Recovery Plan

for the

Sierra Nevada Bighorn Sheep

California/Nevada Operations Office
U.S. Fish and Wildlife Service
Sacramento, California

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Date: AUGUST 31, 2007

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Literature Citation Should Read As Follows:
U.S. Fish and Wildlife Service. 2007. Recovery Plan for the Sierra Nevada Bighorn Sheep. Sacramento, California. xiv + 199 pages.

An electronic version of this recovery plan also will be made available at http://www.fws.gov/cno/es/recoveryplans.html and http://endangered.fws.gov/recovery/index.html#plans.

ACKNOWLEDGEMENTS

This recovery plan was prepared by the Sierra Nevada Bighorn Sheep Recovery Team, with important contributions from Mr. Carl Benz, Dr. Vern Bleich, Dr. Walter Boyce, Ms. Paula Brown, Ms. Diana Craig, Dr. Ben Gonzales, Dr. David Graber, Mr. Troy Kelly, Dr. Howard Quigley, Dr. Peter Stine, Mr. Steve Torres, Dr. Tom Stephenson, Dr. Nancy East, Mr. Brian Croft, and Dr. John D. Wehausen. The recovery team benefited greatly from numerous discussions with Dr. Holly Ernest, Mr. Mike Lawrence, Ms. Kathy Noland, Mr. Christopher Papouchis, Ms. Wendy Philpot, Ms. Lynn Sadler, Mr. Steve Thompson, Mr. John Walter, Mr. Harold Werner, Dr. David S. Zezulak, Ms. Genny Wilson, Ms. Amy Baumer, Mr. Joe Echenique, and Ms. Marianne Lienassar.

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EXECUTIVE SUMMARY

Current Species Status: Sierra Nevada bighorn sheep (*Ovis canadensis sierrae* = *O. c. californiana* at the time of listing) were listed as an endangered species on January 3, 2000, following emergency listing on April 20, 1999. In 1995 the Sierra Nevada bighorn sheep hit a population low of about 100 individuals, distributed across 5 separate areas of the southern and central Sierra Nevada, before increasing to about 125 in 1999. Since 1999, conditions have been particularly favorable for population growth. Based on the most current information, the total population has grown to 325-350 individuals.

Habitat Requirements and Limiting Factors: Sierra Nevada bighorn sheep use habitats ranging from the highest elevations along the crest of the Sierra Nevada (4,000+ meters [13,120+ feet]) to winter ranges at the eastern base of the range as low as 1,450 meters (4,760 feet). These habitats range from alpine to Great Basin sagebrush scrub. Primary elements of preferred habitats are visual openness and close proximity to steep rocky terrain used to escape from predators. Forage resources vary greatly across habitats used by Sierra Nevada bighorn sheep, and plant species eaten vary accordingly. Of particular importance to population parameters is the nutrient content of forage. Nutrient quality of diets varies greatly with season and elevation and is limited primarily by effects of temperature and soil moisture on plant growth and population density. Because of the relationship between elevation and temperature, low-elevation winter ranges provide an important source of high quality forage early in the growing season.

Factors limiting Sierra Nevada bighorn sheep recovery include disease, predation, low population numbers and limited distribution, availability of open habitat, and potential further loss of genetic diversity due to small population sizes and inadequate migration between them. Since the vast majority of Sierra Nevada bighorn sheep habitat is publicly-owned land, loss of habitat has not been a limiting factor. However, management of bighorn sheep habitat (e.g., fire suppression) can result in habitat alterations and loss of key dispersal corridors connecting herds, which could be limiting factors.

Recovery Objective: The recovery objective is to attain population sizes and geographic distribution of bighorn sheep in the Sierra Nevada that assure long-term viability of the overall population and thereby allow its delisting as an endangered species.

Recovery Priority: The Sierra Nevada bighorn sheep has a recovery priority number of 3. Recovery priorities for listed species range from 1 to 18, with 1 being the highest priority. The priority system uses the criteria of: (1) degree of threat, (2) recovery potential, and (3) taxonomy (level of genetic distinctiveness). A fourth factor, conflict, is a supplementary element characterizing whether or not recovery actions are likely to be in conflict with construction or other development projects. A priority of 3 has been assigned to the Sierra Nevada bighorn sheep for the following reasons: (1) there is a high degree of threat because the population is small in size and its distribution is fragmented; (2) there is a high recovery potential; and (3) the listed entity, as described, is a distinct population (which receives the same rating level as a subspecies).

Downlisting Criteria: Potential bighorn sheep habitat in the Sierra Nevada was divided into 16 herd units (Figure 1), and those herd units were grouped into four recovery units on the basis of natural breaks in habitat distribution. Of these 16 herd units, 12 were identified as essential to recovery of the species because of habitat characteristics that make them the most likely areas where recovery will occur (Figure 4). Two criteria must be met for downlisting.

Downlisting Criterion A1: A minimum of 50 yearling and adult females exist in the Kern Recovery Unit (Great Western Divide), 155 in the Southern Recovery Unit (Olancha Peak to Coyote Ridge), 50 in the Central Recovery Unit (Mount Tom to Laurel Mountain), and 50 in the Northern Recovery Unit (Mount Gibbs and Mount Warren), for a minimum total of 305 females. The number of females is the limiting factor in reproductive output because one male can produce offspring with several females. Consequently, we have not set a delisting criterion that considers the male population size within recovery units. However, Delisting Criterion B2 does address males in terms of their occupation of some herd units prior to delisting.

Downlisting Criterion A2: The measures to prevent contact between domestic sheep/goats and bighorn sheep have been implemented and are successful.

Delisting Criteria: Three delisting criteria were developed based on biological parameters, distribution of the herd units, and research on threats to the population. All three must be met for delisting.

Delisting Criterion B1: The minimum number of females required for downlisting per recovery unit (Table 5) has been maintained as an average for one bighorn sheep generation (7 years) with no intervention (ie. population management, buffering populations through translocations, captive breeding, etc.). Herd status for delisting must entail at least three censuses, one at the beginning of the period (qualifying for downlisting), one at the end of the period, and one intermediate count for each herd unit. Maintaining this number of females over a generation should be sufficient to indicate that predation is managed and that the number of individuals within the population is large enough to promote regular use of winter range. Sierra Nevada bighorn sheep need herd sizes to reach a certain threshold before they will utilize areas that predators may inhabit. This herd size provides for better herd vigilance against predation.

Delisting Criterion B2: Bighorn sheep of both sexes are distributed such that at least two herd units are 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, for a total of 12 herd units. Currently, seven of those herd units are occupied. Based on current information these herd units are most likely to include those essential herd units identified in Figure 4 and Table 4.

Delisting Criterion B3: A population viability analysis projects that all recovery units are viable. Recovery tasks related to monitoring and research have been accomplished, allowing the severity of secondary threats (including recreational disturbance, competition, loss of genetic diversity, and habitat changes due to altered fire regimes) to be adequately assessed. These threats have either been ameliorated or have been determined not to pose a significant risk to the population.

Delisting Criterion B4: Regulatory mechanisms and land management commitments have been established that provide for long-term protection of Sierra Nevada bighorn sheep and both their summer and winter habitat. Protection considered long-term can be provided through appropriate institutional practices and cooperative agreements between agencies, landowners, and conservation organizations.

Actions Needed:

The following actions are needed immediately:

1. Protect existing herds through:
    a. maximization of population growth;
    b. predator management
2. Augmenting small herds through translocations; larger numbers of individuals are more likely to make adequate use of winter range essential for achieving positive population growth because they are able to be more vigilant to the presence of potential predators.
3. Preventing contact between Sierra Nevada bighorn sheep and domestic sheep or goats.

Future actions include:

1. Reintroduce bighorn sheep to vacant herd units that are essential to recovery (Figure 4 and Table 4).
2. Monitor genetic variation of all herd units; take action to maintain variation if necessary

This recovery plan calls for development of a captive breeding contingency plan and separate implementation plans for: (1) bighorn sheep monitoring; (2) bighorn sheep translocation; (3) predator management; (4) genetic management; and (5) management of a disease outbreak.

Recovery Costs: Cost estimates of all recovery (Part II) tasks except task 1.1 are made in the Implementation Schedule (p. 69), totaling $21,730,000 over 20 years. Additional costs to identify and acquire important habitat not in public ownership (Task 1.1) will be determined as parcels are identified and acquired.

Date of Recovery: With optimal population growth rates, recovery criteria might be met to allow downlisting within 10 years (2017) and delisting within another 10 years (2027). Under less than optimal scenarios, including unexpected catastrophes, one or more additional decades might be needed.

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I. INTRODUCTION

A. BRIEF OVERVIEW

1. LISTING OF BIGHORN SHEEP IN THE SIERRA NEVADA

In 1878, State legislation provided temporary protection from hunting for all bighorn sheep (*Ovis canadensis*) in California. In 1883, that protection became permanent, a status that remains for bighorn sheep in the Sierra Nevada (Wehausen *et al.* 1987). In 1972, the California subspecies (*O. c. californiana*), as defined by Cowan (1940) and including surviving native herds in the Sierra Nevada, was listed as rare under the 1970 California Endangered Species Act (California Department of Fish and Game 1974); that category was changed to threatened in 1984. In 1999, the California Fish and Game Commission upgraded the status of the Sierra Nevada bighorn sheep to endangered. On April 20, 1999, we (the U.S. Fish and Wildlife Service) granted emergency endangered status to bighorn sheep inhabiting the central and southern Sierra Nevada of California as a distinct population segment (DPS) and, simultaneously, published a proposed rule to list the species as endangered (U.S. Fish and Wildlife Service 1999a, 1999b). The final rule granting endangered status to that population segment was published on January 3, 2000 (U.S. Fish and Wildlife Service 2000).

2. ORIGIN, MORPHOLOGY, AND TAXONOMY

Wild sheep crossed the Bering land bridge from Siberia during the Pleistocene and subsequently spread through western North America as far south as Baja California and northern mainland Mexico (Cowan 1940). Divergence from their closest Asian relative (Siberian snow sheep; *Ovis nivicola*) occurred about 600,000 years ago (Ramey 1993). In North America, wild sheep have diverged into two extant species – thinhorn sheep (*Ovis dalli*), which occupy Alaska and northwestern Canada, and bighorn sheep *(Ovis canadensis*), which range from southern Canada to Mexico. The seven subspecies of bighorn sheep proposed by Cowan (1940) have come under recent taxonomic scrutiny. New genetic (Ramey 1993, 1995; Boyce *et al*. 1997, Gutierrez-Espeleta *et al*. 1998) and morphological data (Wehausen and Ramey 1993, 2000), in addition to the reanalysis of Cowan's original data (Ramey 1993), do not support Cowan's original subspecies distinctions.

Lack of support for the traditional taxonomy includes the classification of bighorn sheep from the Sierra Nevada. Based on only four immature specimens collected in the Sierra Nevada, Grinnell (1912) designated Sierra Nevada bighorn sheep a distinct subspecies (*Ovis cervina sierrae*). Cowan (1940) failed to find support for Grinnell's Sierra Nevada subspecies. He included sheep from the Sierra Nevada instead under the California bighorn (*O. canadensis californiana*) subspecies, the distribution of which extended north to British Columbia between the Cascade and Rocky Mountains and extended south to the southern Sierra Nevada. Cowan (1940) considered bighorn sheep immediately east of the southern Sierra Nevada to belong to a different subspecies (*O. c. nelsoni*); he noted, however, that he could not statistically distinguish bighorn sheep in the Sierra Nevada from those to the east or to the north and suggested that they represented intergrades (Wehausen 1991a). Nevertheless, they were classified as California bighorn sheep for over half a century (Shackleton 1985) and have received State rare, threatened and, eventually, endangered status under the California Endangered Species Act as this taxon since 1972.

In contrast to Cowan=s (1940) classification, recent genetic research based on analysis of the mitochondrial DNA control region has found bighorn sheep from the Sierra Nevada are allied more with those occupying the adjacent desert region than with populations to the north (Ramey 1993, 1995). However, Sierra Nevada bighorn sheep were found to be the only distinctive group in the desert region, which extends east to Utah and New Mexico and south to northern Mexico (Ramey 1993, 1995). Sequence data for a 515 base pair section of the mtDNA control region revealed a unique haplotype (sets of closely linked alleles, or genes, inherited as units) in all bighorn sheep in the Sierra Nevada (Wehausen, unpubl. data). Additionally, the sequence of the Sierra Nevada haplotype is as different from the many haplotypes of desert bighorn sheep as are those of Rocky Mountain bighorn. In that unique Sierra Nevada clade are also three related haplotypes found mixed with desert bighorn haplotypes in populations to the immediate east of the southern Sierra Nevada (Wehausen, unpubl. data). Recent morphometric analyses of skull shape (Wehausen and Ramey 2000) corroborate genetic results; bighorn sheep from the Sierra Nevada are distinguishable from those immediately to the east and north. On the basis of concurrence between genetic and morphometric data, Wehausen and Ramey (2000) reassigned populations of California bighorn outside of the Sierra Nevada to other subspecies, leaving bighorn sheep in the Sierra Nevada as their own subspecies. By the rules of zoological nomenclature, they again assume Grinnell=s (1912) subspecies name *sierrae* (Wehausen *et al*. 2005). With that nomenclature change, the California bighorn subspecies was terminated. Concurrent with the proposed designation of critical habitat for Sierra Nevada bighorn, on July 25, 2007, the U.S. Fish and Wildlife Service formally proposed a taxonomic revision to amend the final listing rule from DPS to subspecies, *Ovis canadensis sierrae*.

B. ECOLOGY

1. HABITAT

Survival of bighorn sheep in their habitat requires two characteristics. The first is agility on precipitous rocky slopes, which is their primary means of evading predators. The second is keen eyesight, which is their primary means of detecting predators. Short legs and a stocky build allow agility on rocks but preclude the fleetness, in less rocky terrain, that is necessary to outrun coursing predators that will pursue their prey at full speed rather than employ ambush tactics. Consequently, bighorn sheep select open habitats that allow detection of predators at sufficient distances to allow adequate lead-time to reach the safety of precipitous terrain. Optimal bighorn sheep habitat is visually open and contains steep, generally rocky, slopes. Sierra Nevada bighorn sheep avoid forests and thick brush, but will use open woodland habitats on rocky slopes. Fire can play an important role in creating or improving bighorn sheep habitat in some ecosystems by increasing the visibility of predators. Large expanses lacking precipitous escape terrain, such as the Owens Valley, can be substantial barriers to movement. Even within mountain ranges like the Sierra Nevada, bighorn sheep habitat is patchy and the population structure is naturally fragmented (Bleich *et al*. 1990a).

Bighorn sheep in the Sierra Nevada utilize a wide range of elevations, from alpine peaks in excess of 4,000 meters (13,120 feet) to the base of the eastern escarpment as low as 1,450 meters (4,760 feet) (Wehausen 1980). Within this elevational range there is a wide variety of vegetation communities, including (from lowest to highest): (1) Great Basin sagebrush-bitterbrush-bunchgrass scrub; (2) pinyon-juniper woodland and mountain mahogany scrub; (3) mid-elevation and subalpine forests, woodlands, and meadows; and (4) alpine meadows and other alpine habitats varying from cliffs to plateaus. Because of the overall aridity of this region, meadow habitats are patchy in distribution and occur only where the water table is high due to factors like snow accumulation. The Great Basin scrub and alpine communities offer the most desirable habitats for bighorn sheep in terms of visual openness. However, because of the aridity of the eastern slope of the Sierra Nevada, many of the mid-elevation vegetation communities have some locations near precipitous rocks with sufficiently sparse plant cover to allow use by bighorn sheep (Wehausen 1980). Because of their extreme visual openness and steep rocky nature, alpine environments in the Sierra Nevada provide large expanses of habitat broken only by canyons containing forests and willow stands, which bighorn sheep may avoid. In contrast, low elevation winter habitat has been limited to small areas where topographic and visual features are suitable (Riegelhuth 1965; McCullough and Schneegas 1966; Wehausen 1979, 1980). High elevation habitat in the Sierra Nevada has been noted for its aridity relative to other alpine habitats because precipitation is scant and unpredictable during the summer season when temperatures permit plant growth (Major and Bamberg 1967). As a result, the vegetation depends substantially on snowmelt for moisture. Snow and resulting soil moisture show great spatial variation (Major 1977). Vegetation patterns vary concomitantly with moisture, ranging from meadow patches to areas almost devoid of plants (Major and Taylor 1977).

