et al. 2014; Harrison et al. 2018). We included random intercept and slope terms to allow resource selection patterns to differ among individual females in our study (Gillies et al. 2006, Muff et al. 2020). We used interaction terms to accommodate differences in resource use between the pre-parturition and post-parturition periods (i.e., the 32-day periods prior to and immediately following the peak parturition period).

All statistical analyses and visualizations were performed in the R environment for statistical computing (R Core Team 2026). We fit RSFs using the package "glmmTMB" (Brooks et al. 2017). We used Akaike's Information Criterion for small sample sizes (AICc; Burnham and Anderson 2002) to select top candidate models. We assessed model goodness of fit using the Dharma package in Program R to test for outliers, overdispersion, and uniformity of simulated quantile residuals (Hartig 2022). We visualized the effect of each covariate on log relative selection strength (log-RSS), holding all other covariates at their mean values and using the mean available habitat characteristics as a benchmark for comparison (Avgar et al. 2017). We also used our fitted RSF models to generate predictive maps representing log relative selection strength (log-RSS) relative to mean available habitat conditions for each study area (Avgar et al. 2017).

RESULTS

Between January 2020 and December 2023, we used 1,890 GPS locations, generated from 7 female bighorn sheep (387 ± 110 [mean ± SD] locations per individual) in the source population on Rocky Boy's Reservation in Montana (Table 2). Initially we separated the populations at Fort Berthold Reservation (n=25 collars) and Little Missouri Grasslands (n=43 collars), but after thorough investigation, we concluded that covariate values between Fort Berthold Reservation and Little Missouri National Grassland were similar, and we combined the datasets in our final model for North Dakota. Therefore, we used 10,979 GPS locations from North Dakota, generated from 68 female bighorn sheep (237 ± 101 [mean ± SD] locations per individual) (Table 2).

When examining our final RSF models for both Montana and North Dakota, no other model was within 2 ΔAIC of the top model, so in both cases we chose the top model (Table 3). Our most supported models for both study areas included: tree cover (%), biomass of annual and perennial forbs and grasses (kg/ha), ruggedness, North-South and East-West aspects (rad), and slope (º) (Table 3). During the period prior to parturition, bighorn sheep in Montana selected for moderately rugged terrain and steep, west-facing slopes (Table 4, Figure 3). We observed strong population-level selection for annual forbs and grasses, strong avoidance of tree cover, and moderate avoidance of perennial forbs and grasses during the period prior to parturition (Table 4, Figure 3). During the post-parturition period, females reduced selection of perennial forbs and grasses, but showed little variation in selection of annual forbs and grasses (Figure 3). Females selected for more rugged terrain during the post-parturition period, compared with the period prior to parturition (Table 4, Figure 3). We observed minor shifts in selection for west-facing aspect and slopes between 25% and 31% between time periods (Figure 3). During both time periods, we observed variation among individuals in how they selected resources, especially for aspect and tree cover (Figure 3, Figure 4).

TABLE 2. Descriptive statistics for continuous variables of all used (*n*=10,979 [ND]; *n*=1,890 [MT]) and available locations (*n*=219,580 [ND]; *n*=189,000 [MT]) for adult female Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) in western North Dakota (n=68) and north-central Montana (n=7), USA, 2020–2023.

Model[1]	AICc	δAICc	ω_i
North Dakota			
{AFG, PFG, North-South Aspect, East-West Aspect, Slope, Ruggedness, Tree}	2312.698	0	0.857
{AFG, PFG, North-South Aspect, Slope, Ruggedness, Tree, Shrub}	2316.282	3.584322	0.143
{AFG, PFG, Slope, Ruggedness, Tree}	2330.236	17.53772	0.000
{AFG, PFG, Slope, Ruggedness, Tree, Shrub}	2331.806	19.10806	0.000
{AFG, PFG, North-South Aspect, East-West Aspect, Slope, Ruggedness, Tree, Shrub}	2332.531	19.83293	0.000
{AFG, North-South Aspect, Slope, Ruggedness, Tree}	2341.024	28.32597	0.000
Montana			
{AFG, PFG, North-South Aspect, East-West Aspect, Slope, Ruggedness, Tree}	14291.74	0	1
{AFG, PFG, North-South Aspect, Slope, Ruggedness, Tree, Shrub}	14659.18	367.4471	0.000
{AFG, PFG, Slope, Ruggedness, Tree, Shrub}	14670.04	378.3054	0.000
{AFG, PFG, Slope, Ruggedness, Tree}	14694.99	403.2547	0.000
{AFG, North-South Aspect, Slope, Ruggedness, Tree}	14815.96	524.2248	0.000
{AFG, PFG, North-South Aspect, East-West Aspect, Slope, Ruggedness, Tree, Shrub}	15697.18	1405.439	0.000

[1]All covariates included interaction terms to represent parturition period.

TABLE 3. Ranked models for resource selection functions for 7 adult female bighorn sheep in north-central Montana, USA, and 68 adult female Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) in western North Dakota, USA, 2020–2023. All models were fit with random intercepts and slopes to accommodate among-individual variation. All covariates were fitted separately for the pre- and post-parturition periods via interaction terms.

Model[1]	AICc	δAICc	ω_i
North Dakota			
{AFG, PFG, North-South Aspect, East-West Aspect, Slope, Ruggedness, Tree}	2312.698	0	0.857
{AFG, PFG, North-South Aspect, Slope, Ruggedness, Tree, Shrub}	2316.282	3.584322	0.143
{AFG, PFG, Slope, Ruggedness, Tree}	2330.236	17.53772	0.000
{AFG, PFG, Slope, Ruggedness, Tree, Shrub}	2331.806	19.10806	0.000
{AFG, PFG, North-South Aspect, East-West Aspect, Slope, Ruggedness, Tree, Shrub}	2332.531	19.83293	0.000
{AFG, North-South Aspect, Slope, Ruggedness, Tree}	2341.024	28.32597	0.000
Montana			
{AFG, PFG, North-South Aspect, East-West Aspect, Slope, Ruggedness, Tree}	14291.74	0	1
{AFG, PFG, North-South Aspect, Slope, Ruggedness, Tree, Shrub}	14659.18	367.4471	0.000
{AFG, PFG, Slope, Ruggedness, Tree, Shrub}	14670.04	378.3054	0.000
{AFG, PFG, Slope, Ruggedness, Tree}	14694.99	403.2547	0.000
{AFG, North-South Aspect, Slope, Ruggedness, Tree}	14815.96	524.2248	0.000
{AFG, PFG, North-South Aspect, East-West Aspect, Slope, Ruggedness, Tree, Shrub}	15697.18	1405.439	0.000

[1]All covariates included interaction terms to represent parturition period.

TABLE 4. Mean coefficient estimates (β), 95% confidence interval lower and upper limits for environmental and topographic variables used in modeling resource selection by adult female Rocky Mountain bighorn sheep (*O. c. canadensis*) in north-central Montana and western North Dakota, USA, 2020−2023. Covariates in which P<0.05 are denoted by an asterisk (*).

Variable	Pre-parturition		Post-parturition	
	β	CI	β	CI
North Dakota				
Annual forbs & grasses (kg/ha)	0.98*	0.668 – 1.290	- 0.13*	-0.194 – -0.058
Perennial forbs & grasses (kg/ha)	-0.05	-0.330 – 0.239	-0.76*	-0.842 – -0.676
North-South aspect (rad)	-0.35*	-0.437 – -0.268	-0.28*	-0.364 – -0.1933
East-West aspect (rad)	-0.21*	-0.265 – -0.157	-0.05	-0.108 – -0.004
Slope (°)	0.90*	0.837 – 0.957	0.84*	0.775 – 0.899
Ruggedness	0.51*	0.454 – 0.562	0.55*	0.496 – 0.606
Tree cover (%)	-2.58*	-2.823 – -2.331	-2.04*	-2.279 – -1.801
Montana				
Annual forbs & grasses (kg/ha)	1.53*	1.391 – 1.667	0.52*	0.471 – 0576
Perennial forbs & grasses (kg/ha)	-1.12*	-1.535 – -0.712	-0.74*	-1.99 – -1.37
North-South aspect (rad)	-0.11	-0.253 – - 0.037	-0.04	-0.119 – 0.193
East-West aspect (rad)	-0.72*	-0.845 – -0.585	-0.31*	-0.450 – -0.174
Slope (°)	1.04*	0.921 – 1.150	0.87*	0.742 – 0.989
Ruggedness	0.17*	0.210 – 0.557	0.41*	0.115 – 0.704
Tree cover (%)	-2.08*	-2.677 – -1476	-2.17*	-2.811 – -1.526

For the population in North Dakota, observed trends in selection for steep slopes and rugged terrain were relatively consistent between the pre- and post-parturition periods at the population level; we observed substantial variation, however, among individuals in use of rugged terrain during both time periods (Table 4, Figure 5). We observed selection for northwest-facing slopes during the period prior to parturition, which weakened during the post-parturition period, but we observed substantial variation among individuals in use of aspect during both periods (Table 4, Figure 5). During the period prior to parturition, we observed strong relative selection for areas with high biomass of annual forbs and grasses. Although most females avoided that vegetation type during the post-parturition period there was large variation among individuals ranging from strong selection to avoidance (Figure 5). Despite seasonal increases in biomass of perennial herbaceous plants, bighorn sheep showed little to no selection for perennials prior to parturition, although they exhibited strong avoidance of perennial forbs and grasses during the post-parturition season, which contrasts with their strong selection for annual herbaceous biomass prior to parturition (Figure 5). During the pre-parturition season, our predictive maps showed greater predicted use of landscapes farther away from riparian areas, but more predicted use of rugged terrain during the post-parturition season (Figures 6 and 7).

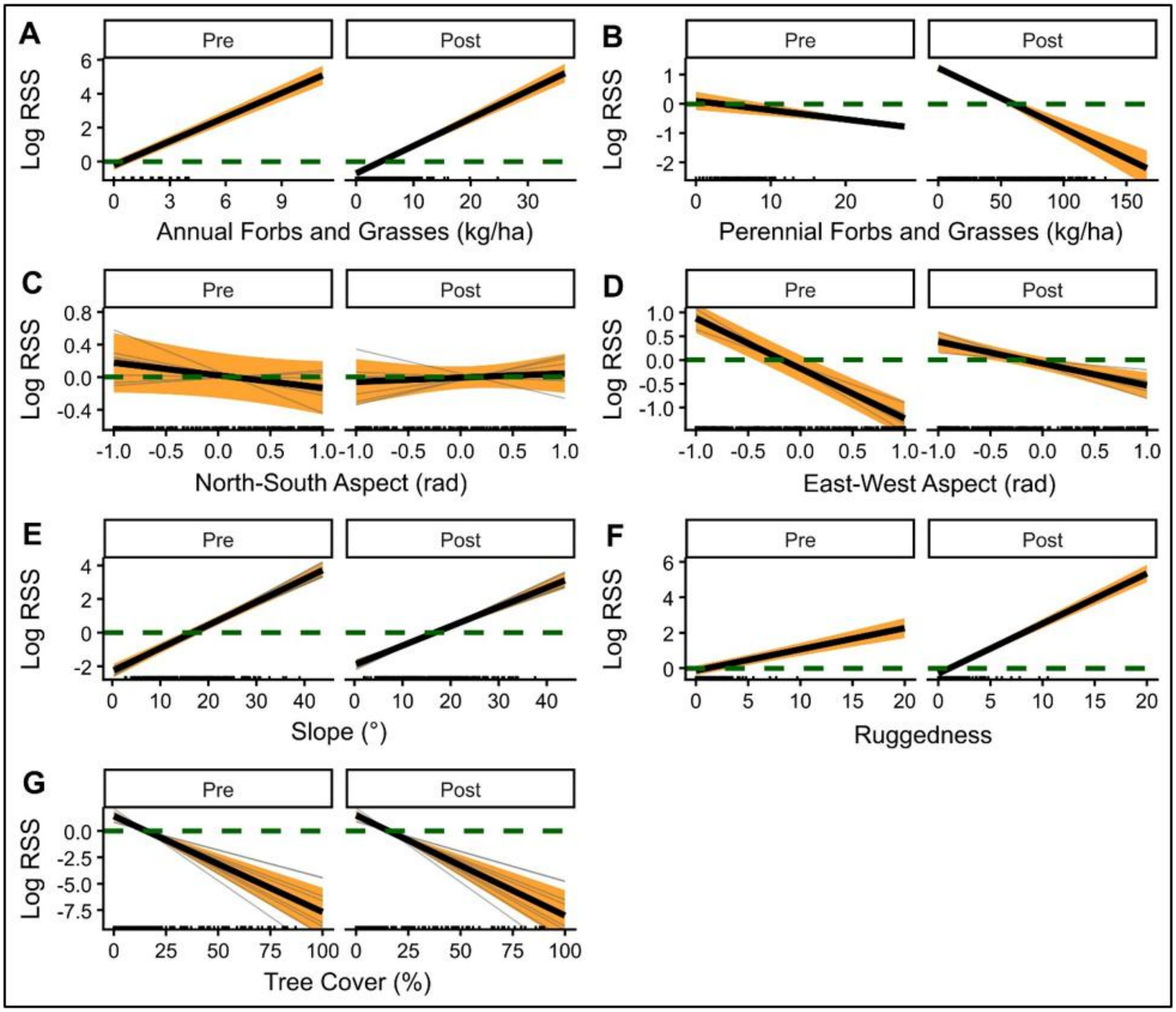

FIGURE 3. Partial-dependence plots representing relative strength of selection (log transformed) for environmental covariates from resource selection functions for female Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) in north-central Montana, USA, 2020–2023. The green dashed line indicates the 0 line of no selection or avoidance, where values above the line indicate selection and values below represent avoidance. Light gray lines represent individual-level responses; black lines represent population-level responses, and orange shading represented 95% confidence intervals. Note that the scale on X and Y axes varies among plots. The left column (A) represents the predicted intensity of selection of resources during pre-parturition, and the right column (B) represents the predicted intensity of selection of resources post-parturition.

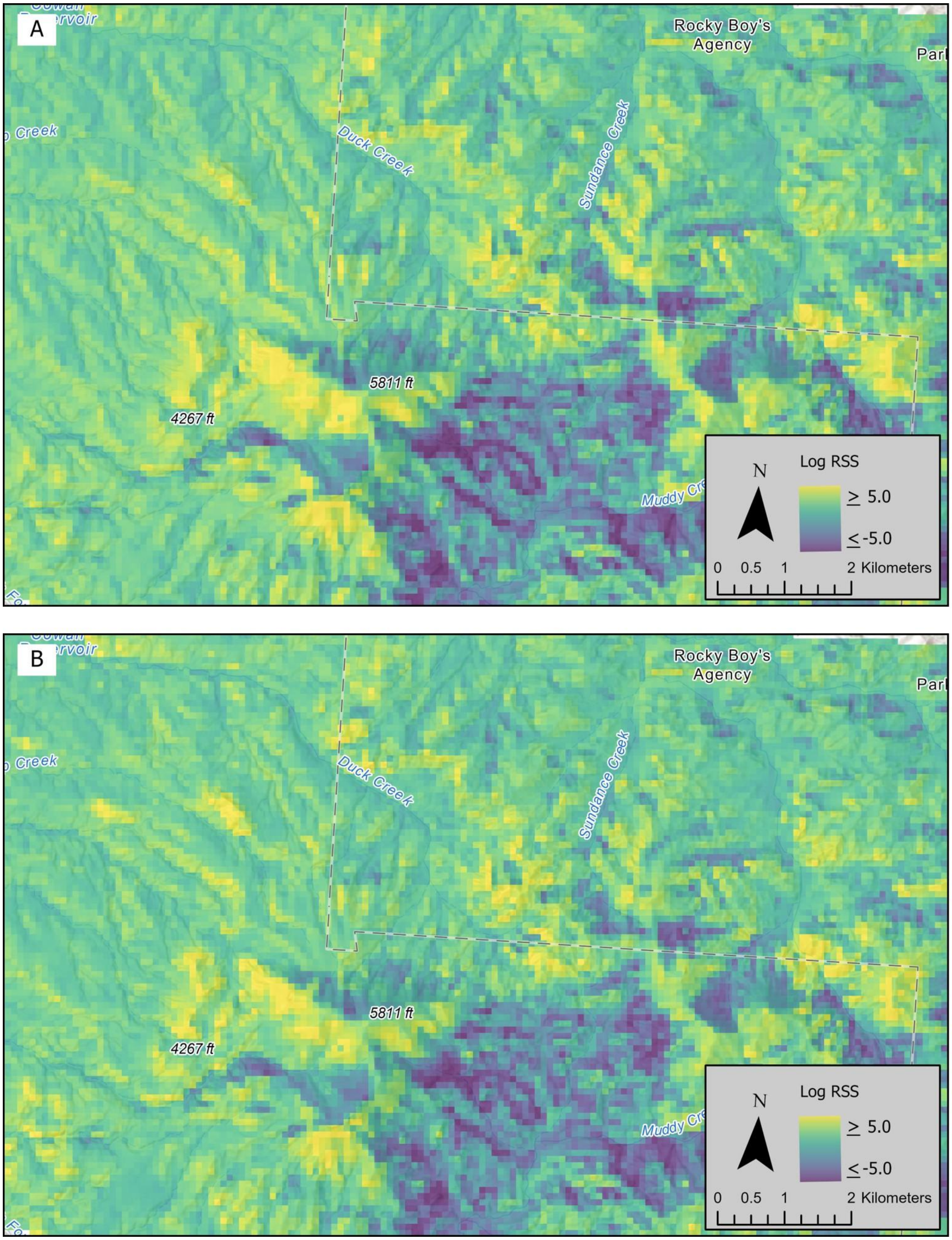

FIGURE 4. Prediction maps, log-transformed Relative Strength of Selection (logRSS), illustrating the spatially explicit habitat use intensities for female Rocky Mountain bighorn sheep (*Ovis c. canadensis*) in north-central Montana, USA, 2020–2023. Pre-parturition selection is shown in the top panel (A), and post-parturition shown in the bottom panel (B).

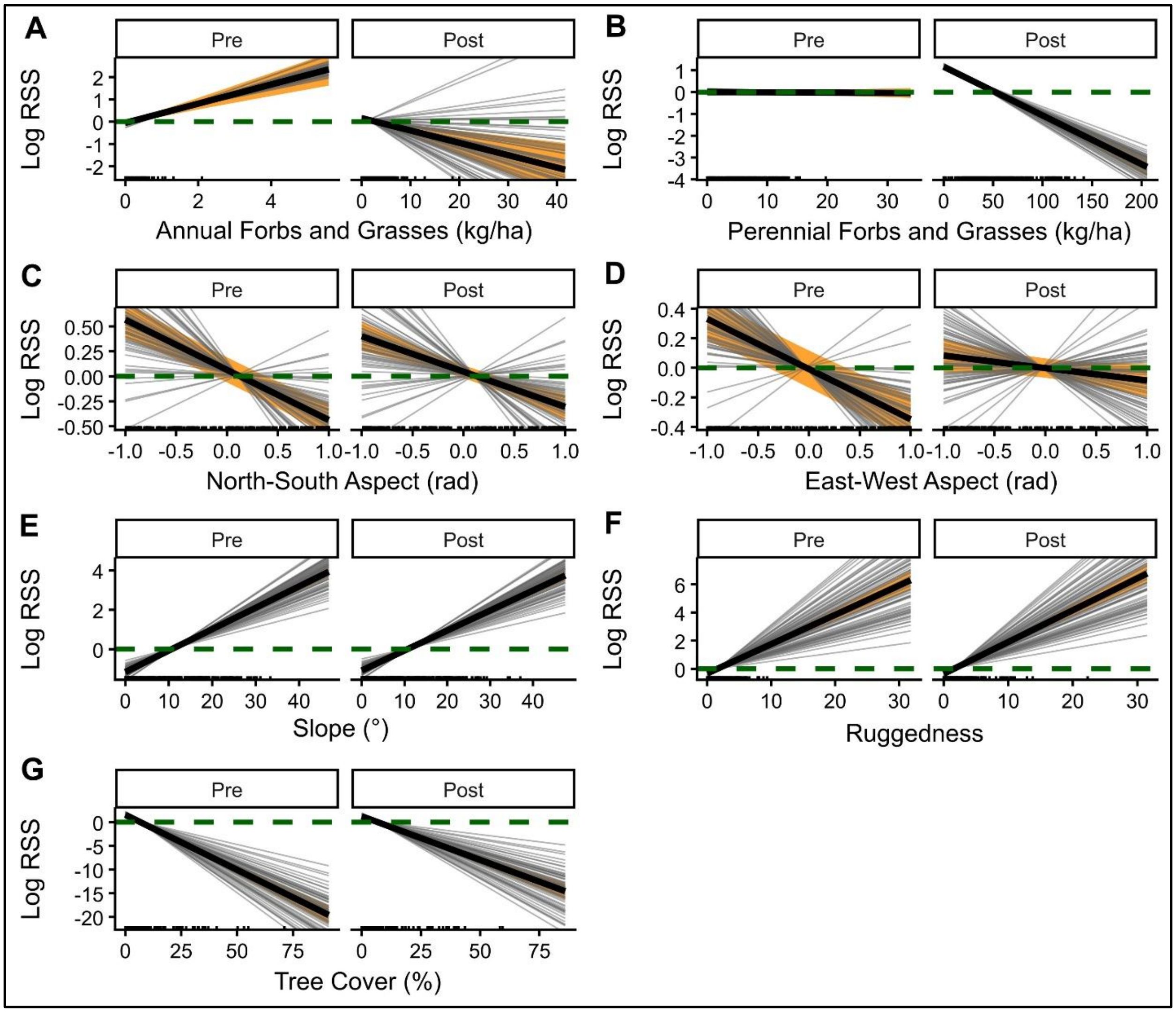

FIGURE 5. Univariate plots representing individual covariates from resource selection functions for female Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) in western North Dakota, USA, 2020–2023. The green dashed line indicates the 0 line of no selection or avoidance, where values above the line indicate selection and values below represent avoidance. Light gray lines represent individual-level responses; black lines represent population-level responses, and orange shading represent 95% confidence intervals. Note that the scale on X and Y axes varies among plots. The left column (A) represents the predicted intensity of selection of resources during pre-parturition, and the right column (B) represents the predicted intensity of selection of resources post-parturition.

DISCUSSION

Our primary objective was to identify how female bighorn sheep selected resources relative to timing of parturition at Rocky Boy's Reservation in Montana, and in a population translocated from Rocky Boy's Reservation to western North Dakota. Prior to peak parturition, we hypothesized that adult females in both areas would select resources associated with higher biomass of vegetation with shallow slopes and low ruggedness, but shift to selection of more rugged terrain and lower selection for vegetation biomass in the post-parturition season. Supporting our hypothesis, bighorn sheep in both study populations engaged in similar tradeoffs between selection for annual forbs and grasses prior to parturition, which was lower in Montana and avoided in North Dakota during the post-parturition period. Additionally, in Montana sheep moved to more rugged terrain during the post parturition period, supporting our hypothesis that females moved to more rugged terrain to increase safety of young. The translocated population in North Dakota showed similar selection for topographic characteristics prior to and following parturition, in contrast to our hypothesis that selection would shift to more rugged terrain following parturition. Sheep in both study areas were fairly similar in how they shifted use of herbaceous vegetation, aspect, and topography, which suggests that the translocated populations were able to select resources similarly to their original locations in Montana.

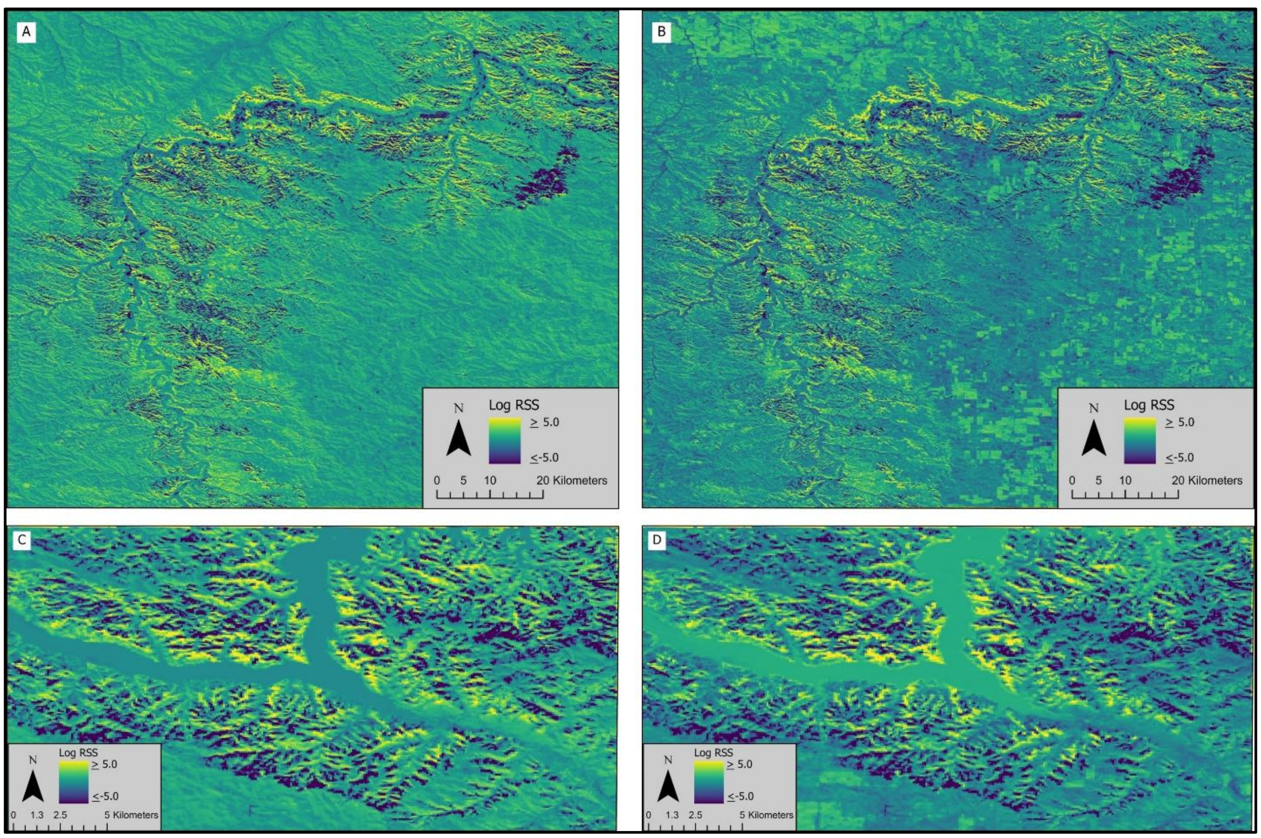

FIGURE 6. Prediction maps, log-transformed Relative Strength of Selection (logRSS), illustrating the spatially explicit probabilities for female Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) in the Little Missouri National Grassland (A and B) and Fort Berthold Reservation (C and D), North Dakota, USA, 2020–2023. Pre-parturition selection of resources is represented by the two panels on the left (A and C), and post-parturition is represented by the panels on the right (B and D).

The substantial increase in available biomass of herbaceous annual and perennial vegetation in Montana and North Dakota between pre- and post-parturition time periods indicated that with greater herbaceous biomass, and presumably greater forage availability, adult females may not need to be as selective of those forage types. If a resource is readily available bighorn sheep would be less dependent on that resource, and selection for that resource could become less intense even if a tradeoff between nutrition and safety does not occur. Conversely, we would predict that selection would become more intense as a resource becomes scarcer on the landscape. If nutrient content is adequate in available forage in areas used by females where predation risk is lower, they may not need to tradeoff maternal nutrition for safety of young. An optimum strategy would occur in instances where females were not forced to make tradeoffs between forage availability and safety of young. Similarly, Heffelfinger et al. (2020) observed that mule deer (*Odocoileus hemionus*) in the Mojave Desert were able to use areas with high forage availability while remaining close to sources of water without having to tradeoff nutritional needs of lactating mothers with safety of young.

The topography of areas used by bighorn sheep in North Dakota was inverted compared to that of Montana, because rugged terrain and steep slopes occupied by bighorn sheep were associated with canyon walls of the Little Missouri River rather than mountain tops occupied by bighorn sheep in Montana. Although biomass of vegetation was greatest on flat mesas above rugged terrain, and in some instances near treeless riparian areas, those areas were used only occasionally by bighorn sheep, probably because of higher perceived risk of predation on young. Females in North Dakota, were more strongly selective of rugged terrain and steep slopes during both seasons with little change between them, which may result from some naiveté of the new study area and that sheep remained close to known escape terrain. Even when using those flat mesas, females remained close to steep, rugged terrain. During both time periods, adult females appeared to prioritize proximity to safe terrain in smaller pockets of rugged habitat near cliffs, rather than on top of mesas with more abundant herbaceous vegetation. Moreover, larger group sizes, especially in open areas, have been associated with decreased risk of predation in bighorn sheep and other ungulates (Berger 1978, Kie 1999; Childress and Lung 2003). Possibly adult females were more likely to use those flat mesas when group sizes were larger, but we have no information on group sizes of bighorn sheep. Additionally, bighorn sheep strongly avoided tree cover in both study areas, possibly because areas with high tree cover may be perceived to have greater risk of predation. Similar avoidance of tree cover has been observed in other studies of Rocky Mountain and desert bighorn sheep, and sheep have been suggested to avoid high tree cover because they rely on vision to detect approaching predators (Risenhoover and Bailey 1980, Geist et al. 1999, Blum et all 2023).

Although, bighorn sheep in Montana shifted to more rugged terrain during the period following parturition, they selected for somewhat more shallow slopes. Conversely, in North Dakota, sheep showed little change in selection for slopes and ruggedness between time periods. This lack of strong changes in use of ruggedness and slope following parturition may be due, in part, to some of the limitations of our study. Our dataset for Montana was limited to only 7 adult females, which may result in some bias associated with small sample size. In both study areas, we were only able to collect locations of individuals at 0600 MST each morning, which limited our inference to selection of resources during early morning hours. Moreover, we were unable to determine pregnancy status, provisioning of lambs, or loss of lamb, which may result in greater variation in selection of resources by individuals primarily during the post-parturition period. Indeed, we observed substantial variation among individuals in selection of resources, which may be a result of not all individuals provisioning young early during the post parturition season. Unfortunately, we were unable to separate sheep into those that recruited young and those that were not pregnant or lost young early. Blum et al. (2023) reported that desert bighorn sheep in central Nevada shifted use to steeper and more rugged terrain when provisioning dependent young, but individuals that were not pregnant or lost young closely following parturition did not show the same behavior. Rachlow and Bowyer (1998) observed similar shifts to steeper and more rugged terrain by Dall's sheep (*Ovis dalli*) while they were provisioning young in Denali National Park and Preserve, Alaska. During the post-parturition time period in Montana, we observed little to no shift in use of steep slopes between time periods. Shifting to steeper slopes may be useful for adult females to evade predators, but may be less advantageous for females accompanied by dependent young. In contrast, rugged terrain was selected strongly during the post-parturition period in both populations, which might provide greater concealment for lambs. The distinction between rugged terrain versus steep terrain was first noted by Sappington et al. (2007) and inspired the first use of the vector ruggedness measure to investigate effects of rugged terrain rather than just slope or elevation in bighorn sheep studies. Our findings also suggest a functional difference between steep versus rugged terrain for Rocky Mountain bighorn sheep (e.g., Riley et al. 1999).

Although greater biomass of herbaceous vegetation was located on elevated mesas, these areas offered limited protection from predators. In the Little Missouri and Upper Missouri River watersheds, tree cover primarily consisted of green ash in gullies and intermittent streams, along with dense stands of aspen, which commonly occurred along riparian valleys. These tree dominated vegetation communities may have been perceived as high-risk areas because of limited visibility with increasing cover of trees (Sayre 1996, Bleich et al. 2018). Additionally, Rocky Mountain juniper often dominated north-facing slopes of our study area (Feist 1997, Ciuti et al. 2014). Dense stands of Rocky Mountain juniper reduce sunlight availability at the forest floor, which may reduce the quality and quantity of forage plants for bighorn sheep as well as reducing visibility of approaching predators (Coultrap et al. 2009, Cuiti et al. 2014, McIver et al. 2022). That reduction in herbaceous biomass also likely resulted in reduced quality and availability of forage for bighorn sheep (Coultrap et al. 2009, Wiedmann et al. 2024). The effect on vegetation productivity and increased predation risk resulting from reduced visibility may explain the strong avoidance of tree cover we observed in our study areas.

Phenology also may play an important role in habitat selection and, ultimately, individual fitness (Renaud et al. in press). During our study, perennial and annual forbs and grasses did not become widely available until late into the pre-parturition period, which in part may explain high selection for annual forbs and grasses pre-parturition and reduced selection post-parturition because forage availability may have exceeded demand during the latter period. We attempted to account for shifts in productive forage selection by including the 16-day biomass estimates for perennial and annual forbs and grasses, but those vegetation classes were likely too broad to capture the selective foraging of bighorn sheep. An examination of forage availability and quality for bighorn sheep combined with a dietary analysis may elicit stronger selection patterns that our broad vegetation categories were unable to capture. Preference for annual grasses and forbs pre-parturition in both study areas suggests that female bighorn sheep were maximizing consumption of these types of vegetation when they first became available (Marshall et al. 2008).

Historically, bighorn sheep translocations in the United States have resulted in mixed outcomes. Some early translocation efforts had limited information regarding appropriate habitat and ecotypes to use as criteria for guidance and resulted in failed introductions or many years of augmentations to supplement lackluster population increases (Singer et al. 2000, Whiting et al. 2023). Translocation strategies have seen continuous improvements, culminating in the use of modern genomics, greater consideration of advantages associated with phenotypes or morphotypes in the selection of source stock, and the use of resource selection functions to identify characteristics that influence long-term population growth between source and target environments, and all of which are apt to enhance success (Jahner et al. 2019, Flesch et al. 2020, Whiting et al. 2023, Lutz and Bleich 2026). We observed some variation in selection of resources between the source population in Montana and the translocated population in North Dakota, where bighorn sheep appeared to be more strongly tied to steep slopes and rugged terrain with little use of areas with greater availability of herbaceous vegetation during both time periods. Similarities in selection of vegetation biomass during both parturition seasons in both Montana and North Dakota may suggest that translocating bighorn sheep from central Montana was an appropriate match for western North Dakota. We suggest that further evaluation of selection of resources combined with demographic and diet information will provide further evidence of the appropriateness of translocating Rocky Mountain bighorn sheep to western North Dakota. Our results are consistent with the prevailing notion that consideration of similarities between habitats at source locations and release sites may improve the success of bighorn sheep translocations.

MANAGEMENT IMPLICATIONS

When considering translocations as a conservation strategy, preference should be given to source populations that are best adapted to the habitat to which they are being translocated (Wiedmann and Sargeant 2014, Bleich et al. 2018, Wiedmann et al. 2024). While we were limited to a single location per day for each individual, it would be advantageous to have locations of individuals on the landscape across the 24-hour day. Additionally, we recommend sampling forage availability and quality in both areas to help quantify responses to vegetation and the level of tradeoff, if any, that females with dependent young might engage. Combining information on selection of resources with demographic data is likely to provide additional evidence that use of appropriate source stock is important, which can be implemented when translocations occur. Our data indicated that sheep were able to find escape terrain, steep slopes and rugged terrain, and used herbaceous vegetation in those areas while reducing use of terrain that may have represented an increased risk of predation. Bighorn sheep avoided tree cover in both areas, and in North Dakota many of the areas with high tree cover consisted of Rocky Mountain Juniper, our findings may support some removal of juniper trees to increase visibility and availability of herbaceous forage for bighorn sheep. Collecting demographic data combined with data on selection of resources to compare source and translocated populations, will provide additional evidence that bighorn sheep are using available habitat for survival and reproduction and may help to improve success of translocations.

ACKNOWLEDGMENTS

Funding was provided by the North Dakota Game and Fish Department (NDGF) and Kuiu Conservation Direct. Expertise, veterinary expertise, and equipment used during capture and transport of bighorn sheep was provided by personnel from the NDGF. We appreciate the support of the Three Affiliated Tribes in North Dakota and the Chippewa Cree Tribe in Montana.

Capture, handling, and transport of bighorn sheep released in North Dakota were in accordance with NDGF protocols and guidelines established by the American Society of Mammalogists for wild mammals used in research (Sikes et al. 2016).

We appreciate the input provided by N. Jackson and J. Brockman, and thank E. Jensen (Desert Research Institute) for acquisition of 16-day productivity data from the Rangelands Analysis Platform. We thank the Guest Editor for handling the peer review process, and two anonymous reviewers for many helpful comments that improved the manuscript. This is Professional Paper 165 from the Eastern Sierra Center for Applied Population Ecology.

REFERENCES

Allred, B. W., B. T. Bestelmeyer, C. S. Boyd, C. Brown, K. W. Davies, and M. C. Duniway. 2021. Improving Landsat predictions of rangeland fractional cover with multitask learning and uncertainty. Methods in Ecology and Evolution 12:841–49.

Arnold, T. W. 2010. Uninformative parameters and model selection using Akaike's Information Criterion. Journal of Wildlife Management 74:1175–1178.

Avgar, T., S. R. Lele, J. L. Keim, and M. S. Boyce. 2017. Relative selection strength: quantifying effect size in habitat-and step-selection inference. Ecology and Evolution, 7:5322–5330.

Barbosa, S., K. R. Andrews, R. B. Harris, D. S. Gour, J. R. Adams, E. F. Cassirer, H. M. Miyasaki, H. M. Schwantje, and L. P. Waits. 2021. Genetic diversity and divergence among bighorn sheep from reintroduced herds in Washington and Idaho. Journal of Wildlife Management 85:1214–1231.

Berger, J. 1978. Group size, foraging, and antipredator ploys: an analysis of bighorn sheep decisions. Behavioral Ecology and Sociobiology 4:91–99.

Berger, J. 1990. Persistence of different-sized populations: an empirical assessment of rapid extinctions in bighorn sheep. Conservation Biology 4:91–98.

Bleich, V. C., G. A. Sargeant, and B. P. Wiedmann. 2018. Ecotypic variation in population dynamics of reintroduced bighorn sheep. Journal of Wildlife Management 82:8–18.

Blum, M. E., K. M. Stewart, K. T. Shoemaker, M. Cox, B. F. Wakeling, T. E. Dilts, J. R. Bennett, and V. C. Bleich. 2023. Changes in selection of resources with reproductive state in a montane ungulate. Movement Ecology 11:20. <https://doi.org/10.1186/s40462-023-00378-1>

Bolker, B. M., M. E. Brooks, C. J. Clark, S.

W. Geange, J. R. Poulsen, M. H. H. Stevens, et al. 2009. Generalized linear mixed models: a practical guide for ecology and evolution. Trends in Ecology and Evolution 24:127–35.

Brewer, C. E., V. C. Bleich, J. A. Foster, T. Hosch-Hebdon, D. E. McWhirter, E. M. Rominger, M. W. Wagner, and B. P. Wiedmann. 2014. Bighorn sheep: conservation challenges and management strategies for the 21st century. Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming, USA.

Brooks, M. E., K. Kristensen, K. J. van Benthem, A. Magnusson, C. W. Berg, A. Nielsen, et al. 2017. Glmmtmb balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. R Journal 9:378–400.

Burnham, K. P., and D. R Anderson. 2002. Model selection and inference: a practical information-theoretic approach. Second edition. Springer-Verlag, New York, New York, USA.

Childress, M. J., and M. A. Lung. 2003. Predation risk, gender and the group size effect: does elk vigilance depend upon the behaviour of conspecifics? Animal Behaviour 66:389–398.

Ciuti, S., W. F. Jensen, S. E. Nielsen, M. S. Boyce, S. K. Johnson, and B. M. Hosek. 2014. An evaluation of historical mule deer fawn recruitment in North Dakota. University of Alberta, Edmonton, Alberta.

Conner, M. M., T. R Stephenson., D. W. German, K. L. Monteith, A. P. Few, and E. H. Bair. 2018. Survival analysis: informing recovery of Sierra Nevada bighorn sheep. Journal of Wildlife Management 82:1442–1458.

Coultrap, D., K. Fulgham, D. Lancaster, J. Gustafson, D. Lile, and M. George. 2009. Relationships between western juniper (*Juniperus occidentalis*) and understory vegetation. Invasive Plant Science and Management 1:3–11.

D'Eon, R.G., and D. Delparte. 2005. Effects of radio-collar position and orientation on GPS radio-collar performance, and the implications of pdop in data screening. Journal of Applied Ecology 42:383–388.

Desert Research Institute and University of Idaho. 2024. Climate data from Climate Engine: temperature and precipitation trends [Data set]. Climate Engine. Accessed 1 February 2023. Retrieved from https://climateengine.org

Dilts, T. E. 2023. Align rasters toolbox for arcgis pro. University of Nevada Reno. Accessed 12 December 2023. <https://www.arcgis.com/home/item.html?id=4f5e9d4e3b974890991d33e7e5251231>.

Dilts, T. E. 2025. Topography toolbox for arcgis pro. University of Nevada Reno. Accessed 25 November 2025. <https://www.arcgis.com/home/item.html?id=247fbe56c7ff48229c9b1fe132d1b5e9>.

Dilts, T. E., M. E. Blum, K. T. Shoemaker, P. J. Weisberg, and K. M. Stewart. 2023. Improved topographic ruggedness indices more accurately model fine-scale ecological patterns. Landscape Ecology 38:1395–1410.

Donovan, V. M., C. P. Roberts, C. L. Wonkka, J. L. Beck, J. N. Popp, C. R. Allen, and D. Twidwell. 2020. Range-wide monitoring of population trends for Rocky Mountain bighorn sheep. Biological Conservation 248: 108639.

Feist, J. 1997. Bighorn sheep (*Ovis canadensis*) ecology and demography in the North Dakota Badlands. M.S. Thesis, University of North Dakota, Grand Forks, North Dakota, USA.

Fieberg, J., J. Signer, B. Smith, and T. Avgar. 2021. A 'how to' guide for interpreting parameters in habitat-selection analyses. Journal of Animal Ecology 90:1027–1043.

Flesch, E. P., T. A. Graves, J. M. Thomson, K. M. Proffitt, P. J. White, T. R. Stephenson, and R. A. Garrott. 2020. Evaluating wildlife translocations using genomics: a bighorn sheep case study. Ecology and Evolution 10:13687–13704.

Geist V. 1999. Adaptive strategies in American mountain sheep: effects of climate, latitude and altitude, Ice Age evolution, and neonatal security. Pages 192–208 *in* R. Valdez and P. R. Krausman, editors. Mountain sheep of North America. University of Arizona Press, Tucson, Arizona, USA

Gillies, C. S., M. Hebblewhite, S. E. Nielsen, M. A. Krawchuk, C. L. Aldridge, J. L. Frair, D. J. Saher, C. E. Stevens, and C. L. Jerde. 2006. Application of random effects to the study of resource selection by animals. Journal of Animal Ecology 75:887–898.

Harrison, X. A., L. Donaldson, M. E. Correa-Cano, J. Evans, D. N. Fisher, C.E.D. Goodwin, et al. 2018. A brief introduction to mixed effects modeling and multi-model inference in ecology. PeerJ 5:e4794. https://doi.org/10.7717/peerj.4794.

Hartig, F. 2022. DHARMa: residual diagnostics for hierarchical (multi-level/mixed) regression models. R package version 0.4.5. https://CRAN.R-project.org/package=DHARMa

Jahner, J. P., M. D. Matocq, J. L. Malaney, M. Cox, P. Wolff, M. A. Gritts, and T. L Parchman. 2019. The genetic legacy of 50 years of desert bighorn sheep translocations. Evolutionary Applications 12:198–213.

Jensen, W. F. 1988. Summer and fall ecology of mule deer in the North Dakota badlands. Dissertation, University of North Dakota, Grand Forks, North Dakota, USA.

Jensen, W. F. 2020. The landscape and flora of North Dakota: "an acquired taste". Pages 23–41 *in* R. W. Seabloom, principal author. The mammals of North Dakota. Second edition. North Dakota State University Press, Fargo, North Dakota, USA.

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. USGS Northern Prairie Wildlife Research Center, Jamestown, North Dakota, USA.

Kie, J. 1999. Optimal foraging and risk of predation: effects on behavior and social structure in ungulates. Journal of Mammalogy 80:1114–1129.

Long, R. A., R. T. Bowyer, W. P. Porter, P. Mathewson, K. L. Monteith, and J. G. Kie. 2014. Behavior and nutritional condition buffer a large-bodied endotherm against direct and indirect effects of climate. Ecological Monographs 84:513–532.

Lula, E. S., B. Lowrey, K. M. Proffitt, A. R. Litt, J. A. Cunningham, C. J. Butler, and R. A. Garrott. 2020. Is habitat constraining bighorn sheep restoration? A case study. Journal of Wildlife Management 84:588–600.

Lutz, D. W., and V. C. Bleich. 2026. Capture and translocation of mountain sheep. Pages 258–279 *in* P. R. Krausman and B. A. Jex, editors. Mountain sheep in North America. CRC Press, Boca Raton, Florida, USA.

Manly, B. F., L. L. McDonald, D. L. Thomas, T. L. McDonald, and W. P. Erickson. 2002. Resource selection by animals: statistical design and analysis for field studies. Second edition. Kluwer

Academic Publishers, Norwell, Massachusetts, USA.

Marshal, J. P., V. C. Bleich, and N. G. Andrew. 2008. Evidence for interspecific competition between feral ass and mountain sheep in a desert environment. Wildlife Biology 14:228–236.

McIver, J., J. B. Grace, and B. Roundy. 2022. Pinon and juniper tree removal increases available soil water, driving understory response in a sage-steppe ecosystem. Ecosphere 13:e4279.

Muff, S., J. Signer, and J. Fieberg. 2020. Accounting for individual-specific variation in habitat-selection studies: efficient estimation of mixed-effects models using Bayesian or frequentist computation. Journal of Animal Ecology 89:80–92.

Northrup, J. M., M. B. Hooten, C. R. Anderson Jr., and G. Wittemyer. 2013. Practical guidance on characterizing availability in resource selection functions under a use-availability design. Ecology 94: 1456–1463.

Osterhout, M. J., K. M. Stewart, B. F. Wakeling, C. A. Schroeder, M. E. Blum, J. C. Brockman, and K. T. Shoemaker. 2024. Effects of large-scale gold mining on habitat use and selection by American pronghorn. Science of the Total Environment 921:170750.

R Core Team. 2026. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rachlow, J. L., and R. T. Bowyer 1998. Habitat selection by Dall’s sheep (*Ovis dallli*): maternal trade-offs. Journal of Zoology London 245:457–465.

Ramey, R. R. II. 1993. Evolutionary genetics and systematics of North American mountain sheep: implications for conservation. Dissertation, Cornell University, Ithaca, New York, USA.

Renaud, L.-A., F.-O. Dufour, F. Rousseu, M. Festa-Bianchet, and F. Pelletier. In press. Effect of spring green-up dynamics on body mass and growth of bighorn sheep. Mammalia (2026). <https://doi.org/10.1515/mammalia-2024-0156>

Riley, S. J., S. D. DeGloria, and R. Elliot. 1999. Index that quantifies topographic heterogeneity. Intermountain Journal of Sciences 5:23–27.

Risenhoover, K. L., and J. A. Bailey. 1980. Visibility: an important habitat factor for an indigenous, low-elevation mountain sheep herd in Colorado. Biennial Symposium of the Northern Wild Sheep and Goat Council. 2:18–28.

Rubin, E. S., W. M. Boyce, and V.C. Bleich. 2000. Reproductive strategies of desert bighorn sheep. Journal of Mammalogy 81:769–786.

Sappington, J. M., K. M. Longshore, and D. B. Thompson. 2007. Quantifying landscape ruggedness for animal habitat analysis: a case study using bighorn sheep in the Mojave Desert. Journal of Wildlife Management 71:1419–1426.

Sayre, R. W. 1996. Ecology of bighorn sheep in relation to habitat and oil development in the Little Missouri Badlands. Dissertation, University of North Dakota, Grand Forks, North Dakota, USA.

Signer, J., J. Fieberg, and T. Avgar. 2019. Animal movement tools (amt): R package for managing tracking data and conducting habitat selection analyses. Ecology and Evolution 9:880–890.

Singer, F. J., C. M. Papouchis, and K. K.

Symonds. 2000. Translocations as a tool for restoring populations of bighorn sheep. Restoration Ecology 8:6–13.

Stewart, K. M., R. Bowyer, J. Kie, N. Cimon, and B. Johnson. 2002. Temporospatial distributions of elk, mule deer, and cattle: resource partitioning and competitive displacement. Journal of Mammalogy 83:229–244.

Turesson, G. 1922. The species and the variety as ecological units. Hereditas 3:100–113.

U.S. Department of Agriculture, Natural Resources Conservation Service, and University of Montana. 2024. Rangeland Analysis Platform (Version 2.0) [Data set]. Accessed 1 February 2024. Available at <https://rangelands.app>

U.S. Geological Survey. 2024. USGS EROS archive – digital elevation: elevation derivatives for national applications (EDNA). U.S. Geological Survey. Accessed 18 February 2024. https://www.usgs.gov/centers/eros/science/usgs-eros-archive-digital-elevation-elevation-derivatives-national

Wakeling, B. F., V. C. Bleich, M. E. Blum, and J. A. Dellinger. 2026. Relationships among mountain sheep and their predators. Pages 160–174 *in* P. R. Krausman and B. A. Jex, editors. Mountain sheep in North America. CRC Press, Boca Raton, Florida, USA.

Whiting, J. C., V. C. Bleich, R. T. Bowyer, and C. W. Epps. 2023. Restoration of bighorn sheep: history, successes, and remaining conservation issues. Frontiers in Ecology and Evolution 11:10/83350.

Whiting, J. C., R. T. Bowyer, J. T. Flinders., and D. L. Eggett. 2011. Reintroduced bighorn sheep: fitness consequences of adjusting parturition to local environments. Journal of Mammalogy 92:213–220.

Wickham H, R. François, L. Henry, K. Müller, and D. Vaughan. 2023. dplyr: a grammar of data manipulation. R package 1.1.4. <https://github.com/tidyverse/dplyr>

Wiedmann, B. P., V. C. Bleich, and C. E. Penner. 2024. North Dakota bighorn sheep management plan (2024–2034). Federal Aid in Wildlife Restoration Project Report A-290. North Dakota Game and Fish Department, Bismarck, North Dakota, USA.

Wiedmann, B. P., and G. A. Sargeant. 2014. Ecotypic variation in recruitment of reintroduced bighorn sheep: implications for translocation. Journal of Wildlife Management 78:394–401.

Zar, J. H. 2010. Biostatistical analysis. Fifth edition. Pearson, Upper Saddle River, New Jersey, USA.

Feral Burro Report—2025

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Desert Bighorn Council Transactions 58:40–44

ABSTRACT This report focuses on the six states that are inhabited by desert bighorn sheep, and that also have burros, horses, or both species of these feral equids on public lands (Arizona, California, Colorado, Nevada, New Mexico, and Utah). The report therefore doesn't include Texas or Mexico. Burro and horse management are closely related in several important ways, so this report includes information on both species.

KEY WORDS competition, desert bighorn sheep, *Equus asinus*, *Equus caballus*, exotic species, feral burro, feral horse, habitat damage, invasive species, *Ovis canadensis*

At a national level, as of March 2025, the Bureau of Land Management (BLM) reported that there were 73,130 horses and burros combined on BLM-administered Herd Management Areas (HMAs) and Herd Areas (HAs), far exceeding the Appropriate Management Level (AML) of 25,556 animals (https://www.blm.gov/whb). This similar pattern is observed at the state level, with each of the six states included in this report exceeding AML for either horses or/and burros on BLM-administered HMAs (Table 1; https://www.blm.gov/whb).

It is important to note that the numbers shown in Table 1 are only those reported by the BLM for BLM-administered HMAs and HAs. In many areas, horses and burros have spread outside these boundaries to lands that are rarely or never surveyed by the BLM. In addition, horses and burros are also found on 34 active Horse and Burro Territories on U.S. Forest Service (USFS) lands, with 24 of these jointly managed with the BLM (https://www.fs.usda.gov/wild-horse-burro/territories/index.shtml). The combined horse and burro AML on these USFS territories is 2,253 animals, while the most recent available estimate (2014) indicated 6,483 animals. Finally, the above referenced numbers don't include Tribal lands, some of which are inhabited by large numbers of burros and horses. For example, based on surveys conducted in 2016, there were an estimated 38,223 horses and an unidentified number of burros on the Navajo Nation alone (Wallace et al. 2021). In 2020, the number of feral horses on all Tribal lands combined was estimated to be 117,384 (Schoenecker et al. 2021).

The BLM continues to remove horses and burros from the range each year. For example, 16,140 (13,154 horses and 2,986 burros) were removed in 2024. Some of these animals were adopted, but 65,189 horses and burros were being cared for in off-range facilities as of March 2025, representing a huge financial burden for the BLM. The BLM's 2024 expenditures for the Wild Horse and Burro Program totaled $153 million and 66% of this ($101 million) was spent on care of animals in off-range pastures and corrals.

TABLE 1. Appropriate Management Levels (AML) and estimated 2025 numbers of burros and horses on BLM-administered HMAs in states occupied by desert bighorn sheep.

Location	High AML Burros	2025 Burro Estimate	High AML Horses	2025 Horse Estimate
Arizona	1,436	10,447	240	233
California	465	4,124	1,735	3,023
Colorado	0	0	827	1,516
Nevada	824	4,408	11,987	30,732
New Mexico	0	0	83	85
Utah	170	282	1,786	4,125

The BLM and other organizations have also continued to research fertility control methods, but the effectiveness of fertility control has not been evaluated on a large scale. In recent years, continued removals have resulted in a slight decrease in on-range numbers, particularly for horses (Figure 1). Although the number of horses on range is slowly declining, the number of burros on the range continues to increase (Figure 1). In addition, and despite these efforts, the number of horses and burros on the range still far exceeds AML (Figure 2). Burros exceed AML most notably in Arizona and California, while horses exceed AML primarily in Nevada and Utah (Figure 3). Current numbers are continuing to threaten native wildlife and the habitats they rely on. If nothing changes, the BLM estimates there could be >2.8 million horses and burros on BLM-administered HMAs by 2040 (BLM 2020).

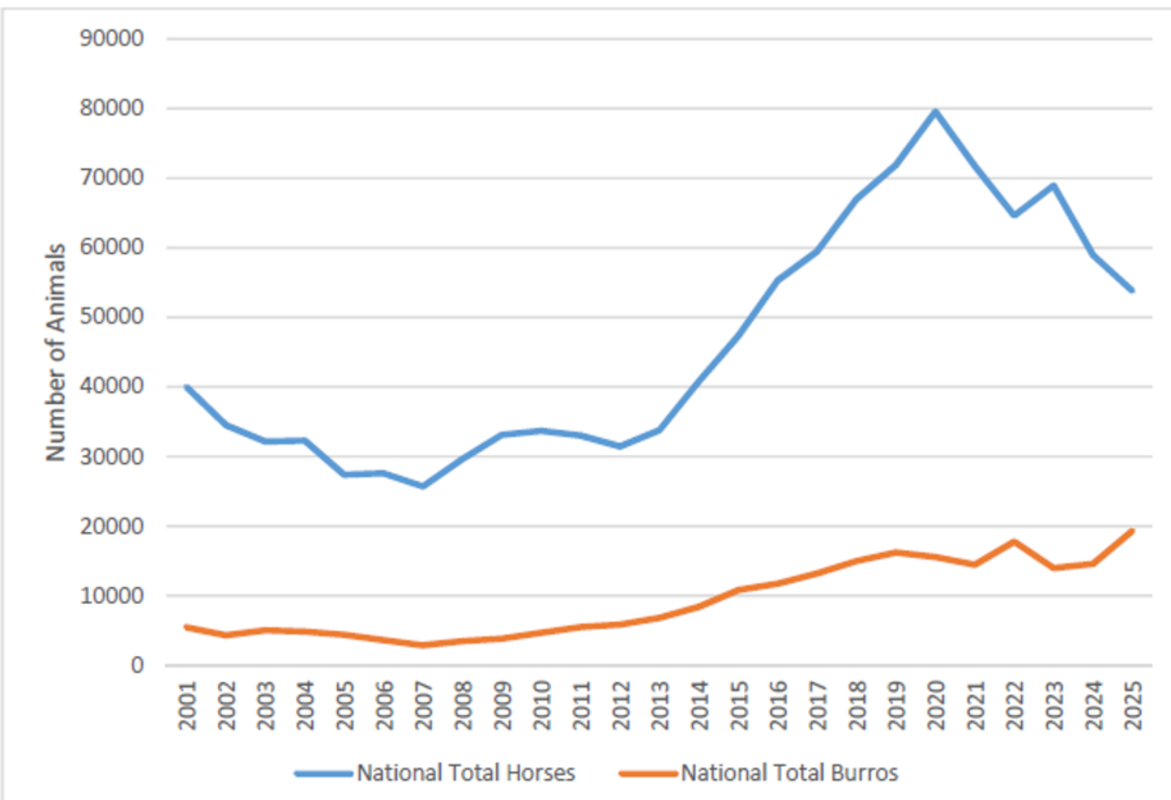

FIGURE 1. Annual Bureau of Land Management estimates of total horses and burros on Herd Management Areas and Herd Areas,2001–2025.

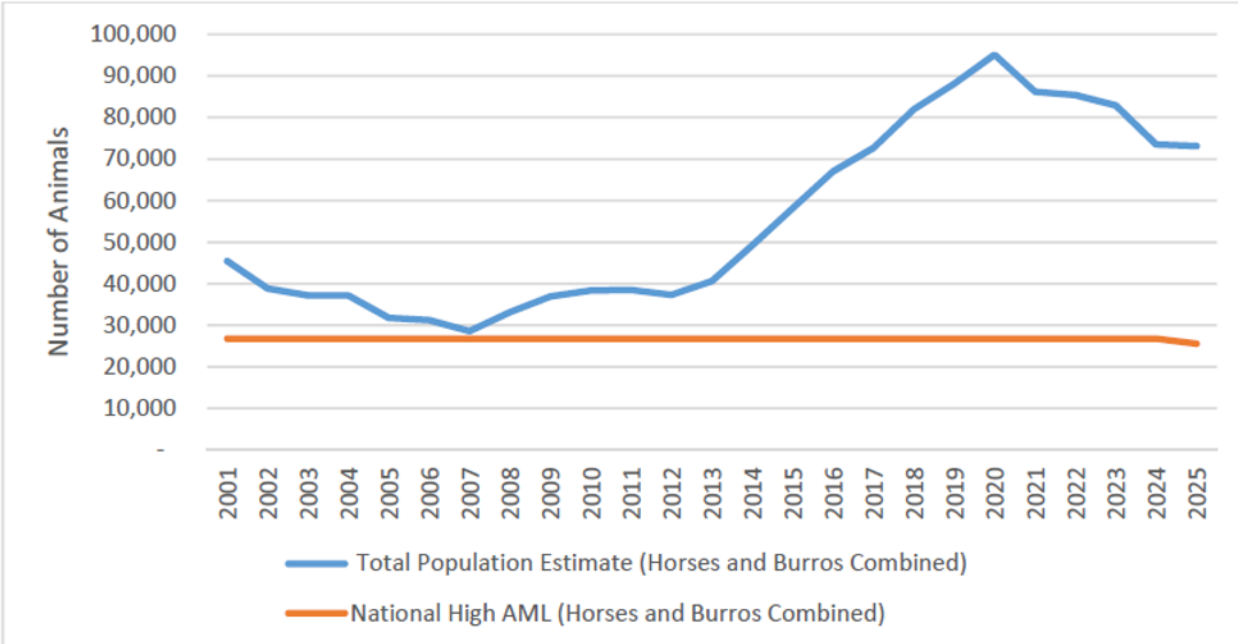

FIGURE 2. Annual Bureau of Land Management estimates, total horses and burros combined, and combined Appropriate Management Level on Herd Management Areas and Herd Areas 2001–2025.

The negative consequences of too many horses and burros are numerous and include overgrazing, damage to vegetation, competition with native species, human safety (e.g., via collision with vehicles), and inhumane conditions for the horses and burros themselves. Many herds are increasing by 15–20% each year, and this level has been determined to not be sustainable and to have negative effects on ecosystems as well as the animals themselves (National Academy of Sciences 2013, Rubin et al. 2024). A detailed summary of these impacts is beyond the scope of this report; however, the movie "Horse Rich and Dirt Poor" (https://youtu.be/q6h242vy_q8), which was supported by the Desert Bighorn Council, provides a good summary of the challenges and the dilemma. Readers are also encouraged to carefully read recent literature that promotes burros as being beneficial to wildlife (Lundgren et al. 2021), and the critiques questioning that contention (Bleich et al. 2021, Rubin et al. 2021).

The negative effects that uncontrolled populations of horses or burros have on ecosystems and native species will only become more serious the longer those populations are allowed to grow. The Wild Sheep Working Group of the Western Association of Fish and Wildlife Agencies (WAFWA) noted the negative effects that overabundant horses and burros have on wild sheep, and emphasized effective management of feral horses and burros as an important strategy (Brewer et al. 2014). The Wildlife Society also has commented on the need to manage feral horses and burros (Leopold 2010) and has developed an issue statement calling for the reduction of horse and burro numbers, including the use of euthanasia as a possible tool (Wildlife Society 2016). In addition, WAFWA adopted a resolution in 2017, calling for the removal of appropriations language that restricts BLM's ability to use all management tools provided by the Wild and Free-Roaming Horse and Burro Act, and urging the BLM to use all available tools to remove animals outside of established HMAs (WAFWA 2017).

