A STRATEGY FOR MANAGING PREDATION ON SIERRA NEVADA BIGHORN SHEEP

24 September 2025

A STRATEGY FOR MANAGING PREDATION ON SIERRA NEVADA BIGHORN SHEEP

DANIEL J. GAMMONS, *California Department of Fish and Wildlife, 787 North Main St., Suite 220, Bishop, CA 93514*

PHILLIP A. D. JOHNSTON, *California Department of Fish and Wildlife, 787 North Main St., Suite 220, Bishop, CA 93514*

JEFFREY L. DAVIS, *USDA APHIS Wildlife Services, 3419A Arden Way, Sacramento, CA 95825*

DAVID W. GERMAN, *California Department of Fish and Wildlife, 787 North Main St., Suite 220, Bishop, CA 93514*

LACEY E. GREENE, *California Department of Fish and Wildlife, 787 North Main St., Suite 220, Bishop, CA 93514*

CODY P. MASSING, *California Department of Fish and Wildlife, 787 North Main St., Suite 220, Bishop, CA 93514*

THOMAS R. STEPHENSON, *California Department of Fish and Wildlife, 787 North Main St., Suite 220, Bishop, CA 93514*

ACKNOWLEDGEMENTS

The Recovery Plan for the Sierra Nevada Bighorn Sheep (Recovery Plan; USFWS 2007) identified the top priority task (i.e., Task 2.1) as being 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." A variety of activities have been undertaken since the listing of Sierra bighorn under the Endangered Species Act in 1999 to protect them from predation losses. These activities have been based, in part, on numerous meetings, discussions, and draft document reviews over the years by the Sierra Nevada Bighorn Sheep Recovery Implementation Team's (RIT) Science subteam, which was formed in 2010 after the completion of the Recovery Plan. After various document reviews reflecting different strategies, priorities, monitoring and funding issues, etc., a strategy for achieving this long-standing priority has been prepared.

The California Department of Fish and Wildlife (Department) is grateful for the insights of the RIT Science subteam. RIT Science subteam members who provided peer review of this document included: Dr. Clint Epps (Oregon State University), Dr. Dave Graber (National Park Service), Dr. Rob Klinger (US Geological Survey), Dr. Connie Millar (US Forest Service), Chris Papouchis (California State University, Sacramento), Dr. Eric Rominger (New Mexico Game and Fish), and Dr. John Wehausen (Sierra Nevada Bighorn Sheep Foundation).

DISCLAIMER

Because additional information may be obtained after finalization of the document, data summaries are subject to change. For that reason, data analyses and summaries presented in this document supersede all previously published data and analyses and interpretations may be subject to change contingent on future analyses and the peer review process.

CITATION

Please cite this document as follows:

Gammons, D. J., P. A. D. Johnston, J. L. Davis, D. W. German, L. E. Greene, C. P. Massing, and T. R. Stephenson. 2025. A strategy for managing predation on Sierra Nevada bighorn sheep. California Department of Fish and Wildlife, Bishop, California, USA.

EXECUTIVE SUMMARY

Since the 1800s, Sierra Nevada bighorn sheep (Sierra bighorn; *Ovis canadensis sierrae*) have declined in abundance and distribution and are federally-listed as endangered under the Endangered Species Act of 1973, as amended. Predation by mountain lions (lions; *Puma concolor*) is one of the primary factors that threatens their recovery, and as a result, the Recovery Plan for the Sierra Nevada Bighorn Sheep (Recovery Plan; USFWS 2007) recommended the preparation and implementation of a management plan to protect Sierra bighorn from predation losses. This document describes the current state of knowledge regarding the impacts of lion predation on Sierra bighorn and delineates a strategy for mitigating these impacts.

The objective of managing predation is to prevent mortality of Sierra bighorn that is likely to impede population growth and as a result, delay or prevent reaching recovery goals established in the recovery plan. Thus, lions that have been found to prey upon Sierra bighorn will be subject to removal (lethal removal or translocation). While it is desirable to limit removal of lions to only those documented to have killed Sierra bighorn, lions that are detected within the designated boundary of a Sierra bighorn herd may be subject to removal, regardless of the individual's predation history. Translocation of lions will be the primary method of predation management when feasible. Lethal removal will be used when translocation is not feasible except in the case of adult female lions with dependent young.

Additional non-lethal methods for managing predation (i.e., harassment, habitat manipulation, and sterilization) may be possible in the future, but all have significant drawbacks that make them infeasible currently. Several other options (including no action) were considered but dismissed for reasons including being ineffective at reducing predation, too experimental given the conservation status of Sierra bighorn, or being ecologically unsound.

During the winter of 2016-2017, the Mt. Langley herd—1 of 4 "source herds" from which surplus animals could be removed for translocation purposes—declined from 53 to 27 ewes, primarily due to lion predation. During 2023, two additional source herds (Sawmill Canyon and Wheeler Ridge) declined below 30 animals largely due to lion predation. In 2024, the Mt. Langley herd continued to suffer predation and only numbered 15 ewes. As a result, these three herds are not currently viable sources of translocation stock. It will take many years for these herds to recover to their former size. With only one other source herd remaining (Mt. Baxter), limiting lion predation in Sierra bighorn herds of all sizes has become a matter of urgency. In 2025, the Sierra bighorn overall estimate of adult and yearling ewes was 180, which is a decline from a high of more than 300 ewes in 2015.

INTRODUCTION

From a pre-settlement estimate of greater than 1,000 individuals and a distribution scattered along the Sierra Nevada from Sonora Pass south to Olancha Peak, Sierra bighorn began declining in both abundance and distribution in the mid-1800s, due to a variety of factors (e.g., unregulated hunting and competition with and disease transmission from domestic livestock; USFWS 2007). The California Fish and Game Commission listed them as rare under the California Endangered Species Act in 1972 and upgraded their status to threatened in 1984. By the late 1990s, the population was composed of just over 100 individuals, and it had become apparent that mortality needed to be minimized. In 1999, the California Fish and Game Commission upgraded their status to endangered. That same year, Sierra bighorn received temporary protection from the federal government as well, when they were emergency listed as endangered under the Endangered Species Act (USFWS 1999). In 2000, a final rule was published in the Federal Register listing the Sierra bighorn as endangered (USFWS 2000).

One of the factors identified in the final rule that threatened the population was predation by lions. Between 1976 and 1988 an increase in both the presence of lions as well as predation rates on Sierra bighorn was implicated in a substantial decline of the Mt. Baxter and Sawmill Canyon herds and the virtual extirpation of Sierra bighorn at Mt. Williamson, which were the surviving native herds (Wehausen 1996). Further evidence of the impacts of lion predation on Sierra bighorn came after the lethal removal of one lion each year for 3 years from the Mt. Warren herd, which had been reintroduced during the 1980s. This herd experienced a steep population decline (caused by heavy snow and lion predation) shortly after being reintroduced, but following these lion removals, the herd experienced a rapid population increase (Bleich et al. 1991, Chow 1991, Wehausen 1996).

The Recovery Plan (USFWS 2007) included a list of actions necessary to recover Sierra bighorn to the point that they would no longer be considered endangered under the Endangered Species Act. These actions included, among others, establishing herds in formerly occupied habitat via translocation and developing a management plan to protect Sierra bighorn herds from predation losses in order to "increase population growth by enhancing survivorship and reproductive output of bighorn sheep" (USFWS 2007). As described below, predation management in large part can directly facilitate the ability to proceed with the needed translocations.

PATTERNS OF PREDATION ON BIGHORN

The literature identifies several patterns of predation on bighorn that are consistent across regions and time. One is that lion predation can have strong impacts on small populations of bighorn sheep. Contrary to the hypotheses of early lion researchers such as Hornocker (1970), who thought that group behavior of bighorn sheep in combination with access to escape cover would prevent predation from being an important regulatory factor, abundant research since then from throughout the southwest US and Alberta, Canada indicates that lions can strongly affect small bighorn herds (see a review of these studies in Rominger 2017). Sierra bighorn are no exception, as evidenced by repeated examples of population declines or stagnation associated with heavy lion predation (Gammons et al. 2021, Stephenson et al. 2022).

A second pattern is that controlling lion predation can aid in reversing population declines. Rominger and Goldstein (2008) and Rominger (2017) presented strong evidence that a program of lion removal during 2001-2016 resulted in increased population growth of state-listed bighorn sheep in New Mexico, to the point where de-listing was possible. Prior to initiating lion removal, between 1998 and 2001 three populations of bighorn in New Mexico were extirpated.

A third pattern is that the availability of alternative prey is likely an important factor driving predation rates on Sierra bighorn. In many instances, lions probably kill bighorn sheep because of opportunistic encounters with them while hunting numerically more abundant mule deer. Johnson et al. (2013) suggested that predation could be limiting for Sierra bighorn herds associated with large mule deer populations, like Mt. Baxter and Wheeler Ridge, but that in other large herds where mule deer populations do not overlap bighorn winter ranges, like Mt. Langley, predation should be relatively unimportant (but see the fourth pattern below). Because mule deer are the primary prey of lions in the eastern Sierra Nevada, most predation on Sierra bighorn occurs when mule deer and Sierra bighorn are sympatric on their respective winter ranges. Johnson et al. (2013) found that as the proportion of overlap between Sierra bighorn winter range and mule deer winter range increased, so did predation rates on Sierra bighorn. Even though this area of overlap constituted only a portion of Sierra bighorn winter range, 92% of lion-killed Sierra bighorn were killed within this region.

The fact that lion densities are not maintained by Sierra bighorn, but rather by mule deer and/or a combination of other prey, has important ramifications for lions killing Sierra bighorn that are in small and/or declining herds. Because declines in Sierra bighorn are unlikely to appreciably impact the lion population, there may be little to stop lions from driving small herds to extinction. Lion-mediated extinctions of bighorn sheep have been documented elsewhere. For example, Rominger et al. (2004) reported that a bighorn sheep translocation effort in New Mexico failed primarily because of lion predation, noting that as the bighorn population declined, the predation rate actually increased, which they suspected to be the result of lions being subsidized by domestic cattle. Similarly, the biological extinction of a herd of desert bighorn (i.e., only a single ewe remained at the end of the study) in the San Andreas Mountains occurred when lions killed most of what was left of a herd of 9 bighorn in a span of less than a year (Rominger and Weisenberger 2000). While the functional response (i.e., how predation rates change with changes in prey density) of lions with respect to bighorn sheep is unknown, it seems unlikely that it is a Type III response, in which prey can largely "escape" impacts from predators when they are at low densities, presumably because search time for finding them becomes inefficient (Holling 1959, Jeschke et al. 2002). The apparent lack of a Type III response by lions to declining bighorn herds is concerning, especially for small Sierra bighorn herds.

