STAFF SUMMARY FOR APRIL 14, 2021

10. CALIFORNIA BIGHORN SHEEP (CONSENT)

Today's Item **Information ☒** **Action ☐**

Receive DFW's five-year status review for California bighorn sheep (*Ovis canadensis californiana*, also known as Sierra Nevada bighorn sheep) under the California Endangered Species Act (CESA).

Summary of Previous/Future Actions

• Determined listing California bighorn sheep as threatened was warranted	1971
• Changed status from threatened to endangered	Mar 4, 1999; Riverside
• **Today receive five-year status review**	**Apr 14, 2021; Webinar/Teleconference**
• DFW presentation	Jun 24-25, 2020; Webinar/Teleconference

Background

California bighorn sheep is a distinct subspecies of bighorn sheep that occurs in 14 relatively isolated subpopulations throughout the Sierra Nevada. California bighorn sheep was listed as a threatened species under CESA by FGC in 1971, was uplisted to endangered in 1999, and is included in FGC's list of endangered animals (Title 14, Section 670.5). The subspecies has been listed as endangered under the federal Endangered Species Act since 2000.

Pursuant to California Fish and Game Code Section 2077, upon the allocation of specific funding DFW is required to reevaluate threatened and endangered species every five years by developing a status review to determine whether conditions that led to the original listing are still present or have changed. DFW has not previously conducted a five-year review of California bighorn sheep.

When DFW undertakes a five-year review of species that are also listed by the United States Fish and Wildlife Service (USFWS) pursuant to the federal Endangered Species Act, California Fish and Game Code Section 2077 states that DFW's review shall be conducted in conjunction with USFWS's five-year review process; USFWS conducted its five-year status review of California bighorn sheep in 2019.

Today, DFW provides a 2021 status review of California bighorn sheep, which updates descriptions, habitat requirements, threats, research needs, and other topics for this species (Exhibit 2). USFWS's 2019 review informed DFW's review. DFW has found that while the distribution and abundance of the subspecies has improved with sustained conservation and management actions, there is sufficient scientific information to indicate that the conditions that led to listing California bighorn sheep as endangered are still present. DFW recommends retaining the status of this species as endangered (exhibits 1 and 2).

Significant Public Comments (N/A)

STAFF SUMMARY FOR APRIL 14, 2021

Recommendation

FGC staff: Receive DFW's status review under a motion to adopt the consent calendar, accept any public comment, and schedule a presentation for the Jun 2021 FGC meeting.

DFW: Retain endangered species status for California bighorn sheep.

Exhibits

1. DFW memo, received Mar 26, 2021
2. DFW five-year status review, received Mar 26, 2021

Motion

Moved by __________ and seconded by ____________ that the Commission adopts the staff recommendations for items 3-10 on the consent calendar.

State of California
Department of Fish and Wildlife

Original on file, received, March 26, 2021

Memorandum

Date: March 1, 2021

To: Melissa Miller-Henson
Executive Director
Fish and Game Commission

From: Charlton H. Bonham
Director

Subject: Five-Year Species Review of Sierra Nevada Bighorn Sheep

The California Department of Fish and Wildlife (Department) has prepared the attached Five-Year Species Review of Sierra Nevada bighorn sheep for the Fish and Game Commission (Commission) pursuant to the California Endangered Species Act (CESA). Pursuant to Fish and Game Code, section 2077, subdivision (a), the Department has prepared this Five-Year Species Review to evaluate whether conditions that led to the original listing of Sierra Nevada bighorn sheep are still present.

In completing this Five-Year Species Review, the Department finds there is sufficient scientific information to indicate that many of the conditions that led to the listing of Sierra Nevada bighorn sheep as endangered have not changed. The scientific information available to the Department indicates the Sierra Nevada bighorn sheep remain in danger of extinction due to one or more causes. Therefore, the Department recommends that no change be made to the Sierra Nevada bighorn sheep's endangered status.

If you have any questions or need additional information, please contact Scott Gardner, Wildlife Branch Chief, at (916) 801-6257 or by email at Scott.Gardner@wildlife.ca.gov.

Attachment

ec: **California Department of Fish and Wildlife**

Valerie Termini
Chief Deputy Director
Valerie.Termini@wildlife.ca.gov

Stafford Lehr, Deputy Director
Wildlife and Fisheries Division
Stafford.Lehr@wildlife.ca.gov

Chad Dibble, Deputy Director
Ecosystem Conservation Division
Chad.Dibble@wildlife.ca.gov

Wendy Bogdan, General Counsel
Office of the General Counsel
Wendy.Bogdan@wildlife.ca.gov

Scott Gardner, Chief
Wildlife Branch
Scott.Gardner@wildlife.ca.gov

Leslie MacNair, Regional Manager
Inland Deserts Region
Leslie.MacNair@wildlife.ca.gov

State of California
Natural Resources Agency
Department of Fish and Wildlife

REPORT TO THE FISH AND GAME COMMISSION
FIVE-YEAR SPECIES REVIEW OF
SIERRA NEVADA BIGHORN SHEEP (*Ovis canadensis sierrae*)

March 2021

Sierra Nevada Bighorn Sheep Ram, photo by Josh Schulgen

Charlton H. Bonham, Director
California Department of Fish and Wildlife

TABLE OF CONTENTS

I. EXECUTIVE SUMMARY

Sierra Nevada bighorn sheep (*Ovis canadensis sierrae;* hereafter Sierra bighorn) were listed as threatened under the California Endangered Species Act in 1971 and uplisted to endangered in 1999. The subspecies has been listed as endangered under the federal Endangered Species Act since 2000. Pursuant to Fish and Game Code section 2077, subdivision (a), the California Department of Fish and Wildlife (Department) has prepared this Five-Year Species Review to evaluate whether conditions that led to the original listing of Sierra bighorn are still present. This species review is based on the best scientific information currently available to the Department regarding each of the components listed under section 2072.3 of the Fish and Game Code, and Section 670.1, subdivisions (d) and (i)(1)(A), of Title 14 of the California Code of Regulations. In addition, this document contains a review of the identification of habitat that may be essential to the continued existence of the species, and the Department's recommendations for management activities and other recommendations for recovery of the species (Fish & G. Code, § 2077, subd. (a)).

After reviewing the best available scientific information, the Department determined the following:

Sierra bighorn, a distinct subspecies of bighorn sheep, occur in 14 relatively isolated subpopulations throughout the Sierra Nevada. Sierra bighorn select for visually open, snow-free habitat in proximity to steep, rugged terrain that may facilitate escape from predators. Historically, subpopulations of Sierra bighorn likely interacted as a functional metapopulation, but the distribution and connectivity of inhabited areas are much reduced from their historical extent. Population trajectories are largely driven by adult female survival, which is variable. The Sierra bighorn population has increased since its listing as a federally endangered species from 122 to 525 individuals, including 266 adult and yearling females. While the subspecies currently meets the distribution requirements for downlisting specified in the Recovery Plan for the Sierra Nevada Bighorn Sheep (U.S. Fish and Wildlife Service 2007), abundance goals have not yet been met.

The primary threats impeding recovery of Sierra bighorn are small population sizes that create a fragile distribution, predation by mountain lions, and disease transmission from domestic livestock. Sierra bighorn are not imminently threatened by habitat loss as their historical range is largely intact, continuous, and publicly owned. However, the current and future impacts of climate change and human recreation on Sierra bighorn habitat are uncertain. Overexploitation and interspecific competition are not thought to be limiting factors for Sierra bighorn recovery.

Certain management actions have demonstrably improved the progress of the subspecies toward recovery. Translocations have increased the distribution of Sierra bighorn subpopulations over a much shorter timeframe than natural colonization could achieve. Targeted removal of mountain lions appears to have been effective in limiting additive mortality and promoting positive population growth. Analyses indicate that a predation management strategy is almost certainly necessary if Sierra bighorn are to be recovered and ultimately removed from state and federal endangered species lists. Efforts to close domestic sheep allotments in proximity to bighorn habitat have reduced the risk of disease transmission. However, continued management is critical to ensure full recovery. Sustained monitoring efforts are needed to evaluate population status, more translocations are needed to augment small herd units and improve genetic diversity, a predation management strategy should be approved and implemented, and potential avenues for disease transmission should be regularly reassessed and mitigated.

In completing this Five-Year Species Review for Sierra bighorn, the Department finds there is sufficient scientific information to indicate that the conditions that led to the listing of Sierra bighorn as endangered are still present and recommends no change to Sierra bighorn's status at this time.

II. INTRODUCTION

A. Five-Year Species Review

This Five-Year Species Review addresses the status of the Sierra bighorn (*Ovis canadensis sierrae* Grinnell), which is designated as an endangered species under the California Endangered Species Act (CESA) (Fish and G. Code § 2050 et seq.; Cal. Code Regs. tit. 14 § 670.5, subd. (a)(6)(A)). Upon a specific appropriation of funds by the Legislature, the California Department of Fish and Wildlife (Department) shall, or if other funding is available, in the absence of a specific appropriation, may, review species listed as endangered or threatened under CESA every five years to determine if the conditions that led to the original listing are still present (Fish and G. Code § 2077, subd. (a)). Sierra bighorn are also listed as endangered under the Federal Endangered Species Act. Pursuant to Fish and Game Code section 2077, subdivision (b), the United States Department of the Interior, U.S. Fish and Wildlife Service (Service) was contacted in an effort to coordinate this species review with their five-year review process. The most recent Service review from September 27, 2019, informed this review.

Using the best scientific information available to the Department, this Five-Year Species Review includes information on the following components pursuant to section 2072.3 and section 2077, subdivision (a), of the Fish and Game Code and section 670.1, subdivision (d), of Title 14 of the California Code of Regulations: species' population trend(s), range, distribution (including a detailed distribution map), abundance, life history, factors affecting the species' ability to survive and reproduce, the degree and immediacy of threats, the impact of existing management efforts, the availability and sources of information, identified habitat essential for the continued existence of the species, and the Department's recommendations for future management activities and other recovery measures to conserve, protect, and enhance the species.

Data within this report is organized by biological year such that the year '2000' in this report represents May 1, 2000 to April 30, 2001. This report includes data through April 30, 2019 (biological year 2018), but most reports of Sierra bighorn population estimates are from the most recent published report (Greene et al. 2018), which summarizes data from biological year 2017 (through April 30, 2018). More recent data have not yet been verified.

B. Listing and Review History

Sierra bighorn have received various levels of protection since hunting restrictions began in 1878. Most recently, the California Fish and Game Commission and the U.S. Fish and Wildlife Service worked together to refine regulatory protections for the subspecies (U.S. Fish and Wildlife Service 2007). The California Fish and Game Commission upgraded the status of Sierra bighorn from threatened to endangered in 1999 after the population size declined significantly from 310 in 1985 to approximately 122 in 1999 (U.S. Fish and Wildlife Service 2007). In 2000, the U.S. Fish and Wildlife Service finalized a rule to list Sierra bighorn as endangered due to small population sizes, which made the subspecies vulnerable to extinction from threats such as mountain lion predation, disease, environmental stochasticity, and genetic problems (U.S. Fish and Wildlife Service 2000). The main threats to the species identified in Recovery Plan for the Sierra Nevada Bighorn Sheep (U.S. Fish and Wildlife Service 2007; hereafter Recovery Plan) are disease, predation, low population numbers, limited distribution, limited availability of open habitat, and low genetic diversity due to small population sizes and inadequate migration between populations. The range of the subspecies is identical under both CESA and the federal Endangered Species Act (ESA); therefore, the Recovery Plan is fully applicable at the California state level and provides the foundation for evaluation of the subspecies' current status.

The Department has not previously conducted a Five-Year Review of this subspecies.

This Five-Year Species Review was prepared by Julia Runcie, Lacey Greene, Daniel Gammons, and Tom Stephenson in the Department's Inland Deserts Region, Sierra Nevada Bighorn Sheep Recovery Program (SNBSRP), Bishop Field Office.

C. Notifications and Information Received

On January 22, 2021, the Department notified persons who had expressed their interest in CESA actions in writing to the Commission and had provided contact information to the Commission (Fish and G. Code, § 2077(a)). The e-mail notification included a link to the Department's dedicated web page for five-year species reviews of threatened and endangered species at https://www.wildlife.ca.gov/Conservation/CESA/Five-Year-Reviews.

III. BIOLOGY

A. Taxonomic and Physical Description

Sierra bighorn are a distinct subspecies of bighorn sheep, as recognized by Grinnell (1912) and confirmed by Wehausen and Ramey (1993, 2000) using morphometric and genetic analysis. North America is home to three subspecies of bighorn sheep: Rocky Mountain bighorn (*Ovis canadensis canadensis*), which inhabit the Rocky Mountains and Pacific Northwest, desert bighorn (*O. c. nelsoni*), which occur in the southwestern United States and northwestern Mexico, and Sierra bighorn, which are endemic to the Sierra Nevada of California. Bighorn sheep are closely related to the thinhorn sheep (*Ovis dalli*) of northwestern Canada and Alaska. Both North American sheep species diverged from Siberian snow sheep (*O. nivicola*) approximately 600,000 years ago after crossing the Bering land bridge (Cowan 1940, Ramey 1993). Sierra bighorn populations declined with the arrival of Euro-Americans as did other bighorn subspecies (Buechner 1960).

Sierra bighorn are ruminant ungulates in the family Bovidae. These stocky, muscular sheep are notable for their large horns, which are permanent and continue growing throughout their lives. Adult females are smaller (average weight 58 kg [128 lbs] than males, with narrow, short horns (average length 25 cm [10 in]). Adult males are larger (average weight 84 kg [185 lbs]) with more massive, curving horns (average length 64 cm [25 in]). The wide, flared shape and smaller overall size of the horns in male Sierra bighorn are often visually distinguishable from the more tightly curled horns of desert or Rocky Mountain bighorn males; Sierra bighorn also have larger, heavier bodies than other bighorn subspecies (Massing et al. in preparation). Sierra bighorn range in color from dark brown to white, with a conspicuous white rump patch and a short brown tail.

B. Life History and Ecology

Sierra bighorn are gregarious, often bedding, moving, and foraging in groups, a behavior that may lessen predation risk and allow individuals to spend more time foraging versus being vigilant for predators (Berger 1978). Adult males and females are segregated for much of the year, but groups of mixed sexes are common during the rut (October to January) and on low-elevation winter range (Wehausen 1980). This sexual segregation affects foraging behavior in Sierra bighorn. Females tend to forage in larger groups that are closer to rugged terrain, whereas males travel longer distances while foraging and occupy more open terrain with greater forage biomass (Schroeder et al. 2010).

Bighorn, including Sierra bighorn, are considered philopatric (Geist 1971), occupying roughly the same area throughout their lives. Home ranges of female Sierra bighorn vary in size and spatial extent from year to year, and home ranges are larger in summer than in winter. The home ranges of females within a single subpopulation (hereafter, herd unit) can vary in size by more than 30 km^2 (12 mi^2, SNBSRP unpublished data). Male Sierra bighorn have larger home ranges than females (SNBSRP unpublished data). Although some degree of philopatry is typical, both males and females can make long-distance movements and colonize new areas. Such movements are more common in males, particularly during the rut, and are a means of maintaining gene flow between otherwise isolated herd units (Stephenson et al. 2012).

Females begin breeding at two years of age and give birth to a single lamb once annually. Lambing occurs after a gestation of approximately 174 days (Shackleton et al. 1984, Hass 1995), usually in May and June, though births have been recorded as early as April and as late as August (SNBSRP unpublished data, Wehausen unpublished data). Sierra bighorn lamb later in the year than desert bighorn that live at lower elevations (Wehausen 1991), likely as an adaptation to the colder winter conditions and later spring green-up of their mountain habitat.

The level of nutrition required for Sierra bighorn to conceive is relatively low, with an ingesta-free body fat over 7.7% corresponding to a probability of pregnancy greater than 90% (Stephenson et al. 2020). Conception rates of female Sierra bighorn are high; on average 85%

of adult females captured in March are pregnant (Greene et al. 2018). However, the proportion of females observed with live lambs each year is low compared to the proportion of pregnant females (Greene et al. 2017, Forshee 2018, Greene et al. 2018), perhaps reflecting a low rate of live births or low survival of neonates. Lamb to ewe ratios during the period since listing ranged from 0.14 to 1.0 with a mean and median of 0.53 (SNBSRP unpublished data). Lamb survival estimates over the same period varied widely by year and herd unit, ranging from 0.37 to 1.0 with a mean of 0.87 (SNBSRP unpublished data). Survival of lambs between six months and one year old was 0.83, suggesting that most lamb mortality occurred among lambs less than six months old (Forshee 2018).

The primary driver of changes in population growth rates for Sierra bighorn is adult female survival, which exceeds 90% in most years but is more variable (Johnson et al. 2010, Conner et al. 2018) than in other ungulates (Gaillard et al. 1998). Adult survival declines with age (Conner et al. 2018); typical lifespans are approximately 9 to 12 years for males and 12 to 14 years for females. Environmental factors affecting adult survival include the length of the previous summer's growing season, avalanche risk, and (for females) mountain lion abundance (Conner et al. 2018). Body fat of lactating females in autumn can predict probability of survival over winter and is also positively related to population growth rate (Stephenson et al. 2020).

C. Habitat Necessary for Species Survival

Sierra bighorn are native to the Sierra Nevada of California, where they inhabit elevations ranging from below 1,500 m to over 4,000 m (below 4,921 ft–over 13,123 ft). Sierra bighorn primarily use sparsely vegetated, mountainous terrain such as ridges, plateaus, and steep rocky slopes, or vegetated but visually open areas like meadows and shrub steppe.