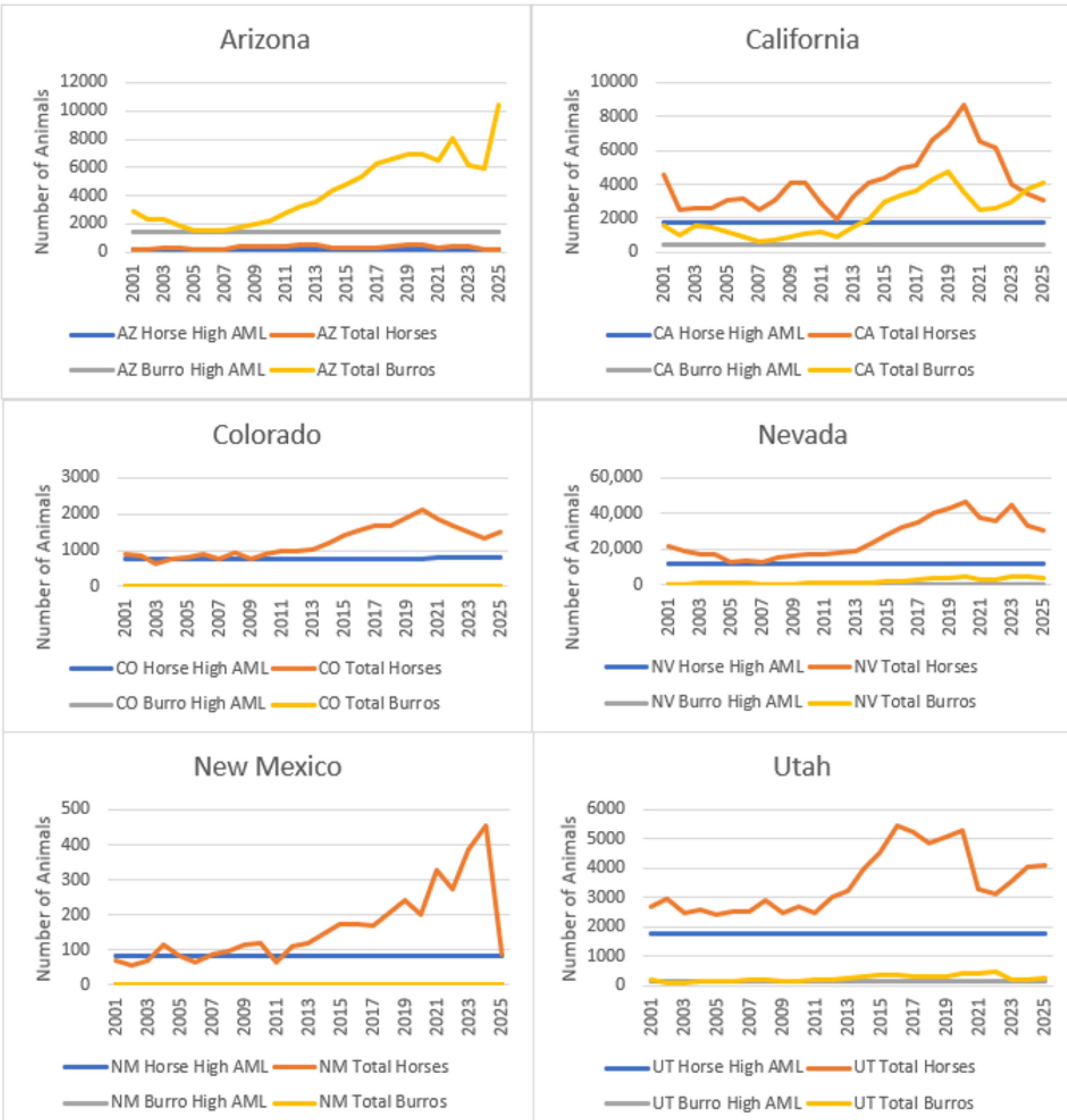

FIGURE 3. Burro and horse abundance during 2001–2025, and combined Appropriate Management Level on BLM-administered Herd Management Areas and Herd Areas, by state.

REFERENCES

Bleich, V. C., C. W. Epps, J. S. Sedinger, C. M. Aiello, C. Gallinger, D. A. Jessup, and E. M. Rominger. 2021. Ecological "benefits" of feral equids command disclosure of environmental impacts. E-letters to Science—19 July 2021 (Online). Available at: https://www.science.org/doi/10.1126/science.abd6775

Brewer C. E., V. C. Bleich, J. A. Foster, T. Hosch-Hebdon, D. E. McWhirter, E. M. Rominger, M. W. Wagner, and B. P. Wiedmann. 2014. Bighorn sheep: conservation challenges and management strategies for the 21st Century. Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming, USA.

Bureau of Land Management. 2020. U.S. Department of the Interior Bureau of Land Management Report to Congress: An Analysis of Achieving a Sustainable Wild Horse and Burro Program. Available at: https://www.blm.gov/sites/blm.gov/files/WHB-Report-2020-NewCover-051920-508.pdf

Leopold, B. D. 2010. Letter to the Bureau of Land Management encouraging the management of feral horses and burros. The Wildlife Society, Bethesda, Maryland, USA. Available at: https://tws1.my.salesforce-sites.com/servlet/servlet.FileDownload?file=01531000008tsnRAAQ

Lundgren, E. J., D. Ramp, J. C. Stromber, J. Wu, N. C. Nieto, M. Sluk, K. T. Moeller, and A. D. Wallach. 2021. Ecosystem engineers: equids engineer desert water availability. Science 372:491–495.

National Research Council. 2013. Using science to improve the BLM Wild Horse and Burro Program: a way forward. National Academies Press, Washington, D.C., USA. Available at: https://doi.org/10.17226/13511

Rubin, E. S., D. Conrad, L. E. Harding, and B. M. Russo. 2024. Associations between a feral equid and the Sonoran Desert ecosystem. Wildlife Monographs 215:e1083.

Rubin, E. S., D. Conrad, A. S. Jones, and J. J. Hervert. 2021. Feral equids' varied effect on ecosystems. Science 373:973.

Schoenecker, K. A., S. R. B. King, and T. A. Messmer. 2021. The wildlife profession's duty in achieving science-based sustainable management of free-roaming equids. Journal of Wildlife Management 85:1057–1061.

The Wildlife Society. 2016. Feral horses and burros in North America. The Wildlife Society, Bethesda, Maryland, USA. Available at: https://wildlife.org/tws-issue-statement-feral-horses-and-burros-in-north-america/

Wallace, Z. P., R. M. Nielson, D. W. Stahlecker, G. T. DiDonato, M. B. Ruehmann, and J. Cole. 2021. An abundance estimate of free-roaming horses on the Navajo Nation. Rangeland Ecology and Management 74:100–109.

Western Association of Fish and Wildlife Agencies. 2017. Resolution 1. Bureau of Land Management wild horse and burro management. Available at: https://wafwa.org/wp-content/uploads/2020/07/Resolution_BLM-Wild-Horse-Burro-Management.pdf

Readers are referred to a special section of *The Journal of Wildlife Management* (85[6]; August 2021) and a special issue of *Human-Wildlife Interactions* (16[2]; Fall 2022) for further information on the management of feral equids—**EDITOR.**

Planimetric Versus Surface Area Measurements of Desert Bighorn Sheep Movements

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Desert Bighorn Council Transactions 58:45–57

ABSTRACT Accurate estimation of home range size and movement metrics is fundamental to understanding the spatial ecology of large mammals. Most studies quantify home range area, movement rates, and distances to resources using planimetric (map-based) measurements that do not account for topographic complexity, potentially underestimating space use in rugged terrain. We evaluated differences between traditional planimetric metrics and surface-area (topographic) measurements for 37 adult female desert bighorn sheep (*Ovis canadensis mexicana*) monitored with GPS collars from 2002–2005 on the Cabeza Prieta National Wildlife Refuge (CPNWR), Arizona, USA. We calculated seasonal minimum convex polygon (MCP) and fixed-kernel (95% and 50%) home ranges, movement rates, and distances to perennial water sources using planimetric and surface-based approaches. Estimates of home ranges, movement rates, and distance to water sources that incorporated topography were 6–18% larger than planimetric estimates, with larger discrepancies occurring in more rugged terrain. These discrepancies are biologically meaningful and have implications for studies of habitat selection, resource availability, bioenergetics, and conservation planning for mountain-dwelling ungulates. Incorporating surface-based measurements provides a more realistic representation of space use and energetic costs in rugged landscapes.

KEY WORDS comparisons, density, energetics, home range, metrics, movement rates, *Ovis canadensis*, planning

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Estimating home range size and movements is integral to research on many aspects of large mammal ecology. Home range estimates are commonly used in studies of habitat selection and use (Tufto et al. 1996, Owen-Smith and Cain 2007, Jerina 2012, Killeen et al. 2014, Reddell et al. 2023, Chui et al. 2024), habitat productivity in relation to space use (Relyea et al. 2000, Oehler et al. 2003, Herfindal et al. 2005), and bioenergetics (Parker et al. 1984, Dailey and Hobbs 1989). Additionally, researchers interested in habitat selection are often interested in distance between animals or animal locations, or distance to key resources (e.g. water; Cain et al. 2008, Harris et al. 2020, Krausman 2026) or anthropogenic disturbance (e.g. roads; Leblond et al. 2013).

Use of GPS collars allows for precise collection of a large amount of location data over an extended time, allowing researchers to investigate animal movements and spatial ecology in greater detail than was feasible with VHF telemetry collars. Home range boundaries have been historically estimated using minimum convex polygons (MCP; Jennrich and Turner 1969), kernel density methods (KDE; Worton 1989, 1995), or nonparametric local convex hull methods (Getz et al. 2007). Both kernel and convex hull methods are improvements over MCPs because they can be used to assess intensity of use and are less sensitive to outlying locations. More recent developments, such as the Brownian Bridge Movement Models and autocorrelated kernel density estimators, represent significant improvements to movement metrics because they incorporate movement-based probability to predict animal space use. These approaches account for the temporal structure and autocorrelation of GPS data (Horne et al. 2007, Fleming et al. 2015).

Most home range estimates and animal movement metrics, however, use planimetric measurements and do not explicitly address topography when quantifying movement distances or home range sizes. For species in areas with minimal topographic variation, such as American pronghorn (*Antilocapra americana*), there is likely little difference in distances or area metrics estimated with planimetric and topographical measurements (Monterroso et al. 2013). For species that occupy rugged, mountainous terrain, omitting topography from movement and home range estimates is liable to underestimate home range area and movements. To date, a few studies have assessed home range topography (Stone et al. 1997, Castleberry et al. 2001, Campbell et al. 2004, Greenberg and McClintock 2008). Use of planimetric measurements can underestimate home range size, ranging from negligible differences <1% up to 38% with differences being largest in mountainous terrain (Oli et al. 1997, Monterroso et al. 2013, Heit et al. 2021).

While some researchers have assessed home range using topographical measurements, most studies use planimetric measurements to estimate movement rates, distances to resources, and home range area. Our goal was to assess differences in home range areas, distance to water, and movement rates of adult female desert bighorn sheep (*Ovis canadensis mexicana*) using traditional planimetric measurements and compare them to measurements that incorporated topography (i.e., surface area). Because there is seasonal variation in movements and use of areas with varying terrain ruggedness (e.g., lambing season), we also evaluated variation in topographical versus planimetric measurements seasonally.

STUDY AREA

The Cabeza Prieta National Wildlife Refuge (CPNWR) encompassed 3,480 km^2 along the international border between the United States and Mexico in southwestern Arizona, USA. Topography was a series of rugged mountain ranges separated by wide valleys with elevation ranging from 200–900 m. Our specific study sites were the Sierra Pinta and the Cabeza Prieta Mountains on the western side of CPNWR.

Annual precipitation was bimodal, with peaks during summer and winter; long-term mean annual precipitation in the area (1969–2005, Tacna, Arizona, ~ 64 km north of the study area) was 107 mm with high interannual variability (CV = 56%). Range in average summer temperatures was 22.3° C to >45° C (Western Regional Climate Center 2026). Mean daily high and low temperatures during winter were 21.1° C and 2.6° C, respectively. Based on long-term climate data, we defined 1 January–31 March as winter, 1 April–30 June as early summer, 1 July–30 September as late summer, and 1 October–31 December as autumn.

Vegetation in the valleys was characterized by creosote bush (*Larrea tridentata*), white bursage (*Ambrosia dumosa*), and ocotillo (*Fouquieria splendens*) with ironwood (*Olneya tesota*), and blue palo verde (*Parkinsonia florida*) as canopy species. Vegetation within desert bighorn habitat in the mountains was characterized by ironwood, catclaw acacia (*Senegalia greggii*), foothill palo verde (*Parkinsonia microphyllum*), white bursage, ratany (*Krameria* spp.), brittlebush (*Encelia farinosa*), and Wright's buckwheat (*Eriogonum wrightii*) also present. Prevalent grasses and forbs included three-awn (*Aristida* spp.), grama (*Bouteloua* spp.), big galleta grass (*Pleuraphis rigida*), globe mallow (*Sphaeralcea* spp.), indian wheat (*Plantago patagonica*), and lupine (*Lupinus* spp.). The most common succulents included giant saguaro (*Cereus giganteus*), barrel cactus (*Ferocactus* spp.), fishhook cactus (*Mammillaria* spp.), teddy bear cholla (*Cylindropuntia bigelovii*), buckhorn cholla (*C. acanthocarpa*), and chain fruit cholla (*C. fulgida*).

METHODS

We captured 37 adult, female bighorn sheep with a net-gun fired from a helicopter (Krausman et al. 1985) from 2002 to 2005 and maintained 6–10 radio-collared animals in each mountain range (Cain et al. 2008). All animals were fitted with a GPS telemetry collar (900 g; models 440 and 3580, Telonics, Mesa, Arizona) programmed with a 13-hour. fix interval; data were transmitted every 3 days via the Argos (Service Argos, Largo, Maryland, USA) satellite system. Our capture and handling methods were approved by the University of Arizona Animal Care and Use Committee (Protocols 01-191 and 04-180).

We assessed the differences in movement rates, distances, and home range areas using the planimetric measurements commonly used in wildlife studies and these same measurements incorporating surface area, thus accounting for topography. We used the animal movements extension for ArcView (Environmental Systems Research Institute 2000, Hooge and Eichenlaub 1997) to estimate seasonal minimum convex polygon (MCP) home ranges for each animal and seasonal 95% and 50% fixed kernel home ranges (Worton 1989, 1995; Seaman and Powell 1996) using least-squares cross validation to select the smoothing parameter (Worton 1989, Seaman and Powell 1996, Seaman et al. 1999). To determine the seasonal movements of desert bighorn sheep we connected all consecutive GPS locations for each animal with a straight line using the animal movements extension for ArcView. Topography, vegetation, and animal behavior can influence GPS fix success rates of GPS telemetry collars (Moen et al. 2001, D'Eon et al. 2002, Cain et al. 2005). To adjust our distances to account for missing GPS locations, we converted our movement distances to movement rates (m/hour) by dividing the distance between consecutive locations by the elapsed time between them. To estimate distance between bighorn locations and perennial water sources, we calculated the distance between each location and the nearest perennial water source.

We modeled the surface of our study

area using a 10-m × 10-m United States Geological Survey digital elevation models (DEM). We then calculated the surface area (km^2) of all MCP and kernel home ranges using the surface areas and ratios extension for ArcView (Jenness 2002, 2004). We used the surface tools for points, lines, and polygons extension for ArcView (Jenness 2005) and the seamless 10-m × 10-m DEM of our study area to calculate the surface distance between bighorn sheep locations and the nearest perennial water source, and the surface distance between consecutive locations and calculated movement rates by dividing the surface distance by the number of hours elapsed between GPS fixes.

We modeled home range area, movement rates, and distance to waters using a linear mixed effects model with season, range, year, and measurement type (i.e., planimetric or topographic) as factors. To account for repeated observations on individual animals within and across seasons and years, we included animal ID as a random intercept in all models in R (R Core Team 2022). We included season and year as factors because we expected that home range size and movements of female bighorn sheep would change annually due to precipitation related changes in forage conditions and would change seasonally due to parturition and lambing. In addition, there were differences in the topography of each mountain range that warranted including mountain range as a factor. To determine if differences in area, distance or movement rates were consistent across seasons and mountain range, we included interaction terms between measurement type and season and measurement type and range. Finally, we modelled the magnitude of the difference between planimetric and surface area metrics as a function of the distance or size of the planimetric measurement to determine if longer distances or larger home ranges were more or less prone to underestimation when not accounting for surface area. We considered a difference in home range area, distance to water and movement rate > 5% to be biologically significant and determined statistical significance at $P = 0.10$ for all analyses.

RESULTS

Home ranges that incorporated topography were larger than planimetric home ranges. The 95% kernel home ranges that incorporated topography were on average 12.8% larger (Table 1) than planimetric home ranges ($\beta = 1.67$, SE = 0.91, $t = 1.84$, $P = 0.067$). Interaction terms between measurement type and season ($\beta = -0.014$, SE = 0.846, $t = -0.017$, $P = 0.986$) and measurement type and range ($\beta = -0.93$, SE = 0.182, $t = -0.512$, $P = 0.609$) indicated that the differences between 95% kernel home range estimates that incorporated topography and planimetric areas were consistent across ranges and seasons. At the 50% core area scale, topographical home ranges were 17.6% larger than planimetric home ranges ($\beta = 0.33$, SE = 0.16, $t = 2.03$, $P = 0.043$; Table 1). Interaction terms between measurement type and season ($\beta = -0.001$, SE = 0.15, $t = -0.007$, $P = 0.994$) and measurement type and range ($\beta = -0.15$, SE = 0.32, $t = -0.47$, $P = 0.640$) indicated that the differences between estimates that incorporated topography and planimetric areas were consistent across ranges and seasons. The magnitude of the difference between kernel home range estimates incorporating surface area versus planimetric area increased with increasing size of the planimetric area for both 95% kernel home ranges and 50% core areas (Figure 1). For a given planimetric home range size the magnitude of the difference between surface area and planimetric area was higher in the Sierra Pinta than in the Cabeza Prieta mountains (Figure 1).

TABLE 1. Mean (± standard error) seasonal 50% core area and 95% kernel home range area (km^2) estimated using planimetric area (2D) and surface area (3D) for female desert bighorn sheep on the Cabeza Prieta National Wildlife Refuge, Arizona, USA, 2002–2005.

		Overall	Early summer	Late summer	Fall	Winter
50%	2D	1.88 ± 0.12	2.06 ± 0.24	1.70 ± 0.17	2.09 ± 0.31	1.66 ± 0.21
	3D	2.21 ± 0.13	2.40 ± 0.28	1.98 ± 0.20	2.45 ± 0.36	2.01 ± 0.25
95%	2D	13.01 ± 0.70	14.19 ± 1.37	11.74 ± 1.01	14.34 ± 1.88	11.89 ± 1.33
	3D	14.68 ± 0.76	15.91 ± 1.50	13.21 ± 1.10	13.21 ± 1.11	13.63 ± 1.49

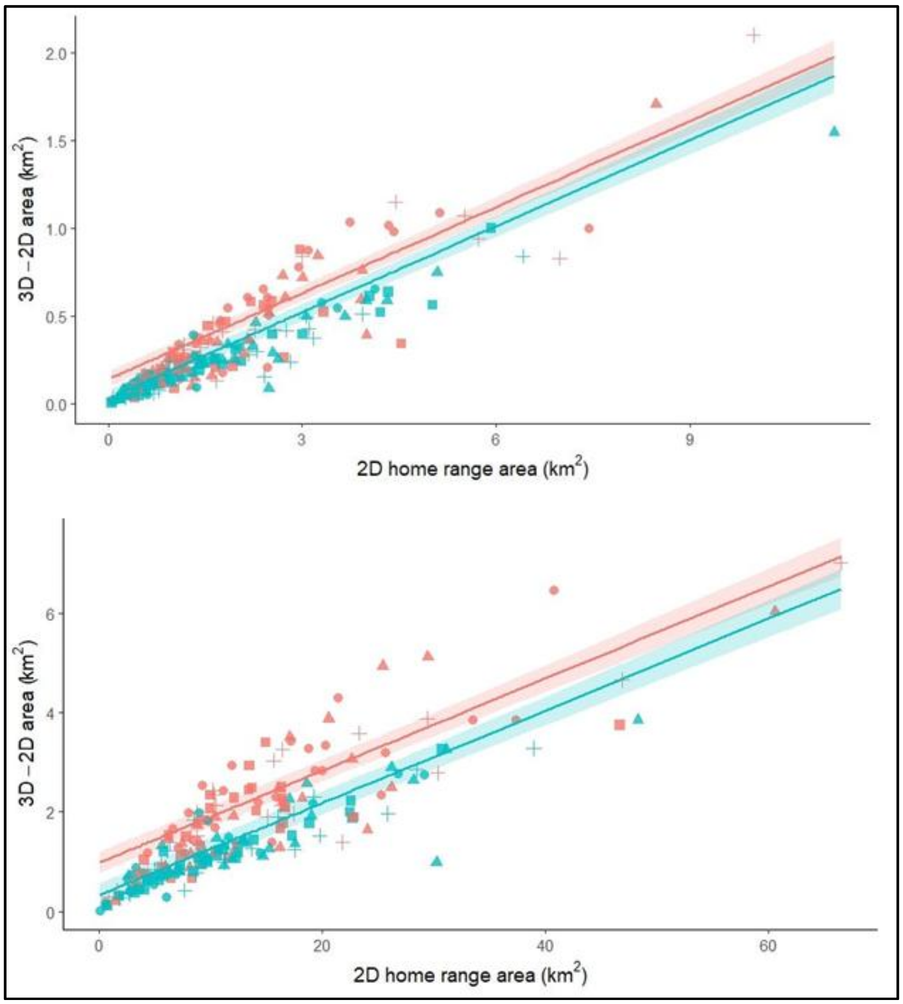


FIGURE 1. Differences between seasonal (circles = winter, triangles = early summer, squares = late summer, crosses = fall) home range estimates (50% top, 95% bottom) for female desert bighorn sheep that incorporate surface area (3D) versus only planimetric (2D) estimates as a function of planimetric home ranges area size in the Sierra Pinta (pink) and Cabeza Prieta (blue) mountains, Cabeza Prieta National Wildlife Refuge, Arizona, USA, 2002–2005. Shaded bands are 95% confidence intervals.

Estimates of MCP home ranges that incorporated surface area were on average 12.9% larger than planimetric home ranges, but the main effect of measurement type was not significant (β = -1.62, SE = 1.74, t = -0.933, P = 0.351; Table 2). The interaction term between measurement type and range was not significant (β = -1.22, SE = 1.39, t = -0.87, P = 0.383) and indicated that the differences between estimates that incorporated topography and planimetric areas were consistent across ranges. The differences between measurement type and season, however, indicated that the difference between estimates that incorporated topography and planimetric areas differed by season (β = 1.37, SE = 0.66, t = 2.08, P = 0.038; Table 2). The magnitude of the difference between MCP home range estimates incorporating surface area versus planimetric area decreased with increasing size of the planimetric area for both 95% kernel home ranges and 50% core areas (Figure 2).

TABLE 2. Mean (± standard error) MCP homer range sizes (km^2) estimated using planimetric area (2D) and surface area (3D) for female desert bighorn sheep on the Cabeza Prieta National Wildlife Refuge, Arizona, USA, 2002–2005.

	Overall	Early summer	Late summer	Fall	Winter
2D	12.82 ± 0.49	13.76 ± 1.09	12.35 ± 0.82	11.41 ± 1.34	13.29 ± 0.61
3D	14.47± 0.54	15.55 ± 0.93	13.74 ± 0.90	15.88 ± 1.57	12.88 ± 1.07

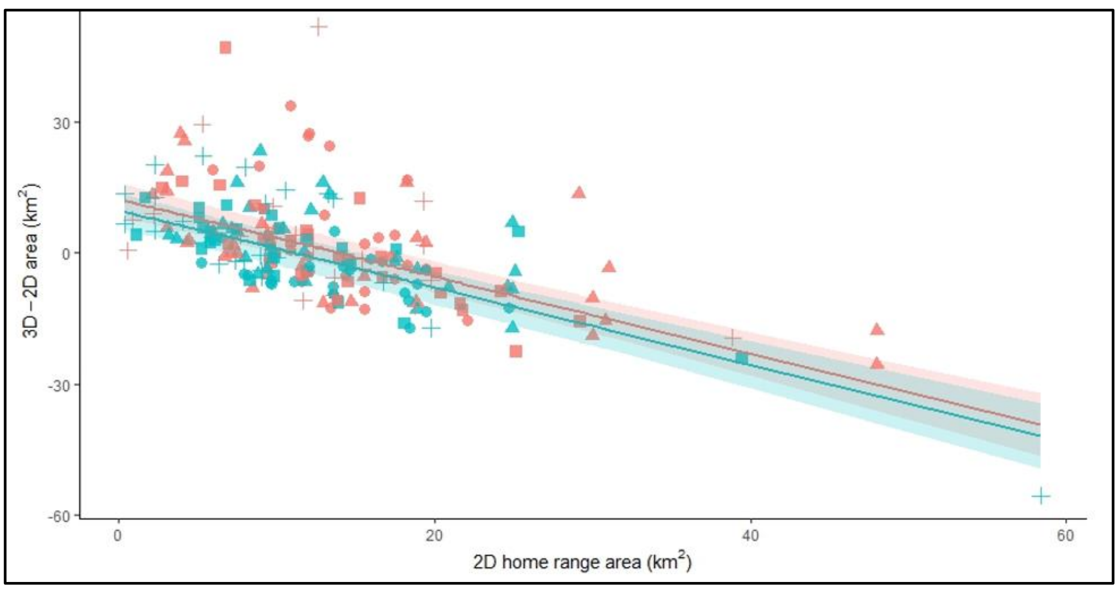


FIGURE 2. Differences between seasonal (circles = winter, triangles = early summer, squares = late summer, crosses = fall) MCP home range estimates for female desert bighorn sheep that incorporate surface area (3D) versus only planimetric (2D) estimates as a function of planimetric home ranges area size in the Sierra Pinta (pink) and Cabeza Prieta (blue) mountains, Cabeza Prieta National Wildlife Refuge, Arizona, USA, 2002–2005. Shaded bands are 95% confidence intervals.

Mean movement rates (m/hour) of desert bighorn sheep were 6% higher when estimated using surface distances compared to planimetric distances (β = 4.89, SE = 1.72, t = 2.84, P = 0.005; Table 3). Interaction terms between measurement type and season (β = -0.210, SE = 0.41, t = -0.506, P = 0.613) and measurement type and range (β = -0.98, SE = 0.898, t = -1.09, P = 0.275) indicated that the differences between estimates that incorporated topography and planimetric areas were consistent across ranges and seasons (Table 3). The magnitude of the difference for movement rates estimated incorporating surface versus planimetric distances increased with increasing planimetric distance (Figure 3). For a given planimetric movement rate the magnitude of the difference between surface rates and planimetric rates was higher in the Sierra Pinta than in the Cabeza Prieta Mountains (Figure 3).

TABLE 3. Mean (± standard error) seasonal movement rates (m/hour) estimated using planimetric distance (2D) surface distance (3D) for female desert bighorn sheep on the Cabeza Prieta National Wildlife Refuge, Arizona, USA, 2002–2005.

	Overall	Early summer	Late summer	Fall	Winter
2D	37.81 ±0.31	38.93 ± 0.54	37.29 ± 0.56	37.12 ± 0.71	37.66 ± 0.71
3D	40.70 ± 0.33	41.79 ± 0.57	39.96 ± 0.59	39.80 ± 0.75	41.02 ± 0.77

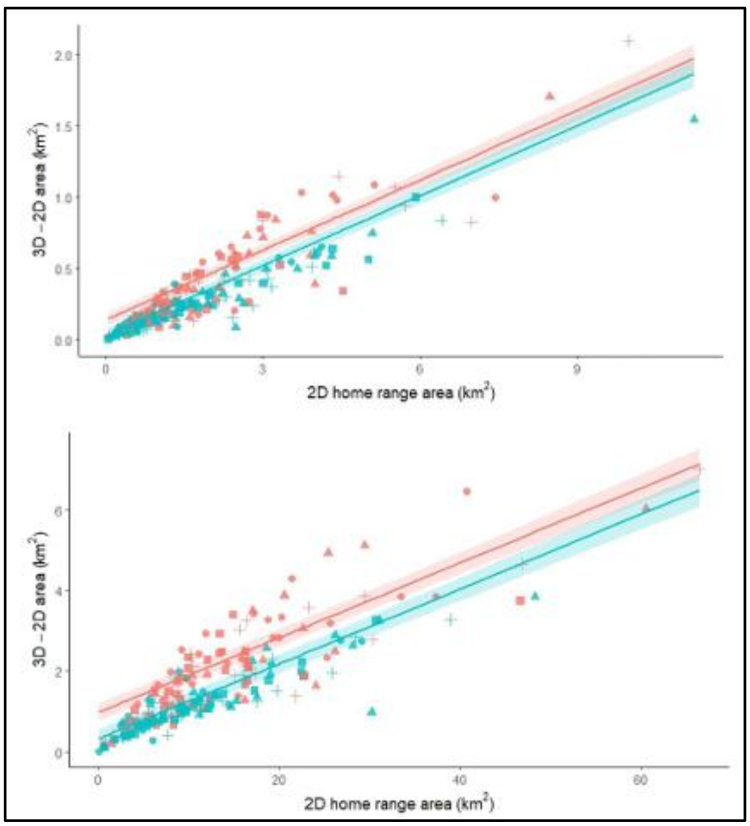


FIGURE 3. Differences between seasonal (circles = winter, triangles = early summer, squares = late summer, crosses = fall) distance to water (km; top) and movement rate (m/hr; bottom) estimates for female desert bighorn sheep that incorporate surface area (3D) versus only planimetric (2D) estimates as a function of planimetric distance in the Sierra Pinta (pink) and Cabeza Prieta (blue) mountains, Cabeza Prieta National Wildlife Refuge, Arizona, USA, 2002–2005. Shaded bands are 95% confidence intervals.

Distance to perennial water was an average of 7.8% greater when measured topographically than planimetrically (β = 3.19, SE = 0.041, t = 7.83, P <0.001). Differences in distance measurements were consistent across seasons (β = 0.006, SE = 0.009, t = 0.608, P = 0.543; Table 4) but differed by mountain range (β = -0.099, SE = 0.021, t = -4.68, P < 0.001); on average the surface distance to the nearest perennial water source was 9.3% greater than the planimetric distance in the Sierra Pinta whereas in the Cabeza Prieta surface distance to water was 5.2% higher than the planimetric distance (Table 4). The magnitude of the difference between distance to water estimated incorporating surface distance versus planimetric distance increased with increasing planimetric distance (Figure 3). For a given planimetric distance, the magnitude of the difference between surface distance and planimetric distance was higher in the Sierra Pinta than in the Cabeza Prieta Mountains (Figure 3).

TABLE 4. Mean (± standard error) seasonal distance (km) to nearest perennial water source by mountain range estimated using planimetric distance (2D) and surface distance (3D) for female desert bighorn sheep on the Cabeza Prieta National Wildlife Refuge, Arizona, USA, 2002–2005

	Early Summer		Late Summer		Fall		Winter	
	Sierra Pinta	Cabeza Prieta	Sierra Pinta	Cabeza Prieta	Sierra Pinta	Cabeza Prieta	Sierra Pinta	Cabeza Prieta
2D	2.53 ± 0.03	2.20 ± 0.03	2.49 ± 0.03	2.43 ± 0.03	2.80 ± 0.03	2.49 ± 0.04	2.46 ± 0.03	2.24 ± 0.03
3D	2.75 ± 0.03	2.33 ± 0.03	2.71 ± 0.03	2.55 ± 0.04	3.06 ± 0.03	2.64 ± 0.04	2.70 ± 0.03	2.38 ± 0.03

DISCUSSION

Home range areas and movement distances are commonly presented in terms of planimetric or map area (Jenness 2004); however, areas inhabited by desert bighorn sheep are steep and rugged, resulting in a high degree of topographical variation (McCarty and Bailey 1994, Krausman et al. 1989, Alvarez-Cárdenas et al. 2001, Krausman 2026). Similar to other assessments comparing planimetric map measurements to those that include surface area (Oli et al. 1997, Monterroso et al. 2013, Heit et al. 2021), our results suggest that failure to incorporate topography or surface area into estimates of desert bighorn sheep home range area, movement distances or rates, and distances to point resources will result in underestimation of these metrics ranging from 6 to 18%. We believe that the magnitude of the difference reported in our study is biologically significant and can have implications for a variety of ecological studies on desert bighorn sheep including those on resource availability-space use relationships, movement ecology, wildlife-habitat relationships, and bioenergetics.

Home range size of terrestrial mammals is commonly associated with body size, resource requirements, resource availability or habitat productivity (Harestad and Bunnell 1979, Oehler et al. 2003). Larger bodied species and those with larger resource requirements generally maintain larger home range areas. Habitat productivity is also related to home range area, with species that occupy highly productive habitats being able to meet their resource requirements in a smaller home range compared to species occupying less productive areas (Jewell 1966, Harestad and Bunnell 1979). This relationship between habitat productivity and home range area has been widely reported for ungulates, including desert bighorn sheep (Leslie and Douglas 1979, Krausman et al. 1989, Tufto et al. 1996, Relyea et al. 2000, Oehler et al. 2003, Cain et al. 2008). Movement rates of desert bighorn are also associated with forage conditions, with higher movement rates in areas with poor foraging resources (Krausman et al. 1989). Seasonal changes in forage resources are associated with changes in home range size and movement rates, both of which tend to be highest for desert bighorn sheep during seasons with low precipitation (Warrick and Krausman 1987, Alderman et al. 1989, Krausman et al. 1989, Cain et al. 2008).

Our results reveal that bighorn sheep home range areas estimated planimetrically underestimated actual surface area. Larger topographical home range estimates were consistent across seasons, years, and between mountain ranges. Movements were also higher when accounting for topography. Lack of variation between topographical and planimetric measurements across seasons is likely attributed to year-round selection for steep, rugged terrain (Simpson et al. 1978). Differences in topographical and planimetric home range sizes were consistent for both MCP and kernel methods. For kernel home ranges, the magnitude of the differences between planimetric and topographic home ranges increased with increasing size of the planimetric home range, larger areas had larger disparities between estimates. With home ranges measured with MCP metrics, however, the magnitude of the differences between planimetric and topographic home ranges attenuated with increases in planimetric MCPs. The differences between the kernel and MCP home ranges was likely due to larger MCPs for desert bighorn sheep typically including outlying points, that result in the inclusion of more areas with flatter, less steep terrain, where planimetric areas more closely approximate surface areas. Conversely, the smoothing that occurs when estimating kernel home ranges, results in the omission of these outlying points, resulting in more of the home range or core area being in typical desert bighorn habitat. Similarly, the magnitude of the difference between surface and planimetric measurements was higher in the Sierra Pinta than the Cabeza Prieta Mountains. We believe this is attributed to the structural differences between mountain ranges. The Sierra Pinta is a long, fault block mountain range with steep ridges and canyons oriented perpendicular to the main direction of the range, whereas the Cabeza Prieta Mountains is a mostly volcanic mountain range complex with numerous flat valleys between rugged terrain, mountain terrain. These flat valleys are narrow enough to be readily crossed by desert bighorn sheep and are thus incorporated into most home ranges.

The distribution of animals in relation to the location of key non-forage resources, like drinking water, is related to the degree of dependency on that resource, which can change seasonally. The location of desert bighorn sheep can be heavily dependent on location of water sources, particularly in summer (Leslie and Douglas 1979, Alvarez-Cárdenas et al. 2001, Cain et al. 2008, Krausman 2026). Consequently, use of topographical measurements of home range are more likely to accurately characterize distance traveled and increased energetic costs associated with navigating more complex terrain (Walter et al. 2013). For example, Dailey and Hobbs (1989) reported that oxygen demand for mountain goats (*Oreamnos americanus*) and bighorn sheep more than doubled when traveling on a 21° slope versus a flat surface. In our study area, the average slope at GPS locations collected by telemetry collars was 28.3° (SD = 10.7°) with over 46% of the locations on slopes of 31° (or 60%; typical definition of escape terrain; J.W. Cain, unpublished data). Such steep slopes could be associated with significant increases in energetic demands that may not be captured if we assumed planimetric home range estimates are sufficient. Incorporating topography into space use measurements for desert bighorn sheep more accurately represents distances traveled and the resulting increased energetic costs associated with movement in mountainous or rugged terrain.

For species located in areas with minimal topographical variation, planimetric measurements are likely adequate (Castleberry et al. 2001, Campbell et al. 2004). However, in areas where topographical variation is a significant part of the landscape, planimetric measurements may underestimate home range area (Smith et al. 1989). Because of the significant difference between topographical and planimetric measurements for desert bighorn sheep, however, and likely other mountain-dwelling ungulates, inclusion of surface area for home range size, movement and distance metrics will more accurately characterize the energetic consequences of movement and habitat selection. The thoughtful use of GPS datasets could allow for further assessment of energetic expenditure of animals traversing their home ranges in such terrain. Additionally, researchers might also use these findings to determine if there are fitness consequences associated with use of home ranges with more topographical variation in alpine ungulates. A better understanding of bighorn sheep ecological needs could also help managers identify key habitat for conservation activities, and this starts with more realistic representation of space use.

ACKNOWLEDGMENTS

Funding was provided by the United States Fish and Wildlife Service. We thank M. Bissell, M. Coffeen, T. Henley, C. S. McCasland, and J. R. Morgart of the Cabeza Prieta National Wildlife Refuge for logistical support. We also thank J. J. Hervert and D. M. Conrad of the Arizona Game and Fish Department for capturing study animals. Comments by V. C. Bleich, K. M. Longshore, and T. D. Nordeen improved an earlier version of this manuscript. We also thank W. P. Smith for helping track down an important reference.

REFERENCES

Alderman, J. A., P. R. Krausman, and B. D. Leopold. 1989. Diel activity of female desert bighorn sheep in western Arizona. Journal of Wildlife Management 53:264–271.

Alvarez-Cárdenas S., I. Guerrero-Cárdenas, S. Díaz, P. Galina-Tessaro, and S. Gallina.2001. The variables of physical habitat selection by the desert bighorn sheep (*Ovis canadensis weemsi*) in the Sierra del Mechudo, Baja California Sur, Mexico. Journal of Arid Environments 49:357–374.

Cain, J. W. III, P. R. Krausman, B. D. Jansen, and J. R. Morgart. 2005. Influence of topography and GPS fix interval on GPS collar performance. Wildlife Society Bulletin 33:926–934.

Cain, J. W. III, P. R. Krausman, J. R. Morgart, B. D. Jansen, and M. P. Pepper. 2008. Responses of desert bighorn sheep to removal of water sources. Wildlife Monographs 171:1–32.

Campbell, T. A., B. R. Laseter, W. M. Ford, and K. V. Miller. 2004. Topographic home ranges of white-tailed deer in the central Appalachians. Southeastern Naturalist 3:645–652.

Castleberry, S. B., W. M. Ford, P. B. Wood, N. L. Castleberry and M. T. Mengak. 2001. Movements of Allegheny woodrats in relation to timber harvesting. Journal of Wildlife Management 65:148–156.

Chui, S. Y., W. M. Getz, M. Henley, D. P. Seidel, M. Keith, F. Parrini, and L. Karczmarski. 2024. Habitat use strategies of African elephants under different seasonal and ecological constraints. Wildlife Research 51(9):WR23139.

Dailey, T. V., and N. T. Hobbs. 1989. Travel in alpine terrain energy expenditures for locomotion by mountain goats and bighorn sheep. Canadian Journal of Zoology 67:2368–2375.

D'Eon, R. G., R. Serrouya, G. Smith, and C. O. Kochanny. 2002. GPS radiotelemetry and bias in mountainous terrain. Wildlife Society Bulletin 30:430–439.

Environmental System Research Institute. 2000. ArcView 3.2. Environmental System Research Institute, Redlands, California, USA.

Fleming, C.H., W. F. Fagan, T. Mueller, K. A. Olson, P. Leimgruber, and J. M. Calabrese. 2015. Rigorous home range estimation with movement data: a new autocorrelated kernel density estimator. Ecology 96:1182–1188.

Getz, W. M., S. Fortmann-Roe, P. C. Cross, A. J. Lyons, S. J. Ryan, and C. C. Wilmers. 2007. Nonparametric kernel methods for constructing home ranges and utilization distributions. PLoS ONE 2:e207

Greenberg, D. B., and W. J. McClintock. 2008. Remember the third dimension: terrain modeling improves estimates of snake home range size. Ichthyology and Herpetology 2008:801–806.

Harestad, A. S., and F. I. Bunnell. 1979. Home range and body weight: a reevaluation. Ecology 60:389–402.

Harris, G. M., M. J. Butler, D. R. Stewart, E. M. Rominger, and C. Q. Ruhl. 2020. Accurate population estimation of Caprinae using camera traps and distance sampling. Scientific Reports 10:17729.

Heit, D. R., W. Ortiz-Calo, and R. A. Montgomery. 2021. Landscape complexity persists as a critical source of bias in terrestrial animal home range estimation. Ecology 102:e03427.

Herfindal, I., J. D. C. Linnell, J. Odden, E. B. Nilsen, and R. Andersen. 2005. Prey density, environmental productivity and home-range size in the Eurasian lynx (*Lynx lynx*). Journal of Zoology 265:63–71.

Hooge, P. N. and B. Eichenlaub. 1997. Animal movement extension to ArcView. Version 2.04. Alaska Biological Science Center, U.S. Geological Survey, Anchorage, Alaska, USA.

Horne, J. S., E. O. Garton, S. M. Krone, and J. S. Lewis. 2007. Analyzing animal movements using Brownian bridges. Ecology 88:2354–2363.

Jenness, J. S. 2002. Surface areas and ratios from elevation grid extension for ArcView 3.x, (v 1.2). <http://www.jennessent.com/arcview/arcview_extensions.htm> Accessed 13 December 2014.

Jenness, J. S. 2004. Calculating landscape surface area from digital elevation models. Wildlife Society Bulletin 32:829–839.

Jenness, J. S. 2005. Surface tools for points, lines, and polygons extension for ArcView 3.x, (v 1.6. <http://www.jennessent.com/arcview/arcview_extensions.htm> Accessed 13 December 2014.

Jennrich, R. I., and F. B. Turner. 1969. Measurement of non-circular home range. Journal of Theoretical Biology 22:227–237.

Jerina, K. 2012. Roads and supplemental feeding affect home-range size in Slovenia red deer more than natural factors. Journal of Mammalogy 93:1139–1148.

Jewell, P. A. 1966. The concept of home range in mammals. Proceedings of the Symposium of the Zoological Society of London 18:85–109.

Killeen, J., H. Thurfjell, S. Ciuti, D. Paton, M. Musiani, and M. S. Boyce. 2014. Habitat selection during ungulate dispersal and exploratory movement at broad and fine scale with implications for conservation management. Movement Ecology 2:15.

Krausman, P. R., J. J. Hervert, and L. L. Ordway. 1985. Capturing deer and mountain sheep with a net gun. Wildlife Society Bulletin 13:71–73.

Krausman, P. R., B. D. Leopold, R. F. Seegmiller, and S. G. Torres. 1989. Relationships between desert bighorn sheep and habitat in western Arizona. Wildlife Monographs 102:1–32.

Krausman, P. R. 2026. Characteristics of habitat for mountain sheep. Pages 347–377 *in* P. R. Krausman and W. Jex, editors. Mountain Sheep in North America: biology, ecology, conservation and management. CRC Press, Boca Raton, Florida, USA.

Leblond, M., C. Dussault, and J. P. Ouellet. 2013. Avoidance of roads by large herbivores and its relation to disturbance intensity. Journal of Zoology 289:32–40.

Leslie, D. M., Jr., and C. L. Douglas. 1979. Desert bighorn sheep of the River Mountains, Nevada. Wildlife Monographs 66:3–56.

McCarty, C. W., and J. A. Bailey, J. A. 1994. Habitat requirements of desert bighorn sheep. (No. 69). Colorado Division of Wildlife, Denver, Colorado, USA.

Moen, R., J. Pastor, and Y. Cohen. 2001. Effects of animal activity on GPS telemetry location attempts. Alces 37:207–216.

Monterroso, P., N. Sillero, L. M. Rosalino, F. Loureiro, and P. C. Alves. 2013. Estimating home-range size: when to include a third dimension? Ecology and Evolution 3:2285–2295.

Oehler, M. W., Sr., R. T. Bowyer, and V. C. Bleich. 2003. Home ranges of female mountain sheep, *Ovis canadensis nelsoni*: effects of precipitation in a desert ecosystem. Mammalia 67:385–401.

Oli, M. K. 1997. Winter home range of snow leopards in Nepal. Mammalia 61:355–360.

Owen-Smith, N., and J.W. Cain III. 2007. Indicators of adaptive responses in home range utilization and movement patterns by a large mammalian herbivore. Israel Journal of Ecology and Evolution 53:423–438.

Parker, K. L., C. T. Robbins, and T. A. Hanley. 1984. Energy expenditures for locomotion by mule deer and elk. Journal of Wildlife Management 48:474–488.

R Core Team., 2022. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Reddell, C. D., G. W. Roemer, D. K. Delaney, T. Karish, and J. W. Cain III. 2023. Anthropogenic subsidies influence resource use during a mange epizootic in a desert coyote population. Oecologia 201:435–447.

Relyea, R. A., R. K. Lawrence, and S. Demarais. 2000. Home range of desert mule deer: testing the body-size and habitat-productivity hypothesis. Journal of Wildlife Management 64:146–153.

Seaman, D. E., and R. A. Powell. 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. Ecology 77:2075–2085.

Seaman, D. E., J. J. Millspaugh, B. J. Kernohan, G. C. Brundige, K. J. Raedeke, and R. A. Gitzen. 1999. Effects of sample size on kernel home range estimates. Journal of Wildlife Management 63:739–747.

Simpson, C. D., L. J. Krysl, D. B. Hampy, and G. G. Gray. 1978. The Barbary sheep: a threat to desert bighorn survival. Desert Bighorn Council Transactions 22:26–31.

Smith, W. P., J. M. Benner, D. Borden, A. Bailey, Y. Robinet-Clark and K. M. Endres. 1989. Evaluating a three-dimensional world with two dimensions: how much difference can it make? International Symposium on Biotelemetry Proceedings 10:679–684.

Stone, K. D., G. A. Heidt, P. T. Caster, and M. L. Kennedy. 1997. Using geographic information systems to determine home range of the southern flying squirrel (*Glaucomys volans*). American Midland Naturalist 137:106–111.

Tufto, J., R. Andersen, and J. Linnell. 1996. Habitat use and ecological correlates of home range size in a small cervid: the roe deer. Journal of Animal Ecology 65:715–724.

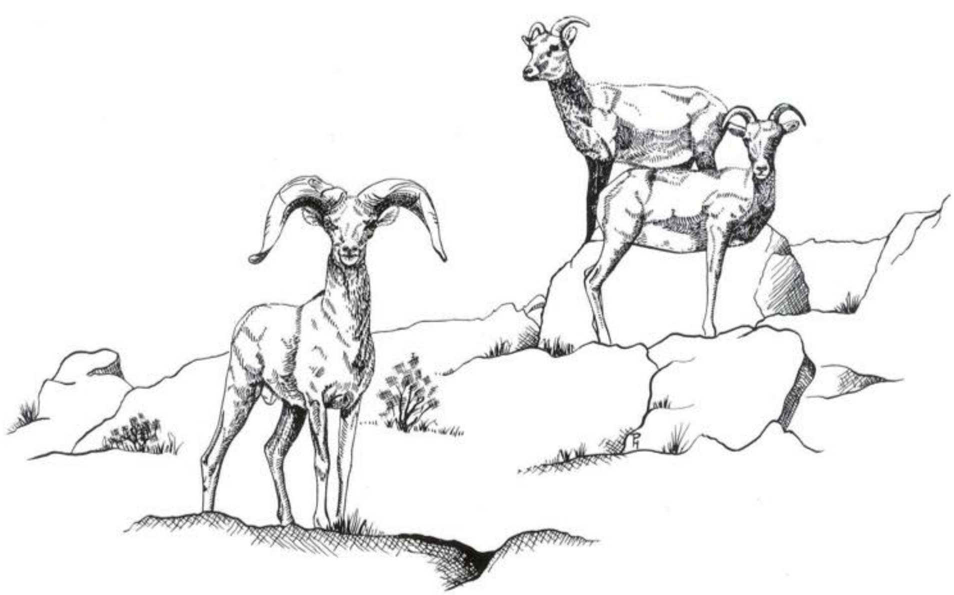
Walter, W. D., J. W. Fischer, T. J. Frink, S. E. Hygnstrom, J. A. Jenks, and K. C. Vercauteren. 2013. Topographic home range of large mammals: is planimetric home range still a viable method? Prairie Naturalist 45:21–27.

Warrick, G. D., and P. R. Krausman. 1987. Foraging behavior of female mountain sheep in western Arizona. Journal of Wildlife Management 51:99–104.

Western Regional Climate Center. 2026. Climate data, Kofa Mine, AZ station. https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?az4702. Accessed 26 Jan 2026.

Worton, B. J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. Ecology 70:164–168.

Worton, B. J. 1995. Using Monte Carlo simulation to evaluate kernel-based home range estimators. Journal of Wildlife Management 59:794–800.



Wildlife Water Developments in Arizona: Advances and Innovations

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Desert Bighorn Council Transactions 58:58–67

ABSTRACT Wildlife management agencies developing water sources for wildlife date to at least the 1940s. The earliest sources often consisted of holding tanks as small as 200 liters and targeting primarily gallinaceous birds. As desert bighorn sheep managers began to research the importance of available free-standing water to these animals, developments began to morph into larger and more sophisticated designs. Triggering these changes were key factors that limited the value of these sources to desert bighorn sheep and other desert wildlife. Water storage capacity is one of the primary reasons that designs were modified, as early designs were small, requiring frequent and costly water hauling to refill these facilities. Another consideration was the need to reduce evaporation. In many southwestern areas evaporation can be as much as 300 cm per year. The current designs include sealing and shading tinajas (natural rock plunge holes), vault and apron tanks (large artificial aprons to catch rainwater and underground storage), and buried PVC pipe developments. Designs should be used as appropriate to a specific site and purpose and there is no single type that is universally ideal. One of the most significant improvements in wildlife water management is the use of remote monitoring tools. These devices measure the available water level, but can also detect unusual rates of water depletion, and via satellite provide managers real-time alerts when situations warrant a quick response. These devices are an essential element of water management, reducing the financial cost and human resources needed to maintain water availability for desert bighorn sheep, and other wildlife.

KEY WORDS desert bighorn sheep, efficiency, habitat enhancement, *Ovis canadensis*, remote sensing, safety, techniques, technology

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Availability of suitable habitat determines the distribution and numbers of desert bighorn sheep (*Ovis canadensis* spp.) that a given area can support (Brewer et al. 2014). To meet the requirements of suitable desert bighorn sheep habitat, the area must contain adequate amounts of forage, escape terrain to evade predators, lambing and loafing areas, water, and unobstructed movement corridors (Hansen 1980, McKinney et al. 2003). These habitat components must be juxtaposed and well-distributed throughout desert bighorn sheep ranges to meet their needs (Brewer et al. 2014).

Most descriptions of wildlife habitat emphasize the importance of food, water, and shelter, and for desert bighorn sheep, free-standing water sources are a particularly vital component of quality habitat. One of the first in-depth study of the need for free-standing water for desert bighorn sheep was conducted by Turner (1973); based on that study, he concluded that desert bighorn sheep could not survive extended periods of hot and dry conditions without water being available. Studies also have shown a close correlation between free-standing water and the presence of desert bighorn sheep (Bates and Workman 1983, Cunningham and Ohmart 1986). These correlations increase during hot, dry periods and particularly during breeding and lactation periods (Hansen 1980, Turner and Weaver 1980).

There have been few reports of desert bighorn sheep living without access to free water, with those being in small mountain ranges and small populations (Krausman and Leopold 1986). Considering the large intermountain movements made by some desert bighorn sheep, it is possible that even in these few cases, the desert bighorn sheep were able to access free water found outside of their typical home range (Witham and Smith 1979, Ough and deVos 1984).

In one study Cain et al. (2008) used an experimental design to evaluate desert bighorn sheep response to the removal of available water on several behavioral and demographic characteristics of desert bighorn sheep in southwestern Arizona. As part of this study, water sources were managed to ensure that water was available to desert bighorn sheep and other wildlife for two years. After this phase, all available water sources were made unavailable for two years during which desert bighorn sheep responses were monitored for differential use patterns at waters and for demographic changes. The pre-treatment period was one of severe drought and the post-treatment was an above average period of rainfall, with the researchers concluding that the differing climate resulted in their inability to measure the desert bighorn sheep response to the drying of the available water sources in a dry period.

In a recent assessment of habitat needs for desert bighorn sheep, deVos and Lee (in press) reported that maintaining or enhancing free-standing water was an important action for agencies and wild sheep advocacy groups to engage in to ensure robust desert bighorn sheep populations or to repatriate this subspecies back to vacant, historical habitat. Those authors summarized that there were several impacts to bighorn habitat including additional human infrastructure such as powerlines and transportation corridors that result in isolation of water resources with this isolation being a factor that began decades before the present time (McQuivey 1975, Leslie and Douglas 1979).

As a result of these and similar impacts, Trombulak and Frissell (2000) suggest that it is important to maintain metapopulation function by ensuring that a smaller segment of this metapopulation had available water to avoid local extirpation. This concept was incorporated in a comprehensive review of habitat needs for wild sheep (Brewer et al. 2014) who also recommend that wildlife management agencies and wild sheep advocacy groups endeavor to ensure adequate distribution of water through protection of existing perennial or ephemeral sources and provision of wildlife water developments when appropriate.

Various researchers that have developed models that predict suitable habitat for desert bighorn sheep or to predict the potential areas for successful desert bighorn sheep translocation areas in vacant habitat, typically value water availability as the most important parameter (Hansen 1980, Brown 1983). As the concept of the importance of free-standing water for desert bighorn sheep was recognized, early projects were typically small, often merely modifications to existing natural waters—mucking out a natural rock plunge hole, perhaps sealing cracks, and maybe putting up a shade to reduce evaporation (Werner 1989; Figure 1). Later, catchment rims were raised, gabions constructed, and steps cut into the rock. Then fences or grates were built to exclude use by feral and domestic livestock, and in some cases, use by predators. Then exclusions were built to preclude feral animal use and, in some cases to exclude bears (*Ursus americanus*) and mountain lions (*Puma concolor*). Eventually, modern projects became quite large, requiring dozens of laborers and heavy equipment (except in wilderness areas), with multiple 9,500-L storage tanks, and remote sensing devices to determine water storage levels and check for leaks.

Halloran and Deming (1958) reviewed the state of water developments for desert bighorn sheep on the Kofa and Cabeza Prieta game ranges in Arizona, and the Desert Game Range in Nevada. A unique element of water development that these authors reported was the engineering plans developed by the U.S. Fish and Wildlife Service and the Civilian Conservation Corps that were used in these projects; many previous water developments were planned on-site and lacked the structural integrity that engineered plans provided. Holloran and Deming (1958) also evaluated a second type of development: improvements to existing tinajas or rock and concrete dams placed in water flow channels. Additionally, these authors discussed a variety of water types developed primarily for livestock or other wildlife such as mule deer (*Odocoileus hemionus*) although spring and tinaja were the primary developments reviewed. To guide development of all types of wildlife waters, a planning guide with engineered plans for most water developments used in the American Southwest (Arizona Game and Fish Department 2014) that is revised periodically; the most recent version is dated 2024.

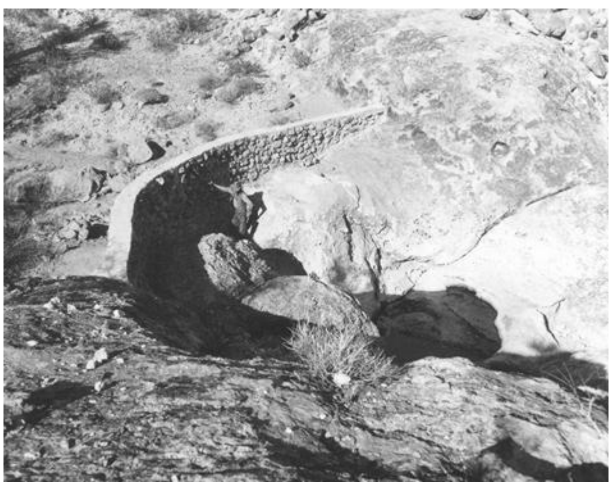


FIGURE 1. Most early developments were improvements to existing plunge pools, with the improvements being construction of a dam to increase storage capacity, as well as sealing cracks and removal of materials that have been trapped with water flows into the plunge pool.

In 1946, the Arizona Game and Fish Department (AZGFD) Development and Maintenance crew built the first 'wildlife guzzler'. Water development continued in the 1950s with the AZGFD and other state and federal wildlife management agencies developing waters primarily for quail (*Callipepla gambelii*) and supporting upland game bird introductions. One of the first developments targeting desert bighorn sheep was at Pusch Ridge, Santa Catalina Mountains, which was developed in the early 1950s using pack animals to transport materials (Figure 2). As was the case with most water developments in the American Southwest, this project was the expansion of an existing, but ephemeral, natural plunge hole.

Over the next five decades, water development design, site selection, materials, and construction methods have continued to evolve. This has resulted in an array of catchment types, some functioning well, others not, but all contributing to a growing maintenance load. Progressing from the bedrock tinaja, the next step was the development of the "apron and vault" catchment where an apron was used to catch rainfall and funnel it into a vault where evaporation was minimized (Figure 3).

FIGURE 2. Pack animals were used to transport equipment to remote wildlife water developments. One of the first developments targeting bighorn sheep populations was this project on Pusch Ridge, Catalina Mountains, Arizona, in 1951. Subsequently, helicopters and heavy equipment are used to transport and place the components of water developments.

As funding and large volunteer workforces became more available, improved designs continued to evolve and large underground storage developments are now used in many places. The advantages of this type of development are that it has exceptionally minimal maintenance requirements, has large storage capacity that virtually eliminates the need for subsequent water hauling to avoid water being unavailable, and evaporation is virtually eliminated. Evaporation loss is a critical issue in managing waters for desert bighorn sheep in the Sonoran Desert. For example, evaporative loss has been reported to be ~299 cm at Bartlett Dam and ~392 cm at Davis Dam, Arizona (Western Regional Climate Center 2025).

FIGURE 3. An apron and vault-type bighorn sheep development offered improvements from the tinaja water source as evaporation was minimized. A disadvantage of this type of catchment was that the apron required considerable maintenance to ensure functionality.

FIGURE 4. This type of system, which consists of a series of large PVC tubes or pipes that feed the drinker virtually eliminates maintenance and improves water availability for desert bighorn sheep.

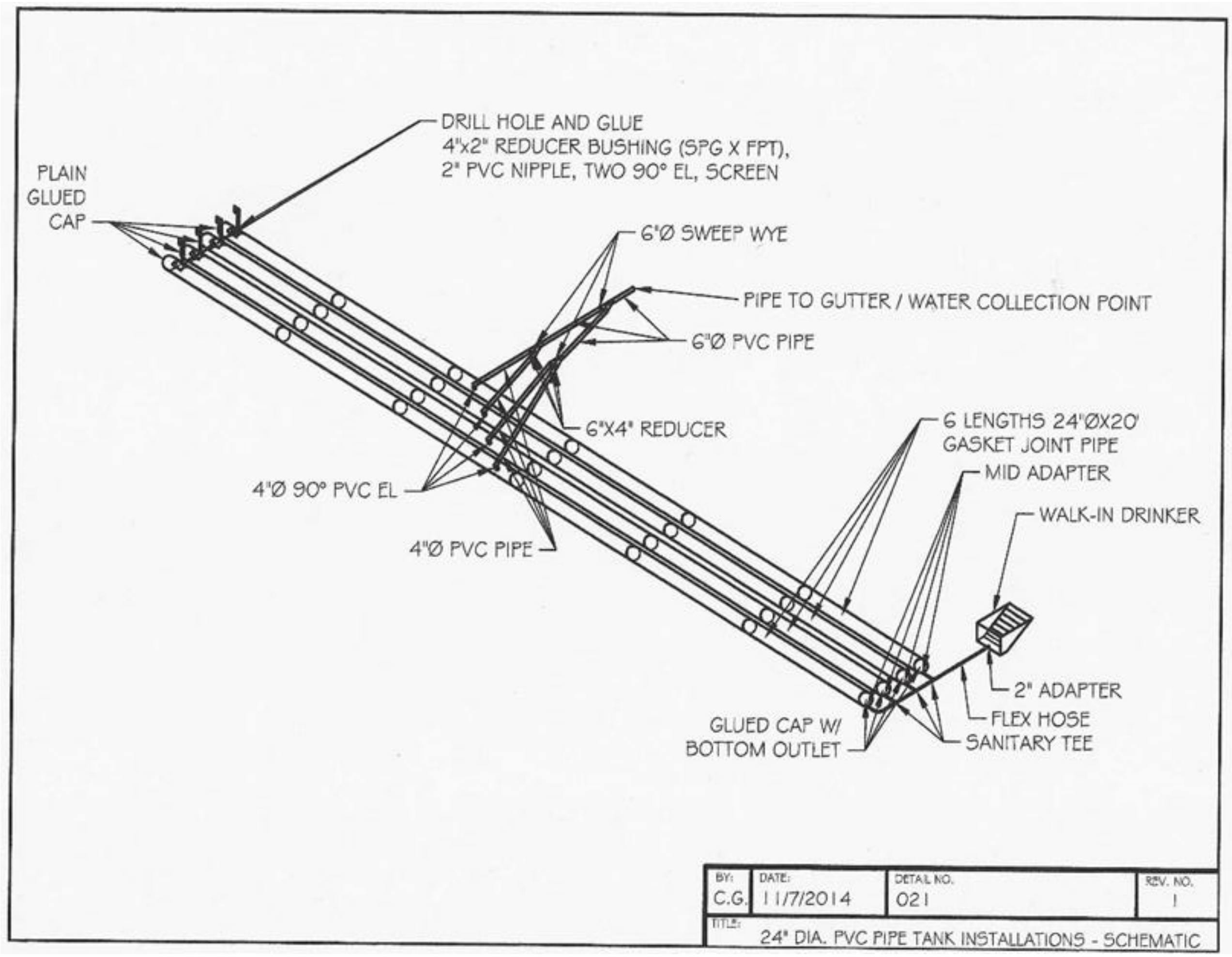


FIGURE 5. Engineered design of the underground PVC vault catchment. Placed in a downslope location, the upper end has small, screened protected water capture tubes that fill the pipes below with ground water flows. At the distal end, the four tubes are combined and feed a single walk-in drinker. The volume of this facility is about 6,000 cubic feet or 24,000 gallons. An advantage is that the system is gravity-fed and is maintenance free.