A fourth pattern is that one or a few lions in a region can be responsible for most predation events within any given period of time. Our data from lions in the Southern Recovery Unit (SRU), where predation on Sierra bighorn has been the most prevalent, indicates that while almost all lions that overlap Sierra bighorn will kill them, during any given period of time, some lions will be more likely to than others. A number of researchers noticing a similar pattern have suggested that such variation in predation rates is largely driven by learned behaviors of individual predators, noting that most lions are not bighorn sheep predators and that the majority of bighorn kills are made by a few "specialist" lions (Ross et al. 1997, Ernest et al. 2004, and Festa-Bianchet et al. 2006). Ross et al. (1997) reported that in Alberta, Canada "the presence of one or a few individual specialist predators may strongly and unpredictably influence demography and behavior." Their data indicated that a single female lion killed 9% (n = 11) of the population and 26% (n=6) of the lambs in a single winter, after having spent >10 years of her life rarely killing bighorn, despite her home range overlapping bighorn winter range. Creeden and Graham (1997) reported that in Colorado "individual lions may now be targeting sheep and have grown adept at killing them…" and speculated that predation was limiting a population that had previously declined due to other causes. Rominger and Weisenberger (2000) reported that in New Mexico "individual behavior of predators can influence population dynamics of prey and are independent of predator density" after describing predation by lions as being the final, proximate cause of extinction in a bighorn population that declined from >200 individuals to a single individual ewe (the ultimate cause was considered disease).

While indeed individual lions have been found to repeatedly kill Sierra bighorn and other lions have not, even with Sierra bighorn available to them, the term "specialist" is problematic, in part because it is often not well defined. We distinguish *specialization* from *selection* following Knopff and Boyce (2007) and Elbroch and Wittmer (2013), where (1) a species that comprises the majority of a predator's diet is one that the predator specializes in and (2) the species that a predator selects disproportionate to availability is one that it selects. Given these definitions, lions could not specialize in killing Sierra bighorn, at least not for any substantial length of time—Sierra bighorn are too rare of a prey item. We suspect that most Sierra bighorn are killed by lions opportunistically when they are hunting mule deer (i.e., both prey species are killed in proportion to availability).

However, during intense predation episodes, lions may temporarily use habitat in a manner that maximizes the availability of Sierra bighorn relative to mule deer. High predation rates on Sierra bighorn in these situations may give the appearance of specialization, selection, or both, and for short periods of time, these behaviors may actually be occurring. For example, Elbroch and Wittmer (2013) found evidence that in Chilean Patagonia, some individual lions preferentially selected endangered huemul (*Hippocamelus bisulcus*) disproportionate to their availability, despite huemul not being selected by the lion population as a whole. But it is also possible that lions are simply killing the most available prey in these situations. Either way, it is important to recognize that stochastic changes in the composition of the lion population, combined with variation between individual lions within a population in their diet choices, can lead to intense and unpredictable episodes of predation on rare prey (Festa-Bianchet et al. 2006, Elbroch and Wittmer 2013, Wittmer et al. 2014).

The finding that only one or a few lions in a region are responsible for the majority of predation events at a given time also indicates that there is no need for wide-scale lion population reductions in order to limit predation on Sierra bighorn. Elbroch and Wittmer (2013) came to the same conclusion in their study of lion predation on endangered huemul, stating "…we conclude that the best strategy for pumas, huemul, and livestock owners is the removal of pumas proven to select rare prey, similar to the management of pumas that select livestock or bighorn sheep in the Sierra Nevada in California…" Certainly, wide-scale population reductions of lions would be less expensive (i.e., there would be no need to radio-collar and monitor lions) and more effective (Ernest et al. 2002, USFWS 2007, Rominger and Goldstein 2008). However, variation in lion behavior permits us to be selective in our removals.

A fifth pattern observed is that Sierra bighorn ewes killed by lions are often of prime-breeding age. During 1999-2017, 42 of the 54 (78%) documented lion-killed ewes were between 2 and 12 years of age. This finding, in combination with body condition data indicating that Sierra bighorn are generally not nutritionally limited (Stephenson et al. 2012, 2020) suggests that little of this predation was compensatory. Predation is expected to be mostly compensatory when populations approach their nutritional carrying capacity, in which case animals would be in poor body condition (Bowyer et al. 2014).

PURPOSE AND NEED

The purposes of this document are to (1) describe the current state of knowledge regarding the impacts of lion predation on Sierra bighorn, and (2) delineate a strategy for mitigating these impacts as recommended by the Recovery Plan (USFWS 2007).

Lion predation is the most common identified cause of death for Sierra bighorn (Table 1). During 2003-2023, lion predation was the cause in 149 of 472 (27%) mortalities of radio-collared Sierra bighorn or 32% of the mortalities for which cause of death could be determined. Lion predation was particularly pronounced in the 4 herds used as source stock for translocations (i.e., Mt. Baxter, Mt. Langley, Sawmill Canyon, and Wheeler Ridge), where the mean annual proportion of mortalities caused by lions for collared Sierra bighorn was 0.48 (± 0.04 SE) (Figure 1). Because predation is manageable, whereas many other causes of mortality are not, mitigation of predation can be an effective method of enhancing Sierra bighorn population growth. Severe winters and snow-related mortality have had a substantial impact on Sierra bighorn, but we cannot manage winter severity. Avalanches are associated with snow, but large snowstorms can occur early in winter or in almost any winter and cause avalanche accidents; the likelihood of being caught in an avalanche is not associated with animal density. Starvation is typically linked to the most severe winters when the least forage is available and deep snow increases expenditure of travel; population density influences the potential for starvation mortality.

Table 1. Causes of death for collared Sierra bighorn and number of deaths observed, 2003-2023.

Cause of death	**Definition**	**Number observed**
Lion predation	Killed by a lion	149
Snow (undetermined)	Died of winter-related causes, including avalanche and starvation, but access limited the ability to differentiate the cause	77
Avalanche	Died in a snow avalanche	62
Starvation	Indicated by lack of fat reserves and/or poor bone marrow condition	38
Accident	Died as a result of physical injury, rock fall, or vehicle-collision	25
Natural causes	Died as a result of old age, birth, or unknown causes; other known causes were excluded	17
Other predator	Killed by a bobcat or coyote	5
Unknown	Cause of death could not be determined	96
Total		469

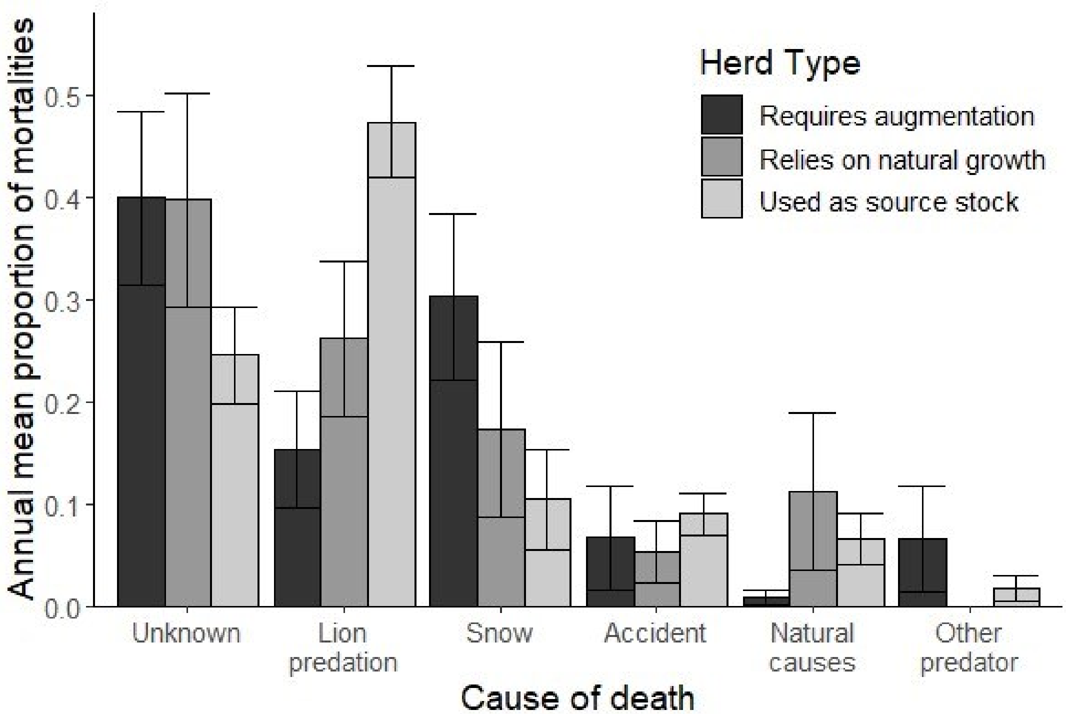

Figure 1. Annual mean proportion (and standard errors) of mortalities caused by different agents within herd types for radio-collared Sierra bighorn, 2003-2023. See Table 1 for definitions of causes of death and Table 2 for herd types. Snow-related includes mortalities caused by avalanche, starvation, and hypothermia.

Limiting predation will reduce extirpation probabilities and increase growth rates for small herds that are vulnerable to further decline from inbreeding, stochastic weather events, and demographic stochasticity. These processes can result in an "extinction vortex" (Gilpin and Soule 1986), which can be exacerbated by predation, especially when an abundant primary prey species such as mule deer (*Odocoileus hemionus*) is available to maintain predator abundance (Rominger et al. 2004, Wittmer et al. 2005, DeCesare et al. 2010, Wittmer et al. 2012, Johnson et al. 2013, Osterback et al. 2013). In these situations, even as secondary prey populations decline, predators may not, meaning that even incidental predation can lead to extirpation of secondary prey populations (Osterback et al. 2013).

Limiting predation is expected to reduce the time needed to reach recovery targets (German and Stephenson 2018, Gammons et al. 2022). The Recovery Plan (USFWS 2007) recommends reaching these targets "as quickly as possible." Given that Sierra bighorn face additional threats besides lion predation, such as the risk of disease introduction from domestic livestock and changing habitat conditions associated with climate change, failure to take advantage of favorable population growth rates when they occur, by translocating Sierra bighorn from source herds, risks that the overall population will be especially vulnerable to changing conditions in the future. While risk of contact with domestic sheep and goats has been reduced since listing, these livestock are still a threat that will prevent delisting of Sierra bighorn if not fully addressed. It is currently unclear to what extent climate change will impact Sierra bighorn, and whether overall climate change impacts will be beneficial or harmful. It is reasonable to conclude, however, that regardless of this uncertainty, larger, more widely distributed Sierra bighorn herds are more likely to persist during a changing climate than smaller, less widely distributed ones. Maximizing Sierra bighorn population growth when conditions are favorable is a strategy that mitigates risks associated with an uncertain future.