Sierra bighorn habitat is highly intact and continuous relative to that of many endangered species (U.S. Fish and Wildlife Service 2007). Nearly all Sierra bighorn habitat occurs on federal public land (U.S. Fish and Wildlife Service 2007), and the majority is within federally designated wilderness.

i. Vegetation Communities and Foraging Habitat

The Sierra Nevada produces a strong rain shadow effect, creating more xeric communities east of the crest where the majority of Sierra bighorn habitat occurs. Sierra bighorn generally avoid dense forests and brush, preferring long sightlines and nearby steep, rugged terrain that facilitates escape from predators (hereafter, escape terrain). Alpine ridges and plateaus, though classified as barren, contain patchy low-growing graminoids (grasses and grass-like plants), forbs, and cushion plants, including two forb species heavily used by bighorn, *Polemonium eximium* and *Hulsea algida*. Alpine meadows and subalpine shrub communities also provide a diversity of forage species, such as shrubs *Holodiscus discolor*, *Ribes montigenum*, *Jamesia americana*, and *Dasiphora fruticosa*, graminoids *Carex helleri*, *Carex rossii*, and *Elymus elymoides*, and forbs *Phacelia hastata var. compacta*, *Silene sargentii*, *Aquilegia pubescens*, and *Ivesia pygmaea* (Wehausen 1980).

On low-elevation winter range, desert needlegrass (*Stipa speciosa*) and other grasses (*Elymus sp.*, *Cercocarpus sp.*, and *Bromus spp.*) form the dominant component of bighorn forage (50%, Greene et al. 2012), followed by shrubs *Eriogonum fasciculatum*, *Artemisia tridentata*, *Ephedra viridis*, *Keckiella breviflora*, and *Purshia tridentata*. When green-up occurs in spring, Sierra bighorn diets shift from mainly grasses to mainly browse of *E. viridis*, *E. fasciculatum*, and *P. tridentata* (Wehausen 1980).

Other plant communities that occur widely within Sierra bighorn range, but do not appear to be preferred habitat, include single-leaf pinyon (*Pinus monophylla*) and juniper (*Juniperus spp.*) woodlands, Jeffrey pine (*Pinus jeffreyi*) forests, and subalpine forests composed of lodgepole (*Pinus contorta*), foxtail (*Pinus balfouriana*), limber (*Pinus flexilis*), or whitebark (*Pinus albicaulis*) pines (Wehausen 1980).

Single-leaf pinyon encroachment on low-elevation winter range may be a potential mechanism limiting connectivity between patches of Sierra bighorn habitat and increasing predation risk by impeding visibility (Torres et al. 1996, U.S. Fish and Wildlife Service 2008). Although such encroachment is minimal on Sierra bighorn winter ranges (Latham 2010). Wildfires and prescribed burns can improve Sierra bighorn habitat by improving visual openness and, in the short term, increasing availability of green forage (Greene et al. 2012).

As ruminants, Sierra bighorn are able to digest a variety of plant species, and individuals that migrate seasonally can take advantage of the most nutritious forage available at each season and elevation (Wehausen and Hansen 1988, Wehausen 1992, Wehausen 1996). However, tradeoffs such as increased predation risk at lower elevations and at greater distances from escape terrain may limit the ability of Sierra bighorn, particularly females, to optimize their nutrient intake in this way (Schroeder et al. 2010, Spitz et al. 2020).

ii. Geology and Soils

Sierra bighorn inhabit portions of the Sierra Nevada that are primarily granitic, composed of plutons emplaced in remnants of older, metamorphosed sedimentary and volcanic rock. The range tilted westward as it was uplifted, resulting in a gentler western slope and a steep eastern escarpment (Bateman 1968). Extensive and repeated glaciation carved the landscape into the deep canyons, cirques, ridges, and plateaus that characterize Sierra bighorn habitat today. Soil development is minimal at high elevations and on the east side of the range due to recent glacial scouring, cold temperatures, and limited precipitation. Most soils are classified as entisols or inceptisols containing a high proportion of rock fragments. Soils in meadows, by contrast, while restricted in spatial extent, are deep, rich in organic material, and high in water content (Taskey 1995).

iii. Climate and Hydrology

Precipitation in Sierra bighorn habitat falls mostly as snow during winter (November–April, Fites-Kaufman et al. 2007). Snow depths can reach over 6 m (20 ft, California Data Exchange Center unpublished data), but strong winds, typically from the southwest, regularly scour exposed ridgelines and high plateaus, maintaining nearly snow-free areas year-round. Summers are comparatively short and dry. Temperatures in the alpine range from –14 °C to –1 °C (7 °F to 30 °F) in winter and –2 °C to 15 °C (28 °F to 59 °F) in summer. In low-elevation habitat, winter temperatures range from –2 °C to 7 °C (28 °F to 45 °F, Conner et al. 2018).

A rain shadow effect causes the east slope of the Sierra Nevada to receive far less precipitation (approximately 10–15 cm [4–6 in] annually, Danskin 1998) than the crest and west slope. Although snow levels can reach below 1,200 m (3,937 ft) (Wehausen 1980), accumulation on Sierra bighorn winter ranges is infrequent and fleeting.

iv. Reproductive Habitat

During lambing season, lactating Sierra bighorn females select for open vegetation types near escape terrain, avoiding areas where the risk of encountering predators is high (e.g., low elevations, gentle slopes, or riparian areas) and where visibility is reduced (Forshee 2018). Typical lambing sites are extremely rugged, rocky, steep slopes. Females often travel distances longer than their average daily movements to reach lambing sites, leaving winter range and other females, and remain at those sites for an average of 26 hours. During that time female movements average only 19 m (62 ft), indicating the temporary cessation of normal foraging behavior. Immediately after giving birth, some females move a short distance to a secondary nursery site in similar terrain, where they may remain for several days (Forshee 2018). During the following two to three weeks, females and lambs may join together in groups to use foraging areas near escape terrain, such as steep, sandy or brushy slopes adjacent to avalanche chutes or rock outcrops, typically at higher elevations than winter range (Wehausen 1980).

v. Wintering Habitat/Hibernacula/Other Seasonal Habitats

Sierra bighorn generally demonstrate two different life history strategies in winter. Some individuals (hereafter, migrants) travel to low-elevation winter ranges, while others (hereafter, residents) remain in the alpine year-round. These two strategies offer inverse tradeoffs: migrants have access to more nutritious forage but experience greater predation risk, while residents are relatively safe from predation but are subjected to severe winter weather conditions and limited forage availability (Spitz et al. 2020). Individuals display plasticity in migration behavior, alternating their migratory strategy on average every four years, and the timing, duration, and elevational distance of migration varies by herd unit and year (Spitz et al. 2018). Some individuals also travel back and forth during the winter between alpine and low-elevation ranges.

Both migrants and residents select for snow-free areas (Spitz et al. 2020). For residents, these areas are generally ridges or high plateaus where wind-scouring prevents significant snow accumulation (Spitz et al. 2018). Migrants avoid snow by traveling to elevations below typical snow lines, where they occupy slopes with high-quality forage close to escape terrain (Wehausen 1980, Spitz et al. 2018).

IV. DISTRIBUTION AND ABUNDANCE

A. Range and Distribution

Bighorn sheep populations often consist of multiple subpopulations interacting as a metapopulation (Bleich et al. 1996). Although each subpopulation may be relatively geographically distinct, gene flow between subpopulations is accomplished by males dispersing to breed. Historically, the Sierra bighorn population likely followed this model, with numerous subpopulations occurring along the Sierra crest between Sonora Pass and Olancha Peak, as well as west of the Kern River near Mineral King, Big Arroyo, and the Kaweah range (Jones 1950).

In 2000, when listed as Endangered under both CESA and ESA, Sierra bighorn existed in seven geographically distinct subpopulations: three remnant populations and four populations that had been reintroduced into historical habitat (Figure 1, U.S. Fish and Wildlife Service 2000). The Recovery Plan assessed all known historical Sierra bighorn habitat and, within this range, identified 16 geographically specific areas (hereafter, herd units) of suitable habitat to support Sierra bighorn subpopulations, including the seven herd units already occupied at the time. These 16 herd units were classified into four Recovery Units, or geographic groupings of multiple adjacent herd units. Recovery Units are expected to function as independent metapopulations of Sierra bighorn (U.S. Fish and Wildlife Service 2007, Few et al. 2015). Habitat analyses predict high habitat connectivity between herd units within recovery units, although recovery units are substantially isolated from one another (Few et al. 2015). Genetic analyses and GPS collar locations of individual bighorn confirm that animal movements and gene flow occur between herd units within Recovery Units, particularly in the Southern Recovery Unit (Few et al. 2015). Movements also occur infrequently between the Southern and Kern Recovery Units (Greene et al. 2016), and one male was detected moving from the Northern to the Central Recovery Unit (Greene et al. 2017).

The Recovery Plan specified distribution requirements for downlisting to threatened status. These requirements identify 12 of the 16 herd units as essential, meaning that these 12 herd units must be occupied for the species to be downlisted (U.S. Fish and Wildlife Service 2007). Since listing under ESA, additional translocations and natural colonization events have established seven new herd units, in addition to the seven herd units occupied at the time of listing, for a total of 14 occupied herd units. All 12 herd units considered essential for downlisting are now occupied, as well as one herd unit deemed nonessential for downlisting, and one herd unit that was not identified in the Recovery Plan (Figure 1). Three herd units identified in the Recovery Plan as nonessential for downlisting are not yet occupied (Figure 1).

The Recovery Plan also identifies distribution requirements at the Recovery Unit level that must be met for Sierra bighorn to be delisted: two herd units must be occupied in the Kern Recovery Unit, six in the Southern Recovery Unit, two in the Central Recovery Unit, and two in the Northern Recovery Unit (U.S. Fish and Wildlife Service 2007). The distribution of Sierra bighorn currently meets this criterion.

With the establishment of new herd units since 1999, Sierra bighorn now inhabit much of their historical range, from Mt. Warren in the north to Olancha Peak in the south, and west to the Big Arroyo and Great Western Divide (Greene et al. 2018).

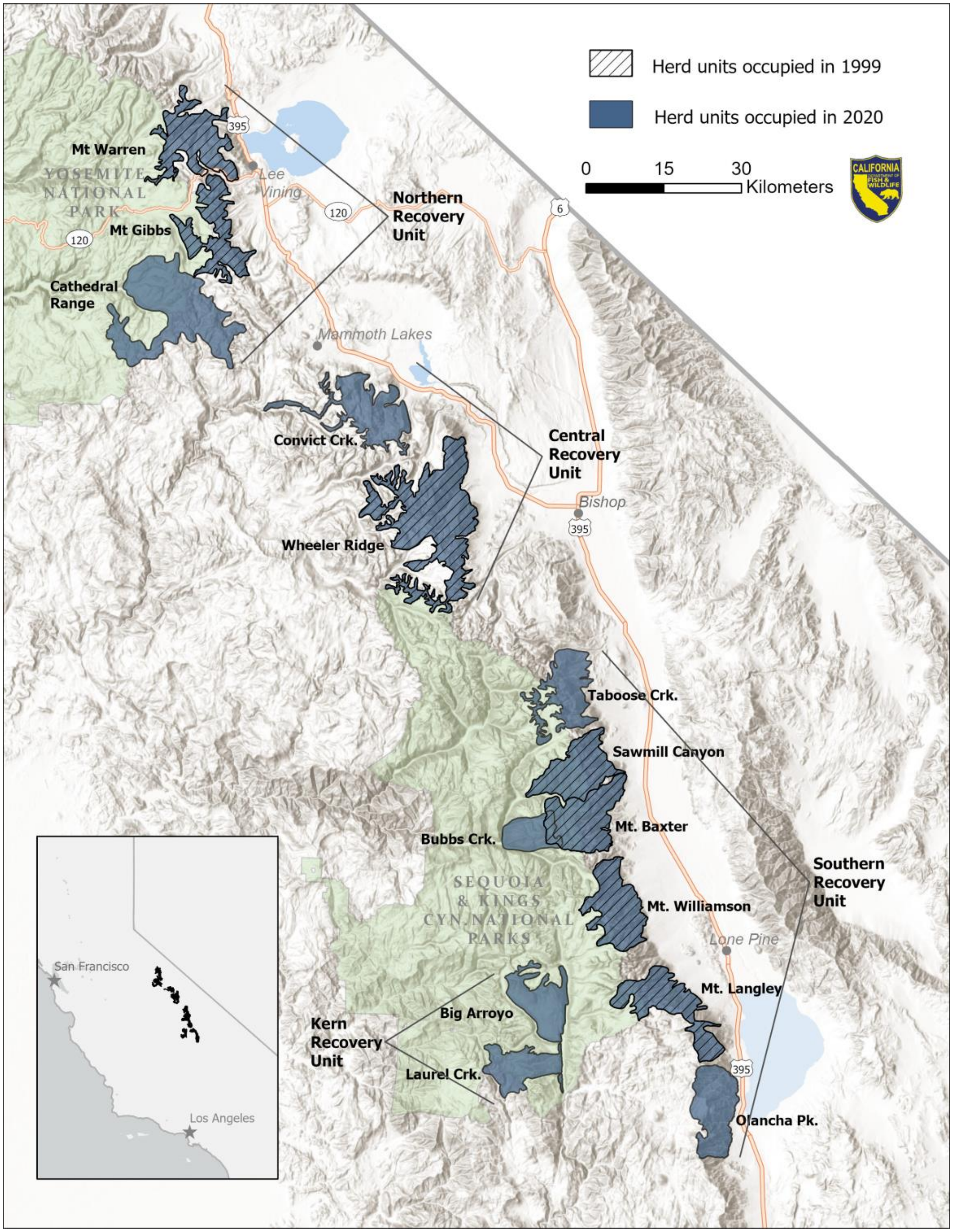

Figure 1. Sierra bighorn distribution at time of listing (1999) and at present (2020).

Population Trend and Abundance

In addition to the distribution requirements for downlisting, the Recovery Plan specified a minimum required abundance of 305 adult and yearling females. Female abundance must be distributed among recovery units as follows: 50 females in the Kern Recovery Unit, 155 females in the Southern Recovery Unit, 50 females in the Central Recovery Unit, and 50 females in the Northern Recovery Unit. For delisting, this minimum female abundance must be maintained as an average for seven years with no interventions (U.S. Fish and Wildlife Service 2007). In 1999, when the species was listed as endangered, the Sierra bighorn population was estimated at 122 animals including 55 females (Wehausen 1999, U.S. Fish and Wildlife Service 2000, Wehausen 2001, U.S. Fish and Wildlife Service 2007).

The Department's SNBSRP conducts regular ground surveys to obtain minimum population estimates for occupied herd units. As of April 30, 2018 (biological year 2017), the total Sierra bighorn population estimate was 525 including 266 females, 149 males, and 109 lambs (Table 1, Greene et al. 2018). The SNBSRP also calculates female abundance using mark-resight estimates for larger herd units (20 or more females) where minimum counts are unlikely to census every animal. Estimates of range-wide female abundance have increased substantially since listing (Figure 2, Greene et al. 2018, SNBSRP unpublished data).

Table 1. Sierra bighorn population estimates by herd unit derived from reconstructed minimum counts. When there was no count for a herd in a given year, the previous year's count was used. Due to the timing of population survey, there may be some double-counting during years with translocations. Lambs are not identified by sex. Some adult animals not identified by sex are included in totals.

Heard Unit	Adult Females	Yearling Females	Total Females	Lambs	Adult Males	Yearling Males	Total Males	Total
Olancha	20	2	22	11	10	2	12	45
Laurel	1	1	2	0	1	0	1	3
Big Arroyo	12	2	14	4	4	5	9	27
Langley	23	0	23	9	15	1	16	48
Williamson[c]	14	2	16	6	5	2	7	29
Baxter[w]	35	7	42	15	35	5	40	97
Sawmill	30	6	36	24	9	11	20	80
Bubbs (2013)	12	1	14	9	5	1	6	29
Taboose	2	1	3	1	5	1	6	10
Wheeler[w]	44	6	50	24	30	4	34	108
Convict	4	0	4	3	2	0	2	9
Cathedral	6	0	6	4	1	0	1	11
Gibbs	20	7	27	16	16	9	25	68
Warren	4	1	5	1	3	1	4	10
Total	231	34	266	109	118	31	149	525

[W] = winter surveys.

[C] = data combined from winter and summer surveys.

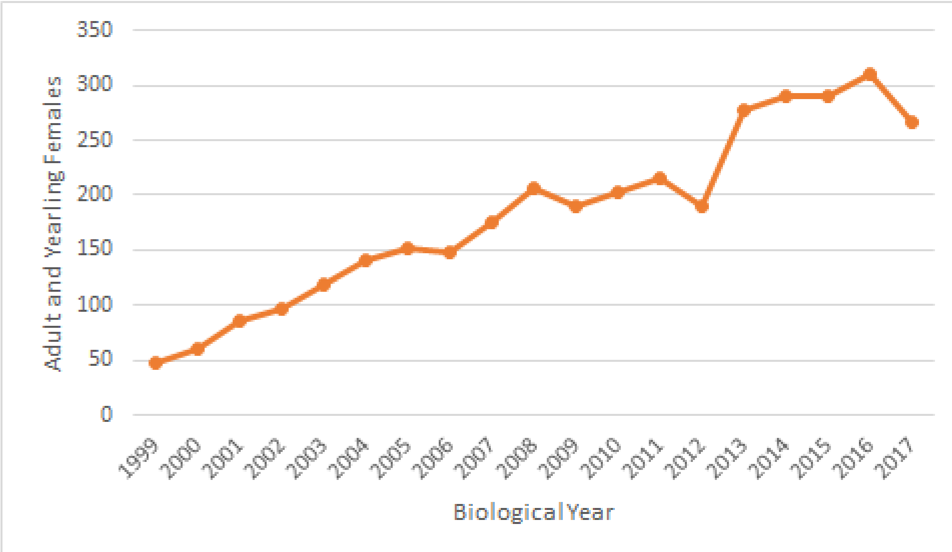

Figure 2. Range-wide abundance estimates for female Sierra bighorn 1999-2017. Data include reconstructed minimum counts and mark-resight estimates (CV < 0.15). Biological years begin on May 1 of the preceding calendar year; i.e., 2017 represents data from May 1, 2017-April 30, 2018.