More recently, project design began to take advantage of the increasing funding and volunteer labor and equipment and very large, complex designs evolved. One of the major advancements in catchment design has been the underground placement of several large diameter PVC tubes that are interconnected but serve a single drinker. These projects require heavy ground moving equipment to dig the trough for these tubes and to bury them once the system is completed. Although the initial cost of this type of development is substantial and varies with the price of energy (in 2025 the cost was $45,000/unit), the long life and minimal maintenance costs of this system have resulted in this system being constructed for desert bighorn sheep (Figure 4, Figure 5). We believe that this is one of the most useful designs for not only desert bighorn sheep but other wildlife species as well, and it has the advantage of a very large capacity (~90,000 L), virtually eliminates evaporative losses, and has proven to have minimal maintenance requirements. Depending on the objective and anticipated wildlife use, the length of the PVC tubes can be varied according to predicted demand.

Although several types of water developments are used to provide water to desert bighorn sheep, an important type is the use of 9,500-L plastic tanks that can be placed above-ground or buried. An advantage of this type of development is that the tanks can easily be delivered to a remote site by helicopter and several can be plumbed together to meet the storage objective for a specific site. Life expectancy for these facilities can exceed 30 years and upon failure, can be easily replaced by helicopter delivery. Unlike some other types of developments, these tanks can be placed in the prime areas needed by desert bighorn sheep. In many areas of the American Southwest, this type of facility is the most used.

Many key advances in wildlife water developments have been documented by the AZGFD as the agency developed a guide to assist in the design and implementation of a wide variety of water developments (AZGFD 2014, as updated). The 2014 version included 23 pages of text, 3 pages of engineering standards, and 25 pages of technical drawings and photos. These standards address: tanks, troughs, precipitation collection aprons, tinaja sealants, shade structures, gabions, dams, fencing, escape passages, membranes (liners), evaporation covers, and camouflaged finishes, such as artificial rocks, and an awareness solar radiation causes some plastics to degrade, with contamination of the water source being a potential result. We find this document to be a great resource for wildlife and land managers involved in creating or improving water sources for desert bighorn sheep and other wildlife.

An important advancement in managing wildlife water sources and availability is the use of remote sensing devices that allow managers to check water levels and detect system failures such as leaks in the system remotely. AZGFD has experimented with multiple systems and are now using a system referred to as the Ranchbot, although there are other useful brands. These systems have been deployed to check open water systems such as tinajas via satellite-connected cameras, ring tanks with depth detectors, and in closed enclosed water systems including large storage tanks (Figure 6).

FIGURE 6. An example of a remote sensing device at a desert bighorn sheep water source. Once installed, this system communicates via satellite with a monitoring computer, and data such as water level and system failures can be detected without costly and time-consuming field visits.

Arizona Game and Fish Department personnel have deployed >100 of these remote-sensing units primarily on desert bighorn sheep water sources, and there are several financial and technical advantages of doing so (M Rice, AZGFD, personal communication). Among these are the following examples.

(1) Time Savings. It takes a 10–12-hour day to check Thompson Tank, Barry M. Goldwater Firing Range, which requires access from the Air Force since you must cross restricted training areas and limits access mostly to weekends and federal holidays. Based on an average cost per hour of $100, the total cost is

approximately $1000. When adding vehicle costs to a single trip, which is about $200 trip, the cost of checking this water is about $1,200/visit.

2. Human Safety. Trigo Tanks in GMU 43B on Yuma Proving Grounds, which also poses restricted access, involves a 2–2.5-hr drive one way, followed by a 2-km hike one way. Due to extreme summer temperatures, which is the most crucial time to monitor such facilities, water checks in very remote areas require hiking in conditions that pose substantial risks to personnel.

3. There are currently 5 remote cameras deployed that send pre-scheduled weekly photos on potholes in southwestern Arizona. It is also possible to upload a photo at any time which is provided within 15 minutes via satellite communication.

4. Satellite or cellular connectivity sends water-level data from remote locations to a cloud platform, enabling near-real-time alerts to text or email when water levels change unexpectedly, and is one of the most important advances in wildlife water management because of immediate notification when water levels are low or drop rapidly due to a system failure, enabling a faster response to ensure water is available for desert bighorn sheep and other wildlife.

The cost of the initial unit is approximately $1,400 and operation requires an annual subscription cost of about $300 per year, which is quickly recovered when comparing the cost of a single monitoring trip to Trigo Tank. When personnel cost is combined with the vehicle costs, this single visit cost is nearly equal to that of the placement of a monitoring unit. If more than one visit is required to check this tank, the cost of the unit is more than offset by the time and travel expenses associated with the important task of maintaining water availability.

Although the cost savings are clear, the efficiency of this system provides tremendous advantages to the wildlife manager responsible for monitoring remote wildlife waters. An unexpected malfunction or system leak may go undetected for months between physical inspections, with the consequence of desert bighorn sheep being unable to access surface water. These systems, however, have remote messaging capabilities that send an alert to the person(s) responsible for monitoring wildlife water developments.

Remote monitoring systems offer wildlife managers a particularly useful tool to improve reliability and enhance dependability of water sources used by a variety of desert-dwelling wildlife. Given the thousands of wildlife waters that exist throughout desert bighorn sheep habitat, these systems offer agencies and conservation organizations a tremendous opportunity for both improved water management and substantial savings in personnel time that can be used in other wildlife management programs. In addition to the information from AZGFD, the Utah Wild Sheep Foundation (Peterson 2025) which has also deployed remote sensing equipment and reported substantial advantages to remote water sensing from both efficiency and cost-saving standpoints.

SUMMARY

We suggest that well-designed and well-placed water sources are essential for healthy and abundant desert bighorn sheep populations, and that can be best accomplished by considering the following.

(1) The impacts to desert bighorn water sources will continue at an increasing rate with isolation due to habitat fragmentation and the consequences of climate change and the resulting difference in the hydrologic cycle making an active water development program an essential part of agency management and

consistency. Schwartz et al. (1986) suggested that desert bighorn sheep occur over large geographic areas and are comprised of smaller, but interconnected groups of animals and therefore, a critical action is maintaining key wildlife waters within each of these habitat components. Without adequate free-standing waters, it is likely that this lack will lead to local extirpation.

(2) Developing close working relationships with wild sheep advocacy groups to help develop funding for water development and with land management agencies to gain permission to build wildlife waters is an essential component of effective water management. It is also important to tap into the large labor pool that these non-governmental organizations provide. In the late 1960s, the Arizona Desert Bighorn Sheep Society was one of the first non-governmental organizations to start helping with wildlife management and land management agencies develop waters primarily for desert bighorn sheep. This program expanded to major development projects with as up to 100 volunteers: with many of the volunteers having construction experience and with dozens of projects under their belts. A number of wild sheep advocacy groups—including the Wild Sheep Foundation and its numerous chapters and affiliates—as well as several other independent organizations all raise funds for wild sheep related projects, which often are water developments.

(3) For new projects such as mines, roadways, and electric transmission lines that adversely impact desert bighorn habitat, wildlife management agencies and desert bighorn sheep advocacy groups should interact with the project proponents, the land management agencies, and nongovernmental organizations to seek adequate mitigation for these impacts.

(4) The advance of remote sensing technology creates an opportunity to optimize desert bighorn sheep water management while creating substantial savings in both operating costs and personnel services required to physically check these waters as had been the case prior to the implementation of this capability.

(5) It is important to recognize that although there are advances in construction methods and differing types of wildlife waters, even the oldest type described here are still practical and often used. Simply, there is no one-size-fits-most development types and site-specific conditions must play a role in the deployment of any water capture and storage system.

(6) There are two prime considerations in any water storage system for desert bighorn sheep and other desert wildlife. Capacity should be as large as practicable and evaporation needs to be minimized to ensure that water is available to the animals while minimizing the need for water hauling or maintenance.

(7) A wildlife water source serves far more than just the target species—bats, bees, birds, and small game all benefit from access to water (Rosenstock et al. 1999). Usually, steps or ramps are built to allow easy escape for an animal.

REFERENCES

Arizona Game and Fish Department. 2014. Wildlife water development standards. Arizona Game and Fish Department, Phoenix, Arizona, USA.

Bates, J. W., Jr., and G. Workman. 1983. Desert bighorn sheep habitat utilization in Canyonlands National Park. Desert Bighorn Council Transactions 27:25–28.

Brewer C. E., V. C. Bleich, J. A. Foster, T. Hosch-Hebdon, D. E. McWhirter, E. M. Rominger, M. W. Wagner, and B. P.

Wiedmann. 2014. Bighorn sheep: conservation challenges and management strategies for the 21st Century. Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming, USA.

Brown, D. E. 1983. Guide to formulating desert bighorn sheep transplant priorities. Federal Aid in Wildlife Restoration Report W-53-R. Arizona Game and Fish Department, Phoenix, Arizona, USA.

Cain III, J. W., P. R. Krausman, J. R. Morgart, B. D. Jansen, and M. P. Pepper. 2008. Responses of desert bighorn sheep to removal of water sources. Wildlife Monographs 171:1–32.

Cunningham, S. C., and R. D. Ohmart. 1986. Aspects of the ecology of desert bighorn sheep in Carrizo Canyon, California. Desert Bighorn Council Transactions 30:14–19.

deVos, J. C. Jr., and R. M. Lee. In press. Habitat management: key to wild sheep conservation. Pages 378–396 *in* P. R. Krausman and B. A. Jex, editors. Mountain sheep in North America; biology, ecology, conservation, and management. CRC Press, Boca Raton, Florida, USA.

Hansen, C. G. 1980. Habitat. Pages 64–99 *in* G. Monson and L. Sumner, editors. The desert bighorn: its life history, ecology, and management. University of Arizona Press, Tucson, Arizona, USA.

Halloran, A. F., and O. V. Deming. 1958. Water development for desert bighorn sheep. Journal of Wildlife Management 22:1–9.

Krausman, P. R., and B. D. Leopold. 1986. Habitat components for desert bighorn sheep in the Harquahala Mountains, Arizona. Journal of Wildlife Management 50:504–508.

Leslie, D. M., and C. L. Douglas. 1979. Bighorn sheep of the River Mountains, Nevada. Wildlife Monographs 66:1–56.

McKinney, T., S. R. Boe, and J. C. deVos Jr. 2003. GIS-based evaluation of escape terrain and desert bighorn sheep populations in Arizona. Wildlife Society Bulletin 31:1229–1236.

McQuivey R. P. 1975. Bighorn research in Nevada. Desert Bighorn Council Transactions 19:15–18.

Ough, W. D., and J. C. deVos Jr. 1984. Intermountain travel corridors and their management implications for bighorn sheep. Desert Bighorn Council Transactions 28:32–36.

Petersen, J. 2025. Using Ranchbot technology for wild sheep. Utah Wild Sheep Foundation Newsletter, November 2025. Available at https://www.utahwsf.org/ranchbots/

Rosenstock, S. S., W. B. Ballard, and J. C. deVos Jr. 1999. The benefits of and impacts of wildlife water development. Journal of Range Management 52:302–311.

Schwartz, O. A., V. C. Bleich, and S. A. Holl. 1986. Genetics and the conservation of mountain sheep *Ovis canadensis nelsoni*. Biological Conservation 37:179–190.

Trombulak, S. C., and C. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18–30.

Turner, J. C. 1973. Water, energy, and electrolyte balance in the desert bighorn, *Ovis canadensis*. Dissertation, University of California, Riverside, California, USA.

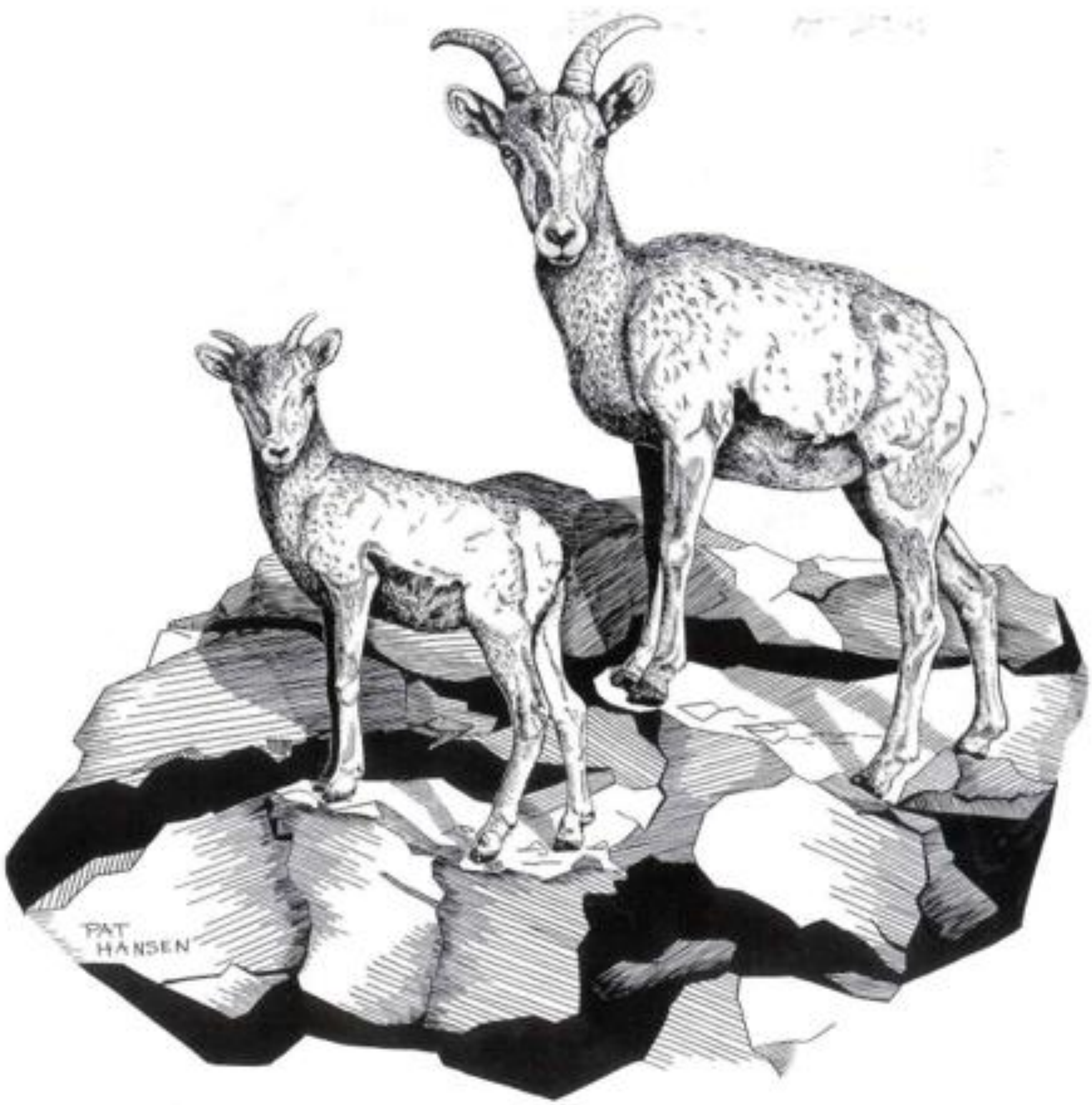
Turner, J. C., and R. A. Weaver. 1980. Water. Pages 100–112 *in* G. Monson and L. Sumner, editors. The desert bighorn: its life history, ecology, and management. University of Arizona Press, Tucson, Arizona, USA.

Werner, W. 1989. Water development. Pages

161–175 *in* R. M. Lee, editor. The desert bighorn sheep in Arizona. Arizona Game and Fish Department, Phoenix, Arizona, USA.

Western Regional Climate Center. 2025. Evaporation report 2016–2025. Western Regional Climate Center, Reno, Nevada, USA.

Witham, J. H., and E. L. Smith. 1979. Desert bighorn movements in a southwestern Arizona mountain complex. Desert Bighorn Council Transactions 23:20–24.



Mycoplasma ovipneumoniae Strain Types in Arizona: Spatiotemporal Trends Inform Risk Assessments

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Desert Bighorn Council Transactions 58:68–72

ABSTRACT Bacterial pneumonia in bighorn sheep (*Ovis canadensis*) has caused periodic all age mortality events and low lamb recruitment in several regions of Arizona. Since 2009, the Arizona Game and Fish Department has used strain-typing of *Mycoplasma ovipneumoniae* (Movi) bacteria as part of routine herd health assessments and to guide translocation and management plans. We found that Movi strain type patterns varied across the state: in the Black mountains Movi strains disappeared from the population and new strains were detected while in the Kofa mountain complex multiple strains have consistently been detected in over several years.

KEY WORDS Desert bighorn sheep, *Ovis canadensis*, *Mycoplasma ovipneumoniae*, strain typing

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Three subspecies of bighorn sheep (*Ovis canadenis canadensis*, *O. c. nelsoni*, and *O. c. mexicana*) are managed by the Arizona Game and Fish Department. The Department has been capturing bighorn sheep for research (habitat use and landscape connectivity) and population management (translocation) for 70 years. During captures, samples are collected to assess the health and disease status of the population. Since 2009, testing for exposure to and infection with *Mycoplasma ovipneumoniae* (Movi) has been included.

Epizootic bacterial pneumonia has caused declines in several populations of desert bighorn sheep in Arizona (Rominger and Goldstein 2007, Wakeling 2007, Justice-Allen et al. 2016). This disease involving multiple bacteria species is initiated by infection with Movi (Besser et al. 2013). Outbreaks are often associated with the incursion of an infected bighorn sheep or domestic sheep or goat or with the movements of infected bighorn sheep (Besser et al. 2012, Cassirer et al. 2018, Justice-Allen et al. 2016). The outcome of the introduction is dependent upon the pathogenicity of the Movi strain, and the disease history of the bighorn sheep population including immunological naivety to the introduced Movi strain (Cassirer et al. 2017, Cassirer et al. 2018). We analyzed the temporal and geographic distributions of Movi strains as identified through multilocus sequence typing (MLST, Besser et al. 2019, Kamath et al. 2019, Manlove et al. 2019) in relation to bighorn sheep mortality events to gain insight into Movi epidemiology.

METHODS

Live animal sampling: Blood, and nasal swabs were collected from bighorn sheep at captures from 2009 to 2024. Swabs were placed in TSB with 20% glycerol and kept cold or frozen until submitted to the Washington Animal Disease Diagnostic Laboratory (WADDL, Pullman, WA). Samples were shipped overnight on gel ice.

Hunter-harvested ram sampling: Nasal swabs were collected from hunter-harvested rams at check in from 2019 to 2022 or, in 2023 and 2024, by the hunters immediately following harvest. Samples were placed in TSB with 20% glycerol and frozen until shipped overnight to the diagnostic laboratory.

Diagnostic testing: WADDL performed Movi real-time polymerase chain reaction (Besser et al. 2019, Manlove et al. 2019); positive samples were tested via MLST at four loci (16-23s intergenic spacer, small ribosomal unit 16S rRNA, RNA polymerase B, gyrase B); generated sequences were aligned via MUSCLE and matched to previously identified strains in the WADDL database (Cassirer et al. 2017, Kamath et al. 2019). When strains differed by more than 4 single nucleotide polymorphisms (SNPs; Kamatha et al. 2019), a new strain type number was assigned.

RESULTS

From 2009 to 2024, 131 samples were successfully tested by MLST. Eighteen strains were identified according to the scheme described by Kamath et al. (2019). Strain distribution was delimited temporally and geographically (Figure 1, Table 1). The variation in the strain type patterns is evident in the differences between the Black Mountain and Kofa-Yuma metapopulations with a series of strains occurring in the Black Mountains one after the other and multiple strains occurring together in the Kofa/Yuma metapopulation.

TABLE 1. *Mycoplasma ovipneumoniae* strain types identified in Arizona bighorn sheep metapopulations. Strain type numbers as identified in Kamath et al. 2019 and as assigned by the Washington Animal Disease Diagnostic Laboratory.

Strain[1]	Metapopulation
BHS-001	Black Mountains
BHS-002	Black Mountains
BHS-003	Black Mountains
BHS-004	Kofa-Yuma
BHS-005	Gila
BHS-006	Gila
BHS-007	Gila, Kofa-Yuma, Bighorn, Cabeza
BHS-008	Grand Canyon
BHS-009	Grand Canyon
BHS-010	Kanab Creek
BHS-011	Kanab Creek
BHS-012	Kanab Creek
BHS-013	Kofa-Yuma, Southern Black Mountains
BHS-014	Virgin River
BHS-024	Cabeza
BHS-096	Grand Canyon
BHS-097	Grand Canyon
BHS-099	Southern Black Mountains
BHS-132	Growlers

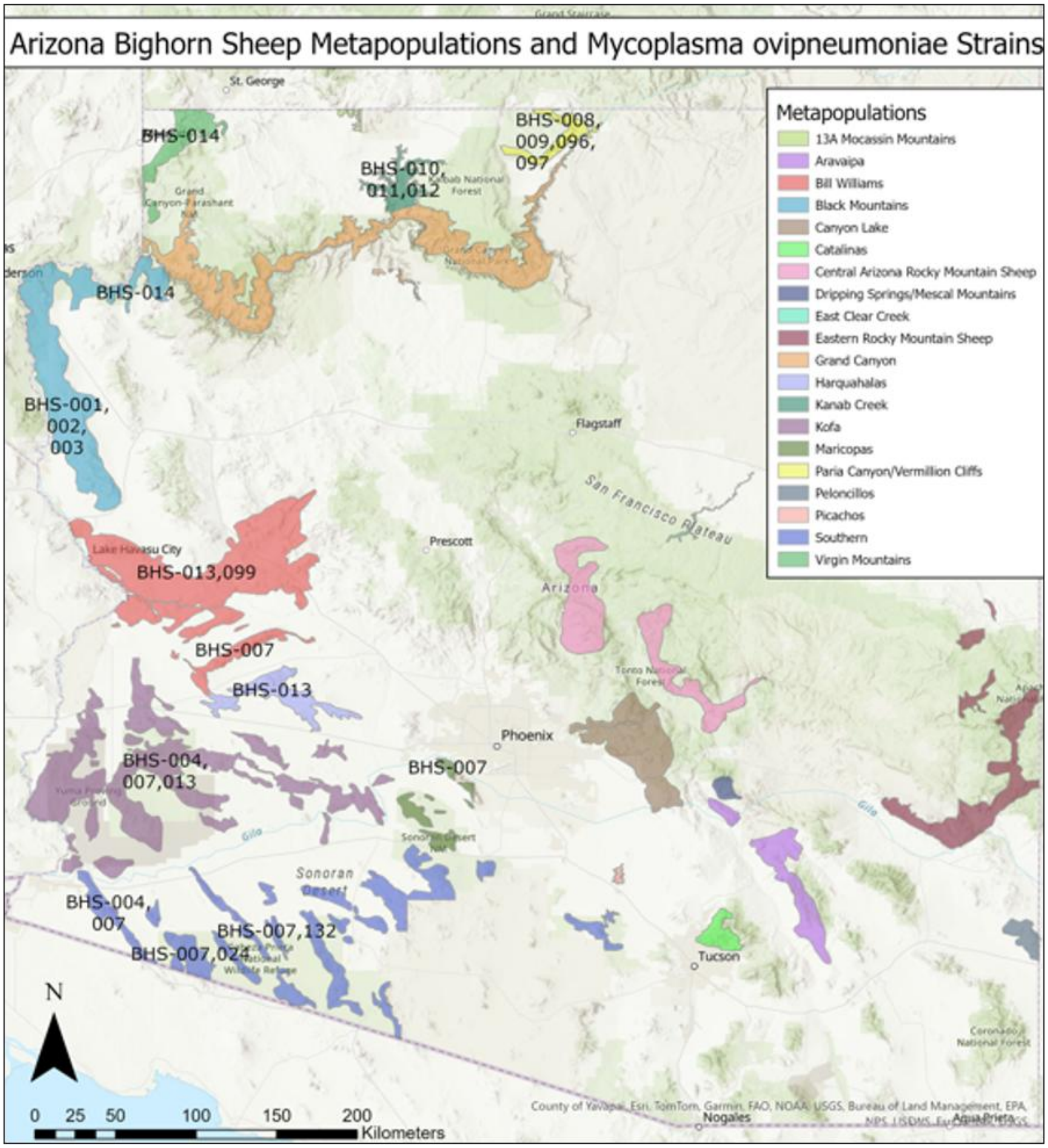

FIGURE 1. Distribution of *Mycoplasma ovipneumoniae* strains identified in Arizona bighorn sheep populations.

TABLE 2. Temporal pattern of strain types in the Black Mountains, Arizona, USA, 2012–2024. Strain types as identified in Kamath et al. 2019; + indicates strain was detected in the population.

	Year								
Strain[1]	2012	2013	2015	2017	2019	2020	2021	2023	2024
BHS-001	+	+	+						
BHS-002			+	+					
BHS-003				+	+	+	+	+	+

The Black Mountain metapopulation is a native population of *O. canadensis nelsoni* located in the northwestern portion of the state. It has served as a source population for translocations in the northern part of the state. Movi has been detected in the population since 2012 (Figure 1, Table 2). In an all age mortality event in 2015 in the Black mountains of northwestern Arizona, we identified the incursion of a strain (BHS-002) initially detected in the Marble Mountains, California and the Spring Range, Nevada during 2013. This event resulted in a 53% decline in the number of bighorns observed on survey. This strain was then replaced by another strain (BHS-003) of unknown origin in 2017, but phylogenetically related to strains found in bighorn sheep across western Arizona (Kamath et al. 2019). This population has not recovered to historic highs at this time. In the early 2000s, the Kofa Mountains population experienced a decline of 50 percent, accompanied by an increase in the seroprevalence to Movi. Since then, we have detected 3 different strains (BHS-004, BHS-007, BHS-013) of Movi in the Kofa Mountains (Figure 1, Table 3). Seroprevalence and detection of the Movi strains by PCR has persisted and yet the population has recovered to previous numbers without additional management actions. This suggests these strains possess a low level of pathogenicity as the population has recovered to pre-decline numbers..

TABLE 3. Temporal pattern of strain types in the Kofa Mountains, Arizona, USA, 2012–2024.

	Year											
Strain[1]	2012	2013	2014	2015	2016	2018	2019	2020	2021	2022	2023	2024
BHS-004			+	+	+	+				+	+	+
BHS-005					+				+			
BHS-006					+				+			
BHS-007		+		+	+		+	+	+	+	+	+
BHS-013	+					+		+	+	+	+	+

In contrast to the well sampled areas of the Black and Kofa/Yuma metapopulations, strain distribution is not well understood in the poorly sampled Kanab Creek-Grand Canyon metapopulation (Figure 1, Table 1). In the early 2005 the population experienced a marked decline with a loss of 80% of the animals. Disease testing in 2006 detected Movi in eight of eleven animals (AZGFD unpublished data). Several different strains (BHS-010, -011, and -012) have been detected animals captured for disease testing in subsequent years (2009, 2015, and 2015, respectively); this population continues to be below historic numbers.

In all, 19 strains with distinct geographic distributions have been identified in Arizona bighorn sheep managed by the Department. Management of Movi endemic populations remains a challenge for the Department. Some endemic populations appear to be doing well in the face of the pathogen as in the Kofa/Yuma complex. However, other populations endemic for Movi remain below historic numbers (Black Mountains, and Kanab Creek). We cannot be certain if this is a result of additional stressors on the population such as drought, population genetics or the pathogenicity of the Movi. Test and remove has demonstrated some success (Cassirer and Besser 2025). Implementation of this management action in Arizona is not being considered at this time. An additional complication for bighorn sheep population management, especially in northern Arizona are the multiple agencies involved. Collar data have demonstrated that many Arizona bighorn sheep populations are connected to populations managed by other agencies (State, Tribal and Federal). In order to better manage disease in bighorn sheep, we should establish regional data-sharing agreements and management objectives for bighorn sheep.

ACKNOWLEDGMENTS

We thank S. Britton, Arizona Game and Fish Department, for preparing the map.

REFERENCES

Besser, T. E., J. Levy, M. Ackerman, D. Nelson, K. Manlove, K. A. Potter, J. Busboom, and M. Benson. 2019. A pilot study of the effects of *Mycoplasma ovipneumoniae* exposure on domestic lamb growth and performance. PLoS One 14:e0207420.

Besser, T. E., M. A. Highland, K. Baker, E. F. Cassirer, N. J. Anderson, J. M. Ramsey, K. Mansfield, D. L. Bruning, P. Wolff, J. B. Smith, and J. A. Jenks. 2012. Causes of pneumonia epizootics among bighorn sheep, western United States, 2008–2010. Emerging Infectious Diseases 18:406–414.

Besser, T. E., E. F. Cassirer, M. A. Highland, P. Wolff, A. E. Justice-Allen, K. Mansfield, M. A. Davis, and W. Foreyt. 2013. Bighorn sheep pneumonia: sorting out the cause of a polymicrobial disease. Preventive Veterinary Medicine 108:85–93.

Cassirer, and T. E. Besser. 2025. Outcomes of selective removals for control of pneumonia in a bighorn sheep metapopulation. Ecology and Evolution 15(5):e70869

Cassirer, E. F., K. R. Manlove, R. K. Plowright, and T. E. Besser. 2017. Evidence for strain-specific immunity to pneumonia in bighorn sheep. Journal of Wildlife Management 81:133–143.

Cassirer E. F., K. R. Manlove, E. S. Almberg, P. L. Kamath, M. Cox, P. Wolff, A. Roug, J. Shannon, R. Robinson, R. B. Harris, B. J. Gonzales, R. K. Plowright, P. J. Hudson, P. C. Cross, A. Dobson, and T. E. Besser. 2018. Pneumonia in bighorn sheep: Risk and resilience. Journal of Wildlife Management 82:32–45.

Justice-Allen A. E., E. Butler, J. Pebworth, A. Munig, P. Wolff, and T. E. Besser. 2016. Investigation of pneumonia mortalities in a *Mycoplasma*-positive desert bighorn sheep population and detection of a different strain of *Mycoplasma ovipneumoniae*. Northern Wild Sheep and Goat Council Proceedings 20:68–72.

Kamath P. L., K. Manlove, E. F. Cassirer, P. C. Cross, and T. E. Besser. 2019. Genetic structure of *Mycoplasma ovipneumon*iae informs pathogen spillover dynamics between domestic and wild Caprinae in the western United States. Scientific Reports 9:15318.

Manlove, K., M. Branan, K. Baker, D. Bradway, E.F. Cassirer, K.L. Marshall, R.S. Miller, S. Sweeney, P.C. Cross, and T.E. Besser. 2019. Risk factors and productivity losses associated with *Mycoplasma ovipneumoniae* infection in United States domestic sheep operations. Preventive Veterinary Medicine 168: 30–38.

Rominger, E. M., and E. J. Goldstein. 2007. Status of desert bighorn sheep in New Mexico, 2006. Desert Bighorn Council Transactions 49:68–70.

Wakeling, B. F. 2007. Status of bighorn sheep in Arizona, 2006–2007. Desert Bighorn Council Transactions 49:52–54.

From Field Notes to Policy: 65 Years of Science to Management in the Desert Bighorn Council Transactions

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Desert Bighorn Council Transactions 58:73–105

ABSTRACT The Desert Bighorn Council (DBC) meetings have been an important forum supporting expertise, applied science, communication, mentorship, scholarship, and best management practices, and much of this has been conveyed through publications in the Desert Bighorn Council Transactions (Transactions). Recent reviews and commentaries on the organizational history and accomplishments of the DBC and a critique of shortcomings ended with a proposal to examine the partnership between science and management, and to determine how the DBC can continue to use or support the application of the best available science to benefit the management and conservation of desert bighorn sheep (*Ovis canadensis nelsoni*). Our objective was to examine this important partnership, consider notable scientific and technological junctures from 1960–2025 and how these developments contributed to a better understanding of desert bighorn sheep natural history and resulted in updated management practices. This co-evolution of science and its resulting application is fundamental for better understanding and for the advancement of any field of science, and this has been a primary objective of DBC. We review many of the early contributions to knowledge published in Transactions, or from more recent articles published in other journals that resulted in a near-immediate action to benefit the management and conservation of desert bighorn sheep. There is a continuing need for such actions in the context of the advantages of applying current knowledge and contemporary theory to conservation efforts, with an emphasis on the wider application of metapopulation dynamics as an example.

KEY WORDS bighorn sheep, conservation, corridor, demography, fragment, landscape, metapopulation, mountain sheep, movement, *Ovis canadensis*, planning, population

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Desert bighorn sheep (*Ovis canadensis* spp.) conservation and management have a broad scope and lengthy histories and are initially presented herein as chronicled through the Desert Bighorn Council (DBC) Transactions (Transactions).

We also expand to include other scientific references in more recent decades in response to conservation science, technology, and publication forums (Berger et al. 2024) across species and landscapes. Although Transactions do not provide a published record for all science and management related to or affecting desert bighorn sheep, the DBC has provided an important forum through meetings, newsletters, and Transactions for researchers and managers to discuss new ideas and concepts since 1957. Through presentations at its annual (1957–2002) and biennial meetings (2003–present), investigators made their work known prior to formal publication either in Transactions or another journal competing for manuscripts to be submitted for publication (Berger et al. 2024).

State status reports, natural history observations, management actions, panel discussions, and abstracts of research publications have been published as part of Transactions since DBC's founding in 1957. These, when combined with the publication of more formal research results, provide an important record of this past and current partnership between science and management. State status reports have documented respective histories of management and other actions. Reviewing past and present management practices are important to recognize successes, possible mistakes, potential opportunities, and future needs to ensure the persistence of desert bighorn sheep on the landscape.

Most importantly, the DBC has served as a forum for scientists and managers to communicate. Part of our motivation for this paper was our collective, but independent, observations that from 1995 to 2025 the co-evolution of science and management appears to be diverging, with management practitioners being slow to implement new scientific approaches and opportunities. In particular, this is evidenced by a continuing absence of metapopulation science in contemporary State management plans. As highlighted by Torres (2023), self-reflection and criticism are fundamental to the DBC fulfilling its mission. While some comments may be critical, challenges and debate are an important part of advancing conservation and have a long history in Transactions.

This historical review of desert bighorn sheep conservation proceeds with an acknowledged bias toward (1) population assessments, habitat use, distribution, and movements; (2) enhancements of technology associated therewith; and (3) the scientific advancements that have resulted from the latter. These tools and data are fundamental to framing conservation in a regional landscape-level context for desert bighorn sheep. Our retrospective commentary will conclude with thoughts on current conservation challenges and will advocate that the DBC continue to support collaboration among scientists and managers that will enhance opportunities for species conservation.

This history includes the simultaneous development of conceptual advances and technological enhancements that allowed data collection previously not available. These are not independent histories, in that new opportunities for data acquisition can influence scientific questions and basic concepts that can be pursued. As an example, the ability to extract DNA of adequate quality from fecal samples of desert bighorn sheep (Wehausen et al. 2004) allowed the topic of gene flow between populations to be researched, a subject that previously would have been ignored because of the inability to develop large enough sample sizes from what were considered to represent neighboring populations.

Our objectives start with presenting key developments in science, technology, and management in a time series to illustrate the evolution and establishment of metapopulation science as it can be applied to management of desert bighorn sheep. In this process we examine the partnership of science and management, future conservation challenges, opportunities of metapopulation science as a management principle, interagency and interstate planning and cooperation, scientific and management collaboration, and the role DBC has played. This historical chronology will help to establish context and emphasize the continued need to apply new conservation science to management.

THE 1960s AND 1970s: PIONEERING SCIENCE AND MANAGEMENT EFFORTS

This early era largely represented a call to document and consolidate knowledge and resulted in a period of discovery through the greater sharing of information. These discoveries included important organizational guidance and changes to better define the purpose and goals of the DBC (Torres 2023). These early efforts and research occurred at a time when new scientific results or knowledge incrementally contributed to advancing management. For example, more comprehensive and pre-telemetry efforts at population assessments (Welles and Welles 1961, Weaver and Mensch 1970a) and development of water resources (Baker 1969, Warburton 1969, Welsh 1970) were advancing during the 1960s. Many other elements of natural history (e.g., information on life requisites, predation, long range movements, disease) were limited by then-available methods or technology that, in some cases, resulted in anecdotal descriptions or speculative results. Shortcomings were compensated by intensive field work, with such efforts "... directed largely toward collection of data pertaining to seasonal distributions, population size, and reproduction and recruitment rates" (Wehausen 1980:27). Nevertheless, these subjects were addressed, and often discussed in detail, in early issues of Transactions. The recognized need in 1962 to collaborate and consolidate knowledge inspired DBC to produce *The Desert Bighorn* (Monson and Sumner 1980).

Intermountain Movements Inspire a Landscape-level Perspective

Early during this period, Simmons (1962:57) pointed out, "Before a wildlife species can be wisely managed, something of its behavior must be known." In referring to behavior, he meant on habitat use and movements. At that time, desert bighorn sheep were not known to make frequent long-range movements that are an essential component of metapopulation dynamics facilitating use of seasonal habitats, breeding, and recolonization. As we know today, these movements occur relatively commonly (Schwartz et al. 1986; Bleich et al, 1990a, 1996; Epps et al. 2003). Regarding long-distance movements, Monson (1964:11) noted, "…we still are not in a good position to draw definitive conclusions regarding this phase of their behavior." He continued, "Their individuality and their thin numbers, in the most difficult terrain, makes them hard to study."

At this point, we emphasize the importance of Monson's comments because they illustrate the evolution of scientific inquiry about behavior and movements at the level of the landscape, which is important to advancing management in a larger regional context, and is foundational to the conservation of metapopulations of desert bighorn sheep and other species. Monson (1964:11) also stated, "The picture is confused by unscientific statements that have won wide acceptance. Somewhat typical is this quotation from Jack O'Connors [sic]

(1939) *Game in the Desert*: The bighorns move from range to range following, the spotty desert rains, and during the mating season the breeding rams wander widely...". Although O'Connor's statement is based on anecdotal experiences, bighorn sheep biologists now know the statement has more validity than was appreciated in 1964. Monson had documented several empirical records of long-range movements from 1942 to 1964, and concluded that long-range movements are very rare and, "… such travel appears to be mainly by males, and long-distance travel occurs mainly during the rutting season" (Monson 1964:17). Although he acknowledged the movements by rams, Monson's dismissal of O'Connor's observations as unscientific reflected the lack of supporting data at that time; that dismissal was unfortunate in the context of its conservation significance.

During the 1970s, the science and management of desert bighorn sheep benefited from newly developed very high frequency (VHF) radiotelemetry technology and its application to wildlife work. This early use and testing of VHF telemetry collars was problematic due to high failure rates (Douglas and White 1979, McQuivey and Pulliam 1980), and expense. Nonetheless, as technology improved during the later 1970s, knowledge about natural history, distribution, survival, and habitat requirements advanced as the result of monitoring radio-collared individual animals and was described widely in Transactions (Cooper and McLean 1974, Golden and Ohmart 1976, McCutchen 1977, Lenarz 1977, Douglas and White 1978, Campbell and Remington 1979). Most large-landscape efforts were assisted by periodic fixed-wing aerial monitoring to determine locations and survival or mortality of marked individuals. Helicopters were being used in desert bighorn sheep research by the 1950s (Jones et al. 1957), and became frequently used for surveys, construction of water developments, and to capture animals using drive netting, corrals, or chemical immobilization via aerial darting (Jessup et al. 2014). The use of fixed-wing aircraft and helicopters augmented more intensive ground monitoring and yielded a better understanding of distribution and movements. As a result of these and other comprehensive population inventories, habitat and distribution assessments began to address additional scientific questions about the spatial scale of movements, pattern and frequency of movements, sexual segregation, philopatry, and mortality. The answers to these were important in building an understanding of natural history and its value for advancing conservation.

Methods to quantify the relative value of habitat patches to desert bighorn sheep were developed in the 1960s (Hansen 1967) and were applied by investigators by the end of that decade (Weaver and Mensch 1970a, 1970b; Breyen 1971; Weaver and Hall 1971). It was not until Ferrier and Bradley (1970) published their findings in Transactions, however, that the potential use of such an approach was realized. The bighorn habitat index of Ferrier and Bradley (1970) was based on data collected through field surveys that quantified grass abundance, distance to water, and topography (i.e., degree of slope) in southern Nevada. This early, albeit simple, model represented an important scientific development that could be applied immediately to management, and inspired future approaches as data became available.

Building further on regional landscape-level assessments, Yoakum (1973) initiated a survey of potential desert bighorn sheep re-introduction sites on all national resource lands in California, Nevada, Arizona, Utah, and New Mexico. Using a survey distributed to all Bureau of Land Management field offices, the potential value of these areas was assessed from historical records, status of water availability, and the quantity and quality of grasses, forbs, and browse available. This effort identified 91 sites as potential desert bighorn sheep habitat (Figure 1). These objective, science-based efforts were particularly important as an increasing number of states were embarking on translocation programs to re-establish bighorn sheep populations. During the same period guidelines for capturing and re-establishing desert bighorn sheep were published in Transactions (Wilson et al. 1973). These guidelines made important recommendations for management efforts, served as a starting structure for translocations, and provided a basis for future improvements.

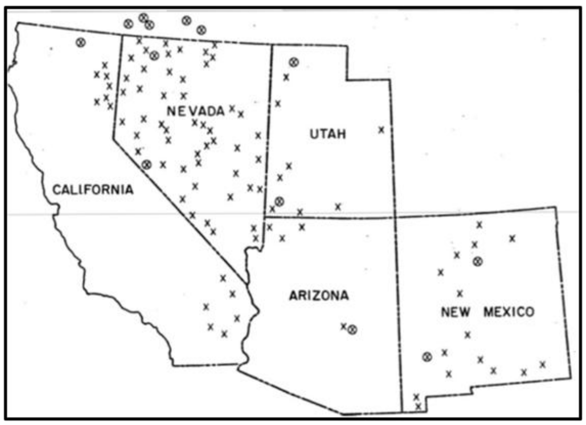

FIGURE 1. Results of an early range-wide survey to determine potential desert bighorn sheep habitats on national resource lands in the southwest (adapted from Yoakum 1973).

After publication of the aforementioned guidelines, a commentary calling for genetic research was published in Transactions (Wilson 1974) and represented very advanced thinking for the time. The author envisioned that genetic research could offer additional tools for desert bighorn sheep management, stating: "Recent publications have presented data and theories indicating that some bighorn populations are declining because of 'genetic factors' " (Wilson 1974:50), and he further suggested four areas to consider: isolation and inbreeding, rutting behavior, selective harvest of rams, and diseases and parasites. Wilson's ideas were visionary, but science and genetics technology in the 1970s were not yet advanced enough to address these topics. Nonetheless, such forethought and insight paved the way for future work that led to important considerations and advances in bighorn sheep research, and eventually to the application of metapopulation theory to population management.

Technology to Reduce Mortality and Maximize Data Acquisition

Bighorn sheep researchers in the 1970s faced other challenges. For example, high rates of capture myopathy or mortality were ongoing concerns for capture and translocation projects (Spraker 1977, Dalton et al. 1978, Jessup 1982) and warranted consideration. These problems were substantially reduced as wildlife managers moved away from the use of chemical immobilization and toward the use of less risky net-guns fired from a helicopter (Sandoval 1980, Jessup et al. 1982, DeForge et al. 1984, Remington and deVos 1985), and the use of drop nets (Erickson 1970, Papez and Tsukamoto 1970, Schmidt et al. 1978, Fuller 1984) or drive nets (Jessup et al. 2014). Today, all of these pioneering methods continue to be refined and are used in wild sheep management (Bleich and Lutz 2024, Lutz and Bleich 2026).

THE 1980s: TECHNOLOGY AND SCIENCE ADVANCE MANAGEMENT AND SPECIES RECOVERY

During the 1980s, desert bighorn sheep science and management continued to benefit from important advancements in technology and the development and improvement of methods for capture, monitoring, and transport. These developments helped increase the feasibility of more research and management projects to benefit species conservation. During this era, state wildlife management agencies embarked on the largest radio-collar based monitoring efforts of extant populations yet undertaken and conducted many translocations of desert bighorn sheep to re-establish populations in historical habitat or augment small or isolated populations. Given this large number of pioneering efforts, we characterize this as the "collar and foller" period, wherein projects weren't necessarily designed to test specific hypotheses. Rather, managers were focusing on restoring historical populations, and thereby adaptively learning more about desert bighorn sheep natural history. The outcomes of these projects provided opportunities to evaluate results and generate best management recommendations for subsequent translocation projects (Leslie 1980, deVos and Remington 1981, deVos et al. 1981, McQuivey and Pulliam 1981, Morgart and Krausman 1981, Rowland and Schmidt 1981, deVos 1982, Dodd 1983, Elenowitz 1984, Remington and deVos 1985). The 1980s continued to represent a period wherein science was directly applied to management practice. For example, revisions of capture procedures for bighorn sheep were produced by Wilson et al. (1982).

During the 1980s the reliability of radiotelemetry collars improved, and acquisition of information increased substantially, resulting in a data-rich period with learning opportunities for researchers. In addition, the increased use of fixed-wing aircraft for aerial monitoring (Krausman et al. 1984) and helicopters for population surveys and captures (Jessup 1982) provided even more data. These efforts provided opportunities for population analyses (Furlow et al. 1981, Leslie and Douglas 1982, DeForge 1984), habitat assessment (Holl 1982, Wilson et al. 1980), and survival and mortality investigations (Munoz 1981). Although habitat analyses and movements provided new information, the ability to reliably interpret those data was limited by locational accuracy of the VHF technology and navigational instrumentation available at that time (Jaeger et al. 1993, Oehler et al. 1996).

It was at this same time that researchers and managers began to appreciate the potential importance of "wandering rams" (Cochran and Smith 1983) and movement corridors (Ough and deVos 1984) to the behavioral ecology of desert bighorn sheep. Cochran and Smith (1983) reported a male crossing large tracts of level terrain (up to 17.5 km) during several intermountain movements. While other investigators previously had described intermountain movements (Monson 1964, Witham and Smith 1979), Cochran and Smith (1983:2) concluded that, "... crossings of this magnitude are uncommon."

During the early 1980s, Ough and deVos (1984) detected additional extended movements that they described as primary movement corridors connecting high-use areas within and between mountain ranges. Primary corridors contrasted with the rarer secondary travel corridors that crossed broad stretches of unsuitable habitat (Figure 2). Intermountain movements were considered in a conservation context: "Knowledge of intermountain travel and the distribution of resources within a mountain complex is necessary to mitigate the impact of travel corridor disruptions effectively" (Ough and deVos 1984:32). This represented an early recognition of movement corridors as an important component of bighorn sheep habitat, and shortly thereafter was found to have a substantial influence on effect the viability of desert bighorn sheep populations (Schwartz et al. 1986).

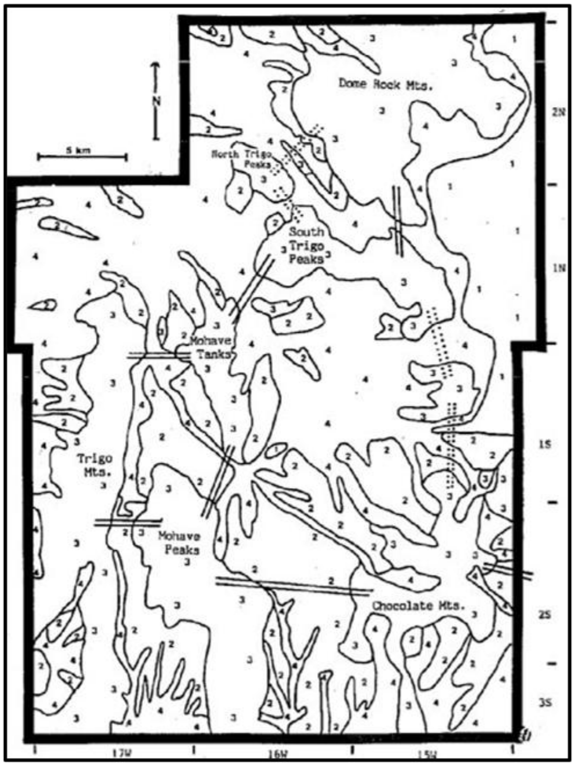

FIGURE 2. Illustration of desert bighorn sheep primary and secondary travel corridors documented by Ough and deVos (1984). Primary corridors were represented by the shorter lines between mountain ranges. Secondary corridors were represented by longer lines over flat terrain (habitat types 1,2).

THE 1980s: CONSERVATION SCIENCE PROMOTES LARGE LANDSCAPE APPROACHES

New conservation science was developing during the 1980s that considered the importance of large landscapes, habitat connectivity, and the management of wildlife populations in the context of long-term viability. Building on the landmark work of MacArthur and Wilson (1967), Soulé and Wilcox (1980) published seminal contributions representing an important juncture that advanced conservation science to a broad scale and was directly applicable to single- and multi-species management approaches.

Although the importance of science and its application to conservation was recognized by wildlife managers and other applied scientists, the new concepts were just emerging and, "... the large majority of their academic colleagues thought the subject was beneath their dignity..." (Soulé and Wilcox 1980:2). Indeed, it was a concept that was recognized by practitioners but not yet accepted by or widely established in academic circles (Soulé and Wilcox 1980) despite the foundational importance of natural history to wildlife conservation (Berger et al. 2024). Desert bighorn sheep managers at this time still viewed populations as occupying independent islands of suitable, mountainous habitat, but largely in the absence of an appreciation for their importance and relevance to each other over a broader region (Schwartz et al. 1986). Consequently, any appreciation for movement corridors and the importance of inter-mountain areas remained a lower priority. This situation also promoted many reintroduction projects focused on restoring historical population(s) that resulted in isolated, less optimal sites being selected (Bleich et al. 1996).

During the 1980s, bighorn sheep population status and viability primarily were determined by size, with the smaller populations considered less viable. Based on a simple analysis of historical data, Berger (1990) modeled desert bighorn sheep populations and predicted the extirpation of populations estimated to number ≤50 sheep within 50 years. This paper was challenged by Krausman et al. (1993), Goodson 1994, and Wehausen (1999) who showed this simplistic basis of predicting population persistence was flawed, concluding that the long-term persistence of many small populations refuted these predictions. As Wehausen (1999:384) pointed out, many factors affect the dynamics of mountain sheep populations and that, "...causes of extinction are likely to be correspondingly complex." Indeed, the application of the small population paradigm (Caughley 1994) to this species is appropriate, but the extirpation of numerous populations largely has been explained by the widespread effects of pathogens and resulting disease (Clifford et al. 2009). Localized and independent extinction, and colonization of formerly occupied or otherwise vacant habitat are, however, fundamental assumptions and important elements in metapopulation dynamics (Lin 2022).

As managers were learning about and beginning to appreciate the potential importance of connectivity between habitat patches, the movement of individual animals through long- and short-distance corridors became an additional factor to be considered in their management.

In one of the most important papers of this era, Schwartz et al. (1986) examined the issue of genetics and inbreeding concerns in desert bighorn sheep populations in California and Nevada and demonstrated that genetic diversity could be maintained by a relatively low frequency of individual movements between mountain ranges. Considering historical and recently known movements of desert bighorn sheep, they concluded the observed rate of movement by individuals between populations was adequate to alleviate inbreeding concerns. Given these movement dynamics, Schwartz et al. (1986) speculated that their study area could more appropriately be thought of as a single metapopulation, or as a system of populations as defined by Levins (1970). This 1986 analysis and presentation further illustrated the potential importance of intermountain movements to the conservation and viability of desert bighorn sheep populations by elevating recognition in the value of open non-traditional habitats between mountain ranges.

The earliest statewide distribution map of desert bighorn sheep in California was a hand-colored map by Joseph Grinnell in 1914 (Figure 3). This early effort generally outlined the distribution of desert bighorn sheep but did not include many attributes other than recording some select years that important observations were made. In the latter 1980s, other investigators were working on an inventory and mapping project of all known historical and extant populations of desert bighorn sheep in California (Wehausen et al. 1987). This important effort helped produce the first accurate representation of desert bighorn sheep populations statewide and assigned demographic attributes to each: native, relocated, and extirpated. As this project continued into the 1990s, this1987 inventory was updated and digitized into a geographic information system format (Figure 4). This new technology proved to be a valuable tool given the land management changes following passage of the California Desert Protection Act (U.S. Congress 1994). The resulting map became an invaluable visual resource that further informed and inspired habitat and population management and served as an important base upon which to build.

During this period, recognition of the vulnerability of desert bighorn sheep populations to pneumonia following association with domestic sheep increased (Foreyt and Jessup 1982, Goodson 1982, Jessup 1985) and resulted in management guidelines for domestic sheep when in the vicinity of bighorn sheep habitat (Desert Bighorn Council Technical Staff 1990). These guidelines helped establish the need for spatial separation and provided parameters that later were adopted by federal and state agencies and remain at the forefront of recommendations regarding the management of domestic sheep grazing in bighorn sheep habitat (Western Association of Fish and Wildlife Agencies 2025).

Despite development of novel methods and the forward-thinking articles that were published in Transactions over a period of nearly 40 years, contributions to the journal dropped substantially starting in the mid-1990s. Thus, citations of papers published in Transactions are less represented in our continuing discussion of the application of science to management. This was coincident with a period wherein large mammal systems ecology expanded across numerous species and fields and the eventual transition of annual DBC meetings to a biennial schedule, with the result that Transactions have been published every other year since 2003. As a result, we expand the following discussion from our initial focus on Transactions to publications in other journals and sources that have contributed to desert bighorn conservation during the more recent past.

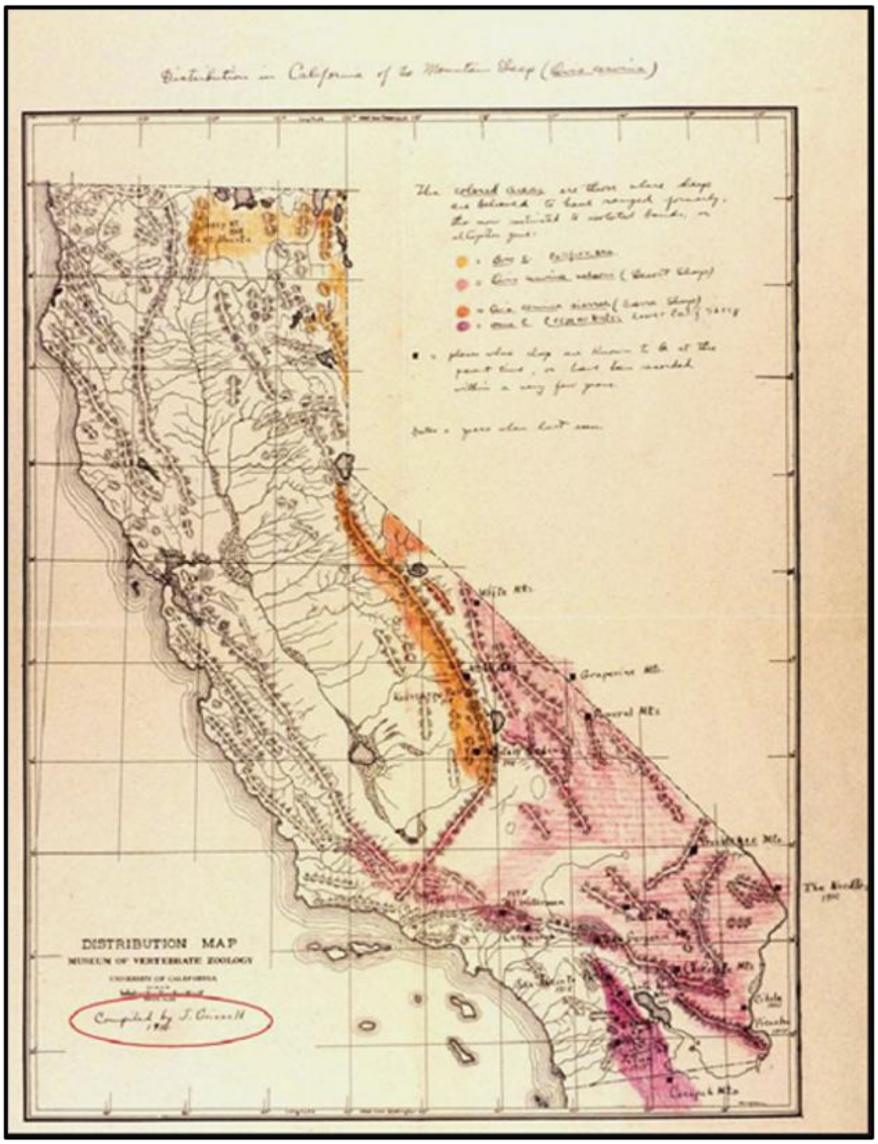

FIGURE 3. The earliest map of the statewide distribution of bighorn sheep in California was prepared by Joseph Grinnell in 1914. California Department of Fish and Game archives.

FIGURE 4. The first precise representation of bighorn sheep populations in California and the population status (native [green], re-established [blue], or extirpated [red]). California Department of Fish and Game archives, 1993).

THE 1990s: SCIENCE AND TECHNOLOGY BUILD NEW APPROACHES TO MANAGEMENT

The 1990s established opportunities where new technology and conservation science inspired the application of management approaches across large landscapes and over longer time frames. Technological advancements included the availability and application of advanced navigational technologies to wildlife science, and particularly large mammals, including desert bighorn sheep. Among these were the use of LORAN-C (Jaeger et al. 1993, Oehler et al. 1996), followed by satellite-based Global Positioning System (GPS) technology (Torres and Bleich 2000) combined with remote data download capabilities; these developments enhanced mapping accuracy of telemetered animals during aerial surveys. In addition, the combination of GPS and satellite technology enhanced opportunities to investigate sudden, rapid movements or migrations, timing of mortality events, and increased mechanistic insights into climate, movements, and population linkages (Hebblewhite and Haydon 2010). The enhanced availability of habitat data across large landscapes (e.g., the USGS GAP Analysis Project), geographic information system software that facilitated processing and presentation of multivariate, spatially explicit data (e.g., ARC/INFO, ESRI, Redlands, California, USA), and the development and application of long-term population viability modeling and risk assessment tools were important. New methods and improved capabilities for storage, testing, and analysis of genetics and disease samples also were developed.

During this era researchers continued to refine understandings of the importance of movements through flat and largely open intermountain habitats between mountain ranges and introduced metapopulations as an ecological construct that fits how desert bighorn sheep populations distribute regionally (Bleich et al. 1990a:384; Figure 5): "…small areas of mountainous habitat that are not permanently occupied but that may serve as 'stepping stones' within such corridors must be recognized for their potential importance to relatively isolated populations of mountain sheep." This work was foundational in the recognition that desert bighorn sheep populations function as a system of interconnected populations (Bleich et. al. 1990a).

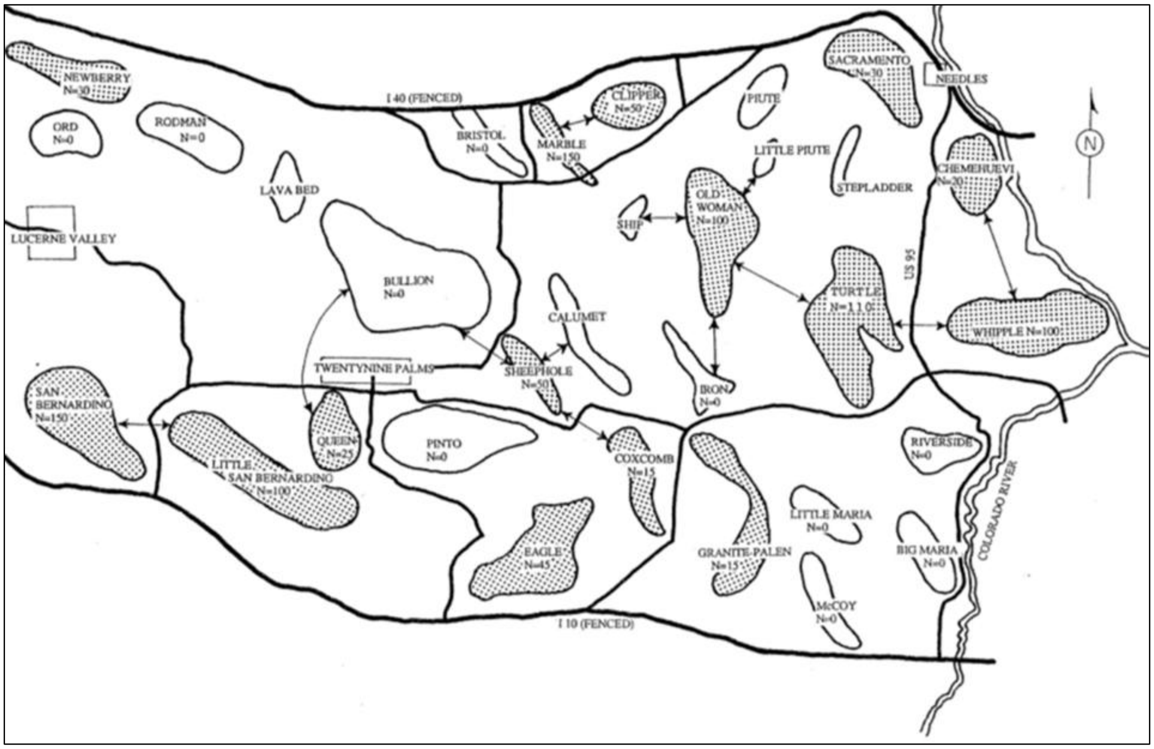

FIGURE 5. Populations of desert bighorn sheep comprising a metapopulation fragment that was created by construction of Interstate Highway 40 and Interstate Highway 10 in San Bernardino and Riverside counties, California. Stippled mountain ranges currently have resident populations of the approximate size listed. Mountain ranges with N = 0 are extirpated populations; ranges with no N value listed are not known ever to have had resident populations. Arrows indicate documented intermountain movements by desert bighorn sheep at the time of publication (Bleich et al. 1990a). Movements between 8 additional pairs of mountain ranges inhabited by bighorn sheep have since been confirmed.