CURRENT STATUS OF SIERRA BIGHORN

Sierra bighorn are distributed along the central and southern Sierra Nevada. In recent years, they have occurred within 14 distinct subpopulations known as herd units (Figure 2) that are grouped into 4 recovery units. Following heavy snow and predation during the winter of 2022-2023, there is uncertainty as to whether adult ewes remain in 3 herds (Laurel Creek, Big Arroyo, and the Cathedral Range).

Bighorn Translocation Needs

To meet recovery goals (i.e., occupation of 50 ewes[1] in the Northern, Central, and Kern Recovery Units each and 155 ewes in the Southern Recovery Unit), translocation of Sierra bighorn from large source herds that can withstand removals without negatively impacting their long-term viability are required (Few et al. 2015; Table 2). Until recently, the herds that could support these removals were the Mt. Baxter, Mt. Langley, Sawmill Canyon, and Wheeler Ridge herds. However, largely due to lion predation, the only currently viable source herd is Mt. Baxter—see *Recent Declines* below. Translocations from these source herds are needed to augment low abundance herds (i.e., Big Arroyo, Laurel Creek, Cathedral Range, Mt. Warren, Convict Creek, and Mt. Gibbs). In addition, translocations not directly related to meeting recovery goals may be needed to

[1] Unless otherwise noted, ewes refers to female adult and yearling Sierra bighorn.

(1) augment herds that have persisted for several decades at low abundance and may have problems with genetic diversity (e.g., Mt. Gibbs), (2) establish new herds in remote formerly occupied habitat, primarily as a refuge from the risk of disease from domestic livestock (e.g., Black Divide), and (3) increase occupied habitat within herds that use only a fraction of available habitat (e.g., expanding the Wheeler Ridge herd to include currently unused habitat at Mt. Tom) (Few et al. 2015, Table 2).

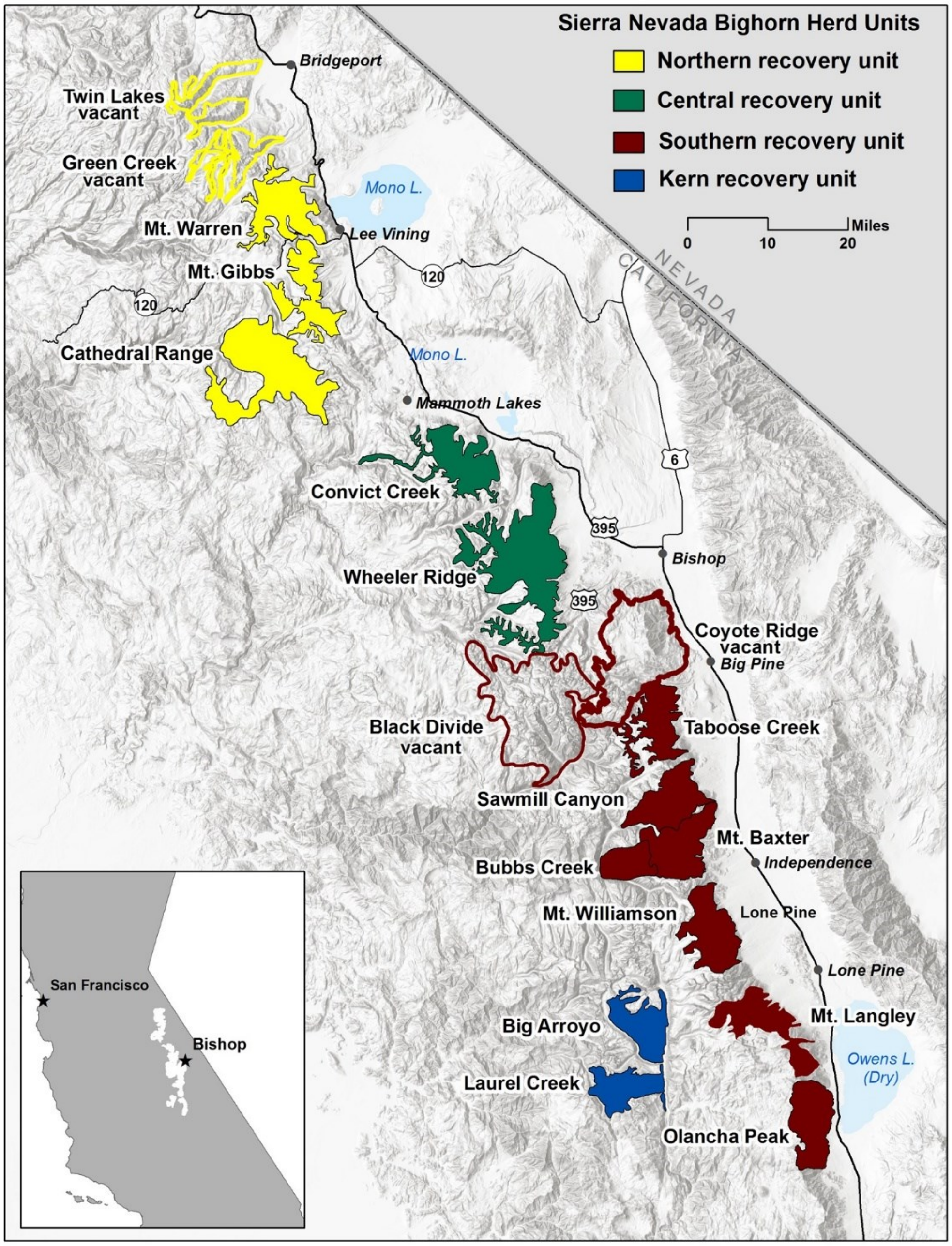

Figure 2. Sierra bighorn distribution. The uncolored polygons have not been occupied in recent years but were believed to be occupied historically. See Table 2 for current estimates on ewe numbers within other herds.

Recent Declines

Recovery efforts since 1999 have resulted in a general trend of increasing abundance of Sierra bighorn until 2016. Heavy snow winters in 2016-2017, 2018-2019, and 2022-2023 depressed abundance of Sierra bighorn through avalanches, starvation, and increased predation risk by concentrating bighorn on winter ranges overlapping with high deer densities (Figure 4). The number of ewes estimated to be present in 2024[2] was only 180 and was well below both the downlisting criteria of 305 ewes (Table 2) and the high of more than 300 ewes observed in 2015. Abundance has declined since 2016 in all 4 recovery units (Figure 3). The number of ewes has declined by about 40% since its maximum in summer 2016.

Table 2. Current status, delisting/downlisting requirements, and translocation plans for Sierra bighorn herds.

Recovery Unit	Downlisting Criteria[1]	2024 Recovery Unit population estimate[2]	Herd Unit	2024 Herd population estimate[2]	Plan to achieve recovery goals	Winter range overlap with deer
Northern	50	11	Cathedral Range	0	Augmentation	None
			Mt. Gibbs	6	Augmentation	None
			Mt. Warren	5	Augmentation	None[4]
Central	50	28	Convict Creek	4	Natural growth[5]	None[4]
			Wheeler Ridge[3]	23	Natural growth[5]	High
Southern	155	136	Bubbs Creek	5	Natural growth	None
			Black Divide	0	Reintroduction	N/A
			Coyote Ridge	0	Reintroduction	N/A
			Mt. Baxter[3]	52	Natural growth	Medium
			Mt. Langley[3]	15	Natural growth	Low
			Mt. Williamson	9	Natural growth	Medium
			Olancha Peak	33	Natural growth[5]	Low
			Sawmill Canyon[3]	30	Natural growth	Medium
			Taboose Creek	2	Natural growth	Medium
Kern	50	0	Big Arroyo	0	Augmentation	None
			Laurel Creek	0	Augmentation	None

[1]Number of ewes required to consider downlisting from endangered to threatened under the Endangered Species Act
[2]Number of ewes estimated to be present from minimum counts
[3]Indicates herd has been used as source of translocation stock
[4]During mild winters, there may be minor winter range overlap
[5]While natural growth is expected to be primarily relied upon, future translocations to these herd units are anticipated to expand distribution within unoccupied areas, improve genetic diversity, etc.

The decline was initiated by a substantial number of mortalities during 2016 in which at least 55 ewes died (17% of the population) along with 67 individuals of other age and sex classes. Subsequently, the winter of 2018-2019 further reduced ewe abundance. The ewe population had rebounded substantially when the severe winter of 2022-2023 occurred; heavy snow reduced ewe populations that lived at higher elevations and predation depressed ewe populations on low elevation winter ranges. For the source herds needed for translocation specifically, lions killed a minimum of 19 Sierra bighorn in the Mt. Langley herd during the winter of 2016-2017 and the

[2] Unless otherwise noted, years refer to biological sheep-years (May 1-April 30).

population decreased from 53 to 27 ewes by the following spring. In 2023, the Sawmill Canyon and Wheeler Ridge herds declined to below 30 animals, largely the result of lion predation. The Mt. Langley herd continued to suffer from lion predation and by 2024, declined to 15 ewes. As a result, the only herd currently large enough to serve as a source of translocation stock is the Mt. Baxter herd. Limiting lion predation in Sierra bighorn herds of all sizes has become a matter of urgency.

The reduction in ewe abundance has set recovery back by decades, both by (1) slowing recovery in the herds that rely on natural growth or augmentation, making them more vulnerable to extirpation, and by (2) reducing the sizes of the source herds from which translocation stock is available, meaning that fewer animals are available for supplying recipient herds (Table 2).

As of 2025, the six herds that require augmentation—Big Arroyo, Cathedral Range, Laurel Creek, Convict Creek, Mt. Gibbs, and Mt. Warren—have been observed to have 0, 0, 0, 3, 6, and 5 ewes in them, respectively. In addition, the number of herds of sufficient size (greater than 40 ewes) to provide translocation stock has declined from four herds to one (Table 2).

Sierra bighorn recovery will only occur in a timely manner if ewe population declines can be halted, population growth rates increase, and adequate translocation stock becomes available to augment herds that require it. A transition from no or low growth rates (r<0.02) to high growth rates (r>0.1) can enable herds to double in size in years, not decades (Gammons et al. 2021). Currently, lion predation is limiting growth in herds used as translocation stock from providing the surplus population growth that is necessary.