Abundance estimates for each recovery unit have also increased since listing (Figure 3). With the current distribution of females, the Central Recovery Unit meets the abundance criterion, and the Southern Recovery Unit exceeds the abundance criterion. The Northern and Kern Recovery Units have not yet met the abundance criterion (Figure 4, Greene et al. 2018, SNBSRP unpublished data). Approximately 100 females (roughly 30% of the known population of females) and 57 males died during the harsh winter of 2016–2017, most due to winter conditions or mountain lion predation, representing the greatest loss of individuals documented by the SNBSRP since its inception. Notably, survival at Mt. Langley, previously one of the largest herd units, declined from 88% to 37%, one of the greatest herd declines recorded for Sierra bighorn (Greene et al. 2017). Female survival has since returned to more typical values (averaging 88% across all herd units in 2017–2018), but the total Sierra bighorn population size, and the abundance of some herd units like Mt. Langley, have not recovered (Greene et al. 2018). Although the population trend and abundance have increased overall since 1999, the abundance remains below the Recovery Plan’s minimum criterion for downlisting to threatened.

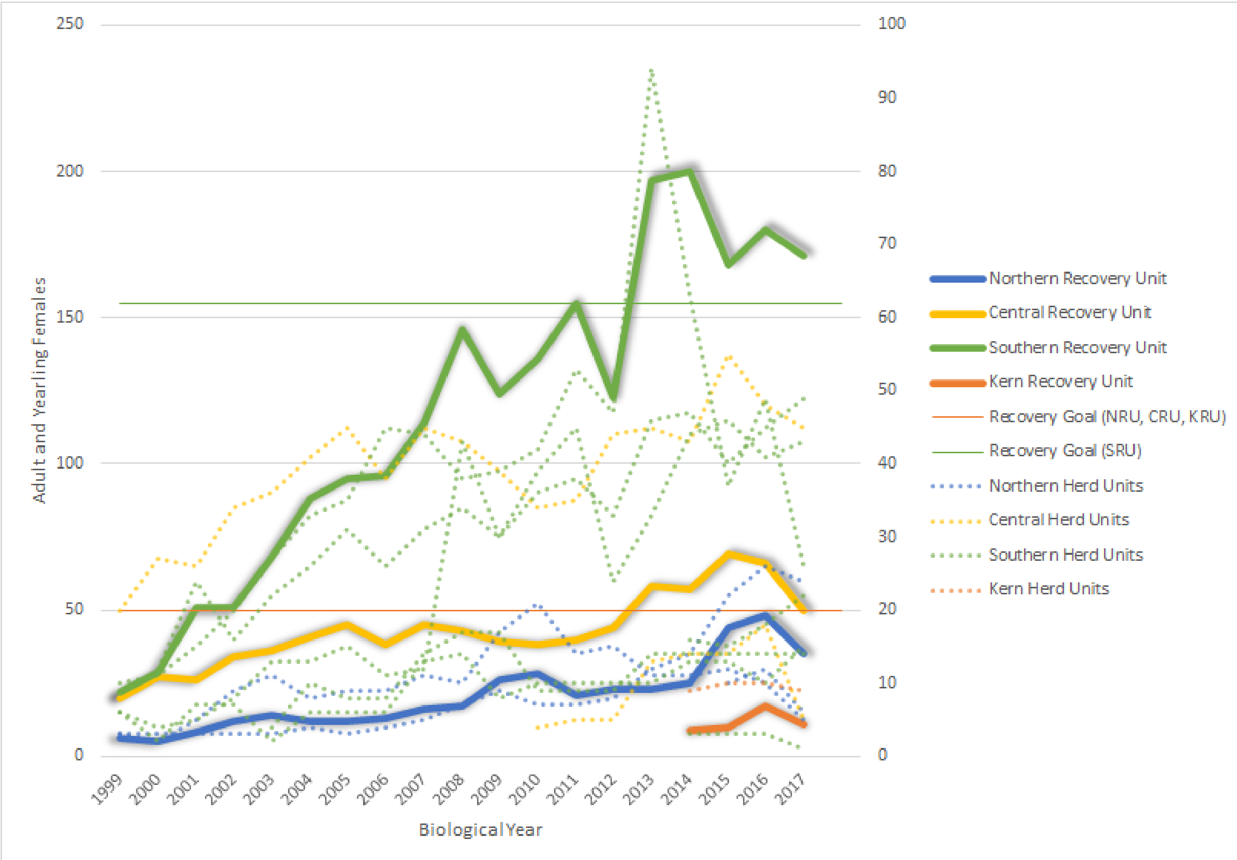

Figure 3. Estimated abundance of female Sierra bighorn 1999-2017 by recovery unit (RU) and herd unit compared to downlisting criteria. Data include reconstructed minimum counts and mark-resight estimates (CV < 0.15).

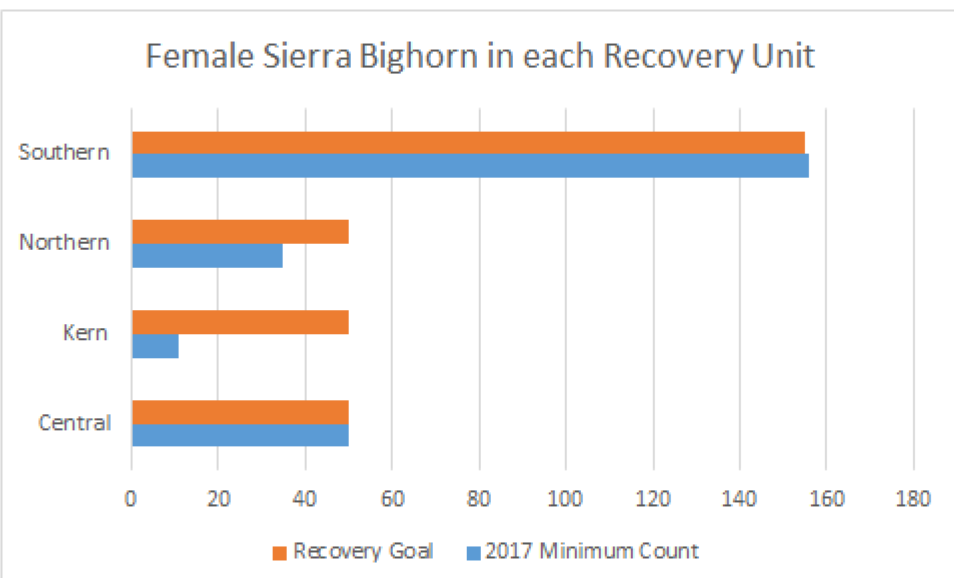

Figure 4. Abundance and distribution of female Sierra bighorn across recovery units compared to downlisting criteria.

V. THREATS AND SURVIVAL FACTORS

A. Factors Affecting Ability to Survive and Reproduce

i. LIMITED DISTRIBUTION AND SMALL POPULATIONS

Small population size and limited distribution are among the primary threats inhibiting Sierra bighorn recovery (U.S. Fish and Wildlife Service 2007). Bighorn sheep populations are typically characterized as metapopulations (Bleich et al. 1996, Valdez and Krausman 1999) consisting of several smaller, connected subpopulations. Within subpopulations, small groups of females often reflect maternal lines (Festa-Bianchet 1986) and are considered the fundamental building blocks of bighorn sheep populations (Bleich et al. 1996). In the Sierra Nevada, these smaller female groups within herd units are called demes. Sierra bighorn are vulnerable both because of low range-wide population size (~122 individuals in 1999 and ~525 individuals in 2017), and because the substructuring of herd units into demes can exacerbate the already small size and relative isolation of many herd units. Small demes are vulnerable to extirpation from demographic stochasticity (e.g., unequal sex ratios), environmental stochasticity (e.g., climatic fluctuations or extreme weather events that affect vital rates), or low genetic diversity.

Sierra bighorn have shown evidence of both positive and negative density dependence, in small and large herd units respectively (Johnson et al. 2010). Positive density dependence occurs when individual or population performance increases with group or population size (Stephens and Sutherland 1999, Gil et al. 2018). This relationship is often not linear, and may include thresholds below which a population is likely to crash, as well as thresholds above which the magnitude of positive density dependence decreases and is overwhelmed by negative density dependence (Schmidt et al. 2015, Gil et al. 2018). Although no herd units are particularly large (the highest female minimum count is 56), negative density dependence affects adult female survival and fecundity in larger herd units (Johnson et al. 2010).

Some Sierra bighorn herds have undergone rapid declines, while others have persisted at small population sizes. Most recently, the Mt. Langley herd unit declined from 49 to 19 females during 2015–2019, the Convict Creek herd unit declined from 18 to five females during 2016–2017 as the result of one severe winter, and the Mt. Warren herd unit declined from 21 to one female during 2010–2019. In contrast, the Mt. Gibbs herd unit persisted with fewer than five females during 1987–2006 without augmentation. Although positive density dependence may play a role in Sierra bighorn population dynamics, small herd unit size alone does not necessarily predict extirpation.

Population bottlenecks often leave a legacy of reduced genetic diversity even after population sizes rebound, and this can be further exacerbated by the polygynous mating system and deme social structure of Sierra bighorn (U.S. Fish and Wildlife Service 2007, Wehausen 2020). Low genetic diversity can result in inbreeding depression (Keller and Waller 2002), but it can also free populations from deleterious recessive alleles or allow for localized adaptation (Bouzat 2010, Buchalski et al. 2016). Sierra bighorn have low genetic variation compared to other bighorn subspecies (Johnson et al. 2011, Few et al. 2015). Johnson et al. (2011) found evidence that reduced genetic diversity was associated with up to a 1.4% reduction in fecundity but was not related to survival rates in adult female Sierra bighorn. The long-term consequences of this level of reduced fecundity are small. Although population trajectories in Sierra bighorn are typically driven by adult survival (Johnson et al. 2010), recent erratic growth rates in the Mt. Gibbs herd unit occurred during a period of variable reproductive success (Wehausen 2020).

The limited distribution of Sierra bighorn makes them sensitive to environmental stochasticity and disease outbreaks and inhibits connectivity and natural augmentation between herd units. In general, bighorn sheep are thought to be poor colonizers (Geist 1971) and may also experience social inertia (Gil et al. 2018), in which social dynamics may reinforce engrained philopatry, making individuals or populations resistant to exploring new areas. Nonetheless, since listing in 1999, Sierra bighorn have naturally colonized four herd units: Mt. Gibbs, Convict Creek, Taboose Creek, and Bubbs Creek. Sierra bighorn have also naturally expanded within herd units, creating new demes including the Lone Pine Peak deme within the Mt. Langley herd unit, the Granite Park deme within the Wheeler Ridge herd unit, and the Barnard deme within the Mt. Williamson herd unit. These expansions constitute a relatively small area, however, compared to the broader historical range (Jones 1950).

Populations with low abundance and limited distribution may be threatened by a single environmental event. For Sierra bighorn, the primary limiting environmental factors are mountain lion predation and winter severity (see section III.B above), both of which can impact multiple herd units at once (Greene et al. 2017). Increasing the abundance and expanding the distribution of Sierra bighorn should increase their resilience to environmental stochasticity as well as providing opportunities for natural augmentation and gene flow. However, improving connectivity between subpopulations also presents the risk of increased potential for disease transmission (Clifford et al. 2009, Cahn et al. 2011).

ii. PREDATION

Several species may prey upon Sierra bighorn lambs, including golden eagles (*Aquila chrysaetos*), black bears (*Ursus americanus*), gray foxes (*Urocyon cinereoargenteus*), bobcats (*Lynx rufus*), coyotes (*Canis latrans*), and mountain lions (*Puma concolor,* Sawyer and Lindzey 2002).Based on repeat observations of neonates with their GPS-collared mothers, Forshee (2018) documented that variation in neonate survival was largely a function of habitat selection by lactating females (i.e., neonate survival decreased with increasing distance to escape terrain) and inferred that predation was the dominant cause of neonate mortality. Because lactating females select habitats with low probabilities of mountain lion encounters, Forshee (2018) suspected that the most common predators of lambs may be golden eagles and coyotes. However, there is no documented evidence of these species killing lambs in the Sierra Nevada although they are present. During 2015–2016, mortalities of nine radio-collared lambs in the Convict Creek, Wheeler Ridge, and Mt. Langley herd units were investigated. Mountain lions killed two (22%) of these individuals and a bobcat killed one (11%). Of the 39 total lamb mortalities (both collared and uncollared individuals) investigated between 2002 and 2019, one (3%) was attributed to bobcats and 19 (49%) were attributed to mountain lions. The remaining

19 individuals died from malnutrition (n = 3), injuries sustained during rockfalls (n = 3), hypothermia (n = 1) or unknown causes (n = 12) (CDFW unpublished data). Based on these data, mountain lions appear to be important predators of lambs, but other predators could be significant as well. Despite consistently high pregnancy rates and a lack of evidence that herd units are nutritionally limited (Stephenson et al. 2020), lamb:ewe ratios have been as low as 0:100 for small herd units containing fewer than 10 females and 15:100 for larger herd units (Greene et al. 2018). This may indicate that regardless of the predator species responsible, predation is likely an important factor influencing lamb survival.

In contrast, predation upon yearling and adult Sierra bighorn is better understood. Mortalities of 316 radio-collared yearlings and adults were investigated between 2003 and 2019 and the cause of death was identified for 193 (61%) of them (CDFW unpublished data). Mountain lions were the dominant predators of these age classes, accounting for 94% of attributable predation mortality (bobcats and coyotes accounted for the remaining 6%). Across all Sierra bighorn herd units, mountain lion predation accounted for 27% of total mortalities from all sources combined (i.e., predation and all other sources of mortality). However, mountain lion predation was particularly important within the three herd units in the Southern Recovery Unit used as sources of translocation stock (Mt. Baxter, Sawmill Canyon, and Mt. Langley). In these herd units, mountain lion predation accounted for 49% and 24% of collared female and male mortalities, respectively, which is likely an underestimate given that the cause of death could not identified for 39 of the 107 mortalities (Figure 5). In the Southern Recovery Unit, females were 2.4 times more likely to die as a result of mountain lion predation than the four other causes combined (i.e., accident (e.g., avalanches), malnutrition, natural causes (e.g., senescence), and other predators).

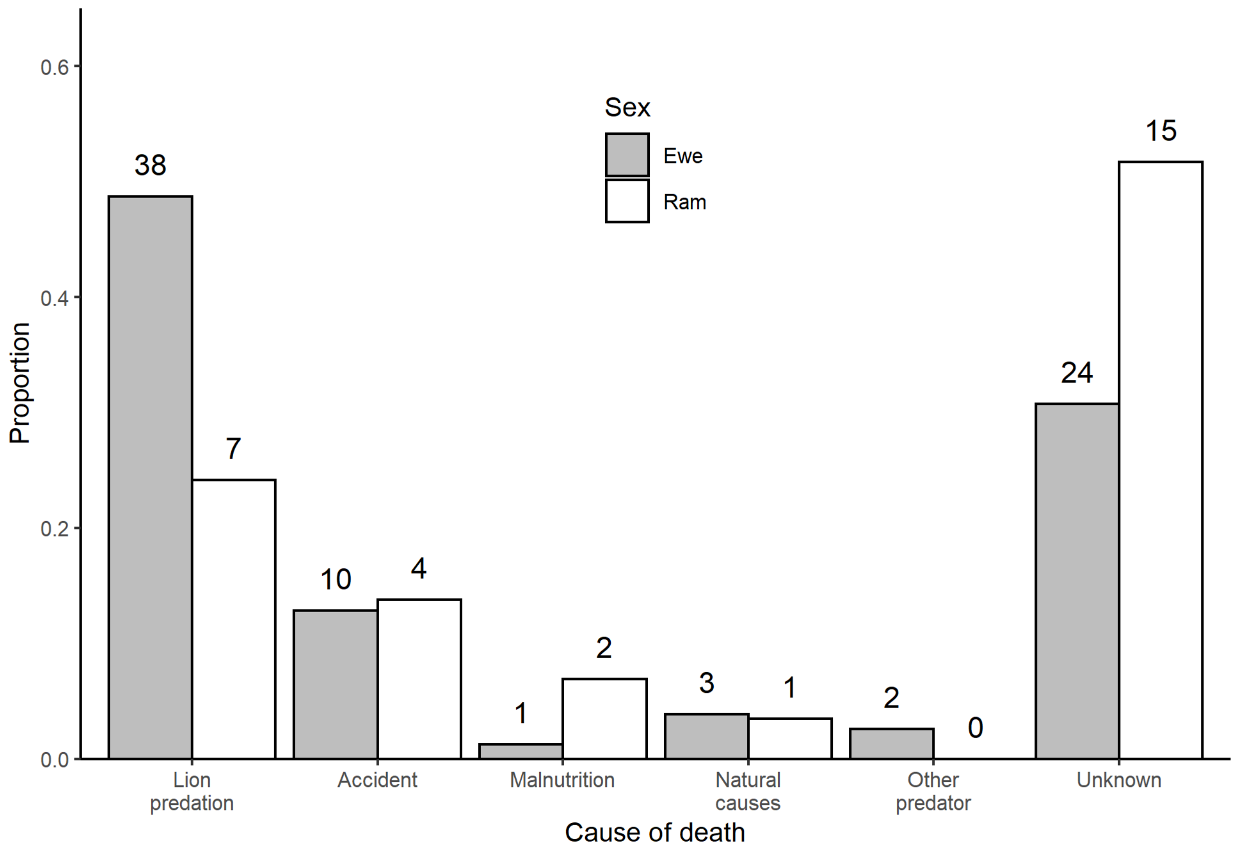

Figure 5. Proportion of mortalities (n = 107) for radio-collared female and male ($\geq$ 1 year old) Sierra bighorn within the Mt. Baxter, Sawmill Canyon, and Mt. Langley herd units, 2003-2019. Numbers above bars are total mortalities.

iii. Disease

Respiratory disease has caused and is currently causing widespread mortality in bighorn populations throughout the western United States and Canada (Besser et al. 2008, 2012, Cassaigne G et al. 2010, Wehausen et al. 2011, Cassirer et al. 2013, 2018, Manlove et al. 2016, Dekelaita et al. 2020). Domestic sheep often carry bacteria associated with pneumonia and can transmit pathogens to bighorn sheep (Besser et al. 2014). The Recovery Plan identifies disease transmission from domestic sheep as a major threat to recovery (U.S. Fish and Wildlife Service 2007). Since annual monitoring began in 1974, there has been no evidence of respiratory disease (from observed symptoms or testing) in the Sierra Nevada (Wehausen 1980; CDFW reports 1979–2018). However, recent outbreaks in desert and rocky mountain bighorn sheep populations indicate respiratory disease could have potentially catastrophic impacts on Sierra bighorn (WAFWA 2017).