Bleich et al. (1996), while recognizing that metapopulation theory initially had been applied to desert bighorn sheep using estimated levels of gene flow (Schwartz et al. 1986), demonstrated how the founding properties (habitat patches, and recolonization and extirpation events) that defined metapopulations (Gilpin 1987, Hanski et al. 1991) fit desert bighorn sheep. Bleich et al. (1996) also showed how desert bighorn sheep distribution over broad regions reflects interconnected and independent populations wherein recolonization and extirpation events are part of a dynamic system of populations occurring at a landscape level. They emphasized that this regional landscape-level conservation approach is necessary to ensure that reserves of adequate size are established and protected (Agee and Johnson 1988) and emphasized that interagency cooperation is essential to implement strategies to manage reserves for the long-term persistence of large mammals (Salwasser et al. 1987).

This fusion of science and technology inspired the application of metapopulation science to the management of desert bighorn sheep. This approach seemed particularly ideal for what we have learned about desert bighorn sheep. With the recognition that the distribution of these large, specialized ungulates reflects a system of demographically independent, yet geographically interconnected, populations that comprise a metapopulation came the realization that many historical metapopulations have been subdivided and now are defined by anthropogenic barriers or activities that have fragmented the landscape (e.g., interstate highways, canals, solar developments, windfarms). Hereafter, we use the term metapopulation fragments in reference to many of the metapopulations identified and use them to define management boundaries. Although a somewhat academic distinction, these fragments represent portions of one or more large metapopulations that historically existed across an intact landscape (Bleich et al. 1996).

Recognizing its applicability to the conservation of desert bighorn sheep (Torres et al. 1994, 1996; Bleich et al. 1996), metapopulation fragments became the bighorn sheep management units in California (Figures 6, 7). Torres et al. (1994, 1996) formally adopted this approach as a management principle and provided a map of 11 extant and historical metapopulations (Figure 6) while also assigning size classes to the populations within each metapopulation fragment. Using this approach (Torres et al. 1994) provided a method of using size classes within metapopulations to estimate statewide numbers, and to provide a way in which those size class profiles can be compared within and among metapopulation fragments over time.. These population inventories later were updated to reflect demographic changes in desert bighorn sheep populations from 1995 to 2004 including extirpations, reestablishments through translocation, or natural recolonization (Epps et al. 2003), providing updated information on the distribution and size of populations and observations on the dynamics of metapopulation fragments in California (Appendix A). In a metapopulation management context, populations can be viewed as both independent and interconnected in a system of populations (i.e. as metapopulation fragments, with extirpation and recolonization as part of a measurable dynamic. Establishing the use of natural metapopulations, or metapopulation fragments, as a management principle has demonstrated its potential to be highly effective in addressing conservation challenges involving the maintenance of movement corridors (or movement conduits; Jenks 2018) or the management of barriers relative to the spillover of pathogens and serves as a strong model for management programs in other jurisdictions.

FIGURE 6. First published map of hypothetical metapopulation fragment boundaries of bighorn sheep in California, including the then putative subspecies *O. c. californiana* and *O. c. cremnobates* (Torres et al. 1994).

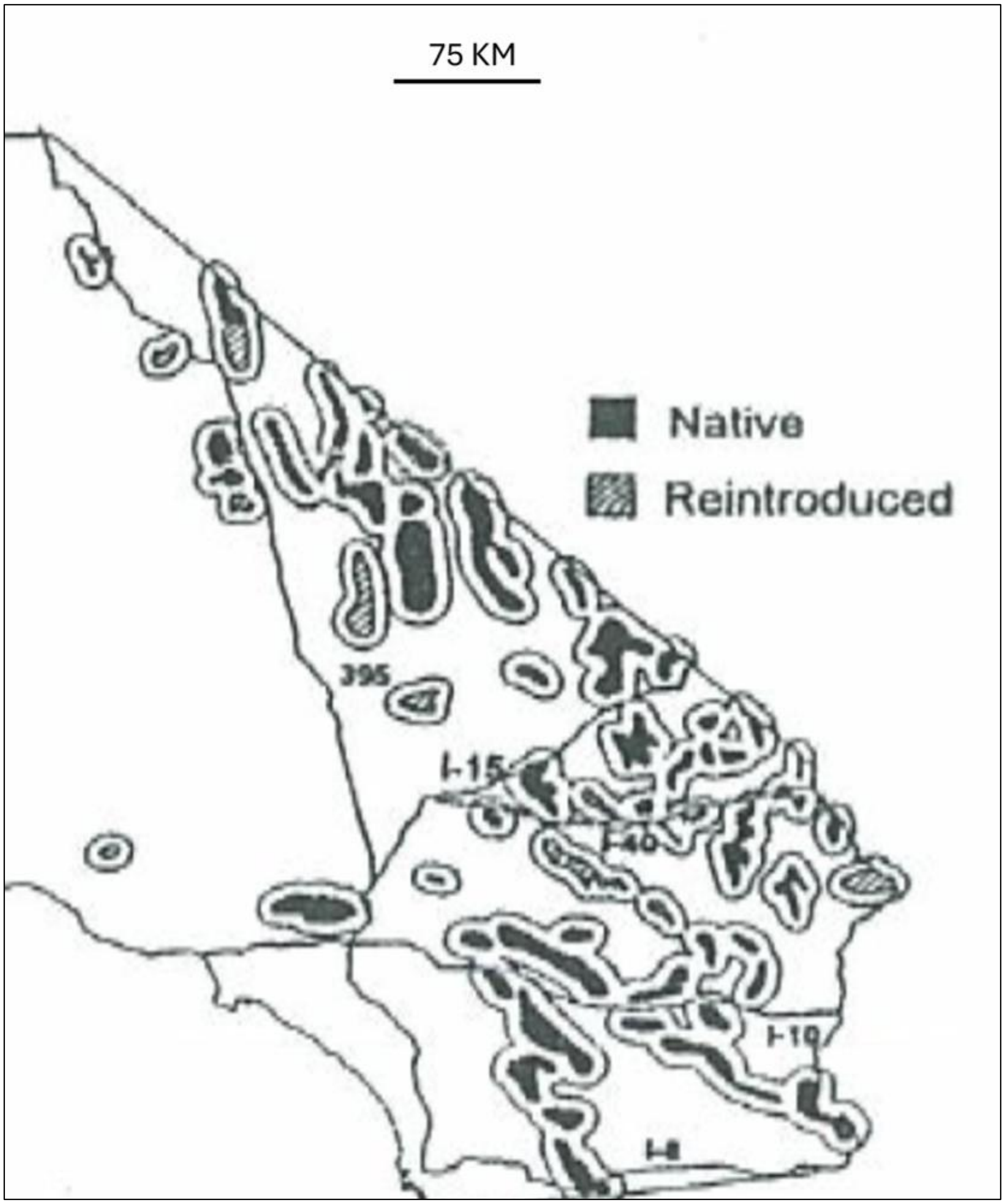

FIGURE 7. Thirteen metapopulations of desert bighorn sheep were spatially defined in California circa 1850 based on historical information at that time (Bleich et al. 1996). By 1970, the number remained similar to that circa 1850 because additional metapopulations created by fragmentation were offset by the loss of what were thought to have been insular populations or were population pairs. Since 1970, proliferation of the interstate highway system in southeastern California further fragmented mountain sheep metapopulations. Also shown are the distributions of Sierra Nevada bighorn sheep, and several insular populations of desert bighorn sheep not linked to the metapopulation criteria of Bleich et al. (1996), from which this image was adapted.

THE 2000s: INTEGRATION OF SCIENCE AND METAPOPULATIONS AS A MANAGEMENT STRATEGY

This period was one that integrated science across many disciplines. Advancements in sciences and technology and the resulting accumulated finer scale data led to improved habitat modeling, a greater recognition of the importance of intermountain movements, enhanced monitoring of cause-specific mortality, implementation of epidemiological investigations, and the addition of genetics investigations into all these sciences. Together, these advancements led to an increase of metapopulation science and its direct application to management practices.

Desert bighorn sheep in the Peninsular Ranges of southern California have been identified as a metapopulation fragment, were classified as a distinct population segment under the Endangered Species Act (ESA, U.S. Congress 1973), which was the first time any species (or subspecies) of North American *Ovis* had been classified as such under the ESA. Although previously considered a distinct subspecies (*O. canadensis cremnobates*), this taxonomic distinction was called into question by Wehausen and Ramey (1993, 2000), who synonymized them with Nelson's bighorn sheep (*O. c. nelsoni*).

Additionally, the classification of a particular subspecies seemed like an inappropriate listing criterion from a conservation standpoint. At the time, endangered species listing petitions primarily relied on population size and habitat boundaries as elemental criteria. This approach appeared to be an inadequate representation for a wide-ranging terrestrial mammal such as bighorn sheep, particularly given the immediate threats to habitat that were associated with development in the Coachella Valley and the need to maintain connectivity among 9 distinct herd units.

Desert bighorn sheep in the Peninsular Ranges occur in a relatively narrow east-facing band of habitat typically below an elevation of 1,400 m from the San Jacinto Mountains at the northern terminus of those mountain ranges in Riverside County, California and southward through much of Baja California, Mexico (U.S. Fish and Wildlife Service 2000, Valdez et al. 2026). Following recognition of bighorn sheep in the Peninsular Ranges as a distinct metapopulation fragment, population viability modeling was used to establish several delisting criteria: a minimum of 25 females must be present in each of 9 recovery regions during 12 consecutive years (2 generations) without continued population augmentation; the range-wide population must average 750 individuals with a stable to increasing population trend over 12 consecutive years; regulatory mechanisms and land management commitments must have been established that provide for long-term protection of desert bighorn sheep and all essential habitat. Essential habitat is that which includes landscape features essential to conservation such as areas for lambing, feeding, and watering. Additionally, connectivity among all portions of habitat must be established to allow sheep to move freely throughout the peninsular ranges.

This initial application of metapopulation science to population recovery and management stands as a demonstrated success by integrating the importance of intermountain habitat, connectivity, and the potential recolonization of unoccupied habitats. The metapopulation approach also was used for bighorn sheep (*O. c. sierrae*) occupying the Sierra Nevada (Figure 8). Given that this metapopulation occurs almost entirely on public land, the primary threats were from domestic sheep grazing allotments and mountain lion (*Puma concolor*) predation (U.S. Fish and Wildlife Service 2007). The discontinuous spatial occurrence of these threats has proven the metapopulation model to be a very effective strategy in developing management priorities and recovery criteria, and metapopulation processes are now well-documented for this subspecies (Wehausen 2023). Natural colonization and localized extirpations have been recorded, and a high potential for gene flow between herd units is evident by movements of telemetered sheep and the application of assignment tests to genetic data. Indeed, actual gene flow has been documented via parentage testing. And, natural colonizations have reduced translocation needs.

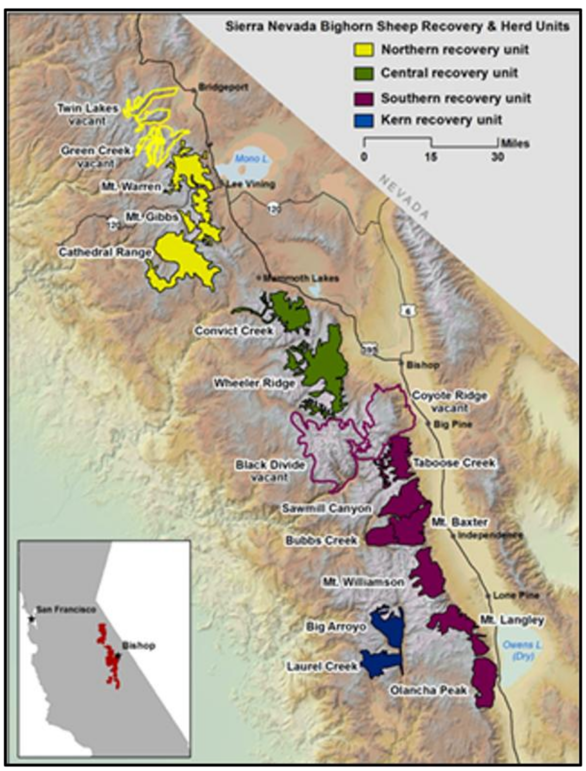

FIGURE 8. The four recovery units and herd units (i.e., populations) that comprise the metapopulations of Sierra Nevada bighorn sheep (U.S. Fish and Wildlife Service 2007).

The concept of managing bighorn sheep based on metapopulation theory was built on the observations and critical thinking of many pioneering members of DBC and the application of those observations in the context of advancements in concepts about population ecology (Soulé and Wilcox 1980, Soulé 1987). As a result, conservation of desert bighorn sheep has shifted toward the paradigm of metapopulation management. In the last 25 years, metapopulation conservation tools have become available, have been applied to desert bighorn sheep management, and have had immediate and largely positive effects following implementation. This conservation approach powerfully blends higher resolution data derived from newer technologies and science, as in the following examples.

Identifying Interconnectivity, Pathways, And Priority Corridors Using Landscape Genetics

Recognizing the need to predict population connectivity and animal movements in complex landscapes, Epps et al. (2007) tested dispersal and corridor models using a combination of "least-cost" modeling and estimates of gene flow. This effort was successful at predicting population connectivity, predicting probable movement corridors, areas where migration rates may be higher, and investigating the role of barriers, or translocations, that have affected connectivity. As a result, this work provides a valuable tool to begin assessing landscape connectivity for management. Following this initial effort, Epps et al. (2018) reexamined functional connectivity in a metapopulation to consider changes over time. While they did observe changes in connectivity over just two generations, it occurred only in specific locations, and the authors recommended that movement patterns be revisited periodically to enhance scientific management, particularly in dynamic landscapes or those that have been fragmented by human constructs or actions.

Investigators have used GPS location data to evaluate movements and derive and calibrate models that then were used to simulate and identify probable high-use locations along highways that may serve as barriers to movements (Crabb and Bristow 2015, Aiello et al. 2023). These results were used to compare previously predicted genetic corridors and roadkill events. Their results demonstrated how simulation may reveal the probability of movements within historical metapopulations that have been fragmented, and how strategies can be developed to restore corridor function and assess potential benefits of restoration. Had these methods been considered prior to the passage of the California Desert Protection Act (U.S. Congress 1994) and had that information been used in the planning process, some of the issues (e.g., wilderness boundary issues, habitat enhancement constraints, isolated populations) that desert bighorn sheep managers currently face would have been lessened, if not eliminated entirely (Bleich et al. 2023).

Predictive Analysis and Modeling Population Persistence Within Metapopulations

Epps et al. (2004) demonstrated how metapopulation structure can be sensitive to climate change patterns and how certain parameters were positively or negatively associated with population persistence. This large landscape analysis allows managers to evaluate suitability of different mountain ranges within metapopulation fragments when considering management actions or priorities, such as translocations, predation management, or habitat enhancements. Wehausen and Epps (2021) revisited this modeling approach and further demonstrated its robustness and immediate applicability to management (Figure 9).

An important additional finding was that habitat patches, identified as individual mountain ranges, varied greatly in their ability to support persisting populations of desert bighorn sheep. The authors further discussed how populations in the best habitat patches need to be provided with the highest protection in the context of metapopulation conservation, a concept upon which recommendations for habitat enhancement was based (Bleich 2009). The work of Wehausen and Epps (2021) serves as an important example for assisting wildlife management agencies to further visualize how metapopulation fragments are structured when establishing management priorities (Wiedmann et al. 2024), particularly as they relate to the conservation or enhancement of habitat.

Prioritizing Management Within a Metapopulation

Creech et al. (2014) creatively used a modeling approach based on network analysis to prioritize management actions within a desert bighorn sheep metapopulation fragment. This method facilitated identification of the most important habitat patches and dispersal corridors requiring protection or restoration with the goal of optimizing landscape connectivity. Their models relied on genetic data to construct networks of genetic and demographic connectivity to identify high priority habitat patches. Wehausen and Epps (2021) later pointed out that this approach can be improved by considering habitat differences among potential patches.

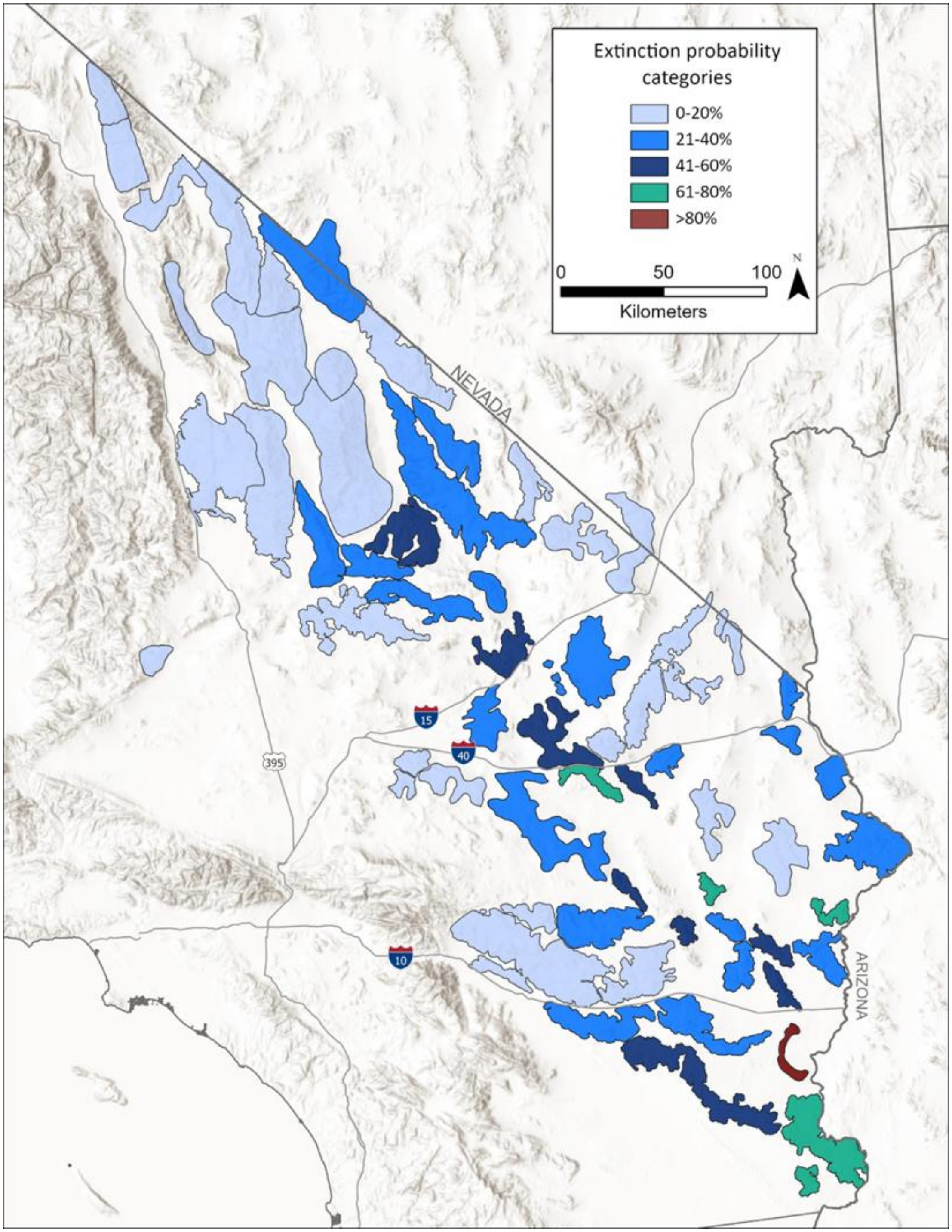

FIGURE 9. Categories of extinction probabilities developed by Wehausen and Epps (2021) for desert bighorn sheep populations comprising metapopulation fragments in southeastern California. Bighorn sheep inhabiting the Sierra Nevada, the Peninsular Ranges, or the western Transverse Ranges were not included in the modeling exercise. Adapted from Wehausen and Epps (2021).

Genetic Analyses for Optimal Strategies to Assist Translocations

Buchalski et al. (2016) examined the phylogeographic and population genetic structure of bighorn sheep in North American deserts and concluded that the subspecies (including the Peninsular Ranges metapopulation) should be managed as if they remained distinct taxonomic entities to preserve maximal biodiversity. These authors further recommended avoiding translocations among peninsular, Nelson's, and Mexican bighorn sheep, and adoption of the 'local is best' translocation strategy (Ramey 1995) as the most reliable means for preserving local adaptation and phenotypes. Gille et al. (2018:838) similarly concluded, "Although translocation management has successfully contributed to the reestablishment of desert bighorn sheep populations in Arizona without diminishing genetic diversity, future translocations should proceed with caution to preserve the genetic integrity and potential local adaptations within the Nelson's and Mexican desert bighorn sheep metapopulations…", a conclusion reached simultaneously for *Ovis c.. canadensis* occupying an entirely different ecosystem (Bleich et al. 2018, Jahner et al. 2026).

Analysis of Disease Risk and Transmission in Metapopulations

An epidemiological approach to investigating disease fits well for species distributed as metapopulations by contrasting exposure or infection measures with demographic parameters, including genetic diversity, at broad regional landscapes. Because habitat fragmentation lowers genetic diversity (Gutiérrez-Espeleta et al. 2010), decisions on managing for connectivity are challenged by the risk of exposure to or the spread of disease, as has been emphasized with respect to translocations (Thorne et al. 1992, Griffith et al. 1993). Thus, connectivity among populations represents a double-edged sword: necessary for gene flow but potentially deleterious from the standpoint of disease transmission (Simberloff and Cox 1987). Dugovich et al. (2023) reported that connectivity was correlated with higher immunogenetic diversity, a protective immune response, lower disease prevalence, and the relative isolation of many of these populations did not protect them from the invasion of pathogens.

Genetic and demographic properties are important to connectivity in desert bighorn sheep metapopulation fragments. Dekelaita et al. (2023) found that sex, age, and infection status at capture influenced intermountain movements and seasonal movement rates during 2013–2018 for 14 populations in California following a pneumonia outbreak. Males, older animals, and uninfected individuals were most likely to make intermountain movements, and females that tested positive at capture had lower mean daily movement rates, providing evidence of pathogen infection decreasing individual mobility and thereby limiting spread of the pathogen.

Likewise, research conducted on 18 populations of desert bighorn sheep within and among metapopulation fragments over a period of 40 years indicated that population connectivity, environmental suitability for disease vectors, and proximity to cattle grazing allotments affected pathogen exposure, specifically for pathogens that can infect desert bighorn sheep and domestic cattle (e.g., bovine respiratory syncytial virus, *Chlamydia* spp., and parainfluenza virus-3; Carpenter et al. 2025). "... only a subset of serological tests had any positive association with population connectivity, challenging the long-debated assertion that increasing metapopulation connectivity will most often lead to increased risk of disease exposure. Instead, these data suggest that the benefits, and costs of population connectivity on managing wildlife disease are dependent on pathogen characteristics" (Carpenter et al. 2025:1). Collectively, these researchers favor increased metapopulation connectivity as a viable conservation strategy in the long term.

Management Planning

The metapopulation approach applied to the statewide management of desert bighorn sheep in California (Torres et al. 1994,1996; Epps et al. 2003) demonstrated an effective framework with which to integrate innovative conservation sciences into management practice. This is especially true for the rapidly advancing sciences of disease and genetics investigations. The California Department of Fish and Wildlife (2025a) recently completed and released the plan for bighorn sheep in California. This document recognizes the metapopulation structure of bighorn sheep populations and incorporates that concept in the delineation of 6 bighorn conservation units (BCUs): Northern Deserts, North Central Deserts, South Central Deserts, Southern Deserts, and Transverse Ranges (Figure 10). The sixth BCU is in extreme northern California, but only transient bighorn sheep from neighboring states currently use this area (Glass et al. 2025).

Delineation of the BCUs are based on or derived from previously designated metapopulation fragments. As dictated in that statewide plan, each BCU is to have a management plan prepared that provides information on: (1) the numbers, age, sex ratios, and distribution of bighorn sheep within the conservation unit; (2) range conditions and competition that may exist as a result of human, livestock, feral burro (*Equus africanus asinus*), or any other mammal encroachment; (3) the need to relocate or re-establish bighorn populations; (4) the prevalence of disease or parasites within the population; and (5) recommendations for achieving the policy objectives. Each of these requisites had been included specifically in the previous plan (California Department of Fish and Game 1983), and 3 years later each requisite was legislatively mandated and codified in state law (California State Legislature 1986).

Unfortunately, the current California bighorn sheep plan has used the term subpopulations when referring to populations known to be independent of each other. This terminology confuses the fundamental recognition of metapopulation structure, independent dynamics, the recolonization-extinction dynamic, genetic connectivity, and the use of metapopulation fragments as a unique measurement variable that provides value for regional assessments or management planning. Subpopulations are not defined as elements in the context of metapopulation dynamics, and we urge the use of that term be abandoned. To date, a management plan has been drafted only for the North Central Deserts BCU (California Department of Fish and Wildlife 2025b).

DISCUSSION

Science and management co-evolved with new approaches to conservation implemented through capture and survey methods, determinations of cause-specific mortality and survival rates, water development planning and development, disease investigations, and habitat suitability assessments. These newer approaches to conservation, however, which emphasize the importance large landscapes, metapopulations, intermountain corridors,

FIGURE 10. The six bighorn sheep conservation units defined in the recently completed management plan for bighorn sheep in California (California Department of Fish and Wildlife 2025).

and population structure and genetics, are not being widely implemented by management agencies, as evidenced by the continued absence of those terms in desert bighorn sheep management plans or in state status reports published in Transactions. In the absence of implementation, new scientific approaches reported in research publications represent missed opportunities limiting a wildlife manager's ability to apply that knowledge proactively. Since 1994, California has been the only state inhabited by desert bighorn sheep that has firmly established the concept of metapopulation structure as a management principle.

If scientists and managers could agree that managing desert bighorn sheep populations as metapopulation fragments over large landscapes is the most appropriate conservation strategy in the long term, that consensus should greatly assist conservation within states, and foster collaboration between or among state wildlife agencies, especially for those populations or metapopulation fragments that straddle state lines Additionally, if state wildlife management programs use a common nomenclature for describing their bighorn sheep population resource, then standards for reference can be established and priorities and research can be shared readily across jurisdictions. Further, and from the human dimensions standpoint, biologically defined metapopulation maps potentially are more meaningful than hunting unit boundaries, would reflect a management approach that is grounded firmly in science and the ecology of the species to which management focus is being applied, yet not preclude harvest constraints on populations-comprising either the metapopulation or a metapopulation fragment. Such an approach would facilitate the application of metapopulation science to address important conservation priorities, including habitat enhancements, population connectivity, barriers to movement, recommendations for translocation(s), and risk of pathogen spillover, while simultaneously permitting appropriate regulatory constraints.

Building on these fundamentals, data visualization is important to establish the biological context for addressing stressors promoting habitat fragmentation, or use in land-use planning, habitat protection, and water developments, and management of exotic ungulates. Using metapopulation fragments as a management foundation allows flexibility in the designation of boundaries that can be established on known connectivity of populations, geographic boundaries or anthropogenic barriers, resource stressors and uncertainties, or management convenience if deemed desirable. Once such boundaries are established and mapped, populations within them can be inventoried and assigned attributes that document the status and management history of each. Boundaries of metapopulation fragments can be modified or adapted as interconnectivity and movements become more evident or are re-established. An approach that documents and serves as a standard baseline of data also preserves program memory (Fisher 2021, Diaz and Corti 2025), communicates the distribution of the resource to the public and agencies, and proactively helps to address future conservation needs. The importance and use of simple data visualization through metapopulation maps should not be underestimated.

Without the ongoing and continuing implementation of evolving applied science in management programs, agencies miss opportunities to demonstrate contemporary science-based conservation. We suggest strongly that desert bighorn sheep management not risk being perceived primarily for hunting or harvest objectives. Rather, those goals should represent the realized benefit of successful management programs based at a landscape level. Numerous organizations, many with a strong focus on sustainable hunting opportunity and are partners in conservation dedicated to the persistence of desert bighorn sheep, agree with that premise.

THE ROLE OF THE DESERT BIGHORN COUNCIL TRANSACTIONS

Transactions have played an important role recording and communicating science and management. Krausman (1992:48) provided an excellent commentary on the use of Transactions and reported that authors used nearly 200 sources when writing about mountain sheep. In ranking these sources, Transactions were the "...sixth of over 170 cited sources of literature and the second most commonly cited source among peer-reviewed journals". Moreover, papers published in Transactions were cited 157 times among the 22 chapters comprising the most recent and authoritative book on North American wild sheep (Krausman and Jex 2026). These statistics confirm the importance of Transactions as a source of information over more than 30 years. If maintained as historically intended, Transactions will remain an outstanding source of information on desert bighorn sheep and their natural history, biology, management, and conservation successes, as investigators and managers continue to rely on them.

Currently, efforts are underway to revitalize and ensure the future utility of Transactions as a meaningful source of scientific information. The first step was to obtain an International Standard Serial Number, which will facilitate use of Transactions by literature review services and the generation of a journal impact factor, both of which will encourage investigators to publish their work in Transactions (Bleich 2023). Such an outcome may be facilitated by the emergence and global proliferation of what have been described as paper mill or predatory journals that offer near-instant gratification to authors by ensuring rapid peer review and publication. There now are so many such journals that the metrics previously used to assess academic performance may no longer be meaningful (Fire and Guestrin 2019), and others are beginning to question the role of those journals in science (Joelving 2024, Crabtree et al. 2025, Richardson et al. 2025). As a result, Transactions may see renewed interest as an outlet for applied research.

In addition to ensuring peer review of technical reports, Transactions are unique because they possess historical and valuable information on desert bighorn sheep management that other publications often do not (Krausman and Jex 2026). This includes state status reports, contemporary and historical commentaries, and they memorialize outcomes of management efforts, whether positive or negative. State status reports remain particularly important because this type of information often cannot be found easily and may not exist in a historical context. It is valuable for state management programs to continue to put a priority on preparation and publication of these reports, as they serve to communicate and document management efforts often unique to the era. When implementing science in management, the authors of such future accounts should consider defining metapopulation fragments and including information on the bighorn sheep resource in that context and report fractures in genetic and demographic linkages that might redefine the metapopulation fragments.

Good examples of Transactions assisting managers and scientists by documenting state management efforts include translocation summaries (Tuskamoto 1993; Bleich et al. 1990b, 2021). Such accounts demonstrate how important it is for managers to publish and thereby retain valuable information that otherwise would be extremely difficult for future investigators to access. Accordingly, we strongly recommend that DBC members and other investigators expand publication of peer-reviewed research, commentaries, noteworthy field observations, and case histories in Transactions, which provide a venue for material that has potentially important management implications.

MANAGEMENT CONSIDERATIONS

We are pleased that conservation science is advancing, but are concerned that implementation of landscape-level scientific concepts in management and plans has been lacking, or has been implemented slowly at best, over the last 3 decades. Previously, science and management were better aligned and more responsive. For some reason, however, the implementation of biologically-based, landscape-level science currently appears to be viewed as an obstacle to resource management.

The Bureau of Land Management (1989) prepared and published a management plan for bighorn sheep occupying all applicable desert mountain ranges in the southwestern United States, setting as a goal, "... the recovery of 115 populations to viable status (≥100 sheep)". Although this proposed objective emphasized population size as the metric that characterized success at the time, the plan was visionary in that it promoted a broad, landscape-level approach to conservation. Bleich et al. (1990a:386) recognized the value of this approach but noted, however, that for it to be successful, "...there remains a need to map all potential metapopulations of mountain sheep as well as known and potential intermountain corridors throughout their desert range, and to develop conservation strategies on that geographic scale". This should also include metapopulation fragment designations so an historical account of what once was, and what conditions could arise in the future, is memorialized.

After further demonstrating and recognizing the need for landscape-level conservation efforts, Bleich et al. (1996:367) emphasized that, "The ramifications of metapopulation structure for mountain sheep conservation are clear: managers must ensure that anthropogenic extirpations are minimized and that opportunities for natural recolonization by females and the migration of nuclear genes via males are not impeded. For mountain sheep, the future is now. Adequate planning and interagency cooperation will best serve the future of this species". We emphasize that opportunities to develop proactive, rather than reactive conservation strategies, should not be wasted (Wilcove 1987).

There is still important work to do for the future of desert bighorn sheep conservation. Do state wildlife and federal land management agencies, however, support a regional landscape-level approach to management that includes using metapopulation biology as a management principle? If so, then there is an opportunity to define the desert bighorn sheep resource in a stronger biological context that includes management units based on a structure and on terminologies that can be used consistently across jurisdictions and international boundaries. To do so would facilitate interagency, interstate, and international collaborations and the sharing of scientific tools to address stressors such as habitat fragmentation, defining movement corridors (perhaps more appropriately described as movement conduits; Jenks 2018), water availability, identification of priority translocation sites, renewal of partnerships with land management agencies, or developing partnerships with private landowners, addressing influences of exotic animals, and modeling disease risks. All of these issues could be addressed and statistically analyzed with more scientific power, which would also help future managers prioritize communication with the public. “There is ... a need for better communications between the research technician or scientist and others both outside and in the field of wildlife management” (Hansen 1967:80).

It is essential that researchers and wildlife managers work together to apply newfound scientific strategies to benefit desert sheep conservation and management; “…I'd like to say that one of the biggest complaints today about the research biologists in the wildlife field is that they do not apply their research or they do not or cannot communicate to others outside of their field the reason behind their research, or they don't communicate the knowledge they have gained from their research” (Hansen 1967:83). Within the Desert Bighorn Council, this has been recognized for decades and we hope our thoughts will help keep scientists and managers collaborating in applied research (Torres 2023). Moreover, “In this second part of the purpose of the Council we deal not with the gathering of information and its dissemination but in the translation of this information into *decisions* [sic] and *actions* [sic] that will have a definite effect on the welfare of the animals. This part of the purpose calls for action and the achievement of definitely stated results” (Graf 1966:10).”

We emphasize that it is important and necessary for the DBC to continue serving the vital role of linking professionals and advancing conservation. To do so, Transactions must remain a viable outlet for the dissemination of knowledge and serve to help managers adapt to conservation challenges as they arise. For this to occur, we must encourage individuals to collaborate and implement optimal science in their approach to management and conservation. We thereby encourage and support DBC member states to better align current management with scientific advancements.

As the late Dick Weaver—a founding member of the Council—had said many times, “We need to do what’s best for the sheep.” Transactions thus far have played a prominent role in advancing desert bighorn sheep conservation and management, and it is our hope that this role will continue.

ACKNOWLEDGMENTS

We thank B. Jex and B. Wakeling for providing many thoughtful comments and suggestions that greatly improved the manuscript. The second author (VCB) thanks the special Guest Editor for this manuscript and thereby avoiding a conflict of interest in the review process, as well as for his additional helpful comments. This is Professional Paper 166 from the Eastern Sierra Center for Applied Population Ecology.

REFERENCES

Agee, J. K., and D. K. Johnson (editors). Ecosystem management for parks and wilderness. University of Washington Press, Seattle, Washington, USA.

Aiello, C. M., N. L. Galloway, P. R. Prentice, N. W. Darby, D. Hughson, and C. W. Epps. 2023. Movement models and simulation reveal highway impacts and mitigation opportunities for a metapopulation-distributed species. Landscape Ecology 38:1085–1103.

Baker, J. K. 1969. The Stubbe Spring guzzler: an artificial method to conserve water. Bighorn sheep and naturalness in Joshua Tree National Monument. Desert Bighorn Council Transactions 13:103–107.

Berger, J. 1990. Persistence of different sized populations: an empirical assessment of rapid extinctions in bighorn sheep. Conservation Biology 4:91–98.

Berger, J., V. C. Bleich, and R. Terry Bowyer. 2024. Must we lose our biological connection to nature to endure changing times? Journal of Wildlife Management 88:e22639.

Bleich, V. C. 2009. Factors to consider when reprovisioning water developments used by mountain sheep. California Fish and Game 95:153–159.

Bleich, V. C. 2023. The Desert Bighorn Council Transactions: past, present, and future? Desert Bighorn Council Transactions 57:2–6.

Bleich, V. C., C. M. Aiello, C. W. Epps, and J. D. Wehausen. 2023. Green energy at odds with conservation. Science 380:1021.

Bleich, V. C., and D. W. Lutz (editors). 2024. Wild sheep capture and handling guidelines. Second edition. Western Association of Fish and Wildlife Agencies, Boise, Idaho, USA.

Bleich, V. C., G. A. Sargeant, and B. P. Wiedmann. 2018. Ecotypic variation in population dynamics of reintroduced bighorn sheep: implications for management. Journal of Wildlife Management 82:8–18.

Bleich, V. C., J. D. Wehausen, and S. A. Holl. 1990a. Desert-dwelling mountain sheep: conservation implications of a naturally fragmented distribution. Conservation Biology 4:383–390.

Bleich, V. C., J. D. Wehausen, K. R. Jones, and R. A. Weaver. 1990b. Status of bighorn sheep in California, 1989 and translocations from 1971 through 1989. Desert Bighorn Council Transactions 34:24–26.

Bleich, V. C., J. D. Wehausen, R. R. Ramey II, and J. L. Rechel. 1996. Metapopulation theory and mountain sheep: implications for conservation. Pages 353–373 *in* D. R. McCullough, editor. Metapopulations and wildlife conservation. Island Press, Covelo, California, USA.

Bleich, V.C., J. D. Wehausen, S. G. Torres, K. A. Anderson, and T. R. Stephenson. 2021. Fifty years of bighorn sheep translocations: details from California (1971–2020). Desert Bighorn Council Transactions 56:1–32.

Breyen, L. J. 1971. Desert bighorn habitat evaluation in the Eldorado Mountains of southern Nevada. M.S. Thesis, Nevada Southern University, Las Vegas, Nevada, USA.

Bureau of Land Management. 1989. Rangewide plan for managing habitat of desert bighorn sheep on public lands. USDI Bureau of Land Management, Washington, D.C., USA.

Buchalski M. R., B. N. Sacks, D. A. Gille, M. C. T. Penedo, H. B. Ernest, S. A. Morrison, and W. M. Boyce. 2016. Phylogeographic and population genetic structure of bighorn sheep (*Ovis canadensis*) in North American deserts. Journal of Mammalogy 97:823–838.

California Department of Fish and Game. 1983. A plan for bighorn sheep. California Department of Fish and Game, Sacramento, California, USA.

California Department of Fish and Wildlife. 2025a. The conservation and management plan for bighorn sheep in California. California Department of Fish and Wildlife, West Sacramento, California, USA.

California Department of Fish and Wildlife.

2025b. The north central deserts bighorn conservation unit plan. California Department of Fish and Wildlife, West Sacramento, California, USA.

California State Legislature. 1986. California Fish and Game Code Chapter 11: Sections 4901–4903 (Bighorn Sheep). California State Legislature, Sacramento, California, USA.

Campbell, B. H. and R. Remington. 1979. Bighorn use of artificial water sources in the Buckskin Mountains, Arizona. Desert Bighorn Council Transactions 23:50–56.

Carpenter, S. A., N. J. Shirkey, P. R. Prentice, E. L. Lantz, B. A. Munk, C. W. Epps, B. R. Beechler, and A. E. Jolles. 2025. Landscape of exposure: metapopulation dynamics and local environment structure pathogen exposure in desert bighorn sheep. Ecosphere: Volume 16(12).

Caughley, G. 1994. Directions in conservation biology. Journal of Animal Ecology 63: 215–244.

Clifford, D. L., B. A. Schumaker, T. R. Stephenson, V. C. Bleich, M. L. Cahn, B. J. Gonzalez, W. M. Boyce, and J. A. K. Mazet. 2009. Assessing disease risk at the wildlife-livestock interface: a study of Sierra Nevada bighorn sheep. Biological Conservation 142:2559–2568.

Cochran, M. H., and E. L. Smith.1983. Intermountain movements by a desert bighorn ram in western Arizona. Desert Bighorn Council Transactions 27:1–2.

Cooper, J. B., and D. J. McLean. 1974. Cooperative management and research of the River Mountain herd, Nevada. Desert Bighorn Council Transactions 18:53–60.

Crabb, M., and K. Bristow. 2015. Trans-highway movements and use of underpasses by desert bighorn sheep. Desert Bighorn Council Transactions 53:1–23.

Crabtree, R., M. Conner, and A. Treves. 2025. Misleading biases in methods for estimating wolf abundance using spatial models. Academia Biology 2025:3.

Creech, T. G., C. W. Epps, R. J. Monello, and J. D. Wehausen. 2014. Using network theory to prioritize management in a desert bighorn sheep metapopulation. Landscape Ecology 29:605–619.

Dalton, L. B., J. A. Roberson, and J. W. Bates. 1978. Capture myopathy in desert bighorns—literature review and treatments. Desert Bighorn Council Transactions 22:31–36.

DeForge, J. R. 1984. Population estimate of peninsular desert bighorn sheep in the Santa Rosa Mountains, California. Desert Bighorn Council Transactions 28:44–45.

DeForge, J. R., R. Valdez, V. M. Suarez, and M. Garcia. 1984. Status of investigations of desert bighorn sheep in Sonora, Mexico. Desert Bighorn Council Transactions 28:41–43.

Dekelaita D. J., C.W., D. W. German, J. G. Powers, B. J. Gonzales, R. K. Abella-Vu, N. W. Darby, D. L. Hughson, and K. M. Stewart. 2023. Animal movement and associated infectious disease risk in a metapopulation. Royal Society Open Science 10:220390. Available at: https://doi.org/10.1098/rsos.220390

Desert Bighorn Council Technical Staff. 1990. Guidelines for management of domestic sheep in the vicinity of desert bighorn habitat. Desert Bighorn Council Transactions 34:33–35.

deVos Jr., J. C. 1982. Preliminary report on four free releases of desert bighorn in Arizona. Desert Bighorn Council Transactions 26:111–112.

deVos Jr., J. C., W. Ough, D. Taylor, R. Miller, S. Walchuk, and R. Remington. 1981. Evaluation of a wild-release of desert bighorn sheep. Desert Bighorn Council Transactions 25:29–30.

deVos Jr., J. C., and R. Remington. 1981. A summary of capture efforts in Arizona since 1977. Desert Bighorn Council Transactions 25:57–59.

Diaz, N. I., and P. Corti. 2025. Ensuring the quality of historical data for wildlife conservation: a methodological framework. Perspectives in Ecology and Conservation 23:32–38.

Dodd, N. L. 1983. Ideas and recommendations for maximizing desert bighorn transplant efforts. Desert Bighorn Council Transactions 27:12–16.

Douglas, C. L., and L. D. White. 1978. Radio-telemetric studies of movements in desert bighorn sheep, Joshua Tree National Monument. Desert Bighorn Council Transactions 22:21–22.

Douglas, C. L., and L. D. White. 1979. Movements of desert bighorn sheep in the Stubbe Spring area, Joshua Tree National Monument. Desert Bighorn Council Transactions 23:71–77.

Dugovich, B. S., B. R. Beechler, B. P. Dolan, R. S. Crowhurst, B. J. Gonzales, J. G. Powers, D. L. Hughson, R. K. Vu, C. W. Epps, and A. E. Jolles. 2023. Population connectivity patterns of genetic diversity, immune responses and exposure to infectious pneumonia in a metapopulation of desert bighorn sheep. Journal of Animal Ecology 92:1456–1469.

Elenowitz, A. 1984 Group dynamics and habitat use of transplanted desert bighorn sheep in the Peloncillo Mountains, New Mexico. Desert Bighorn Council Transactions 28:1–8.

Ellenberger, J. H. 1997 The difference between rhetoric and action. Desert Bighorn Council Transactions 41, Keynote speaker commentary: no page numbers.

Epps, C. W., D. R. Mccullough, J. D. Wehausen, V. C. Bleich, and J. Rechel. 2004. Effects of climate change on population persistence of desert dwelling mountain sheep in California. Conservation Biology 18:102–113.

Epps, C. W., J. D. Wehausen, V. C. Bleich, S. G. Torres, and J. S. Brashares. 2007. Optimizing dispersal and corridor models using landscape genetics. Journal of Applied Ecology 44:714–724.

Epps, C. W., V. C. Bleich, J. D. Wehausen, and S. G. Torres. 2003. Status of bighorn sheep in California. Desert Bighorn Council Transactions 47:20–35.

Epps, C. W., R. S. Crowhurst, B. S. Nickerson 2018. Assessing changes in functional connectivity in a desert bighorn sheep metapopulation after two generations. Molecular Ecology; 27:2334–2346.

Erickson, J. A. 1970. Use of drop net and collars in study of Dall sheep. Northern Wild Sheep Council Proceedings 1:20–21.

Ferrier, G. J. and W. G. Bradley. 1970 Bighorn habitat evaluation in the Highland Range of southern Nevada. Desert Bighorn Council Transactions 14:66–93.

Fire, M., and C. Guestrin. 2019. Over-

optimization of academic publishing metrics: observing Goodhart's Law in action. GigaScience 8:1–20.
Fisher, R. 2021. Generational amnesia: the memory loss that harms the planet. Nature and Health In The News, June 24, 2021. <natureandhealth@uw.edu>.
Foreyt, W. J., and D. A. Jessup. 1982. Fatal pneumonia of bighorn sheep following association with domestic sheep. Journal of Wildlife Diseases 18:163–168.
Fuller, A. F. 1984. Drop net capture of bighorn sheep in Arizona. Desert Bighorn Council Transactions 28:39–40.
Furlow, R. C., M. Haderlie, and R. Van den Berge. 1981. Estimating a bighorn population by mark-recapture. Desert Bighorn Council Transactions 25:31–33.
Gille, D. A., M. R. Buchalski, D. Conrad, E. S. Rubin, A. Munig, B. F. Wakeling, C. W. Epps, T. G. Creech, R. Crowhurst, B. Holton, R. Monello, W. M. Boyce, M. C. T. Penedo, and H. B. Ernest. 2018. Genetic outcomes of translocation of bighorn sheep in Arizona. Journal of Wildlife Management 82:838–854.
Gilpin, M. 1987. Spatial structure and population vulnerability. Pages 125–140 *in* M. Soulé, editor. Viable populations for conservation. Cambridge University Press, Cambridge, Massachusetts, USA.
Goodson, N. J. 1982. Effects of domestic sheep grazing on bighorn sheep populations: a review. Northern Wild Sheep and Goat Council Proceedings 3:287–313.
Goodson, N. J. 1994. Persistence and population size in mountain sheep: why different interpretations? Conservation Biology 8:617–618.
Golden, F. H. and R. D. Ohmart. 1976. Summer observations on desert bighorn sheep in the Bill Williams Mountains, Arizona. Desert Bighorn Council Transactions 20:42–45.
Graf, W. 1966. How wide is the scope of the Desert Bighorn Council? Desert Bighorn Council Transactions 10:9–12.
Griffith, B., J. Scott, J. W. Carpenter, and C. Reed. 1993. Animal translocations and potential disease transmission. Journal of Zoo and Wildlife Medicine 24:231–236.
Gutiérrez-Espeleta, G.A., S. T. Kalinowski, P. W. Hedrick. 2010. Genetic population structure in desert bighorn sheep: implications for conservation in Arizona. Pages 227–236. *in* A. G. Young and G. M. Clarke, editors. Genetics, demography and viability of fragmented populations. Cambridge University Press, Cambridge, United Kingdom.
Hansen, C. G. 1967. The future needs in desert bighorn research. Desert Bighorn Council Transactions 11:80–85.
Hanski, I., and M. Gilpin. 1991. Metapopulation dynamics: brief history and conceptual domain. Biological Journal of the Linnean Society 42:3–16.
Hebblewhite, M., and D. T. Haydon. 2010. Distinguishing technology from biology: a critical review of the use of GPS telemetry data in ecology. Philosophical Transactions of the Royal Society B—Biological Sciences 365:2303–2312.
Holl, S. A. 1982. Evaluation of bighorn sheep habitat. Desert Bighorn Council Transactions 26:47–49.
Jaeger, J. R, J. D. Wehausen, V. C. Bleich, and C. L. Douglas. 1993. Limits in

the resolution of Loran-C for aerial telemetry studies. Desert Bighorn Council Transactions 37:20–23.

Jahner, J. P., T. L. Parchman, M. D. Matocq, M. Cox, R. S. Crowhurst, L. M. Galland, S. M. Burdo, M. R. Buchalski, J. M. Hallas, S. Barbosa, D. W. Coltman, S. Deakin, H. B. Ernest, S. M. Love Stowell, H. Miyasaki, K. L. Monteith, A. Roug, H. Schwantje, R.S. Spaan, T. R. Stephenson, J. Taylor, L. P. Waits, J. D. Wehausen, and C. W. Epps. 2026. Resolving the evolutionary history of bighorn sheep to inform future management: an answer to the California bighorn lineage question. Evolutionary Applications 19, no. 3: e70205. https://doi.org/10.1111/eva.70205

Jenks, J. A. 2018. Mountain lions of the Black Hills: history and ecology. Johns Hopkins University Press, Baltimore, Maryland, USA.

Jessup, D. A. 1982.The use of the helicopter in the capture of free-roaming wildlife. Pages 289–303 *in* L. Nielsen, J. C. Haigh, and M. E. Fowler, editors. Chemical immobilization of North American wildlife. Wisconsin Humane Society, Milwaukee, Wisconsin, USA.

Jessup, D. A. 1985. Diseases of domestic livestock which threaten bighorn sheep populations. Desert Bighorn Council Transactions 29:29–33.

Jessup, D. A., S. R. deJesus, W. E. Clark, and V. C. Bleich. 2014. Evolution of ungulate capture techniques in California. California Fish and Game 100:491–526.

Jessup, D. A., R. Mohr, and B. Feldman. 1982. A comparison of four methods of capturing bighorn. Desert Bighorn Council Transactions 26:21–25.

Joelving, F. 2024. Paper trail. Science 383:253–255.

Jones, F. L., G. Flittner, and R. Gard. 1957. Report on a survey of Bighorn Sheep in the Santa Rosa Mountains, Riverside County. California Fish and Game 43:179–191.

Krausman, P. R. 1992. The use of the Desert Bighorn Council Transactions. Desert Bighorn Council Transactions 36:48.

Krausman, P. R., and B. A. Jex (editors). 2026. Mountain sheep in North America. CRC Press, Boca Raton, Florida, USA.

Krausman, P. R., R. C. Etchberger, and R. M. Lee. 1993. Persistence of mountain sheep. Conservation Biology 7:219.

Krausman, P. R., J. J. Hervert, and L. L. Ordway. 1984. Radio tracking desert mule deer and bighorn sheep with light aircraft. Pages 115–118 *in* P. R. Krausman and N. Smith, editors. Deer in the southwest: a workshop. School of Renewable Natural Resources, University of Arizona, Tucson, Arizona, USA.

Lenarz, M. S. 1977. Population status of the desert bighorn, Big Hatchet Mountains, New Mexico. Desert Bighorn Council Transactions 21:29.

Leslie Jr., D. M. 1980. Remnant populations of desert bighorn sheep as a source for transplantation. Desert Bighorn Council Transactions 24:36–44.

Leslie Jr., D. M., and C. L. Douglas. 1982 Simulated demography of the River Mountain herd. Desert Bighorn Council Transactions 26:97–99.

Levins, R. 1970. Extinction. Pages 77–107 *in* M. Gerstenhaber, editor. Some mathematical problems in biology. American Mathematical Society, Providence, Rhode Island, USA.

Lin, Z. 2022 An overview on metapopulation and its theory. Journal of Phylogenetics and Evolutionary Biology 10:196.

Lutz, D. W., and V. C. Bleich. 2026. Capture and translocation of mountain sheep. Pages 258–279 *in* P. R. Krausman and B. A. Jex, editors. Mountain sheep in North America. CRC Press, Boca Raton, Florida, USA.

MacArthur, R., and E. O. Wilson. 1967. The theory of island biogeography. Princeton University Press, Princeton, New Jersey, USA.

McCutchen, H. E. 1977. The Zion restoration project, 1976. Desert Bighorn Council Transactions 21:9–10.

McQuivey, R. P., and D. Pulliam. 1980. Preliminary results of a wild-release desert bighorn sheep transplant in Nevada. Desert Bighorn Council Transactions 24:57–61.

McQuivey, R. P., and D. Pulliam. 1981. Results of a direct release desert bighorn transplant in the Virgin Mountains of Nevada. Desert Bighorn Council Transactions 25:55–56.

Monson, G. 1964. Long distance and nighttime movements of desert bighorn sheep. Desert Bighorn Council Transactions 8:11–17.

Monson, G., and L. Sumner (editors). 1980. The desert bighorn: its life history, ecology, and management. University of Arizona Press, Tucson, Arizona, USA.

Morgart, J. R., and P. R. Krausman. 1981. Status of a transplanted bighorn population in Arizona using an enclosure. Desert Bighorn Council Transactions 25:46–49.

Munoz, R. 1981. Movements and mortalities of desert bighorn sheep in the San Andreas Mountains, New Mexico. Desert Bighorn Council Transactions 25:64–65.

O’Connor, J. 1939. Game in the desert. Derrydale Press, New York, New York, USA.

Oehler, M. W., V. C. Bleich, and R. T. Bowyer. 1996. Error associated with LORAN-C: effects of aircraft altitude and geographic location. Desert Bighorn Council Transactions 40:19–21.

Ough, W. D., and J. C. deVos Jr. 1984. Intermountain travel corridors and their management implications for bighorn sheep. Desert Bighorn Council Transactions 28:32–36.

Papez, N. J., and G. K. Tsukamoto. 1970. The 1969 sheep trapping and transplant program in Nevada. Desert Bighorn Council Transactions 14:43–50.

Ramey, R. R. 1995. Mitochondrial DNA variation, population structure, and evolution of mountain sheep in the south-western United States and Mexico. Molecular Ecology 4:429–440.

Remington, R., and J. C. deVos Jr. 1985. Arizona’s first desert bighorn sheep transplant into a natural population. Desert Bighorn Council Transactions 29:20–23.

Richardson, R. A. K., S. S. Hong, J. A. Byrned, T. Stoegterf, and L. A. N. Amara. 2025. The entities enabling scientific fraud at scale are large, resilient, and growing rapidly. Proceedings of the National Academy of Science 122(32): e2420092122.

Rowland, M. M., and J. L. Schmidt. 1981. Transplanting desert bighorn sheep—a review. Desert Bighorn Council Transactions 25:25–28.

Salwasser, H., C. Schonewald-Cox, and R. Baker. 1987. The role of interagency cooperation in managing for viable populations. Pages 159–173 *in* M. E. Soulé, editor. Viable populations for conservation. Cambridge University Press, Cambridge, United Kingdom.

Sandoval, A. V. 1980. Management of a sarcoptic scabies epizootic in bighorn sheep (*Ovis canadensis mexicana*) in New Mexico. Desert Bighorn Council Transactions 24:21–28.

Schmidt, R. L., W. H. Rutherford, and F. M. Doderstam. 1978. Colorado bighorn capture techniques. Wildlife Society Bulletin 6:159–163.

Schwartz, O. A., V. C. Bleich, and S. A. Holl. 1986. Genetics and the conservation of mountain sheep *Ovis canadensis nelsoni*. Biological Conservation 37:179–190.

Simberloff, D., and J. Cox. 1987. Consequences and costs of conservation corridors. Conservation Biology 1:63–71.

Simmons, N. M. 1962. Rocky Mountain bighorn sheep movements. Desert Bighorn Council Transactions 6:57–64.

Soulé, M. E. (editor). 1987. Viable populations for conservation. Cambridge University Press, Cambridge, United Kingdom.

Soulé, M. E., and B. A. Wilcox (editors). 1980. Conservation biology—an evolutionary-ecological perspective. Sinauer Associates, Sunderland, Massachusetts, USA.

Spraker, T. A. 1977. Capture myopathy of Rocky Mountain bighorn sheep. Desert Bighorn Council Transactions 21:14–16.

Thorne, E. T., M. W. Miller, D. A. Jessup, and D. L. Hunter. 1992. Disease as a consideration in translocating and reintroducing wild animals: western state wildlife management agency perspectives. American Association of Zoo Veterinarians and American Association of Wildlife Veterinarians Joint Meeting Proceedings 1992:18–25.

Torres, S. G. 2023. The Desert Bighorn Council: a partner in the evolution of science and management. Desert Bighorn Council Transactions 57:12–18.

Torres, S. G., and V. C. Bleich. 2000. Mountain lions—California's elusive predator. Outdoor California 61(3):4–6.

Torres, S. G., V. C. Bleich, and J. D. Wehausen. 1994. Status report of bighorn sheep in California, 1993. Desert Bighorn Council Transactions 38:17–28.

Torres, S. G., V. C. Bleich, and J. D. Wehausen. 1996. Status of bighorn sheep in California, 1995. Desert Bighorn Council Transactions 40:27–34.

Tsukamoto, G. K. 1993. Restoring bighorn sheep in Nevada. Desert Bighorn Council Transactions 37:41–45.

U.S. Congress. 1973. Endangered species act of 1973. Public Law 93-205. 93rd Congress of the United States, Washington, D.C., USA.

U.S. Congress. 1994. California Desert Protection Act of 1994. Public Law 103-433. 103rd Congress of the United States, Washington, D.C., USA.

U.S. Fish and Wildlife Service. 2000. Recovery plan for bighorn sheep in the Peninsular Ranges, California. U.S. Fish and Wildlife Service, Portland, Oregon, USA.

U.S. Fish and Wildlife Service. 2007. Recovery plan for the Sierra Nevada bighorn sheep. U.S. Fish and Wildlife Service, Sacramento, California, USA.

Valdez, R., R. M. Lee, H. S. Gallardo, and J. M. S. Galan. 2026. Mountain sheep management in Mexico. Pages 305–329 *in* P. R. Krausman and B. A. Jex, editors. Mountain sheep in North America. CRC Press, Boca Raton, Florida, USA.

Warburton, J. L. 1969. A desert bighorn habitat management plan. Desert Bighorn Council Transactions 13:14–21.

Weaver, R. A., and J. Hall. 1971. Bighorn sheep in Joshua Tree National Monument and adjacent areas. Wildlife Management Administrative Report 71-7. California Department of Fish and Game, Sacramento, California, USA.

Weaver, R. A., and J. L. Mensch. 1970a. Bighorn sheep in northwestern San Bernardino and southwestern Inyo counties. Wildlife Management Administrative Report 70-3. Wildlife Management Branch, California Department of Fish and Game, Sacramento, California, USA.

Weaver, R. A., and J. L. Mensch. 1970b. Desert bighorn sheep in northern Inyo and southern Mono counties. Wildlife Management Administrative Report 70-7. California Department of Fish and Game, Sacramento, California, USA.

Wehausen, J. D. 1980. Sierra Nevada bighorn sheep: history and population ecology. Ph.D. Dissertation, University of Michigan, Ann Arbor, Michigan, USA.

Wehausen, J. D. 1999. Rapid extinction of mountain sheep populations revisited. Conservation Biology 13:378–384.

Wehausen, J. D. 2023. A simple genetic method to distinguish mule deer and bighorn sheep fecal pellets and its application to detecting bighorn sheep colonization events in California. California Fish and Wildlife Journal 109:e18.

Wehausen, J. D., S. T. Kelley, and R. R. Ramey II. 2011 Domestic sheep, bighorn sheep, and respiratory disease: a review of the experimental evidence. California. Fish Game 9: 7–24.

Wehausen, J. D., and R. R. Ramey II. 1993. A morphometric reevaluation of the peninsular bighorn subspecies. Desert Bighorn Council Transactions 37:1–10.

Wehausen, J. D., V. C. Bleich, and R. A. Weaver. 1987. Mountain sheep in California: a historical perspective on 108 years of full protection. Transactions of the Western Section of The Wildlife Society 23:65–74.

Wehausen, J. D., and R. R. Ramey II. 2000. Cranial morphometric and evolutionary relationships in the northern range of *Ovis canadensis*. Journal of Mammalogy 81:145–161.

Wehausen, J. D., and C. W. Epps. 2021. Population extinction and conservation planning for desert bighorn sheep in California. Desert Bighorn Council Transactions 56:54–74.

Welles, R. E., and F. B. Welles. 1961. The bighorn of Death Valley. National Park Service Fauna Series 6. U.S. Government Printing Office, Washington, D.C., USA.

Welsh, G. W. 1970 Arizona desert bighorn sheep status report. Desert Bighorn Council Transactions 14:179–188.

Western Association of Fish and Wildlife Agencies. 2025. Recommendations for domestic sheep and goat management in wild sheep habitat. Western Association of Fish and Wildlife Agencies, Boise, Idaho, USA.

Wiedmann, B. P., V. C. Bleich, and C. E. Penner. 2024. North Dakota bighorn sheep management plan (2024–2034). Federal Aid in Wildlife Restoration Project Report A-290. North Dakota Game and Fish Department, Bismarck, North Dakota, USA.

Wilcove, D. S. 1987. From fragmentation to extinction. Natural Areas Journal 7:23–29.

Wilson, L. O. 1974. The need for genetic research in desert bighorn sheep. Desert Bighorn Council Transactions 18:50–52.

Wilson, L. O., J. Day, J. Helvie, G. Gates, T. L. Hailey, and G. Tsukamoto. 1973. Guidelines for capturing and re-establishing desert bighorns. Desert Bighorn Council Transactions 17:137–154.

Wilson, L. O., J. Blaisdell, G. Welsh, R. Weaver, R. Brigham, W. Kelly, J. Yoakum, M. Hinks, J. Turner, and J. DeForge. 1980. Desert bighorn habitat requirements and management recommendations. Desert Bighorn Council Transactions 24:1–7.