2. FOOD HABITS AND NUTRITION

Bighorn sheep are ungulates (hooved, typically herbivorous, quadraped mammal) that possess a large rumen and reticulum (compartments of the stomach of a mammal that chews the cud) relative to body weight (Krausman *et al*. 1993), which permits flexibility in plants consumed and, notably, allows the digestion of graminoids (grasses, sedges, and rushes) in all phenological stages (Hanley 1982). This flexibility in food consumption, in turn, allows flexibility in feeding habitats utilized. Wehausen (1980) and Moore (1991) provided detailed information on the species composition of diets of bighorn sheep on different seasonal ranges in the Sierra Nevada. Those authors found great variation in diets, from those dominated by graminoids to diets dominated by non-graminoid species. Wehausen (1980) provided nutritional data on plant species in different phenological stages and noted that bighorn sheep altered their diets based on what provided the best nutrition at the time. Wehausen (1980, 1992a), Wehausen and Hansen (1988), and Moore (1991) provided curves of fecal crude protein, which indexes digestibility of the forage consumed and, thus, general diet quality (Wehausen 1995). Analyses of fecal nitrogen patterns over 14 years for one wintering area indicated that timing of the first soaking winter storm (2.5 centimeters or about an inch of precipitation) that initiated plant growth most affected winter-spring diet quality for bighorn sheep utilizing low elevation winter ranges. Earlier initiation of plant growth resulted in improved diet quality later in the growing season. In addition, warmer winter temperatures aided plant growth and thereby improved diet quality (Wehausen 1992a). The amount of snowfall from the previous winter appeared to positively influence diet quality on summer ranges, presumably through the influence of summer snow pack on soil moisture for alpine plants (Wehausen 1980); overall, summer diet quality was higher following a winter with heavy snowfall.

Phosphorus may be somewhat lacking in the diets of bighorn sheep in the Sierra Nevada. Klickoff (1965) found alpine soils in the region of Yosemite National Park consistently deficient in this mineral, which may reflect leaching of soils by snowmelt (Major and Bamberg 1967). Wehausen (1983a) found notably lower levels of phosphorus relative to crude protein (a covariate correcting for phenological stage) for alpine graminoids in the central and southern Sierra Nevada when compared to the nearby White Mountains. Wehausen (1980) found bighorn sheep in the Sierra Nevada consistently selected alpine plants of higher phosphorus content, sometimes at the cost of higher protein levels. It is not known if lower phosphorus levels in the Sierra Nevada have population-level effects on bighorn sheep there.

3. BEHAVIOR

Bighorn sheep exhibit a variety of behavioral adaptations to avoid predation. One such adaptation is group living (Hamilton 1971, Alexander 1974); groups provide more eyes and ears, allowing members to spend less time surveying for predators and more time feeding. Studies of this phenomenon have shown that increased in-group size up to six (or more) bighorn sheep confers an advantage in the proportion of time allocated to feeding (Berger 1978, Risenhoover and Bailey 1985). The selfish herd concept of Hamilton (1971) suggests that yet greater group sizes may confer further behavioral comfort. Such comfort may be an important factor enabling bighorn sheep to utilize habitats with greater risks of predation, notably low elevation winter ranges in the Sierra Nevada.

Bighorn sheep are primarily diurnal (active during the daylight hours) (Krausman *et al*. 1985). Coupled with their strong reliance on keen eyesight to detect predators, diurnal behavior minimizes predation risks. Nights generally are spent on rocky slopes, but bighorn sheep may venture a short distance away from rocky escape terrain to feed during daylight. How far they venture from safer habitat varies and is apparently influenced by visual openness (both habitat and weather influences), wind, gender, season (e.g., whether vulnerable young are present), and abundance of predators.

Bighorn sheep commonly exhibit seasonal changes in habitat use that reflect various resource needs. Surface water, although important in many desert ranges, is rarely utilized by bighorn sheep in the Sierra Nevada. Instead, bighorn sheep in the Sierra Nevada obtain needed moisture from forage or occasional consumption of snow. Because of relationships between elevation and temperature (Major 1977) and the influences of those variables on plant growth (Wehausen 1980), altitudinal migration in high mountain ranges like the Sierra Nevada allows bighorn sheep to maximize nutrient intake (Hebert 1973, Wehausen and Hansen 1988, Wehausen 1996). In past years, bighorn sheep in the Sierra Nevada used low elevation ranges extensively in winter and early spring, alpine ranges in summer and fall, and some intermediate ranges during transition periods (Wehausen 1980). These seasonal migration patterns changed during the second half of the 1980s, when Sierra Nevada bighorn sheep stopped using the low-elevation winter range (Wehausen 1996) (see also section I.C.2 for additional discussion).

Male and female bighorn sheep commonly live in separate groups during much of the year, and often occupy different habitats (Geist and Petocz 1977, Wehausen 1980, Bleich *et al*. 1997). In the Sierra Nevada, both sexes may share common winter ranges, but they show progressive segregation from winter to spring (Wehausen 1980). During summer, the two sexes utilize different habitats, with females restricted largely to alpine environments along the crest and males often at somewhat lower elevations in subalpine habitats west of the crest (Wehausen 1980). Males again join females during the breeding season in late fall.

Bighorn sheep have developed conservative philopatric behaviors (reluctance to disperse from their home range) that make them slow to colonize unoccupied habitat (Geist 1967, 1971). These behaviors are likely an adaptation to the naturally fragmented habitats that bighorn sheep commonly occupy.

4. METAPOPULATION STRUCTURE

a. Inbreeding and Small Populations

The naturally fragmented distribution of bighorn sheep has led to the application of a broad landscape approach to their population ecology. This approach groups geographically distinct herds into metapopulations, which are networks of interacting herds (Schwartz *et al*. 1986, Bleich *et al*. 1990a, 1996, Torres *et al*. 1996). Thus, this approach considers long-term viability not of individual herds, *per se*, but rather of entire metapopulations; consequently, both genetic and demographic factors are considered. Increasing coefficients of inbreeding (mating among relatives) and genetic drift (random changes in gene frequencies) accompany decreasing population sizes and, over time, can lead to decreasing levels of heterozygosity (a measure of genetic diversity) that may have negative demographic effects through inbreeding depression (reduction in fitness due to mating among relatives) (Soulé 1980) and loss of adaptability. At some level, inbreeding and associated low genetic variation are likely to be a conservation problem for bighorn sheep, but that level is not known and will be influenced by their general history of inbreeding and other factors that challenge them. It has been suggested that lamb survival and horn growth in bighorn sheep are influenced by inbreeding (Sausman 1982, Stewart and Butts 1982, Fitzsimmons *et al*. 1995). Moreover, there is growing evidence that disease resistance is related to levels of heterozygosity (Carrington *et al*. 1999, Coltman *et al*. 1999).

A small amount of genetic exchange among herds via movements by males can counteract inbreeding and associated increases in homozygosity (having two identical forms of a gene) that might otherwise develop within small, isolated populations (Schwartz *et al*. 1986). Males have a much greater tendency than females to explore new ranges, which they may do in search of other females with which to breed (Bleich *et al.* 1996). If geographic distances between groups of females within metapopulations are not great, gene migration via males occurs readily (Epps *et al.* 2005). In the absence of such a metapopulation structure, populations will be isolated and may benefit from genetic enrichment via induced migration by individuals translocated between herds (Epps *et al.* 2006).

Substructuring also can occur within what are often designated as single herds of bighorn sheep (Geist 1971, Holl and Bleich 1983, Festa-Bianchet 1986, Wehausen 1992a, Jaeger 1994, Andrew *et al*. 1997, Rubin *et al*. 1998). Such substructuring is defined by separate home range patterns. Although more evident in females, it can occur in both sexes. Because separate female groups often reflect matrilines (maternal lines) (Festa-Bianchet 1986), differences in (maternally inherited) mitochondrial DNA profiles between them may be detectable (Bleich *et al*. 1996, Boyce *et al*. 1999). Population substructuring has been recognized in Sierra Nevada bighorn sheep (Wehausen 1979) and was incorporated in a previous conservation plan for these bighorn sheep (Sierra Nevada

Bighorn Interagency Advisory Group 1984). Bleich *et al*. (1996) suggested that separate female groups are the fundamental building blocks of bighorn sheep metapopulations.

b. The Balance between Extinction and Colonization

The other important long-term process in metapopulation dynamics is the balance between rates of natural extinction and colonization among constituent populations. Colonization rates must exceed extinction rates for a metapopulation to persist (Hanski 1991). This balance has not occurred for Sierra Nevada bighorn sheep since about 1850 due to the high rate of local extinctions, resulting in an increasingly fragmented distribution. In addition to fragmentation resulting from past extinctions, the reintroduction program during 1979-88 (Bleich *et al*. 1996) and the more recent collapse of all herds together resulted in small, isolated groups of bighorn sheep. These small groups showed a greater propensity to winter at high elevations, resulting in greater vulnerability to extirpation due to small population size and difficulty surviving severe winter climates.

5. POPULATION DYNAMICS

Populations change in size over time through gains and losses of individuals from reproduction, immigration, mortality, and emigration. Immigration and emigration are sufficiently infrequent events in bighorn sheep (Geist 1971) that they can be largely ignored. Thus, this section addresses reproduction, mortality, and population regulation through density-dependent feedback loops. Generally, variation in recruitment (surviving young), rather than adult survivorship (survival), drives the dynamics of wild ungulate populations (Gaillard *et al*. 1998, 2000). However, bighorn sheep can incur all-age die-offs from occasional disease epizootics (epidemic disease in animals) or other events that radically affect population dynamics due to significant effects on adult survivorship. Changes in adult survivorship have notably greater effects on population dynamics than variation in recruitment (Gaillard *et al* 2000).

a. Reproduction

Bighorn sheep generally give birth to single young, but there is a low incidence of twins (Buechner 1960). Bighorn sheep occupying many desert mountain ranges have protracted lambing seasons covering many months, while those living under colder winter temperature regimes give birth during short periods in late spring and early summer (Thompson and Turner 1982, Bunnell 1982, Rubin *et al*. 2000, Wehausen 2005). Bighorn sheep in the Sierra Nevada fit this latter pattern (Wehausen 1980). The birthing season there can begin as early as the second half of April, and end as late as early July (Wehausen 1991a), with most births occurring in May and June (Wehausen 1996). Occasional later-born lambs have been seen. Timing of births correlates with the nutritional regime of females; later birthing appears to be a consequence of lower annual nutrient intake (Wehausen 1996). The gestation period for bighorn sheep is approximately 174 days (Shackleton *et al*. 1984, Hass 1995). The breeding (rutting) season in the Sierra Nevada, therefore, occurs during late fall and early winter (mostly November and December), when bighorn sheep are usually still at high elevations.

Nutrient intake can also influence birth rates (Wehausen 1984), including the frequency with which adult females produce young and the age at which young females first bear offspring. Two years of age is the youngest that females in the Sierra Nevada are known to give birth, and age at first lambing may be as high as 4 years under poor nutritional circumstances, as has been recorded for Dall's sheep (*Ovis dalli*; Bunnell and Olson 1981). Measuring the actual proportion of females producing young is difficult because of possible unrecorded losses soon after birth. The upper range of summer ratios of lambs to females recorded shortly after the birthing season in the Sierra Nevada has been 75-83:100 (Wehausen 1980, Chow 1991), while the lowest reported value was 30:100 (Wehausen 1980).

Survivorship of lambs to yearling age also can vary with environmental and nutritional factors. For the Mount Baxter and Sawmill Canyon herds in the Sierra Nevada during 1965-79, 73 percent of the variation in winter lamb:female ratios was explained by variation in precipitation 8 to 12 months prior to conception (Wehausen 1980). That model suggested that variation in the production of young, rather than offspring survival, was the primary variable affecting winter recruitment ratios during that period. However, with decreasing use of winter ranges during the 1980s, lamb survival declined considerably in that population (Wehausen 1996). Thus, lamb survival may be sensitive to habitat use patterns and associated environmental factors.

b. Mortality Factors

1. Diseases and Parasitism

Numerous diseases of bighorn sheep have been documented (Bunch *et al*. 1999), of which pneumonia and psoroptic scabies have had the greatest population-level effects. Bighorn sheep show a high susceptibility to pneumonia, usually caused by bacteria of the genus *Pasteurella* (some species now called *Mannheimia*; Post 1971). Pneumonia caused by *Pasteurella* alone, or in combination with other pathogens, is the most significant disease threat for bighorn sheep (Bunch *et al*. 1999). Lungworms of the genus *Protostrongylus* can be important contributors to pneumonia and mortality in bighorn sheep in the Rocky Mountains (Forrester 1971, Woodard *et al*. 1974), and methods have been developed to control these nematode parasites in some wild populations (Schmidt *et al*. 1979). Bighorn sheep in the Sierra Nevada carry *Protostrongylus* lungworms, but parasite loads have been too low to be considered a management concern (Wehausen 1979, 1980).

Many early die-offs of bighorn sheep, including some in the Sierra Nevada, were attributed to scabies thought to have been contracted from domestic sheep (Jones 1950, Buechner 1960). Over the past 20 years, this disease has been a significant mortality factor among bighorn sheep in the San Andres Mountains of New Mexico (Lange *et al*. 1980, Hoban 1990, Rominger and Weisenberger 2000). Scabies also has been found recently in bighorn sheep in California, east of the Sierra Nevada (Clark *et al*. 1988). However, in a large sampling of bighorn sheep in the Sierra Nevada during 1979-88, no clinical evidence of scabies was noted. Similarly, serum samples from those sheep showed no evidence of exposure to *Psoroptes* (Mazet *et al*. 1992).

Other infectious diseases may be of concern for bighorn sheep in selected instances. Bluetongue virus was responsible for die-offs of bighorn sheep in the Lava Beds enclosure in California (Blaisdell 1975) and at the Red Rock facility in New Mexico (Singer *et al*. 1998). For the Red Rock facility, a comparative study of bluetongue exposure in adjacent cattle indicated that those bovids likely were not the source of infection (Singer *et al*. 1998). Similarly, Singer *et al*. (1997) found that neither deer nor cattle caused the Lava Beds die-off. Bluetongue is known to be present east of the southern Sierra Nevada in the Owens Valley, but the midges that transmit it do not occur at the elevations occupied by bighorn sheep during the summer when transmission would typically occur.

The importance of these diseases and their role in the listing and management of Sierra Nevada bighorn sheep is discussed further in section I.D.3 and appendix B.

2. Predation and Other Mortality Factors

Bighorn sheep die from a variety of causes other than disease, including predation and accidents. Of particular interest relative to the conservation of endangered populations are factors that remove animals at younger ages when considerable reproductive potential remains.

Various predators kill wild sheep in North America, including wolves, mountain lions, coyotes, bears, bobcats, wolverines, and eagles (Kelly 1980, Berger 1991, Nichols and Bunnell 1999, Bleich 1999). Wolves are not known to have occurred in the central and southern Sierra Nevada in the original range of bighorn sheep (Young and Goldman 1944). In the Sierra Nevada, mountain lions have been the primary predator of bighorn sheep, accounting for 96 percent of losses attributed to predation (Table 1). Of 147 bighorn sheep deaths recorded in the Sierra Nevada from 1975 to 2000, a minimum of 54.5 percent could be attributed to predation; the actual percentage could be considerably

Table 1. Causes of known bighorn sheep mortalities in the Sierra Nevada by population, 1975-2000. Sources include Andaloro and Ramey (1981), Chow *et al*. (1993), Wehausen (1996) and many unpublished records. Data include radio collared individuals and remains of uncollared individuals encountered during field surveys. Baxter includes the Mount Baxter and Sawmill Canyon herd units, and Mono Basin includes the Mount Warren and Mount Gibbs herd units.

Herd	Predation			Avalanche/ Accidents	Post Release Exposure	Highway Collision	Not Known
	Lion	Coyote	Bobcat				
Langley	7						4
Williamson	5						2
Baxter	50			1			27
Wheeler	3			15			2
Mono Basin	12	2	1	3	5	1	7
Totals	77	2	1	19	5	1	42
Percent	52.4	1.4	0.7	12.9	3.4	0.7	28.6

higher due to numerous mortalities for which no definitive cause could be assigned (Table 1).