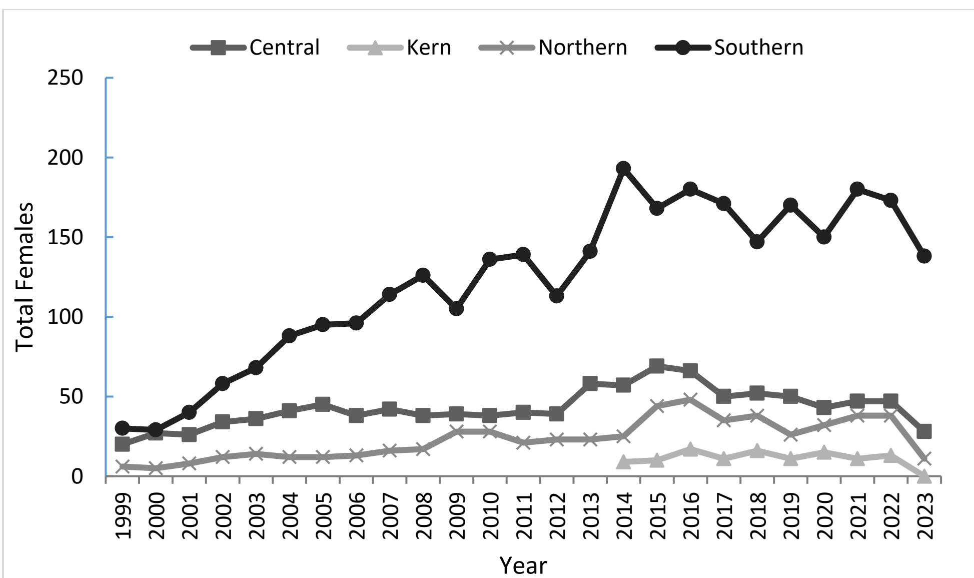

Figure 3. Abundance of Sierra bighorn ewes (females >1 year old) within each of the 4 recovery units, 1999-2023.

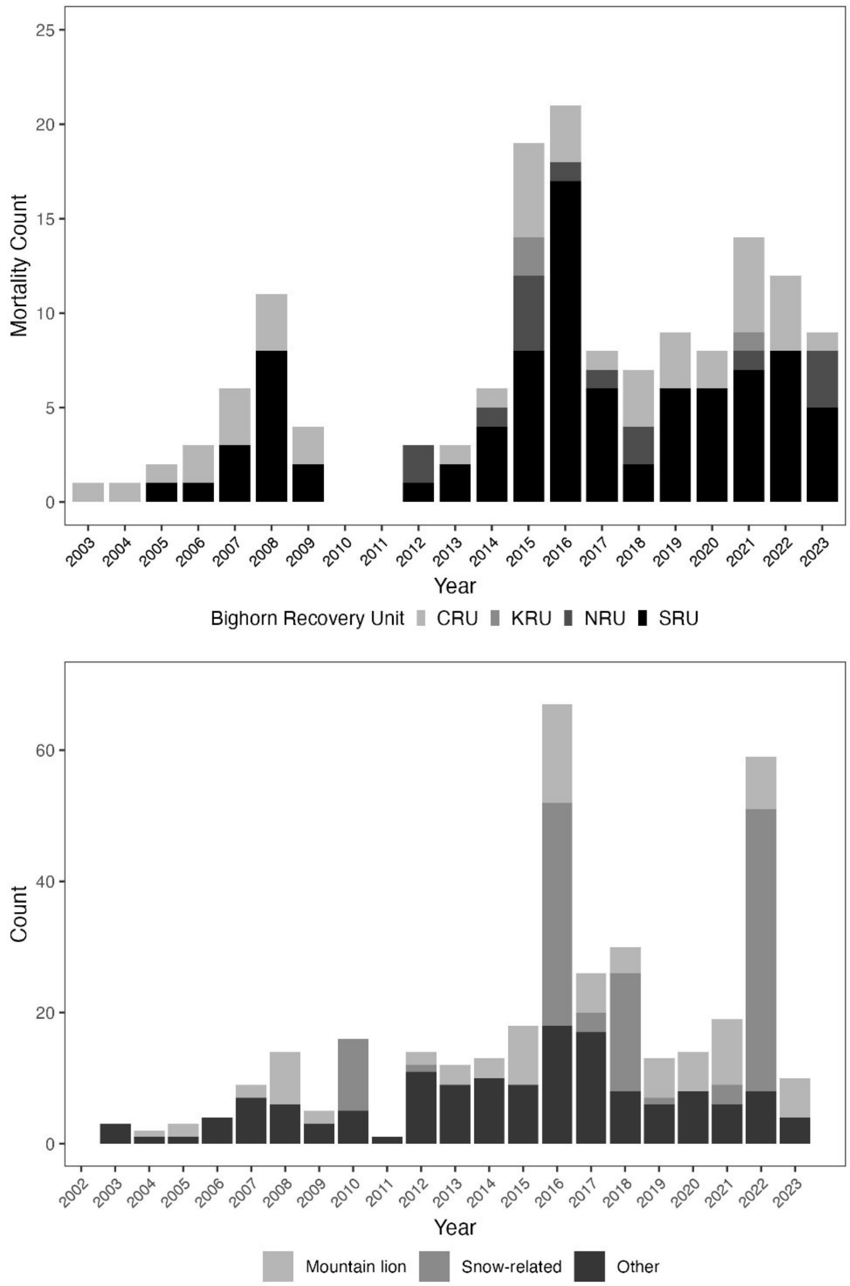

Figure 4. Sierra bighorn mortalities from 2003-2023. Top: Lion-killed collared Sierra bighorn by recovery unit. Bottom: Collared female Sierra bighorn mortalities within each of the 4 recovery units. Snow-related includes mortalities caused by avalanche, starvation, and hypothermia.

OBJECTIVE

The objective of managing predation is to prevent mortality of Sierra bighorn that is likely to impede Sierra bighorn population growth and as a result, further delay or prevent reaching the recovery goals established in the Recovery Plan (USFWS 2007). Lion predation of Sierra bighorn must be restricted to ensure that distribution and population sizes represent a significant buffer against extinction and loss of genetic diversity. This objective will be met by monitoring both

Sierra bighorn and lions to document when predation occurs and removing lions when certain conditions have been met.

AUTHORITY

Section 4801 of the California Fish and Game Code states: "The department may remove or take any mountain lion, or authorize an appropriate local agency with public safety responsibility to remove or take any mountain lion, that is perceived to be an imminent threat to public health or safety or that is perceived by the department to be an imminent threat to the survival of any threatened, endangered, candidate, or fully protected sheep species."

LION REMOVAL

Translocation of lions will be the primary method of predation management, when feasible. Following documented threats of predation on Sierra bighorn, every effort will be made to translocate target lion(s). Translocation is defined as the capture and transport of lions to a release site that is sufficiently distant from the capture location to minimize the likelihood of return.

Lethal removal may be considered when translocation is not feasible except in the case of adult females with dependent young. The Department requires approval by internal upper management prior to taking either action, translocation or lethal removal, and it will be consistent with current Department policies and procedures.

While it is likely that many lions in the eastern Sierra prey primarily upon mule deer, the dominant prey item available, prey selection can be variable among individual lions (Elbroch and Wittmer 2013, Wittmer et al. 2014, Lowrey et al. 2016), and not all individuals are expected to prey upon Sierra bighorn to the same degree, or even at all. Thus, we will employ a targeted approach focusing on the removal of individual lions known to threaten Sierra bighorn.

- Detection of lion-killed Sierra bighorn and identification of the responsible lions

  Lion-killed Sierra bighorn will be identified by (1) investigating deaths of collared Sierra bighorn, (2) locating Sierra bighorn mortalities opportunistically while conducting fieldwork, and (3) investigating GPS clusters of collared lions. Because lions often repeatedly return to sites where they have cached a large prey item over the course of several days, locations that collared lions visit on consecutive nights can be investigated for Sierra bighorn prey (Anderson and Lindzey 2003).

  Since 2017, 62.5% of lion predation on Sierra bighorn (n=120) has been detected through feeding activity clusters observed in GPS data from collared lions. Thus, maintaining functioning GPS collars on a high proportion of the lions that live within and adjacent to Sierra bighorn is critical.

  Lions that prey upon and threaten Sierra bighorn will be identified by: 1) GPS feeding clusters from collared lions, 2) capture efforts at predation sites (cage-trapping and pursuit with hounds on lion-killed bighorn carcasses), 3) physical evidence outlined in McBride et al. 2008 including unique markings in photographs, morphometric track measurements, and age of dependent offspring.

- Lion removals – translocation vs. lethal

Lions which are documented to prey on Sierra bighorn will be removed either by translocation or lethally. Translocation will be the only method used to remove adult females and their dependent offspring, which will be translocated together as a group. Translocation will be the preferred method (i.e., used whenever feasible) to remove (1) adult females that are confirmed to be without dependent young and (2) independent subadults, as these sex and age classes have shown equivalent or increased probability of annual survival in translocated vs. non-translocated individuals (CDFW, unpublished data). Translocation of adult males will be evaluated on a case-by-case basis. Translocation may not be used when it is deemed infeasible due to inhospitable terrain or unacceptable levels of loss posed to vulnerable Sierra bighorn herds. Lethal removal may be used when translocation is deemed infeasible. Lethal removal will not be used on adult females unless they are confirmed to be non-reproductive.

- Translocation of mountain lions as an effective method to reduce predation on Sierra bighorn

Annual survival was high in translocated females (0.83 ± 0.18 SE) and independent subadults (0.875 ± 0.13 SE), but lower in adult males (0.33 ±0.81 SE). In a small sample size of three, two adult males have shown a tendency to return to their established home-ranges after translocation, potentially limiting the effectiveness of this predation reduction strategy for that age class, though further evaluation may be warranted. Adult females tend to pose a greater predation risk to Sierra bighorn due to their tendency to concentrate their movements around smaller areas of dense prey availability and exhibit increased kill-rates while rearing young. Alternatively, adult males tend to distribute their movements over a broader geographic area in an effort to maximize their breeding opportunities, generally resulting in lower predation rates on any given herd. Removing adult females from Sierra bighorn herd units and adjacent areas may also limit use of those areas by adult males and reduce the value of that habitat through a lack of breeding opportunities. These results are encouraging because the annual survival rates of the age/sex classes of translocated lions broadly mirror their respective predation patterns on Sierra bighorn.

- Translocation of lions threatening Sierra bighorn when predation is unconfirmed

In addition to removing lions known to prey on Sierra bighorn we will also proactively translocate lions that are deemed to pose an unacceptable threat to Sierra bighorn herds in the following instances:

1. <u>Larger herds</u>

Because even the larger herds may have an annual available surplus of only 2-3 ewes/year (Few et al. 2015), once 2 bighorn of either sex have been preyed upon within a year, the risk of further predation should be limited, even if the responsible lion(s) cannot be definitively identified. Therefore, lions overlapping Sierra bighorn herds of any size may be translocated whether or not they have been documented preying on Sierra bighorn if the herd has reached this predation threshold.