Wilson, L. O., C. L. Douglas, and the Desert Bighorn Council Technical Staff. 1982. Revised procedures for capturing and re-establishing desert bighorn. Desert Bighorn Council Transactions 26:1–7.

Witham, J. H., and E. L. Smith.1979. Desert bighorn movements in a south-western Arizona mountain complex. Desert Bighorn Council Transactions 23:20–24.

Yoakum, J. 1973. Survey of potential bighorn habitats on national resource land in the southwest. Desert Bighorn Council Transactions 17:123–136.

APPENDIX A. Desert bighorn sheep population size class profile and summary by metapopulation for the 2004 population inventory (Epps et al 2003), with comparisons to the 1995 inventory (Torres et al. 1996).

	Number of Sheep Comprising the Metapopulation							
Metapopulation	0	<25	25-50	51-100	101-150	151-200	201-300	>300
Peninsular Ranges	2	0	1	20	1	0	0	0
San Gabriel	0	0	4	1	2	0	1	0
W. Transverse Range	0	0	0	0	0	0	1	0
Sonoran	1	0	1	0	0	0	0	0
South Mojave	7	4	5	7	1	1	0	0
Central Mojave	1	0	5	2	0	0	1	0
Central North Mojave	1	0	1	3	0	0	0	0
North Mojave	2	3	2	5	1	0	1	0
Very Southern Sierra	2	0	0	0	0	0	0	0
Southern Sierra Nevada	3	2	1	3	0	0	0	0
Central Sierra Nevada	4	0	1	0	0	0	0	0
Northeastern California	7	0	0	0	0	0	0	0
Total	30	9	21	23	5	1	4	0
1995 Total	36	13	20	17	10	10	0	0
Change since 1995 (N)	-6	-4	+1	+6	-5	-9	+4	0

The Influence of Cattle on Populations of Desert Bighorn Sheep

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Desert Bighorn Council Transactions 58:106–122

ABSTRACT Bighorn sheep are well documented to experience major population reductions from diseases contracted from domestic sheep. The relationship between cattle and bighorn sheep is notably less clear, despite the widespread grazing of cattle in and near bighorn sheep habitat. Herein we review the literature on the question of the influence of cattle on desert bighorn sheep in the context of potential ways in which that influence might be manifested. Regardless of how cattle grazing might affect desert bighorn sheep, to be a conservation concern it would have to depress bighorn sheep populations. Such an effect could be evaluated by assessing the impact of a major change in cattle grazing. We present three data sets from the Mojave Desert of California in which cattle grazing was eliminated or greatly reduced and use circumstantial data from helicopter surveys and other population metrics to test predictions on population dynamics of desert bighorn sheep from the hypothesis that the presence of cattle leads to reduction of bighorn sheep populations. We also test the alternative hypothesis that cattle do not have a demographic effect on desert bighorn sheep, in which case population trends instead would be expected to track rainfall variation as it influences nutrient availability. In all three study areas, the population trends did not track variation in a diet quality index based on rainfall. Instead, those trends were consistent with the hypothesis that cattle grazing can substantially depress populations of desert bighorn sheep. Our results, however, exhibit shortcomings associated with circumstantial data. We recommend a purposeful experimental approach to this question that develops high-resolution demographic data on bighorn sheep populations before and after removal or a major reduction of cattle that is replicated in different locations.

KEY WORDS cattle, competition, demography, disease, grazing, livestock, pathogens, bighorn sheep, *Ovis canadensis*

Through most of their range in North America, bighorn sheep (*Ovis canadensis*) have been influenced by interactions with domestic livestock (Buechner 1960). Notable have been die-offs due to respiratory disease spillover from domestic sheep, and occasionally domestic goats (Goodson 1982, Wehausen et al. 2011, Besser et al. 2013, Cassirer et al. 2018). Bighorn sheep readily intermingle with domestic sheep and goats, which facilitates exchange of respiratory tract microbes through direct contact. The respiratory disease relationship involving domestic sheep best explains the widespread extirpation of bighorn sheep from much of its historic distribution, in contrast with the lack of extirpation of native sheep populations in North America north of where most domestic sheep grazing occurred (Wehausen et al. 2011). Such spillover events continue to occur and the one fundamental principle from a large amount of research is that bighorn sheep conservation requires minimizing the probability of contact with domestic sheep or goats (Wild Sheep Initiative 2025).

Cattle also have been grazed in or close to a large proportion of bighorn sheep habitat (Aardahl 2023). Although one respiratory disease epizootic in Rocky Mountain bighorn sheep was thought to be attributable to spillover from cattle (Wolfe et al. 2011), the potential negative effects of cattle grazing on bighorn sheep lacks the clear association seen for domestic sheep. One reason is that disease spillover from direct contact is less likely because bighorn sheep do not readily intermingle closely with cattle. Second is that cattle rarely carry the bacterium *Mycoplasma ovipneumoniae* (Wolfe et al. 2010, Carpenter et al. 2025) that in recent decades has been considered the primary precursor for most outbreaks of respiratory disease in bighorn sheep (Besser et al. 2013, Cassirer et al. 2018).

Cattle might have negative effects on desert bighorn sheep in multiple ways. One is through direct competition for forage sought by both species (Buechner 1960, Ferrier and Bradley 1970, Whiting et al. 2026). Localized overgrazing by cattle in desert bighorn sheep habitat has frequently been reported (Webb 1972, Gallizioli 1977, Wehausen and Hansen 1986). Both species have digestive systems with large combined rumen and reticulum capacities relative to body mass that allow them to consume and digest grass in a full spectrum of phenological states (Hanley and Hanley 1982, Krausman et al. 1993), thereby increasing the potential for forage competition.

In addition to direct competition for forage there is also the potential for interference competition, whereby bighorn sheep avoid using habitat patches because of the presence of cattle, or forage less efficiently due to increased vigilance behavior (Brown et al. 2010, Bissonette and Steinkamp 1996, Garrison et al. 2016). Bighorn sheep can utilize steeper and more rocky slopes than cattle, but they also forage on less-steep slopes that are readily available to cattle. Albrechtsen and Reese (1970) and King and Workman (1984) noted that attributing minimal range overlap between these species to differences in habitat selection may, in reality, be a misinterpretation of the effects of interference competition. Reports of changes in habitat use by bighorn sheep following the introduction or removal of cattle also have been consistent with interference competition influencing habitat use by desert bighorn sheep (Irvine 1969, Wilson 1975). Interference competition can be particularly detrimental to desert bighorn sheep relative to surface water that is a notably limited and important resource in the hot, arid ecosystems they inhabit. In addition to the presence of cattle potentially limiting the availability of some water sources to bighorn sheep, cattle can foul water sources and thereby make that important resource undesirable for use by bighorn sheep (Wehausen and Hansen 1986). This phenomenon similarly has been documented for desert bighorn sheep relative to feral burros (Dunn 1993).

Apparent competition is yet another way in which cattle can have adverse influences on populations of desert bighorn sheep by serving as non-native prey that subsidizes mountain lions (*Puma concolor*), which also prey on bighorn sheep. In particular, predation on domestic calves can allow mountain lions to exist in desert ecosystems with a prey base otherwise too low to support that predator. Such subsidized mountain lions have the potential to kill substantial numbers of bighorn sheep (Rominger et al. 2004), and evidence of such has been reported in the Old Woman Mountains of California (Wehausen 1992).

Disease transmission is yet another way in which cattle can negatively affect desert bighorn sheep. Cattle may rarely be a source for transmission of *M. ovipneumoniae*, but there are numerous other diseases that may spillover to bighorn sheep from cattle. Considerable testing of blood serum from bighorn sheep captured in California for antibodies over four decades has documented exposure to a variety of diseases (Turner and Payson 1982; Clark et al. 1985,1993; Dunbar et al. 1985; Jessup et al. 1993; Sanchez et al. 2022). Of the diseases potentially associated with cattle, these reports suggested low rates of exposure to bovine herpes virus, bovine viral diarrhea, and *Leptospira* spp. In contrast, considerable levels of exposure were reported for bovine respiratory syncytial virus, *Chlamydia*, *Toxoplasma gondii*, *Anaplasma* spp., Parainfluenza-3, *Brucella ovis*, bluetongue virus (BTV), and epizootic hemorrhagic disease (EHD).

Bluetongue virus and EHD are closely related hemorrhagic diseases vectored by *Culicoides* gnats (Ruder and Christensen 2023), facilitating transmission of those viruses to bighorn sheep from nearby cattle that are not strictly sympatric with bighorn sheep. BTV has caused deaths of some captive bighorn sheep (Blaisdell 1975), but such documented deaths of free-ranging bighorn sheep are rare, raising the question of whether BTV and EHD influence the demography of bighorn sheep in the wild, in part because multiple factors are involved.

Transmission of either virus to bighorn sheep can lead to a range of outcomes: subclinical infection, mild and transient disease, severe and fatal disease, or moderate disease and tissue damage followed by the chronic form of hemorrhagic disease (Ruder and Christensen 2023). Additionally, physical symptoms of these diseases overlap evidence of other diseases, thereby requiring virus isolation or a positive PCR test to establish the cause (Ruder and Christensen 2023), which greatly limits the ability of investigators to confirm these viruses as the cause of deaths. Further, cattle typically have subclinical infections of BTV or EHD (Ruder and Christensen 2023), making them potential reservoirs for these viruses for extended periods of time. BTV has been isolated from a few desert bighorn sheep in California (Sanchez et al. 2022), but those infections were not associated with clinical evidence of disease, thereby making it difficult to interpret serological evidence of widespread exposure to these two hemorrhagic viruses. The same can be said of data suggesting exposure to other diseases listed above. They may be causative agents of clinical disease only when combined with additional stressors, or the effects of other pathogens (Dubay et al. 2004).

In a study focused on the question of disease transmission involving cattle, mule deer (*Odocoileus hemionus*), and desert bighorn sheep in the San Bernardino Mountains of California, cattle were well documented to harbor BTV, but there was no evidence of transmission to the bighorn sheep (Singer et al. 1997). Nevertheless, it is possible that pathogens transmitted from cattle can negatively affect bighorn sheep, as suggested by Wolfe et al. (2010). Carpenter et al. (2025) found for blood serum data from California that proximity to cattle grazing allotments was by far the strongest predictor of pathogen exposure in desert bighorn sheep. For such exposures to be considered problematic, however, there must be a demographic effect.

The same can be said of potential effects of ecological factors discussed above. Gallizioli (1977) concluded that a growing body of circumstantial evidence indicated that bighorn sheep populations do poorly or disappear in the face of sympatric cattle grazing. This finding is supported by parallel natural experiments in which bighorn sheep populations declined following the introduction of cattle, or increased substantially following the removal of cattle (Webb 1972, Gallizioli 1977, Bates 1982). Here we present additional circumstantial evidence on population changes of desert bighorn sheep in three different desert mountain ranges in California after cattle grazing was eliminated or greatly reduced.

Our research design included two alternative hypotheses. One is that the presence of cattle is a factor that depresses populations of desert bighorn sheep. From that hypothesis we deduced two predictions. First is that following the introduction of cattle the bighorn sheep population will experience a declining trend until it is extirpated or stabilizes at a lower number. A temporal series of metrics of population size of the bighorn sheep after cattle have been present for some years might therefore exhibit trends varying from no change (at a lower population size) to a declining trend. The second prediction is that the removal of cattle, or a substantial reduction in cattle numbers, after numerous years of cattle presence, will lead to an upward trend in the bighorn sheep population until it stabilizes at a greater number. Depending on how the cattle serve as a depressing factor on the bighorn sheep, there may be a lag time in when the bighorn sheep population increases.

The alternative hypothesis is that the presence of cattle does not lead to changes in the size of desert bighorn sheep populations. The prediction from that hypothesis is that the dynamics of bighorn sheep populations in the presence of cattle, or after the removal of or a major reduction in cattle, will reflect other influences, notably rainfall variation as it affects diet quality (nutrient availability). We considered diet quality variation to be the more parsimonious explanation of bighorn sheep population trends if corroborated.

STUDY AREAS

Our study populations are all in the Mojave Desert of California, and each experienced a recent major change in cattle grazing in and near bighorn sheep habitat, in which that grazing was eliminated or greatly reduced (Aardahl 2023). All grazing allotments were open range, but some localized fencing kept cattle off of major highways and away from some key habitat for desert tortoises.

Cady Mountains

The Cady Mountains extend from Interstate Highway 15 (I-15) southward to Interstate Highway 40 (I-40) in the Mojave Desert about 50 km east of Barstow, San Bernardino County, ranging in elevation from 400 to 1400m (Figure 1). They include Afton Canyon, through which the Mojave River once flowed. There has remained a subsurface water flow in Afton Canyon that rises to the surface locally, providing water for bighorn sheep. Two additional artificial water systems were installed in this range in 1972 and 1982 to provide bighorn sheep water across a larger geographic region.

The Cady Mountains were grazed by an unknown number of cattle beginning in 1965 and by approximately 172 cattle beginning about 1975 on an allotment of 25,900 ha. That grazing ended in 2005 when the Department of Defense purchased the

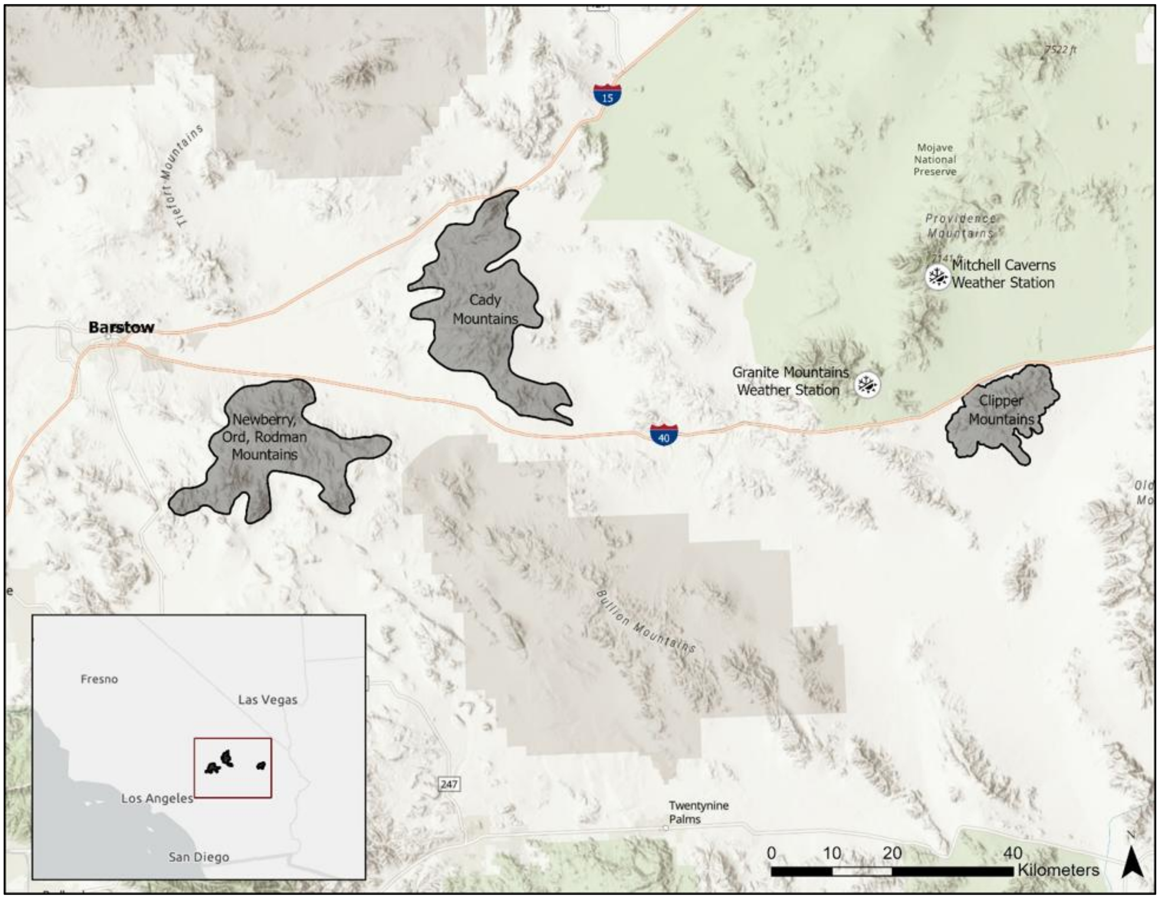

FIGURE 1. Map of study areas in the western Mojave Desert, San Bernardino County, California, in which cattle grazing occurred and wherein we investigated population responses of bighorn sheep following removal or reduction of cattle, San Bernardino County, California, USA, 1984–2020.

Afton Canyon grazing permit as mitigation for expansion of the National Training Center at Fort Irwin, located north and northeast of the Cady Mountains. The Cady Mountains include extensive terrain of shallow slope and low ruggedness that cattle readily negotiated. Consequently, there was a large spatial overlap between cattle and bighorn sheep where cattle were clearly consuming a large amount of forage that otherwise would have been available to bighorn sheep (Wehausen 1992).

Newberry, Ord, and Rodman Mountains

The Newberry, Ord, and Rodman Mountains (hereafter N-O-R Mountains) also are in San Bernardino County, immediately south of I-40 a short distance southwest of the Cady Mountains, and about 20 km east of Barstow (Figure 1). They range in elevation from 750 to 1900 m.

The Newberry Mountains were grazed by cattle continuously beginning about 1900, and the Ord Mountains are thought to have been grazed sporadically up to about 1960. During 1975–1980 this allotment was grazed year-long by 108 cattle. In 1984 the Bureau of Land Management (BLM) expanded this year-round allotment to 26,913 ha and 307 cattle in an amendment to the 1980 California Desert Conservation

Area (CDCA) Plan. That plan called for the elimination of livestock grazing in bighorn sheep habitat south of I-40 (Aardahl 2023). Such grazing, however, was not eliminated in the Newberry and Ord Mountains at that time because the bighorn sheep population in those ranges was considered extinct by 1957 (Weaver 1975). The grazing permittee later informed J. Wehausen, however, that he knew that bighorn sheep persisted there. Beginning in 2006, the number of cattle was voluntarily reduced to about 30.

Clipper Mountains

The Clipper Mountains are a small range immediately south of I-40 and west of Essex Road, 150 km east of Barstow, also in San Bernardino County (Figure 1). They range in elevation from 750 to 1400 m. There are three springs fed by underground aquifers that provide year-round water (Zdon et al. 2018). In addition, four rainwater or seep catchments and drinkers have been installed in the Clipper Mountains to provide water for bighorn sheep.

Cattle were grazed in this range beginning as early as 1920 on a 3,391 ha portion of the Colton Hills grazing allotment south of I-40, but the stocking rate is not known; a helicopter survey in 1983 documented a minimum of 21 cattle. We also know from personal observations that in the cooler season some cattle wandered westward from the Clipper Mountains to the neighboring Marble Mountains. Cattle were not removed from the Clipper Mountains following the completion of the CDCA Plan because of a failure to implement that provision (Aardahl 2023). Those cattle were removed in 1993, after the California Department of Fish and Game brought that failure to the attention of BLM.

Vegetation and Climate

At lower elevations all three study areas have creosote bush (*Larrea tridentata*) scrub communities that also include burro-weed (*Ambrosia dumosa*), littleleaf rattany (*Krameria erecta*), brittlebush (*Encelia farinosa*) and joint fir (*Ephedra spp*.). Washes include smoke tree (*Psorothamnus spinosus*), cheesebush (*Hymenoclea salsola*), catclaw (*Acacia greggii*), and desert willow (*Chilopsis linearis*). The perennial grasses big galleta (*Hilaria rigida*) and Indian ricegrass (*Oryzopsis hymenoides*) occur in suitable sandy areas that in the Cady Mountains are widespread due to considerable blow sand from the Mojave River drainage that runs through Afton Canyon in that study area. In that canyon the higher water table supports patches of honey mesquite (*Prosopis glandulosa*) and saltgrass (*Distichlis spicata*). Higher elevations on Ord Mountain pick up additional shrub species: spiny hopsage (*Grayia spinosa*), desert almond (*Prunus fasciculata*), California buckwheat (*Eriogonum fasciculatum*), rubber rabbitbrush (*Ericameria nauseosa*), bladder-sage (*Salazaria mexicana*), blackbrush (*Coleogyne ramosissima*) and sagebrush (*Artemisia tridentata*).

Rainfall in this region is bimodal with about two-thirds during the cooler months (October–May) and one-third during the hot season (July–September; Wehausen 2005). Annual rainfall varies with elevation; Mitchell Caverns (Figure 1) at 1,300 m elevation averages 26.3 cm, while at 585 m just east of Barstow (Figure 1) at the Daggett airport that average is only 9.5 cm. At the Daggett airport, representing low elevations in bighorn sheep ranges, monthly average high and low temperatures vary from 15.6 and 1.7 C in December to 40 and 22.8 C in July. Higher elevations experience lower temperatures.

METHODS

Population Data

We compiled population data for our three study populations from a variety of sources. These included many helicopter surveys conducted by the California Department of Fish and Wildlife, but also included some mark-resight population estimates. Helicopter surveys differed from such estimates in providing only minimum counts of populations.

To account for variation in the length of helicopter surveys, bighorn sheep observations per hour (catch per unit effort) is sometimes utilized to compare results from surveys with varying levels of effort (actual survey time). Wehausen and Bleich (2007) noted, however, that the relationship between survey length and the number of sheep observed is not linear, but instead is asymptotic. That relationship was evident in results they presented from an experiment in helicopter counts of desert bighorn sheep in the Marble Mountains. They suggested that for helicopter surveys in the intensity region near the asymptote that raw count data would be a better metric to compare between surveys as a good index of population size, rather than sheep observed per hour. We were able to use that approach only for the Clipper Mountains. Wehausen and Bleich (2007) expressed survey intensity in minutes/km^2. Based on their survey intensities, we determined that past helicopter surveys of the Clipper Mountains lasting 1.67–2.65 hours represented that asymptote region. For that population we eliminated helicopter surveys outside of that range and compared raw count data. For helicopter surveys of the Cady and N-O-R Mountains we compared sheep seen per hour because of considerable variation in survey duration. For the Cady Mountains a minimum count from a helicopter surveys also was used to compare with an early mark-resight population estimate.

As the reproductive base, we considered adult females as the most desirable bighorn sheep class for which to examine changes in population size. Desert bighorn sheep exhibit sexual segregation during much of the year (Bleich et al. 1997). Population dynamics based on size metrics that include males have the potential to be misleading if dominated by the sampling of males, and can have ramifications for the interpretation of survey results for a variety of reasons (Rubin and Bleich 2005). For these reasons, where possible we focused on females in our examination of available population data, but we also included all sheep as corroborating evidence in some cases.

Rainfall Effects

Wehausen (2005) identified cool season rainfall as the variable that accounted for most of the large year-to-year variation in annual nutrient intake by desert bighorn sheep in the region of our study areas. That was based on 17 years of continuous tracking of diet quality in the Marble Mountains via the log of % fecal nitrogen. Wehausen (1995) showed that fecal N closely tracks digestibility of the diet in a curvilinear relationship that can be linearized with a log transformation. Digestibility correlates well with nutrient intake. Wehausen (2005) found that October through April (hereafter, cool season) rainfall was a strong (r^2 = 0.808) predictor of fecal N data integrated from February to June for monthly samples. That winter-spring diet quality index covers the critically important period during which lambs are reared. Wehausen (2005) found that the relationship between that diet quality index and rainfall was curvilinear (asymptotic). An important consequence of that curvilinearity is that small differences in rainfall at the lower (drought) end of the relationship have large influences on diet quality in contrast to a much lower sensitivity to equivalent rainfall variation at the high end of that relationship. Rainfall differences across the range of variation are therefore not the same relative to bighorn sheep diet quality and, thus, also population dynamics. To accommodate this asymmetry, we did not compare raw cool season rainfall data as an alternative potential explanation (hypothesis 2) of population trends we found. Instead, we used the equation in Figure 7 in Wehausen (2005) to convert cool season rainfall each year to a February–June diet quality index. We then compared yearly values of that index for different time periods via t-tests, but also looked at the variation among years. The relationship between cool season rainfall and February–June diet quality will be somewhat different for different mountain ranges, but all mountain ranges in this region would be expected to have the same basic curvilinear relationship. We could use the relationship developed for the Marble Mountains because our comparisons were only within mountain ranges.

Because the rainfall data Wehausen (2005) used to develop the relationship between February–June diet quality and cool season rainfall all were from the National Weather Service Cooperative Station at Mitchell Caverns (Figure 1), we used those same data for all of our analyses. The rainfall data set at Mitchell Caverns ended in 2011, so we used rainfall data from the nearby Sweeney Granite Mountains Desert Research Center (Figure 1) to predict cool season rainfall for Mitchell Caverns for 2012–2018 via regression analysis.

Rainfall in the cool season when lambs are born greatly influences the survival of lambs that year (Wehausen 2005). Rainfall in that year therefore also will greatly influence yearling recruitment the following year. Our demographic analyses treated yearling females as adults. Consequently, for population trend periods of interest, our consideration of rainfall as an alternative explanation of population trends did not include rainfall in the final cool season of the trend.

Wehausen (2005) also presented data indicating that the relationship between diet quality during the lamb-rearing season and lamb survival was not monotonic. Lamb survival increased linearly with increasing diet quality for most of the variation in diet quality, but at the highest rainfall levels that relationship suddenly reversed in a pattern that Wehausen (2005) suggested might reflect a disease process associated with very high rainfall. In examining the data in that high rainfall zone plotted in Wehausen (2005), we found that it was only in years when the combined February and March rainfall exceeded 17.8 cm (7 inches) that lamb survival exhibited a large departure from what otherwise would be expected for high February–June diet quality associated with high cool season rainfall. However, because those departures were still in the range of lamb:adult female ratios associated with population increases, we concluded that they would have little influence on our results. There were only six years in that extreme high February–March rainfall category over the 59 years of rainfall data that we used.

RESULTS

Cady Mountains

In September of 1988, one of us (JDW) participated in a five-hour helicopter survey of the Cady Mountains during which only 11 desert bighorn sheep were observed for a sighting rate of 2.2 sheep/hour and 0.6 females/hour. Only three of those were adult females, and one of them was captured and collared. The following day an additional five females were captured and collared. Two years earlier, in May of 1986, four females had been collared. In December of 1988 a total of seven collared females were available for mark-resight population estimates. Extensive ground sampling between December 1988 and early March 1990 produced a random sample of 52 females that was used to generate a mark-resight estimate of 24 females (95% CI = 16–41) for the 1989 population (Wehausen 1992).

It was 16 years later when all cattle were removed from the Cady Mountains in 2005. Two years after cattle removal a 5.6-hour helicopter survey documented a minimum of 109 desert bighorn sheep, of which 59 were adult females.

To enable consistent future helicopter surveys, in 2009 the Cady Mountains were divided into sampling polygons, with a survey time allocated to every polygon. In September of that year that survey plan was implemented in an 8.6-hour survey during which 167 bighorn sheep were recorded, of which 92 were females. The 2007 and 2009 helicopter surveys produced almost identical sighting rates of 10.5 and 10.7 females/hour, respectively, and 19.5 and 19.4 sheep/hour. These 2007 and 2009 survey sighting rates were 17.7 times the 1988 rate for females and 8.8 times that for all sheep seen. Another helicopter survey in 2010 used results from the 2009 flight to improve the survey efficiency. That 2010 survey recorded a minimum count of 102 females and 174 total sheep in 6.7 hours. It bumped sighting rates up to 15.2 females and 26.0 total sheep per hour, which respectively were 25.3 and 11.8 times the 1988 sighting rates. The 2010 minimum female count was four times the mark-resight estimate from 1989 when cattle were present and well outside of the 95% confidence interval. Given that such fall helicopter surveys in that time period and region recorded consistently a little less than half of the sheep present (Wehausen and Bleich 2007, J. Wehausen unpublished data), the actual population may have contained about 200 ewes, or about 8 times the 1989 estimate. Population estimates based on helicopter flights and camera traps between 2015 and 2025 suggest that the reproductive base of this population has stabilized at about three times the 1989 estimate (R. Ianniello, personal communication).

N-O-R Mountains

Once it was determined that bighorn sheep persisted in the N-O-R Mountains, helicopter surveys were initiated by the California Department of Fish and Game. A short (1.75 hours) helicopter survey in May of 1988 detected only 15 bighorn sheep, of which 8 were females. In 1994 a 3.93-hour helicopter survey yielded observations of only 21 bighorn sheep, of which 12 were females. Helicopter surveys resumed in 2016, 2018, and 2019 with much longer flights (5.65–6.98 hours) 11 years after the cattle in this area were greatly reduced. The hourly observation rate in 2016 was 2.6 times the rate in 1994 for females and 4.6 times for all sheep, then increased steeply in 2018 and 2019 (Figure 2). For the 2019 survey, sighting rates were 6.0 and 8.7 times the 1994 rates for females and for all sheep, respectively. Population estimates from the 2019 helicopter survey and more recent camera data strongly suggest that this population exceeds 300 sheep (Prentice et al. 2019, Vu et al. 2021).

The short 2016–2019 period of a well-documented steep increase in population had considerable variation in predicted diet quality, but in the middle of the range of this diet quality index (Figure 2), and was not different from the 1959–2004 average (P = 0.852).

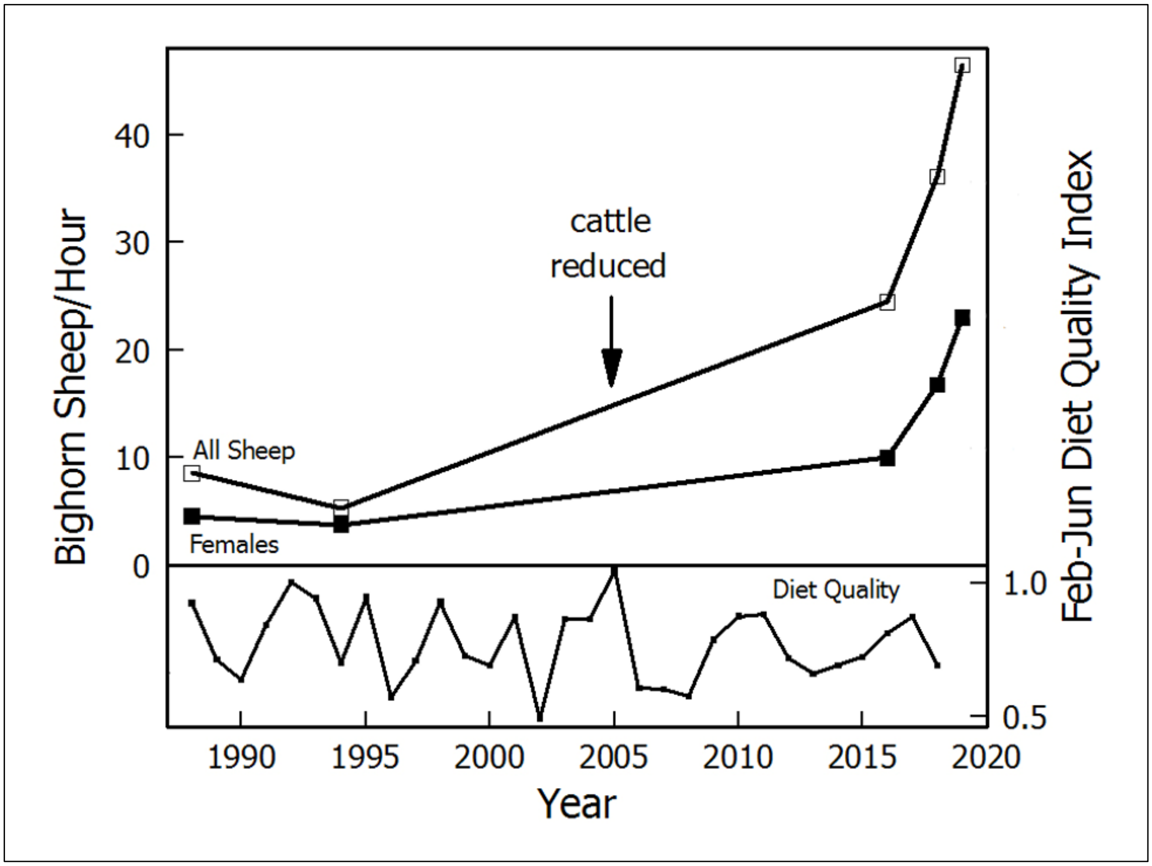

FIGURE 2. Numbers of female and all bighorn sheep (*Ovis canadensis nelsoni*) seen per hour in helicopter surveys of the Newberry, Ord, and Rodman Mountains, San Bernardino County, California, 1988–2019; and February–June diet quality index for the same time period based on October–April rainfall data from Mitchell Caverns and the Granite Mountains.

Clipper Mountains

Fifteen helicopter surveys of the Clipper Mountains between 1983 and 2015 met our duration criterion. The number of adult females counted in those surveys varied considerably within a limited range of variation that suggested major population dynamics (Figure 3). The patterns included first a declining trend between 1983 and 1997, a period that overlapped the presence of cattle up to 1993, a steep increase for five years from 1999 to 2005 during which the number of females counted increased from 4 to 21, then a major population crash between 2005 and 2006, which was followed by a second strong population increase between 2006 and 2015 with 20 females recorded in 2015 (Figure 3). The most recent (2022–2025) population estimates from camera data put the reproductive base of this population around 30 females (R. Ianniello, personal communication).

Average winter-spring predicted diet quality during the 1983–1997 declining population trend was 6.7% higher than that of the previous 24 years (1959–1982), but not statistically different (P = 0.213). Average predicted diet quality associated with the 2000–2005 steeply increasing population trend (Figure 3) was 3.3% lower than the previous 40 years, but statistically very similar (P = 0.664). That period of steep population gains included environmental variation ranging from an extreme drought year with very low predicted diet quality to years of high predicted diet quality (Figure 3). The second sustained population increase for 2006–2015 again included a considerable mixture of levels of predicted diet quality (Figure 3) with an average diet quality index 12.7% below the 1983–1997 period of population decline (P = 0.069) and 9.1% below the average for the first 40 years of data (P = 0.107). The population crash between 2005 and 2006 coincided with the highest (56.9 cm) cool season rainfall in the 53 years of data for Mitchell Caverns, 3.1 times the average and 22.8% higher than the next highest value.

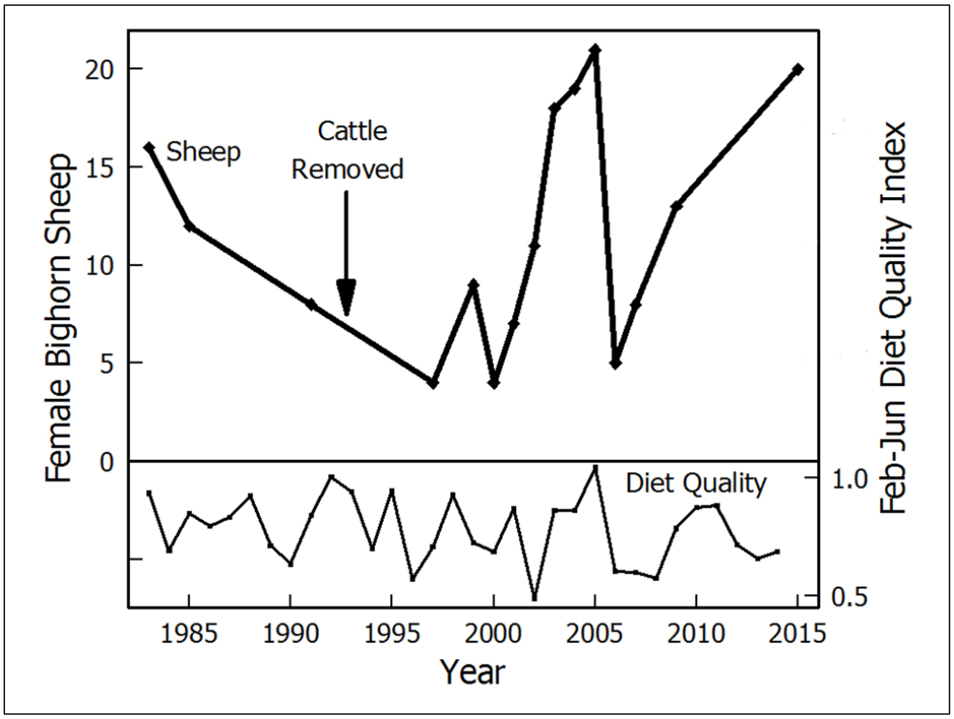

FIGURE 3. Numbers of female bighorn sheep (*Ovis canadensis nelsoni*) counted in helicopter surveys of 1.67–2.65 hours duration of the Clipper Mountains, San Bernardino County, California, 1983–2015; and February–June diet quality index for the same time period based on October–April rainfall data from Mitchell Caverns and the Granite Mountains.

DISCUSSION

In contrast to previous literature on cattle and desert bighorn sheep, we assembled and presented data in an attempt to choose between two alternative hypotheses that might explain bighorn sheep population dynamics associated with cattle grazing in the Mojave Desert of California. Our results appear to be consistent with the hypothesis that the presence of cattle can cause population declines for desert bighorn sheep, leading to depressed populations. For the Cady and N-O-R populations, data obtained after major grazing reductions documented notably larger populations of bighorn sheep compared with data from before grazing was reduced. However, the data we assembled relative to this question are circumstantial and potentially suffer from the limitations of such data. A primary problem is that the data on bighorn sheep populations were not collected to be temporally coordinated with when cattle grazing was eliminated or greatly reduced. Given that limitation, we cannot know if some of the bighorn sheep population trends we elucidated might have occurred in a temporal pattern uncorrelated with changes in cattle grazing. For the Cady Mountains there was a 19-year gap between earlier demographic data and the first helicopter survey after cattle were eliminated. Despite different minimum numbers of female bighorn sheep counted in the 2007–2010 helicopter surveys, it is unclear that those three helicopter surveys represent more than a single data point, given the variation in survey length and amount of habitat covered. That data point clearly indicated a large population increase relative to data from 1988–1989, but we cannot know if it grew to the larger size before or after cattle removal. It was therefore not possible to make a meaningful test of the alternative hypothesis.

For the N-O-R study area there was a 22-year (1994–2016) gap between sets of helicopter surveys, in the middle of which cattle numbers were greatly reduced (Figure 2). It is therefore not possible to know if the apparent increase in the bighorn sheep population detected in 2016 might have occurred prior to the reduction in cattle. In contrast, the steep population increase after 2016 (Figure 2) to recent estimates of >300 total sheep in this population all took place after the major reduction in cattle. For that study area the bighorn sheep population effectively has increased from being considered extinct for decades during which it was grazed by cattle to >300 sheep after most cattle were removed. The midrange variation in predicted diet quality clearly did not limit that increase after 2016 (Figure 2).

The Clipper Mountains had considerably more years of population data than the other two study areas, but also lacked data immediately before and after the year when cattle were removed (Figure 3). The data nevertheless exhibited a history of considerable population dynamics, most of which was consistent with predictions from hypothesis 1: a declining bighorn sheep population during cattle presence and strong increasing trends after cattle removal. There were two such episodes of population increase separated by a major population crash in a single year (Figure 3). That crash coincided with a year in which cool season rainfall was the highest ever recorded at Mitchell Caverns. That population crash also is consistent with the suggestion (Wehausen 2005) that very high cool season rainfall may produce conditions conducive for disease(s) in desert bighorn sheep. In the Clipper Mountains there was apparently a high mortality of adult females sometime after the 2005 fall helicopter survey that had yielded no observations of lambs with the 21 females recorded. That this severe population decline lasted for only one year also is consistent with the idea that it was related to very high rainfall. The immediate sustained growth of the population after that crash is consistent with what would be expected from a severely depressed population. That population response occurred despite three consecutive years of low predicted diet quality after the population crash (Figure 3). The first period of steep population growth also included an early year of extremely low predicted diet quality (Figure 3).

Both of these increasing population trends in the Clipper Mountains support the interpretation that the population was severely depressed at the time cattle were removed. Density dependence can be viewed as a force to increase populations that is strongest at low densities and weakens as populations increase in density. In wild ruminants this operates through competition among females for the most nutritious bites of forage, particularly during seasons and years when such bites are less abundant. That the population in the Clipper Mountains could increase readily during drought years of low nutrient availability speaks to how depressed the population was and how little competition there was for nutritious forage early in each period of strong population increase. As population densities increase, the influence of rainfall on the availability of nutritious forage has a steadily increasing influence on the ability of females to successfully rear young; thus, the relationship between diet quality (nutrient availability) and lamb:adult female ratios that Wehausen (2005) reported.

There are multiple reasons why there may be a time lag between when cattle are removed or reduced and a population response by bighorn sheep. If pathogen spillover is involved in a population decline of the bighorn sheep, it may take some years for the disease(s) involved to be cleared from the bighorn sheep population. Another potential source of a lag is the time needed for vegetation to recover from overgrazing. Time lags were evident in two of our study populations. For the Clipper Mountains there was an eight-year lag after cattle removal before sustained population growth began (Figure 3). For the N-O-R population, the few available data points suggest the possibility of a time lag of perhaps about 10 years before that population also entered a period of rapid, sustained population growth (Figure 2).

Habitat carrying capacity for desert bighorn sheep and stocking rates for cattle both are influenced by the elevational range and area of occupied habitat. The difference in habitat among our study areas is reflected in the numbers of cattle grazed and the recent sizes of the recovered bighorn sheep populations. Of our study populations, the habitat in the Clipper Mountains is most limited in area and elevational range. The Cady Mountains have a slightly greater elevational range, but contain a much larger area of habitat available to bighorn sheep. The N-O-R study area has the greatest elevational range and also a large area of habitat. Numbers of cattle grazed track this ordinal series: probably <50 in the Clipper Mountains, 172 in the Cady Mountains and 307 for N-O-R Mountains. Recent data on sizes of bighorn sheep populations follow the same pattern. Our study area with the highest habitat potential and the highest number of cattle (N-O-R) may have seen the greatest negative impact on the bighorn sheep population; for many years the bighorn sheep population was so reduced that it was considered extirpated. Wehausen and Epps (2021) noted the conservation problem that better habitat patches for desert bighorn sheep are more likely to suffer competition from domestic and feral ungulates.

Looking forward, there is the need for additional research on the influence of cattle on desert bighorn sheep using an experimental approach (Macnab 1983) that includes the acquisition of consistent, high-resolution demographic data on the bighorn sheep for at least several years immediately prior to cattle removal and for potentially many years after the removal of cattle. Data from such a research design should allow more fine-grained tracking of bighorn sheep population dynamics. We recommend an approach that attempts to distinguish a data signal associated with a change in cattle grazing from the inherent population dynamics noise in the bighorn sheep population driven largely by variation in rainfall. The circumstantial data we have presented suggest that such a signal related to cattle grazing may be strong relative to that environmental noise. Unfortunately, other factors such as mountain lion predation and introduced respiratory disease have the potential to derail such studies by confounding the data.

Given the politics of livestock grazing, it may not be predictable when cattle grazing might be terminated in any particular mountain range. It is therefore important to choose candidate populations and collect pre-removal population data until the opportunity for cattle removal occurs. The major shortcoming of the data we relied on is that cattle removal or reduction occurred suddenly, and there was no attempt, opportunity, or even recognition of the importance of collecting high quality demographic data prior to and immediately after major changes in grazing. Such investigations must measure population variables for bighorn sheep at high resolution to produce data that can be readily compared over time. This might include methods based on fecal DNA or cameras carefully placed at water sources to allow recognition of naturally marked females (Bleich et al. 2026).

As emphasized by Macnab (1983:401), "Science advances most rapidly by manipulative experiments." Cattle grazing occurs in and near desert bighorn sheep in numerous mountain ranges across multiple states, and opportunities to further explore the effects of cattle on bighorn sheep likely will present themselves in the future. We suggest that our recommended experimental approach to determine the effects of cattle on desert bighorn sheep populations be replicated in different locations to the extent possible.

ACKNOWLEDGMENTS

This paper is dedicated to the memory of Richard A. (Dick) Weaver and Richard K. (Rick) Clark, both of whom played prominent roles in the production of data we used for this analysis. Dick Weaver had a great concern about the potential negative effects of cattle grazing on desert bighorn sheep in California, and contracted one of the authors (JDW) beginning in 1984 to research this question in the Mojave Desert of California. Dr. Clark served as the primary net-gunner for CDFG's early bighorn sheep capture work to obtain blood samples for disease exposure investigations, during which many collars were installed, including all of those used for the 1989 Cady Mountains population estimate. Rick Ianniello of the California Department of Fish and Wildlife (formerly CDFG) provided many of the more recent population survey and population estimate data for desert bighorn sheep, Kathleen Andersen from the same agency produced Figure 1, and Steve Torres provided important past helicopter survey data from the Cady Mountains for 2010. We thank the Guest Editor for handling the peer-review for this manuscript, and we thank him and three anonymous reviewers for many helpful comments that greatly improved this paper. This is Professional Paper 167 from the Eastern Sierra Center for Applied Population Ecology.

REFERENCES

Aardahl, J. B. 2023. Cattle grazing and bighorn sheep in the California Desert Conservation Area: a chronology of management actions by the Bureau of Land Management. Desert Bighorn Council Transactions 57:25–43.

Albrechtsen, B. R., and J. B. Reese. 1970. Problem analysis of habitat management for desert bighorn sheep. Desert Bighorn Council Transactions 14:63–65.

Bates, Jr., J. W. 1982. Desert bighorn habitat utilization in Canyonlands National Park. M.S. Thesis. Utah State University, Logan, Utah, USA.

Besser, T. E., E. F. Cassirer, M. A. Highland, P. Wolff, A. Justice-Allen, K. Mansfield, M. A. Davis, and W. Foreyt. 2013. Bighorn sheep pneumonia: sorting out the causes of a polymicrobial disease. Preventive Veterinary Medicine 108:85–93.

Bissonette, J. A., and M. J. Steinkamp. 1996. Bighorn sheep response to ephemeral habitat fragmentation by cattle. Great Basin Naturalist 56:319–325.

Bleich, V. C., R. T. Bowyer, and J. D. Wehausen. 1997. Sexual segregation in mountain sheep: resources or predation? Wildlife Monographs 134:1–50.

Bleich, V. C., D. W. Lutz, M. E. Blum, D. M. Glass, S. G. Torres, and J. C. Whiting. 2026. Mountain sheep survey methods. Pages 233–257 *in* P. R. Krausman and B. A. Jex, editors. Mountain sheep in North America. CRC Press, Boca Raton, Florida, USA.

Blaisdell, J. A. 1975. Progress report: the Lava Beds reestablishment program. Desert bighorn Council Transactions 19:36–37.

Brown, N. A., K. E. Ruckstuhl, S. Donelon, and C. Corbett. 2010. Changes in vigilance, grazing behavior, and spatial distribution of bighorn sheep due to cattle presence in Sheep River Provincial Park, Alberta. Agriculture, Ecosystems and Environment 135:226–231.

Buechner, H. K. 1960. The bighorn sheep in the United States, its past, present, and future. Wildlife Monographs 4:1–174.

Carpenter, S. A., N. J. Shirkey, P. R. Prentice, E. L. Lantz, B. A. Munk, C. W. Epps, B. R. Beechler, and A. J. Jolles. 2025. Landscape of exposure: metapopulation dynamics and local environment structure pathogen exposure in desert bighorn sheep. Ecosphere 2025;16:e70504

Cassirer, E. F., K. R. Manlove, E. S. Almberg, P. L. Kamath, M. Cox, P. Wolff, A. Roug, J. Shannon, R. Robinson, R. B. Harris, B. J. Gonzales, R. K. Plowright, P. J. Hudson, P. C, Cross, A. Dobson and T. E. Besser. 2018. Pneumonia in bighorn sheep: Risk and resilience. Journal of Wildlife Management 82:32–45.

Clark, R. K., D. A. Jessup, M. D. Kock, and R. A. Weaver. 1985. Survey of desert bighorn sheep in California for exposure to selected infectious diseases. Journal of the American Veterinary Medical Association 187:1175–1179.

Clark, R. K., W. M. Boyce, D. A. Jessup, and L. F. Elliott. 1993. Survey of pathogen exposure among population clusters of bighorn sheep (*Ovis canadensis*) in California. Journal of Zoo and Wildlife Medicine 24:48–53.

Dubay, S., H. Schwantje, J. deVos, and T. McKinney. 2004. Bighorn sheep (*Ovis canadensis*) diseases: a brief literature review and risk assessment for translocation. Proceedings of the Annual Meeting of the United States Animal Health Association 107:600–621.

Dunbar, M. R., D. A. Jessup, J. F. Evermann, and W. J. Foreyt. 1985. Seroprevalence of respiratory syncytial virus in free-ranging bighorn sheep. Journal of the American Veterinary Medical Association 187:1173–1174.

Dunn, W. C. 1993. Use of springs by desert bighorn sheep before and after removal of feral burros. Desert Bighorn Council Transactions 37:11–15.

Ferrier, G. J., and W. G. Bradley. 1970. Bighorn habitat evaluation in the

Highland Range of southern Nevada. Desert Bighorn Council Transactions 14:66–93

Gallizioli, S. 1977. Overgrazing on desert bighorn ranges. Desert Bighorn Council Transactions 21:21–23.

Garrison, K. R., J. W. Cain III, E. M. Rominger, and E. J. Goldstein. 2016. Sympatric cattle grazing and desert bighorn sheep foraging. Journal of Wildlife Management 80:197–207.

Goodson, N. J. 1982. Effects of domestic sheep grazing on bighorn sheep populations: a review. Northern Wild Sheep and Goat Council Proceedings 3:287–313.

Graham, A, and R. Bell. 1989. Investigating observer bias in aerial survey by simultaneous double-counts. Journal of Wildlife Management 53:1009–1016.

Hanley, T. A., and K. A. Hanley. 1982. Food resource partitioning by sympatric ungulates on Great Basin Rangeland. Journal of Range Management 35:152–158.

Irvine, C. A. 1969. The desert bighorn sheep in southeastern Utah. M.S. Thesis. Utah State University, Logan, Utah, USA.

Jessup, D. A., W. L. Goff, D. Stiller, M. N. Oliver, V. C. Bleich, and W. M. Boyce. 1993. A retrospective serologic survey for *Anaplasma* spp. infection in three bighorn sheep (*Ovis canadensis*) populations in California. Journal of Wildlife Diseases 29:547–554.

King, M. M., and G. W. Workman. 1984. Cattle grazing in desert bighorn sheep habitat. Desert Bighorn Council Transactions 28:18–22.

Krausman, P. R., J. D. Wehausen, M. C. Wallace, and R. C. Etchberger. 1993. Rumen characteristics of desert races of mountain sheep and mule deer. Southwestern Naturalist 38:172–174.

Macnab, J. 1983. Wildlife management as scientific experimentation. Wildlife Society Bulletin 11:397–401.

Prentice, P., R. Ianniello, J. Colby, E. Schaeffer, J. N. Sanchez, J. T. Villepique, L. E. Greene, and T. R. Stephenson. 2019. Status of bighorn sheep in California, 2019. Desert Bighorn Council Transactions 55:70–84.

Rominger, E. M., H. A. Whitlaw, D. L. Weybright, W. C. Dunn, and W. Ballard. 2004. The influence of mountain lion predation on bighorn sheep translocations. Journal of Wildlife Management 68:993–999.

Rubin, E. S., and V. C. Bleich. 2005. Sexual segregation: a necessary consideration in wildlife conservation. Pages 379–391 *in* K. E. Ruckstuhl and P. Neuhaus, editors. Sexual segregation in vertebrates: ecology of the two sexes. Cambridge University Press, Cambridge, United Kingdom.

Ruder, M. G., and S. A. Christensen. 2023. Bluetongue, epizootic hemorrhagic disease, and cervid adenoviral hemorrhagic disease. Pages 180–197 *in* R. Radcliffe and D. Jessup, editors. Wildlife Health, Disease, and Conservation. Johns Hopkins University Press, Baltimore, Maryland, USA.

Sanchez, J. N., B. A. Munk, J. Colby, S. G. Torres, B. J. Gonzales, J. R. DeForge, A. J. Byard, L. Konde, N. J. Shirkey, P. S. Pandit, R. A. Botta, A. Roug, M. H. Ziccardi, and C. K. Johnson. 2022. Pathogen surveillance and epidemiology in endangered peninsular bighorn sheep (*Ovis canadensis nelsoni*). Conservation Science and Practice 4:1–17.

Singer, R. S., D. A. Jessup, I. A. Gardner, and W. M Boyce. 1997. Pathogen exposure patterns among sympatric populations of bighorn sheep, mule deer, and cattle. Journal of Wildlife Diseases 33:377–382.

Turner, J. C., and J. B. Payson. 1982. The occurrence of selected infectious diseases in the desert bighorn sheep *Ovis canadensis cremnobates*, of the Santa Rosa Mountains, California. California Fish and Game 68:235–243.

Vu, R. K., R. Ianniello, J. Colby, E. Schaeffer, J. N. Sanchez, J. T. Villepique, L. E. Greene, and T. R. Stephenson. 2021. Status of bighorn sheep in California, 2021. Desert Bighorn Council Transactions 56:87–95.

Weaver, R. A. 1975. Status of bighorn sheep in California. Pages 58–64 *in* J. B. Trefethen, editor. The wild sheep in modern North America. The Winchester Press, New York, New York, USA.

Webb, P. M. 1972. Status of desert bighorn sheep in Arizona. Desert Bighorn Council Transactions 16:105–111.

Wehausen, J. D. 1995. Fecal measures of diet quality in wild and domestic ruminants. Journal of Wildlife Management 59:816–823.

Wehausen, J. D. 2005. Nutrient predictability, birthing season, and lamb recruitment for desert bighorn sheep. Pages 37–50 *in* J. Goerrissen and J. M André, editors. Sweeney Granite Mountains Desert Research Center 1978–2003: a quarter century of research and teaching. University of California Natural Reserve Program, Riverside, California, USA.

Wehausen, J. D. 1992. Demographic studies of mountain sheep in the Mojave Desert. Final report completed under interagency agreement FG-9239 with the California Department of Fish and Game, Sacramento, California, USA.

Wehausen, J. D. and V. C. Bleich. 2007. The effect of survey intensity on bighorn sheep helicopter counts. Desert Bighorn Council Transactions 49:23–29.

Wehausen, J. D. and C. W. Epps. 2021. Population extinction and conservation planning for desert bighorn sheep in California. Desert Bighorn Council Transactions 56:54–74.

Wehausen, J. D. and M. C. Hansen. 1986. Impacts of cattle grazing on bighorn sheep. Final report completed under interagency agreement C-913 with the California Department of Fish and Game, Sacramento, California, USA.

Wehausen, J. D., S. T. Kelley, and R. R. Ramey II. 2011. Domestic sheep, bighorn sheep, and respiratory disease: a review of the experimental evidence. California Fish and Game 97:7–24.

Whiting, J. C., V. C. Bleich, and T. Smith. 2026. Competition among mountain sheep and other ungulates. Pages 175–190 *in* P. R. Krausman and B. A. Jex, editors. Mountain sheep in North America. CRC Press, Boca Raton, Florida, USA.

Wild Sheep Initiative. 2025. Recommendations for domestic sheep and goat management in wild sheep habitat. Western Association of Fish and Wildlife Agencies, Boise, Idaho, USA.

Wilson, L. 1975. Discussion. Pages 103–104 *in* J. B. Trefethen, editor. The wild sheep in modern North America. The Winchester Press, New York, New York, USA.

Wolfe, L., B. Diamond, T. R. Spraker, M. A. Sirochman, D. P. Walsh, C. M. Machin, D. J. Bade, and M. W. Miller. 2010. A bighorn sheep die-off in southern Colorado involving a *Pasteurellaceae* strain that may have originated from syntopic cattle. Journal of Wildlife Diseases 46:1262–1268.

Zdon, A., M. L. Davisson, and A. H. Love. 2018. Understanding the source of water for selected springs within Mojave Trails National Monument, California. Environmental Forensics 19:99–111.

Status Reports, Case Reports, and Case Histories

Status of Bighorn Sheep in Arizona—2024

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Desert Bighorn Council Transactions 58:124–128

Estimates of Arizona's desert bighorn sheep (*Ovis canadensis mexicana* and *O. c. nelsoni*) populations have remained relatively stable statewide. Ram:100 ewes and lamb:100 ewe ratios averaged 59:100:30 in 2024/2025 with 1,823 bighorns observed. Arizona currently has an estimated population of 5,500–6,000 desert bighorn sheep based on survey data.

The desert bighorn sheep population in the Kofa Mountains (Units 45A, 45B, and 45C) in southwestern Arizona remains strong and once again surpassed the recovery threshold met in 2019. The 2024 aerial survey resulted in a population estimate of 1,121 bighorn sheep, exceeding the previous estimate of 800 in 2000. The Black Mountains (Units 15A, 15B, 15C, and 15D) of northwestern Arizona experienced a disease outbreak which resulted in a 53% decrease in the number of bighorn sheep observed on a survey in 2016 and 2017. Even though Unit 15D is somewhat isolated from the rest of the Black Mountains by Highway 68, the disease crossed the highway and impacted that portion of the population. Aerial surveys in 2022 showed signs of recovery in Unit 15C, but a slight decline in Unit 15BW and 15D.

Rocky Mountain bighorn sheep (*O. c. canadensis*) continue to prosper in Arizona. The surveyed population is estimated at 1,200 animals. Ram:100 ewes:lamb ratios averaged 44:100:35 in 2024 with 533 observed. Arizona currently has an estimated population of 1,000–1,500 Rocky Mountain bighorn sheep based on survey data alone, but surveys are not flown in all known populations. Arizona surveys about one-third of the Rocky Mountain and desert bighorn populations annually, although some areas of specific concern or recent translocations are surveyed annually.

RESEARCH

Disease Monitoring

A total of 188 nasal swab and additional biological samples were collected from bighorn sheep in 2023 through capture, hunter submission during check-in, roadkill inspection, or other encounters, and tested for disease agents. A trial was conducted to investigate detection rates of *Mycoplasma ovipneumoniae* (Movi) between hunter harvest samples at the time of harvest in comparison with Department samples taken at check-in that typically occurs several days post-harvest. A new Movi strain was identified in Unit 46A (Growlers) through this hunter-sampling effort. In 2024, 200 samples collected by hunters and through the Department's check-in process were analyzed to repeat this trial A report was drafted and oral and poster presentations were delivered at regional and international meetings. Results concluded that the collection of samples at harvest yielded slightly better results than collection of samples at check in. Going forward, we will ask hunters to collect samples at harvest in units where Movi detection and monitoring is a high priority.

Movement and Corridor Studies

Tonto National Forest – Region 6 staff renewed a Minimum Requirements Analysis Framework (MRAF) to complete several capture efforts over a 5-year period within FS Wilderness on the Tonto National Forest to continue monitoring efforts for disease and track movements in response to fires. Special conditions included restricting helicopter landings to less than 30 in a 1-year period. Throughout the area, 36 collars were placed on desert and Rocky Mountain bighorn sheep in 2020, 21 additional collars were deployed in 2021, 10 were deployed in 2022, 21 were deployed in or near the approved Wilderness Areas in 2023 and 14 more were deployed in 2024. The additional collars deployed during 2021–2024 have provided much needed information in the areas where gaps in data were identified from previous collar deployments versus known and anticipated occupied habitat. Monitoring the movements of these collared bighorn sheep have allowed Department staff to modify their aerial survey routes, thereby producing more effective surveys.

Unit 16A – In February of 2022, 26 bighorn sheep (9 rams, 17 ewes) were captured across five mountain ranges in Unit 16A. All were collared to aid in survey efforts, and sampled to establish a disease profile for Unit 16A. Several mortalities occurred in the first six months following deployment and were redeployed in November 2022 and again in October 2023. The data collected by these collars revealed long-range movements by bighorn sheep from this herd into other units (Unit 44A) as suspected. The re-designed survey polygons were flown and bighorn sheep were observed at a rate of 4.3 per hour, an increase of 0.8 over the 9-year average of 3.5 per hour. After a second year of data analysis, re-designed survey polygons were flown in 2024 and bighorn sheep were observed at a rate of 2.5 per hour, a decrease of 1.0 bighorn sheep per hour, likely due to the dramatic total number of bighorn sheep seen on the survey. The data is being evaluated in conjunction with BLM for risk analysis between neighboring units.

Yuma Proving Grounds – Document water catchment selection and seasonal/corridor movements through the use of GPS collars. Five bighorn sheep were collared November 2022 and five more May 2023. One ewe mortality was documented in August 2023 and a ram collared failed at the same time. Ewes express more tightly defined home ranges than rams who express more movement between mountain ranges using many different catchments. Four additional collars failed by November 2024. There was no change in water catchment use or area used from 2023 to 2024. This information will prioritize water hauling activities during the limited windows of accessibility into the restricted airspace, as well as guide decisions about permit allocations for the accessible hunt areas.

Galiuro FireScape Project – In 2016, the Safford District of the United States Forest Service (USFS) began implementing the Galiuro FireScape, an eight-year plan to treat 137,000 acres of USFS land in the Galiuro Mountains (Units 31/32) with prescribed fire. The long-term goal of the Galiuro Firescape is the return of the historical natural fire regime. The treatment area was divided into 8 burn units, one unit treated each year. As of February 2022, over 60,000 acres have been treated, and every burn unit at least partially treated.

In conjunction with this project, the Department augmented populations of desert bighorn sheep in Aravaipa and Redfield canyons in 2016 (n = 31); two rams and 8 ewes were fitted with GPS-transmitting collars to evaluate the post-release success of populations and response to the prescribed burns. The collars deployed in 2016 reached the end of their life expectancy before prescribed burns were completed in currently utilized habitat, so the Department collared an additional 9 rams and 1 ewe in November 2019. The data from the ewe collared in 2019 showed longer periods of use in an area treated with prescribed fire in February of 2022.

Maintaining active collars on this landscape has allowed for the accumulation of GPS data identifying the home range and habitat use by bighorns in occupied habitat before and after prescribed burn efforts. Unused desert bighorn sheep habitat and a potential corridor between the two existing desert bighorn sheep populations have been identified, as the gap between the Aravaipa and Redfield bighorn sheep populations has closed from 30 km to 11 km.