During the 1990s, bighorn sheep in the Sierra Nevada incurred major winter losses while remaining at high elevations during the winter, a change in habitat selection that Wehausen (1996) suggested was a response to increased mountain lion predation on winter ranges. Those losses were a key factor that put these sheep in danger of extinction. The development of winter range avoidance and the demographic consequences of that behavioral change are discussed in detail in I.C.2.

c. Population Regulation

No population increases indefinitely. Various factors can limit population growth, depending on the species and its ecological niche. Large herbivores frequently exhibit S-shaped population growth curves, in which the rate of increase declines with increasing population size (Caughley and Sinclair 1994). This occurs primarily because of declining reproductive success associated with increasing population density (McCullough 1979).

Recent strong population increases for bighorn sheep herds in the Sierra Nevada, beginning in the late 1990s, have provided opportunities to investigate such density-dependent relationships. We have consistently high quality demographic data for the Wheeler Ridge and Mount Langley herd units, and both have exhibited strong density-dependent relationships for ratios of lambs to adult females. The most graphic of these occurred for the Mount Langley herd, where a 3-fold increase from 11 to 33 females over 6 years produced a nearly linear decline in summer ratios of lambs to adult female from 1.00 to 0.41 for a period in which the population carrying capacity may have been limited by minimal use of low elevation winter ranges (Wehausen and Stephenson 2005b).

The Wheeler Ridge herd exhibited similar strong declines in winter lamb:adult female ratios with increasing population sizes. However, that herd had similar relationships for the period prior to low elevation winter range use and after those winter ranges were re-occupied. Additionally, following re-colonization of that winter range, the winter ratio of lambs to adult females more than doubled, from 0.42 to 0.89, then showed the second episode of decline with further population increases (Wehausen and Stephenson 2004). These findings indicate that population density in conjunction with forage utilization may tightly regulate bighorn sheep herds in the Sierra Nevada. It appears that density-dependent effects precipitate expansion of habitat use to fully utilize the large nutrient base of low elevation winter ranges. This has been observed at Wheeler Ridge and Mount Langley, both of which exhibited greatly expanded use of low elevation winter ranges after lamb:adult female ratios dropped to about 0.40, and both have seen a major increase in that ratio beginning a year after expanded winter range use began.

These findings have important implications for recovery goals. First, they underline the importance of utilization of low elevation winter ranges to achieve adequate population sizes. Second, even with the use of such winter ranges, the observed density-dependent recruitment relationships and population trajectories indicate that population carrying capacities will be limited in most herds. For instance, under current habitat use patterns, it appears that the Wheeler Ridge herd is limited in size by its summer range and may not support more than 50 females. These findings are used in section II.B.2 to develop attainable recovery goals.

6. INTERSPECIFIC COMPETITION AND HUMAN DISTURBANCE

Interspecific competition occurs when a resource shared by two species is in short supply for at least one of those species (Krebs 1972). For bighorn sheep exhibiting altitudinal migration, questions of competition commonly have focused on winter ranges, where grazing animals are more concentrated and forage is more limited (Stelfox 1976). Both native deer (*Odocoileus hemionus*) and introduced tule elk (*Cervus canadensis nannodes*) have overlapped winter ranges used by bighorn sheep in the Sierra Nevada (Riegelhuth 1965). However, quantitative studies of utilization of key forage species on the Mount Williamson and Mount Baxter winter ranges did not suggest any competition (Wehausen 1979, 1980). Wehausen (1992b) attributed limitations on nutrient intake by bighorn sheep on these ranges to nutritive quality rather than quantity of forage.

Leopold (1933) considered bighorn sheep to be a wilderness species because they fail to thrive in contact with urban development. Human disturbance has been suggested to be detrimental to bighorn sheep in a variety of situations (Graham 1980, MacArthur *et al*. 1982, Etchberger *et al*. 1989, Papouchis *et al*. 2001). Similarly, Dunaway (1971) postulated that disturbance of bighorn sheep in the Sierra Nevada by humans was a factor limiting populations. Results of subsequent research did not support that hypothesis (Wehausen *et al*. 1977, Hicks and Elder 1979, Wehausen 1980). Bighorn sheep have habituated to human activity in many places in the Rocky Mountains, and occasionally in desert habitats. Any conclusions about the effects of human disturbance, however, must be limited to the situations studied. Thus, the question should be revisited as situations change in a direction that suggests disturbance could be detrimental, such as increased presence of humans in bighorn sheep habitat.

C. ABUNDANCE AND DISTRIBUTION

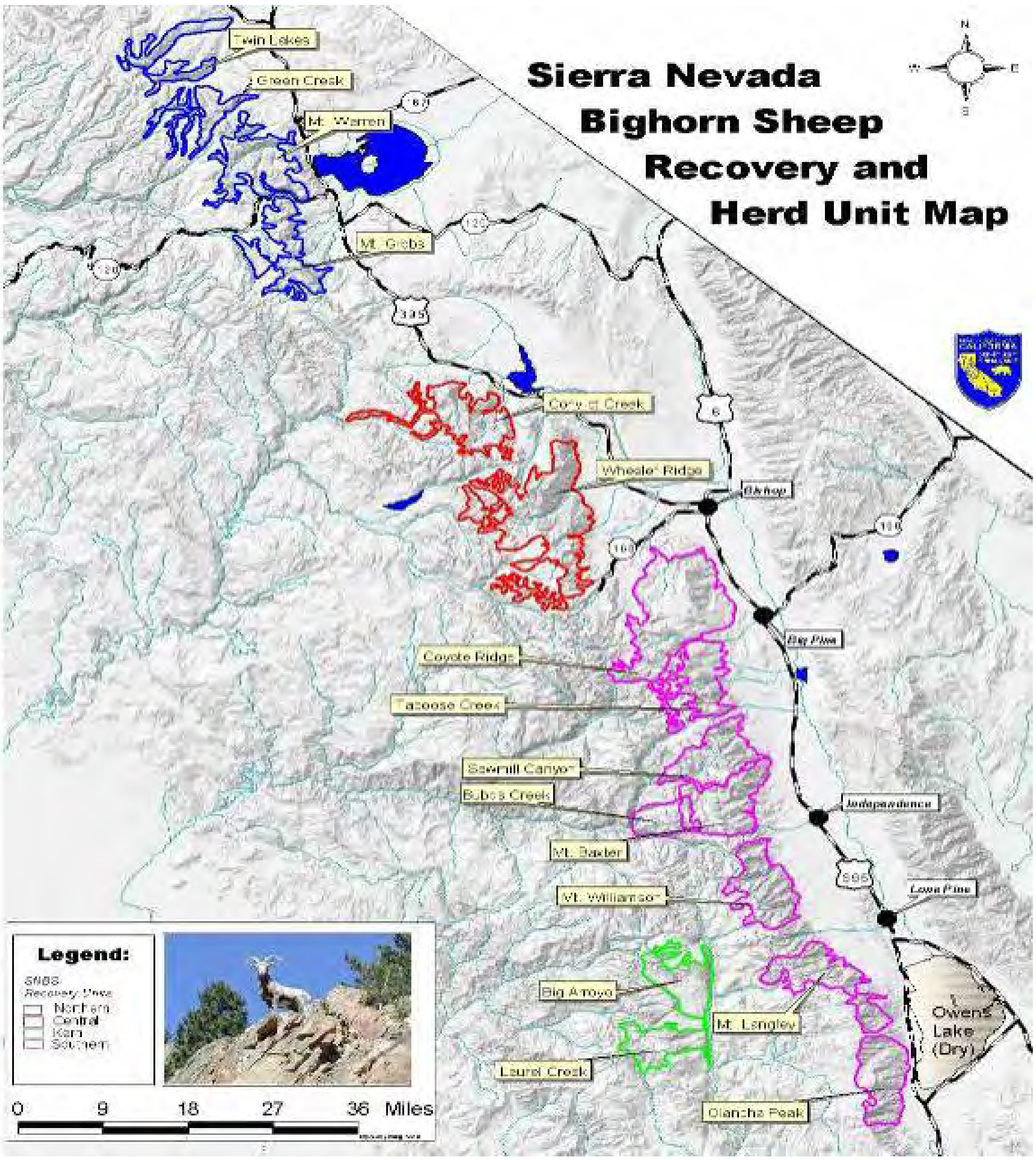
1. HISTORICAL DISTRIBUTION, ABUNDANCE, AND TRENDS

Bighorn sheep herds were once scattered along and east of the alpine crest of the Sierra Nevada from the Sonora Pass area south to Olancha Peak (Figure 1). They also occurred in similar habitat west of the Kern River as far south as Maggie Mountain, with concentrated use in the regions of Mineral King, Big Arroyo, and Red Spur (Jones 1950). Additional evidence suggested that herds utilized nonalpine habitat farther south near Walker Pass (Jones 1949, Garlinger 1987, Wehausen *et al*. 1987). Whether those southernmost herds were taxonomically the same as those that occurred farther north in the Sierra Nevada is unknown.

The total population of bighorn sheep in the Sierra Nevada prior to settlement is unknown, but it probably exceeded 1,000 individuals. In some cases, early records provide clear evidence of the occurrence of populations now extirpated. However, the overall historical record is incomplete and may lack records of some herds that might have disappeared early in recorded history. Wehausen (1988) postulated some additional areas that might have supported populations of bighorn sheep, but records for these areas are lacking.

Population losses for bighorn sheep apparently began shortly after the immigration of Europeans to the Sierra Nevada in the mid-1800s, and those losses continued through most of the twentieth century (Wehausen *et al*. 1987). Of 16 areas in the Sierra Nevada that likely had separate bighorn sheep herds (excluding the southernmost non-alpine region), only nine are known to have persisted to the beginning

Figure 1 - Essential and non-essential herd units within the four recovery units (indicated by colors). Recovery units are likely to support bighorn sheep, based on analysis of historic distribution and current habitat characteristics. A subset of these herd units is essential to recovery of the Sierra Nevada bighorn sheep (see section II.B.2 and Figure 4).



of the twentieth century (Table 2). By 1948, the number of areas thought to support bighorn sheep had dropped to five (Jones 1950). Jones (1950) documented bighorn sheep in three areas and postulated their existence in two other regions based on sign and reported observations; he also produced an estimate of 390 bighorn in those five herds. By the 1970s, sheep remained in only two of those areas, but the one known as the Mount Baxter herd was found later to represent two demographically distinct, contiguous herds (Mount Baxter and Sawmill Canyon in Table 2; Wehausen 1979, 1980).

Table 2. Probable locations of historic bighorn sheep herds in the Sierra Nevada, based on historic records and habitat characteristics.

Region/Population	Last Records of Viable Native Herds	Sources for Sightings, Skulls, or other Data
KERN RIVER	1800s	Jones 1950
Mineral King		
Big Arroyo, Kaweah Peaks	1800s	Jones 1950
SOUTHERN		
Olancha Peak	1920s	Jones 1949
Mount Langley	1960s	Wehausen 1979
Mount Williamson	Extant	Wehausen 1980, 1999
Mount Baxter	Extant	Wehausen 1980, 1999
Sawmill Canyon	Extant	Wehausen 1980, 1999
Taboose Creek, Birch Mountain	1920s	Ober 1914, Jones 1949
CENTRAL		
Mount Tom to Mount Emerson	1920s	Ober 1914, 1931; Wolfe 1979
Pine Creek to Rock Creek	1920s	Jones 1949
McGee Creek to Convict Creek	1940s	Jones 1949
NORTHERN		
Mount Ritter to Dana Plateau	1870s	Muir 1894, Jones 1949
Mount Warren, Tioga Crest	skulls only	Bailey 1932, Jones 1949
Mount Conness		
Shepherds Crest	skulls only	Jones 1949
Matterhorn Peak area	skulls only	Jones 1949
Sonora Pass	1878	Grinnell and Storer 1924

Specific causes of most population losses in the Sierra Nevada are unknown. Market hunting for mining towns may have played a role in some areas. A die-off in the 1870s west of the Kern River was attributed to scabies (Jones 1950), presumably contracted from domestic sheep. Die-offs from pneumonia contracted from domestic sheep may have been the most important cause of losses, but have not been documented. Beginning in the 1860s, and extending into the twentieth century, large numbers of domestic sheep were grazed seasonally in the Sierra Nevada (Austin 1906, Vankat 1970).

2. RECENT DISTRIBUTION, ABUNDANCE, AND TRENDS

Bighorn sheep persisted in only two areas in the Sierra Nevada by the 1970s, constituting three herds (Wehausen 1979, 1980). Intensive field studies from 1975 to 1979 provided the first accurate census data for those herds. The contiguous Mount Baxter and Sawmill Canyon herds together contained at least 220 sheep in 1978 (Wehausen 1980), with 150 in the Mount Baxter herd and 70 in the Sawmill Canyon herd. Detailed annual monitoring of the Mount Baxter and Sawmill Canyon herds through 1986 repeatedly verified similar large numbers (Wehausen 1987, Figure 2). In contrast, the Mount Williamson herd contained only 30 sheep in 1978. The Mount Williamson herd was found to be static at 30 individuals during winter censuses in 1983 and 1985 (Wehausen 1983b; Figure 2).

Because of large size and productivity, the Mount Baxter and Sawmill Canyon herds were used as sources of reintroduction stock beginning in 1979, with subsequent removals in 1980, 1982, 1986, 1987, and 1988, totaling 103 individuals. Those sheep were used to reestablish populations at Wheeler Ridge (1979, 1980, 1982, 1986), Mount Langley (1980, 1982, 1987), Lee Vining Canyon (1986, 1988), and the south Warner Mountains in northeastern California (1980; Bleich *et al*. 1990b). The Warner Mountains population died out in 1988, following contact with domestic sheep (Weaver and Clark 1988), but the other three persist (Figures 1, 2).

The Wheeler Ridge and Mount Langley herds began increasing soon after they were reintroduced. In contrast, the Lee Vining Canyon population declined initially due to post-release mortality from particularly inclement weather, followed by reductions due to mountain lion predation while on winter-spring range in Lee Vining Canyon (Chow 1991). Following supplementation in 1988 and removal of one mountain lion from Lee Vining Canyon in each of three consecutive winters (Bleich *et al*. 1990b), this population increased rapidly (Chow 1991; Figure 2).

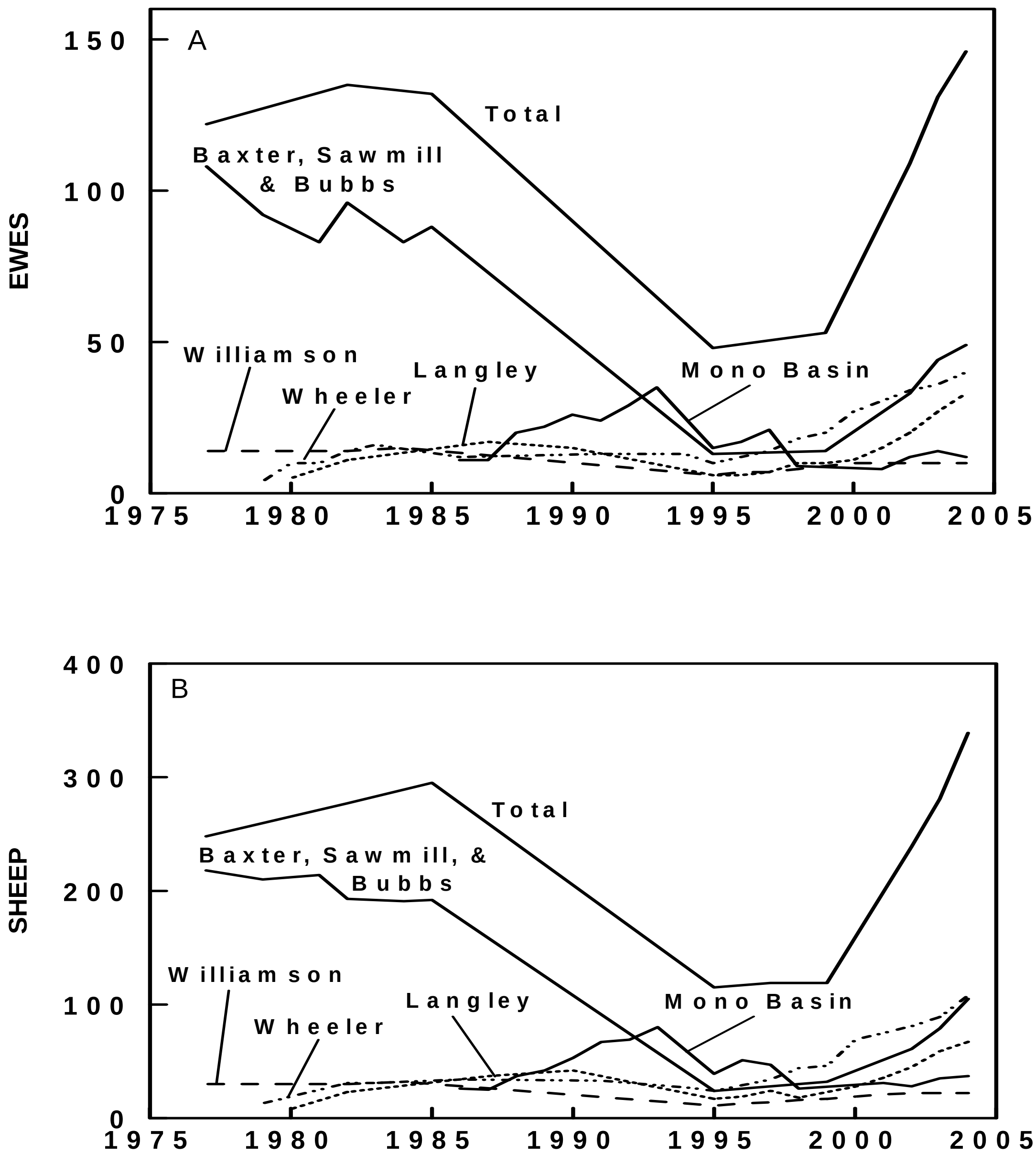


Figure 2. Minimum summer population sizes of Sierra Nevada bighorn sheep, 1977-2004. (A) Yearling and adult females. (B) All bighorn sheep. (From Andaloro and Ramey 1981; Chow 1991; Moore and Chow 1990; Ramey and Brown 1986; Wehausen 1980, 1983b, 1987, 1999, 2001, 2002; Wehausen and Stephenson 2004, 2005b). Mono Basin (Lee Vining Canyon, Lundy Canyon, Mt. Warren, and Mt. Gibbs) includes the Mt. Warren and Mt. Gibbs essential herd units (see Figures 1 and 4). Where data on males were incomplete, the typical ratio of 7 adult males per 10 adult females was used to project total population size.