Disease outbreaks typically begin with catastrophic die-offs of all age classes followed by persistent reduced recruitment (Cassirer et al. 2018) and sometimes include sporadic interannual mortality among adults (Cassirer et al. 2013). Persistent high juvenile mortality from disease has caused some overall populations to decline (Manlove et al. 2016). However, demographic impacts may vary by population size (Cassaigne G et al. 2010), season and habitat quality (Dekelaita et al. 2020).

Bighorn pneumonia is associated most consistently with the bacteria *Mycoplasma ovipneumoniae* (M. ovi.; Besser et al. 2008, 2012), but has also been associated with various *Pasteurellacea* (Besser et al. 2008, 2012, Dassanayake et al. 2010, Garwood et al. 2020). M. ovi. may be acting “as a primary agent that increases the susceptibility of infected bighorn to secondary bronchopneumonia [from M. ovi. or other bacteria i.e. *Pasteurellacea*]” (Besser et al. 2008). M. ovi. strains associated with domestic goats have been found in at least one bighorn disease outbreak indicating that in addition to domestic sheep, goats may also be important disease vectors (Besser et al. 2017). Since intensive sample began with the recovery effort, Sierra bighorn have not tested positive for M. ovi but it is considered the disease threat of greatest concern in bighorn sheep.

Surveillance for a broad suite of potential ungulate diseases occurs annually using samples obtained during captures. Sierra bighorn blood samples have consistently tested negative for Bluetongue Virus (BTV), Bovine Herpesvirus-1 antibody, Brucella ovis antibody, Border Disease Virus type 1 (BDV-1) virus antibody, and BVD type 2 (BDV-2) antibody. Sierra bighorn have intermittently tested positive for the following: contagious ecthyma (CE), bovine respiratory syncytial virus (BRSV) antibody, epizootic hemorrhagic disease (EHD) virus antibody, parainfluenza virus 3 (PI-3) antibody, Chlamydia, anaplasma, and anaplasma marginale. The presence of antibodies indicates past exposure to the disease but does not necessarily indicate a recent outbreak. The timing and impact of these exposures is not known.

Clinical symptoms of CE also have been observed in Sierra bighorn during captures and in the field. CE is caused by a parapoxvirus and can be transmitted to humans. In domestic sheep, the disease causes lesions, most commonly around the mouth, that last from 1–4 weeks. Severely affected individuals may develop further infection and lambs may be unable to eat normally (https://www.merckvetmanual.com/). CE has occasionally been observed in at least two herds (Wheeler Ridge and Mt. Warren).

Blue tongue virus (BTV) and the closely related equine hemorrhagic disease (EHD) are spread by gnats and antibodies for these viruses have been found in bighorn sheep throughout California (Gibbs and Greiner 1989). These diseases, as well as PI-3 and BRSV may be increasing mortality from bighorn pneumonia. BTV or EHD may have contributed to high lamb mortality from pneumonia in several desert bighorn populations in California (DeForge et al. 1995, Wehausen 1992). Additionally, PI-3 and BRSV were detected in a die-off of bighorn sheep infected with pneumonia in Colorado (Wolfe et al. 2010).

It is thought that the presence of lungworm *Protostrongylid* sps., increases bighorn susceptibility to pneumonia (Forrester 1971, Woodard et al. 1974). Lungworm and threadworm were present in the majority of 34 fecal samples collected 2005–2006. In fecal samples from 1974–1979 (n = 115), lungworm densities varied by season and between herd units, but along with low levels of nematode and pinworm, were not thought to influence Sierra bighorn demography (Wehausen 1980).

iv. Habitat Modification or Destruction

Habitat loss is not likely impacting Sierra bighorn because almost all historical and currently occupied habitat is publicly owned and managed to support Sierra bighorn habitat requirements.

v. Climate Change

Climate projections for the Sierra Nevada include warmer temperatures, more precipitation as rain instead of snow, earlier runoff, and increasing variation in both severe winter and drought conditions (Dettinger et al. 2018, Reich et al. 2018). Recent large fires in the Sierra Nevada (the Creek Fire in 2020, the Ferguson Fire in 2018, the Rough Fire in 2015, and the Rim Fire in 2013, CAL FIRE unpublished data), the severe winter of 2016–2017, and the drought of 2012–2016 also suggest that extreme events may be becoming more common (California Environmental Protection Agency 2018). Although the average snowpack is projected to decline, more variable conditions will likely increase snowpack for some individual years (Dettinger et al. 2018, Reich et al. 2018), with potential for record-breaking snowfall (Zhao et al. 2020) which could reduce Sierra bighorn survival over winter.

The Recovery Plan suggests that the availability of open habitat may be limiting for Sierra bighorn (U.S. Fish and Wildlife Service 2007). Open habitat may provide bighorn with increased visibility and better forage availability. As the climate changes, vegetation communities within the Sierra Nevada are projected to shift, resulting in a severe loss of tundra and subalpine forest as lower elevation plant species move upward in distribution (Morelli et al. 2011). These changes could reduce the availability of open habitat for Sierra bighorn and change the distribution, abundance, and phenology of forage species.

Vegetation changes will likely also lead to longer fire seasons (Reich et al. 2018) with more frequent and severe fires (Morelli et al. 2011, Dettinger et al. 2018). Fire can change vegetation structure and the quantity, quality, and species composition of forage; for example, Greene et al. (2018) found that forage quality and visibility improved in burned areas of Sierra bighorn habitat temporarily. While natural fire regimes may be beneficial in maintaining openness and forage quality within Sierra bighorn habitat, the effects of more large-scale catastrophic wildfires are uncertain.

vi. Human Recreation

Human recreation has unknown effects on Sierra bighorn and their habitat. In other bighorn populations, studies have documented abandonment of lambing habitat in the vicinity of a hiking trail (Weidmann and Bleich 2014) and avoidance of high-quality habitat that is used by recreationists (Papouchis et al. 2001, Courtemanch 2014). Whether motorized or non-motorized, recreation that is irregular and unpredictable appears to cause a greater behavioral response in bighorn (Papouchis et al. 2001, Weidmann and Bleich 2014). Most of the recreation that occurs in areas used by Sierra bighorn is non-motorized (hiking and rock climbing). There is considerable overlap between Sierra bighorn habitat and popular, heavily used recreation areas.

vii. Overexploitation

Since emergency listing, there is no evidence of poaching of Sierra bighorn. One uncollared male was killed by a domestic dog in 2004 and one collared male was killed by vehicle on Highway 395 in 2003.

viii. Competition

Both mule deer (*Odocoileus hemionus*) and tule elk (*Cervus canadensis nannodes*) can overlap with Sierra bighorn on low-elevation winter ranges (Riegelhuth 1965), but studies quantifying utilization of important forage species in the Mt. Williamson and Mt. Baxter herd units found no evidence for interspecific competition (Wehausen 1979, Wehausen 1980).

B. Degree and Immediacy of Threats

i. Limited Distribution and Small Populations

The range-wide Sierra bighorn population was estimated at 525 individuals in 2017, including 266 females: 35 in the Northern Recovery Unit, 50 in the Central Recovery Unit, 154 in the Southern Recovery Unit, and 11 in the Kern Recovery Unit (Greene et al. 2018). For the USFWS to downlist Sierra bighorn from endangered to threatened, a minimum of 305 females is required, with 150 in the Southern Recovery Unit and 50 each in the Northern, Central, and Kern Recovery Units (U.S. Fish and Wildlife Service 2007).

As of 2018, the six largest herd units contained the majority of female Sierra bighorn (80%, 209/266), each with more than 20 females. The largest herd unit (Mt. Baxter) had a minimum count of 49 females (Greene et al. 2018, Table 1). Even these larger herd units are relatively small, and could rapidly decline within a few years due to predation, disease outbreaks, or severe winter weather (e.g., Mt. Langley, Greene et al. 2017, Gammons et al. 2019).

There are four essential herd units with five or fewer females. It is uncertain whether these herd units will remain viable without augmentation from translocations, although Mt. Gibbs did persist from 1987–2006 with fewer than five females. In addition to demographic or environmental stochasticity, which could extirpate these smaller herd units, they may also be vulnerable to inbreeding depression without genetic enhancement.

The current distribution includes occupancy in all herd units considered essential by USFWS for downlisting (U.S. Fish and Wildlife Service 2007, Greene et al. 2018). While additional herd units would restore the subspecies to more of its historical range, the current distribution includes both the benefits and risks of connectivity versus isolation.

Sierra bighorn appear to have undergone a genetic bottleneck. A 2011 study found some of the lowest measures of genetic diversity reported for wild bighorn (Johnson et al. 2011). Recent microsatellite analyses calculated expected heterozygosity values among six Sierra bighorn herd units ranging from 0.303 to 0.484, in contrast to values of 0.578–0.663 for wild desert bighorn populations, and determined that Sierra bighorn have the lowest number of alleles per locus of any populations sampled (Few et al. 2015). Heterozygosity of females may affect whether they have offspring (Johnson et al. 2011) but does not appear to influence the survival of their lambs during the first six months of life (Forshee 2018).

ii. Predation

Predation, particularly by mountain lions, has been identified as a substantial threat to the recovery of Sierra bighorn for decades. The Recovery Plan identified the preparation and implementation of “a management plan to temporarily protect Sierra Nevada bighorn sheep herds from predation losses, where needed, until viable herd sizes are reached” as a top priority (U.S. Fish and Wildlife Service 2007). The first peer-reviewed work that illustrated the importance of mountain lion predation on Sierra bighorn was Wehausen (1996). In that paper, Wehausen (1996) documented that an increase between 1976 and 1988 in both the presence of lions and in predation rates on Sierra bighorn coincided with a substantial decline of the Mt. Baxter and Sawmill Canyon herd units and the virtual extirpation of Sierra bighorn at Mt. Williamson (the only surviving remnant herds at the time). Further evidence of the impacts of lion predation on Sierra bighorn came after the removal of one lion each year for three years from the reintroduced Mount Warren herd unit. The lion removals appeared to convert a steep population decline into a rapid population increase (Bleich et al. 1991, Chow 1992, cited in Wehausen [1996]). Since this early report, additional observations and studies have identified mountain lion predation as a predominant factor limiting a timely recovery of Sierra bighorn. A summary of these observations and studies, along with additional data obtained after their publication, is provided below.

Johnson et al. (2010) found that, contrary to most ungulate populations where adult survival is relatively invariant and high, there was wide variation in adult Sierra bighorn survival from 1980 to 2007 and as a result, different management actions would be better suited for different herd units. Modelling efforts indicated that predator control would be beneficial for all the herd units examined (e.g., Wheeler Ridge, Mt. Langley, and the Mono Basin, the latter of which is currently recognized as the Mt. Gibbs and Mt. Warren herd units separately) but predator control would be particularly beneficial to the Wheeler Ridge herd unit.

Stephenson et al. (2012) presented a review of the Sierra bighorn recovery program from its inception in 1999 to 2011 and observed that predation was an important driver of Sierra bighorn population dynamics during the decade, with 62 Sierra bighorn mortalities identified as mountain lion kills. Predation was particularly problematic in the Southern Recovery Unit, where mountain lion predation accounted for 40% of all radio-collared female mortalities and was the largest known cause of death. For example, a substantial decline in the survival rate of females in the Southern Recovery Unit in 2007 and 2008 was caused by an increase in mountain lion predation.

Johnson et al. (2013) described the relationship between mountain lion predation and survival in greater detail, regressing annual Sierra bighorn survival rates against annual lion predation rates from 2002 to 2010 and documenting that for two herd units (Mt. Baxter and Wheeler Ridge), variation in survival was primarily a function of lion predation rates (0.12 and 0.05, respectively), concluding that mortality from lion predation was additive to other causes of mortality in these herd units (Figure 6). One noteworthy finding from this work was that mountain lion predation on Sierra bighorn appeared to be mediated by habitat overlap with mule deer (*Odocoileus hemionus*), the primary prey of mountain lions. Mountain lion predation increased in direct proportion to the amount of overlap between Sierra bighorn and mule deer winter ranges. Because the Mt. Langley herd unit has little winter range overlap with mule deer, Johnson et al. (2013) suggested that while predation could be limiting for Sierra bighorn herd units associated with large mule deer populations, predation should be relatively unimportant for the Mt. Langley herd unit. As discussed further below, it is now known that this hypothesis was false and mountain lion predation had a pronounced impact on the Mt. Langley herd unit during the 2016–2017 winter.

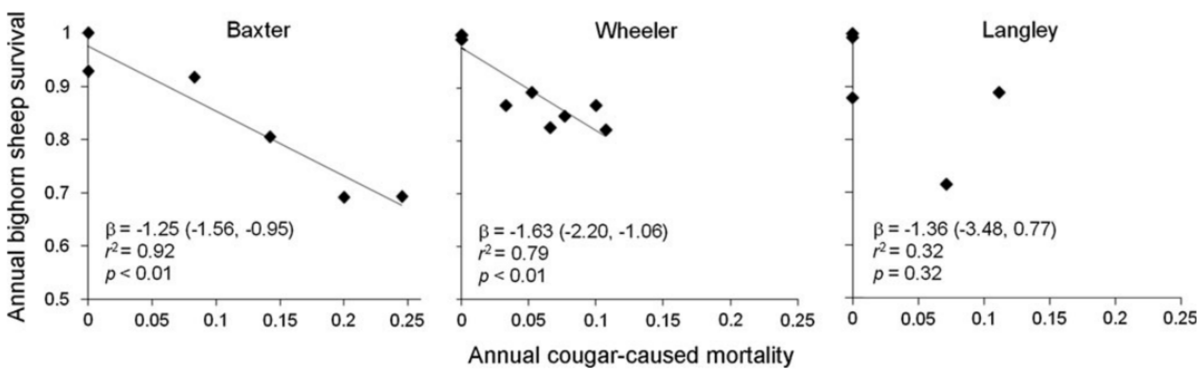

Figure 6. Annual survival rates regressed against annual mountain lion (cougar) predation rates in the Baxter, Wheeler, and Langley populations of Sierra bighorn, 2002-2010. From Johnson et al. (2013).

Conner et al. (2018) conducted a known-fate survival analysis of radio-collared Sierra bighorn during 2001 to 2013 to determine what population-level factors (e.g., climate, habitat, population size, predation) affect survival. A small number of the 25 covariates examined were retained in the top models, one of which was an index of mountain lion abundance. Female survival was found to decrease with increasing mountain lion abundance (Figure 7).

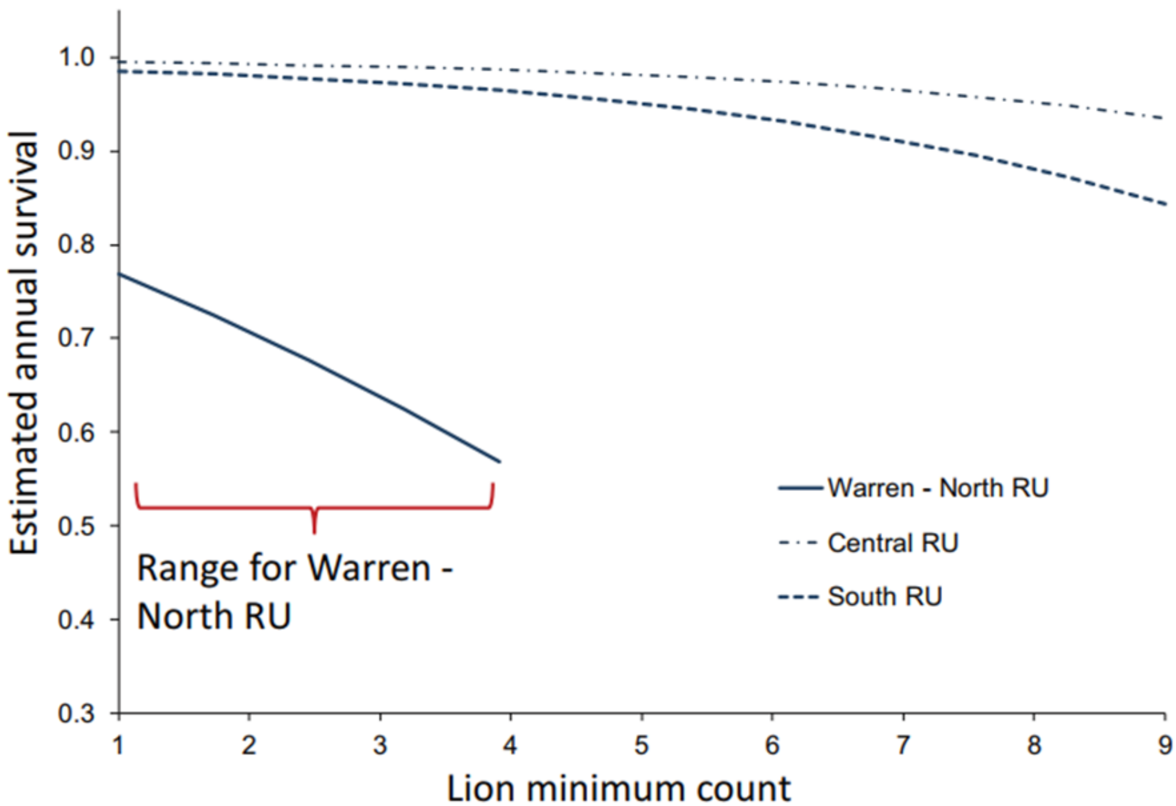

Figure 7. Estimates of annual survival relative to minimum mountain lion count and recovery unit for female Sierra bighorn in the Sierra Nevada, California, USA, 2002–2013. Survival for Gibbs in the north recovery unit (RU) is not shown because no females died during the study period. From Conner et al. (2018).