2. <u>Vulnerable herds</u>

   Lions occupying herd units with 15 ewes or fewer may be translocated whether or not they have been documented to prey on Sierra bighorn, as even the loss of one individual in these cases greatly increases that herds vulnerability to extirpation.

3. <u>Female lions in proximity to vulnerable herds</u>

   Female lions may be translocated if they live within or adjacent to vulnerable herds (those with 15 ewes or fewer or having experienced 2 or more predation losses within the animal year) in order to dissuade males from occupying the area by limiting breeding opportunities.

4. <u>Extremely vulnerable herds</u>

   Sierra bighorn herds that reach a minimum threshold of 5 ewes or fewer may be protected from predation via lion removals by either translocation or lethal removal as necessary to avert the imminent threat of extirpation.

MANAGEMENT PHILOSOPHY

It is important to recognize that there are differences between Sierra bighorn and lion populations that result in differential consequences for mortality and therefore different thresholds of removal tolerance between the two species (Table 3). Sierra bighorn are federally-listed as endangered, and predation mortality can be catastrophic. It may result in (1) substantial decreases in source herds that are needed for translocation efforts or (2) extirpation of herds that will not recolonize on their own in any reasonable time frame.

On the other hand, the removal of lions to protect Sierra bighorn is not catastrophic to the viability of lion populations, which are widely distributed throughout the western US. In California specifically, lions are not exposed to traditional human mortality sources such as regulated hunting that occur elsewhere within their distribution due to their designation as a "specially protected species" (California Fish and Game Code section 4800). As apex predators, lions exist at low densities, but they are in no danger of extinction. In contrast to Sierra bighorn, lions have excellent dispersal and recolonization capabilities (Pierce and Bleich 2003). For example, after all known lions were removed from the Southern Recovery Unit in 2009 and 2010 (n = 8 lions that killed at least 33 Sierra bighorn), a female lion was detected in the area the following winter and by March of 2011 a male who had previously lived north of the Southern Recovery Unit had moved south to occupy the area (Davis et al. 2012). Finally, removal of lions by the Department will be restrained to the minimum necessary.

These differential consequences for removal between Sierra bighorn and lions mean that as a matter of management philosophy, given the choice between occasionally removing lions and permitting an unmanaged lion population to impede Sierra bighorn population growth and recovery, the former choice is appropriate.

Additional Considerations

When contemplating removal of a lion, it will be important to consider a variety of factors such as age, sex, family history (i.e., whether the mother, if known, has a history preying upon Sierra bighorn), availability of alternate prey, weather conditions, season of the year, stalking cover availability, relative value of expending resources to pursue and capture one lion vs. another, etc.). As an example, consider an old male that has been collared for several years without a history of Sierra bighorn predation occupying the winter range of a small Sierra bighorn herd of < 15 ewes. Removing this lion may actually be counter-productive if it results in an increased density of younger-male lions via immigration (Robinson et al. 2008). On the other hand, it may be prudent to risk trading a known lion for one or more unknown lions, especially if the Sierra bighorn herd could benefit from a predator-free environment, prior to the vacant lion home range being re-filled. The circumstances warranting removal of an individual lion (whether by translocation or lethal removal) as outlined above will guide predation management efforts and will be modified when necessary to ensure the best outcomes for Sierra bighorn recovery and minimize unnecessary removal of lions.

Table 3. Comparison of characteristics between Sierra bighorn and lions.

	Sierra bighorn	**Lions**
Conservation status	Federally and state listed as endangered, defined as "in danger of extinction within the foreseeable future throughout all or a significant portion of its range"	Specially protected, a legal designation that does not imply rarity
Source of conservation status	Scientific investigation and federal law	Public referendum in CA
Distribution	Restricted to Sierra Nevada	Throughout much of North and South America
Recolonization ability following localized extirpation	Low; decades to centuries	High; weeks to months
Can recolonize vacant habitat without management assistance	Not generally	Yes
Connectivity with other populations	Extremely low; isolated for the last 300,000 years	Gene flow with other populations is common
Reproductive potential	Low; 1 lamb/ewe/year Upon loss of offspring, cannot breed until following breeding season	High; 2-4 kittens/female/1.5 yrs Upon loss of offspring, may breed soon thereon
Susceptibility to other mortality factors (e.g., droughts, severe winters, disease)	High	Low
Genetic concerns	High	Low

Special Considerations for National Parks

Several Sierra bighorn herds are wholly or largely within national parks (i.e., Big Arroyo, Bubbs Creek, Cathedral Range, and Laurel Creek). These herds are currently quite small, meaning that predation could increase their risk of extirpation. While both Yosemite and Sequoia and Kings Canyon National Parks previously agreed to "cooperate with the pursuit and removal of bighorn sheep predators from park lands" (USDA 1999), predation management in these herds may be difficult. The remoteness of these areas would make collaring and capturing lions logistically more challenging compared to herds that are located outside of national parks. In addition, predation management within National Park Service units is likely to be controversial with the public, therefore predation management activities will not be conducted within National Park Service lands without consultation with and approval by park superintendents. It may also be prudent to work with National Park Service public affairs specialists to develop outreach materials explaining the importance of predation management.

OTHER OPTIONS TO CONSIDER FOR REDUCING PREDATION

Harassment

Early predation management to protect Sierra bighorn called for experimental use of harassment (USDA 1999). Davis et al. (2012) described 9 attempts to use harassment during 1999-2011 with limited success although noting that objective assessment was difficult. Davis et al. (2012) suggested that harassment may be most beneficial with lions that are outside of their core home range (which could only be determined by examination of the space use patterns of collared animals, an example of the importance of monitoring individual lions) or with sub adults near their age of dispersal. While harassment is not anticipated to be a substantial component of Sierra bighorn predation management, its use may be incorporated occasionally.

Habitat Manipulation

The Recovery Plan (USFWS 2007) recommends the use of prescribed fire to enhance Sierra bighorn habitat. Greene et al. (2012) found that large natural fires can benefit Sierra bighorn by increasing forage availability on their winter range and suggested that a reduction in cover could also decrease predation risk, by increasing visibility for Sierra bighorn to detect predators. While conducting large-scale prescribed burns on Sierra bighorn winter ranges is outside the authority of the Department, the National Park Service, USFS (US Forest Service), and BLM (Bureau of Land Management), who manage most Sierra bighorn winter range, may be encouraged to let wildfires burn, when possible, in addition to implementing prescribed burns.

Sterilization

Sterilization of female lions, particularly if estrus can be interrupted, may result in reduced predation on Sierra bighorn, for the following reasons:

- If a substantial portion of the resident female lions can be sterilized, a decrease in lion density is expected over time. This will likely reduce encounter probabilities between lions and Sierra bighorn.
- If there is a reduction in the proportion of estrus females it may also result in decreased male lion densities as well. Estrus females likely attract concentrations of potential mates from substantial distances away (Allen et al. 2015).

Other potential benefits of sterilization include reduced need for removing lions to protect Sierra bighorn and reduced costs associated with their pursuit and capture. There are substantial hurdles with sterilizing lions (e.g., capturing lions in areas accessible to veterinary staff, ensuring a sterile surgical environment, providing adequate post-operative care, etc.). It is also unknown how sterilization would affect lion behavior, habitat selection, and prey choices. Consequently, this option is not available in the immediate future.

OPTIONS CONSIDERED BUT DISMISSED

No Action

Taking no action to address predation management for Sierra bighorn is dismissed because of the documented negative impacts that predation has on recovery efforts. Taking no action would be contrary to the recommendations of the recovery plan (USFWS 2007).

Permit Additional Lion Predation

We considered limiting predation to a "sustainable level", where the amount of predation would not likely contribute to negative Sierra bighorn growth rates (i.e., setting a predation threshold that would attempt to prevent ewe survival rates from falling below 0.90, a value that, assuming other demographic rates remain within the range of historic variability, would permit annual population growth rates to remain stable). While such a strategy could prevent lion predation from driving herds to dangerously low abundance, it would inhibit the ability to translocate surplus ewes from source herds and slow population growth rates in the smaller herds, increasing the probability that demographic or environmental stochastic catastrophes will occur. Because the Recovery Plan (USFWS 2007) recommended translocating Sierra bighorn into vacant habitat "as quickly as possible," permitting lions to prey upon Sierra bighorn at higher rates is in conflict with the Recovery Plan.

Deer Population Reduction

Wittmer et al. (2012) suggested that the simultaneous control of predators and alternate prey is the strategy most likely to increase abundance of rare prey in the long-term. Gibson (2006) recommended this approach specifically for Sierra bighorn. However, there are reasons that adopting such an approach would be difficult. These include the following:

- The most effective method of reducing the deer population would be to institute an antlerless harvest. However, antlerless harvests of mule deer have been controversial in California since the 1950s, when authority to grant antlerless harvests was given to County Boards of Supervisors in 37 of California's 58 counties, including Inyo and Mono Counties where Sierra bighorn occur. Public opinion has often not supported these hunts and, therefore, county Supervisors often reject them (CDFW 2008). During February-June 2024, members of the public expressed concern about a declining mule deer population in the eastern Sierra and encouraged the Department to prevent the decline. The Department does not have the authority to solely authorize antlerless hunts and this is unlikely to change in the near future. Nevertheless, a natural decline in eastern Sierra mule deer appears to be occurring.
- There does not appear to be a clear relationship between Sierra bighorn abundance, deer abundance, and predation rates on Sierra bighorn. Villepique et al. (2011) examined scats of lions during 1991-1995 in the Central Recovery Unit and found that few contained remains of Sierra bighorn. They suggested that there was little evidence that lions switched prey species during a period of relative scarcity of their primary prey (this study was conducted when the mule deer population was less than 25% of its former size). However, the Central Recovery Unit Sierra bighorn population was extremely small (i.e., less than10 ewes in the Wheeler Ridge herd) at the time of the study and a substantial amount of predation on the herd would have been unlikely to have been detected through scat

analysis. In contrast to the suggestion by Villepique et al. (2011) that low deer abundance may not result in increased predation on Sierra bighorn, current data are less conclusive. Predation rates are highest in the Southern Recovery Unit, where deer densities are lower than the Central Recovery Unit. Further research is necessary to more fully understand the relationship between mule deer, Sierra bighorn, and lions.

- Reducing deer density may result in reduced lion abundance, but there would likely be a significant time lag. Pierce et al. (2012) found that in Round Valley, this lag was up to 8 years following a natural decline in deer abundance. If the lions that remain following mule deer population reduction do increase predation rates on Sierra bighorn, lion removal rates will also likely have to increase. To minimize lion removal to the minimum extent necessary, it is prudent to avoid manipulating deer herds.