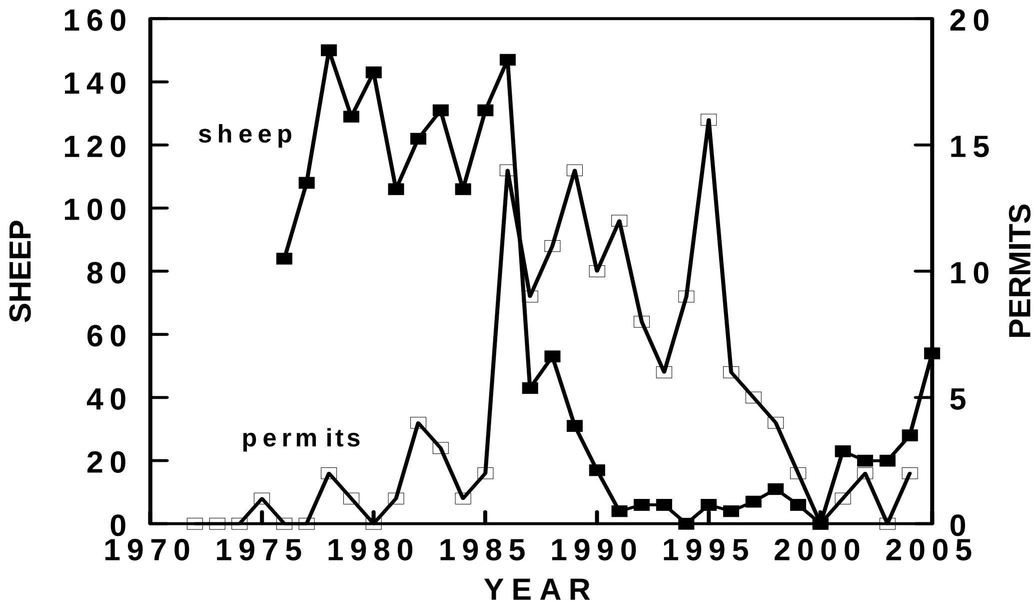


Figure 3. Mountain lion depredation permits issued in Inyo and Mono Counties, 1972-2004, and bighorn sheep winter range census results for the Mount Baxter essential herd unit (Wehausen 1996, 1999, 2001; Wehausen and Stephenson 2004, 2005).

Beginning in the 1970s, mountain lions apparently became an increasing source of mortality for Sierra Nevada bighorn sheep populations. Wehausen (1996) reported evidence of rapid increases in mountain lion activity and kills on the winter ranges of the Mount Baxter and Sawmill Canyon herds between 1976 and 1988, with documented kills totaling 49 bighorn sheep. More detailed analysis of those kills by the years in which they occurred shows two distinct periods of steeply increasing numbers of kills (1974-82 and 1983-88) punctuated by a large decline in kills in 1983 following the removal of one lion in 1982. Mountain lion depredation problems involving livestock and pets along the eastern Sierra Nevada in Inyo and Mono Counties also increased notably during the 1980s, especially in the middle of that decade (Figure 3).

Bighorn sheep herds in the Sierra Nevada ceased regular use of low elevation winter ranges during the 1980s. The timing of those changes in winter habitat use varied by herd from 1983 for the Sawmill Canyon herd to 1986 for the Mount Williamson herd and 1987 for the Mount Baxter herd (Figure 3). Similar changes in winter range use were observed for reintroduced herds. Wehausen (1996) considered three possible explanations for this behavioral change and concluded that widespread increases in mountain lion predation of bighorn sheep on winter ranges was the only one that plausibly explained this widespread phenomenon that was not synchronous, yet occurred over relatively few years.

However, other influences may have affected the habitat preference of bighorn sheep during this period. Extremely high densities of mule deer were present at the same time, with a subsequent population crash exacerbated by long-term drought (Kucera

1988). In addition to the risk of predation, changes in forage availability and quality due to a variety of factors may have influenced habitat selection. Nevertheless, the failure of bighorn sheep to move to lower elevations during the year likely resulted in direct and indirect impacts to the population (Wehausen 1996).

Population Declines

Regardless of the cause, Sierra Nevada bighorn sheep that remained at high elevations during the winter were exposed to extreme cold, deep snow and avalanches in heavy winters. Remaining at high elevation during winter also resulted in notably lower nutrient intake (Wehausen 1996). For the Mount Baxter and Sawmill Canyon herds, the consequences were manifested in later lambing and poor lamb survival, which led to recruitment well below that needed to balance adult mortality. This diminished recruitment resulted in a population decline (Wehausen 1996) that reached a low in the reproductive base of about 17 females by 1995 (Wehausen and Chang 1995), or about 15 percent of peak numbers. Summer field surveys in the Mount Williamson herd range beginning in 1996 coupled with fecal DNA analyses suggested that this population might have reached a reproductive base low of about five females in 1995.

Reintroduced herds also remained at high elevations during the winter and suffered similar impacts. Significant losses to one such herd occurred because of the severe winter of 1995. Winter losses in the Wheeler Ridge herd that year included 12 sheep that died in a single snow avalanche, with only 18 known to have survived that winter. Earlier surveys of that herd (Ramey and Brown 1986, Wehausen 1991b) indicated that it might not have reached 40 individuals between the time of its reintroduction in 1979 and 1995. The population trajectory for that herd lacked an initial exponential phase (Figure 2), which probably reflected low carrying capacity due to minimal use of low elevation winter range relative to the number of sheep translocated.

The population in Lee Vining Canyon suffered excessive losses from particularly inclement weather immediately after sheep were translocated in 1986, followed by lion predation that threatened to extirpate this fledgling herd. Following supplementation with eight females and three males in 1988 and the removal of three mountain lions during 1988 to 1990, this herd exhibited strong recovery (Chow 1991; Figure 2), and had grown to at least 77 and possibly 86 individuals by 1993 (Chang 1993). A less-than-complete count the following summer yielded a minimum of 43 for that area, and a potential maximum of only 69 (Jensen 1994). Beginning in the mid 1990s, a decline in the use of the Lee Vining Canyon winter range became apparent. During the winter and spring of 1995, few bighorn sheep used low-elevation winter range and many sheep disappeared. Repeated thorough counts of this herd the following summer consistently produced only 29 bighorn sheep (Wehausen and Chang 1995), representing a loss of at least 50 individuals. Additional winter declines occurred in 1998 and 1999 (Wehausen and Chang 1998, Wehausen 1999). Further mountain lion predation was documented in the spring of 1998 in Lee Vining Canyon, and no females have been found on that winter range since then. In the summer of 1998, the reproductive bases for the Mount Warren and Mount Gibbs essential herd units were only seven and two females, respectively. The former declined to three a year later; however, genotype matches from recent fecal DNA analyses indicate that at least one of the females missing in 1999 had apparently moved to Lundy Canyon. Only 22 adult bighorn sheep are known to have existed in the two essential herd units in the Mono Basin at the time of emergency listing in 1999 (Table 3).

The Mount Langley herd also appears to have suffered a major reduction in the winter of 1995 due to heavy snowfall. Repeated census efforts beginning in the summer of 1996 accounted for only 6 females and 11 males that survived that winter (Wehausen 1999), in contrast to 42 bighorn sheep counted there in the summer of 1990 (Moore and Chow 1990).

After increasing from 250 in 1978 to almost 300 in 1985 during the initial phase of the reintroduction program, the total number of bighorn sheep in the Sierra Nevada declined about 60% to just over 100 in 1995, with a reproductive base of about 50 females (Wehausen and Stephenson 2005).. The winter of 1995 was particularly difficult, with sheep attempting to live at high elevations, and apparently played a major role in that decline (Wehausen and Chang 1995, 1997).

Population Recovery

Bighorn sheep numbers have increased dramatically in the Sierra Nevada since the low in 1995. The first 4 years had somewhat slow and inconsistent overall increases due to further losses in the Mono Basin and delayed recovery in some other herds (Figure 2). At the time of emergency endangered listing in spring 1999, a minimum of 117 sheep could be definitely accounted for throughout the Sierra Nevada; but additional data suggested that the actual total was probably somewhat higher (Wehausen 1999). Subsequent data increased that minimum to 122 sheep (Table 3).

Table 3. Minimum numbers of Sierra Nevada bighorn sheep existing at the time of emergency endangered listing in spring 1999, based on counts in 1998 (Wehausen 1999) and subsequent years (Wehausen 2001) and known mortalities. Baxter includes the Mount Baxter and Sawmill Canyon essential herd units, and Mono Basin includes the Mount Warren and Mount Gibbs essential herd units.

	BIGHORN SHEEP IN 1999			
Population	Ewes	Rams	Lambs	Total
Langley	10	7	1	18
Williamson	6	1	3	10
Baxter	13	9	3	25
Wheeler	18	16	10	44
Mono Basin	8	14	3	25
TOTALS	55	47	20	122

Data on mountain lions indicate that their population along the eastern Sierra Nevada declined markedly in the 1990s, especially toward the end of that decade, and hit a low in 1999 (Figure 3). Following the emergency endangered listing of Sierra Nevada bighorn sheep, a program of focused control of mountain lions was initiated. In 2000, that program began placing telemetry collars on mountain lions near bighorn sheep ranges and closely monitoring them in an effort to be as selective as possible in the removal of mountain lions for the benefit of bighorn sheep. On average, one mountain lion per year has been removed to protect bighorn sheep under that program.

The overall population of bighorn sheep in the Sierra Nevada showed dramatic annual increases after 1999 (Figure 2). Six years after emergency listing, the minimum number of yearling and adult females that could be accounted for had increased by 265 percent from 55 to at least 146 B an annual compounded increase rate of 17.7 percent (Wehausen and Stephenson 2005a). The minimum number of lambs that could be accounted for in 2004 was 66. With the addition of adult males, the total population in 2004 can be projected at 325 to 350 (Figure 2). While evidence of density-dependent population regulation has emerged for two herds (see I.B.5; Wehausen and Stephenson 2004, 2005b), one of those (Mount Langley) has only recently begun to use low elevation winter ranges again. The Mount Baxter herd also is in the process of expanding use of low elevation winter ranges. Those habitat expansions are expected to increase carrying capacities for both herds and can be expected to result in a further increase in overall numbers. These recent winter range utilizations are in addition to extensive use of winter range in the Wheeler Ridge herd unit.

D. REASONS FOR LISTING

The following discussion is organized according to the listing criteria under section 4(a)(1) of the Endangered Species Act.

1. THE PRESENT OR THREATENED DESTRUCTION, MODIFICATION, OR CURTAILMENT OF ITS HABITAT OR RANGE

Almost all of the historical and currently occupied habitat of bighorn sheep in the Sierra Nevada is in public ownership and administered by the U.S. Forest Service, National Park Service, or Bureau of Land Management. While there are some small parcels that are owned by the Los Angeles Department of Water and Power or are patented mining claims, they amount to a very small fraction of the habitat. Thus, habitat throughout the historic range of Sierra Nevada bighorn sheep remains essentially intact; it is neither fragmented nor degraded. Consequently, habitat loss was not a reason for listing.

2. OVERUTILIZATION FOR COMMERCIAL, RECREATIONAL, SCIENTIFIC, OR EDUCATIONAL PURPOSES

While unregulated hunting may have played a role in early population declines (Wehausen 1988), there is no evidence that commercial, recreational, scientific, or educational activities currently are significant threats. Poaching of Sierra Nevada bighorn sheep has not been documented in recent decades.

3. DISEASE OR PREDATION

Disease

The potential for the transfer of virulent disease organisms from domestic sheep to bighorn sheep in the Sierra Nevada was a key factor in listing the Sierra Nevada bighorn sheep. As discussed earlier, pneumonia, caused by *Pasteurella* alone, or in combination with other pathogens, is the most significant disease threat for bighorn sheep (Bunch *et al*. 1999). Sheep in general are susceptible to pneumonia and bighorn sheep appear particularly susceptible. Although die-offs of bighorn sheep due to disease have occurred that are unrelated to domestic sheep (Miller *et al*. 1991), the history of bighorn sheep in the United States provides numerous examples of major die-offs following contact with domestic sheep (Goodson 1982, Foreyt and Jessup 1982, Singer *et al*. 2001, Coggins 2002), and pneumonia epizootics can extirpate entire populations (Martin *et al*. 1996).

Transmission of pathogens from domestic sheep bands to populations of bighorn sheep under range conditions is extremely difficult to document conclusively because researchers cannot collect pre- and post- epizootic samples from the domestic and wild sheep that are involved. This would require researchers to predict when and where an epizootic was going to occur. Because of these difficulties, there is no conclusive evidence that directly documents the transmission of pneumonia-causing pathogens from domestic sheep to bighorn sheep under free-ranging conditions. However, numerous independent trials in captive bighorn sheep have resulted in mortality of bighorn sheep due to respiratory disease following contact with domestic sheep (Onderka and Wishart 1988; Foreyt 1989, 1990, 1994; Callan *et al*. 1991). In addition, inoculations of bighorn sheep with *Pasteurella* from the respiratory tract of healthy domestic sheep (Onderka *et al*. 1988, Foreyt *et al*. 1994, Foreyt and Silflow 1996) has resulted in respiratory disease and death of the bighorn sheep, but not of domestic sheep treated identically. Given the evidence from these captivity and inoculation studies in combination with the field observations of pneumonia related die-offs, mentioned previously, disease contracted from domestic sheep is considered a potentially significant source of mortality that requires management.

Diseases transferred through contact with domestic sheep are suspected to have played a major role in the disappearance of certain bighorn sheep herds in the Sierra Nevada beginning around 1870 (Wehausen 1985). Currently, domestic sheep grazing on both private and federal land occurs adjacent to Sierra Nevada bighorn sheep subpopulations. The potential for contact between the species occurs when stray domestic sheep enter bighorn sheep habitat, or when bighorn sheep encounter domestic sheep herds.

See Appendix B for a more detailed discussion of disease and the risk of transmission between domestic sheep and Sierra Nevada bighorn sheep.

Predation

Mountain lion predation of bighorn sheep on winter ranges has accounted for the majority of documented mortalities since the late 1970s. This predation increased from the 1970s to the 1980s and is postulated as the cause of a coincident and marked decrease in winter range use by bighorn sheep in the Sierra Nevada (Wehausen 1996). Subsequent population declines have been attributed to this change in winter habitat selection. During 1982 and 1988 to 1990, four mountain lions that preyed on bighorn sheep in two winter ranges were removed to help protect those sheep herds (Stephenson pres. comm. 2007).