German and Stephenson (2018) evaluated the consequences of different predator management strategies and the subsequent effects on time and cost to recovery for Sierra bighorn. Based on demographic modeling, a strategy of lion removal following all detected predation events decreased the time to recovery by 40% (28.6 years to 17.3 years) or 33% (38.6 years to 25.9 years), depending on the type of model used, compared to a baseline strategy where adult survival was left unchanged at current lion predation rates. Under both models, implementing enhanced predator control resulted in cost decreases of over 10 million dollars relative to the baseline strategy.

The most recent example of the impact that mountain lion predation can have, occurred during a five-month period from December 2016–May 2017, when mountain lions killed a minimum of 19 Sierra bighorn, including 11 females (22% of the entire herd unit) at Mt. Langley, although the true number is almost certainly higher (Figure 8, SNBSRP unpublished data). In 2017 at Mt. Langley, two lions were lethally removed from five lions known to be in the area. However, in the years since, lion predation has continued to occur, even as the population continues to decline. Importantly, the Mt. Langley herd unit has declined to the point that it can no longer be used as a source of translocation stock, meaning that only three of the original four source herds (the others being Wheeler Ridge, Mt. Baxter, and Sawmill Canyon) remain viable for this purpose. For this herd unit to once again produce enough females to be used as translocation stock, management to reduce predation rates will almost certainly be required. However, the Mt. Langley herd may not persist at all unless the declines in population growth that have occurred annually between the onset of this predation event and the present can be reversed.

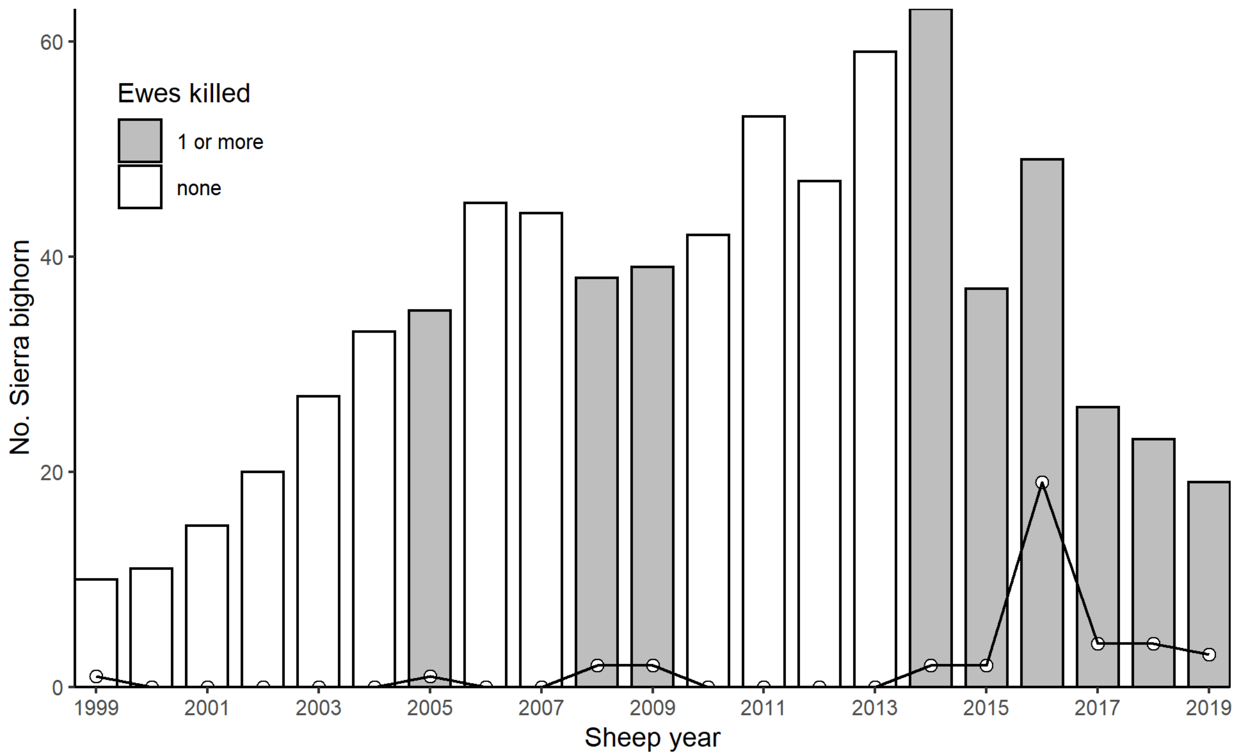

Figure 8. Sierra bighorn female abundance (bars) and number of detected lion-killed individuals (circles) in the Mt. Langley herd unit, 1999-2019.

iii. DISEASE

Respiratory disease continues to be the greatest existential threat to populations of wild sheep throughout North America. Every year bighorn populations somewhere in the western U.S. experience respiratory disease outbreaks (WAFWA 2017).

Extensive research demonstrates that bighorn sheep held in proximity to domestic sheep will contract respiratory pathogens that are usually lethal (Besser et al. 2014). Respiratory disease epizootics tend to be followed by years of poor lamb survival and recruitment (Manlove et al. 2016). A respiratory disease outbreak in Sierra bighorn would lead to significant all age mortality and significantly increase the probability of extinction (Clifford et al. 2009, Cahn et al. 2011). Pneumonia epizootics have the potential to reduce populations by as much as 50-80% (WAFWA 2017); such an event could devastate numerous populations of Sierra bighorn, result in further loss of genetic diversity, waste millions of dollars spent on the current recovery progress, and risk extinction of the subspecies.

Until recently, culling of entire herds has been considered the standard response and the primary management option for outbreaks in wild populations of bighorn (WAFWA 2017). A more recent approach for managing outbreaks now includes extensive field testing for pathogens and removal of all individuals in a population that continue to shed the bacteria (M. ovi.; Garwood et al. 2020).

Thousands of domestic sheep continue to be grazed on public land in the Sierra Nevada in proximity to designated critical habitat for Sierra bighorn (A. Coogan, USFS, personal communication). Commercial domestic sheep operators typically graze bands of domestic sheep of 1000 or more per allotment (CDFG 2004). Best management practices are unable to completely control straying so there is always some risk of domestic sheep moving into bighorn habitat when domestic sheep are grazed in proximity to bighorn sheep (CDFG 2004). Straying of domestic sheep into bighorn habitat has been documented in the Sierra Nevada (USFWS 2007). Further risk of contact occurs because bighorn sheep that travel in search of mates are attracted to domestic sheep. If contact occurs, pathogens may be transferred from domestic sheep to wandering bighorn sheep who may then carry the pathogen back to their herd which can lead to a disease outbreak (Clifford et al. 2011). Bighorn that contract respiratory pathogens can live for weeks before dying, and if they are a ram during rut, may spread disease within their herd as well as to adjacent herds (Besser et al. 2008). The Northern and Central Recovery Units are at highest risk for a disease outbreak given the proximity of habitat occupied by Sierra bighorn to domestic sheep grazing (Clifford et al. 2011).

iv. Habitat Modification or Destruction

Habitat loss is likely not significantly impacting Sierra bighorn. Almost all historical and currently occupied habitat is publicly owned and more than 80% of it is designated wilderness.

The Recovery Plan suggests that pinyon encroachment has reduced open habitat for Sierra bighorn (U.S. Fish and Wildlife Service 2007). However, a more thorough and geographically specific analysis found pinyon encroachment reduced open habitat for Sierra bighorn by less than 3% since the mid-twentieth century (Latham 2010), although there is some variation across the range (Gruell 2001, Latham 2010).

v. Climate Change

Climate change may have a significant impact on Sierra bighorn due to the increased frequency of extreme weather events. Cause-specific mortality analyses found that severe winter conditions cause substantial Sierra bighorn mortality (from avalanche and malnutrition; Conner et al. 2018). Sierra bighorn may be limited in their ability to adapt to climate change because of their low levels of genetic diversity (Johnson et al. 2011, Few et al. 2015, Buchalski et al. 2016) and small, isolated population structure (Cahn et al. 2011, Few et al. 2015). However, Sierra bighorn may have some behavioral or phenotypic plasticity that could support adaptation to changing climatic and vegetation conditions. Other bighorn subspecies display plasticity in the timing of parturition (Whitting et al. 2011, Renaud et al. 2019), which could enable them to adjust to changing vegetation phenology or winter weather patterns. Sierra bighorn also display plasticity in seasonal migration strategies (Spitz et al. 2018) and may shift their habitat use to locate sparse forage (Greene 2010).

vi. Human Recreation

Human recreation may affect Sierra bighorn movements and habitat use. Research in the 1970s indicated that disturbance by humans at that time (mostly in the form of hiking) was not limiting Sierra bighorn populations (U.S. Fish and Wildlife Service 2007), however recent research on Rocky Mountain bighorn documented lower recruitment rates and lower abundance of females in an area with limited habitat and heavy recreation use (Weidmann and Bleich 2014). As rock climbing has grown in popularity, use by this recreational group has increasingly overlapped Sierra bighorn habitat. This overlap is most conspicuous in the Pine Creek climbing area, a relatively new destination for climbers that is also used by Sierra bighorn for lambing and wintering. The SNBSRP monitors the density of climbing use and Sierra bighorn habitat use in Pine Creek. No specific impacts have been documented to date, but continued monitoring is needed. Courtemanch (2014) documented disturbance to bighorn sheep in the Grand Tetons from backcountry skiers when bighorn sheep were confined to limited windswept habitat in alpine terrain.

vii. Overexploitation

The recovery area is primarily designated wilderness areas on both U.S. Forest Service and National Park Service land; it is bisected by only one major paved road (Highway 120). In the eastern Sierra Nevada, several paved roads extend to the base of the escarpment and travel along the base of winter ranges. The minimal proximity of roads to Sierra bighorn habitat limits the potential for roadkill and poaching from roads.

viii. Competition

The Recovery Plan considered interspecific competition a minor threat (U.S. Fish and Wildlife Service 2007). To date, there has been no evidence of competition between mule deer, tule elk, or Sierra bighorn on low-elevation winter ranges (Wehausen 1979, Wehausen 1980).

VI. MANAGEMENT AND RECOVERY

A. Impact of Existing Management Efforts

Many conservation actions occurred before listing, beginning with full protection from hunting in 1876. Additional conservation activities targeting Sierra bighorn included prescribed fire to improve habitat, recreational monitoring, limited access and even closures for humans, dogs, and domestic goats, domestic sheep grazing allotment modifications and closures, allowing helicopter use to enable captures and translocations, mountain lion monitoring and removal, and Sierra bighorn monitoring and translocation. These are described in the Recovery Plan. Here we cover activities since listing under CESA in 1999.

i. Translocations

In order to mitigate some of the negative impacts of small populations and limited distribution, the SNBSRP has implemented an extensive translocation program. In addition to increasing the distribution of Sierra bighorn, translocations are designed to improve the viability of small populations by increasing their size and genetic diversity. Since 1979, the SNBSRP has translocated 210 Sierra bighorn: 130 females (most pregnant) and 80 males (Appendix A). Translocations between 1979 and1988 established the Mt. Langley, Wheeler Ridge, and Mt. Warren herds (Bleich et al. 1990). The Mt. Gibbs herd was created when animals initially translocated into Mt. Warren unexpectedly moved there in 1986, immediately after translocation (Wehausen 2020). Translocations from 2013 to the present have established the Olancha Peak, Laurel Creek, Big Arroyo, and Cathedral Range herd units (Few et al. 2013, 2015). Within herd units, augmentations have sometimes created new demes including the Alger deme at Mt. Gibbs. The recent observation of a Mt. Gibbs male in the newly established Cathedral Range herd unit demonstrates that translocations have also increased connectivity within the Northern Recovery Unit. Although both distribution and abundance have increased, the range-wide Sierra bighorn population remains small and sensitive to stochastic and environmental variation as well as low genetic diversity (section IV.A, section IV.B).

One translocation where Sierra bighorn were moved outside of the Sierra Nevada occurred in 1980 prior to their designation as endangered. Ten Sierra bighorn were translocated into the Warner Mountains in northern California (Bleich et al. 1990), but were later extirpated following contact with domestic sheep.

Translocation plans try to balance the benefits of connectivity (facilitating movement, promoting genetic diversity, and ensuring recolonization) while maintaining sufficient isolation to prevent disease spread (Few et al. 2015). It was initially thought that the Kern River would act as a barrier between the newly established Kern Recovery Unit and herd units in the eastern Sierra Nevada if a disease outbreak occurred. However, subsequent Sierra bighorn movement across the Kern River indicate the Kern Recovery Unit may have some connectivity to the Southern Recovery Unit.

At this time, all herd units created by translocation within the Sierra Nevada have persisted, although not without additional augmentations (Appendix A, Greene et al. 2018). Population viability analyses of herd units receiving augmentations predicted that, with positive population growth, the probability of reaching delisting recovery goals in 20 years ranged from 0.369 to 0.761 depending on the number of animals translocated and number of translocations (Few et al. 2015). Although translocations have clearly increased the distribution of Sierra bighorn, they have also reduced the size of source herds. The range-wide impact on abundance is difficult to determine, particularly in light of complicating environmental factors, and a comprehensive evaluation of translocation effects on abundance has not been completed. Mt. Baxter has contributed the most Sierra bighorn for translocation (n = 107, Appendix A), followed by Sawmill

Canyon, Wheeler Ridge, and Mt. Langley. These removals have reduced the size of source populations, at least temporally, and by doing so may also have limited natural colonization events. On the other hand, removing animals from larger herd units may reduce the impacts of negative density dependence in those herd units. Recent translocation plans specify that translocations should not reduce the source population to less than 30 females, and include a population viability analysis to evaluate the impact of removals on source populations (Few et al. 2013, 2015).

Genetic management, particularly of newly established herd units, is necessary because many Sierra bighorn herd units are small and disjunct from one another such that natural and regular connectivity was limited (U.S. Fish and Wildlife Service 2007, Cahn et al. 2011). The SNBSRP has carried out several recent translocations to create new herd units or increase genetic diversity in existing herd units. Individuals from three gene pools (Mt. Langley, Mt. Baxter/Sawmill Canyon, and Wheeler Ridge) were determined to have sufficiently high heterozygosity to serve as source stock for founding new populations or augmenting existing populations, particularly if sequential translocations utilized individuals from different source populations (Few et al. 2015).

Genetic rescue of inbred populations can occur through both natural and human-mediated processes. Notably, in 2012 the Mt. Gibbs herd unit had the lowest expected heterozygosity value recorded for Sierra bighorn, but by 2019 this value had increased almost to the average heterozygosity level of the Mt. Baxter/Sawmill Canyon gene pool, the most genetically diverse population of Sierra bighorn and the original source for animals in the Mt. Gibbs herd unit. This increase in heterozygosity was likely the result of multiple events: 1) the immigration of two males into the population in 2012; 2) the death of two resident, possibly dominant males in the same year; and 3) the translocation into the Mt. Gibbs herd unit of three pregnant females with high heterozygosity in 2013 (Wehausen 2018, Wehausen 2020). Translocations can supplement metapopulation processes such as immigration to enhance the genetic diversity of small populations.

Genetic diversity is considered in the current translocation plan (Few et al. 2015) and animals with high heterozygosity have often been selected for augmentations. The impacts of these genetic management efforts have not yet been fully analyzed (Wehausen 2020).

ii. Predation Management

The primary tool for mitigating predation on Sierra bighorn has been the lethal removal of mountain lions that use Sierra bighorn winter ranges, which is where the majority of predation occurs (Johnson et al. 2013). The impacts of predation and predator management on Sierra bighorn is difficult to evaluate because there are so few Sierra bighorn and both the impacts and management can be diffuse and variable. For example, in the Wheeler Ridge herd unit, the impacts of predation and predator management remain unclear. However, in other herds, at specific times, there is clear evidence that predation is having a negative impact on Sierra bighorn survival and predator management is having a positive impact on Sierra bighorn survival. Evidence of the positive impact of predator management is summarized here.

Early evidence of the beneficial impacts of lethal mountain lion removal came after mountain lion predation threatened the continued persistence of the Mt. Warren herd unit, shortly after their reintroduction into Lee Vining Canyon in 1986. In contrast to the performance of the Wheeler Ridge and Mt. Langley herd units, which began increasing shortly after they were reintroduced (U.S. Fish and Wildlife Service 2007), during the first year following reintroduction, 18.5% of the Sierra bighorn in Mt. Warren herd unit died and mountain lions accounted for 80% of the mortalities (Chow 1992). In response, one mountain lion was removed during each of the next three years and Sierra bighorn abundance increased dramatically (Wehausen 1996, U.S. Fish and Wildlife Service 2007).

Mountain lions were occasionally removed from Sierra bighorn habitat between 1999 and 2006, averaging 1.0 mountain lion removed/year (Table 2). During 2007–2009 however, the removal rate increased to 3.3 mountain lions removed per year within just the Southern Recovery Unit (Table 2), which, because mountain lion abundance was substantially reduced in that area, permits an evaluation of the utility of this management action. These removals were initiated in response to substantial increases in both mountain lion abundance and predation within the Mt. Baxter, Sawmill Canyon, and Mt. Langley herd units (Figure 9) (CDFW unpublished data).