While there is some evidence that deer density manipulation combined with lion removal may be beneficial to Sierra bighorn, substantial uncertainty in effects exists and this option is dismissed due to the endangered status of Sierra bighorn and a lack of support from the public. While it may be beneficial to experiment with these techniques to gain a better understanding of ecosystem function, it is not prudent at this time to conduct such an experiment.

Range-Wide Lion Removal

Range-wide removal of lions, as opposed to selective methods, has been suggested as the most efficacious method for reducing predation on bighorn sheep (Rominger and Goldstein 2008). This would certainly increase population growth rates in Sierra bighorn, and the Recovery Plan (USFWS 2007) states “the one sure way of protecting endangered Sierra Nevada bighorn sheep from the potential negative effects of predation would involve long-term, indiscriminate removal of predators.” This type of control program is undesirable for the following reasons:

- Lions are classified as a “specially protected species” in California and as such, their removal should be minimized to the extent possible.
- Lions serve a variety of important and often overlooked ecological roles (e.g., providing “habitats” for carrion-dependent invertebrate species, *see* Barry et al. 2019), and thus their complete absence from the local ecosystem is undesirable. As apex predators, lions clearly impact prey populations, although the role that lions have in limiting mule deer populations is controversial. For example, Hurley et al. (2011), in a large-scale predator manipulation experiment, found that lion control was ineffective at increasing mule deer population growth in Idaho, and that climate was the most significant factor impacting mule deer dynamics. In contrast, Pierce et al. (2012) found that in Round Valley, lion predation can be important in limiting, but not necessarily regulating, mule deer abundance. Regardless, potential irruptions in mule deer following range-wide lion removal must at least be considered a possibility (Binkley et al. 2006, Ripple and Beschta 2006). Should such an irruption occur, there may be wide-ranging negative ecological consequences.
- There may be benefits to Sierra bighorn of living in a “landscape of fear” where predators exist (Laundré et al. 2001). Anti-predator behaviors may wane in animals that are not

exposed to the threat of predation[3] (Griffin et al. 2000). If the threat of predation is eliminated, it is possible that once control of lions is released, Sierra bighorn that have lived for generations will be naive to the risk and be highly susceptible to predation.

UNCERTAINTIES AND RISK REGARDING PREDATION MANAGEMENT

Sierra Bighorn Carrying Capacity

Carrying capacity and the strength that density dependence has in regulating population dynamics are fundamental ecological concepts (Caughley and Sinclair 1994). They are especially important to consider with respect to predation management because the effects of predator removal will be largely dependent on whether a population is well below or near carrying capacity. Predation management is expected to provide benefits to populations well below carrying capacity, where mortality is likely additive, but for populations that are near carrying capacity and experience strong density-dependent reductions in vital rates, predator removal may have little effect, as the prey animals "saved" from predation are the "doomed surplus" that will die anyway (Bergman et al. 2015). Because carrying capacity can fluctuate widely as weather affects forage supply, the same amount of predation on the same size population can vary from completely additive to completely compensatory, depending on the year (Bergman et al. 2015).

Determining where a population is on the trajectory towards its carrying capacity is difficult (Bergman et al. 2015). Johnson et al. (2010) found evidence that both adult female survival and recruitment/fecundity decreased in the Mt. Langley and Wheeler Ridge herds as they increased in size but could not distinguish the extent that apparent carrying capacities were food-based or predator-based. Stephenson et al. (2012) analyzed several lines of evidence for these two herds and found some evidence of density dependence but could not make definitive conclusions despite access to extensive data on a number of demographic parameters. The small size of current populations of Sierra bighorn suggests that they remain below nutritional carrying capacity. Stephenson et al. (2020) quantified body fat of Sierra bighorn across the majority of herds and noted that most females had sufficient fat reserves to survive winter, particularly on low elevation winter ranges.

Gammons et al. (2021) identified multiple lines of evidence to suggest that predation by mountain lions on Sierra bighorn was additive. Given the status of Sierra bighorn as a federally-listed endangered species, the consequences of incorrectly assuming that predation management is not beneficial are more severe than incorrectly assuming that it is.

Impacts to Lions from Predator Management

Monitoring of lions via radio-telemetry, using VHF and/or GPS collars, is an essential component of managing predation on Sierra bighorn. Collars facilitate identification of specific individual lions that may be of concern as well as aid in removing uncertainty in distinguishing uncollared individuals from each other (McBride et al. 2008). Detailed information on life-history characteristics can also be obtained, such as age and sex-specific survival and reproductive rates, immigration, emigration, causes of mortality, and habitat use.

[3] Perhaps the most vivid example of this phenomenon is with ungulates in national parks where hunting is prohibited. In these areas, the threat of the human predation has been eliminated and ungulates often do not exhibit avoidance behavior, becoming habituated to the presence of their former predator.

Lions will be captured and collared primarily east of the Sierra crest and west of Highway 395, in areas where there is high potential for overlap with Sierra bighorn winter range. It is possible to collar most lions that may overlap with Sierra bighorn (Davis et al. 2012). With a large proportion of the lion population collared, annual counts of the minimum number known alive will be made by categorizing physical evidence during repeated surveys using remote cameras and physical sign such as tracks, scat, scrapes, and kills to distinguish between and count uncollared individuals (McBride et al. 2008). Counts made in this manner are expensive and rely on expert lion trackers. They produce no quantitative assessment of error relative to the true population size, but are considered to be a most reliable method to monitor lion population density, age and sex ratios, etc. (CMGWG 2005). Mark-resight estimates with confidence intervals may be calculated using marked lions detected on a camera array (Murphy et al. 2019). Information collected from this intensive monitoring program will be used to assess the impacts of lion removals on the lion population, helping to put Sierra bighorn recovery efforts in a larger ecosystem context (USFWS 2007). Anticipated impacts, based on previously collected data, are described below.

The Environmental Assessment (USDA 1999), in which the impacts of killing lions to protect Sierra bighorn were initially evaluated, removals of 3-5 lions per year (identified as the most likely scenario) were concluded to result in a "low magnitude" impact to lion populations. From 1999-2011, an average of 1.8 lions (1.3 adults) were killed annually to protect Sierra bighorn (a total of 24 lions), substantially less than the "worst-case" scenario projected by the Environmental Assessment (USDA 1999) (Figure 6). For future predation management activities, the Department anticipates conducting similar levels of lion reductions. Minimum counts of adult lions in the eastern Sierra during 1999-2010 ranged from 7-15, averaging 5.3 adult males and 5.4 adult females (Figure 5). Starting in 2022 we significantly increased capture and survey efforts by more than doubling camera deployments and hiring additional capture staff, which yielded a minimum count of 43 adults (27 females, 16 males) for that year. It is unclear whether this dramatic increase in lion minimum counts is due to an actual population increase or improved detection probability resulting from greater effort.

During 2020-2023, 19 lions were translocated out of Sierra bighorn habitat to protect Sierra bighorn (average of 4.75 per year; Figure 6). We anticipate removing approximately 10-30% of the adult population in the eastern Sierra annually, based on minimum count data. This rate is within the range of human-caused mortality under which hunted lion populations remain stable, likely because of high immigration rates from surrounding areas (Robinson et al. 2008, Cooley et al. 2009). However, the rate may be higher than the maximum harvest threshold of 14% suggested by Beausoleil et al. (2013) for minimizing disruption to lion social organization (i.e., higher harvests may shift lion populations to a younger age structure).

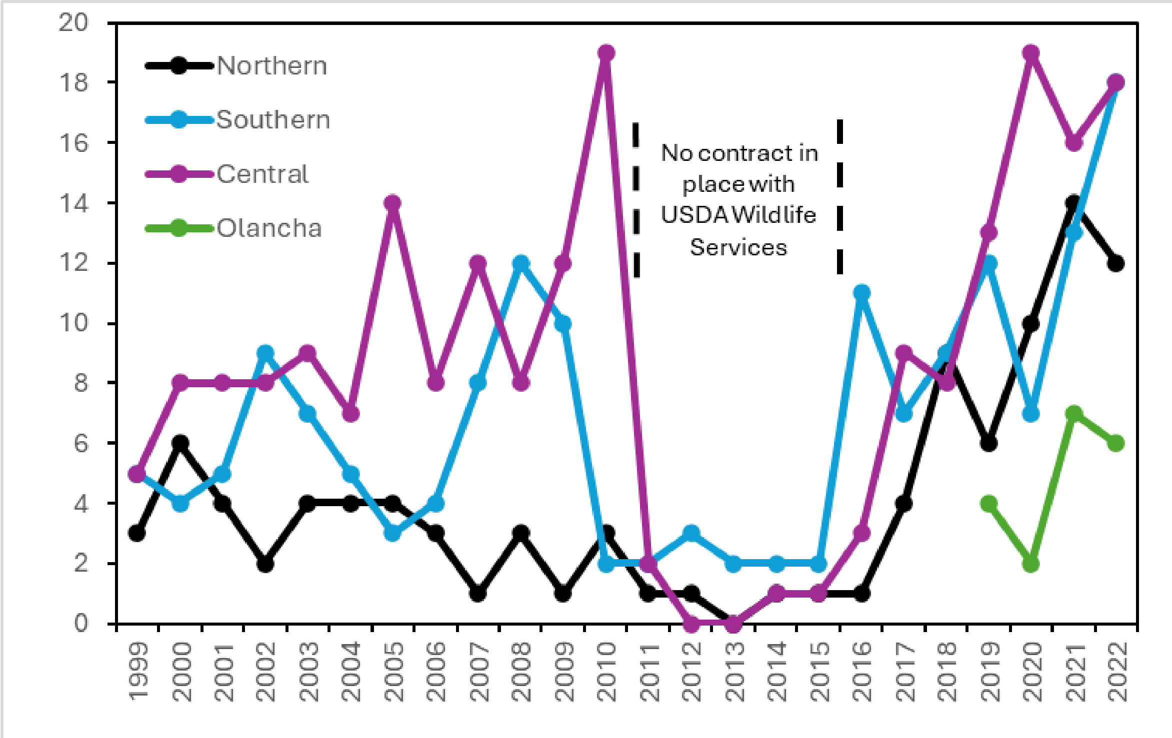

Figure 5. Minimum counts of mountain lions in eastern Sierra count zones, 1999-2021. Efforts to monitor lions have varied over time.