Ten additional collars were deployed in November 2023 in Redfield Canyon. These collars, and the collars deployed since 2015, have documented an expanded use of habitat by resident bighorn sheep, and longer periods of time spent in areas post-treatment with prescribed fire. It is recommended that the Department continue to support the efforts of the USFS and BLM in managing this landscape through their Firescape plan, survey additional areas adjacent to former survey blocks, and implement a predation management plan, if feasible.

HABITAT

The Department works with private organizations (primarily the Arizona Desert Bighorn Sheep Society (ADBSS) and the Wild Sheep Foundation (WSF)) and federal agencies to achieve habitat improvements for bighorn sheep. In 2023, the Department's Development Branch and the ADBSS teamed up to repair four catchments in bighorn sheep habitat, Rock Trick Tank #431, Frank Reservoir #478, Javelina Mountain #885 and Paloma Wash #1047. In 2024, Development Branch partnered with the same organizations and refurbished a water catchments Gonzales Pass #77, Slurry Tanks #824, Marquetta Pass #1000 and Sheep Mountain #1050. Ranchbot water monitoring systems have been deployed on over 50% of the Department's maintained waters.

Much of east-central Arizona is still recovering from several large fires totaling 574,275 acres between 2019–2021. A marked decrease in bighorn sheep observations occurred in the Mescal Fire burn area of Unit 24B, although poor flying conditions were noted. Special surveys and collaring efforts are being conducted to monitor the effects of these large wildfires on bighorn populations in these units.

Water hauling efforts due to extended periods of drought has become regular practice in many parts of the state, with Region 4 (SW AZ) bearing the brunt of the activity due to the high number of catchments on the landscape. The region experienced a slight reprieve from water hauling in 2023, but in 2024 demand rose again and staff and volunteers delivered 651,010 gallons of water to catchments, many of which solely benefit bighorn sheep. About 143,500 gallons were delivered by helicopter to catchments inaccessible to water trucks. The Department is actively working to improve collection and storage capacity at many of these water catchments so the demand for hauling water is continually reduced.

HARVEST

Bighorn sheep permits remain the most sought-after hunting permits in Arizona. In 2024, 28,993 individuals applied for the 156 desert and Rocky Mountain bighorn sheep permits available for draw.

During the 2024 season, 156 hunters participated (including three Special Big Game

Tags), harvesting 150 rams in 693 days of hunting. Hunt success was 96%. The age of harvested rams ranged from 4 to 11 ($\bar{x}$ = 7.7), and horns green-scored from 107 2/8 to 193 6/8 ($\bar{x}$ = 162 3/8 B&C).

In 2023, 156 permits were issued to those drawn from the pool of 27,232 applicants. One of those drawn did not hunt. Of the 155 hunters in the field, 96% were successful, with a combined total of 726 hunter days in the field. The average age of harvested rams in 2023 was 8 years; B&C green-scores ranged from 70 3/8 to 184 6/8 with an average of 162 2/8.

The Arizona Game and Fish Commission awarded the Special Big Game Tags for bighorn sheep (two tags per year) to ADBSS in 2023 and 2024, with a third tag to the Arizona Big Game Super Raffle (AZBGSR). Each year, ADBSS has traditionally partnered with the WSF to auction one tag and auction the second at their fundraising banquet; the third is raffled through AZBGSR. In 2023, a total of $555,950 and in 2024, a total of $921,340 was raised via these Special Big Game Tag Sales. 100% of the proceeds of all three tags come back to the Arizona Game and Fish Department to fund the conservation and management of bighorn sheep in Arizona. Since its inception (1984), the Arizona Bighorn Sheep Special Big Game Tags have brought in more than $15.8 million USD through 2025 to support bighorn sheep management in Arizona.

TRANSLOCATIONS

Desert Bighorn Sheep

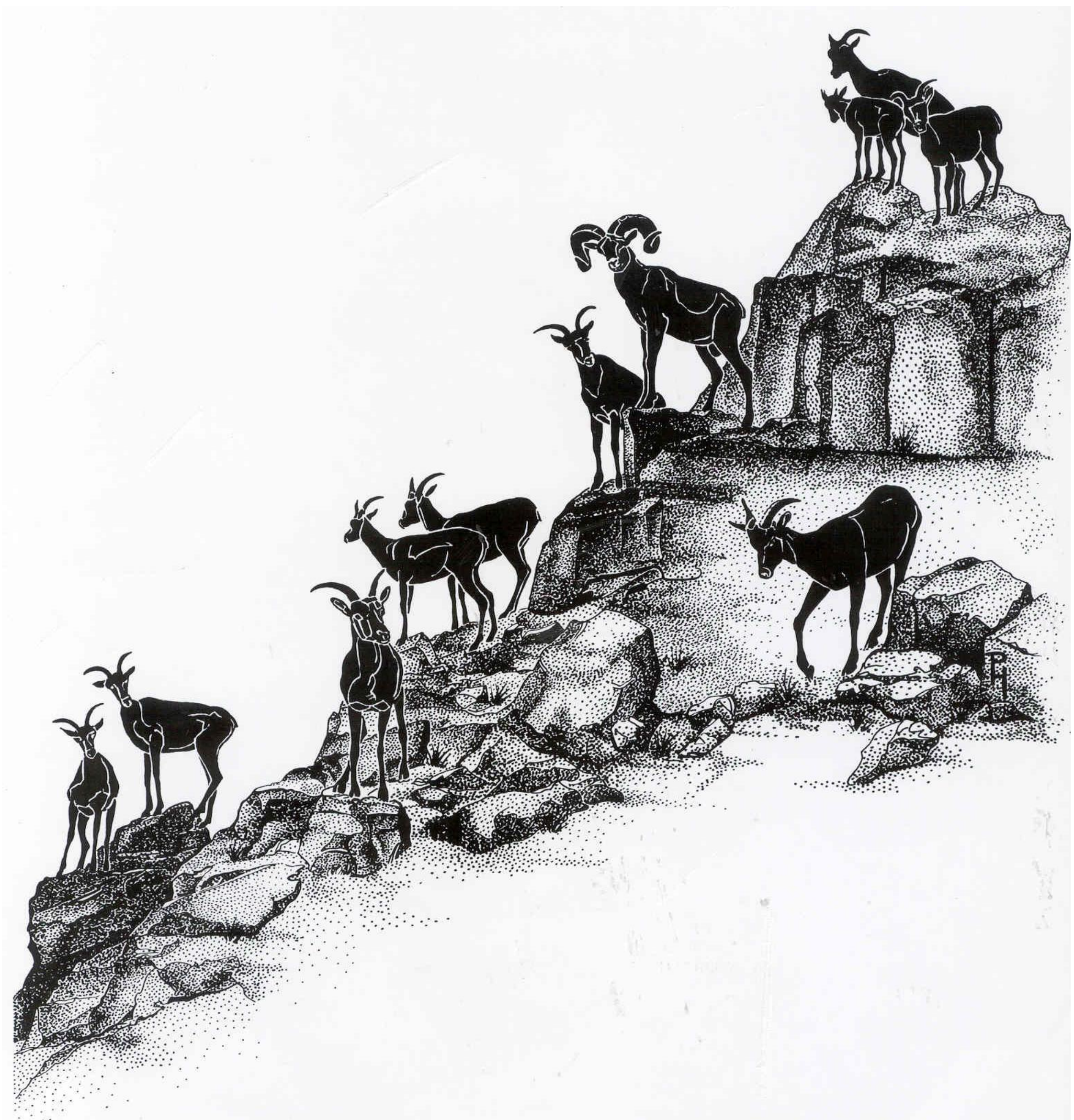
A project to expand the desert bighorn herd in the Harcuvar Mountains in Unit 44A into unoccupied portions of their range was initiated in 2021. A total of 23 bighorns (20 ewes, 3 rams) were captured and translocated from the Plomosa Mountains in Unit 44B in November of 2021 with 22 GPS collars deployed during this event. A follow-up translocation of an additional 30 bighorns (3 rams, 27 ewes) from the Trigo Mountains in Unit 43B was conducted in 2022 with an additional 25 GPS collars. No bighorn sheep were translocated in 2023 due to source population disease testing results. In 2024, a total of 28 bighorn sheep (4 rams, 24 ewes) were relocated from the Kofa Mountains in Unit 45 with 10 collars.

Rocky Mountain Bighorn Sheep

Efforts to relocate Rocky Mountain bighorn sheep from the Morenci Mine area in Units 27S and 28N have been ongoing since 2002 with drop-net and darting operations resulting in the capture of 386 bighorn sheep through 2024. In 2023, six bighorn sheep (3 rams, 3 ewes) and in 2024 six bighorn sheep (4 rams, 2 ewes) were translocated to Upper Blue River (Unit 27N). These bighorn sheep are being monitored to see if they return to Morenci Mine or establish home ranges in Upper Blue River. This brings the total of desert and Rocky Mountain bighorn sheep captured and translocated in Arizona or to other states to 2,797.

BIGHORN SHEEP AND DOMESTIC SHEEP AND GOAT INTERACTIONS

The Department regularly responds to reports of domestic sheep or goats in areas that create the potential for interactions with bighorn sheep. In 2023, two domestic goats were located in bighorn habitat in Unit 15C (where Movi is already present) and were captured using aerial net-gunning, collected and turned over to the Department of Agriculture, and both tested negative for Movi. A lone domestic goat was observed commingling with Rocky Mountain bighorn sheep in Unit 28 in November 2023; a helicopter and capture crew were diverted from a nearby collaring project to catch and remove the goat from the area. They were successful, and also deployed two collars to monitor movements of bighorns observed with the goat. Tests on the samples collected from the goat and the bighorns captured were negative for Movi. In 2024, two domestic goats and three wild bighorn sheep were located together in East Clear Creek Unit 4A/5A and four wild bighorn sheep were located with domestics in Unit 6A. Neither of the domestic animals tested negative for Movi. All seven wild bighorn sheep were euthanized in the two areas, of which, none tested positive. Routine monitoring conducted annually on harvested rams after these events found no positive Movi cases.



Status of Bighorn Sheep in California—2025

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Desert Bighorn Council Transactions 58:129–143

The California Department of Fish and Wildlife (CDFW) oversees two subspecies of bighorn sheep including the Sierra Nevada bighorn sheep (*Ovis canadensis sierrae*) and the desert bighorn sheep (*Ovis canadensis nelsoni*). The Sierra Nevada bighorn are federally listed as endangered and managed under the Sierra Nevada Bighorn Sheep (SNBS) Recovery Program. A portion of the desert bighorn population, known as Peninsular bighorn, are considered a distinct population segment, are also federally listed as endangered, and are managed by the Peninsular Bighorn Sheep (PBS) Recovery Program. The remainder of the non-endangered desert bighorn are primarily managed by the Desert Bighorn Sheep (DBS) Program, although there are a few populations along the Transverse Ranges that are overseen by unit biologists. Finally, there are two areas in Northern California where introduced populations of California bighorn from neighboring states occasionally immigrate to California, but these are considered transient individuals and CDFW is not actively managing them (Figure 1). For more details, please see the Conservation and Management Plan for Bighorn Sheep in California (CDFW 2025).

This status update will provide general updates on population trends, translocations (SNBS), harvest (DBS), habitat improvements (DBS and PBS), recent and ongoing research, and key conservation concerns for all three bighorn sheep programs for the years of 2024 and 2025. Please refer to Appendix A for a detailed breakdown of population size-class estimates for all the populations of bighorn sheep across California.

POPULATIONS

Sierra Nevada Bighorn Sheep Recovery Program

Sierra Nevada Bighorn Sheep were federally and state listed as endangered in 1999 at which time the population was estimated to be approximately 150 individuals including 55 females distributed among seven herds (Figure 2, Female SNBS 1999–2025, USFWS 2007). The population peaked in 2016 with 316 females distributed among 14 herds at which point the geographic recovery goals were met but numerical goals were met in only 2 of the 4 recovery units. Since 2017 the subspecies trended indirectly downward and was driven by losses during the big winters of 2017, 2019 and 2023 in which female mortality was 33%, 25% and 55% respectively. In the last ten years, the leading causes of mortality have been snow in the form of avalanche, and starvation and lion predation. Since the extreme snowfall during the winter of 2023, the population has increased with the most recent population estimate from 2025 of 197 females distributed across 11 herds.

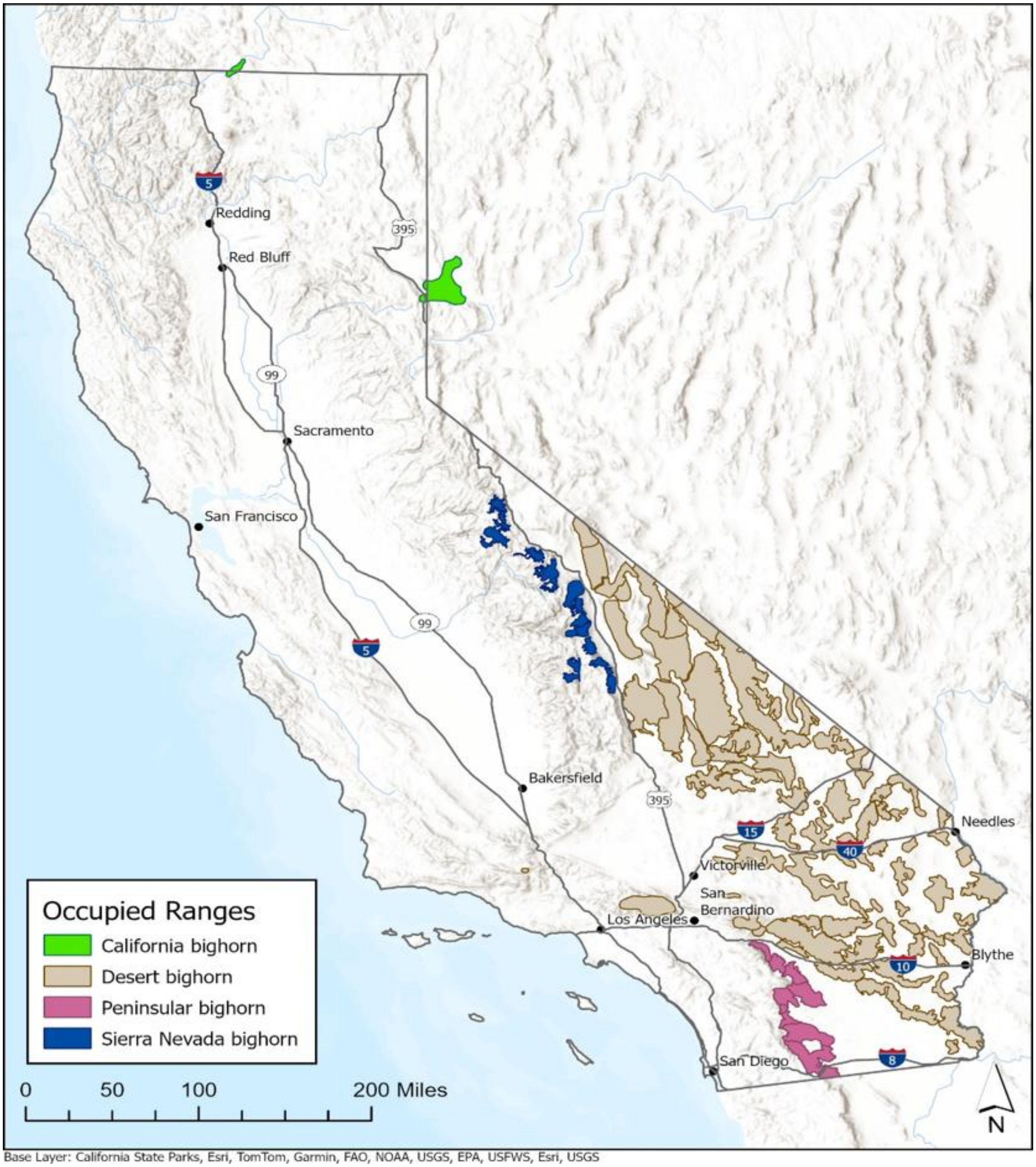

FIGURE 1. Distribution of mountain ranges currently and formerly occupied by bighorn sheep (*Ovis canadensis*) in California, including occupied ranges that cross state boundaries.

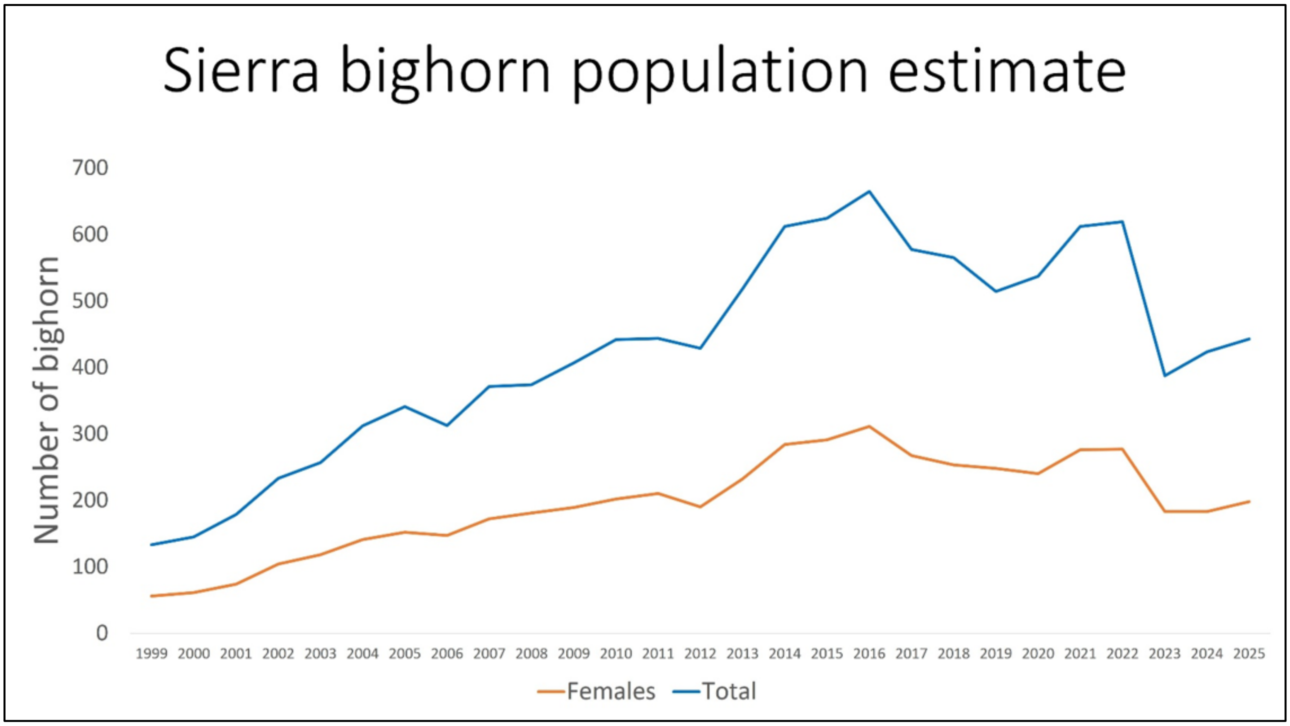

FIGURE 2. The Sierra Nevada bighorn sheep population trend through time (1999–2025) and the female-only estimates.

Peninsular Bighorn Sheep Recovery Program

Peninsular bighorn were first listed as endangered in 1998 when the population declined to less than 300 individuals (USFWS 2000). Since then, CDFW has worked in close collaboration with the U.S. Fish and Wildlife Service (USFWS) and partners to monitor this population and approached the delisting criteria including maintaining a minimum abundance of 750 individuals and distribution of at least 25 ewes in each of the 9 recovery regions with a stable or increasing trend for 12 consecutive years. While the population did rebound substantially, reaching a peak estimate of 981 (95% CI: 842–1120) individuals in 2010, the population has since experienced a gradual decline (Figure 3). Mark-resight estimates from a range-wide helicopter survey in December 2024 resulted in an estimate of 743 (656–830 CI) individuals, along with several of the recovery regions falling below the minimum count of 25 ewes.

Desert Bighorn Sheep Program

The first comprehensive effort to survey desert bighorn in California began in the 1960s (Weaver et al. 1968, Weaver and Mensch 1969, and Weaver et al. 1969). Estimates of desert bighorn abundance in California have increased as survey methods have improved, and effort has intensified. Between 1983 and 2006, the Department translocated desert bighorn within southern California to reestablish historic populations, increase population numbers to sustainable levels, and provide increased opportunities for recreational, aesthetic, and educational use (Bleich et al. 1990b, Bleich et al. 2021). Extreme drought in 2020 and 2021 decreased desert bighorn numbers, but good recruitment was observed in 2023 and 2024. Between 2015 and 2023, the Department conducted population surveys in 48 of 70 desert bighorn populations yielding an estimate of 3,250 individual animals. The Department plans to survey the remaining populations but based on historical data it is estimated that in 2025 the statewide desert bighorn population was around 4,250 individuals (Figure 4).

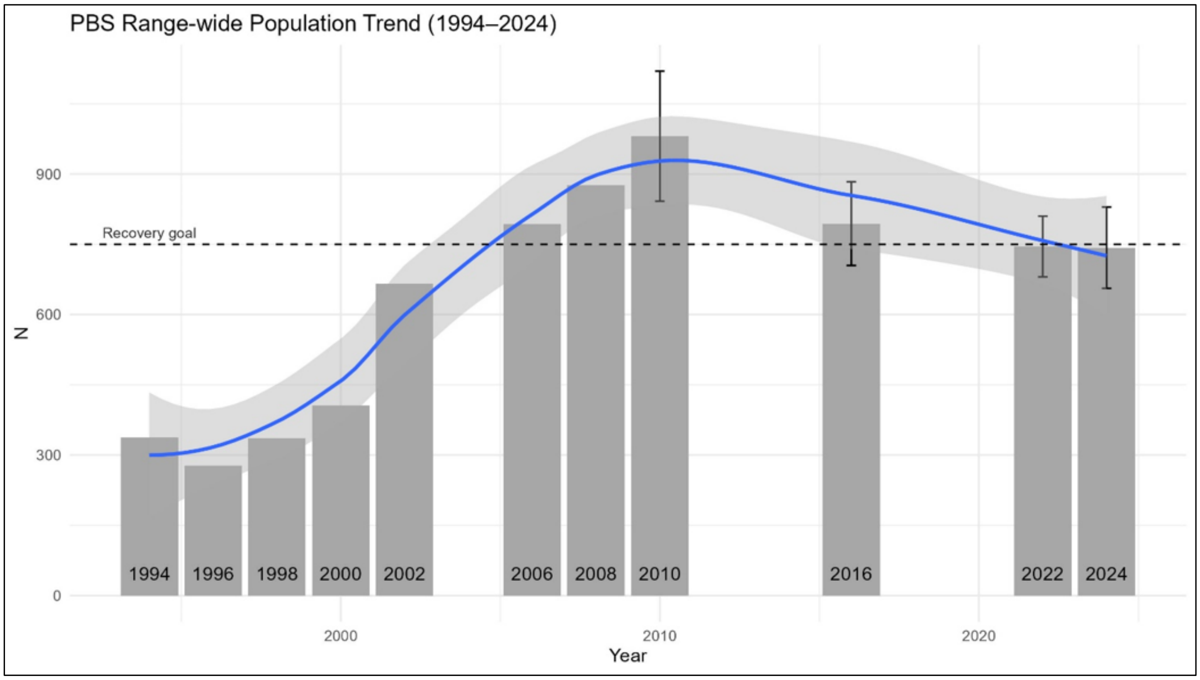

FIGURE 3. Abundance estimates plotted over time of Peninsular bighorn sheep with a local estimated scatterplot smoothing (LOESS) trendline. The dashed line marks 750 individual bighorn, one of the delisting criteria for the Recovery Plan.

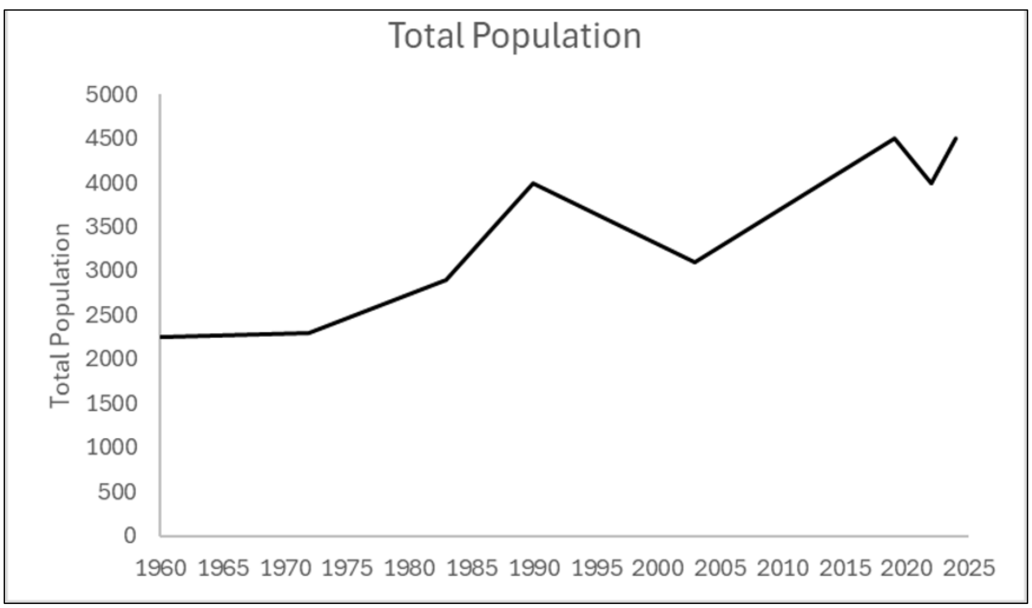

Figure 4. Population estimates of desert bighorn (excluding Peninsular bighorn) in California during 1960–2024. Early estimates likely reflect less robust methods used to count bighorn across >70 mountain ranges.

TRANSLOCATIONS

The only translocations that took place in California between 2024 and 2025 were part of the Sierra Nevada Bighorn Recovery Program. Five pregnant adult females were translocated in March 2025 from the Mt. Baxter herd to augment the Mt. Gibbs herd.

HARVEST

CDFW oversees 10 desert bighorn sheep hunt zones across the state. During the 2024-2025 season there were 9 hunt zones open, and a total of 20 rams harvested. Leading into the 2025-2026 hunt season the California Fish and Game Commission (CFGC) approved several changes aimed at increasing hunter opportunity and maximizing fundraising potential. These changes included giving CDFW the ability to assign the two single-zone fundraising tags to new zones each year (as needed); adjusting the hunt zone boundary for Zone 6 to include more known ram habitat; adding a winter season to Zone 7; and splitting Zone 10 into two periods. For the 2025-2026 season, there is a total of 30 tags (3 fundraising, 27 general) across all 10 hunt zones. CDFW is also proposing three new hunt zones, near and within the Mojave National Preserve, to the CFGC for the 2026-2027 hunt season. If approved, these zones will be the first new desert bighorn hunt zones in California since 2019.

HABITAT IMPROVEMENT PROJECTS

Like many desert bighorn populations, natural springs are becoming more ephemeral across the Peninsular bighorn recovery region, making water management a key component to population recovery. Many of the wildlife water developments (WWDs) used by PBS are located within Anza Borrego Desert State Park.

Peninsular Bighorn Sheep Recovery Program

Between 2022 and 2024, in collaboration with State Parks, the California Chapter of the Wild Sheep Foundation, the Society for the Conservation of Bighorn Sheep (SCBS), Backcountry Hunters and Anglers, and the US Marine Corps, a total of five WWD replacement projects took place. Updating the tanks, rain mats, and drinker boxes (as needed) at Whale Peak, Harper, Pinyon Wash, Nolina, and Sunset WWDs. There are still a couple of systems that need to be updated and the Department is working with State Parks and partners to address those. Furthermore, there are several springs (e.g. Rattlesnake Spring) that have gone dry and alternative solutions need to be evaluated. In addition to these water sources there are some additional conservation and habitat concerns in the southernmost recovery region (9) involving Interstate-8 and the USA-Mexico border fence (see the Conservation Concerns section for more details).

Habitat improvements in the Northern Recovery Regions look a little different than your average desert bighorn population. The most notable is that in January 2025 CDFW installed a one-way fence in La Quinta along the PGA West Golf Course property to bait and lure bighorn off the golf course and onto the “wild-side” of the fence. This one-way gate was installed after PGA West built a fence around their property (through lambing habitat), essentially trapping bighorn on the “urban-side” of the fence. Multiple PBS have drowned in the canals along this property, and different conflicts have arisen with the presence of bighorn on the golf course. The one-way fence was successful in getting most of the PBS onto the wild-side of the fence, however a maintenance gate was left open later in the year, resulting in many PBS returning to the golf course. In addition to the golf course, there is another group of PBS that are prone to frequent incursions into downtown Palm Springs, posing risks to both vehicle and bighorn sheep safety. CDFW is working closely with the City of Palm Springs and Animal Control, as well as volunteers from the Bighorn Institute and Oswit Land Trust to develop a responder network. Long-term, ideally barriers will be put at key access points to minimize PBS access to downtown Palm Springs.

Desert Bighorn Sheep Program

CDFW's desert bighorn program continues to partner with SCBS (with support of the California Chapter of the Wild Sheep Foundation) and Desert Wildlife Unlimited (DWU) to monitor springs and construct and maintain wildlife water developments (WWDs) within bighorn habitat. SCBS has leased 90 California State Lands parcels throughout the Mojave Desert on which the plan is to build WWDs. Since Fall 2024, SCBS has constructed 4 WWDs on these parcels in the Cady Mountains, South Bristol Mountains, North Bristol Mountains and Ludlow area. CDFW and DWU have transformed 5 small game WWDs into big game WWDs across the south-central desert. CDFW staff, SCBS volunteers, and DWU volunteers have performed countless water hauls and maintenance tasks. CDFW is committed to working with the relevant land management agencies to create a programmatic Environmental Assessment in order to upgrade the multitude of antiquated WWDs throughout the desert.

RESEARCH

CDFW's bighorn sheep managers have a long history of collaborating with independent researchers and academic personnel to help expand research capacity and address key conservation questions.

Sierra Nevada Bighorn Sheep Recovery Program

Research on Sierra bighorn continues to expand our understanding of factors that drive resource selection. Sierra bighorn are partially migratory with some animals remaining at high elevations during winter, foraging on wind-swept slopes and other individuals descending to lower elevations where they gain access to earlier green forage in areas with higher predation risk. In a classic, but complex forage predation trade-off, we found that for rams, body fat measured during fall capture via ultrasound was correlated with the decision to migrate. Fatter animals remained at higher elevations throughout the winter and individuals with less fat decided between longer and shorter distance migrations to access better forage quality, at the risk of higher predation (Denryter et al. 2024). Additionally, migratory Sierra bighorn tended to follow the green wave, selecting for destinations at their peak annual biomass, but specifically, precipitation events were a key component forcing Sierra bighorn down to lower elevations and relatively high temperatures drove them up in elevation (John et al. 2025). During winter, Sierra bighorn showed a preference to avoid popular back-country ski zones, but would use these areas more frequently during winters with more extensive snow cover when their options for selecting snow free habitat were more limited (Kolek et al. 2025). And finally, we quantified that group size influenced resource selection; forage availability increased with group size because larger groups utilized areas farther from escape terrain with greater forage biomass (Rankins et al. 2025).

Peninsular Bighorn Sheep Recovery Program

CDFW is working with graduate students in the Conservation Ecology Lab at

San Diego State University to help address some key Peninsular Recovery Program questions. Specifically, Daniel Gordon's research is assessing the predation risk of Peninsular bighorn compared to deer in areas where they co-occur. Gordon's research quantifies the effects of mountain lion predation on bighorn and how risk increases with deer density. Furthermore, Corey Kramer is developing an integrated population model (IPM) accounting for varying rates of recruitment, survival, and fecundity across all nine recovery regions. This model will help CDFW better understand the different factors (e.g. low adult survival vs. poor recruitment) affecting each recovery region, thereby informing specific management actions. In addition, building on Buchalski's et al. (2016) research, Kramer is also using GPS and genetic data to better understand connectivity between each recovery region. Coupled with the IPM, these data will help inform if the existing recovery goals are realistic or if CDFW and the U.S. Fish & Wildlife Service should reevaluate the Recovery Plan (USFWS 2000) and delisting criteria.

In addition, CDFW is also collaborating with Wildland's Network biologist and Oregon State University researcher, Dr. Christina Aiello, to assess the impacts of a full U.S.A.-Mexico border wall closure on the Jacumba ewe group. In collaboration with UC Davis and partners, Dr. Aiello has used CDFW's GPS data to analyze potential wildlife crossing locations along Interstate-8. See the Conservation Concerns section below for more information on both topics.

Desert Bighorn Sheep Program

The Desert Bighorn Program has been working closely with researchers out of Oregon State University (OSU) since 2013. Recent collaborations with both the Epps Lab and the Jolles/Beechler Lab cover a range of topics from desert bighorn immune phenotypes to water use to landscape-level movements. Dr. Aiello used desert bighorn GPS data to build movement models to highlight the impacts of Interstates 15 and 40 on desert bighorn connectivity through the simulation of habitat use without highways (Aiello et al. 2023). These interstates are such extreme barriers for desert bighorn in large part because there are no safe at-grade crossing areas and the highway underpasses offer little to no crossing opportunities for bighorn (Aiello et al. 2024). Research on the use of artificial intelligence to identify images of bighorn sheep in trail camera photographs revealed that a specialized model achieved 89.33% accuracy of bighorn sheep photo identification (Okuley et al. 2025). Several studies focus on how environmental conditions and factors drive pathogen exposure (Carpenter et al. 2025), disease transmission (Meza et al. in review), and risk to *Anaplasma* from ticks (Hawkes et al. in prep). To help researchers and managers' detect diseases in the field, an immune toolkit was developed for measuring bighorn immune phenotypes (Weinstein et al. in review). Research using ruminal implant transmitters tracks desert bighorn body temperature and water consumption highlighting differences in seasonal sex-based thermoregulatory patterns and the importance of year-round surface water during drought years (Prentice et al. in review). Additionally, activity sensors on GPS collars are being utilized to differentiate between time spent feeding, resting, and traveling, unveiling sex-specific shifts in seasonal and lunar cycle behavior (Millward et al. in prep.).

CDFW's desert bighorn sheep GPS data from Mojave National Preserve and Death Valley National Park were used as part of a larger, multispecies study that examined the influence of human presence and footprint on animal space use (Gaynor et al. 2025). This study leveraged the temporary closures of

United States National Parks to investigate the effects of infrastructure and human presence on wildlife. Across the six national parks with geolocation data, bighorn sheep avoided the human footprint pre-pandemic but had a neutral response to the footprint during the pandemic closure. In Mojave National Preserve and Death Valley National Park, bighorn sheep avoided the human footprint both before and during the pandemic. CDFW is also collaborating with University of California Berkeley post-doctoral fellow Diego Ellis-Soto on a multispecies study on the daily and hourly behavioral responses of mammals to an extreme summer heatwave.

In addition, desert bighorn program staff are working on (1) an investigation into the influence of hunting pressure, ewe population density, seasonal variation, and landscape topography on inter-deme movements by males; (2) a species distribution model for desert bighorn sheep across the Mojave Desert; (3) an inquiry into the effect of GPS collar weight on bighorn sheep survival; and (4) an evaluation of the factors that influence hunter success and harvested bighorn green score.

CONSERVATION CONCERNS

Sierra Nevada Bighorn Sheep Recovery Program

The recent snow and predation driven declines have increased the importance of reducing Sierra bighorn mortality. A predation management plan was finalized this September that focuses mainly on translocation but also allows for some lethal removal of mountain lions within Sierra bighorn habitat (Gammons et al. 2025). Between 2024 and 2025, there were 64 mountain lion capture events, 6 translocations, and 1 lethal removal. As of 2025, there have been no detections of *Mycoplasma ovipneumoniae* in Sierra bighorn and maintaining this status is a high priority.

Peninsular Bighorn Sheep Recovery Program

Disease continues to be a challenge to the recovery of Peninsular bighorn sheep, specifically the threat of wandering domestic sheep and goats. In April 2024, a domestic ram was seen exhibiting nose to nose contact with a wild bighorn ewe outside of Borrego Springs, CA. Unfortunately, the domestic ram disappeared before it could be captured and removed despite using a helicopter to survey the area. Thankfully, captured animals in the vicinity of this region tested negative for *Mycoplasma ovipneumoniae* in October 2024. In addition to disease, predation risks occur throughout the range with increased risk in habitat that overlaps or is in proximity to deer. However, mountain lions are not being actively monitored or managed in this region.
The Northern Recovery Regions (1–3) continue to face challenges along the urban interface including but not limited to conflicts along golf courses, individuals drowning in canals, and roadkill events. Whereas Peninsular bighorn in the Southern Recovery Regions (4–9) are potentially more vulnerable to drought, but the most pressing conservation concerns are within the southernmost Recovery Region (9) along Interstate-8 and the US-Mexico border. Close to 30 bighorn sheep have been killed along I-8 since 2012—posing threats to both vehicular traffic as well as the recovery of this population. With funding from the Wildlife Conservation Board, a group of stakeholders including the UC Davis Road Ecology Center, CDFW, California Department of Transportation, Wildlands Network, Dudek Engineering, and CA Backcountry Hunter and Anglers are working together to identify potential wildlife overpass crossing structure locations and developing engineering plans for both crossings and fencing. Once the project design phase is complete and there is an estimated budget, this group will work towards obtaining

funding for the building and completion of the project. CDFW and partners are also working on plans to provide a more reliable water source along the Mountain Springs area—the only developed water source in the In-Koh-Pah ewe group areas. The existing spring-fed concrete holding tank is prone to vegetation growth and is not always reliable in the late summer.

Further south, in the Jacumba ewe group, the rapid development of a border barrier along the U.S.A. and Mexico border is threatening to separate bighorn from critical habitat. Approximately 60% of this ewe groups' homerange is north of the border, including key lambing habitat; but there are critical water sources located on the southern side (Figure 5). CDFW has been working closely with Dr. Aiello at Wildlands Network along with USFWS partners to analyze GPS data and identify key crossing locations. Analyses demonstrate that bighorn are regularly crossing through this area year-round. Recommendations have been made to the U.S. Customs and Border Protection (CBP) to maintain at least four large mammal, permanent, year-round wildlife crossings. Furthermore, CDFW is working with partners to identify potential locations to build new WWDs along the northern side of the border. As of 2025, CBP has placed concertina wire along the entire Lower Crossing Zone, raising concerns for animal entrapment. Construction along all three sections is anticipated to begin in 2026. The complete closure of this area would eliminate bighorn sheep movement across the border, thereby severing any and all geneflow into the southern end of this population, along with access to critical habitat.

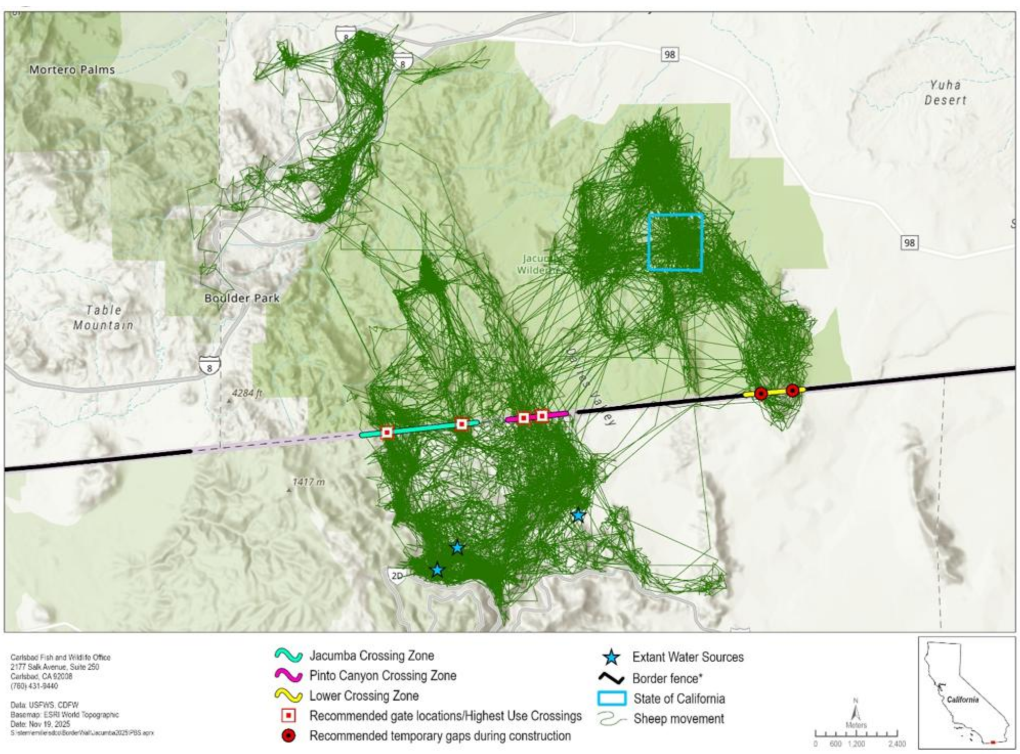

FIGURE 5. GPS collar data (green lines) from peninsular bighorn sheep within the Jacumba ewe group along the USA-Mexico border. Black line depicts the existing border fence; the 3 colored lines are main crossing areas; stars are existing water sources. USFWS Carlsbad Field Office December 2025.

Desert Bighorn Sheep Program

Disease and drought remain the largest concerns for California's desert bighorn sheep populations. Both factors decrease lamb survival and through time decrease overall population numbers (Cassirer et al. 2018, Colchero et al. 2009, Spaan et al. 2021, CDFW unpublished data). Rapid population declines without animals testing positive for *Mycoplasma ovipneumoniae* in the San Bernardino Mountains in 2019, the southern Bristol Mountains in 2023, and the Orocopia Mountains in 2024 raise concerns of an unknown pathogen. While water can be supplemented through WWDs, a decrease in forage quality due to drought remains a troubling concern for bighorn sheep at the lower elevations in the Mojave Desert (Epps et al. 2004, Wagler et al. 2023). Metapopulation fragmentation due to Interstates 15, 40, and 10, as well as State Route 62, continue to reduce genetic diversity in California's desert bighorn sheep (Epps et al. 2005).

Three wildlife overpasses are planned on California Interstate 15 as part of the Brightline West high-speed rail linking Los Angeles and Las Vegas. These overpasses will be located at Cave Mountain, Zzyzx, and Mountain Pass, allowing the Cady, Soda, and Clark Mountain bighorn populations respectively to cross the Interstate. Construction on the high-speed rail has started with an expected completion date of September 2029.

Wildlife overcrossings have also been proposed on State Route 62 to increase connectivity between San Gorgonio and Little San Bernardino bighorn populations. This effort is being led by the Mojave Desert Land Trust. In addition, California Department of Transportation is proposing to open State Route 39 (SR 39) through the San Gabriel Mountains for the first time in over 50 years. This section of SR 39 goes straight through known bighorn sheep lambing habitat and the re-opening poses potential concerns for this population. In October 2025, three ewes and two rams were captured in this area allowing CDFW staff to more closely monitor habitat use prior to opening, along with any changes in behavior if SR 39 is re-opened.

REFERENCES

Aiello, C., N. L. Galloway, P. R. Prentice, N. W. Darby, D. L. Hughson, and C. W. Epps. 2023. Movement models and simulation reveal highway impacts and mitigation opportunities for a metapopulation-distributed species. Landscape Ecology 38:1085–1103.

Aiello, C., N. L. Galloway, K. Fratella, P. R. Prentice, N. W. Darby, D. L. Hughson, and C. W. Epps. 2024. Highway underpasses offer little fragmentation relief for desert bighorn sheep near Mojave National Preserve, California. California Fish and Wildlife Journal 110:e5.

Buchalski, M. R., B. N. Sacks, D. A. Gille, M. C. T. Penedo, H. B. Ernest, S. A. Morrison, and W. M. Boyce. 2016. Phylogeographic and population genetic structure of bighorn sheep (*Ovis canadensis*) in North American deserts. Journal of Mammalogy 97:823–838.

California Department of Fish and Wildlife. 2025. The conservation and management plan for bighorn sheep in California. California Department of Fish and Wildlife, West Sacramento, California, USA.

Carpenter, S. A., N. J. Shirkey, P. R. Prentice, E. L. Lantz, B. A. Munk, C. W. Epps, B. R. Beechler, and A. E. Jolles. 2025. Landscape of exposure: metapopulation dynamics and local environment structure pathogen exposure in desert bighorn sheep. Ecosphere 16(12):e70504.

Cassirer, E. F., K. R. Manlove, E. S. Almberg, P. L. Kamath, M. Cox, P. Wolff, A. Roug, J. Shannon, R. Robinson, R. B. Harris, and B. J. Gonzales. 2018. Pneumonia in bighorn sheep: risk and resilience. Journal of Wildlife Management 82:32–45.

Colchero, F., R. A. Medellin, J. S. Clark, R. Lee and G. G. Katul. 2009. Predicting population survival under future climate change: density dependence, drought and extraction in an insular bighorn sheep. Journal of Animal Ecology 78:666–673.

Denryter, K., T. R. Stephenson, and K. L. Monteith. 2024. Migratory behaviors are risk-sensitive to physiological state in an elevational migrant. Conservation Physiology 12:1–12.

Epps, C.W., D.R. McCullough, J. D. Wehausen, V. C. Bleich, and J. L. Rechel. 2004. Effects of climate change on population persistence of desert-dwelling mountain sheep in California. Conservation Biology 18:102–113.

Epps, C. W., P.J . Palsbøll, J. D. Wehausen, G. K. Roderick, R. R. Ramey, and D. R. McCullough. 2005. Highways block gene flow and cause a rapid decline in genetic diversity of desert bighorn sheep. Ecology Letters 8:1029–1038.

Gammons, D. J., P. A. D. Johnston, J. L. Davis, D. W. German, L. E. Greene, C. P. Massing, and T. R. Stephenson. 2025. A strategy for managing predation on Sierra Nevada bighorn sheep. California Department of Fish and Wildlife, Bishop, California, USA.

Gaynor K. M. *et al*. 2025 The influence of human presence and footprint on animal space use in US national parks. Proceedings of the Royal Society B 292:20251013.

John, C., T. Avgar, K. Rittger, J. A. Smith, L. W. Stephenson, T. R. Stephenson, and E. Post. 2024. Pursuit and escape drive fine-scale movement variation during migration in a temperate alpine ungulate. Scientific Reports 14:15068

Kolek, J., T. R. Stephenson, K. Rittger, and K. L. Monteith. 2025. With great powder comes great responsibility: winter severity modulates antipredator responses of wildlife to recreation. Biological Conservation 310:111374.

Massing, C. P., D. W. German, and T. R. Stephenson 2024. Morphological differences in bighorn populations of California. Southwestern Naturalist 67:263–273.

Okuley, O. S., C. M. Aiello, W. Glad, K. Perkins, R. Ianniello, N. Darby, and C. W. Epps. 2025. Improving AI performance in wildlife monitoring through species and environment-specific training: a case study on desert bighorn sheep. Ecological Informatics: 103179.

Rankins, S. T., T. R. Stephenson, and K. L. Monteith. 2024. Sociality modulates nutritional carrying capacity of an endangered species. Frontiers in Ecology and Evolution 10.3389/fevo.2024. 1417970

Spaan, R. S., C.W. Epps, R. Crowhurst, D. Whittaker, M. Cox, and A. Duarte. 2021. Impact of *Mycoplasma ovipneumoniae* on juvenile bighorn sheep (*Ovis canadensis*) survival in the northern basin and range ecosystem. Peer Journal 9:e10710.

U.S. Fish and Wildlife Service. 2000. Recovery plan for bighorn sheep in the Peninsular Ranges. U.S. Fish and Wildlife Service, Portland, Oregon, USA. U.S. Fish and Wildlife Service. 2007. Recovery plan for the Sierra Nevada bighorn sheep. U. S. Fish and Wildlife Service, Sacramento, California, USA.

Wagler, B. L., R. A. Smiley, A. B.

Courtemanch, D. Lutz, D. McWhirter, D. Brimeyer, P. Hnilicka, T. J. Robinson, and K.L. Monteith. 2023. Implications of forage quality for population recovery of bighorn sheep following a pneumonia epizootic. Journal of Wildlife Management 87:e22452.

Wagner, G. D., and J. M. Peek. 2006. Bighorn sheep diet selection and forage quality in central Idaho. Northwest Science, 80:246.

Appendix A begins on the following page—**Editor**.

Appendix A. Extant and extirpated populations of bighorn sheep in California. Due to the varying precision of population estimates they are categorized by size class.

Metapopulation Fragment	Population	Status[1]	Size (N) Category	Source and Year
Peninsular Ranges	San Jacinto*	N	51–100	CDFW 2024[2,5,6]
	North Santa Rosa*	N	51–100	CDFW 2024[2,5,6]
	Central Santa Rosa*	N	151–200	CDFW 2024[2,5,6]
	South Santa Rosa*	N	51–100	CDFW 2024[2,5,6]
	Coyote Canyon*	N	25–50	CDFW 2024[2,5,6]
	North San Ysidro*	N	25–50	CDFW 2024[2,5,6]
	South San Ysidro*	N	25–50	CDFW 2024[2,5,6]
	Vallecito*	N	51–100	CDFW 2024[2,5,6]
	Carrizo Canyon*	N	151–200	CDFW 2024[2,5,6]
W Transverse Range	San Rafael Peak	R	50–100	CDFW 2025[2]
	Caliente Peak	E	0	No new data
San Gabriel	San Gabriel Mtns	N	25–50	CDFW 2025[2,7]
Sonoran	W. Chocolate	N	51–100	CDFW 2009[5]
	E. Chocolate*	N	51–100	CDFW 2004[5]
	Orocopia-Mecca Hills*	N	51–100	CDFW 2024[2,6,8]
	Chuckwalla	A	<25	CDFW 2025[2,4,5]
	Cargo Muchacho	T	0	No new data
	Palo Verde	E	0	No new data
South Mojave	Newberry-Ord-Rodman*	N	401–500	CDFW 2023[2,6,8]
	Bullion*	R	100–150	S. Murray 2025[2,6,8]
	Sheep Hole*	A	51–100	CDFW 2024[2,6,8]
	San Gorgonio*	N	51–100	CDFW 2025[2,,6]
	N. San Bernardino[9]	N	<25	CDFW 2019[6,7]
	Little San Bernardino*	N	25–50	CDFW 2023[2,5]
	Queen*	N	25–50	B. Sloan 2025[2,4]
	Pinto	E	0	No new data
	Eagle*	N	51–100	Epps 2002–2003[3,4]
	Coxcomb	N	<25	Epps 2002–2003[3,4]
	East Riverside Complex[10]	N	51–100	CDFW 2025[2,5,6]
	Riverside	C	<25	CDFW 2025[2,5]
	Iron	C	<25	CDFW 2025[2,5]
	Turtle*	N	51–100	Epps 2001–2003[3,4]
	Whipple	R	25–50	CDFW 1999[5]
	Old Woman*	N	25–50	CDFW 2018[6,7]
	Chemehuevi*	N	25–50	Epps 2002–2003[3,4]

	Sacramento	T	0	C. Aiello 2021[3,4]
	Clipper*	N	51–100	CDFW 2025[2,6,8]
	South Bristol*	C	51–100	CDFW 2024[2,6,8]
	Marble*	N	51–100	CDFW 2025[2,6,7,8]
Central Mojave	Cady*	N	101–150	CDFW 2023[2,6,8]
	South Soda*	C	51–100	CDFW 2024[2,5,6]
	North Bristol*	R	51–100	CDFW 2023[2,5,6]
	Old Dad-Kelso-Marl-Club	N	101–150	CDFW 2024[2,6,8]
	Granite*	N	51–100	CDFW 2019[5,6]
	Providence*	N	101–150	CDFW 2022[2,6,8]
	Woods-Hackberry*	N	51–100	CDFW 2025[2,5,6]
	Castle-Hart-Piute*	N	101–150	CDFW 2023[2,6,8]
	Dead*	N	<25	CDFW 2021[5]
North Mojave	Granite-Quail	E	0	No new data
	Owlshead	T	0	CDFW 2008[5]
	Eagle Crags	R	25–50	T. Campbell 2010
	Argus-Slate	R	51–100	R. Osgood 2003[4]
	Coso	C	<25	Epps et al. 2010[3,4]
	Black-Greenwater*	N	51–100	CDFW 2023[2,6,8]
	South Panamint*	N	51–100	CDFW+NPS 2018[4,5]
	Tucki	N	51–100	CDFW 2023[2,6,8]
	Panamint Butte-Hunter*	N	51–100	No new data
	Funeral*	N	151–200	CDFW 2023[2,6,8]
	Tin*	N	51–100	J. Wehausen 2006[3]
	Grapevine*	N	51–100	NPS 2017[4,7]
	Dry Mtn-Last Chance	N	51–100	CDFW 2017[4,7]
	Inyo*	N	51–100	J. Wehausen 2008[5]
	Deep Springs*	C	<25	CDFW 2024[2,6,8]
	North White*	N	151–200	CDFW 2025[2,6,7]
	South White*	R	25–50	CDFW 2019[7]
	Clark*	N	51–100	CDFW 2023[2,5,6]
	Kingston/Mesquite*	N	101–150	CDFW 2024[2,6,7]
	Nopah*	N	101–150	CDFW 2019[5,6,7]
	Resting Spring	N	<25	CDFW 2019[5]
	North Soda	T	0	G. Sudmeier 2010
	Avawatz*	A	<25	CDFW 2018[5]
Sierra Nevada	Twin Lakes	E	0	SNBS Report 2017
	Green Creek	E	0	SNBS Report 2017
	Cathedral Range	R	<25	CDFW 2025[2,7]
	Mt. Warren	R	<25	CDFW 2025[2,7]
	Mt. Gibbs	R	<25	CDFW 2025[2,7]

	Convict & McGee Creek	C	<25	CDFW 2025[2,7]
	Wheeler Ridge	R	25–50	CDFW 2025[2,7]
	Coyote Ridge	E	0	SNBS Report 2017
	Taboose Creek	C	<25	CDFW 2025[2,7]
	Sawmill Canyon	N	25–50	CDFW 2025[2,7]
	Bubbs Creek	C	<25	CDFW 2025[2,7]
	Mt. Baxter	N	51–100	CDFW 2025[2,7]
	Mt. Williamson	N	<25	CDFW 2025[2,7]
	Mt. Langley	R	<25	CDFW 2025[2,7]
	Olancha Peak	R	51–100	CDFW 2025[2,7]
	Big Arroyo	R	<25	CDFW 2025[2,7]
	Laurel Creek	R	<25	CDFW 2025[2,7]
NE California	Truckee River	E	0	No new data
	Skedaddle-Smoke Creek	E	0	No new data
	Warner	E	0	No new data
	Lava Beds-Mt. Dome	E	0	No new data
	Mt. Shasta	E	0	No new data
	Goosenest Mt.	E	0	No new data
	Bogus Mt.	E	0	No new data

[1] N = native; C = natural re-colonization (population may have been re-established by remnantsof a previous population or re-colonized by nearby populations); A = augmented; R = reintroduced; E = extirpated; T = transient range, seasonal use
[2] Population status has been revised since 2021
[3] Partially based on genotypic capture-recapture estimates from non-invasive genetic data
[4] Field observations of animals or sign
[5] Helicopter survey-capture
[6] Mark-resight population estimates
[7] Direct counts from ground and/or camera observations
[8] Estimate from trail cameras placed at water sources in the summer months
[9] Cushenbury Canyon and vicinity
[10] This term is used because of space constraints; the East Riverside Complex includes the Granite, Palen, Big Maria, Little Maria, and McCoy mountains—EDITOR
* *Mycoplasma ovipneumoniae* (*M. ovi*) has been detected in this population since 2013

Status of Bighorn Sheep in Colorado—2025

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Desert Bighorn Council Transactions 58:144–146

POPULATION STATUS

The overall trend of Colorado's bighorn sheep herds have been stable to increasing over the last 10 years. The estimated post-hunt population of Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*), the predominant bighorn in Colorado, was 7,060 in 2024. Over the last few years, Colorado's desert bighorn (*Ovis canadensis nelsoni*) populations have been largely stable. The 2024 post-hunt population estimate for all herds was 500, with little change over the last 10 years (Fig. 1). This follows an increase in population size that began in 2005. Colorado's desert bighorn population is made up of 3 different populations: the Black Ridge herd (Game Management Unit [GMU] S-56) in Mesa County near Grand Junction, the Uncompahgre/Dominguez herd (GMU S-62) on the northeast corner of the Uncompahgre Plateau, northeast of Montrose, and the Dolores River herd (GMUs S-63 and S-64) along the Dolores River from Dove Creek to Bedrock (Fig. 2). The Black Ridge herd has shown a decrease of 150 bighorns. The Uncompahgre herd is stable to increasing at 165. The Dolores River population (comprising the Upper and Middle Dolores herds) has also been stable to increasing, with a post-hunt population estimate of 185 in 2024.

HARVEST STATUS

Conservative hunter harvest is taking place in Colorado desert bighorn herds. The Black Ridge herd (S-56) currently has four ram licenses, with license allocation at 2.7% 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 was 6.9, which has been stable in recent years. Five ram licenses were allocated in the Uncompahgre bighorn herd (S-62) at 3.0% of the population, with a 3-year average hunter success rate of 93%. The average rams harvested in S-62 have 6.6 growth rings measured on a 3-year average. The Dolores River population license allocation is six ram licenses per year, which is 3.2% of the population estimate. Licenses in the Dolores River population are allocated to GMUs S-63 (three licenses) and S-64 (three licenses) separately. The 3-year harvest success rate was 94% with the 3-year average growth rings measured from harvested rams being 5.8.

COLLABORATIVE PROJECTS AND MANAGEMENT

DENCA Recreation Study

From 2020 to 2024, a study occurred in the Dominquez-Escalante National Conservation Area (DENCA) to determine outdoor recreation impacts and disturbances on desert bighorn sheep. This was a collaborative effort with New Mexico State University and graduate student, Ashley Evans, Colorado Parks and Wildlife, and the BLM. Field work began in December 2020 with 30 ewes captured, ear tagged, and collared with GPS collars. In 2021, 18 additional ewes were captured to add collars in locations lacking data. Additionally, 80 camera traps were installed throughout the study area to quantify recreational and wildlife trail use. Moreover, stress hormones were measured using fecal glucocorticoid metabolites from opportunistically collected fresh fecal pellets from marked individuals. These three methods allowed individual sheep behavior to be monitored in response to outdoor recreation. This study found that although recreation did not show significant changes in bighorns' vigilance or foraging behavior, fecal glucocorticoid metabolites showed stress indicators from non-motorized recreation. Recreational impacts may not have been fully realized in bighorn behavior because of several factors, including habituation to activity, availability of adequate refugia, and recreation was concentrated in predictable locations such as trails and roads.

Disease Management

Mycoplasma ovipneumoniae, sinus tumors, and *Pasteurella multocida,* have been detected in Colorado desert bighorn sheep. S-56 and S-62 have a higher prevalence of these diseases, and there are concerns in these herds that they may be affecting lamb recruitment. Psoroptic mange (*Psoroptes* spp.) has also been detected in portions of S-62. Larger concerns of these diseases in Colorado's Rocky Mountain bighorn sheep herds have led to increased monitoring and project proposals to study respiratory pathogen strain types in all bighorn herds across the state.

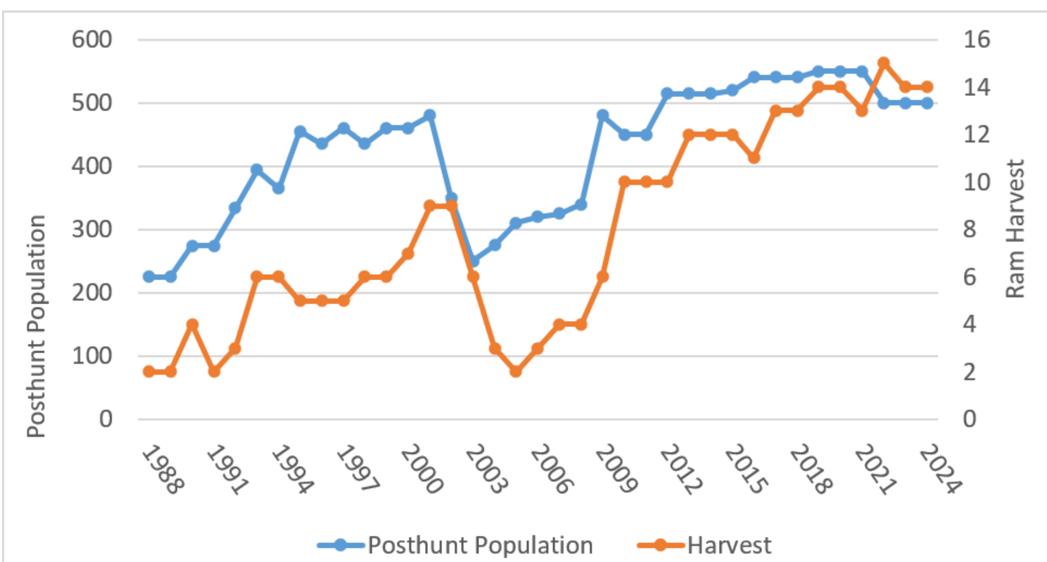

FIGURE 1. Desert bighorn sheep population estimate and ram harvest from 1988 to 2024.