During the early years of the SNBSRP (1999–2006), despite the continual presence of mountain lions within these herd units, predation of Sierra bighorn was rare (averaging 0.2 lion kills detected annually), likely because the herd units were still small, with only an average of 17.8 females, and presumably encounter rates with mountain lions were commensurately small). However, during 2007–2009, as these herd units were increasing in abundance, the mean number of mountain lions detected within them almost doubled, increasing from a mean of 4.2 (SE = 1.1) during 1999–2006 to 7.6 (SE = 2.0) during 2007–2009. At the same time, the mean number of mountain lion-killed Sierra bighorn detected each year significantly increased from 0.2 (SE = 0.2) during 1999–2006 to 2.7 (SE 1.4) during 2007–2009. In response to this predation, nine mountain lions were lethally removed from the Southern Recovery Unit winter ranges (one in 2007, three in 2008, and six in 2009; Table 2), which resulted in reduced lion abundance ($\bar{x}$ = 1.7, SE = 1.1) and a reduction in detected mountain lion-killed Sierra bighorn ($\bar{x}$ = 0.5, SE = 0.4) over the next five years (2010-2014) (CDFW unpublished data).

Table 2. Number of mountain lions removed annually (i.e., biological years) from Sierra bighorn winter range within three recovery units.

Year	Northern Recovery Unit	Central Recovery Unit	Southern Recovery Unit
1999	1	1	0
2000	0	0	1
2001	0	0	0
2002	0	0	0
2003	0	2	0
2004	0	1	0
2005	0	0	1
2006	0	1	0
2007	0	0	1
2008	0	0	3
2009	0	2	6
2010	0	4	0
2011	0	0	0
2012	0	0	0
2013	0	0	0
2014	0	0	0
2015	0	0	0
2016	0	0	2
2017	0	0	0
2018	0	0	0
2019	0	0	0

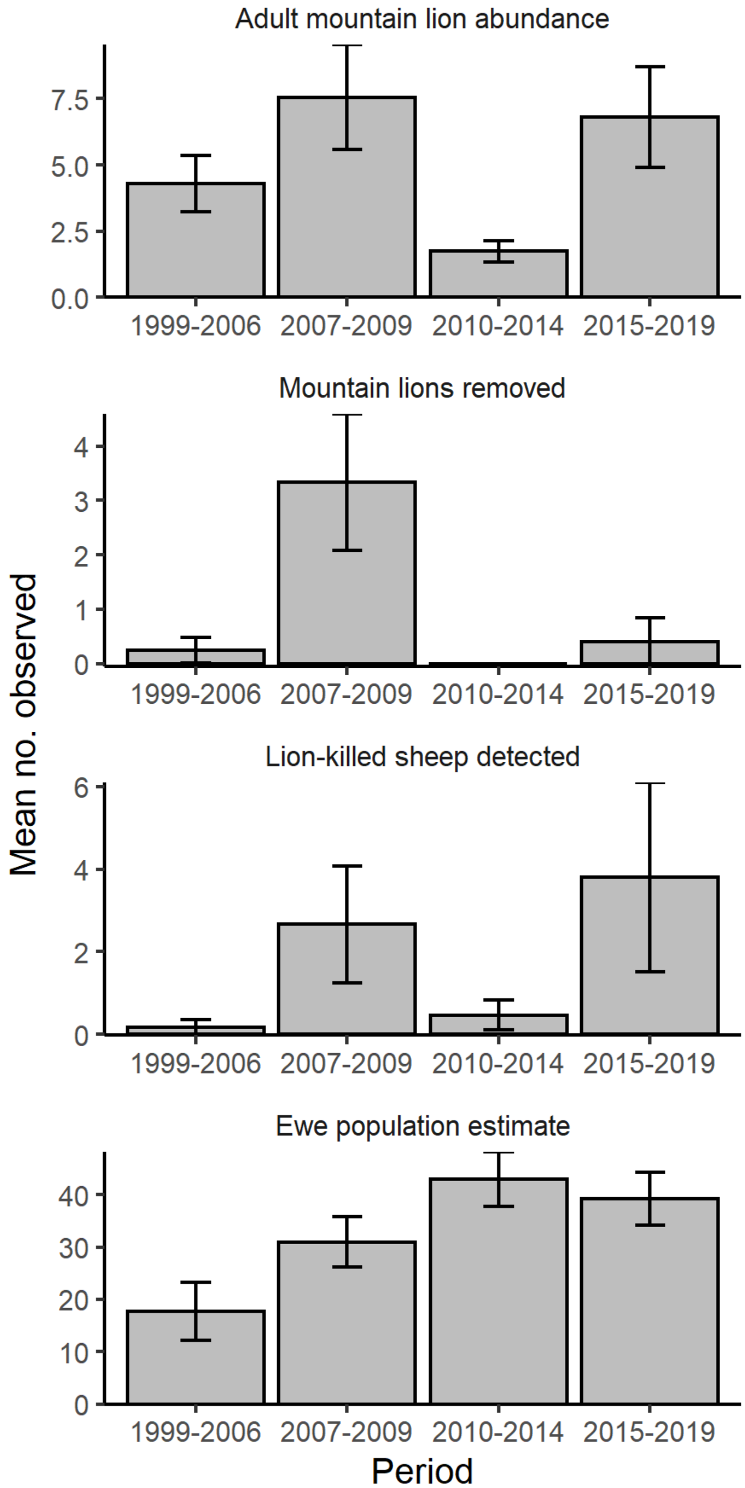

Figure 9. Mean (± SE) adult mountain lion abundance (minimum counts), number of mountain lions lethally removed, number of lion-killed Sierra bighorn detected, and Sierra bighorn female population estimates, within the Mt. Baxter, Sawmill Canyon, and Mt. Langley herd units during four periods of mountain lion management, 1999–2019.

During the relatively predation-free period of 2010–2014, these Sierra bighorn herd units experienced high growth rates, permitting the SNBSRP to remove 39 females for translocation, aiding in the establishment of the Olancha Peak, Big Arroyo, Laurel Creek, and Cathedral Range herd units and to augment the small herd units of Convict Creek, Mt. Gibbs, and Mt. Warren. By 2016, the mountain lion population had recovered from the 2007-2009 removals, with six adults detected that year and 9 adults counted in 2019, matching a previous high count in 2008. That winter, mountain lions killed 22% of the ewes within Mt. Langley herd unit within a five-month period (Figure 8). While two mountain lions were removed in response to that event (Table 2), the Mt. Langley herd unit had already declined in abundance to the point that it could no longer be used as a source of translocation stock. Annual population declines in the subsequent years (2017–2019) have continued, along with continued mountain lion predation (CDFW unpublished data), and it currently remains unclear if this herd unit will return to its former abundance, or, in fact, whether it will persist at all.

Although Sierra bighorn have benefitted from the removal of some mountain lions, management has also experimented with non-lethal techniques. Davis et al. (2012) described nine attempts to harass mountain lions using dogs and/or barking dog recordings during 1999-2011 to disperse six individual mountain lions away from Sierra bighorn habitat. Although objective assessment of effectiveness was difficult, the success of these efforts was clearly limited. While it was possible to force mountain lions to travel long distances during the day (a behavior that rarely occurs under natural conditions), none of the mountain lions subjected to harassment avoided Sierra bighorn habitat for more than a few weeks. These experiences are not surprising because based on animal behavior theory (Domjan 1996), there is little reason to expect harassment to be effective at extinguishing undesirable behavior of mountain lions (i.e., preying upon Sierra bighorn or traveling within Sierra bighorn habitat) within the Sierra Nevada ecosystem.

The first attempt at a different non-lethal approach to mitigating mountain lion predation—translocation—occurred in May 2020. A dispersing female mountain lion, with a history of Sierra bighorn predation, was translocated 75 km from Lundy Canyon to the Slinkard Wildlife Management Area, in response to her presence adjacent to a nursery group of Mt. Warren Sierra bighorn. The objective of this action was the permanent removal of this mountain lion from Sierra bighorn habitat—as would have occurred had she been lethally removed. As of October 2020, this translocation appears to have been successful in meeting the objective. The mountain lion has established a home range on the southeast perimeter of Lake Tahoe. However, caution is warranted in assuming that this circumstance will persist. Following her release in mid-May, she remained within the area she currently occupies until mid-July, but then traveled south approximately 100 km (62 mi) to her original capture location in Lundy Canyon, where she remained for approximately three weeks until returning north again to Lake Tahoe (CDFW unpublished data). In addition, while there have been few studies conducted on mountain lion translocation, it appears that when translocated individuals are placed in areas occupied by a resident mountain lion population, the risk of mortality is high, likely as a result of chronic stress associated with intraspecific aggression (Ross and Jalkotzy 1995, Ruth et al. 1998). Thus, until additional experimentation with mountain lion translocation occurs, the utility of translocation as a management tool remains unclear.

Management to reduce predation by mountain lions has benefitted Sierra bighorn and is likely to be necessary to downlist them in a timely manner. Lethal removal has proven to be an effective method of predation mitigation, without causing long-term changes to mountain lion abundance and distribution because they have rebounded quickly from past removals. (Figure 9). It is also important to continuously monitor mountain lions, because lion removals to aid prey species may be more effective if the social structure of mountain lions is considered (Elbroch 2020).

Harassment of mountain lions in wildland settings appears likely to have limited effectiveness, based both on limited field trials and animal behavior theory. Translocation shows promise as an effective tool and may be used in the future in situations in which mountain lions would have been lethally removed in the past. However, there are important logistical constraints to capturing and transporting mountain lions in remote wilderness areas that may make this method infeasible in some circumstances.

An important question is when will predation management no longer be necessary? The Recovery Plan (U.S. Fish and Wildlife Service 2007) provides for a 7-year period (i.e., 1 bighorn sheep generation) following downlisting (i.e., transition from endangered to threatened status) in which Sierra bighorn abundance requirements must be maintained in the absence of management interventions, such as predation management, in order for removal from the federal endangered species list to be considered (Criterion B2). It is anticipated that after this period, a thorough population viability analysis (Criterion B3) will be conducted that considers what, if any, additional predation management measures will be warranted once recovery targets have been met.

iii. Disease Monitoring and Management

The factors that explain the lack of disease observed in Sierra bighorn in recent decades have varied over time. During the 1970s to the early 2000s, Sierra bighorn were less widely distributed and present in lower numbers; those factors would have reduced the probability of contact with domestic livestock. In more recent years, as the population has expanded and grown, considerable progress has been made to remove domestic sheep from critical habitat and habitat adjacent to the recovery area through allotment closures and education of landowners, further reducing the probability of contact.

Section E of the Recovery Plan recommended a strategy for preventing contact between Sierra bighorn and domestic sheep and goats. In the mid-2000s a Recovery Team subteam developed a risk assessment to prevent contact between bighorn and domestic sheep in the Sierra Nevada (Baumer et al. 2009). An interagency team refined and applied this risk assessment to identify high risk allotments (Figure 10) on USFS and BLM lands (Croft et al. 2010). Of the 35 high-risk allotments identified by Croft et al. (2010), 19 are currently vacant or closed to prevent contact between domestic sheep and Sierra bighorn and 16 are open and grazed with domestic sheep (Figure 10). Of those that are open, a variety of methods are being used to reduce risk such as only grazing portions of allotments that lie outside the high-risk threshold or implementing grazing practices that reduce the potential for contact.

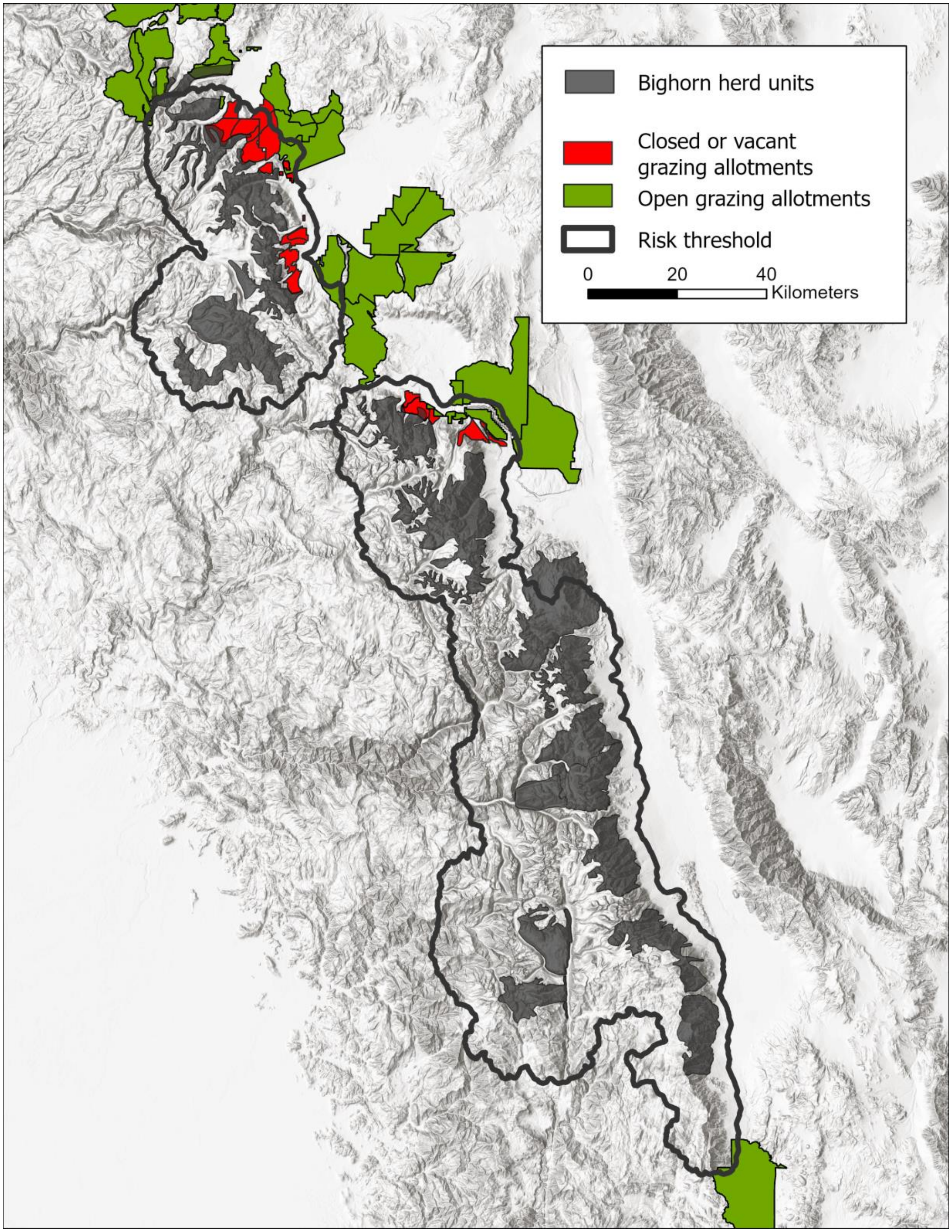

Figure 10. Occupied herd units for Sierra bighorn, U.S. Forest Service and Bureau of Land Management grazing allotments for domestic sheep, and a polygon that defines areas with a high risk of contact between the two species in east-central California, 2000.

Efforts to refine the potential for and define the effects of disease transmission from domestic sheep to Sierra bighorn have included several approaches. Clifford et al. (2009) used probability density functions based on detailed GPS collar data to model the likelihood of contact. Cahn et al. (2011) developed a demographic model to predict the probability of extinction associated with a respiratory disease outbreak. More recently, Manlove et al. (2016) noted that Clifford et al. (2009) and Cahn et al. (2011) underestimated the severity of outbreak effects because the duration of effects on lamb recruitment were modeled for fewer years than the effects have been observed in more recent empirical studies.

An interagency team of professionals continues to meet periodically to review the risk of contact model results and make management recommendations to prevent disease transmission from domestic sheep to bighorn sheep. Disease management currently includes monitoring for disease and working with public and private landowners to reduce the risk of contact between domestic sheep and Sierra bighorn.

From 2001 to 2020, six properties were conserved by the Wildlife Conservation Board with Sierra bighorn listed as a beneficiary (Table 5). Fee simple acquisition and conservation easements reduce disease risk by eliminating or restricting the grazing of domestic sheep and goats in proximity to bighorn habitat.

Currently both blood and nasal swab samples are collected from all captured animals to evaluate for M. ovi. Blood samples are also currently tested for bluetongue virus antibody, BRSV antibody, EHD virus antibody, and PI-3 antibody.

Table 3. Land acquisitions and conservation easements obtained with funds from the Department or Wildlife Conservation Board that identify Sierra bighorn as a beneficiary.

Project	Type	Year	Acres
Hunewill Ranch Conservation Easement (CE)	Conservation Easement with sheep and goats only in limited area and time period	2020	2040
Summers Meadow (Green Creek Wildlife Area)	CDFW acquisition	2015	2036
Sinnamon Meadows CE	Sheep and goats prohibited	2014	1240
Wheeler Ridge Wildlife Area, Expansion 3 (CE)	Sheep and goats prohibited*	2011	108
Wheeler Ridge Wildlife Area	Conservation Easement with sheep and goats prohibited	2007	10
Round Valley Wildlife Area, Swall Meadows Unit	CDFW acquisition(s)	1993–2019	278

*Temporary use of goats may be allowed with approval, for vegetation management with precautions against disease transfer.

iv. Habitat Protection and Enhancement

In 2008, the U.S. Fish and Wildlife Service designated critical habitat for Sierra bighorn comprising the 12 herd units whose occupation is considered essential for downlisting (U.S. Fish and Wildlife Service 2007, U.S. Fish and Wildlife Service 2008). This designation prohibits any federal actions within these areas from destroying or adversely modifying habitat for Sierra bighorn.