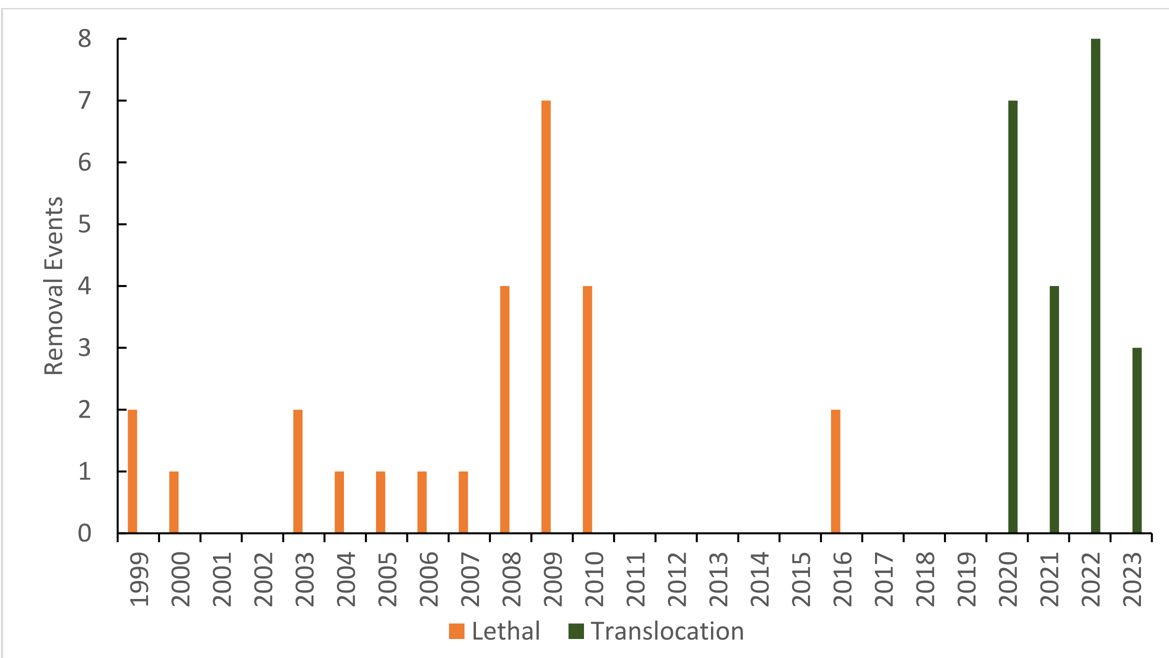

Figure 6. Mountain lions removed both lethally and by translocation 1999-2023 in the eastern Sierra for protection of Sierra bighorn. Three lions were translocated multiple times; removal "events" include every translocation or lethal removal of every individual lion.

An annual removal rate of 10-30% is likely an overestimate, given that (1) lion abundance estimates are based on minimum rather than complete counts and (2) these minimum counts occur only within count zones associated with Sierra bighorn herds (Figure 7). The actual population of lions in the eastern Sierra will be higher than minimum counts. Additional lions that comprise the eastern Sierra lion population will be present in areas between the Department's count zones. As a result, the annual removal rate may be substantially less than 10-30% of the total population in the region.

It is possible that removals to protect Sierra bighorn, combined with other anthropogenic causes of mortality (e.g., vehicle collisions, depredation permits, etc.), could cause periodic lion population declines and a younger lion age structure. For example, during 2008-2010, in response to high predation rates at Mt. Baxter and Sawmill Canyon, lions were removed at a higher than average rate (i.e., 5.0/yr; 3.3 adults/yr), which coincided with a 3-year decline in the minimum count of adult lions known to be present (Figure 5). Unfortunately, it is unclear how quickly the population rebounded because counts were not performed during 2011-2016. During the 2017 count, the number of resident adults (n = 11) was similar to the long-term trend. This finding demonstrates that lion populations can successfully rebound after declines occur.

Given the sporadic nature of lion predation on Sierra bighorn and therefore the sporadic need for lion removal, it is anticipated that impacts to the lion population will not be evenly distributed, temporally or spatially. Targeted and clustered removals from specific areas, as opposed to range-wide population reduction, will facilitate dispersal of lions, particularly females, from higher density areas where removals have not occurred to lower density areas where removals have occurred (Stoner et al. 2013). This type of spatial clustering of lion removals is similar in concept to the approach advocated by Laundré and Clark (2003) for management of lion hunting, in which even low-density lion populations can be sustainably hunted provided that hunting pressure is spatially variable. In addition, it is likely that immediately following years in which multiple lions are removed, the need for removals will be reduced, which would allow for lion population recovery.

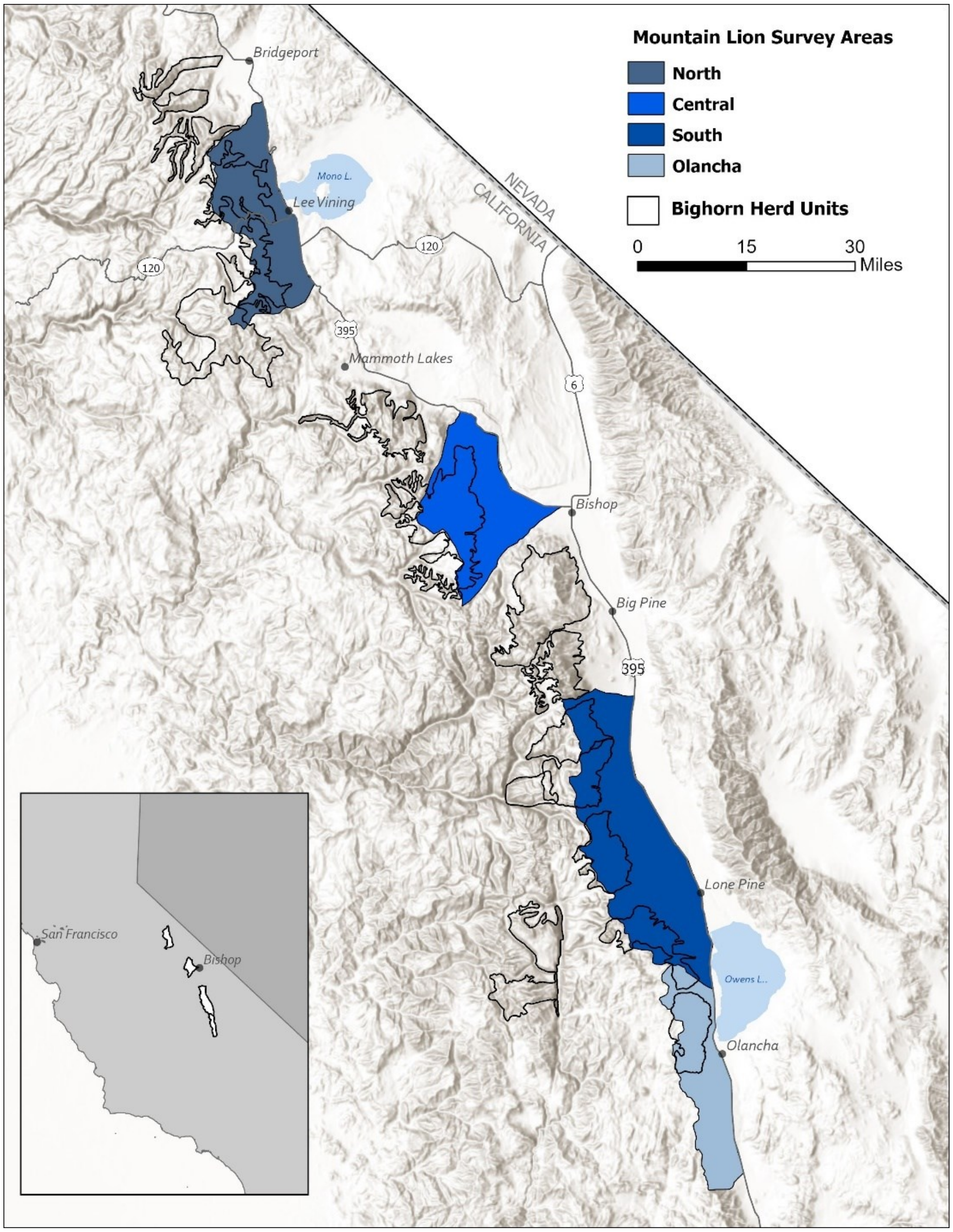

Figure 7. Overview of Sierra bighorn herd units and mountain lion count zones.

MONITORING PREDATION MANAGEMENT OUTCOMES

The impacts of removing lions to protect Sierra bighorn sheep from predation on both Sierra bighorn herds and the lion population itself will be monitored. The effectiveness of lion removals on Sierra bighorn will include determining bighorn abundance, survival rates, proportion of mortalities caused by lion predation, and habitat use (i.e., whether habitat use shifts with changes in lion density). The success of translocating lions will continue to be evaluated by assessing the lion's ability to establish a home range in a new location, reproduce, and survive following translocation.

The impacts of lion removal on the lion population will be monitored using minimum count and mark-resight methods, in combination with location data obtained from collared lions. Specific questions to consider may include:

- What percentage of the adult lion population must be removed in year *t* to result in reduced lion abundance in year *t + 1*?
- How quickly do vacated home ranges become occupied by different lions? When vacated home ranges become re-occupied, are the new lions previously adjacent residents that expand or shift their prior home ranges, or are they immigrants from elsewhere?
- Do temporary increases in the density of subadult males within the home ranges of removed adult males occur? If so, how long does the density increase last? Does it result in increased predation on Sierra bighorn?
- Does removal of adult lions result in increased survival rates of subadult lions (e.g., perhaps from reduced competition for prey)? Does removal of adult lions result in decreased survival rates of subadult lions (e.g., perhaps from increased rates of infanticide)?

ENDING PREDATION MANAGEMENT

The Recovery Plan called for ending predation management activities within herds once they reach a reproductive base of 25 ewes, with the possible exception of herds that serve as sources of translocation stock (USFWS 2007). Since the Recovery Plan was written, additional data on the impacts of lion predation on Sierra bighorn have become available. The decline of the Mt. Langley herd during the winter of 2016-2017 from 53 to 27 ewes, primarily due to lion predation, indicates that Sierra bighorn herds of all sizes must be protected from lion predation during the recovery process. Predation losses to the Mt. Langley herd continued through 2023. Predation on additional herds during subsequent winters (2018-2019 and 2022-2023) reduced bighorn abundance in additional herds (Sawmill Canyon and Wheeler Ridge) below levels for which they can be used for translocation stock. As a result, predation management is expected to continue until Sierra bighorn are downlisted from endangered to threatened status. The degree to which predation management could be necessary for Sierra bighorn to be delisted may depend on whether the disequilibrium of predator and prey persists in the Sierra Nevada ecosystem (Berger and Wehausen 1991). Continued expansion of wolves in California may ultimately determine the abundance of mountain lions and their primary prey (mule deer) in the recovery area for Sierra bighorn.

LITERATURE CITED

Allen, M.L., H.U. Wittmer, P. Houghtaling, J. Smith, L.M. Elbroch, and C. C. Wilmers. 2015. The role of scent marking in mate selection by female pumas (*Puma concolor*). PLoS One < https://doi.org/10.1371/journal.pone.0139087>

Anderson, C. R. Jr., and F. G. Lindzey. 2003. Estimating cougar predation rates from GPS location clusters. The Journal of Wildlife Management 67:307-316.