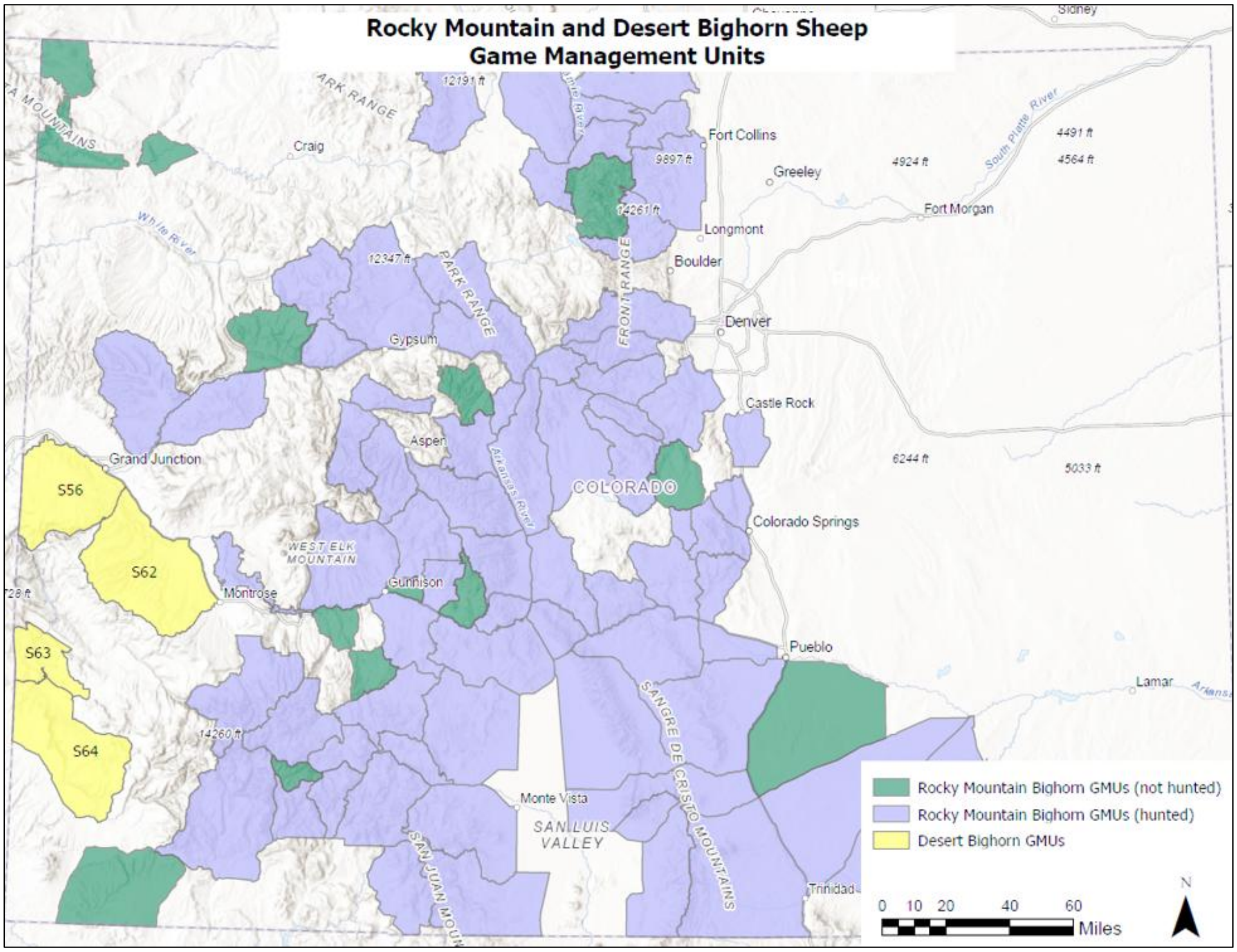

FIGURE 2. Distribution of Rocky Mountain and desert bighorn sheep Game Management Units in Colorado, USA.

Status of Bighorn Sheep in Nevada—2025

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Desert Bighorn Council Transactions 58:147–152

POPULATION ESTIMATES AND MONITORING

Bighorn sheep (*Ovis canadensis*) were once widespread across western North America, occupying the mountainous regions of the western United States, southern Canada, and northern Mexico. Historical accounts, archeological evidence, and traditional knowledge put an estimate of 30,000 or more desert bighorn sheep (*Ovis canadensis nelsoni*) in Nevada around 1860 (Cox et. al. 2001) where they existed in a single, diverse metapopulation (Ramey 1993, Ramey 2000, Wehausen and Ramey 2000). Bighorn sheep were extirpated from much of their historical range by the mid-20th century (Buechner 1960; Valdez and Krausman 1999), and Nevada's population dwindled to between 2,000 and 3,000.

In the late 1960's, approximately 2,000 desert bighorn sheep were translocated from these isolated remnant herds to repopulate historically occupied ranges in Nevada. Additional translocations introduced California (*O. c. californiana*) and Rocky Mountain (*O. c. canadensis*) subspecies, and natural pioneering events have expanded the range of bighorn sheep in the state (Figure 1). Today, an estimated 8,300 bighorn sheep live in Nevada. Of these, approximately 1,700 of the California subspecies reside in the mountains in the northwest, and 330 Rocky Mountain bighorn sheep inhabit scattered ranges in the northeast. Great care has been taken to ensure separation of the three subspecies, but evidence of hybridization, either before or after translocation, has been detected via recent genetic analysis (NDOW, unpublished).

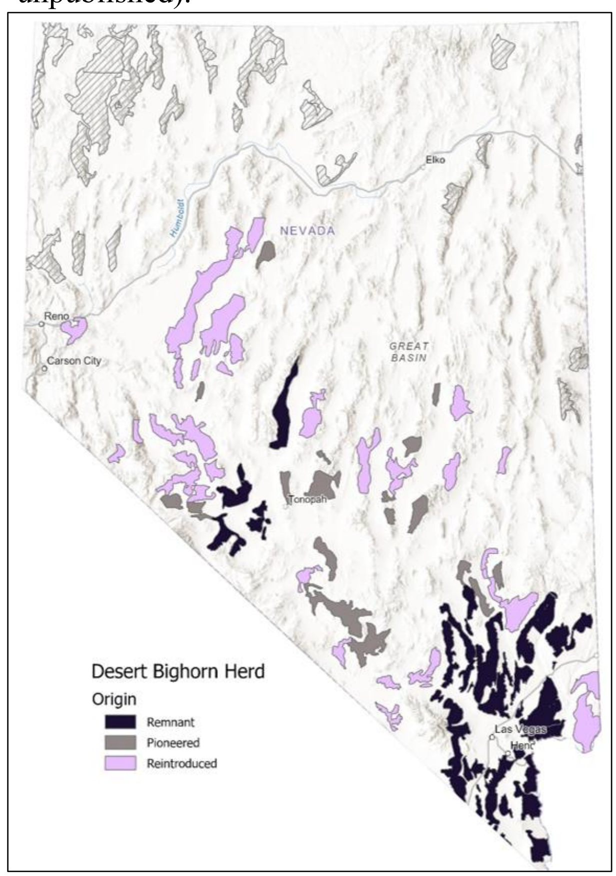

FIGURE 1: Occupied desert bighorn sheep habitat in Nevada (remnant, pioneered, or reintroduced). Grey hatched polygons represent areas occupied by California and Rocky Mountain subspecies.

Desert bighorn sheep are the most numerous and widespread subspecies in Nevada, occupying many mountain ranges south of Interstate 80. The statewide population of desert bighorn sheep experienced continuous growth between 2003 and 2019 to an estimated high of 10,300 individuals due to extensive translocation efforts. There are an estimated 6,300 desert bighorn sheep comprising 70 distinct herds in Nevada as of 2025. This represents a modest 2% decline from the previous year's estimate of 6,400 and a 39% decrease since 2019. Two major contributing factors to this decline in overall population are respiratory disease and habitat degradation.

Most population surveys are conducted from helicopters, but ground surveys are utilized where access and observability are favorable. Aerial surveys of occupied range are conducted on a biennial basis to document numbers, distribution, age and sex ratios, and overall health of bighorn sheep focusing on units with huntable populations. Additional data on habitat conditions, water developments, incidental wildlife observations, and feral horses, burros and livestock are also collected during surveys. Estimates for each herd are generated from deterministic models that reconstruct population dynamics based on observed production/recruitment, average survival rates across age classes, numbers and ages of harvested animals, and translocation events.

HARVEST

A total of 221 standard desert bighorn ram tags were issued in 2025, up from 189 issued in 2024 (Figure 2). NDOW uses a quota guideline of not less than 8% of total rams and not more than 50% of 6+ year old rams for a given hunt unit or unit group and allocates 10% of tags to non-residents. Statewide hunter success for desert bighorn rams was 89% in 2024, which matches the average of the previous 20 years. There are also no age or horn size limits for ram hunts; any ram has been legal ram on a standard tag since 1996. Since adopting this policy, the average age of harvested rams has been 6.4 years, and the 2024 average ram age was 6.9 years.

NDOW also uses ewe hunts as a management tool to control populations with high growth potential. Only Hunt Unit 268, in which the Muddy Mountains lie, has had continuous ewe hunts since their inception in 2014. Sixty ewe tags were issued in 2024 with 70% successful harvest. High adult survival and recruitment in this subpopulation is largely due to overlap of occupied range with state and federal lands closed to hunting, low predator density, and lack of *M. ovi.*

DISEASE

Polymicrobial pneumonia continues to impact bighorn sheep populations statewide. Reintroduction and translocation efforts greatly increased the number and distribution of bighorn sheep across Nevada, and natural pioneering events expanded occupancy into adjacent ranges. An unintended consequence of this expansion was disease spillover events into previously isolated populations. NDOW initiated statewide pathogen surveillance of bighorn sheep herds in 2011 focusing on *Mycoplasma ovipneumoniae* (*M. ovi*). Most herds have been tested by coordinated captures, hunter harvest, or opportunistic sampling, and herds with active infection have been sampled to identify the genetic strain type(s) of *M. ovi* present (Figure 3). NDOW is currently working on a database documenting strain types, exposure date, herd loss, and recovery status for most bighorn sheep populations in the state. This database has been used to identify transmission corridors and spillover sources and facilitate management decisions such as translocations and strategic depopulation.

There is growing evidence that some strains of *M. ovi* have different initial and residual effects on population performance, and some strains may be easier to clear from a population than others (Cassirer et al. 2017; Manlove et al. 2022). The Tobin herd, the northernmost population of desert bighorn sheep in Nevada, was exposed to *M. ovi* in 2020 and experienced up to 60% total herd loss and depressed lamb recruitment. By 2024, adult survival was back to pre-exposure levels and estimated lamb recruitment was above 60 lambs:100 ewes. Additional sampling in early 2025 resulted in no detection of active infection or presence of antibodies to indicate exposure.

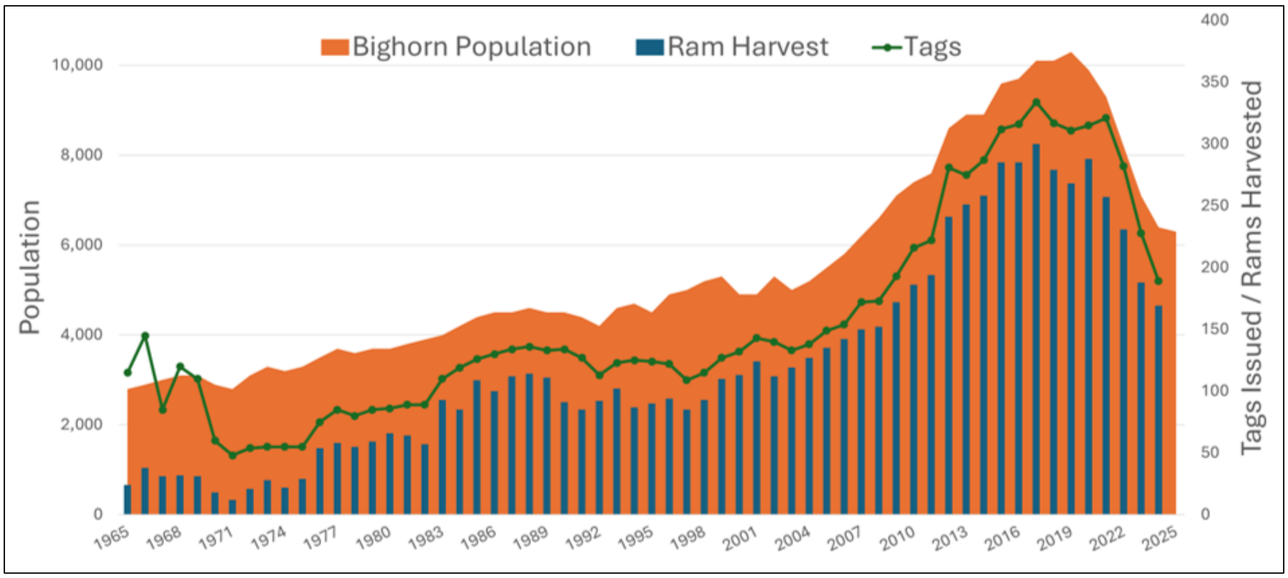

FIGURE 2: Total population, number of tags issued, and harvest numbers for desert bighorn sheep in Nevada between1965 and 2024. Tag numbers are typically commensurate with total population in each hunt unit or unit group.

TRANSLOCATIONS

NDOW is currently exploring opportunities to use translocation to reduce herd density in drought-impacted areas and augment populations within and outside Nevada. In June of 2025, 139 bighorn sheep were captured in the Muddy and Black Mountains west of Las Vegas and released in northern Nevada and Utah. Forty-three desert bighorn sheep were released to augment the existing herd in the Tobin Range, which had shown evidence of recent recovery from *M. ovi*. Fifty-eight were released into the Cortez Range, an area where bighorn sheep had been absent for 75 years, to re-establish a population there. NDOW has also collaborated with the Utah Division of Wildlife Resources (UDWR) to translocate desert bighorn sheep from Nevada to establish and maintain a disease-free nursery herd in Utah. A total of 89 bighorn sheep have been translocated thus far: 31 in June 2022, 20 in June 2024, and 38 in June 2025.

DROUGHT IMPACTS

Climate change associated drought is a major factor limiting Nevada's bighorn sheep populations. Much of the western US experiences regular periods of drought, with the most exceptional degree concentrated in the desert Southwest. High temperature records have been broken with more consecutive days above average temperature in recent years. Seasonal monsoons have also become less reliable, as was the case in 2024. Southern Nevada experienced record high temperatures and received no significant precipitation between April 2024 and February 2025. This greatly impacted the quality and availability of forage and water for wildlife.

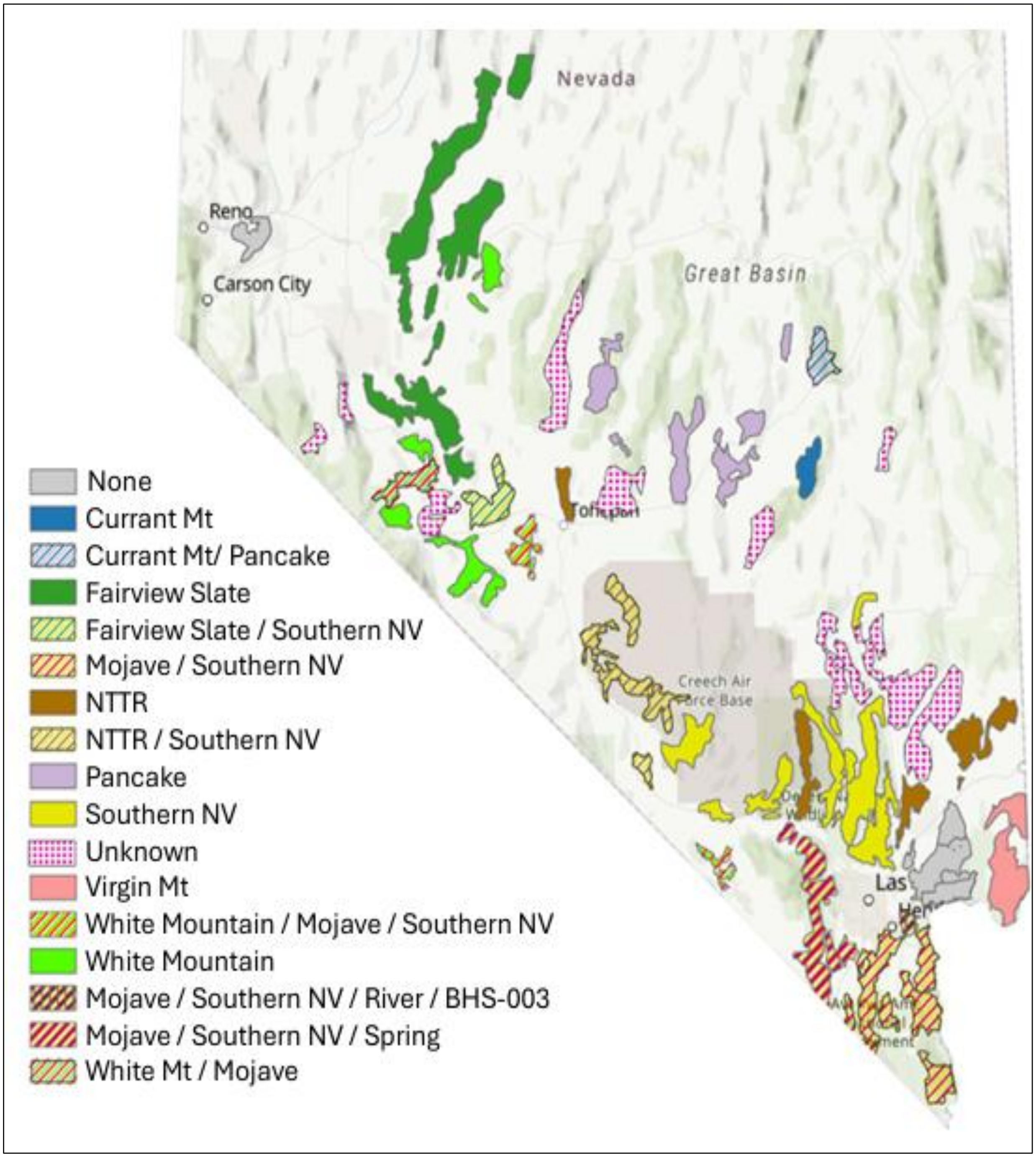

FIGURE 3: Genetic strain types of *M. ovi.* in desert bighorn sheep herds. At least 23 unique strain types have been identified in bighorn sheep herds across all three subspecies in Nevada.

Desert bighorn sheep acquire most of their water from the vegetation they consume and will drink surface water as needed, especially during the hot summer months (Turner 1973). However, prolonged drought reduces the availability of water in both forage and natural springs and basins, and bighorn sheep may increase their use of artificial or developed water sources. There are just over 200 wildlife water developments in core bighorn sheep range in Nevada, mostly in the far south. These guzzlers were designed as supplemental water sources to store precipitation and support wildlife through occasional dry stretches. As drought cycles become more extreme and less predictable, bighorn sheep depend more on supplemental water (Epps et al. 2004; Longshore et al. 2009).

NDOW has been improving water distribution by replacing old water developments with more efficient designs to capture and store precipitation in unpredictable drought regimes. The largest system has a collection apron of nearly 15,000 square feet and 18,000 gallon capacity, so about an inch of rain will nearly fill the system. In addition, NDOW has been utilizing remote water monitoring devices provided by federal and NGO partners. There are currently over 50 devices tracking real-time changes in rainfall, water collection, and draw-down. These remote monitors have also been used to identify malfunctions in systems and give insight into landscape conditions in remote areas.

Previous management actions centered on increasing populations of bighorn sheep in Nevada. However, future strategies will focus on managing sustainable populations in the face of growing challenges. *M. ovi* spillovers from domestic and wild sheep continue to impact populations and limit the areas available to translocate animals. Suitable habitat is also shrinking due to human development and energy expansion, and the quality of habitat is degrading as the climate warms. NDOW is currently drafting a new species management plan for bighorn sheep to guide decisions with a focus a focus on sustainability for this iconic species.

REFERENCES

Buechner, H. K. 1960. The bighorn sheep in the United States, its past, present, and future. Wildlife Monographs 41:1–174

Carpenter, T. E., V. L. Coggins, C. McCarthy, C. S. O'Brien, J. M. O'Brien, and T. J. Schommer. 2014. A spatial risk assessment of bighorn sheep extirpation by grazing domestic sheep on public lands. Preventive Veterinary Medicine 114:3–10.

Cassirer, E. F., K. R. Manlove, R. K. Plowright, and T. E. Besser. 2017. Evidence for strain-specific immunity to pneumonia in bighorn sheep. Journal of Wildlife Management 81:133–143.

Cox, M., K. Gray, M. Dobel, T. Wasley, C. Stevenson. P. Cummings, and C. Hampson. Bighorn sheep management plan. Nevada Department of Wildlife. Reno, Nevada, USA.

Epps, C. W., D. R. McCullough, J. D. Wehausen, V. C. Bleich, and J. L. Rechel. 2004. Effects of climate change on population persistence of desert-dwelling mountain sheep in California. Conservation Biology 18:102–113.

Longshore, K. M., C. Lowrey, and D. B. Thompson. 2009. Compensating for diminishing natural water: predicting the impacts of water development on summer habitat of desert bighorn sheep. Journal of Arid Environments 73:280–286.

Manlove, K. R., A. Roug, K. Sinclair, L. E. Ricci, K. R. Hersey, C. Martinez, M. A. Martinez, K. Mower, T. Ortega, E. Rominger, C. Ruhl, N. Tatman, and J.

Taylor. 2022. Bighorn sheep show similar in-host responses to the same pathogen strain in two contrasting environments. Ecology and Evolution 12:e9109.

Ramey, R.R. II. 1993. Evolutionary genetics and systematics of American mountain sheep: implications for conservation. Ph.D. Dissertation, Cornell University, Ithaca, New York, USA.

RAMEY, R.R. II. 2000. New perspectives on the evolutionary origins, historic phylogeography, and population structure of North American mountain sheep. North American Wild Sheep Conference Transactions 2:9–16.

Turner, J. C. 1973. Water, energy, and electrolyte balance in the desert bighorn, *Ovis canadensis*. Dissertation, University of California, Riverside, California, USA.

Valdez, R., and P. R. Krausman (editors). 1999) Mountain sheep of North America. University of Arizona Press, Tucson, Arizona, USA.

Wehausen, J. D., and R. R. Ramey II. 2000. Cranial morphometric and evolutionary relationships in the northern range of *Ovis canadensis*. Journal of Mammalogy 81:145–161.

Status of Desert Bighorn Sheep in New Mexico — 2023–2024

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Desert Bighorn Council Transactions 58:153–156

POPULATION STATUS

Restoration of Mexican desert bighorn (*Ovis canadensis mexicana*) in New Mexico began in 1972. Today, the New Mexico Department of Game and Fish (NMDGF) manages 9 discrete populations concentrated in the southwest bootheel and south-central interior of the state. NMDGF ascertains population estimates via double-observer minimum count helicopter surveys with counts of each discrete population occurring annually or biennially. The 2023 mid-point estimate was 1,168 desert bighorn sheep and the 2024 mid-point estimate is 1,088 (Figure 1). The ratio of lambs per 100 ewes has been stable at 45:100 in 2023 and 40:100 in 2024. Rams per 100 ewes increased from 76:100 in 2023 to 93:100 in 2024. These lamb:ewe and ram:ewe rates are sufficient for stable or increasing population trends.

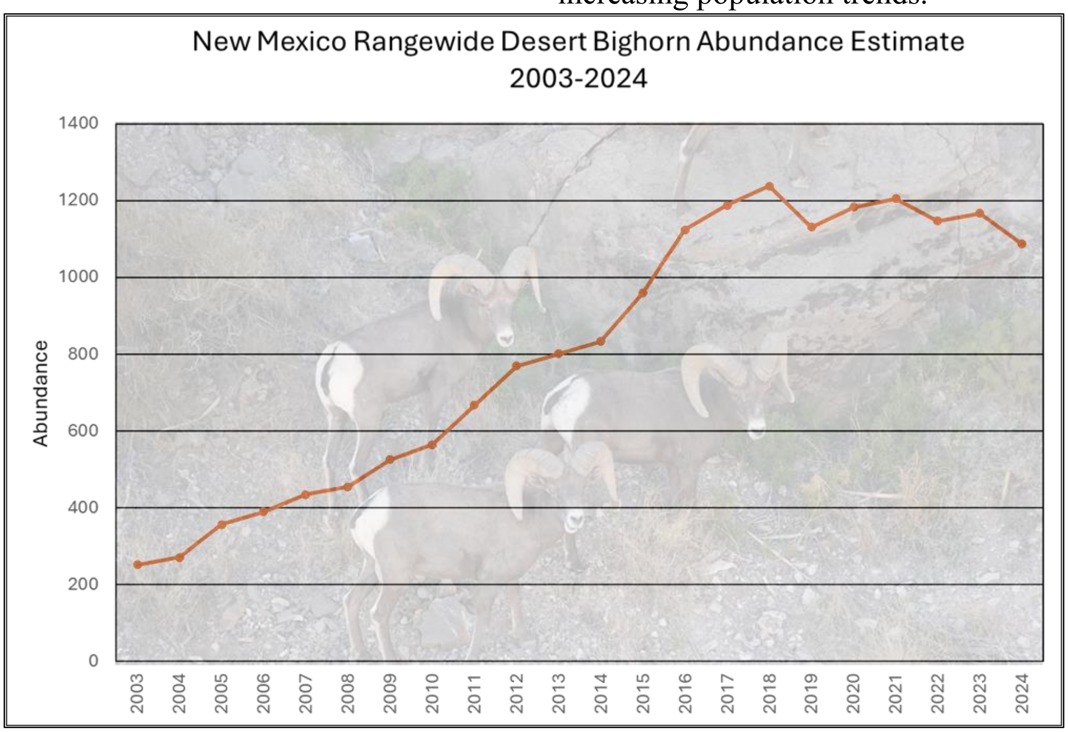

FIGURE 1. Rangewide Mexican desert bighorn abundance estimates in New Mexico, 2003–2024.

Peloncillo Mountains

The Peloncillo population has experienced rapid decline in the last 5 years from 140 to 160 in 2019 to 40 to 60 in 2024. Minimum survey counts in 2023 and 2024 were the lowest observed since 2003 with 29 and 24 bighorn counted respectively. Survey time has increased while observations continue to decrease. There is some uncertainty regarding the cause of the decline in bighorn abundance. Drought, poor habitat quality, and mountain lion predation are likely influencing this population. A range shift or source-sink dynamic from the New Mexico side of the Peloncillos to the Arizona side may also contribute to lower observed abundance. Eleven new GPS collars were deployed in October 2023. There were 4 mortalities in 2023 (1 predation within the post-capture period, 2 legal harvests, and 1 unknown) and 3 in 2024 (2 lion predations, 1 unknown). Two collared bighorn known to occupy the New Mexico side of the Peloncillos were tracked in Arizona close in time to the 2024 survey period. NMDGF will initiate a project in 2025 to evaluate diet and nutrition in this herd. Fecal pellets and vegetation samples will be collected for dietary metabarcoding to describe bighorn diet and assess nutritional availability on the landscape. If sufficient surplus bighorn are counted in the Red Rock Wildlife Area during the May 2025 ground survey, a translocation to the Peloncillos will be planned for Fall 2025 to augment the herd while NMDGF continues to investigate factors contributing to decline.

Hatchet Metapopulation

The Hatchet metapopulation is comprised of three individually managed bighorn herds: the Little Hatchets, Big Hatchets, and Alamo Hueco Mountains. The small, remnant Alamo Hueco population was augmented in 2021 and 2023 with surplus bighorn from Red Rock Wildlife Area and is currently estimated to have 50–80 sheep. The 2024 survey documented a lamb:ewe ratio of 95:100. To the north, the Big Hatchets have remained stable over the last 5 years with an estimate of 85–115 bighorn and lamb:ewe ratios of 53:100 in 2023 and 42:100 in 2024. The 2024 survey of the Little Hatchets observed a minimum of 79 bighorn, the most documented in the past 6 years supporting an increased population estimate of 90–110. Two collared rams were harvested out of the Big Hatchets in 2023 including one ram that was originally released in the Alamo Huecos. Fifteen new GPS collars were deployed in the Big Hatchets in November 2024 to monitor adult survival, causes of mortality, and movement between ranges. One mortality occurred within the two-week post-capture window and was attributed to capture myopathy. In 2023 and 2024, multiple GPS collared rams forayed between the Little and Big Hatchets and the Big Hatchets and Alamo Huecos, demonstrating functional connectivity across the metapopulation.

Fra Cristobal and Caballo Metapopulation

The Fra Cristobal population appears to have stabilized in 2023–2024 at 130–180 individuals following a 50% decline from 2017 to 2019 that was attributed to a removal translocation effort and apparent disease outbreak. There were three GPS collared bighorn mortalities (1 unknown, 1 legal harvest, 1 entrapment in a shrub) and one collar that stopped transmitting in 2023. An additional collar stopped transmitting in 2024. The 2023 Caballo survey documented 216 sheep and a lamb:ewe ratio of 59:100, the most observed in this range in a single survey. The 2024 survey was limited by airspace restrictions, however the current estimate is 210–240. Eighteen new GPS collars were deployed in the Caballos in 2024 and there was one mortality due to legal harvest.

Ladron Mountains

The Ladron population appears stable or marginally decreasing as of 2024, numbering between 125–175 bighorn. The lamb:ewe ratio was 44:100. There was one GPS collar mortality in 2023 attributed to lion predation. The southern extent of the population range has expanded to include the Chupadera Mountains. The installation of new drinkers in the Chupaderas is likely a factor in this range expansion.

San Andres Mountains

The San Andres survey is performed using two helicopters flying simultaneously over discrete survey blocks across two days. The 2024 survey was the first complete survey of the range since 2021. The survey in 2022 was incomplete due to high winds and access to the White Sands Missile Range airspace could not be coordinated in 2023. Despite this, the population remains stable with 180–220 bighorn sheep. The lamb:ewe ratio was 21:100 which is within the normal range for the population.

Sacramento Mountains

The Sacramento population is considered stable at 40–45 bighorn sheep. The minimum count for this herd has never surpassed 41 (2022) since it's reintroduction of 34 bighorn in 2018. NMDGF staff hypothesized that complex terrain and restricted airspace may be limiting sightability during surveys. Barbary sheep are known to overlap in this range so competition and possible disease transmission were also speculated to be limiting bighorn abundance. In 2024 NMDGF partnered with Owyhee Air Research to conduct a forward-looking infrared (FLIR) survey of bighorn and barbary across the entire range. The FLIR survey covered approximately three times the area of the traditional helicopter survey but found 34 bighorn and 14 barbary compared to our 29 bighorn observations using traditional helicopter survey methodology. These results supported that the traditional helicopter survey was effective. NMDGF is now exploring alternative limiting factors including lamb recruitment, diet, and predation. A 2025 augmentation is also being considered to boost the ewe demographic and support increased reproduction and recruitment. Sixteen new GPS collars were deployed in 2024 to improve monitoring efforts of adult survival and causes of mortality. Three collared bighorn died in 2024 (1 poaching, 2 unknown). Although competition and disease transmission between the species does not appear to be a factor limiting bighorn in this range, the overlap has led to four known bighorn illegally harvested by barbary sheep hunters in 2023–2024 including the poached collared ewe. The New Mexico Chapter of the Wild Sheep Foundation funded new signs at access points alerting barbary hunters to the presence of bighorn sheep and the Wild Sheep Foundation initiated the "Be Sure" campaign and distributed pamphlets to increase awareness (Wild Sheep Foundation 2024).

Red Rock Wildlife Area

The Red Rock Wildlife Area is home to NMDGF's captive desert bighorn herd. The 1,500 acre high-fence area is ground surveyed annually over a two-day period. In May 2023, the count resulted in 94 (35 adult ewes, 2 yearling ewes, 21 lambs, 36 rams) bighorn observed. In October 2023, 28 (11 adult ewes, 1 yearling ewe, 2 lambs, and 14 rams) bighorn were removed using helicopter net-gun capture methods and translocated to augment the Alamo Hueco population. The ground count in May 2024 observed 75 (35 adult ewes, 8 yearling ewes, 15 lambs, and 17 rams) bighorn sheep. Mountain lions and coyotes can breach the high-fence necessitating removal efforts when predator sign is found within or adjacent to the pens. One tom was removed in 2024. Several coyotes were observed inside the enclosure over both years, but removal attempts have been minimally successful.

DISEASE

Mycoplasma ovipneumoniae (*M. ovi*) continues to be the primary pathogen of concern in New Mexico's bighorn populations. All bighorn captured in the state are sampled and tested for active infection and prior exposure. Hunters are encouraged to collect samples at harvest to include annual monitoring in populations that do not have capture events. The Fra Cristobal, Caballo, Ladron, San Andres, and Sacramento desert bighorn sheep ranges are known to be *M. ovi* positive. Currently, the Kofa strain is the only strain that has been detected and is assumed to have arrived during the 2002 translocation of bighorn from the Kofa National Wildlife Refuge. Disease surveillance in 2023–2024 show that the Peloncillo and Bootheel metapopulation continues to be *M. ovi* negative.

MOUNTAIN LION MANAGEMENT

Mountain lion control efforts are active in 6 of 9 occupied desert bighorn ranges. NMDGF contractors operate in 5 of those ranges while Armendaris Ranch oversees lion management in the Fra Cristobal range. In 2023 (n = 14) and 2024 (n = 12), 26 lions were removed from desert bighorn habitat. NMDGF will continue lion management in desert bighorn ranges to protect and increase populations to provide surplus sheep for future translocations into existing areas of vacant and under-occupied habitat in the state.

HUNTING

New Mexico desert bighorn ram licenses continue to be "once-in-a-lifetime" unless they are acquired through the annual auction, raffle, or private authorization. There were 29 desert ram licenses in 2023 (26 public draw, 1 auction, 1 raffle, 1 private) and 27 in 2024 (24 public draw, 1 auction, 1 raffle, 1 private). The desert bighorn ram auction tags raised $385,000 and raffle proceeds contributed $180,000 in funding for bighorn sheep conservation in New Mexico during this period (Table 1).

REFERENCE

Wild Sheep Foundation. 2024. Be sure field identification: bighorn sheep versus Barbary Sheep (aoudad). Wild Sheep Foundation, Bozeman, Montana, USA.

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TABLE 1. Total funds generated from enhancement authorizations and green scores from desert bighorn sheep rams hunted on auction and raffle licenses, 2021–2024.

	2021	2022	2023	2024
Auction	$193,000	$210,000	$200,000	$185,000
Raffle	$98,000	$74,000	$102,000	$78,000
Auction Score	185 3/8	175 0/8	172 6/8	174 4/8
Raffle Score	168 6/8	176 2/8	173 5/8	169 3/8

Status of Desert Bighorn Sheep In Texas—2023–2025

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Desert Bighorn Council Transactions 58:157–163

POPULATIONS

From 2002 to 2008, desert bighorn populations in Texas were rising, and seemingly leveled off after 2008 where it remained for several years (Figure 1). In late Fall of 2019, however, the first-ever desert bighorn disease die-off associated with *Mycoplasma ovipneumoniae* (M. ovi), was detected. Two other M. ovi-related die-offs were documented in distinct mountain ranges in Spring 2020 (Black Gap Wildlife Management Area) and the summer of 2023 (Sierra Diablo Mtns). The annual aerial desert bighorn surveys were suspended in August 2020 after only 35 hrs of flight time due to a fatal helicopter crash. Afterwards, only a selected few mountain ranges were accessed through ground counts. During the 2023 survey, 568 bighorns were observed with a lamb ratio (lambs per 100 ewes) of 26:100. In 2024, the count resulted in 615 bighorns observed with a lamb ratio of 40:100.

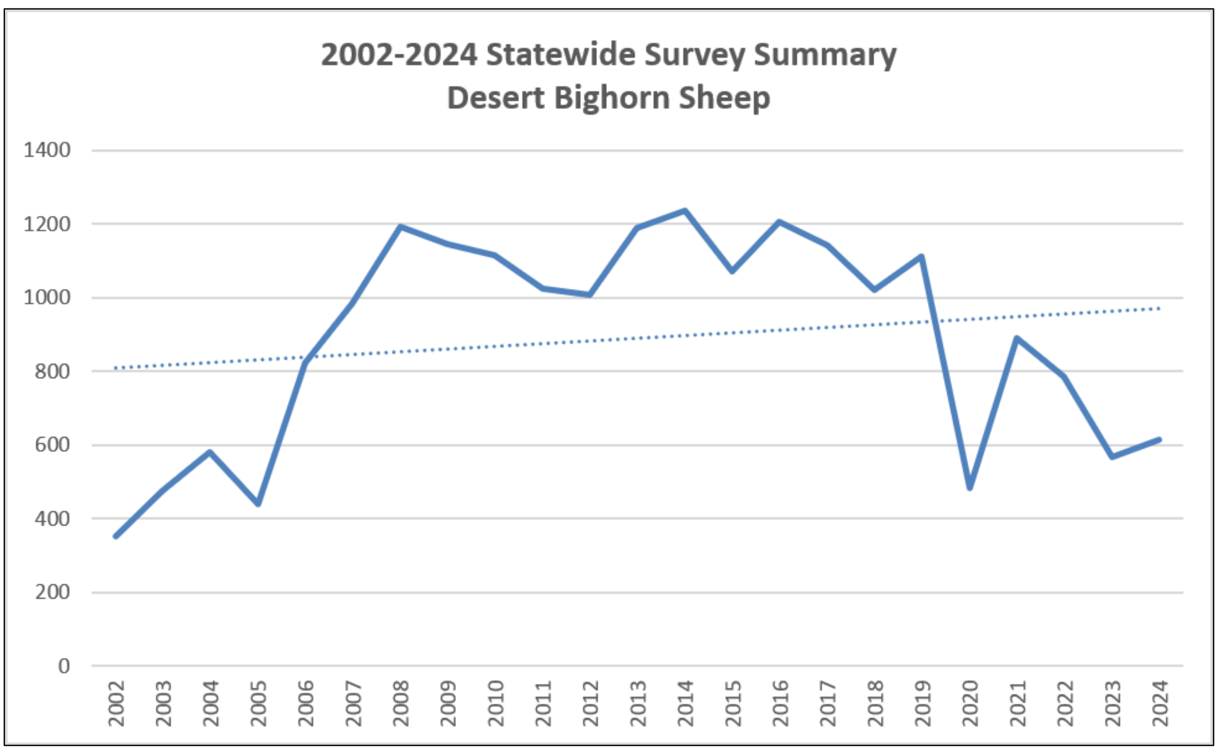

FIGURE 1. Statewide desert bighorn survey results for Texas. 2002–2024.

HARVEST

The desert bighorn hunt season spans from 15 November through 31 August of the following year. Due to ongoing disease issues, permits were allocated on a case-by-case basis during the 2023-2024 and 2024-2025 hunt seasons. A total of 4 permits were issued in the 2023-2024 hunt season, and 7 permits had been issued for the 2024-2025 hunt season at time of print (Table 1). In the 2023-2024 hunting season, out of the 4 permits issued 2 were allocated to the state (1 public hunt program and 1 auction) and 2 to private landowners. One of the private landowner permits was unfilled.

For the 2024-2025 hunt season, only 7 permits had been issued at the time of reporting, of which 4 were issued to private landowners and 3 issued to the state (2 public, 1 auction). Total permit issuance and the final success rate for the 2024-2025 hunt season had not been determined at the time this report was prepared because hunt season had not ended and there still were 5 outstanding permits, as well as other possible permits not yet issued due to the case-by-case allocations.

WATER DEVELOPMENT AND HABITAT IMPROVEMENTS

Five (5) new water catchment guzzlers were constructed in strategic locations which will benefit desert bighorns and other wildlife. These water guzzlers were built on public land and private property within expansive mountain ranges. This added a potential 25,000 total gallons of water for those 5 guzzlers across the landscape. In addition to the new guzzlers, repairs were performed on existing water guzzlers which were within bighorn ranges. Furthermore, and in collaboration with the Mule Deer Foundation, other guzzlers on the fringes of bighorn habitat were reworked.

Even though supplemental water benefits native wildlife, some wildlife biologist question whether there might be unintended consequences, such as benefiting undesirable species, including aoudad (*Ammotragus lervia*), also known as Barbary sheep. These artificial man-made watering sources could potentially be congregation points potentially serving as disease transmission points. Additionally, there are discussions now that these water sources could also influence predation.

Over 10 Ranchbot® Water Monitoring units were deployed to several water guzzlers to monitor the water level in water storage tanks. More water monitoring units are scheduled to be deployed at guzzlers throughout the desert bighorn range on public as well as private land.

RESTORATION

Aoudad are found in most of the West Texas mountains, including the mountains considered prime desert bighorn habitat. Recent disease monitoring and surveillance identified the aoudad as carriers of the M. ovi bacteria.

Because aoudad inhabit all mountains surrounding Elephant Mountain, currently considered the only known M. ovi-free in-state brood source for desert bighorn restoration efforts, it was imperative to protect that herd, and thereby the future of desert bighorns in TX.

As such, the Franklin Mountains were identified not only as prime bighorn habit, but were also found to be devoid of aoudad which made them a prime candidate for a desert bighorn restoration area. Because the Franklins are nestled within El Paso and devoid of aoudad, they limit the potential for aoudad migrating into the area as well as reducing the disease transmission risk. This, in essence, made the Franklins a sanctuary for desert bighorns.

In December 2024, 77 desert bighorns (37 M, 40 F) were captured on Elephant Mountain and translocated to the Franklin Mountains. Tissue samples were collected from all animals, tested for M. ovi, and determined clean. Over 80% of the ewes were pregnant and all animals were fitted with radio-telemetry collars to facilitate post-release monitoring. To date, there have only been 3 mortalities out of the 77 released. An aerial assessment was conducted in early April in the Franklin Mtns. All animals appeared in good health and a 45% lamb crop was observed. Lambs of different ages were observed. A better sense on actual recruitment will be revealed during Fall surveys (October).

The goal of the Franklin Mtns restoration effort is to create another M. ovi-free productive free-ranging broodstock source, much like Elephant Mountain, to continue future restoration efforts in Texas.

TABLE 1. 2023-2024 and 2024-2025 hunt seasons Desert Bighorn permit issuance and harvest. The average age and score for rams harvested through TPWD hosted/guided/outfitted hunts was 10 yrs old and 172 inches, respectively.

Permit Year	Private	Public	Auction	Total Permits	Permits Used	Success
2023-2024	2	1	1	4	3	75%
2024-2025[1]	4	2	1	7	2	N/A
TOTAL	6	3	2	11	5	N/A

[1] five permits had been issued but not hunted at time of print.

DISEASE MONITORING

Though efforts to collect tissue samples from aoudad to surveille for diseases and pathogens potentially threatening to desert bighorns were first conducted in Oct 2008, those efforts were not continued annually. In Oct 2018, TPWD actively began monitoring aoudad populations for potential disease threats to desert bighorns throughout the West Texas mountains on an annual basis. To date, aoudad tissue samples have been collected from over 14 distinct mountain ranges and areas from identified habitat within historical desert bighorn range (Appendix A).

As part of the aoudad disease surveillance and monitoring program, in July 2023 an aoudad sampling effort was conducted in the mountains surrounding Elephant Mountain. The mountains surrounding Elephant Mountain are particularly important because of their proximity and potential for aoudad to readily "infiltrate" Elephant Mountain. In August 2023, immediately following the sampling of the Elephant Mtn surrounding mountains, the sampling efforts were expanded to mountain ranges currently unoccupied by desert bighorns, but still within historical range. These ranges included the Hueco, Wylie, Davis and Glass mountains.

While the goal was to collect tissue samples in equal proportions of rams and ewes from each mountain range or target areas, aoudad were opportunistically dispatched from what was readily available and/or encountered. In total, tissue samples were collected from 180 aoudad (53 M, 127) (Table 2).

TABLE 2. Results of aoudad tissue sampling conducted during July and August 2023.

Mountain Range	**Males**	**Females**	**Total**
EMWMA Surroundings	16	44	60
Hueco	14	16	30
Wylie	0	30	30
Davis	11	19	30
Glass	12	18	30
TOTAL	**53**	**127**	**180**

The focus of the aerial gunning efforts was disease surveillance and monitoring, however, because of increasing landowner concern for high aoudad densities, in some areas more aoudad were dispatched, in addition to the ones being sampled. During the Jul-Aug 2023 operation, a total of 1,135 aoudad were observed, of which 505 were removed (Table 3). The 180 animals sampled during Jul-Aug 2023 are included in the 505 removed.

Due to time and logistical constraints, none of the mountain ranges or areas were flown in their entirety. Therefore, the totals for "Aoudad Observed" do not actually reflect potential aoudad densities, which are believed to be higher.

Among the tissues collected from the 180 animals were blood, nasal swabs, tonsil swabs, feces, ear biopsy (DNA) and ticks. Nasal swabs and blood were submitted to the Washington Animal Disease Diagnostic Laboratory (WADDL) for M. ovi PCR and ELISA testing (Table 4, Table 5). These sampling efforts were in collaboration with Texas Tech University-Natural Resource Management Department (TTU-NRM). TTU-NRM is also interested in aoudad pathogen surveillance, and their research will help us gain a greater understanding of Mycoplasma ovipneumoniae (M. ovi) transmission dynamics within aoudad herds.

TABLE 3. Total aoudad observed and removed per mountain range during Jul–Aug 2023.

Mtn Range	**Aoudad Observed**	**Aoudad Removed[1]**
EMWMA Surrounding	212	75
Hueco	357	285
Wylie	209	89
Davis	303	26
Glass	54	30
TOTAL	**1135**	**505**

TABLE 4. July and August 2023 aoudad tissue sampling ELISA results.

Mtn Range	Detected	Indeterminate	Not Detected	Total Tested	% Detected
EMWMA Surroundings	37	4	19	60	62%
Hueco	4	1	25	30	13%
Wylie	20	3	7	30	67%
Davis	20	2	8	30	67%
Glass	14	6	10	30	47%
Grand Total	**95**	**16**	**69**	**180**	**53%**

TABLE 5. July and August 2023 aoudad tissue sampling PCR results.

Mtn Range	Detected	Indeterminate	Not Detected	Total Tested	Percent Detected
EMWMA Surroundings	6	4	50	60	10%
Hueco	0	1	29	30	0%
Wylie	3	1	26	30	10%
Davis	2	3	25	30	7%
Glass	0	1	29	30	0%
Grand Total	**11**	**10**	**159**	**180**	**6%**

RESEARCH

Three MS research projects were initiated in March/April 2023. A brief abstract detailing the 3 projects follow. The principal investigator for each individual study presented their preliminary findings. Therefore, results were not included in the Texas State Status Report.

Space use and disease risk of desert bighorn sheep in the Trans-Pecos region, Texas

During a recent study in the Trans-Pecos, researchers analyzed niche overlap, temporal resource partitioning, and dietary overlap amongst desert bighorn, aoudad and mule deer. Their findings supported the hypothesis that desert bighorn and aoudad have significant niche overlap in optimal habitat. Niche variation among desert bighorn populations in the Trans-Pecos is lacking, however, as well as how individual space use within each population may shape disease transmission hotspots. The aim of this study is to investigate the connection between space use and disease dynamics to predict pathways of M. ovi transmission. The study will address two main objectives: 1) model spatial and temporal desert bighorn co-occurrence on the landscape to predict potential disease transmission hotspots, and 2) assess niche variation among Trans-Pecos desert bighorn populations.

Seasonality of competition potential between desert bighorn and mule deer on Elephant Mountain Wildlife Management Area

Elephant Mountain Wildlife Management Area serves as a source population for ongoing desert bighorn restoration efforts. Consequently, the primary management objective is production of surplus animals for use as stock for translocation objectives. However, EMWMA also provides public hunting opportunities, particularly for mule deer. Thus, maintaining a healthy mule deer population is also a key management goal on EMWMA. The area is unique because of apparent spatial overlap between the two species, presumably leading to competition for resources. Moreover, seasonal shifts in space use by each species may exacerbate or curtail competition. The goal of the study is to identify seasonal space use by both species and temporal patterns potentially influencing competition.

Space use of sympatric aoudad and mule deer in the Trans-Pecos

Aoudad ecology, space-use, daily activity cycles, and social dynamics is largely unknown and poorly understood, particularly where the species coexist and potentially interact with the native mule deer in the Trans-Pecos region of Texas. With improved quantitative techniques in movement ecology, aoudad space-use can be readily assessed using the Brownian Bridges Movement Model (BBMM), calculated using collar data. No literature has quantified aoudad utilization distributions using the BBMM or examined the influence of aerial gunning relative to changes in movement behavior. The focus of this study is to compare pre- and post-aerial gunning movement to understand spatial and temporal aoudad response and behavior to aggressive aerial gunning to develop appropriate big game recovery strategies in the Trans-Pecos.

EMERGING THREATS AND CHALLENGES

In addition to disease issues, Texas continues to face the growing challenges posed by aoudad. Aoudad hunting has become a substantial financial incentive for many landowners, making it difficult to lethally remove aoudad across desert bighorn range. Additionally, M. ovi has been detected in all aoudad populations within 13 distinct mountain ranges. This threatens the success of future restoration efforts.

CLOSING

Undoubtedly, disease events have impacted desert bighorn populations in Texas. However, TPWD is committed to expanding the disease monitoring and surveillance program, and continuing activities and projects which will further restoration efforts. TPWD will continue to work collaboratively with all interested parties to ensure that Texas's restoration, management, research, and hunting of desert bighorn sheep keeps moving forward.

APPENDIX A. Mountain ranges within identified desert bighorn habitat and wherein aoudad samples have been collected to date are highlighted in green.

Status of Bighorn Sheep in Utah—2025

Rusty Robinson

Utah Division of Wildlife Resources, Salt Lake City, UT 84116, USA

Desert Bighorn Council Transactions 58:164–165

POPULATION STATUS

Over the last two years, Utah's bighorn sheep populations have shown slight decreases in both desert bighorn sheep (*Ovis canadensis nelsoni*) and Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*). California bighorns (*Ovis canadensis californiana*) are included in Rocky Mountain bighorn estimates. Current statewide population estimates are approximately 3100 desert bighorns and 1600 Rocky Mountain bighorns (Fig. 1). Utah currently has 16 different huntable populations of desert bighorns including the Mineral Mountains population in Millard County, which was reintroduced in 2019 and was hunted for the first time in 2024. There are currently 11 huntable populations of Rocky Mountain bighorns including Antelope Island which was reintroduced in 2020 following a die-off event and will be hunted again in fall of 2025. The Pilot Mountain population, which has a small number of sheep, is shared with Nevada, and the administration of hunting permits alternates between the two states when mature rams are available. Currently, the Pilot Mountain population is not being hunted by either state.

HARVEST

The statewide bighorn sheep management plan is a 10 year plan written in 2018. The plan dictates that aerial surveys will be conducted every 2-3 years. All observed animals are counted and classified as ewes, lambs, and rams, with rams being further classified as Class I (2.5 years old), II (2.5–5.5 years old), III (6.5–7.5 years old), or IV (8.5+ years old) (Geist 1971). Previous studies have shown that sightability on bighorn sheep populations varies between 60 and 70%, depending on the unit and conditions. However, the plan further dictates that hunting permit recommendations are made based on the number of rams actually observed on the most recent survey. Biologists can select from two different sets of sideboards for recommending harvest permits; 12–25% of the total number of rams observed yearling and older or 30–60% of class III and class IV rams (6 years of age or older) observed. This year, 88 desert bighorn permits are being recommended. This is an increase of 12 permits statewide. Rocky Mountain bighorn permits are being recommended at 52 statewide which is a five-permit reduction from last year. Also, for the past few years, there has been a ewe hunt on the Newfoundland Mountains for which five permits have been allocated each year. Harvest success rates are generally very high with 2024 success for desert bighorn rams at 92% and 98% for Rocky Mountain bighorn rams. The success rate for the ewe hunt was 80%. Bighorn sheep are managed as a once-in-a-lifetime hunting species in Utah.

PROJECTS

In December of 2023, the desert bighorn nursery herd was relocated to a 1000 acre facility purchased by Sportsmen for Fish and Wildlife. The property is on Promontory Point in Box Elder County and is double fenced. Thirteen bighorns remained from the original nursery herd and were augmented with 20 additional bighorns from the Muddy Mountains in Nevada in June of 2024. Another transplant from the Muddy Mountains is scheduled for June of 2025.
During the winter of 2023-2024, 196 bighorn sheep were captured, tested, and fitted with GPS collars as part of Utah's ongoing disease sampling efforts (102 RMBHS and 94 DBS). During the winter of 2024-2025, an additional 107 bighorns were captured (31 RMBHS and 76 DBS).

INTERAGENCY BIGHORN OUTREACH COORDINATOR

The Utah Division of Wildlife Resources (UDWR) entered into an agreement with the Utah Department of Agriculture and Food (UDAF) to create an interagency position to aid in bighorn management. The position is housed under UDAF and is tasked with creating separation between bighorns and domestic sheep and goats by working directly with livestock producers and private landowners. Duties include identifying and prioritizing areas of potential spillover and disease risk, educating producers, providing fencing, disease sampling, and assisting in removing wandering bighorns and stray domestics. The position has been a success and has already helped avoid several potential disease events.

REFERENCE

Geist, V. 1971. Mountain sheep: a study in behavior and evolution. University of Chicago Press, Chicago, Illinois, USA.

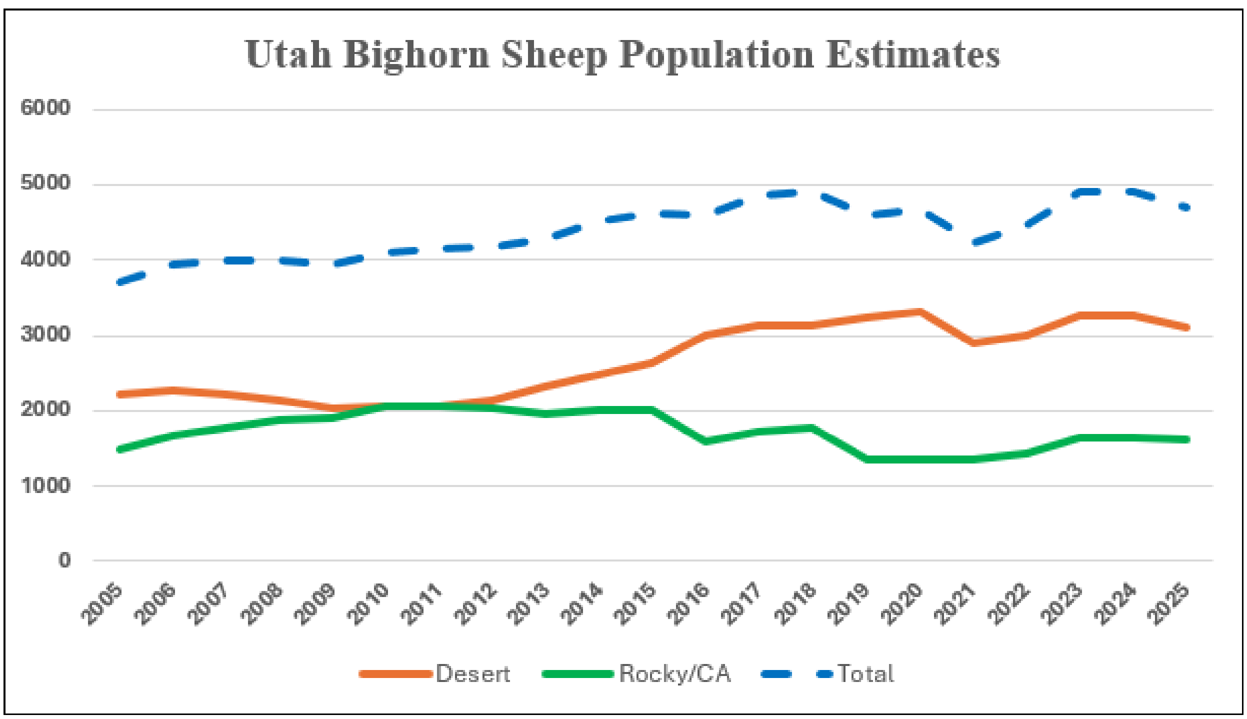

FIGURE 1. Statewide bighorn sheep population estimates in Utah, 2005–2025.

CASE REPORT

Survey of the Amedee, Skedaddle, and Warner Mountains, Northeastern California, for Bighorn Sheep

***Danielle Glass*[1], *Arioch M'Greene*[1], *Phil Keefe*[1], *Samantha Stelter*[1], *Paige Prentice*[2], *Jeff Villepique*[3], and *John Wehausen*[4]**

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[2] California Department of Fish and Wildlife, West Sacramento, CA 95605, USA

[3] California Department of Fish and Wildlife, Ontario, CA 91764, USA

[4] Sierra Nevada Bighorn Sheep Foundation, Bishop, CA 93515, USA

Desert Bighorn Council Transactions 58:166–171

Petroglyphs and faunal remains from archaeological sites suggest that bighorn sheep (*Ovis canadensis*) existed in northeastern California for thousands of years (Schultz and Simons 1973). This evidence, in combination with documented sightings and hunter-kill data from the 1880s to the 1920s, suggests that bighorn sheep occupied patches of suitable habitat at Mt. Shasta, Bogus Mountain, Goose Nest Mountain, Lava Beds, Warner Mountains, Observation Peak, and Smoke Creek areas (Figure 1; Buechner 1960, Cowan 1940, Grinnell et al. 1930, Wehausen et al. 1987, Wolfe 1979), but had been extirpated from northeastern California by about 1930 (Buechner 1960, Wehausen et al. 1987). Pathogens contracted from domestic sheep (*Ovis aires*) or domestic goats (*Capra hircus*) and excessive hunting likely resulted in this extirpation (Buechner 1960, Goodson 1982, Wehausen et al. 2011, Cassirer et al. 2018).

The subspecies to which the sheep native to northeastern California belonged has been a question of long standing (Cowan 1940, Wehausen and Ramey 2000). In an effort to reestablish bighorn sheep in this region, bighorn sheep (*O. c. californiana*) were introduced into a fenced area in Lava Beds National Monument from British Columbia and the Sheldon National Wildlife Refuge, Nevada in 1971 and 1973, respectively (Bleich et al. 2021). In 1980, four of these Lava Beds animals were translocated to the Warner Mountains along with ten additional animals from the Mt. Baxter herd in Sierra Nevada (Bleich et al. 2021). Between 1980 and 1987, the Warner Mountains population grew steadily to 50–55 animals (Weaver and Clark 1988), but the entire population died of respiratory disease during the winter of 1987-1988, the cause of which was attributed to contact to domestic sheep (Foreyt and Jessup 1982, Weaver 1983, Weaver and Clark 1988, Jessup et al. 2014).

No additional bighorn sheep have been translocated to northeastern California since the most recent extirpation. The Nevada Department of Wildlife (NDOW) and the Oregon Department of Fish & Wildlife (ODFW), however, have introduced populations of California bighorn sheep into mountain ranges near the California border. There have been occasional observations of bighorn sheep in northeastern California along the borders of Nevada in the Warner Mountains, Skedaddle Mountains, and the Hallelujah Junction Wildlife Area, and Oregon in the Klamath River basin between 1989 and 2025, but no colonization events have been documented.

Recent observations have raised the question of potential colonizations by bighorn sheep immigrating from neighboring states. One bighorn ewe was recorded on a trail camera in Siskiyou County near the Oregon border on 3 July 2025, and it was hypothesized this ewe was the last survivor of translocations to the Klamath River basin from the Branson Creek herd in Oregon during in 2014 and 2015 (Mike Moore, ODFW, personal communication). A helicopter survey by the ODFW in the Klamath River area of Oregon and California did not document additional bighorn sheep.

Also of note were observations of ≥6 yearling and adult females between 22 April and 2 May 2025 along Highway 395 between Viewland and Wendel, Lassen Co., California. It is hypothesized that these animals originated from the Virginia Mountains herd in Nevada, and crossed Sand Pass and the Skedaddle Mountains to Highway 395. Aerial and ground surveys on 7 May 2025 failed to locate this ewe group. Given that males are more likely to make long forays than are females (Ricci et al. 2024), the composition of this group raised the possibility of a colonization event.

During 11–15 August 2025, we surveyed the Amedee and Skedaddle mountains, and the Warner Mountains, devoting 1.5 days to each of the two areas (Figure 2). These efforts focused on the steepest, rockiest habitat in each range, but no bighorn sheep were observed. Cattle were observed in the Amedee and Skedaddle mountains. No domestic sheep were observed within the ranges proper, but occurred on fenced private property within two miles. Hundreds of domestic sheep were observed in the southern end of the Warner Mountains (Figure 3). Additionally, a weathered horn sheath from a female bighorn sheep was located in the Warner Mountains (41.20431°N, 120.05757°W). Twelve fecal samples from the Amedee and Skedaddle mountains, and 3 fecal samples from the Warner Mountains were collected.

Nine fecal samples (7 from the Amedee or Skedaddle mountains; 2 from the Warner Mountains) were tested genetically; the remaining samples were considered to be too degraded or likely from an animal already sampled. The test was used to determine whether fecal samples were from mule deer (*Odocoileus hemionus*) or sheep (*Ovis* spp.;Wehausen 2023), but not designed to distinguish pronghorn (*Antilocapra americana*) from sheep (*Ovis* spp.), or between domestic sheep (*O. aires*) and bighorn sheep. Of the nine samples, two were from sheep, six were from deer; and one showed no amplification and is suspected to be from a pronghorn because of notably different characteristics of the fecal pellets. Both of the sheep fecal samples from the Warner Mountains were collected within two miles of where domestic sheep were observed. As a result, we conclude these samples likely were deposited by domestic sheep and not by bighorn sheep. We did not consider the old weathered horn a candidate for genetic testing.

We found no evidence of a bighorn population currently existing in the Amedee, Skedaddle, or Warner mountains. The horn sheath found in the Warner Mountains may stem from the population present in the late 1980s, or a transient immigrant. The reported sightings of 6 females in April and May 2025 suggests that northeastern California receives occasional visits from bighorn sheep originating from the Hayes Canyon, Painted Point, or Virginia ranges in Nevada. Given the extensive presence of domestic sheep in this part of California, wildlife biologists from California, Nevada, and Oregon will investigate further reports of movements by bighorn sheep in NE California. Managers should not consider translocating bighorn sheep into either the Amedee, Skedaddle, or Warner mountains until domestic sheep are no longer grazed there.