Although Sierra bighorn habitat is largely intact and unchanged from its historical state, management to enhance habitat may be beneficial at small scales. Prescribed fire has been recommended as a management tool to increase open habitat for Sierra bighorn (U.S. Fish and

Wildlife Service 2007) and to improve forage quantity and quality, though it may also expand overlap with predators (Greene 2010). In April 2001, the Inyo National Forest implemented a prescribed fire in the Diaz Creek area of the Mt. Langley herd unit; this fire improved habitat conditions and the area has since seen heavy use by Sierra bighorn (Wehausen 2001, Stephenson et al. 2012). The Inyo National Forest currently has a policy to allow wildfires to burn when it is safe to do so. The Seven Oaks Fire in 2007 improved forage quality and visibility for Sierra bighorn in the short term (Greene et al. 2012), and the Horseshoe Fire (2016) and Georges Fire (2018) removed conifer cover on 200 and 1,600 acres, respectively, potentially increasing the suitability of habitat in those areas for Sierra bighorn (U.S. Fish and Wildlife Service 2019).

v. Human Recreation Research and Outreach

In an effort to educate the rock climbing community about potential impacts of their activities on Sierra bighorn, the SNBSRP collaborated with various stakeholders including the Alpine Association of America and the Inyo National Forest to place an informational kiosk in the Pine Creek climbing area. The SNBSRP continues to monitor use of this area by recreationists and Sierra bighorn.

An interagency review of the effects of backcountry users in the U.S. Forest Service Bighorn Zoological Areas determined that hikers and backpackers were unlikely to be negatively impacting Sierra bighorn (T. Stephenson, CDFW, personal communication 2020). Agency personnel recognized that the majority of backcountry users in those areas confined their travel to trails or commonly used use routes and considered it unlikely that bighorn were harassed. Consequently, it was recommended that the Forest Orders that restricted backcountry travel in those Zoological Areas no longer continue.

vi. Competition Mitigation

Because interspecific competition does not appear to threaten Sierra bighorn, no management activities have been undertaken.

B. Recommendations for Management Activities and Other Recommendations for Recovery of the Species

i. Monitoring and Translocations

Population and demographic rate monitoring should continue for all herd units. Monitoring of source herds (i.e., those used for translocation stock) should be prioritized, followed by any newly established herd units. Translocations in the near term should be focused on augmenting existing herds as necessary to meet the numeric recovery goals (Few et al. 2015). Once all recovery goals are met, translocations can be expanded to enhance connectivity within and among herds and create new herds that are not considered essential for recovery.

Translocation objectives should be updated using new analyses that evaluate the impact of the most recent wave of translocations (2014–2019) on both recipient and source herds (Few et al.

2015). Increasing the distribution and genetic diversity of Sierra bighorn through translocations has likely made the population more resilient to the effects of climate change. Modeling indicated that, if survival of translocated animals is equivalent to survival of residents, herd units receiving augmentations did best when small augmentations were spread over time after an initial large population was founded (Rubin et al. 2002).

ii. Captive Breeding

During the initial phase of planning for Sierra bighorn recovery, a Captive Breeding Contingency Plan (Ernest 2001) was prepared to determine the feasibility of captive breeding and predict likely outcomes. The plan modeled suitability of sources, evaluated potential sites for a captive breeding facility, enumerated logistical considerations and costs for such a facility, and provided a decision tree to guide managers in selecting appropriate captive breeding alternatives. The plan concluded that the establishment of a captive herd could reduce the risk of extinction for Sierra bighorn but cautioned that a successful captive breeding program would require a long-term commitment to funding, planning, construction, and management (Ernest 2001).

Captive breeding has not been implemented for Sierra bighorn because other management actions have been successful in growing the subspecies. Facilitating population growth by animals in their native habitat is preferable to captive breeding when possible and will continue to be the preferred approach as long as the approach remains viable. The existence of the captive breeding plan provides a useful framework should such an initiative be considered in future.

iii. Predation Management

Mountain lion predation remains a substantial threat to the recovery of Sierra bighorn because it reduces adult survival, which both threatens the persistence of small herd units and reduces or eliminates the ability of larger herd units to provide animals for translocations. Continued monitoring and management of predators are critical components of Sierra bighorn recovery efforts. The completion and implementation of a predator management plan (as recommended in the Recovery Plan) will be an important next step in identifying a strategic approach to mountain lion management, including thresholds for action (e.g., based on predation rates or mountain lion and Sierra bighorn abundance).

Mountain lions in California are a specially protected species (Fish and G. Code § 4800), and the Department exhausts all other recourses before considering translocation or lethal removal (e.g. CDFW Departmental Bulletin 2017-07 Human/Wildlife Interactions in California: Mountain Lion Depredation, Public Safety, and Animal Welfare). However, it is the policy of the state to use all methods and procedures which are necessary to recover threatened and endangered species, explicitly including the regulated taking of other species (Fish and G. Code §§ 2052, 2061), and the Department is authorized to remove or take mountain lions perceived to be an imminent threat to the survival of any threatened, endangered, candidate, or fully protected sheep species (Fish and G. Code § 4801). In some cases, removal (whether lethal or non-lethal) of mountain lions may be prudent to protect Sierra bighorn from predation losses. When mountain lions are lethally removed, the most humane methods feasible should be employed (i.e., those that minimize pain and distress and induce rapid unconsciousness). Methods should be selected in consultation with the Department's Wildlife Investigation Lab (WIL). Removal of mountain lions could be minimized by capturing and radio-collaring as many individual mountain lions as possible, so that (1) only those individuals that pose a threat to Sierra bighorn are targeted for removal and (2) the level of threat posed by a given individual can be evaluated in comparison with conspecifics and prioritized accordingly. Additionally, having more lions collared would enable a more thorough evaluation that any removals have on mountain lion population and social structure, as well as the results of translocation and hazing efforts.

The recommendation to complete and implement a predation management plan is made with the acknowledgement that the Department is currently evaluating the status of several mountain lion populations in central and southern California pursuant to a petition to list a Southern California/Central Coast Evolutionarily Significant Unit (ESU) of mountain lions, or one or more of the six subpopulations, singularly or in combination within the proposed ESU as threatened or endangered under CESA. However, the Eastern Sierra Nevada mountain lion ESU is not proposed for listing and is among the most robust and genetically diverse ESUs in the state. Gustafson et al. (2018) found that Eastern Sierra Nevada ESU, along with the Western Sierra Nevada, Nevada, and North Coast ESUs, are large, genetically diverse, and well-connected, and together may form a single large ESU (Figure 11). Additionally, there is little evidence of gene flow from the Eastern Sierra ESU to the nearest ESUs petitioned for listing (e.g., the Central Coast South, San Gabriel-San Bernardino, Santa Ana, and Eastern Peninsular Range ESUs (Gustafson et al. (2018). Consequently, the petition to list a Southern California/Central Coast (ESU) of mountain lions has no bearing on the take of mountain lions from the Eastern Sierra Nevada ESU.

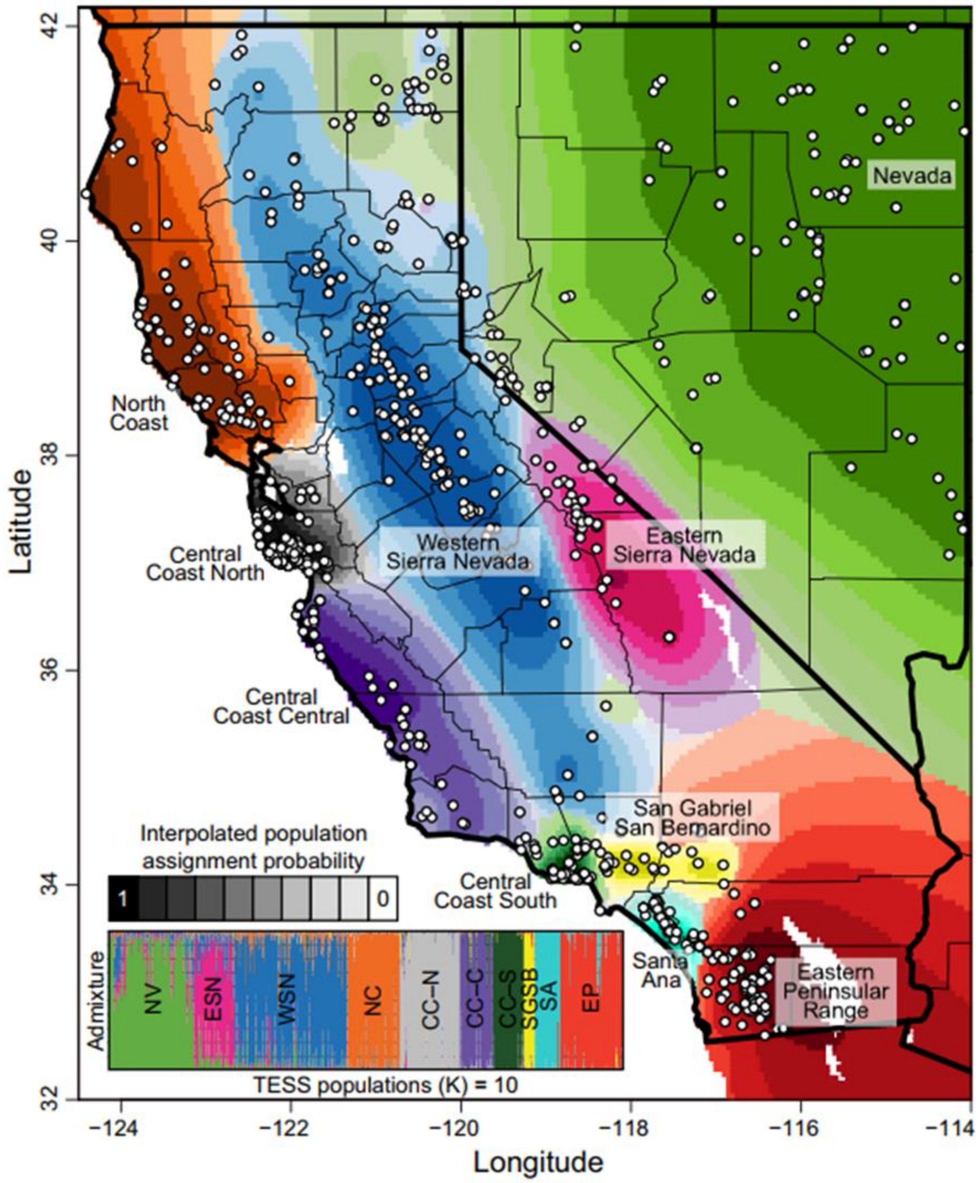

Figure 11. Population genetic structure of pumas across California and Nevada. Individual admixture proportions from TESS spatial population genetic analyses algorithm. Each color represents a genetic population. The decay in color intensity on the map represents lower probabilities of population assignment and indicates areas with admixture between populations. From Gustafson et al. (2018)

iv. Disease Monitoring and Prevention

Continue disease monitoring of bighorn populations by collecting nasal swab and blood samples from captured animals. Captures should occur annually for such disease surveillance to occur. Herds used as sources for translocation should continue to be sampled prior to moving animals.

Continue updating models used to assess the risk of contact between bighorn and domestic sheep. As bighorn sheep populations grow and expand, GPS collars should continue to be deployed on males and females to quantify changes in use of the landscape.

Continue to work with land managers and property owners to eliminate the potential for contact between bighorn and domestic sheep. Domestic sheep should be removed from allotments that are in proximity to bighorn habitat and are identified as high risk (Figure 10). Expand efforts to communicate disease risk to private landowners that have or potentially could have domestic sheep. Encourage cities and counties to discontinue leases for grazing of domestic sheep in proximity to critical habitat. Sierra bighorn cannot be downlisted until the recovery goal is met that ensures measures to prevent contact between bighorn and domestic sheep and goats are implemented and successful.

Authority and approved methods must be established to rapidly euthanize bighorn sheep that come in contact with domestic sheep. Euthanasia is recommended because infected bighorn cannot be reliably treated to prevent subsequent disease transmission. When infected bighorn sheep are permitted to travel back into their habitat and encounter other conspecifics, disease may spread throughout a herd or population with catastrophic consequences. Furthermore, develop a disease response plan that incorporates a test and remove strategy in the event respiratory disease is transmitted to Sierra bighorn.

v. Habitat Protection and Enhancement

Prescribed fires planned for improving habitat for Sierra bighorn should be evaluated to assess forage benefits for bighorn (Greene 2010). Land managers should promote wildland fire policies that allow natural wildfire to burn forest and shrub landscapes in Wilderness that will create open habitats that Sierra bighorn prefer.

Habitat suitability should continue to be considered as translocations are implemented to increase the distribution and genetic diversity of the population (Few et al. 2015). Translocation plans should be reevaluated with updated habitat information and habitat selection analyses as climate and vegetation conditions change.

vi. Human Recreation

Continue to monitor recreational activities that occur in sensitive bighorn habitats such as those used for lambing or wintering. Publication of recent guidebooks has increased rock climbing and backcountry skiing within occupied bighorn habitat.

vii. Competition Mitigation

No action is needed.

VII. RECOMMENDATION TO THE COMMISSION

Pursuant to Fish and Game Code section 2077, the Department has prepared this Five-Year Species Review based upon the best scientific information available to the Department to determine if conditions that led to the original listing are still present. Based on this Five-Year Species Review, the Department submits the following recommendation to the Commission:

In completing this Five-Year Species Review for Sierra bighorn, the Department finds that while Sierra bighorn distribution and abundance have improved with sustained conservation and management actions, there is sufficient scientific information to indicate that the conditions that led to the listing of Sierra bighorn as endangered are still present and recommends no change to the status of Sierra bighorn on the list of endangered species at this time.

VIII. Sources

A. Literature Cited

Bateman, P. C. 1968. Geologic structure and history of the Sierra Nevada. University of Missouri at Rolla Journal: V. H. McNutt Colloquium Series, Volume 1, Article 8.

Baumer, A., N. East, J. Echenique, M. Haworth, M. Leinassar, C. Papouchis, T. Stephenson, D. Weaver, and G. Wilson. 2009. A Process for identifying and managing risk of contact between Sierra Nevada bighorn sheep and domestic sheep. U.S. Fish and Wildlife Service, Ventura, CA.

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

Besser, T. E., E. F. Cassirer, K. A. Potter, J. VanderSchalie, A. Fischer, D. P. Knowles, D. R. Herndon, F. R. Rurangirwa, G. C. Weiser, and S. Srikumaran. 2008. Association of Mycoplasma ovipneumoniae infection with population-limiting respiratory disease in free-ranging Rocky Mountain bighorn sheep (Ovis canadensis canadensis). Journal of Clinical Microbiology 46:423–430.

Besser, T. E., E. F. Cassirer, K. A. Potter, K. Lahmers, J. L. Oaks, S. Shanthalingam, S. Srikumaran, and W. J. Foreyt. 2014. Epizootic pneumonia of bighorn sheep following experimental exposure to Mycoplasma ovipneumoniae. PLoS ONE 9. <https://doi.org/10.1371/journal.pone.0110039>.

Besser, T. E., E. F. Cassirer, K. A. Potter, and W. J. Foreyt. 2017. Exposure of bighorn sheep to domestic goats colonized with Mycoplasma ovipneumoniae induces sub-lethal pneumonia. PLoS ONE 13. <https://doi.org/10.1371/journal.pone.0192006>.

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.

Bleich, V. C., C. D. Hargis, J. A. Keay, and J. D. Wehausen. 1991. Interagency coordination and the restoration of wildlife populations. Pages 277–284 in Natural areas and Yosemite: prospects for the future. J. Edelbrock and S. Carpenter, editors. U. S. Park Service, Denver Service Center, Colorado.

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

Bleich, V. C., J. D. Wehausen, R. R. Ramey II, and J. L. Rechel. 1996. Metapopulation theory and mountain sheep: implications for conservation. Pages 453–473 in Metapopulations and wildlife conservation. D. R. McCullough, editor. Island Press, Washington, D.C.

Bouzat, J. L. 2010. Conservation genetics of population bottlenecks: the role of chance, selection, and history. Conservation Genetics 11:463-478.

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.

Buechner, H. K. 1960. The bighorn sheep in the United States, its past, present, and future. Wildlife Monographs 4:3–174.

Cahn, M. L., M. M. Conner, O. J. Schmitz, T. R. Stephenson, J. D. Wehausen, and H. E. Johnson. 2011. Disease, population viability, and recovery of endangered Sierra Nevada bighorn sheep. Journal of Wildlife Management 75:1753–1766.

California Department of Fish and Game. 2004. Sierra Nevada bighorn sheep recovery and domestic livestock: preliminary risk assessment of disease in the Eastern Sierra. Sierra Nevada Bighorn Sheep Recovery Program, California Department of Fish and Game, Bishop, California. 16 pp., plus appendices.

California Environmental Protection Agency, Office of Environmental Health Hazard Assessment. 2018. Indicators of climate change in California. Sacramento.

Cassaigne I., R. A. Medellín, and J. A. Guasco. 2010. Mortality during epizootics in bighorn sheep: effects of initial population size and cause. Journal of Wildlife Diseases 46:763–771.

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.

Cassirer, E. F., R. K. Plowright, K. R. Manlove, P. C. Cross, A. P. Dobson, K. A. Potter, and P. J. Hudson. 2013. Spatio-temporal dynamics of pneumonia in bighorn sheep. Journal of Animal Ecology 82:518–528.

Chow, L. S. 1992. Population dynamics and movement patters of bighorn sheep reintroduced in the Sierra Nevada, California. Cooperative National Park Resources Studies Unit, University of California at Davis.

Clifford, D. L., B. A. Schumaker, T. R. Stephenson, V. C. Bleich, M. L. Cahn, B. J. Gonzales, 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.

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

Courtemanch, A. B. 2014. Seasonal habitat selection and impacts of backcountry recreation on a formerly migratory bighorn sheep population in northwest Wyoming, USA. M.S. Thesis, University of Wyoming, Laramie.

Cowan, I. M. 1940. Distribution and variation in the native sheep of North America. American Midland Naturalist 24:505–580.

Croft, B., A. Fesnock, M. Haworth, R. Mazur, L. Murphy, S. Nelson, R. Perloff, and T. Stephenson. 2010. Application of the Document Entitled A process for identifying and managing risk of contact between Sierra Nevada bighorn sheep and domestic sheep. U.S. Fish and Wildlife Service, Ventura, CA

Danskin, W. R. 1998. Evaluation of the hydrologic system and selected water-management alternatives in the Owens Valley, California. U.S. Geological Survey Water Supply Paper 2370-H.