4.   THE INADEQUACY OF EXISTING REGULATORY MECHANISMS

In 1883, an earlier moratorium on the take of bighorn sheep in California was extended indefinitely (Wehausen *et al*. 1987), and bighorn sheep in the Sierra Nevada remain a fully protected species. In 1972, California listed the California bighorn sheep as “rare.” The designation was changed to “threatened” in 1984 to standardize the terminology of the amended California Endangered Species Act (Sierra Nevada Bighorn Sheep Interagency Advisory Group 1997), and the California Fish and Game Commission upgraded the species' status to “endangered” in 1999.

In 1971, Inyo National Forest established sanctuaries totaling about 16,500 hectares (41,000 acres) for the Mount Baxter and Mount Williamson herds of Sierra Nevada bighorn sheep and called them the California Bighorn Sheep Zoological Areas (Wehausen 1979; Inyo National Forest 1988). Those sanctuaries were designated to regulate human use in some areas (Hicks and Elder 1979), and reduce domestic sheep/wild sheep interaction by constructing a fence below the winter range of the Mount Baxter herd along the U.S. Forest Service and Bureau of Land Management boundary (Wehausen 1979). Adjacent summer range on National Park Service land also was designated to reduce human disturbance (Wehausen 1979), and those restrictions continue.

Numerous efforts for the conservation of bighorn sheep in the Sierra Nevada have taken place in recent decades including but not limited to: (1) intensive field studies; (2) reestablishment of three additional populations in historical habitat; (3) creation, in 1981, of the Sierra Nevada Bighorn Sheep Interagency Advisory Group, including representatives from Federal, State, and local resource management agencies, which has produced the Sierra Nevada Bighorn Sheep Recovery and Conservation Plan (1984) and a Conservation Strategy for Sierra Nevada Bighorn Sheep (1997); and (4) removal of four mountain lions that were taking Sierra Nevada bighorn sheep, which played a significant role in efforts to reestablish the Mount Warren herd (Chow 1991).

Despite these efforts, the bighorn sheep population declined significantly in the 15 years prior to listing (Figure 2). Regulatory mechanisms to address the threats contributing to the listing of the Sierra Nevada bighorn sheep were inadequate. First, although efforts had been underway for many years, the U.S. Forest Service was unable to eliminate, or even reduce, the threat of contact between domestic sheep and Sierra Nevada bighorn sheep by eliminating or modifying grazing allotments. Second, because of the passage of Proposition 117 in 1990 by the California Legislature, the California Department of Fish and Game lost the authority to remove mountain lions to protect the Sierra Nevada bighorn sheep. However, between the Federal emergency and final listings, the California State Legislature enacted AB 560, which amended Proposition 117 and allowed the California Department of Fish and Game to remove mountain lions that are a threat to bighorn sheep in California.

5. OTHER NATURAL OR MANMADE FACTORS AFFECTING ITS CONTINUED EXISTENCE

At the time of its listing, the Sierra Nevada bighorn sheep population was very small, with only about 125 adults among five geographic areas (Wehausen 2001), and little probability of interchange among those areas. Additionally, multiple independent groups of females, defined by distinct home range patterns, were known in some of those areas and resulted in yet smaller population units (Wehausen and Chang 1997, Wehausen 2001). Evidence has suggested that many of these contained five or fewer females in recent years (Wehausen 2001). Thus, small population effects alone made these bighorn sheep vulnerable to extinction. These effects might be random naturally occurring population fluctuations (see section II.A.1), loss of genetic variation (see section II.A.2), or both.

E. PAST AND CURRENT MANAGEMENT AND CONSERVATION ACTIVITIES

1. FEDERAL AGENCIES

a. U.S. Department of the Interior - Fish and Wildlife Service

The Endangered Species Act of 1973, as amended (Act) (16 U.S.C. 1531 et seq.), requires that the Secretary of Interior identify wildlife and plant species that are endangered or threatened, based on the best available scientific and commercial information. As part of the program to accomplish this purpose, we maintain a list of species regarded as candidates for listing. We maintain this list for a variety of reasons including: to provide advance knowledge of potential listings that could affect decisions of environmental planners and developers; to solicit input from interested parties to identify those candidate species that may not require protection under the Act or additional species that may require the Act’s protections; and to solicit information needed to prioritize the order in which species will be proposed for listing.

On September 18, 1985, we published a Notice of Review in which we designated the Sierra Nevada bighorn sheep as a Category 2 candidate and solicited status information (U.S. Fish and Wildlife Service 1985). Category 2 candidate species included species for which we had information indicating that proposing to list as endangered or threatened was possibly appropriate, but for which sufficient data on biological vulnerability and threats were not currently available to support a proposed rule. Category 1 candidates were those species for which we had sufficient information on file to support issuance of proposed listing rules. In our January 6, 1989 and November 21, 1991 Notices of Review (U.S. Fish and Wildlife Service 1989, 1991), we retained the Sierra Nevada bighorn sheep in Category 2. Beginning with the February 28, 1996, Notice of Review (U.S. Fish and Wildlife Service 1996), we discontinued the designation of multiple categories of candidates, and now consider only species that meet the definition of former Category 1 as candidates for listing. At that point, the Sierra Nevada bighorn sheep was not identified as a candidate.

Nevertheless, we remained in contact with the California Department of Fish and Game and participated in the Sierra Nevada Bighorn Sheep Interagency Advisory Group regarding the status of the species. In 1998, as new information became available regarding the continual decline in the Sierra Nevada bighorn sheep population, we initiated a status review. On April 20, 1999, we published an emergency rule to list the Sierra Nevada distinct population segment (DPS) of California bighorn sheep as endangered (U.S. Fish and Wildlife Service 1999a), as well as a proposed rule (U.S. Fish and Wildlife Service 1999b) to list the species as endangered. The emergency rule provided Federal protection pursuant to the Act for a period of 240 days. After a thorough review of all comments received on the proposed rule, we published a final rule listing the Sierra Nevada bighorn sheep DPS as endangered in accordance with section 4 of the Act on January 3, 2000 (U.S. Fish and Wildlife Service 2000).

Section 4 further directs us to develop and implement recovery plans for listed species; this recovery plan was developed according to that direction and following our "Policy and Guidelines for Planning and Coordinating Recovery of Endangered and Threatened Species" (U.S. Fish and Wildlife Service 1990). Once a species has recovered and is removed from the list, we must, in cooperation with the State government, "effectively monitor for not less than 5 years" the species' status, and we must be prepared to restore the species to the list if necessary. Section 5 of the Act authorizes the Department of the Interior to acquire habitat essential to preserving listed species, and section 6 directs us to cooperate with the States to maintain adequate programs for their conservation. Through section 7 of the Act, Federal agencies are required to use their authorities to carry out programs for the conservation of listed species and to consult with us when a Federal action may have an effect on listed species. Section 9 of the Act provides for protection of listed species, and section 10 permits exceptions to the protections granted under section 9. The exceptions are permitted in the form of scientific, recovery, and incidental take permits, and other circumstances as detailed in section 10.

During the period of Federal protection provided by the emergency rule, we worked with the Inyo National Forest and the California Department of Fish and Game regarding measures to protect the bighorn sheep. We assumed the lead agency role in the development of a Final Environmental Assessment for Predator Damage Management to Protect the Federally Endangered Sierra Nevada Bighorn Sheep (U.S. Department of Agriculture Wildlife Services 1999). This document was prepared by the U.S. Department of Agriculture, Wildlife Services, and identified the cooperating agencies: the California Department of Fish and Game, U.S. Forest Service, and National Park Service. This environmental assessment was for the proposed program to protect the bighorn sheep from predation on and around its current range.

In response to the threat of disease transfer from domestic sheep to Sierra Nevada bighorn sheep and to facilitate a consistent and comprehensive approach to consulting on the taking of Sierra Nevada bighorn sheep under the Act, we organized an interagency team of biologists and rangeland management specialists from the Bureau of Land Management, California Department of Fish and Game, U.S. Forest Service, and Los Angeles Department of Water and Power to develop a grazing strategy for domestic sheep for the Owens Valley. This strategy (U.S. Fish and Wildlife Service 2001) was based on analyses of the risk of disease transmission between domestic sheep and bighorn sheep for each of the allotments/leases within the Owens Valley on the Inyo National Forest (seven allotments and one trail), Humboldt-Toiyabe National Forest (one allotment), Bureau of Land Management (one allotment and one trail), and Los Angeles Department of Water and Power (three leases). Based on this strategy, domestic livestock grazing within the Owens Valley has been modified by the Bureau of Land Management, U.S. Forest Service, and Los Angeles Department of Water and Power, including a July 2000 Environmental Assessment and Decision Notice that closed two grazing allotments on the Inyo National Forest.

Pursuant to section 7 of the Endangered Species Act, we have been in formal and informal consultation with the Inyo National Forest, Humboldt-Toiyabe National Forest, and the Bureau of Land Management on their grazing operations. All agencies are working cooperatively to identify high-risk areas and address unacceptable risks, so that domestic sheep grazing does not threaten the existence of the bighorn sheep.

b. U.S. Department of the Interior - National Park Service

Historical Management

A significant portion of the historic summer range of the Mount Baxter herd occurred, and to some extent still does occur in Kings Canyon National Park (Wehausen 1980). Since reestablishment in 1980 (Bleich et al. 1990b), the Mount Langley herd has utilized a limited part of the Sequoia National Park during the summer (Moore and Chow 1990). Males of the reestablished Lee Vining herd have occasionally visited Yosemite National Park, and it is surmised that should the herd recover fully, parts of the crest in the national park will be included in summer range. Lastly, to replace the herd(s) that once occupied the Great Western Divide (Wehausen 1979), an eventual reintroduction is planned to occur entirely inside Sequoia National Park. Similarly, the bighorn sheep currently occupying the Bubbs Creek herd unit live year round in Kings Canyon National Park.

During the early 1960s, biologists from Sequoia and Kings Canyon National Parks conducted surveys along the crest, trying to locate remaining bands of bighorn sheep (Riegelhuth 1965). The National Park Service was a substantial sponsor of the definitive research conducted by Dr. John Wehausen from 1976 through 1979 (Wehausen 1980).

Following the lead of the U.S. Forest Service, Sequoia and Kings Canyon National Parks in the early 1970s closed "the female/lamb range of the Sierra Nevada bighorn sheep . . . to all pack animals and to off-trail travel by humans [in the national park]." This closure was later codified in the Superintendent's Compendium. The associated map identified an area representing the known range of females and lambs within King Canyon National Park. Because off-trail travel by pack stock is impractical along the crest of the Sierra Nevada and the occasional use by mountaineers and climbers does not pose a significant threat to bighorn sheep, and because the areas used by bighorn sheep will be in a state of flux for the indefinite future, the permanent closure was terminated in 2001.

Representatives of the National Park Service have participated in the Sierra Nevada Bighorn Sheep Interagency Advisory Group since its inception in 1981. In addition to the Recovery and Conservation Plan authored by that group (Sierra Nevada Bighorn Sheep Interagency Advisory Group 1984), Sequoia and Kings Canyon National Parks produced a "Bighorn Sheep Management Plan" for those parks (National Park Service 1986) that outlined steps to recover populations, such as the Great Western Divide herd, that historically used the national parks.

In 1985, the Yosemite Association solicited funds from the Goldman Fund and the Sacramento Safari Club that were paid to the Lee Vining Canyon grazing allotment holder in exchange for vacating the allotment, which was then later terminated by the U.S. Forest Service. Subsequently, the National Park Service conducted follow-up monitoring and research after bighorn sheep were translocated there in 1986 (Chow 1991, Moore 1991).

During the late 1980s, the National Park Service sponsored and conducted aerial and ground surveys to establish the availability of winter and summer habitat in the Great Western Divide and Kern River as a necessary precursor to eventual translocations there.

Current Management on National Park Service Lands

National Park Service biologists from Sequoia, Kings Canyon, and Yosemite National Parks participated in preparation of this recovery plan and will participate in its implementation, particularly by sponsoring the use of National Park lands by existing herds of Sierra Nevada bighorn sheep and the reestablishment of Sierra Nevada bighorn sheep in the Great Western Divide area of Sequoia National Park.

c. U.S. Department of Agriculture - Forest Service

Historical Management

Much of the historic habitat of the Sierra Nevada bighorn sheep occurs on National Forest System lands within the Pacific Southwest Region (Inyo, Sequoia, Sierra, and Stanislaus National Forests) and the Intermountain Region (Humboldt-Toiyabe National Forest). The current populations primarily occupy the Inyo and Humboldt-Toiyabe National Forests, but some use also occurs in the Sequoia/Kings Canyon National Park, Yosemite National Park, and the Sierra National Forests.

The U.S. Forest Service is authorized by Acts of Congress and by regulations issued by the Secretary of Agriculture to administer, manage, and protect National Forest System lands for multiple uses, including the provisions of habitat for fish, wildlife, and plants. Typically, the U.S. Forest Service is responsible for managing habitats (e.g., food, water, and cover) on National Forest System lands and coordinating with the appropriate State agency regarding management of the animal populations. 36 CFR 219.19 directs the U.S. Forest Service to manage fish and wildlife habitat to maintain viable populations of existing native and desired nonnative vertebrate species. One way this mandate is met is through the Forest Service Sensitive Species Program, under which each Region establishes a list of sensitive plant and animal species that are given special consideration under the multiple use mandate. The objectives of the program are to ensure the continued existence of viable, well-distributed populations and to prevent a trend toward listing under the Endangered Species Act of 1973. Each National Forest is required to develop a Land and Resource Management Plan, which sets the framework for multiple use management of the Forest and incorporates management strategies to maintain viable populations within the Forest and to promote recovery of federally listed species. In addition, the U.S. Forest Service, like other Federal agencies, has responsibilities under the Federal Endangered Species Act (section 7a). Accordingly, the U.S. Forest Service coordinates and consults with us on activities it conducts, funds, or authorizes that may affect federally listed endangered, threatened, or proposed species and designated or proposed critical habitat.

In 1940, concern about bighorn sheep in the Sierra Nevada (Dixon 1936) prompted the National Park Service and Sierra Club to jointly propose the creation of a sanctuary on Inyo National Forest land for the Mount Baxter population (Colby 1940a, 1940b; Blake 1940). The U.S. Forest Service and California Department of Fish and Game rejected this proposal because insufficient information existed to justify the need, as well as because of concern that the publicity of such a sanctuary might exacerbate poaching, rather than having the opposite effect (Blake 1941).

The U.S. Forest Service became active in the management of Sierra Nevada bighorn sheep in 1971, when the Inyo National Forest created two Bighorn Sheep Zoological Areas (Mount Baxter and Mount Williamson Units) for the two surviving native herds (Dunaway 1971). These areas, totaling 1,823 hectares (4,505 acres) outside designated wilderness areas, were created to give top priority to the requirements of the bighorn sheep through protection and maintenance of their habitat and through the regulation of human use in certain sections of the bighorn range to minimize human disturbance. Similar restrictions were applied to adjacent habitat of these herds under National Park Service management (Wehausen 1985). The U.S. Forest Service has been a member of the Sierra Nevada Bighorn Sheep Interagency Advisory Group since its inception in 1981, and assisted in the funding and development by that group of a Recovery and Conservation Plan in 1984 and the Conservation Strategy in 1997. California bighorn sheep were classified as a Regional Forester's Sensitive Species in California in 1982. In 1985, the Inyo National Forest facilitated, in cooperation with the California Department of Fish and Game and other members of the Interagency Advisory Group, the reintroduction of bighorn sheep to the Lee Vining Canyon area. On November 25, 1998, due to the rapid decline of Sierra Nevada bighorn sheep, the Pacific Southwest Region Regional Forester issued a letter directing the Forest Supervisors of the National Forests within the historic range of the Sierra Nevada bighorn sheep to take specific actions to provide habitat and other assistance contributing to the viability of the Sierra Nevada bighorn sheep. Various management actions were initiated by this letter; these included providing funding to U.S. Department of Agriculture Wildlife Services to monitor mountain lion activity within occupied bighorn sheep habitat, working with permittees to modify grazing management to reduce the risk of disease transmission, initiating informal consultation with the Fish and Wildlife Service, and using prescribed fire to improve winter range.