Barry, J.M., L.M. Elbroch, M. E. Aiello-Lammens, R. J. Sarno, L. Seelye, A. Kusler, H. W. Quigley, and M. M. Grigione. 2019. Pumas as ecosystem engineers: ungulate carcasses support beetle assemblages in the Greater Yellowstone Ecosystem. Oecologia 189:577-586.

Beausoleil, R.A., G.M. Koehler, B.T. Maletzke, B.N. Kertson, R.B. Wielgus. 2013. Research to regulation: cougar social behavior as a guide for management. Wildlife Society Bulletin 37:680-688.

Bergman, E. J., P. F. Doherty, Jr., G.C. White, and A.A. Holland. 2015. Density dependence in mule deer: a review of evidence. Wildlife Biology 21: 18-29.

Binkley, D., M. M. Moore, W. H. Romme, and P. M. Brown. 2006. Was Also Leopold right about the Kaibab deer herd? Ecosystems 9:227-241.

Bowyer, R.T., V.C Bleich, K.M. Stewart, J.C. Whiting, and K.L. Monteith. 2014. Density dependence in ungulates: a review of causes, and concepts with some clarifications. California Fish and Game 100: 550-572.

[CDFW] California Department of Fish and Wildlife. 2008. Why no doe hunts? < https://californiaoutdoorsqas.com/2008/08/28/why-no-doe-hunts/>. Accessed 2 Nov 2017.

[CMGWG] Cougar Management Guidelines Working Group. 2005. Cougar management guidelines. Wild Futures, Bainbridge Island, Washington, USA.

Caughley, G.C., and A.R.E. Sinclair. 1994. Wildlife Ecology and Management. Blackwell Science, Cambridge, Massachusetts, USA.

Cooley, H.S., R. B. Wielgus, G.M. Koehler, H.S. Robinson, and B.T. Maletzke. 2009. Does hunting regulate cougar populations? A test of the compensatory mortality hypothesis. Ecology 90:2913-2921.

Creeden, P.J., and V.K. Graham. 1997. Reproduction, survival, and lion predation in the Black Ridge/Colorado National Monument desert bighorn herd. Desert Bighorn Council Transactions 41:37-43.

Davis, J.L., S.W. Carlson, C.C. Coolahan, D. L. Orthmeyer. 2012. Sierra Nevada bighorn sheep recovery program: the role of USDA Wildlife Services, 1999-2011. USDA Wildlife Services, Sacramento, California, USA.

DeCesare, N.J., M. Hebblewhite, H.S. Robinson, and M. Musiani. 2010. Endangered, apparently: the role of apparent competition in endangered species conservation. Animal Conservation 13:353-362.

Elbroch, L.M., and H.U. Wittmer. 2013. The effects of puma prey selection and specialization on less abundant prey in Patagonia. Journal of Mammalogy 94:259-268.

Ernest, H.B., E.S. Rubin, and W.M. Boyce. 2002. Fecal DNA analysis and risk assessment of lion predation of bighorn sheep. Journal of Wildlife Management 66: 75-85.

Festa-Bianchet, M, T. Coulson, J. Gaillard, J. T. Hogg, and F. Pelletier. 2006. Stochastic predation events and population persistence in bighorn sheep. Proceedings of the Royal Society B 273: 1537-1543.

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, California, USA.

Gammons, D. J., J. L. Davis, D. W. German, K. Denryter, J. D. Wehausen, and T. R. Stephenson. 2021. Predation impedes recovery of Sierra Nevada bighorn sheep. California Fish and Wildlife Special CESA issue:444-470.

Gibson, L. 2006. The role of lethal control in managing the effects of apparent competition on endangered prey species. Wildlife Society Bulletin 34:1220-1224.

Gilpin, M.E. and Soule, M.E. 1986. Minimum viable populations: processes of extinction. Pages 19-34 *in* M.E. Soule, editor. Conservation biology: the science of quantifying the extinction vortex. Sinauer Associates, Sunderland, Massachusetts, USA.

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.

Griffin, A.S., D.T. Blumstein, and C.S. Evans. Training captive-bred or translocated animals to avoid predators. Conservation Biology 14:1317-1326.

Holling, C.S. 1959. Some characteristics of simple types of predation and parasitism. The Canadian Entomologist 91: 385-398.

Hornocker, M.G. 1970. An analysis of mountain lion predation on mule deer and elk in the Idaho Primitive Area. Wildlife Monographs 21.

Jeschke, J.M., M. Kopp, and R. Tollrian. 2002. Predator functional responses: discriminating between handling and digesting prey. Ecological Monographs, 72: 95–112.

Johnson, H.E. L.S. Mills, J.D. Wehausen, and T.R. Stephenson. 2010. Combining ground count, telemetry, and mark-resight data to infer population dynamics in an endangered species. Journal of Applied Ecology 47: 1083-1093.

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

Knopff, K.H., and M.S. Boyce. 2007. Prey specialization by individual cougars in multiprey systems. Pages 194-210 in Transactions of the 72nd North American Wildlife and Natural Resources Conference, Portland, Oregon.

Laundré, J.W., L. Hernandez, and K. B. Allendorf. 2001. Wolves, elk, and bison: reestablishing the "landscape of fear" in Yellowstone National Park, U.S.A. Canadian Journal of Zoology 79:1401-1409.

Laundré, J. and T. W. Clark. 2003. Managing puma hunting in the western United States: through a metapopulation approach. Animal Conservation 6: 159-170.

Lowrey, B., L.M. Elbroch, and L. Broberg. 2016. Is individual prey selection driven by chance or choice? A case study in cougars (*Puma concolor*). Mammalian Research 61:353-359.

McBride, R. T., R. T. McBride, R. M. McBride, and C. E. McBride. 2008. Counting pumas by categorizing physical evidence. Southeastern Naturalist 7:381-400.

Murphy, S. M., D. T. Wilkens, B. C. Augustine, M. A. Peyton, and G. C. Harper. 2019. Improving estimation of puma (Puma concolor) population density: clustered camera-trapping telemetry data, and generalized mark-resight models. Scientific Reports 9:4590.

Osterback, A.-M. K., D. M. Frechette, A. O. Shelton, S. A. Hayes, M. H. Bond, S. A. Shaffer, and J. W. Moore. 2013. High predation on small populations: avian predation on imperiled salmonids. Ecosphere 4(9):116. doi:10.1890/ES13-00100.1

Pierce, B.M., and V.C. Bleich. 2003. Lion. Pages 744-757 in Feldhammer, G.A., B. Thompson, and J. Chapman, eds. Wildlife Mammals of North America. The Johns Hopkins University Press, Baltimore, Maryland, USA.

Pierce, B.M., V.C. Bleich, K.L Monteith, and R.T. Bowyer. 2012. Top-down versus bottom-up forcing: evidence from lions and mule deer. Journal of Mammalogy 93:977-988.

Ripple, W. J., and R. L. Beschta. 2006. Linking a cougar decline, trophic cascade, and catastrophic regime shift in Zion National Park. Biological Conservation 133:397-408.

Robinson, H.S., R.B. Wielgus, H.S. Cooley, and S.W. Cooley. 2008. Sink populations in carnivore management: cougar demography and immigration in a hunted population. Ecological Applications 18:1028-1037.

Rominger, E.M. 2017. The Gordian knot of mountain lion predation and bighorn sheep. Journal of Wildlife Management. 82: 19-31.

Rominger, E.M., and E.J. Goldstein. 2008. Evaluation of an 8-year lion removal management action on endangered desert bighorn sheep recovery. Wildlife Management Division Report. New Mexico Department of Game and Fish, Santa Fe, New Mexico.

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

Rominger, E.M. and M.E. Weisenberger. 2000. Biological extinction and a test of the “conspicuous individual hypothesis” in the San Andres Mountains, New Mexico. North American Wild Sheep Conference 2: 293-307.

Ross, P.I., M.G. Jalkotzy, and M. Festa-Bianchet. 1997. Cougar predation on bighorn sheep in southwestern Alberta during winter. Canadian Journal of Zoology 75: 771-775.

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

[USDA] US Department of Agriculture. 1999. Final environmental assessment: predator damage management to protect the federally endangered Sierra Nevada bighorn sheep.

[USFWS] US Fish and Wildlife Service. 1999. Endangered and threatened wildlife and plants; emergency rule to list the Sierra Nevada distinct population segment of California bighorn sheep as endangered. Federal Register 64:19300-19309.

[USFWS] US Fish and Wildlife Service. 2007. Recovery Plan for the Sierra Nevada Bighorn Sheep. Sacramento, California, USA.

[USFWS] US Fish and Wildlife Service. 2000. Endangered and threatened wildlife and plants; final rule to list the Sierra Nevada distinct population segment of California bighorn sheep as endangered. Federal Register 65:20-30.

Stephenson, T. R., P. Johnston, C. P. Massing, D. W. German, K. Anderson, and L. E. Greene. 2022. Sierra Nevada Bighorn Sheep Recovery Program Annual Report 2021-22.

Stephenson, T. R., D. W. German, E. F. Cassirer, D. P. Walsh, M. E. Blum, M. Cox, K. M. Stewart, and K. L. Monteith. 2020. Linking population performance to nutritional condition in an alpine ungulate. Journal of Mammalogy 101:1244-1256.

Stephenson, T.R., J.D. Wehausen, A.P. Few, D.W. German, D.F. Jensen, D. 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, California, USA.

Stoner, D.C., M.L. Wolfe, C. Mecham, M.B. Mecham, S.L. Durham, and D.M. Choate. 2013. Dispersal behavior of a polygynous carnivore: do cougars Puma concolor follow source-sink predictions? Wildlife Biology 19:289-301.

Villepique, J.T., B.M. Pierce, V.C. Bleich, and R. T. Bowyer. 2011. Diet of cougars (Puma concolor) following a decline in a population of mule deer (Odocoileus hemionus): lack of evidence for switching prey. The Southwestern Naturalist 56:187-192.

Wittmer, H.U., A.R.E. Sinclair, and B. N. McLellan. 2005. The role of predation in the decline and extirpation of woodland caribou. Oecologia 144:257-267.

Wittmer, H.U., M. Hasenbank, L.M. Elbroch, and A.J. Marshall. 2014. Incorporating preferential prey selection and stochastic predation into population viability analysis for rare prey species. Biological Conservation 172:8-14.

Wittmer, H.U., R. Serrouya, L.M. Elbroch, and A.J. Marshall. 2012. Conservation strategies for species affected by apparent competition. Conservation Biology 27:254-26.