Dassanayake, R. P., S. Shanthalingam, C. N. Herndon, R. Subramaniam, P. K. Lawrence, J. Bavananthasivam, E. F. Cassirer, G. J. Haldorson, W. J. Foreyt, F. R. Rurangirwa, D. P. Knowles, T. E. Besser, and S. Srikumaran. 2010. Mycoplasma ovipneumoniae can predispose bighorn sheep to fatal Mannheimia haemolytica pneumonia. Veterinary Microbiology 145:354–359.

Davis, J. L., S. W. Carlson, C. C. Coolahan, and D. L. Orthmeyer. 2012. Sierra Nevada Bighorn Sheep Recovery Program: the role of USDA Wildlife Services, 1999–2011. Sacramento.

Dekelaita, D. J., C. W. Epps, K. M. Stewart, J. S. Sedinger, J. G. Powers, B. J. Gonzales, R. K. Abella-Vu, N. W. Darby, and D. L. Hughson. 2020. Survival of adult female bighorn sheep following a pneumonia epizootic. Journal of Wildlife Management 84:1268–1282.

Dettinger, M., H. Alpert, J. Battles, J. Kusel, H. Safford, D. Fougeres, C. Knight, L. Miller, and S. Sawyer. 2018. Sierra Nevada summary report. California’s fourth climate change assessment.

Domjan, M. 2006. Principles of Learning and Behavior. Fifth edition. Thomson Wadsworth, Belmont, California, USA.

Elbroch, M. 2020. The Cougar Conundrum: Sharing the World with a Successful Predator. Island Press, Washington, D.C.

Ernest, H. B. 2001. A captive breeding contingency plan for Sierra Nevada bighorn sheep. California Department of Fish and Game, Sacramento, CA.

Festa-Bianchet, M. 1986. Seasonal dispersion of overlapping mountain sheep ewe groups. Journal of Wildlife Management 50:325–330.

Few, A. P., D. W. German, B. M. Pierce, J. D. Wehausen, and T. R. Stephenson. 2012. 2011-2012 annual report of the Sierra Nevada Bighorn Sheep Recovery Program. California Department of Fish and Wildlife, Bishop.

Few, A. P., D. W. German, J. D. Wehausen, B. M. Pierce, and T. R. Stephenson. 2013. Translocation plan for Sierra Nevada bighorn sheep. California Department of Fish and Wildlife, Bishop.

Few, A. P., K. Knox, D. W. German, J. D. Wehausen, and T. R. Stephenson. 2015. 2015 Translocation plan for Sierra Nevada bighorn sheep: A focus on strategic planning. California Department of Fish and Wildlife, Bishop.

Fites-Kaufman, J. A., P. Rundel, N. Stephenson, and D. A. Weixelman. 2007. Montane and subalpine vegetation of the Sierra Nevada and Cascade ranges. Pages 456–501 in Terrestrial vegetation of California, 3rd edition. M. Barbour, T. Keeler-Wolf, and A. A. Schoenherr, editors. University of California Press, USA.

Forrester, D.J. 1971. Bighorn sheep lungworm-pneumonia complex. Pages 158–173 in Parasitic diseases of wild mammals. J. W. Davis and R. C. Anderson, editors. Iowa State University Press, Ames.

Forshee, S. 2018. Life on the Edge: Risk of predation drives selection of habitat and survival of neonates in endangered Sierra Nevada bighorn sheep. M.S. Thesis, University of Montana, Missoula.

Gaillard, J.-M., M. Festa-Bianchet, and N. G. Yoccoz. 1998. Population dynamics of large herbivores: variable recruitment with constant adult survival. Trends in Ecology and Evolution 13:58v63.

Gammons, D. J., J. L. Davis, J. A. Dellinger, D. W. German, L. E. Greene, and T. R.

Stephenson. 2019. DRAFT: A strategy for managing predation on Sierra Nevada bighorn sheep. California Department of Fish and Wildlife, Bishop.

Garwood, T. J., C. P. Lehman, D. P. Walsh, T. E. Besser, J. A. Jenks, and E. F. Cassirer. 2020. Removal of chronic Mycoplasma ovipneumoniae carrier ewes eliminates pneumonia in a bighorn sheep population. Ecology and Evolution 10:3491–3502.

Geist, V. 1971. Mountain sheep: a study in behavior and evolution. The University of Chicago Press.

German, D. W., and T. R. Stephenson. 2018. Cost-benefit analysis of mountain lion management for the recovery of endangered Sierra Nevada bighorn sheep. Proceedings of the Vertebrate Pest Conference 28.

Gibbs, E. P. J., and E. C. Greiner. 1988. Bluetongue and epizootic hemorrhagic disease. Pages 39–70 in The arboviruses: Epidemiology and ecology, Volume 2. CRC Press, Inc. Boca Raton, Florida.

Gil, M. A., A. M. Hein, O. Spiegel, M. L. Baskett, and A. Sih. 2018. Social information links individual behavior to population and community dynamics. Trends in Ecology and Evolution 33:535–548.

Greene, L. E. 2010. The short-term effects of wildfire on Sierra Nevada bighorn sheep habitat ecology. M.S. Thesis, University of Montana, Missoula.

Greene, L. E., C. P. Massing, D. W. German, A. C. Sturgill, K. Anderson, E. A. Siemion, J. Davis, D. Gammons, and T. R. Stephenson. 2017. 2016–17 annual report: Sierra Nevada Bighorn Sheep Recovery Program.

Greene, L. E., C. P. Massing, D. W. German, A. C. Sturgill, K. Anderson, E. A. Siemion, J. Davis, D. Gammons, and T. R. Stephenson. 2018. 2017–18 annual report: Sierra Nevada Bighorn Sheep Recovery Program.

Greene, L., M. Hebblewhite, and T. R. Stephenson. 2012. Short-term vegetation response to wildfire in the eastern Sierra Nevada: Implications for recovering an endangered ungulate. Journal of Arid Environments 87:118–128.

Grinnell, J. 1912. The bighorn of the Sierra Nevada. University of California Publications in Zoology 10:143–153.

Gruell, G. E. 2001. Fire in Sierra Nevada forests: A photographic interpretation of ecological change since 1849. Mountain Press Publishing Company, Missoula, Montana.

Hass, C. C. 1995. Gestation periods and birth weights of desert bighorn sheep in relation to other Caprinae. Southwestern Naturalist 40:139–147.

Johnson, H. E., L. S. Mills, J. D. Wehausen, T. R. Stephenson, and G. Luikart. 2011. Translating Effects of Inbreeding Depression on Component Vital Rates to Overall Population Growth in Endangered Bighorn Sheep. Conservation Biology 25:1240–1249.

Johnson, H. E., L. S. Mills, T. R. Stephenson, and J. D. Wehausen. 2010. Population-specific vital rate contributions influence management of an endangered ungulate. Ecological Applications 20:1753–1765.

Johnson, H. E., M. Hebblewhite, T. R. Stephenson, D. W. German, B. M. Pierce, and V. C. Bleich. 2013. Evaluating apparent competition in limiting the recovery of an endangered ungulate. Oecologia 171:295–307.

Jones, F. L. 1950. A survey of the Sierra Nevada bighorn. Sierra Club Bulletin 35:29–76.

Latham, E. L. S. 2010. Changes in bighorn sheep habitat of the Sierra Nevada. MGIS Thesis, University of Calgary, Canada.

Keller, L. F. and D. M. Waller. 2002. Inbreeding effects in wild populations. Trends in Ecology and Evolution 17:230-241.

Manlove, K., E. F. Cassirer, P. C. Cross, R. K. Plowright, and P. J. Hudson. 2016. Disease introduction is associated with a phase transition in bighorn sheep demographics. Ecology 97:2593–2602.

Massing, C. P., D. W. German, and T. R. Stephenson. In preparation. Morphological differences in bighorn populations of California.

Morelli, T. L., M. C. McGlinchy, and R. P. Neilson. 2011. A climate change primer for land managers: An example from the Sierra Nevada. U.S. Forest Service, Pacific Southwest Research Station. Albany, California.

Papouchis, C. M., F. J. Singer, and W. B. Sloan. 2001. Responses of desert bighorn sheep to increased human recreation. Journal of Wildlife Management 65:573–582.

Ramey, R. R. II. 1993. Evolutionary genetics and systematics of North American mountain sheep. Ph.D. Dissertation, Cornell University, Ithaca, New York.

Reich, K., N. Berg, D. Walton, M. Schwartz, F. Sun, X. Huang, and A. Hall. 2018. Climate change in the Sierra Nevada: California's water future. University of California, Los Angeles Center for Climate Science.

Renaud, L., G. Pigeon, M. Festa-Bianchet, and F. Pelletier. 2019. Phenotypic plasticity in bighorn sheep reproductive phenology: from individual to population. Behavioral Ecology 73. <https://doi.org/10.1007/s00265-019-2656-1>.

Riegelhuth, R. 1965. A reconnaissance of Sierra bighorn and bighorn ranges in the Sierra

Nevada. Desert Bighorn Council Transaction 9:35–39.

Ross, P.I, and M.G. Jalkotzy. 1995. Fates of translocated cougars, *Felis concolor*, in Alberta. Canadian Field Naturalist 109:475–476.

Rubin, E. S., W. M. Boyce, and E. P. Caswell-Chen. 2002. Modelling demographic processes in an endangered population of bighorn sheep. Journal of Wildlife Management 66:796–810.

Ruth, T. K., K.A. Logan, L.L. Sweanor, M.G. Hornocker, and L.J.Temple. 1998. Evaluating cougar translocation in New Mexico. Journal of Wildlife Management 62: 1264-1275.

Sawyer, H., and F. Lindzey. 2002. A review of predation on bighorn sheep (*Ovis canadensis*). Wyoming Cooperative Fish and Wildlife Research Unit, Laramie.

Schmidt, K. A., J. Johansson, and M. G. Betts. 2015. Information-mediated Allee effects in breeding habitat selection. The American Naturalist 186. <https://doi.org/10.1086/683659>.

Schroeder, C. A., R. T. Bowyer, V. C. Bleich, and T. R. Stephenson. 2010. Sexual segregation in Sierra Nevada Bighorn Sheep, Ovis canadensis sierrae: ramifications for conservation. Arctic, Antarctic, and Alpine Research 42:476–489.

Shackleton, D. M., R. G. Petersen, J. Haywood, and A. Bottrell. 1984. Gestation period in Ovis canadensis. Journal of Mammalogy 65:337–338.

Spitz, D. B., M. Hebblewhite, T. R. Stephenson, and D. W. Geman. 2018. How plastic is migratory behavior? Quantifying elevational movement in a partially migratory alpine ungulate, the Sierra Nevada bighorn sheep (Ovis canadensis sierrae). Canadian Journal of Zoology 96:1385–1394.

Spitz, D. B., M. Hebblewhite, and T. R. Stephenson. 2020. Habitat predicts local prevalence of migratory behavior in an alpine ungulate. Journal of Alpine Ecology 89:1032–1044.

Stephens, P. A. and W. J. Sutherland. 1999. Consequences of the Allee effect for behavior, ecology, and conservation. Trends in Ecology and Evolution 14:401-405.

Stephenson, T. R., J. D. Wehausen, A. P. Few, D. W. German, D. F. Jensen, D. B. Spitz, K. Knox, B. M. Pierce, J. L. Davis, J. Ostergard, and J. Fusaro. 2012. 2010–2011 annual report of the Sierra Nevada Bighorn Sheep Recovery Program: a decade in review. California Department of Fish and Game, Bishop.

Stephenson, T. R., D. W. German, E. F. Cassirer, D. P. Walsh, M. E. Blum, M. Cox, K. M. Stewart, K. L. Monteith. 2020. Linking population performance to nutritional condition in an alpine ungulate. Journal of Mammalogy. <https://doi.org/10.1093/jmammal/gyaa091>.

Taskey, R. D. 1995. Soil survey of High Sierra area, California. U.S. Department of Agriculture: Forest Service, Pacific Southwest Research Station.

Torres, S. G., T. M. Mansfield, J. E. Foley, T. Lupo, and A. Brinkhaus. 1996. Mountain lion and human activity in California: testing speculations. Wildlife Society Bulletin 4:451–460.

U.S. Fish and Wildlife Service. 2000. Endangered and threatened wildlife and plants; final rule to list the Sierra Nevada Distinct Population Segment of the California bighorn sheep as endangered. Federal Register 65:20–30.

U.S. Fish and Wildlife Service. 2007. Recovery Plan for the Sierra Nevada Bighorn Sheep. Sacramento, California.

U.S. Fish and Wildlife Service. 2008. Endangered and threatened wildlife and plants; designation of critical habitat for the Sierra Nevada bighorn sheep (Ovis canadensis sierrae) and taxonomic revision. Federal Register 73:45534–45604.

U.S. Fish and Wildlife Service. 2019. 5-year review: Sierra Nevada bighorn sheep (Ovis canadensis sierrae). Sacramento, California.

Valdez, R., and P. R. Krausman, editors. 1999. Mountain Sheep of North America. University of Arizona, Tucson.

(WAFWA), Western Association of Fish and Wildlife Agencies, Wild Sheep Working Group, W. 2017. Adaptive Wild Sheep Disease Management Venture (DMV) Strategy.

Wehausen, J. D. 1979. Sierra Nevada bighorn sheep: an analysis of management alternatives. Cooperative Administrative Report, Inyo National Forest and Sequoia, Kings Canyon, and Yosemite National Parks, Bishop, California.

Wehausen, J. D. 1980. Sierra Nevada bighorn sheep: History and population ecology. Ph.D. Dissertation, University of Michigan.

Wehausen, J. D. 1991. Some potentially adaptive characters of mountain sheep populations in the Owens Valley region. Pages 256–267 in C. A. Hall, Jr., V. Doyle-Jones, and B. Widawski, eds. Natural history of eastern California and high-altitude research. University of California, White Mountain Research Station, Bishop.

Wehausen, J. D. 1992. The role of precipitation and temperature in the winter range diet quality of mountain sheep of the Mount Baxter herd, Sierra Nevada. Proceedings of the Biennial Symposium of the Northern Wild Sheep and Goat Council 8:279–292.

Wehausen, J. D. 1996. Effects of mountain lion predation on bighorn sheep in the Sierra Nevada and Granite mountains of California. Wildlife Society Bulletin 24:471–479.

Wehausen, J. D. 1999. Sierra Nevada bighorn sheep: 1999 population status. Unpublished report. University of California, White Mountain Research Station, Bishop.

Wehausen, J. D. 2001. Sierra Nevada bighorn sheep: 2001 population survey results.

Unpublished report to the California Department of Fish and Game.

Wehausen, J. D. 2018. 2018 Status of Sierra Nevada bighorn sheep herds in Yosemite National Park. Annual report to Yosemite National Park. Sierra Nevada Bighorn Sheep Foundation.

Wehausen, J. D. 2020. 2015–2020 Status of bighorn sheep herds that utilize Yosemite National Park. Final report to Yosemite National Park. Sierra Nevada Bighorn Sheep Foundation.

Wehausen, J. D., and M. C. Hansen. 1988. Plant communities as the nutrient base of mountain sheep populations. Pages 256–268 in Plant biology of eastern California. C. A. Hall, Jr. and V. DoyleJones, editors. University of California, White Mountain Research Station, Bishop.

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

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

Weidmann, B. P., and V. C. Bleich. 2014. Demographic responses of bighorn sheep to recreational activities: a trial of a trail. Wildlife Society Bulletin 38:773–782.

Whitting, 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.

Wolfe, L. L., B. Diamond, T. R. Spraker, M. A. Sirochman, D. P. Walsh, C. M. Machin, D. J. Bade, 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.

Woodard, T. N., R. J. Gutierrez, and W. H. Rutherford. 1974. Bighorn lamb production, survival, and mortality in south-central Colorado. Journal of Wildlife Management 38:771–774.

Zhao, Z., P. Di, S. hua Chen, J. Avise, A. Kaduwela, and J. DaMassa. 2020. Assessment of climate change impact over California using dynamical downscaling with a bias correction technique: method validation and analyses of summertime results. Climate Dynamics 54:3705–3728.

IX. LIST OF FIGURES

X. LIST OF TABLES

XI. List of Appendices

Appendix A. Sierra bighorn translocations.

Table 1. Number of translocated Sierra bighorn received by herd unit during 2001–2019, Sierra Nevada, California.

Herd Unit	1979	1980	1982	1986	1987	1988	2001	2003	2005	2009	2013	2014	2015	2016	2017	2018	2020	Total
Big Arroyo												14				5		19
Cathedral Range													13	5	2			20
Convict Creek											3							3
Laurel Creek													11	4				15
Mt. Baxter									1									1
Mt Gibbs				2							3		5					10
Mt Langley		11	15				1											27
Mt. Warren				25		11		2		6							6	50
Mt. Williamson					2				1									3
Olancha Peak											14	4	2			2		22
Sawmill Canyon									3									3
Warner Mtns		10																10
Wheeler Ridge	9	10	4	4														27
Year Total	9	31	19	31	2	11	1	2	5	6	20	18	31	9	2	7	6	210

Table 2. Number of Sierra bighorn donated for translocations by source herd unit (1979–present). The majority of females translocated were pregnant.

Year	Mt. Baxter Herd	Mt. Langley Herd	Sawmill Canyon Herd	Wheeler Ridge Herd	Year Total
1979	2		7		9
1980	25		6		31
1982	10		9		19
1986	31				31
1987	2				2
1988	11				11
2001				1	1
2003				2	2
2005				5	5
2009		3		3	6
2013	1	8	11		20
2014	3		4	11	18
2015	12	12	6	1	31
2016	4		1	4	9
2017	1		1		2
2018	5			2	7
2020				6	6
Total	107	23	45	35	210