Current Management on National Forest System Lands

Since the emergency listing of the Sierra Nevada bighorn sheep on April 20, 1999, the U.S. Forest Service has been consulting with the Fish and Wildlife Service on various Federal actions allowed under their Forest Land and Resource Management Plan with the potential to affect Sierra Nevada bighorn sheep or their habitat. These actions include term grazing permits for domestic sheep allotments adjacent to occupied bighorn sheep habitat, recreational use of occupied bighorn sheep habitat, helicopter use within and adjacent to bighorn habitat, prescribed fire, normal fire suppression activities, and special use permits for outfitter guides and packers. In May 2000, a temporary Emergency Forest Order was issued, which prohibited dogs and domestic goats from entering key Sierra Nevada bighorn sheep habitat areas on the Inyo National Forest. The final version of this Forest Order is currently being prepared.

The Inyo National Forest continues to use prescribed fire within bighorn sheep winter range in an attempt to open up habitats, decrease cover for mountain lions, and potentially allow bighorn sheep increased access to areas with highly nutritional food sources.

2. STATE AGENCIES

The first management action for Sierra Nevada bighorn sheep was full protection from hunting. Decimation of native sheep occurred quickly following the influx of gold miners in the mid-1800s, and declines of native game led the State Legislature to enact legal protections beginning in the 1870s. For wild sheep, legal protection first occurred in 1876, when a law of 1872 that provided seasonal protection for elk, deer, and pronghorn was amended to include all bighorn sheep. Two years later this law was further amended to establish a 4-year moratorium on the taking of any pronghorn, elk, mountain sheep, or female deer; in 1883, the moratorium was extended indefinitely for bighorn sheep (Wehausen *et al*. 1987). Sierra Nevada bighorn sheep remain fully protected by the State of California.

In 1972, the California subspecies, as defined by Cowan (1940) and including surviving native populations in the Sierra Nevada, was listed as rare under the 1970 California Endangered Species Act (California Department of Fish and Game 1974). This category was changed to threatened in 1984. Through the listing process, the Fish and Game Commission recommended development and implementation of a recovery plan, including field research and reintroductions. Intensive field study began in 1975, and the results of those investigations led to a series of translocations beginning in 1979. A conservation and recovery plan was completed in 1984 (Sierra Bighorn Interagency Advisory Group 1984). The goals of that plan were: (1) to create two additional populations numbering at least 100 bighorn sheep that could serve as translocation stock in the event of catastrophic decline of the Mount Baxter herd, and (2) to reestablish bighorn sheep populations throughout historic ranges in the Sierra Nevada where it was biologically and politically feasible. To date, no reintroduced population has met the first goal, while unforeseen ecosystem level changes have resulted in a major reduction of the Mount Baxter population.

It is the responsibility of the California Department of Fish and Game (Fish and Game Code Section 1802) to conserve, protect, and manage fish, wildlife, native plants, and habitat necessary for biologically sustainable populations of those species. It also is the policy of the State to conserve, protect, restore, and enhance endangered or threatened species and their habitats. The role of the California Department of Fish and Game, as trustee for fish and wildlife resources, includes working with other State, Federal, and private entities to further conservation and recovery of threatened and endangered species on their lands. Conservation goals for bighorn sheep (California Department of Fish and Game 1983) are to:

1. Maintain, improve, and expand bighorn sheep habitat where possible or feasible.

2. Reestablish bighorn sheep populations on historic ranges where feasible.

3. Increase bighorn sheep populations so that all races become numerous enough to no longer require classification as rare or fully protected.

4. Provide for aesthetic, educational, and recreational uses of bighorn sheep.

The California Department of Fish and Game supports the concept of regional management for the long-term viability of bighorn sheep populations. In support of this strategy, the California Department of Fish and Game's Bighorn Sheep Conservation Program maintains an inventory of the distribution of bighorn sheep in California. The populations of bighorn sheep in California are grouped into metapopulations, or 'systems' of populations, that best represent logical regions to manage for the long-term viability of the species. This regional approach recognizes the importance of inter-mountain areas that allow movement and exchange of individuals between populations, the recolonization of vacant habitats, and the need for interagency coordination of land management. The concept of regional populations considers not only vegetative and geographic boundaries, but also man-made barriers that define distributions and which have resulted in the fragmentation of habitat. Given the need to understand the status and dynamics of regional populations of bighorn sheep, this type of inventory should provide an index for documenting regional population changes over time and a basis for evaluating the success or failure of management actions at a meaningful level.

Although a metapopulation approach is an important biological principle for understanding the long-term survival of bighorn sheep populations, it is equally important as a management concept that establishes a priority for regional coordination for bighorn sheep population and habitat management. For example, data regarding extinction and recolonization are limited, and we therefore have an incomplete biological justification for considering some regions as true metapopulations. Nevertheless, given the need for regional management of bighorn sheep populations, the California Department of Fish and Game has defined the metapopulations based on the best information available for the regions, and utilizes this regional strategy for the management of bighorn sheep throughout the State.

In 1997, a conservation strategy was produced for bighorn sheep in the Sierra Nevada that reflected the significant changes in the status of those animals (Sierra Nevada Bighorn Sheep Interagency Advisory Group 1997). Unfortunately, funding constraints encountered by the California Department of Fish and Game limited the recovery efforts identified in this conservation strategy. We and the Fish and Game Commission took emergency action in 1999 to list the Sierra Nevada bighorn sheep as endangered under the State and Federal Endangered Species Acts. This action was in response to a significant decline in the population size, from approximately 310 in 1985 to an estimated 125 adults in 1999. With the small population of Sierra Nevada bighorn sheep in decline, the threat of this unique population becoming extinct was great.

Due to the high level of public attention and concern, the California Department of Fish and Game was provided funding (in 1999) through the legislature to implement a population recovery program for bighorn sheep in the Sierra Nevada. This funding will support the start of a long-term comprehensive population recovery program, and the recovery potential for Sierra Nevada bighorn sheep populations is high if conservation actions are taken immediately. Elements of the recovery program include monitoring the population, intensively reducing mortality, reestablishing additional populations in historic range, and preparing for and potentially implementing captive breeding efforts to increase population size and maintain genetic diversity.

II. RECOVERY

A. CONSERVATION PRINCIPLES USED IN DEVELOPING THIS RECOVERY PLAN

The following sections apply general conservation principles in the context of our current knowledge regarding Sierra Nevada bighorn sheep and outline the relationship of these principles to the recovery criteria for this species. Conservation theory recognizes that population dynamics and genetic issues need to be addressed in species conservation. Although threats to population persistence are of more immediate importance to Sierra Nevada bighorn sheep, potential loss of genetic variation also has implications for the long-term conservation of this taxon (Lande 1988). Fundamentally, the recovery strategy revolves around three main conservation issues: population dynamics, genetic variation, and ecosystem integrity.

1. POPULATION DYNAMICS

Demographic processes are especially important considerations in the conservation of small populations (Gilpin and Soulé 1986). Variation in birth, death, immigration, and emigration rates, as well as the age and sex structure of populations, can cause fluctuations in population size that make small populations especially vulnerable to extinction. Lande (1988) noted that a shortcoming of some past recovery plans was an inadequate emphasis on the implications of such population parameters for recovery and cautioned that, for many wild populations, risks concerning population parameters are of more immediate importance than genetic concerns.

Spatial distribution of animals across the landscape is an important consideration. Sierra Nevada bighorn sheep, like other forms of bighorn sheep and many other taxa, are distributed as a collection of subpopulations, each occupying a patch of suitable habitat within a matrix of otherwise less suitable or unsuitable habitat. The complex topography and the vegetation structure of the southern and central Sierra landscape, coupled with the intrinsic biology and behavior of these bighorn sheep, has resulted in a naturally fragmented distribution of animals, a metapopulation (Bleich *et al*. 1990a). This metapopulation is composed of multiple subpopulations that interact intermittently to varying degrees, depending on site-specific geography, movement characteristics of males (occasional) and females (rare), and chance.

Metapopulation structure has profound implications for the conservation of Sierra Nevada bighorn sheep. Conservation objectives for this taxon must simultaneously address all levels of population organization to achieve recovery goals. Recovery units, herd units, and separate female groups within herd units are all relevant to overall recovery of Sierra Nevada bighorn sheep. For further detail on the definitions of these terms, refer to the discussion of recovery objectives (section II.C.2).

Metapopulations typically are assumed to exist in a state of balance between population extinction and colonization (Hanski and Gilpin 1991). However, bighorn sheep are relatively slow colonizers (Geist 1967, 1971, Bleich *et al*. 1996) and, therefore, metapopulation extinction-colonization processes must be considered over appropriate periods. Although bighorn sheep typically have a naturally fragmented distribution (Bleich *et al*. 1990a), any external factor that further fragments existing populations poses a heightened threat to persistence (Schwartz *et al*. 1986, Bleich *et al*. 1996). Hanski and Gilpin (1991) cautioned that species subject to accelerated habitat and/or population fragmentation must be managed carefully, as they may not necessarily be able to function as a metapopulation in equilibrium. This situation may be exacerbated in the Sierra Nevada because the metapopulation is largely linear in geographic distribution, resulting in fewer populations that could serve as sources of colonists.

There is little threat to Sierra Nevada bighorn sheep due to habitat loss. Virtually all land that provides habitat for the Sierra Nevada bighorn sheep is managed by the Federal government and is likely to remain in a wild condition for the indefinite future. However, population fragmentation due to decreased habitat quality resulting from an altered fire regime, random natural fluctuations in population parameters or deleterious effects of disease or predation could affect overall metapopulation dynamics.

Population processes are of primary concern in the recovery of Sierra Nevada bighorn sheep due to their small numbers (an estimated 325 to 350 individuals in 2004). Furthermore, Sierra Nevada bighorn sheep occur as discrete female groups with significance to the distributional structure of the population (Wehausen 1979). Because these female groups are independent segments of populations, they are the fundamental demographic units and should be treated as the basic conservation units (Soulé 1987).

In the southern Sierra Nevada, most herds of bighorn sheep were reduced to such low levels at the time of listing that random natural variation in population and environmental factors posed serious immediate threats. For example, some female groups consisted of only five females at the time of listing. Therefore, recovery efforts for Sierra Nevada bighorn sheep have focused on actions that increase sizes of individual female groups (decreasing adult mortality rates, increasing recruitment, and augmentation through translocations) and increasing overall distribution through reintroductions to historic ranges.

2. GENETIC CONSIDERATIONS

The Sierra Nevada bighorn sheep was recently recognized as a unique subspecies (see I.A.2.). As such, this taxon appears to have distinctive genetic characteristics that may include adaptations to conditions in the Sierra Nevada. One of the fundamental objectives of this recovery program is the conservation of the unique gene pool embodied in the remaining animals of this metapopulation.

Maintaining genetic variation is an important conservation goal because loss of genetic variability can result in inbreeding depression (a loss of fitness) and the inability of populations to respond to long-term environmental changes (Gilpin and Soulé 1986, Ralls *et al*. 1988, Lande 1988, Meffe and Carroll 1994, Fitzsimmons *et al*. 1995). Rate of evolutionary change in a population is proportional to the amount of genetic variation available (Fisher 1958), and loss of genetic diversity reduces future evolutionary options (Meffe 1999). By reducing the fitness of individuals, loss of genetic variation also can reduce the growth rates and resilience of populations (Lacy 1997).

Loss of genetic variation is a special concern among small populations because heterozygosity is lost more quickly in small populations than in large ones (Meffe and Carroll 1994). In the past, occasional long-range movements north or south along the Sierra Nevada, especially by males, likely helped to maintain gene flow, but it is unclear to what extent such movements now occur. The current, fragmented distribution of populations of these animals likely reduces connectivity among groups. In small herds of bighorn sheep, random natural variability in population parameters can be an overriding determinant of population survival and is mitigated by immigration of both sexes. If small herds become isolated and stay small, they potentially face an increased loss of genetic variability, in addition to the risks to persistence associated with stochastic demographic events (e.g., several consecutive years of low reproduction and/or high mortality within a small herd). Even if gene flow is maintained among female groups throughout the Sierra Nevada, the overall small population size (approximately 325-350 individuals in 2004) is of concern. Thus, an important goal of this recovery plan is to increase the abundance of Sierra Nevada bighorn sheep to the level that the habitat can sustain, combined with further examination and consideration of existing and future genetic variation in this metapopulation.

Although genetic variation among bighorn sheep herds in the Sierra Nevada is not known to confer adaptive advantage in local environments, genetic theory holds that existing genetic variation should be maintained "in as near a natural geographic distribution as possible, so that evolutionary and ecological processes may be allowed to continue" (Meffe and Carroll 1994). Adaptation to future changes in the environment, such as may occur through global climate change, may depend on maintenance of genetic diversity within this taxon.

Because the most immediate problem facing bighorn sheep in the Sierra Nevada concerns depleted population sizes, the potential implications of loss of genetic heterozygosity implied by genetic theory should not override management objectives to maintain and expand the number and size of herds throughout much of the Sierra Nevada bighorn sheep's historic range. Nonetheless, as more is learned about the actual genetic diversity in the remaining individuals, it may be necessary to incorporate genetic management, such as moving males between some populations.

3. ECOSYSTEM INTEGRITY

Loss of habitat is recognized as the primary cause of species endangerment and the leading threat to global biodiversity (Groombridge 1992, Noss and Murphy 1995). It is also considered the most significant threat to the viability of many bighorn sheep populations (Bleich *et al*. 1996). However, habitat loss is not considered a proximate threat to the conservation of the Sierra Nevada bighorn sheep. Virtually all habitat used by this taxon is managed by the Federal government.

A stable and functional ecosystem is of paramount concern. For Sierra Nevada bighorn sheep, a primary emphasis is continued access to suitable habitat. Habitat conditions within the range of Sierra Nevada bighorn sheep generally are not subject to obvious human-induced changes. What is primarily at stake for these animals is continuing, safe access to preferred habitats, notably winter ranges. Recent declines in population sizes have been linked to the decreased use of key resources on winter ranges. A basic premise of the recovery strategy, therefore, is to reduce factors that inhibit the ability of Sierra Nevada bighorn sheep to utilize all components of their habitat. However, such actions need to take place in the context of all ecosystem components; potential effects of actions to enhance bighorn sheep herds on other components of the ecosystem must be considered.

Maintaining ecosystem integrity for the Sierra Nevada bighorn sheep should revolve around providing suitable habitat conditions and safe access to those habitats. Safe access implies that exposure to exotic diseases and unsustainable levels of predation are prevented. Exposure to diseases carried by domestic sheep or goats that may be lethal to bighorn sheep is a significant threat that could have catastrophic effects on recovery efforts for this taxon. All habitats, both summer and winter, should be managed to prevent contact between bighorn sheep and domestic sheep or goats. Similarly, predation should be managed within herds that are still at low levels. Bighorn sheep in the Sierra Nevada appear to be especially vulnerable to predation when herds are low in number, and that small group size may preclude the use of important foraging areas. As long as the populations of this taxon remain below viable levels, special predator management actions are warranted to ensure adequate use of important foraging habitat. However, it is also important to recognize that top predators play a crucial and irreplaceable role in maintaining the integrity of a variety of ecosystems (Terborgh *et al*. 1999), including, potentially, the ecosystem inhabited by Sierra Nevada bighorn sheep.

Habitat factors, such as visual openness, that may have been influenced by past management practices, also must be addressed. Because recovery is contingent on full use of the nutritional resources available to these bighorn sheep, the vegetative structure of some winter ranges needs to be considered with respect to the recovery strategy. Fire suppression of lands within some winter ranges has been a common management practice over the last century. The implications of fire suppression for vegetation succession and the loss of visual openness in some winter range habitat are not fully understood. Thus, consideration should be given to how the habitat changes induced by fire suppression might affect use of some winter ranges by bighorn sheep.

B. OBJECTIVES

1. CONSERVATION CHALLENGE AND GOALS

"Given its small population size and recent population declines [Sierra Nevada bighorn sheep] are currently more deserving of conservation attention than any other group of bighorn sheep. Sierra Nevada bighorn sheep are currently one of the rarest mammalian taxa in North America" (Wehausen and Ramey 2000).