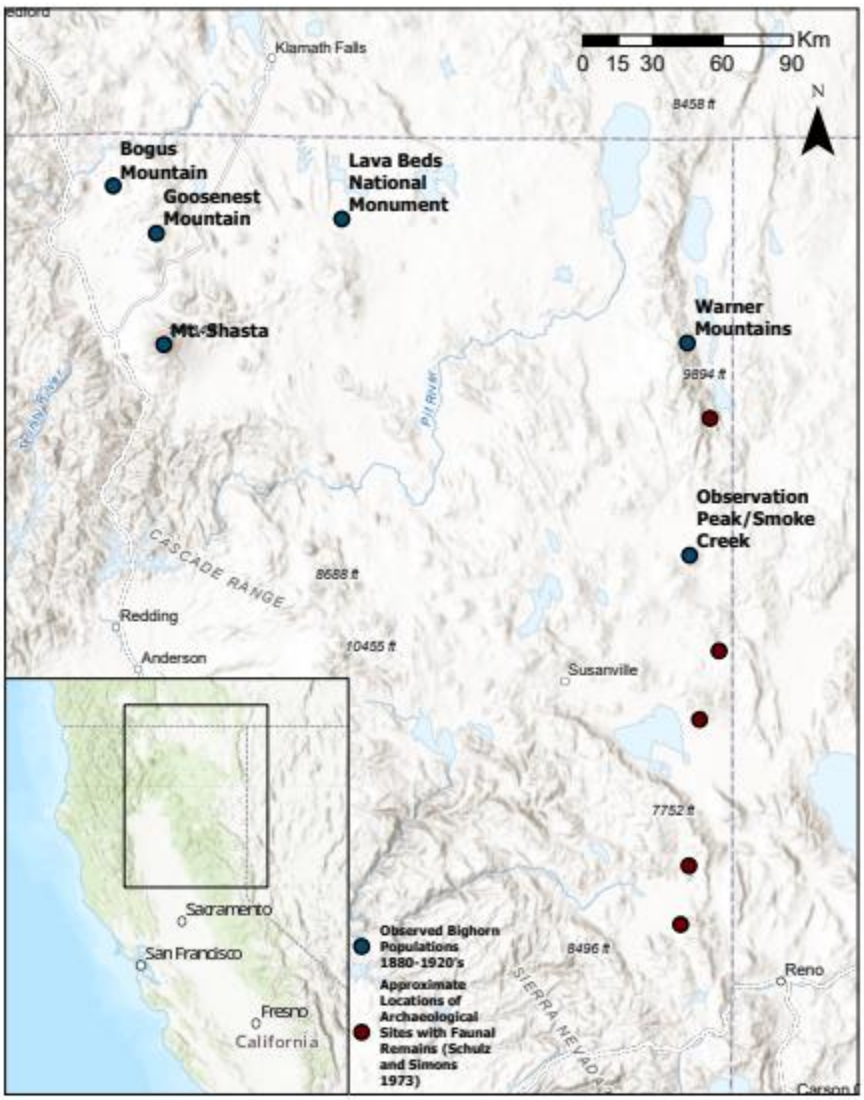


FIGURE 1. Bighorn sheep populations in northeastern California during the 1880s–1920s, and approximate locations of archaeological sites with faunal remains of bighorn sheep.

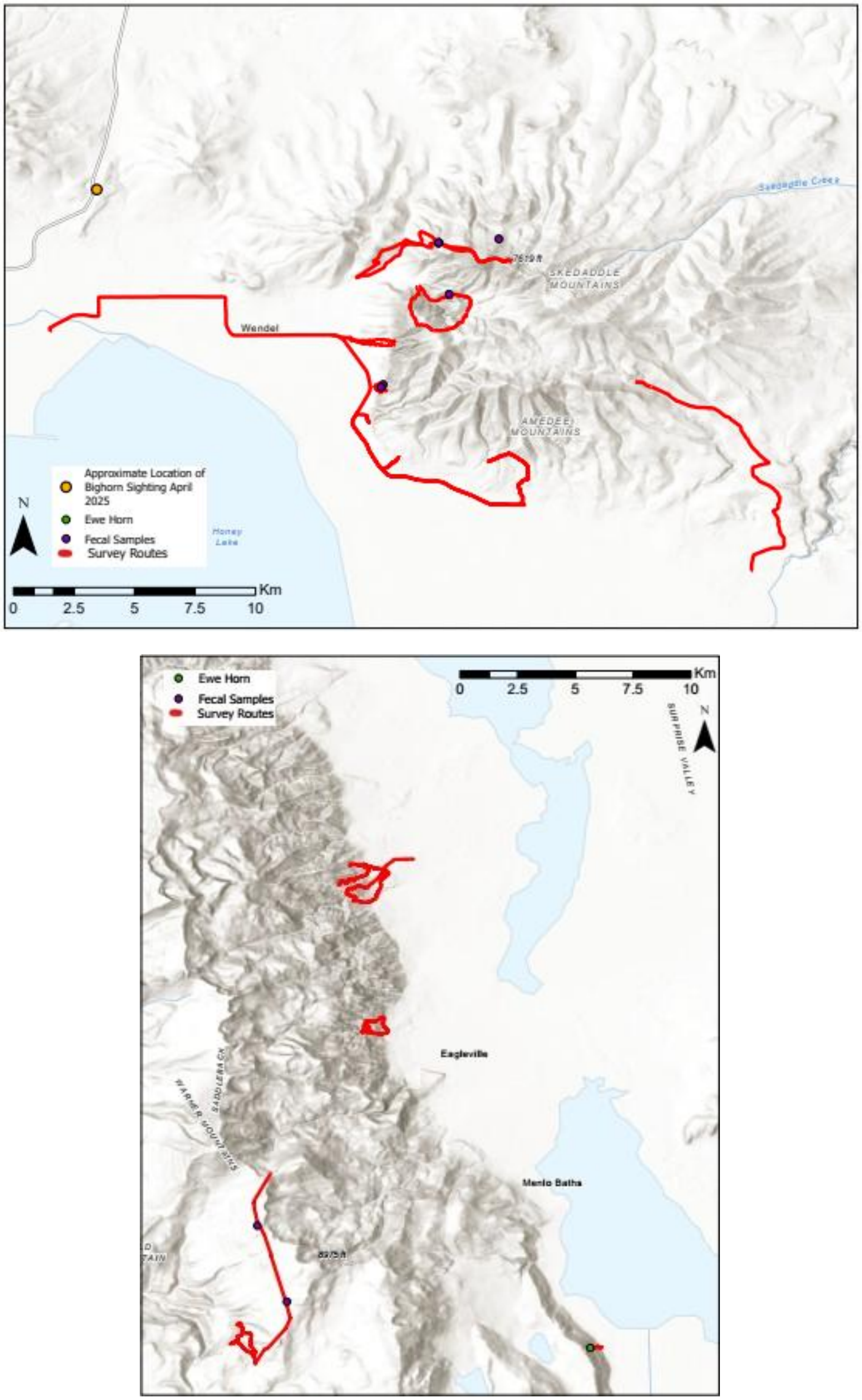


FIGURE 2. Amedee-Skedaddle (upper panel) and Warner (lower panel) survey routes and sample locations. The Amedee-Skedaddle map also provides the location where the female bighorn sheep were seen in April 2025, and the Warner map includes the location at which the female horn sheath was discovered.

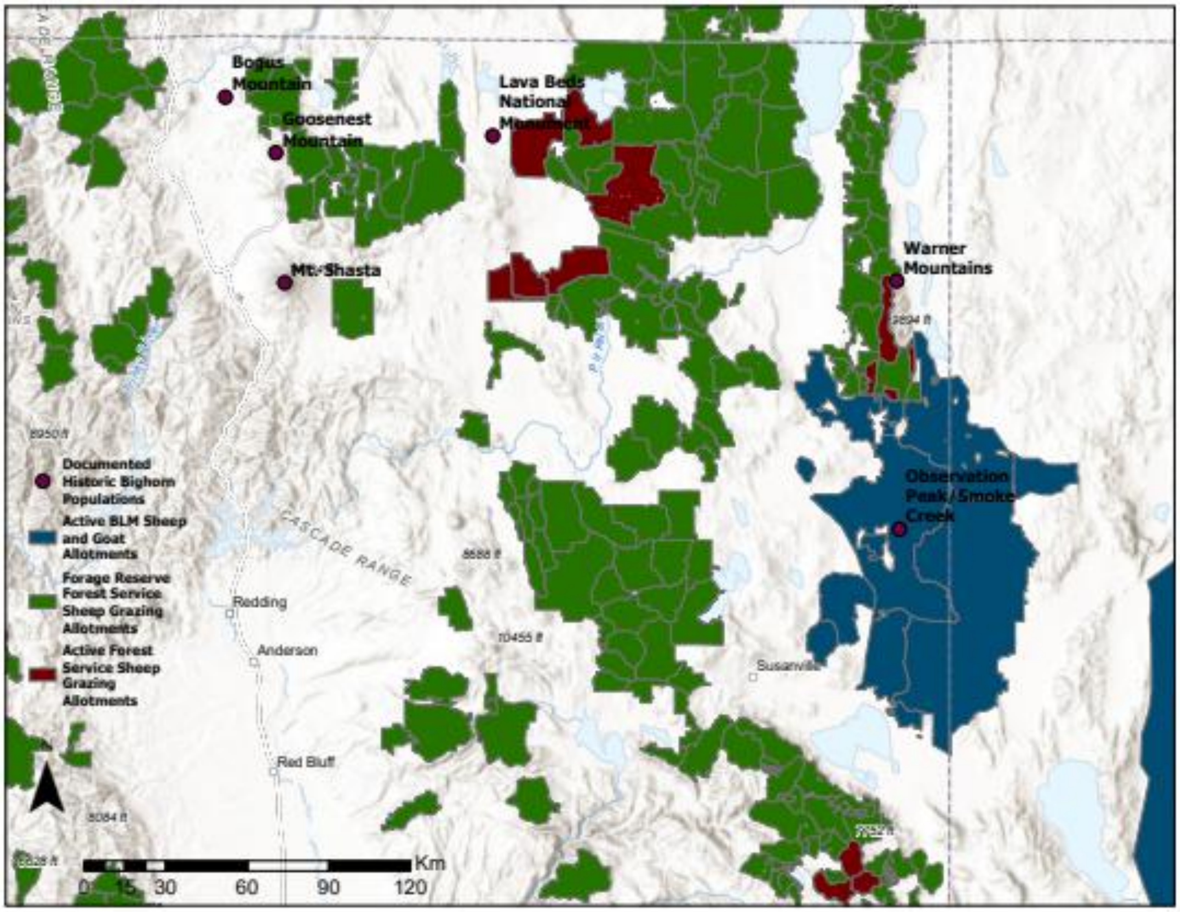


FIGURE 3. Active Bureau of Land Management (BLM) and Forest Service (USFS) domestic sheep and goat grazing allotments (BLM 2025, USFS 2025) and historic bighorn sheep populations.

REFERENCES

Bleich, V. C., J. D. Wehausen, S. G. Torres, K. Anderson, and T. R. Stephenson. 2021. Fifty years of bighorn sheep translocations: details from California (1971–2020). Desert Bighorn Council Transactions 56:1–32.

Buechner, H. K., 1960. The bighorn sheep in the United States, its past, present, and future. Wildlife Monographs 4:1–174.

Bureau of Land Management (BLM). 2025. BLM National Sheep and Goat Authorized Grazing Allotments. Updated April 2025. < BLM Natl Sheep and Goat Authorized Grazing Allotments | BLM GBP Hub>.

Cassirer, E. F., K. R. Manlove, E. S. Almberg, P. L. Kamath, M. Cox, P. Wolff, A. Roug, J. Shannon, R. Robinson, R. B. Harris, and B. J. Gonzales. 2018. Pneumonia in bighorn sheep: risk and resilience. Journal of Wildlife Management 82:32–45.

Cowan, I. McT., 1940. Distribution and variation in the native sheep of North America. American Midland Naturalist 24:505–580.

Foreyt, W. J., and D. A. Jessup. 1982. Fatal pneumonia of bighorn sheep following association with domestic sheep.

Journal of Wildlife Diseases 18:163–168.

Goodson, N. J. 1982. Effects of domestic sheep grazing on bighorn sheep populations: a review. Northern Wild Sheep and Goat Council Proceedings 3:287–313.

Grinnell, J., J. S. Dixon, and J. M. Linsdale. 1930. Vertebrate natural history of a section of northern California through the Lassen Peak region. University of California Publications in Zoology 35(5):1–594.

Jessup, D. A., S. R. deJesus, W. E. Clark, and V. C. Bleich. 2014. Evolution of ungulate capture techniques in California. California Fish and Game 100:491–526.

Ricci, L. E., M. Cox, and K. R. Manlove. 2024. Movement decisions driving metapopulation connectivity respond to social resources in a long-lived ungulate, bighorn sheep (*Ovis canadensis*). Philosophical Transactions of the Royal Society B 379:20220533.

Schulz, P. D. and D. D. Simons. 1973. Prehistoric bighorn sheep in the northern Sierra Nevada, California. Great Basin Naturalist 33:221–224.

United States Forest Service (USFS). 2025. Range: Unit Allotment. Available at <https://data-usfs.hub.arcgis.com/datasets/8683e877aa084121abdebf6caac04b10_0/explore?location=40.166228%2C-102.517457%2C4>.

Weaver, R. A. 1983. The status of bighorn sheep in California. Desert Bighorn Council Transactions 27:44–45.

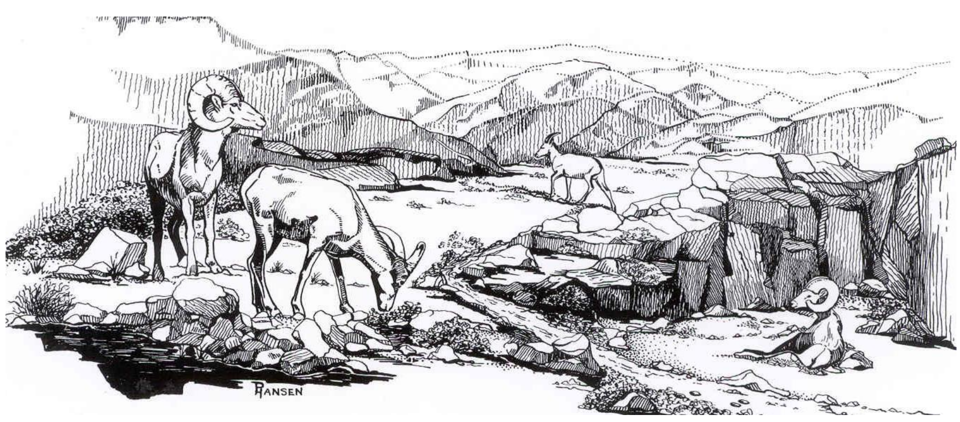
Weaver, R. A., and R. K. Clark. 1988. Status of bighorn sheep in California, 1987. Desert Bighorn Council Transactions 32:20.

Wehausen, J. D. 2023. A simple genetic method to distinguish mule deer and bighorn sheep fecal pellets and its application to detecting bighorn sheep colonization events in California. California Fish and Wildlife Journal 109:e18.

Wehausen, J. D., V. C. Bleich, and R. A. Weaver. 1987. Mountain sheep in California: a historical perspective on 108 years of full protection. Transactions of the Western Section of the Wildlife Society 23:65–74.

Wehausen, J. D., S. T. Kelley, and R. R. Ramey II. 2011. Domestic sheep, bighorn sheep, and respiratory disease: a review of the experimental evidence. California Fish and Game 97:7–24.

Wolfe, L. M. (editor). 1979. John of the mountains: the unpublished journals of John Muir. The University of Wisconsin Press, Madison, Wisconsin, USA.



2025 DBC Awardee

During the 58th Meeting of the Desert Bighorn Council in Gold Valley, Arizona, a long-standing, highly respected, and active member of the Desert Bighorn Council was recognized for his contributions to the Council and to the conservation of Desert Bighorn Sheep. Steven G. Torres, of the California Department of Fish and Game, has been involved with the conservation and management of bighorn sheep for > 5 decades, and received the Desert Bighorn Ram Award in recognition of his career-long contributions to research, the management and conservation of desert bighorn sheep, and his many years of dedicated service to the Desert Bighorn Council. The text of the award follows.

THE DESERT BIGHORN COUNCIL RECOGNIZES

STEVEN G. TORRES

WITH THE

DESERT RAM AWARD

**For a lifetime of unselfish dedication and commitment working with agencies,
wildlife conservation organizations, the academic community,
and professional societies on behalf of desert bighorn sheep.
Your numerous contributions to science, willingness to mentor young scientists,
and your ability to resolve disagreements and conflict.
Your support of scientific rigor as being foundational to successful conservation and
Your capable leadership of California's Bighorn Sheep Conservation Program.**

**PRESENTED AT THE 58TH DESERT BIGHORN COUNCIL
GOLD CANYON, ARIZONA
APRIL 2025**

Recipients of the Desert Bighorn Council's Awards, 1960–2025

Ram Award

2025—Steven G. Torres (CDFG)
2023—Kathleen M. Longshore, U.S.G.S
2021—Pat Cummings, Nevada Department of Wildlife
2019—Ben J. Gonzales, California Department of Fish and Game
2019—Ross Haley, National Park Service
2017—Walter M. Boyce, University of California Davis
2017—Clinton W. Epps, Oregon State University
2015—Don Armentrout, Bureau of Land Management
2013—Elise Goldstein, New Mexico Department of Game and Fish
2013—Eric M. Rominger, New Mexico Department of Game and Fish
2011—Jack Kilpatric, Texas Parks and Wildlife Department
2011—Texas Parks & Wildlife Department
2011—Texas Bighorn Society
2011—Society for the Conservation of Bighorn Sheep
2009—Mark C. Jorgensen, California Department of Parks and Recreation
2009—Esther S. Rubin, Conservation Biology Institute
2007—Joe Cresto, Bureau of Land Management
2007—Raymond Lee, Foundation for North American Wild Sheep
2007—Nevada Bighorns Unlimited—Reno Chapter
2007—Fraternity of the Desert Bighorn
2007—California Department of Fish and Game Wildlife Investigations Lab
2002—Rick W. Brigham, Bureau of Land Management
2002—Vernon C. Bleich, California Department of Fish and Game
2000—Paul R. Krausman, University of Arizona
1999—John D. Wehausen, White Mountain Research Station
1997—Rob Roy Ramey, University of Colorado
1986—Richard A. Weaver, California Department of Fish and Game
1984—George Welsh, Arizona Game and Fish Department
1983—Charles L. Douglas, National Park Service
1983—David M. Leslie, Jr., Oregon State University
1979—Robert P. McQuivey, Nevada Department of Fish and Game
1978—Fauna-Silvestre, Mexico
1974—Arizona Desert Bighorn Sheep Society, Inc.
1969—M. Clair Aldous, U.S. Bureau of Sport Fisheries and Wildlife
1968—Steve James, Jr., Fraternity of the Desert Bighorn
1966—Charles G. Hansen, U.S. Bureau of Sport Fisheries and Wildlife
1965—John P. Russo, Arizona Game and Fish Department
1963—Oscar V. Deming, U.S. Bureau of Sport Fisheries and Wildlife
1960—Ralph and Florence Welles, NPS

Honor Plaque

2023—Jimmy Cain, New Mexico Cooperative Fish and Wildlife Research Unit
2021—Clay E. Brewer, Wild Sheep Foundation
2021—Desert National Wildlife Refuge
2017—Marine Corps Air Ground Combat Center Twentynine Palms
2017—Raul Valdez, New Mexico State University
2015—Brian Wakeling, Nevada Division of Wildlife
2015—Leon and LaVelle Lesicka, Desert Wildlife Unlimited
2015—Steven R. deJesus, Landells Aviation
2013—Bill Montoya, New Mexico Game and Fish Commission
2013—Mara Weisenberger, U.S. Fish and Wildlife Service
2013—New Mexico Game and Fish Commission
2013—New Mexico Department of Game and Fish
2011—Clay Brewer, Texas Parks and Wildlife Department
2011—Mike Pittman, Texas Parks and Wildlife Department
2011—Mike Hobson, Texas Parks & Wildlife Department
2009—CEMEX
2007—William E. Clark, California Department of Fish and Game
2007—Sierra Nevada Bighorn Sheep Recovery Program
1997—Kathy Rollins, Bureau of Land Management
1994—Jerry Wolfe, Colorado Division of Wildlife
1993—Raymond Lee, Arizona Game and Fish Department
1991—California Department of Fish and Game Wildlife Investigations Lab
1988—Andrew Sandoval, New Mexico Department of Game and Fish
1986—Warren Kelly, U.S. Forest Service
1985—United States Naval Weapons Center China Lake
1982—Maurice “Bud” Getty, California Department of Parks and Recreation
1982—Desert Bighorn Council Ewes
1981—Thomas D. Bunch, Utah State University
1981—Grant Kinzer, New Mexico State University
1981—New Mexico Department of Game and Fish
1980—The Society for the Conservation of Bighorn Sheep
1979—Jim Blaisdell, National Park Service
1973—Lydia Berry, Desert National Wildlife Refuge
1972—Inyo National Forest
1969—Pat Hansen, Independent Bighorn Illustrator
1968—Nevada Operations Office, Atomic Energy Commission
1962—Ralph and Florence Welles, National Park Service

Award of Excellence

1986—Charles L. Douglas, National Park Service
1975—Gale Monson, Arizona-Sonora Desert Museum
1975—Lowell Sumner, National Park Service

DESERT BIGHORN COUNCIL MEETINGS 1957–2025

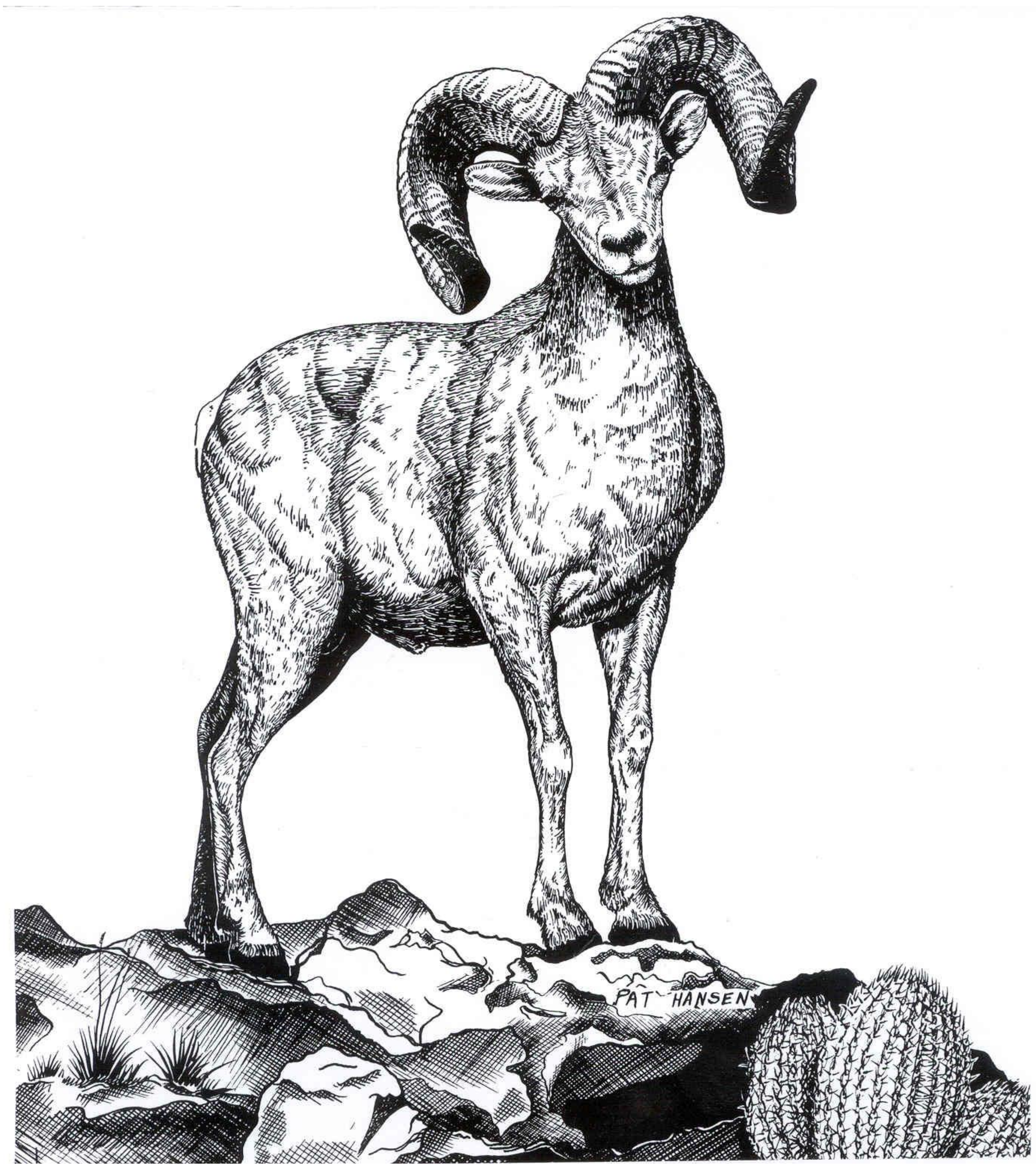
Year	Location	Chairperson	Secretary	Treasurer	Transactions Editor
1957	Las Vegas, NV	M. Clair Aldous			
1958	Yuma, AZ	G. Monson, W. Kelly			
1959	Death Valley, CA	M. Clair Albous	Fred Jones	Fred Jones	
1960	Las Cruces, NM	Warren Kelly	Fred Jones	Fred Jones	
1961	Hermosillo, MX	John B. Van den Akker	Ralph Welles	Ralph Welles	
1962	Grand Canyon, AZ	James Blaisdell	Charles. Hansen	Charles Hansen	C. Hansen, E. Fountain
1963	Las Vegas, NV	Al Jonez	Charles Hansen	Charles Hansen	Jim Yoakum
1964	Mexicali, MX	Rudulfo Corzo	Charles Hansen	Charles Hansen	C. 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	Ralph and Buddy Welles	W. G. Bradley	W. G. Bradley	Jim Yoakum
1970	Bishop, 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 C. Bleich	Don Armentrout	Don Armentrout	Paul Krausman
1989	Grand Jct., 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	S. 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
1996	Holtville, CA	Andy Pauli	Charles Douglas	Charles Douglas	Ray Boyd
1997	Grand Jct., CO	D. Reed, V. Graham	Steve Torres	Charles Douglas	Raymond Lee
1998	Las Cruces, NM	E. Rominger, D. Holdermann	Darren Divine	Charles Douglas	Raymond Lee
1999	Reno, NV	R. Brigham, K. Hurley	Darren Divine	Charles Douglas	A. and H. Thomas
2000	Bullhead City, AZ	Ray Lee, Jim deVos, Jr.	Darren Divine	Charles Douglas	Jon Hanna
2001	Hermosillo, MX	Carlos Castillo, Jim deVos, Jr.	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	S. Ostermann	Brian Wakeling
2007	Las Vegas, NV	Ross Haley	Esther Rubin	S. Ostermann	Brian Wakeling
2009	Grand Jct., CO	Scott Wait	Esther Rubin	K. Longshore	Brian Wakeling
2011	Laughlin, NV	Brian Wakeling	Esther Rubin	K. Longshore	Brian Wakeling
2013	Las Cruces, NM	E. Rominger, P. Morrow	Esther Rubin	K. Longshore	Brian Wakeling
2015	Borrego Spr, CA	Ben Gonzales, R. Abella	Amber Munig	K. Longshore	James W. Cain
2017	St. George, UT	R. Robinson, J. Shannon	Amber Munig	K. Longshore	James W. Cain
2019	Mesquite, NV	Steven Kimble, Mike Cox	Erin Butler	K. Longshore	James W. Cain
2021	Alpine, TX (Virtual)	F. Hernandez, C. Brewer	Erin Butler	K. Longshore	James W. Cain
2023	Alpine, TX	F. Hernandez	Erin Butler	K. Longshore	Vernon C. Bleich
2025	Gold Valley, AZ	R. Murphy	Erin Butler	K. Longshore	Vernon C. Bleich

Registrants for the 58th Meeting of the Desert Bighorn Council, Gold Canyon, Arizona, 2025

Name	Affiliation
Aiello, Christina	Oregon State University
Amman, Brendan	Texas Tech University
Bantus, Oana	Lotek Wireless, Inc.
Barton, Hailey	Sul Ross State University
Batter, Tom	New Mexico Department of Game & Fish
Blum, Marcus	Texas A&M University
Bock, Genevieve	University of Arizona
Bohannon, Austin	Texas Parks and Wildlife Department
Bristow, Kirby	Arizona Game and Fish Department
Britton, Sean	Arizona Game and Fish Department
Butler, Erin	Arizona Game and Fish Department
Cain III, James	New Mexico Cooperative Wildlife Research Unit
Campbell, John Clayton	Texas Parks and Wildlife Department
Cho, Austin	University of Nevada Las Vegas
Conrad, David	Arizona Game and Fish Department (Retired)
Cross, Joshua	Texas Parks and Wildlife Department
Cummings, Patrick	Nevada Department of Wildlife (Retired)
Cunningham, Sam	Texas Bighorn Society
Darveau, Dustin	Arizona Game and Fish Department
Davenport, Bill	Arizona Game and Fish Department
Davis, Bill	Arizona Desert Bighorn Sheep Society
deVos, Jim	Arizona Game and Fish Department
Dickson, John	Arizona Game and Fish Department
Dietz, Brian	Arizona Game and Fish Department
Dotray, Andrew	Borderlands Research Institute
Drake, Gary	Arizona Desert Bighorn Sheep Society
Evans, Ashley	New Mexico State University
Fan, Ann	Arizona Game and Fish Department
Feichter, Lyndsay	Telonics, Inc.
Flickinger, Alexandra	Arizona Game and Fish Department
Fuller, Genevieve	Colorado Parks and Wildlife
Garlinger, Bruce	EREMICO Biological Services, LLC
Garrett, Mark	Texas Parks and Wildlife Department
Glass, Danielle	California Department of Fish and Wildlife
Godon, Travis	Track Tag, LLC
Gray, Ryan	Track Tag, LLC
Hernandez, Froylan	Texas Parks and Wildlife Department
Herrera, AJ	Arizona Game and Fish Department
Hull, Will	Arizona Game and Fish Department
Hurley, Kevin	Wild Sheep Foundation
Jahner, Josh	University of Wyoming
Jensen, Brian	Arizona Game and Fish Department
Jorgensen, Mark	California State Parks (Retired)
Justice-Allen, Anne	Arizona Game and Fish Department
Kelly, Charlie	Wild Sheep Foundation
Kircher, Alyssa	Colorado Parks and Wildlife

Name	Affiliation
Kuhn, David	Arizona Game and Fish Department
Langley, Rick	Arizona Game and Fish Department
Lazenby, Kade	Nevada Department of Wildlife
Lee, Raymond	Ray Lee LLC
Longshore, Kathleen	US Geological Survey
Lutz, Daryl	Wyoming Game and Fish Department
Marten, Sarah	U.S. Fish and Wildlife Service
Mattausch, Dave	Arizona Desert Bighorn Sheep Society
McEntire, Cody	Texas Parks and Wildlife Department
Meis, Jon	Advanced Telemetry Systems
Miller, Kalyn	Arizona Game and Fish Department
Millward, Lindsay	Oregon State University
Murphy, Rana	Arizona Game and Fish Department
Nash, Sandra	Wildlife Enthusiast, LLC
Nelson, Robert	Arizona Game and Fish Department
Padilla, Matt	Arizona Game and Fish Department
Parsons, Chris	Arizona Desert Bighorn Sheep Society
Piecora, Katie	New Mexico Department of Game and Fish
Poorman, Emma	Telonics, Inc.
Prentice, Paige	California Department of Fish and Wildlife
Robinson, Rusty	Utah Division of Wildlife Resources
Rominger, Eric	New Mexico Department of Game and Fish (Retired)
Rubin, Esther	Arizona Game and Fish Department
Sayer, Joe	Arizona Game and Fish Department
Scott, Brenton	California Wild Sheep Foundation
Scott, Tammy	International Professional Hunters Association
Sheehey, Joe	Arizona Desert Bighorn Sheep Society
Sheer, Seth	Arizona Game and Fish Department
Sitzmann, Paul	Kofa National Wildlife Refuge
Smith, Travis	Texas Parks and Wildlife Department
Smythe, Lindsay	National Park Service
Stewart, Dylan	Texas A&M University
Sutherland, Elle	Sul Ross State University
Thompson, Luke	Arizona Game and Fish Department
Torres, Steven	California Department of Fish and Game (Retired)
Tucker, Darren	Grand Slam Club/Ovis
Uhalde, Gracian	Track Tag
Vanderlin, Grady	Arizona Game and Fish Department
Warren, Keith	ASARCO
Wehausen, John	Sierra Nevada Bighorn Sheep Foundation
Weise, Christa	Desert National Wildlife Refuge
Winter, Justin	Arizona Game and Fish Department
Wong, Andrew	Arizona Game and Fish Department
Wood, Erin	Nevada Department of Wildlife
Wood, Hunter	Arizona Game and Fish Department
Wyckoff, Sara	Texas Parks and Wildlife Department
Zoratti, Ray	Arizona Desert Bighorn Sheep Society
Zufelt, Allen	Arizona Game and Fish Department

Abstracts of Papers Presented



Abstracts of Papers Presented at the 58th Desert Bighorn Council, Gold Canyon, Arizona, 22–25 April 2025

Desert Bighorn Council Transactions 58:179–189

BIGHORN-TARGETED WILDLIFE CROSSING STRUCTURES: CHALLENGES AND WORKFLOWS FOR RESEARCH AND DESIGN

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Major highways and other infrastructure have limited gene flow, dispersal, and habitat access for many desert bighorn populations, but wildlife crossing structures (WCS) can mitigate some of the negative effects of roads. Both the location and design of WCS can influence their use by target species and expected benefits, so research-informed planning is crucial to successful mitigation. Steps to identify when a WCS is warranted and where the structure would be most effective will be context-dependent, but should be informed by the behavior of the target species and the complex relationships between habitat risks, rewards, and ecological scale. We discuss two case studies where three major highways (I-15, I-40, and I-8) limit bighorn sheep connectivity in desert regions of Southern California, USA. Each barrier differs in permeability, which affected the data available to assess ideal crossing structure locations, but data included: GPS collar-recorded movements with different road crossing frequency, landscape resistance models and crossing events identified with genetics, camera monitoring of nearby underpasses, and roadkill events. Through these case studies, we discuss how data collection and model approaches were adapted to address the limitations of the data, bighorn behavior and habitat selection, and the temporal and spatial scale of the ecological processes affected by the highway. We show draft and final optimal locations for WCS based on the implemented workflow – with three crossings planned for construction in 2025 – 2028. We also provide in situ over-crossing designs that provide habitat continuity, are designed for bighorn sheep, and meet bridge engineering requirements.

USING SATELLITE IMAGERY TO ESTIMATE CARRYING CAPACITY OF BIGHORN SHEEP ON ELEPHANT MOUNTAIN WILDLIFE MANAGEMENT AREA

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Elephant Mountain Wildlife Management Area (EMWMA) is the nursery population for ongoing desert bighorn (*Ovis canadensis*) restoration efforts in Texas. Consequently, the primary management objective is production of surplus animals for translocation. However, EMWMA also provides public hunting opportunities, particularly for mule deer (*Odocoileus hemionus*). Thus, maintaining a healthy mule deer population is also a key management goal. Estimating EMWMA's carrying capacity of bighorn is essential to mitigate competition between bighorn and mule deer, as well as preserve habitat quality. Traditional methods of estimating carrying capacity are time-consuming, imprecise, and costly. Due to these constraints, assessments occur infrequently. However, carrying capacity is not constant through time, as environmental conditions vary from year to year, causing dramatic shifts in habitat quality. To keep pace with these shifts, biologists require an efficient method of assessing habitat quality and carrying capacity on an annual basis. Our objective is to leverage satellite imagery to monitor desert bighorn nutrition on EMWMA. Previous studies established a relationship between satellite vegetation indices and bighorn nutritional performance but we expect this relationship to be density dependent, allowing us to estimate carrying capacity remotely. Because increased density reduces per capita resource availability, we hypothesize interspecific competition makes the slope of the relationship between vegetation greenness indices and fecal nitrogen inversely related to desert bighorn abundance. If this is the case, this density dependence can be leveraged to provide a framework for efficient monitoring of desert bighorn carrying capacity via satellite, providing managers essential information at little to no cost.

ADAPTING BETWEEN EXTREMES IN A DESERT ECOSYSTEM: BIGHORN SHEEP ON THE MOVE

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MIKE COX, Nevada Department of Wildlife, Reno, NV 89511
BRIAN F. WAKELING, Montana Fish, Wildlife, and Parks, PO Box 200701, Helena, MT 59620
JOE R. BENNETT, Nevada Department of Wildlife, Reno, NV 89511
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Translocations have been a cornerstone of bighorn sheep (*Ovis canadensis*) restoration across their historic range. While this management tool has widely been considered a success, it has not been without challenges. Despite decades of implementation, knowledge gaps remain and likely reduce the effectiveness of this management tool. To address these shortcomings, we studied 15 female desert bighorn sheep (*Ovis canadensis nelsoni*) translocated from Lone Mountain, NV, to the Garfield Hills, NV, while maintaining a minimum of 15 collared females at Lone Mountain for

comparison. Captures were held annually over 3 years in each range and we obtained morphometric information, nutritional condition, pregnancy status, and placed vaginal implant transmitters in pregnant females. Additionally, we captured neonates in each mountain range and tracked reproductive success of females throughout the study period. We assessed the success of the translocated population by comparing variation in resource selection, movement behavior, reproductive rates, nutritional condition, diet composition, diet quality, and survival between the study sites. Results revealed significant differences in movement patterns, body condition, diet composition, and survival rates between the two ranges. Notably, females in the Garfield Hills exhibited a two-month earlier shift in parturition timing during the second-year post-translocation. This study represents the most comprehensive assessment of post-translocation success for a bighorn sheep population to date. Our findings highlight the importance of site-specific factors in shaping translocation outcomes and provide valuable insights to enhance the efficacy of this critically important conservation tool.

HABITAT SELECTION OF BIGHORN SHEEP IN JOSHUA TREE NATIONAL PARK: INFLUENCES OF VEGETATION ASSOCIATION, ESCAPE TERRATIN, AND WATER

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Desert bighorn sheep (*Ovis canadensis nelsoni*) in Joshua Tree National Park (JOTR) are known to select rugged, steep terrain during Spring lambing and habitat areas closer to water sources during the Summer. Using data from a NPS JOTR vegetation survey and two-years of location data from six GPS radio-collared bighorn ewes, we evaluate habitat selection related to the 36 vegetation associations mapped within JOTR. We compared vegetation utilized by sheep in three seasons with vegetation available (17,779 sheep; 53,337 random locations) and detected strong habitat selection. Of the 36 categories of vegetation, 76% of sheep locations occurred in 6 categories at higher frequencies than random. Throughout the year 21 – 25% of bighorn sheep locations occurred in Desert Sunflower – California Buckwheat – Jojoba Shrubland despite low availability of this association (5.3% of random locations). Depending on season, an additional 13 – 26% of sheep locations were found in two types of Creosote Bush - White Bursage Associations. This analysis reveals previously unknown, strong, consistent habitat selection by bighorn ewes and use of vegetation associations that comprise only 27% of plant communities. The vegetation preferences also interact with escape terrain and distance to water providing new insights on habitat characteristics essential to consider in future management of anthropogenic impacts within the park.

WILDLIFE WATER DEVELOPMENTS – HISTORY, NEW TECHNOLOGY, AND FUTURE NEEDS

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Development of waters for various wildlife species has nearly an 80-year history in Arizona, with the first targeting enhancement of quail and upland game bird populations. In the 1950s, research and conservation efforts to enhance bighorn sheep populations began in Arizona. Russo (1956) suggested that loss of natural water sources had an adverse effect on sheep populations and an era of water developments for this species began in earnest. Earliest builds were mostly minor repairs to existing tinajas, including removing debris and maybe a rock/concrete lip to increase storage capacity. Through time, technology advanced, and more sophisticated designs were developed. Now there are engineering plans, use of large construction equipment, helicopters, and large volunteer

forces making the water projects of old seemingly simple. Legal elements also play a role in complicating wildlife water development including surface water rights, historical preservation statutes, and costs which have dramatically increased. With the increase in bighorn sheep habitat fragmentation and environmental changes associated with global climate change, the need for future water developments will continue to increase. Newer designs, larger capacities leading to less need for water hauling, and remote sensing capabilities are all key to supplying bighorn sheep with an adequate water supply to support the metabolic demands of a desert-adapted species.

SPATIAL ECOLOGY OF AOUDAD AND MULE DEER: RESPONSES TO POPULATION MANAGEMENT EFFORTS

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The interactions between non-native aoudad (*Ammotragus lervia*) and native desert bighorn (*Ovis canadensis*) and mule deer (*Odocoileus hemionus*) are poorly understood. However, they are presumed to compete at greater population densities and may shift space use to mitigate resource competition. We sought to understand how aoudad population reduction affects the space use of both aoudad and mule deer, relative to preferred desert bighorn habitat. In April 2023, we captured and collared 40 aoudad and 40 mule deer in the Chinati and Quitman Mountain ranges in the Trans-Pecos and fit them with tracking collars that recorded locations every 2 hours. To assess aoudad and mule deer interactions, we lethally removed aoudad (n = 5,773) in the Chinati Mountains in August 2024. We estimated monthly space use patterns of both species using dynamic Brownian bridge movement models and compared space use pre- and post-aoudad removal. Aoudad ranges were larger ($\bar{x} \pm$ SD; 5.99±3.50 km^2, 5.62±3.64 km^2) than mule deer (2.74±2.14 km^2, 2.67±2.16 km^2) in the Quitman and Chinati Mountains, respectively. In the Chinati Mountains, aoudad space use was similar pre- and post-aoudad removal (5.63±3.68 km^2, 5.5±3.17 km^2). However, range size shrank following aoudad removal from 2.77±2.19 km^2 to 1.78±1.63 km^2. Results suggest these two species have differential responses to the lethal removal of aoudad. Additionally, range stability among aoudad suggests population management may not negatively impact aoudad hunting but does not shift remaining aoudad from desert bighorn habitat. This may reduce competitive effects on desert bighorn, though its effects on disease risks are uncertain.

THE INFLUENCE OF RECREATIONAL DISTURBANCE ON DESERT BIGHORN SHEEP BEHAVIOR AND STRESS IN WESTERN COLORADO

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CHARLES R. ANDERSON JR., Colorado Parks and Wildlife, 317 W Prospect Rd, Ft. Collins, Colorado 80526

MICHAELA BUENEMANN, New Mexico State University, Department of Geography and Environmental Studies, Las Cruces, NM 88003
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In recent decades, outdoor recreation in the United States has increased dramatically, with continued increases in the number of user days projected in the coming years as well as the expansion of recreation infrastructure. Recreational disturbance impacts ungulate populations by altering activity budgets, increasing physiological stress, reducing habitat quality, and causing avoidance of heavily trafficked areas. Desert bighorn sheep (*Ovis canadensis* ssp.) are susceptible to the effects of long-term disturbance due to their life history characteristics including low recruitment rates, naturally fragmented and isolated distributions, and habitat specialization. Our goal was to determine the impacts of recreation on desert bighorn sheep behavior and physiological stress in the Dominguez-Escalante National Conservation Area. We assessed the differences in desert bighorn sheep foraging and vigilance behaviors and fecal glucocorticoid metabolite concentrations relative to temporal, group, terrain, and recreation variables. Overall, recreation did not have a strong effect on desert bighorn sheep foraging and vigilance behaviors, indicating a tradeoff between these behaviors is not imposed by recreation. Fecal glucocorticoid metabolites had a significant positive relationship with the sum of non-motorized recreation of the nearest trail in the preceding 24 hours, indicating that non-motorized recreation imposes physiological stress on desert bighorn sheep. Habituation, spatial predictability of recreation, and mesas without recreation to provide refugia likely contributed to a lack of detection of strong impacts of recreational activity on desert bighorn sheep behavior.

COMPARISON OF TWO SAMPLING PROTOCOLS FOR *MYCOPLASMA OVIPNEUMONIAE* DETECTION IN HUNTER-HARVESTED DESERT BIGHORN SHEEP

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ANNE JUSTICE-ALLEN, Arizona Game and Fish Department, Phoenix, AZ 85086

Bighorn sheep populations in Arizona have been impacted by pneumonia caused by *Mycoplasma ovipneumoniae* and the Department routinely includes testing for this disease when conducting capture operations for research or translocation. Temporal spatial shifts in the occurrence of strain-types can significantly affect the health of bighorn populations. Therefore, regular surveillance for *M. ovipneumoniae* is important for bighorn health management. Capture operations have been limited to a few select populations at irregular intervals. In order to assess populations that are not captured as well as to collect additional samples from monitored populations more frequently, the Department began collecting swab samples from hunter-harvested rams at check in 5 years ago. During the last two harvest seasons (2023 and 2024), we compared detection rate of *M. ovipneumoniae* from swabs collected by hunters at harvest to that of swabs collected at check in. In year one, paired samples were collected from 22 bighorns. There were an additional 40 samples collected at check in and 28 samples collected by hunters. There was no difference in detection between paired samples. For all samples collected, M. *ovipneumoniae* was detected in 15 of 62 (24 percent) samples collected by the Department and 10 of 50 (20 percent) samples collected by hunters. The second year of the study has just concluded. Based on the first year, the sensitivity samples collected by hunters is equivalent to samples collected by the Department.

DESERT BIGHORN SHEEP DISTRIBUTION, CONNECTIVITY, AND WATER MANAGEMENT IN CALIFORNIA'S MOJAVE DESERT

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In the southwestern United States, bighorn sheep form a metapopulation with each population residing largely on one mountain range. Using ground and helicopter observations collected between 2012 and 2023, I (a) predicted habitat suitability for desert bighorn sheep (*Ovis canadensis nelsoni*) within southern California, (b) modeled landscape connectivity among the extant populations, and (c) mapped where the installation of wildlife water developments would benefit desert bighorn. I used six remotely-sensed proxies of elevation, slope, landscape ruggedness, topographic insolation, and vegetation productivity and structure, as well as one ground-truthed dataset of surface water, to model habitat suitability in Google Earth Engine. I validated the habitat suitability prediction using 10-fold spatial block cross validation and by calculating the area under the precision-recall curve (AUC-PR), sensitivity, and specificity for each model iteration. I also used a geolocation dataset collected from GPS collars fitted on desert bighorn as independent validation. Models showed good predictive performance with a mean AUC-PR of 0.80, sensitivity of 0.71, and specificity of 0.91. 91% of independent GPS collar geolocations were located in predicted suitable habitat. Desert bighorn occupied the majority of their potential habitat, but unoccupied suitable habitat existed in the Ivanpah, Piute, Sacramento, McCoy, Big Maria, and Riverside Mountains. Connectivity was relatively uniform due to the lowlands found between mountain ranges, but areas of high connectivity existed between populations in the central Mojave. Installation of wildlife water developments would benefit desert bighorn in the western section of the Mojave on both sides of Interstate 40.

THE HISTORY OF BIGHORN SHEEP DIVERSIFICATION INFORMS FUTURE MANAGEMENT

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All bighorn sheep (*Ovis canadensis*) populations in the United States that have been managed as the California lineage, part of a formerly recognized subspecies (*O. c. californiana*), originate from serial translocations of individuals sourced from a few populations in British Columbia, resulting in reduced genetic diversity and elevated risk of inbreeding. After morphological studies refuted the validity of that subspecies, some jurisdictions treated the California lineage as part of the Rocky Mountain subspecies (*O. c. canadensis*) and have mixed them in subsequent translocations because such mixing could quickly increase genetic diversity of bottlenecked populations. Yet, detailed genetic data addressing validity of those putative lineages were lacking. We reconstructed the range-wide genetic history of bighorn sheep by sampling the major putative subspecies or lineages, with a focus on native (remnant) genetic variation, and generating a DNA sequencing dataset consisting of thousands of genetic markers (20 populations, 15,000-25,000 SNPs). Genetic analyses supported the distinctiveness of at least four bighorn sheep lineages at levels corresponding to subspecies, including California bighorn sheep. Additionally, analyses revealed hierarchical genetic structure within some lineages that correspond with major biogeographical regions. Moving forward, we recommend that managers 1) maintain the natural variation held in native populations by protecting them from intentional translocations or unintentional mixing with nearby translocated populations from different lineages; 2) prioritize within-lineage translocations for population

augmentation or repatriation to previously occupied regions; and 3) carefully consider any translocations that would lead to mixing of distinct evolutionary lineages or establishment of populations in ecologically novel habitats.

VARIATION IN PREDATION PATTERNS FOR MOUNTAIN LION BY RANGE AND SEXES

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Mountain lions (*Puma concolor*) occupying bighorn sheep (*Ovis canadensis*) ranges can cause declines or prevent population increases through predation. We captured 57 mountain lions between 2007 and 2019 in southwestern Arizona. We monitored GPS data to determine predation patterns of each animal. We maintained 2 areas; north and south of I-10. Predation on deer (*Odocoileus hemionus*) and carnivores was equivocal between north and south areas. However, bighorn predation was dramatically higher in the south, than in the north. Conversely, predation on javelina (*Pecari tayacu*), donkeys (*Equus* spp.), and cattle was higher in the north. We found no sex-specific predation on mule deer, bighorn, or carnivores in the south. We did find sex-specific bias in the north, with females preying heavily on mule deer and bighorn sheep and males preying to a lesser extent on mule deer and bighorn sheep, and more on javelina and donkeys. Female mountain lions preyed more on the young for both mule deer and bighorn sheep, versus male mountain lions that preyed more on adults. Areas with abundant multiple prey species potentially experience sex-specific bias in predation that could be ameliorated by sex-specific lethal removal. Whereas areas with few prey species might experience high predation rates on bighorn sheep due to differences in prey vulnerabilities. In areas with few prey species, management should consider removal of all mountain lions, whereas areas with multiple prey species might benefit from a more targeted approach.

***MYCOPLASMA OVIPNEUMONIAE* STRAIN TYPES IN ARIZONA: SPATIOTEMPORAL TRENDS INFORM RISK ASSESSMENTS**

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Abstract: Bighorn sheep pneumonia has caused periodic all age mortality events and low lamb recruitment in several regions of Arizona. Since 2009, the Department has used strain-typing of *Mycoplasma ovipneumoniae* bacteria as part of routine herd health assessments and to guide translocation plans. In an all age mortality event in 2015 in the Black mountains of northwestern Arizona, we identified the incursion of strain originally detected in the Marble Mountains, California and Spring Range, Nevada in 2013. This strain was then replaced by another strain of unknown origin in 2017. In the early 2000s, the Kofa mountain population experienced a population decline of 50 percent accompanied by a change in the seroprevalence to *M. ovipneumoniae*. Since then, we have detected 3 different strains of *M. ovipneumoniae*. These strains appear to possess a low level of pathogenicity as the population has recovered to pre-decline numbers. In the early 2000s, disease was also detected in the Kanab Creek region of the north rim of the Grand Canyon. Several strains have been detected in subsequent years; these strains appear to have a significant level of pathogenicity as this population continues to underperform with low levels of recruitment. In all, 19 strains with distinct geographic distributions have been identified in Arizona bighorns managed by the Department. Collar data has demonstrated that many Arizona bighorn sheep populations are connected to populations managed by other agencies. In order to effectively manage disease in bighorn sheep, we should establish regional data-sharing agreements and management objectives.

SUCCESSES IN MANAGING A BIGHORN SHEEP POPULATION ON AN ACTIVE, OPEN-PIT COPPER MINE

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Abstract: Since 2005, more than 250 bighorn sheep have been killed on the roads and highways in and around the Morenci copper mine in southeastern Arizona. Not only is the loss of valuable wildlife very concerning, but the high prevalence of motor vehicle-wildlife collisions is a threat to human health and safety and causes a great deal of property damage. The Arizona Game and Fish Department and the mining company, Freeport McMoRan, Inc., have developed an excellent working relationship to help mitigate the hazards of bighorn sheep living in and around the mine and the towns of Clifton and Morenci, Arizona. Since 2005, the Arizona Game and Fish Department has analyzed movement and roadkill data to recommend crossing structures and attempted to reduce the density of bighorn sheep in the area. There were many challenges and opportunities with this project, which involved working in an active mine environment while establishing new bighorn populations in unoccupied habitat across Arizona.

ANNUAL ACTIVITY PATTERNS OF DESERT BIGHORN SHEEP REVEAL BEHAVIORAL TRADE-OFFS WHEN MANAGING EXTREME HEAT

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Desert-adapted animals use physiological, morphological, and behavioral mechanisms to thermoregulate and conserve water resources, helping them to avoid life-threatening dehydration from exposure to intense solar radiation and summer heat. A behavioral response is far more flexible than physiological and morphological traits because this response is influenced by the real-time environment and the individual's internal state. This study explores the behavioral response of desert bighorn sheep (*Ovis canadensis nelsoni*), specifically foraging activity patterns, to extreme heat in the Mojave Desert of southern California. We classified behavior using accelerometer data of 49 individuals across six populations in the region and analyzed the relationship between time spent foraging and ambient temperature plus interactions with sex and spatial covariates. We used multiple temporal models to evaluate relationships at a 24-hour cycle and hourly time scale. Furthermore, we aimed to identify specific temperature thresholds that cue desert bighorn sheep to increase nocturnal foraging activity as a strategy to compensate for reduced time spent feeding during day due to extreme heat, despite other risk (i.e., predation). We found that both sexes reduce time spent foraging during the day as temperature increases, but males are more likely to increase foraging at night than females across all populations. Our findings support a growing body of literature that diurnal ungulates will shift activity towards nighttime as a strategy for managing consistently increasing temperatures under a global climate change. The extent to which this temporal behavioral shift will impact predation pressures on desert bighorn sheep in this region remains unknown.

EFFECTS OF *MYCOPLASMA OVIPNEUMONIAE*, ABUNDANCE, AND CLIMATE CONDITIONS ON BIGHORN SHEEP LAMB:EWE RATIOS IN NEW MEXICO

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Abstract: Understanding the impacts of *Mycoplasma ovipneumoniae* on bighorn sheep populations is paramount to ensuring population persistence. In New Mexico, most bighorn sheep (*Ovis. canadensis*) populations were thought to be free of this pathogen prior to 2017; however, infections in multiple herds since that time have raised concerns surrounding impacts to population size and lamb survival. We evaluated the impacts of *M. ovipneumoniae* infection, abundance, climate, and predation on bighorn sheep lamb:ewe ratios across New Mexican populations. We characterized these relationships using lamb:ewe ratios from aerial and ground surveys from 2000 to 2022 and *M. ovipneumoniae* testing data from 2007 to 2022 (n = 466 individuals) for both Rocky Mountain (*O. c. canadensis*) and desert bighorn sheep (*O.c. mexicana*). From 2007 to 2022, we sampled n = 466 bighorn sheep across 19 populations in New Mexico for *M. ovipneumoniae* exposure. While timing of initial herd infections varied across populations, one population sustained active infections for over 15 years. We found reduced juvenile:female ratios post *M. ovipneumoniae* exposure for both desert and Rocky Mountain bighorn sheep populations. Evaluation of the effects of population size and environmental conditions on lamb:ewe ratios indicated varying impacts for each subspecies. Notably, population size was negatively related to lamb:ewe ratios for Rocky Mountain bighorn only after populations were exposed to *M. ovipneumoniae*. Additionally, climatic conditions in the previous lambing season and pre-parturition timeframe were associated with lamb:ewe ratios for Rocky Mountain populations while lamb:ewe ratios of desert bighorn appeared to only be affected by pre-parturition climatic conditions.

ASSOCIATIONS BETWEEN FERAL BURROS AND SONORAN DESERT VEGETATION: IMPLICATIONS FOR DESERT BIGHORN SHEEP HABITAT

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We studied the associations between feral burros (*Equus asinus*) and Sonoran Desert vegetation in Arizona, USA during 2017–2019. We identified areas with and without established burro herds, and collected data on vegetation and ungulate sign at multiple, randomly selected grids within these areas. We predicted that burros would be associated with differences in vegetation metrics such as lower ground cover, smaller perennial plant size, and lower plant density, foliage density, recruitment, and species richness among perennial native plants. We also predicted that these differences would be most pronounced near water. Although our findings did not consistently support all of our predictions, burro presence was associated with lower ground cover, plant density, foliage density, or smaller plant size in several species, and changes were often influenced by distance from water. Bighorn sheep forage items such as white bursage (*Ambrosia dumosa*), Anderson wolfberry *(Lycium andersonii*), velvet mesquite (*Prosopis velutina*), and Engelman's prickly pear (*Opuntia engelmannii*) exhibited reduced metrics in burro areas. Of notable concern was that burro presence was also associated with lower recruitment of saguaro cactus (*Carnegiea gigantea*) and lower foliage density in yellow paloverde (*Parkinsonia microphylla*) and desert ironwood (*Olneya tesota*). Our findings indicate that burros were associated with changes in the plant community that may forecast long-term effects in ecosystem function. We will discuss the relevance to desert bighorn sheep and also suggest that current management of feral burros may not be adequate for maintaining the long-term viability of this arid and fragile ecosystem.

IS ANYONE THERE? RESIDENT CONSPECIFICS INFLUENCE BEHAVIOR OF TRANSLOCATED DESERT BIGHORN SHEEP

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Translocation is a primary tool for restoring bighorn sheep (*Ovis canadensis*) populations to their historical range. However, ~50% of reintroductions are considered unsuccessful, necessitating investigation into behavioral strategies of sheep that increase the probability of population establishment. Our objectives were to quantify behavioral states following release and determine behavior-specific habitat selection of translocated desert bighorn sheep (*O. c. mexicana*) in Sonora, Mexico. We captured and fitted 16 bighorn sheep (9 females, 7 male) with GPS collars in November 2022. We used nonparametric Bayesian methods to identify latent behavioral states, validated behavioral states using social networks and video footage from collars, and predicted habitat selection using a random forest model. We identified three behavioral states: 1) unsettled and settled 2) close or 3) farther away from the release site, but grouped the two settled states for further analyses. On average, female and male bighorn sheep shifted from unsettled to settled states within 4.3 days (± 1.3 SE) and 6.4 days (± 4.0 SE) after the day of translocation, respectively, which was related to when sheep integrated into native herds. Bighorn sheep selected higher elevations when in a settled state, which was not observed when in an unsettled state, because sheep were likely moving more at lower elevations to maximize the viewshed for locating resident conspecifics. Once located, sheep integrated with resident conspecifics at higher elevations. Overall, our results suggest that integration of translocated bighorn sheep into native herds will reduce search time, which may increase the probability of survival.

HISTORY AND ROLE OF THE DESERT BIGHORN COUNCIL — ADAPTING TO FUTURE CONSERVATION NEEDS

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Established in 1957, The Desert Bighorn Council (DBC) is the oldest wildlife management/conservation organization in North America that has held annual or biennial meetings and published transactions. The past and present role of the DBC has been an important forum supporting expertise, applied science, communication, mentorship, scholarship, and best management practices. Desert bighorn management history and the role of the DBC will be presented as chronicled through DBC Transactions. We will identify important junctures in this co-evolution of

management, science, and technology. A critical examination of current conservation challenges will be presented to consider the role of the DBC for best supporting collaboration to ensure the long-term population persistence of desert bighorn sheep.

PLASTICITY AND PERIL: NICHE ADAPTATIONS OF DESERT BIGHORN SHEEP FACING COMPETITION AND DISEASE

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Desert bighorn sheep (*Ovis canadensis nelsoni)* co-occur with invasive aoudad (*Ammotragus lervia*) in Trans-Pecos, Texas. Research has demonstrated that aoudad and desert bighorn niches overlap in optimal habitat, raising concern about disease transmission risk and potential for competition. It is essential to understand how desert bighorn niches may shift in the face of competition, particularly as we seek to manage populations in a disease landscape. I explored variation in niche breadth, position and configuration among seven desert bighorn populations and 12 population years in the Trans-Pecos to determine whether desert bighorn exhibit niche plasticity. The populations had significant variation in niche size, the difference in niche volume between the largest and smallest niche (BGWMA and BBRSP respectively) was $\log(D) = 19.64$. BBRSP:Diablos had the smallest distance between niche centroids (MD =0.51), the farthest distance between centroids was EMWMA:Diablos (MD = 5.23). Niche dissimilarity was greatest between EMWMA:Diablos (BD =11.42) and smallest between BBRSP:Diablos (BD = 1.44). BGWMA individuals had the greatest average distance from the population centroid (MD, $\mu = 4.86$, $\sigma = 4.52$), and Diablos the smallest (MD, $\mu = 4.37$, $\sigma = 2.10$). Individuals with greater distance from their population centroid had a higher risk of death ($\beta = 0.209$, $p = 0.0000443$). These results suggest constrained potential for desert bighorn to respond to aoudad competition via niche shifting and provide a framework for predicting how niche partitioning may result in shifts in desert bighorn sheep geographic distributions, social structure, and consequent changes in disease risk.

INSIGHTS INTO THE EVOLUTIONARY HISTORY OF NORTH AMERICAN WILD SHEEP FROM ANALYSES OF SKULL SHAPE AND MITOCHONDRIAL DNA SEQUENCE DATA

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In an attempt to unravel some of the evolutionary history of North American wild sheep, this talk will explore apparent conflicts between analysis of cranial shape and analysis of mtDNA, including >4000 bp of sequence data for 5 mtDNA protein-coding genes. That history is considerably more complex than previously thought, involving two colonizations of North America and hybridization events between subspecies and species. Molecular dating allows key events in this history to be plotted on a time line of Pleistocene climate change and major volcanic events.