The challenge and objective of this plan is (1) to define a desired future size and distribution of the overall bighorn sheep population in the Sierra Nevada, at which point continued protection under the Federal and California Endangered Species Acts is no longer needed and, (2) to outline steps necessary to reach that condition. From a species perspective, the conservation challenges of these bighorn sheep concern long-term viability of the overall population and preservation of this unique gene pool. From an ecosystem standpoint, the challenge involves finding the long-term population viability of bighorn sheep relative to other elements of the ecosystems involved, as well as returning this large native herbivore to most of those regions of the Sierra Nevada from which it has been extirpated. Thus, the conservation goal of this recovery plan is to restore Sierra Nevada bighorn sheep in a geographic distribution throughout most of their native range with genetic representation that assures their long-term viability as a unique life form. The ultimate goals of this recovery plan are to: 1) recover the Sierra Nevada bighorn sheep to a self-sustaining population size and geographic distribution that buffers them against extinction; 2) maintain long-term viability through establishment of programs and mechanisms that ensures the protection of these populations from outside threats following a potential delisting.

2. RECOVERY CRITERIA

A species is considered to be endangered when it is in danger of extinction throughout all or a significant portion of its range, likely to become extinct in the near future, and it is considered to be threatened when it is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range. Downlisting criteria identify the conditions at which the status of the species has improved to the point that it is no longer endangered, and may be proposed to be reclassified as threatened. Delisting criteria represent the minimum conditions necessary to propose removing the taxon from the endangered species list.

a. Downlisting Criteria

This plan concerns the bighorn sheep in the southern and central Sierra Nevada, from near Olancha Peak and the Great Western Divide north to Twin Lakes, near Bridgeport, California. In this region 16 herd units have been identified (Table 4, Figure 1). These areas are known from sightings or skulls to have been occupied historically. We based herd units in the Draft Recovery Plan for the Sierra Nevada Bighorn Sheep (U.S. Fish and Wildlife Service 2003) on topography, terrain features, and habitat openness. The resulting lines were largely the result of expert opinion, which identified the herd unit boundaries based on these features and knowledge about bighorn sheep movement and habitat utilization patterns in the Sierra Nevada.

In 2004-2005, the California Department of Fish and Game developed a model that looked at variables of habitat selection that included slope, elevation, aspect, hillshade, distance to escape terrain, vegetation, and terrain ruggedness relative to known sheep locations during the winter and summer. The model identified the relative probability, from 0 to 100 percent, that bighorn sheep were likely to select a given area within the Sierra Nevada based on that area's habitat characteristics. These probabilities were identified for both summer and winter seasons. All areas with probabilities greater than 90 percent were identified as either winter or summer range for the Sierra Nevada bighorn sheep (i.e. if the winter range probability value was greater than 90 percent for a given area, that area was identified as winter range; if the summer range probability value for a given area was greater than 90 percent, that area was considered to be summer range).

The predicted areas of summer and winter range largely conformed with the herd units identified in the 2003 draft recovery plan, but some modifications to the herd unit boundaries were made based on the model results. The Twin Lakes (non-essential) and Mount Langley (essential) herd units were increased in size, the Bubbs Creek (non-essential) herd unit was added, and the Sawmill Canyon (essential) herd unit was slightly modified. In addition, the Mount Warren and Lundy Canyon Herd Units were combined, and the Wheeler Ridge and Mount Tom Herd Units were combined.

Some areas that the model predicted as summer or winter range were not included in the new herd unit boundaries because they were not located in areas that would facilitate movement between them and other areas of predicted summer or winter range. Conversely, some areas within the herd units that the model did not identify as summer or winter range were still included because they provide the required connectivity between summer and winter range to facilitate migration.

Eight of the herd units currently support bighorn sheep. Herds to be re-established in the remaining units are expected to support geographically distinct groups of females. It is possible, however, that some may support more than a single group of females exhibiting distinct home range patterns. Of the 16 herd units, 12 herd units have been identified as essential because they are most likely to support recovery of the species (Figure 4, Table 4).

We have determined that Twin Lakes, Green Creek, Bubbs Creek, and Coyote Ridge Herd Units are not essential for the conservation of the Sierra Nevada bighorn sheep. These herd units are considered not essential because we believe that the 12 essential units will provide the necessary habitat and area to insure the viability and long-term survival of the Sierra Nevada bighorn sheep at the local and DPS population levels.

These are the herd units where recovery actions will be focused in order to achieve the recovery criteria below.

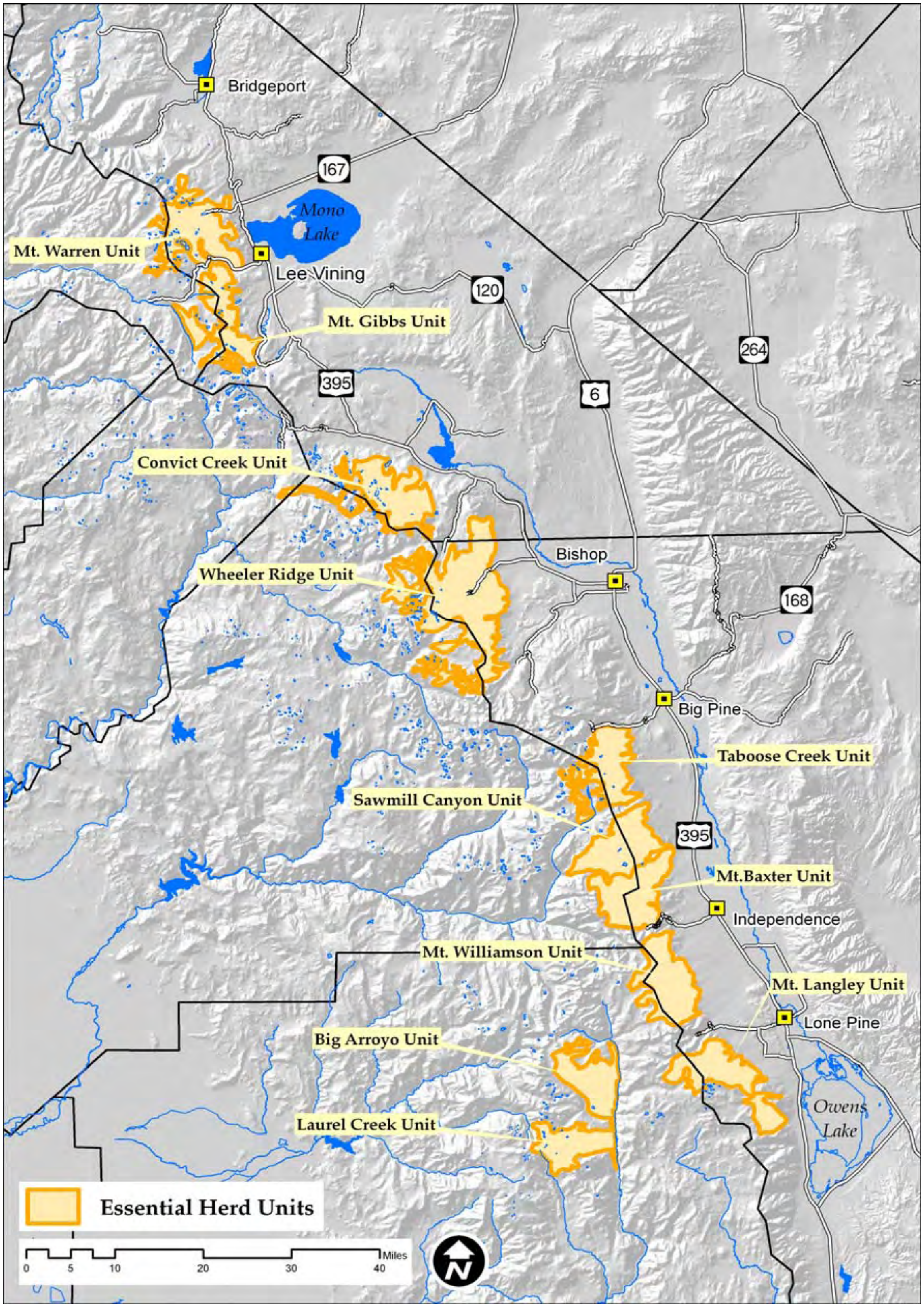


Figure 4 - Essential herd units within the four recovery units. These are locations essential to the recovery of the bighorn sheep.

Table 4. Recovery units and herd units (essential and non-essential) used as the basis of recovery goals (see Figure 1). Asterisks identify herd units that must be occupied for delisting (i.e., are essential).

Recovery Units and Herd Units	Minimum Elevation (ft)
Kern Recovery Unit	
1. Laurel Creek*	6800
2. Big Arroyo*	6900
Southern Recovery Unit	
3. Olancha Peak*	4800
4. Mount Langley*	4800
5. Mount Williamson*	6200
6. Bubbs Creek	6800
7. Mount Baxter*	4900
8. Sawmill Canyon*	4800
9. Taboose Creek*	6800
10. Coyote Ridge	5600
Central Recovery Unit	
11. Wheeler Ridge*	5600
12. Convict Creek*	7900
Northern Recovery Unit	
13. Mount Gibbs*	7600
14. Mount Warren*	7600
15. Green Creek	9000
16. Twin Lakes	7200

Three natural breaks in the distribution of the 16 herd units separate them into four distinct regions. Those four larger regions are termed recovery units, and are treated as the basic units for recovery of this taxon. Within recovery units, males are expected to move between herd units. However, movement between recovery units is likely to occur less frequently. Movements by males are likely to be the primary source of natural gene flow.

The rate at which females in the Sierra Nevada colonize vacant habitat is unknown. Dispersal between adjacent herd units within recovery units should occur with considerably higher probability than across the gaps that define recovery units, and thus has implications for the natural recolonization of herd units that become extirpated. However, inter-herd movements also can spread diseases (Dobson and May 1986, Bleich *et al*. 1990a, 1996). Consequently, unoccupied areas between some recovery units may be considered zones of isolation that could limit the spread of epizootics throughout the range of Sierra Nevada bighorn sheep.

Downlisting Criterion A1: Downlisting will require a minimum total of 305 females at least 1 year of age. At least 50 of those females must be 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 (Table 5). The number of females is the limiting factor in reproductive output because one male can produce offspring with several females. Consequently, we have not set a delisting criterion that considers the male population size within recovery units. However, Delisting Criterion B2 does address males in terms of their occupation of some herd units prior to delisting.

Justification: The relative number of requisite females for each of the four recovery units is based on differences in habitat quantity and quality among the herd units. Analyses of recent population growth curves for the Mount Langley and Wheeler Ridge herds have shown density-dependent patterns of lamb recruitment that allowed quantitative estimates of carrying capacities. Population carrying capacities also could be estimated for two other herds in the late 1970s when population growth rates indicated that they were at or close to carrying capacity. Habitat differences between those four populations and other herd units were used to estimate unknown carrying capacities. Habitat characteristics that were considered included the amount and minimum elevations (Table 4) of winter ranges and relative amount of high elevation habitat where it was likely to be limiting. Resulting carrying capacities varied from 15 to 80 females. Those carrying capacities were summed for each recovery unit for the essential herd units (Table 4), and that sum was halved to arrive at the minimum number of females needed by actual count for downlisting and delisting. That total was then adjusted to average at least 25 females per herd unit. The 50 percent criterion was based on recognition of the following:

(1) There is a need for these goals to be realistic and attainable. The data used as the basis of downlisting will be minimum counts that likely will be less than actual sizes for many herds. There is evidence that minimum counts for some Sierra Nevada herds have recently accounted for essentially every female. However, as herds increase in size, it is anticipated that it will become more difficult to make such complete counts. This may be particularly difficult for some herds that will be reintroduced to more remote areas in the Sierra Nevada where the intensive, repeated ground efforts needed for complete counts will not be possible. The greater number of herds that will need to be monitored also may decrease the efficiency of counts of individual herds through dilution of effort. Relative to recovery goals, use of data from minimum counts as the basis of recovery goals provides an important buffer in the form of uncounted sheep.

(2) Carrying capacities used were estimates that involve error. While the magnitude of that error is not known, it is very unlikely to approach 50% of the estimated carrying capacity. An alternative approach in which a minimum average of 25 females per herd unit identified for recovery is applied to all recovery units

produces essentially the same downlisting numbers listed in Table 5. The dynamics of populations may not be synchronous; thus, all herds might not be at or near carrying capacity at the same time. Dropping downlisting requirements well below estimated carrying capacities provided for that possibility.

(3) Growth of the last herd to be reintroduced to the Kern Recovery Unit can be expected to limit attainment of overall downlisting criteria, at which time many other herds probably will have approached carrying capacity. Consequently, when minimum goals are actually reached, total numbers can be expected to exceed those goals by a considerable margin. If carrying capacities estimated for these recovery goals are not significant overestimates, the actual total number of females may approach or exceed 500 when downlisting criteria are attained, which could put the total population over 1000. Prior to reaching those goals, there also will have been a substantial period of overall population growth, which will provide an additional metric of demographic health.

Downlisting can occur upon reaching these reproductive base thresholds, which will minimize extinction risk through: (1) considerable geographic distribution; (2) sufficient numbers to provide multiple sources of sheep for translocation to help any faltering herds and/or to establish sheep in unoccupied areas identified as necessary for recovery; and, (3) minimal loss of genetic variation through drift. The recovery plan's science team has determined that occupation of all four geographic conservation areas (Recovery Units) is necessary to: (1) develop sufficient numbers of sheep; (2) have sheep in enough isolated areas to make it highly unlikely that all would go extinct simultaneously from a stochastic event; (3) minimize the loss of genetic diversity; and (4) to protect against ecological changes brought on by climate change. Because of the possibility of natural, independent dynamics among the different herds, minimum sizes were set for each of the recovery units, but not for any individual herd units. However, based on current information recovery is most likely to occur in the essential herd units depicted in Table 4 and Figure 4.

<u>Downlisting Criterion A2</u>: The measures to prevent contact between domestic sheep/goats and bighorn sheep have been implemented and are successful.

Justification: Any contact between domestic sheep or goats and bighorn sheep could lead to the loss of entire herds of bighorn sheep in the Sierra Nevada. Hence, potential for contact between bighorn sheep and domestic sheep or goats must be eliminated to avoid the possibility of a catastrophic epizootic. Bighorn sheep and domestic sheep or goats can come into direct contact through the movements of either species. As recovery proceeds, and the numbers and geographic distribution of bighorn sheep increase, the potential for contact also will increase.

b. Delisting Criteria

Delisting Criterion B1: The number of female bighorn sheep required for downlisting by recovery unit (Table 5) will be maintained as an average for at least seven years (one generation) without intervention (i.e. population management, buffering populations through translocations, captive breeding, etc.). Herd status for delisting must entail at least three censuses, one at the beginning of the period (qualifying for downlisting), one at the end of the period, and one intermediate count for each herd unit.

Delisting Criterion B2: Bighorn sheep of both sexes will be present in a minimum of 12 specifically identified herd units distributed as two in the Kern Recovery Unit, six in the Southern Recovery Unit, two in the Central Recovery Unit, and two in the Northern Recovery Unit (Table 4 and Figure 4).

Justification: The target number of occupied herd units for delisting (Table 5) was based on realistic expectations. There is uncertainty about whether it will be possible to establish herds of bighorn in three of the herd units (Coyote Ridge, Green Creek, and Twin Lakes; Figure 1, Table 4) because of habitat limitations; thus, those three were not included in the delisting criteria. Additionally, the Bubbs Creek herd unit is not required to be occupied in the delisting criteria. Bighorn sheep discovered there in 2001 were likely a recent colonization. That herd unit is west of the crest of the Sierra Nevada where snowfall is much greater than the east side of the range. Because there are no historical records of bighorn sheep in the Bubbs Creek region, there is uncertainty as to the long-term viability of this herd unit. Consequently, it is not required to contain bighorn sheep for delisting.

These criteria result in a total requirement of 12 occupied essential herd units (Figure 4) and 305 females at least 1 year of age necessary for delisting (Table 5). With a natural adult sex ratio of about 70 males:100 females (Wehausen 1980), the minimum total population at both downlisting and delisting will be about 520 adults. Because this number is based on minimum requirements for each recovery unit, the total population will almost certainly be higher and probably will be considerably higher with young of the year included and larger numbers well above minima in some recovery units, as discussed above. The time requirement of one generation will assure the maintenance of these populations and distribution conditions across all recovery units while much of the population is replaced through mortality and recruitment. In addition, a period of substantial population growth will necessarily precede the initial attainment of conditions necessary for delisting. Thus, a period of favorable population conditions encompassing multiple generations will precede attainment of minimum population requirements for delisting.

Delisting Criterion B3: A population viability analysis projects that all recovery units are viable. Recovery tasks related to monitoring and research have been accomplished, allowing the severity of secondary threats (including vegetation succession, recreational disturbance, and loss of genetic diversity) to be adequately assessed. Threats have either been ameliorated or have been determined not to pose a significant risk to the population.

Justification: Before we determine that the Sierra Nevada bighorn sheep warrants delisting, additional information is needed regarding which threats significantly endanger the population. Research is needed on the threats noted above which may have potential for long-term adverse effects on the population. Research and monitoring tasks should assess which threats are significant and if necessary identify appropriate management actions to implement.

Delisting Criterion B4: Regulatory mechanisms and land management commitments have been established that provide for long-term protection of Sierra Nevada bighorn sheep and both their summer and winter habitat. Protection considered long-term can be provided through appropriate institutional practices and cooperative agreements between agencies, landowners, and conservation organizations. For example, management plans (e.g., forest plans) for Federal lands should provide adequate assurances of habitat protection prior to consideration of delisting. Reasonable assurance must exist, on a case-by-case basis, that conditions that brought about population stability will be maintained.

Justification: Delisting would no longer require protection under the Endangered Species Act; therefore, continued protection by other means must be assured. This protection should include alternative regulatory mechanisms, land management commitments, or conservation programs that would provide the long-term protection needed for continued population viability.

c. Recovery Units

The delisting criteria include only 12 of the 16 herd units within the four recovery units because of uncertainty as to whether viable bighorn sheep herds can persist in four of those units (numbers 6, 10, 15, and 16 in Table 4). The recovery plan's science team has determined that all four recovery units and the 12 essential units (Figure 4) within those recovery units are necessary for the recovery of the species for multiple reasons. First, it may be necessary for all 12 herd units to be occupied to attain the minimum total population size of 305 females.

Second, given the likelihood that the four recovery units may function as independent metapopulations to some extent, it is important to develop sufficient distribution in each to buffer them against catastrophic losses of individual herds. There is also a need to have enough recovery units as a buffer against a catastrophic loss of an entire recovery unit. By the nature of the distribution of habitat in the Sierra Nevada, only one recovery unit (Southern) has enough herd units to potentially support a large population of sheep. Two of the remaining three recovery units (Kern and Central) contain only two herd units each, while the Northern Recovery Unit has four, of which the two northernmost may not support many sheep and are not considered essential to recovery. The Southern Recovery Unit provided the translocation stock for the early reintroduction, and should be able to do the same in the future to restore sheep to vacant habitat that exists (i.e., herd units that are essential to recovery) or might become vacant in other recovery units. The limited number of herd units in those other recovery units makes them less reliable as potential sources of translocation stock, should a catastrophe occur in the Southern Recovery Unit, requiring sources of stock from other recovery units for restoration. The uncertainties about the overall population sizes that those smaller recovery units may support is an important reason why all four recovery units are needed to assure the future of these sheep.

Third, it is also important to have as many bighorn sheep in each recovery unit to minimize the loss of genetic diversity through genetic drift. Similarly, there is a need to maximize geographic continuity in the distribution of herds in order to facilitate genetic interchange among herd units within recovery units, as well as some interchange among recovery units. Stemming further loss of genetic diversity in Sierra Nevada bighorn sheep may prove to be the greatest challenge for their recovery (Appendix H).

Fourth, it is important to provide recovery units and essential herd units that protect sheep and their habitat across a range of latitudes. Gradual climate changes are likely to induce ecological changes in southern recovery units and essential herd units over time. These changes would likely preclude the recovery of populations in these areas. Consequently, bighorn sheep populations in more northerly latitudes can buffer the rangewide population against the loss of populations in essential herd units that are further to the south.

Table 5. Minimum number of females and occupied herd units (see Table 4) required for downlisting and delisting of Sierra Nevada Bighorn Sheep by recovery units. As of 2005, at least 146 additional females were needed for downlisting, and 4 herd units needed for delisting were vacant.

Herd Units Occupied					Females at least 1 year of age		
Recovery Unit	Current	Potential	Delisting/ Downlisting	Additional Needed	Delisting/ Downlisting Minimum	2005 Minimum	2004 Minimum
Kern	0	2	2	2	50	0	0
Southern	5	8	6	1	155	102	92
Central	1	2	2	1	50	45	40
Northern	2	4	2	0	50	12	16
Total	8	16	12	4	305	159	148

C. RECOVERY STRATEGY

Because bighorn sheep are naturally slow to disperse and colonize new habitat, recovery of Sierra Nevada bighorn sheep within a reasonable period will ultimately depend on translocations of bighorn sheep into unoccupied herd units that are needed for recovery, or to aid in the recovery of occupied herd units. A translocation program will require one or more sources of Sierra Nevada bighorn sheep with known bacterial and viral histories. Identifying and developing those sources from the current limited herds is one of the greatest challenges to recovering this subspecies. The rate of recovery will, in part, be tied to the number of herds capable of producing bighorn sheep for translocation. The protection and enhancement of existing herds to maximize population growth is the first step. The major threats to existing herds have been decreased survivorship and reproductive success associated with remaining at high elevations throughout the year, and potential outbreaks of disease contracted from domestic sheep or goats. Therefore, predator management (to reduce direct mortality and encourage use of low-elevation wintering ranges) and changes in domestic sheep grazing practices (to prevent contact) are key aspects of the recovery strategy. This strategy will necessarily be supplemented by habitat management (to promote open habitat where predators are readily visible) and perhaps establishment of a captive breeding facility. Genetic considerations are also critical because the small size and isolation of existing populations threatens to reduce the variability of this unique gene pool. Because maintaining a viable metapopulation will require a broad, minimally fragmented spatial distribution of subpopulations over the landscape, recovery criteria have been defined based on population sizes and occupied herd units within specified recovery units (section II.B.2).

Monitoring and research are necessary to provide the basis for adaptive management and, as such, are essential components of this recovery plan. Recovery actions for the bighorn sheep will depend on regularly updated information on population parameters and habitat use patterns for each herd. Similarly, a detailed assessment of the genetic population structure of each herd is necessary as the basis for genetic management. Monitoring of mountain lions near bighorn sheep winter ranges will greatly enhance efforts to protect herds. Finally, outreach to enlist public support for recovery efforts will be important to the success of this plan.

D. NARRATIVE OUTLINE OF RECOVERY ACTIONS

1 Protect bighorn sheep habitat.

1.1 Identify and acquire important habitat not in public ownership from willing landowners. While the vast majority of historic bighorn sheep range in the Sierra Nevada is in public ownership, a small number of in-holdings exist. A list of all private land holdings that might affect bighorn sheep should be developed and prioritized relative to importance to bighorn sheep. Key parcels should be acquired or protected under conservation easements. See Task 2.3.1 and Section E (below) for more detail on implementation of this recovery action.

1.2 Maintain and/or enhance integrity of bighorn sheep habitat. Habitat integrity could be compromised by fire suppression that affects vegetation succession (see Task 2.2.3), or a variety of human uses (see Task 2.4). Human activities resulting in blockage or alteration of movement corridors (e.g., San Joaquin Ridge) would have ramifications for gene flow between or among populations (Bleich *et al*. 1990a, 1996). Further, the potential for natural recolonization of vacant habitats would be severely reduced. Although these issues are considered with respect to bighorn sheep behavior and population parameters, they also are important relative to structural attributes of the habitat. All proposed Federal actions in the vicinity of bighorn sheep habitat should be analyzed relative to influences on that habitat and, ultimately for negative impacts to the viability of bighorn sheep.

2 Increase population growth by enhancing survivorship and reproductive output of bighorn sheep. Recovery of these bighorn sheep requires an overall population increase. Enhancing survivorship and reproduction wherever possible will speed recovery. To the extent that these parameters are enhanced through increased nutrient intake by more extensive use of habitat, the carrying capacity of herd units also will be increased.

2.1 Prepare and implement a management plan to temporarily protect Sierra Nevada bighorn sheep herds from predation losses, where needed, until viable herd sizes are reached. The management plan must address the immediate needs for selective predator management while allowing for a long-range approach that restores and maintains the health of the larger predator-prey system. Known predation losses have been primarily attributed to mountain lions (Table 1). Thus, efforts to prevent further losses should focus on this predator, but not ignore other potential predators.

Individual mountain lions can vary in behavior, including whether they prey on bighorn sheep and whether immigrating lions become potential threats for each herd when resident lions are removed. Therefore, this management plan should attempt to set up criteria to remove only lions that are a threat. Radio-collaring and careful monitoring of mountain lions near bighorn sheep winter ranges will help with selective removal (see Task 5.2 and Appendix E). Additionally, the need to protect bighorn sheep should be carefully balanced with concerns for the viability of the mountain lion population. Potential effects of mountain lions on winter habitat selection by bighorn sheep should be included in this predator management plan; this aspect is addressed below in Task 2.2.

Predator management should be viewed as a temporary measure. It should be terminated when herd units reach a reproductive base of 25 females, with the possible exception of herd units serving as sources of translocation stock. It should be reinstated if a herd unit subsequently declines below 20 females and predators are preventing recovery of that herd unit. Biologists familiar with bighorn sheep have independently arrived at a threshold of 25 females as the minimum number for herd viability (Sierra Nevada Bighorn Sheep Interagency Advisory Group 1997, Fisher *et al*. 1999, U.S. Fish and Wildlife Service 2000).

2.2 Increase use of low elevation winter ranges. Increased use of low elevation winter ranges will increase nutrient intake and thereby enhance reproductive output and success. Increased low elevation winter range use will also decrease mortality associated with the use of high elevations during severe winters.

2.2.1 Reduce influences of predation on winter habitat selection by Sierra Nevada bighorn sheep. Adult survivorship and recruitment can be negatively affected when bighorn sheep avoid low elevation winter ranges. Winter habitat selection may influence population dynamics more than direct losses from predation. Reducing influences of predators on winter habitat selection may, therefore, be important. Until some herds build sufficient numbers, it could be necessary to remove mountain lions from key winter range areas or condition mountain lions to avoid those areas (see Task 6.5). If aversive conditioning is successful, the maintenance of home ranges by conditioned resident lions may discourage immigration of unconditioned lions and thereby reduce the number of lions that need to be removed.

2.2.2 Supplement small female groups where appropriate to attain threshold herd sizes that will encourage behavioral attributes favorable to winter range use. Because bighorn sheep find security in groups, habitat selection during winter may be affected by the number of bighorn sheep available to form groups. Adding healthy females to small female groups in herd units that are needed for recovery (identified with asterisks in Table 4) may produce significant increases in uses of winter ranges and, thereby, increase adult survivorship as well as recruitment rates. Further, behavior of bighorn sheep previously translocated in the Sierra Nevada indicates that females translocated from populations that use low elevations will initially attempt to do the same on new ranges. The ability to augment small herds is currently limited by the lack of sources of bighorn sheep that can be moved. The development of sources of bighorn sheep to move is fundamental to achieving this task and is addressed in task 3.2.

2.2.3 Enhance bighorn sheep winter range habitat to increase visibility where appropriate. Favorable attributes of bighorn sheep habitat are steepness, rockiness, and visual openness. Although steepness and rockiness cannot be changed, openness can be modified via management of vegetation. In the past, fires may have burned in bighorn sheep habitat much more frequently than has occurred over the past century. Early ground and aerial photos indicate that habitats in the eastern Sierra Nevada had little vegetation tall enough to obstruct vision of bighorn sheep, and pinyon pine woodlands largely have developed since 1860 (Miller and Tausch 2001). In opening up habitats, fire can decrease the effectiveness of mountain lions as ambush predators and, perhaps, allow bighorn sheep greater access to low elevation winter ranges that provide nutritious forage. Policies to let fires burn in bighorn sheep habitat, coupled with prescribed fire or other methods of habitat manipulation, should be used to enhance winter ranges where visibility for bighorn sheep needs to be increased. Such habitat enhancements will likely produce greater connectivity among herd units and promote greater gene flow needed to conserve genetic diversity (see Appendix H).

2.3 **Minimize probability of bighorn sheep contracting diseases causing mortality and morbidity.** Introduced diseases have probably been the primary cause of extirpation of bighorn sheep herds in North America. They represent one of the greatest threats.

2.3.1 **Prevent contact between bighorn sheep and domestic sheep or goats.** Prevention of contact between domestic sheep or goats and bighorn sheep will require coordination and cooperation between grazing permittees, land management agencies, and regulatory agencies. We recognize the need to provide specific guidance to land managers regarding allotments and grazing practices that are likely to result in contact between domestic sheep or goats and bighorn sheep. A risk assessment is currently being developed to be used as a tool for analyzing grazing practices on certain allotments. Land management agencies should utilize this risk assessment and coordinate with other agencies to implement measures that will prevent contact between domestic sheep and bighorn sheep. These measures may include seasonal grazing restrictions, implementation of specific herding practices (penning, trailing restrictions, etc.), or removal of bighorn sheep from certain high-risk areas, but may require the ultimate closure of some allotments that cannot be grazed in a manner that prevents contact.

Based on current data on bighorn sheep movements, we are recommending the closure of some high-risk allotments and seasonal restrictions on other allotments in the interim (See Section E below). In addition, we recognize the need to address the potential for contact between domestic sheep or goats and bighorn sheep on private lands, so we are recommending a strategy of landowner education, conservation easements, and land acquisition (See Section E below). In addition, we are recommending a strategy for incorporation of the risk assessment for analysis of future disease transmission risk on other allotments that may become higher risk as bighorn sheep expand their current distribution (See Section E below).

2.3.2 **Develop an action plan in the event that a pneumonia outbreak occurs.** History is replete with examples of decimation and extirpation of bighorn sheep herds from pneumonia epizootics.

Quick and decisive actions may save part of a herd, or other nearby herds, in such an event. The development of an action plan prior to such an occurrence may be critically important to taking timely actions. This plan should include actions needed if a bighorn sheep is found in contact with domestic sheep or goats.

2.4 Manage human use locally where it is found to cause bighorn sheep to avoid important habitat and thereby compromises survivorship or reproductive success. This action will take place only if research (see Task 6.4) results in a recommendation to limit human use in some areas; at present there appear to be few locations where recreational disturbance has the potential to significantly affect bighorn sheep. Focused research on effects of human activities on bighorn sheep will determine whether any limitations on human use are required. If it is concluded that limitations will be beneficial, appropriate actions should be taken to limit human use that is found to be detrimental. Disturbance by humans (or possibly by off-trail domestic dogs) will be significant to bighorn sheep if nutrient intake of a herd is compromised by avoiding key foraging areas because of human activity. Both quality and quantity of forage vary greatly across the landscape, and bighorn sheep visit key locations where more nutritious forage is available. If bighorn sheep are regularly displaced from such areas and cannot procure equivalent nutrient intake at an alternative site, population parameters of the herd will be negatively affected. If they frequently flee encounters with humans, there may also be an unnecessary waste of energy that can have population-level effects.

3 Increase the number of herds, and thereby the number of bighorn sheep. It will be necessary to increase the geographic distribution and overall numbers of bighorn sheep in the Sierra Nevada to attain criteria necessary for downlisting and delisting.

3.1 Develop and implement a strategy for translocations. Because of the slow rates of natural colonization by bighorn sheep, recovery can be accelerated by translocations to originate herds in unoccupied herd units that are needed for recovery and to augment currently occupied herd units that are needed for recovery. Because there are domestic sheep grazing allotments in close proximity to the unoccupied Green Creek and Twin Lakes Herd Units and because these areas are not needed for recovery, these herd units should not be considered for translocations. It will be important to utilize the limited number of Sierra Nevada bighorn sheep available for translocations in a way that maximizes recovery of Sierra Nevada bighorn sheep in the shortest period. A strategy is needed that clearly identifies issues, options, and tradeoffs, and analyzes different herd units as potential recipients of translocated bighorn sheep (See Appendix C). This strategy should seek to avoid translocations that could result in introduction of disease-causing pathogens into a herd that is not adapted to them. Extensive records of disease and pathogen sampling histories need to be kept for translocation stock herds and for existing herds that may receive translocated bighorns to reduce the likelihood of introducing pathogens that the recipient herd is not adapted to.

3.2 **Develop sources of translocation stock.** Availability of bighorn sheep to be translocated has been, and continues to be, the primary factor limiting recovery of bighorn sheep in the Sierra Nevada. Only one source of stock was available for previous restoration efforts (see section I.C.2). The vulnerability of that situation led to the proposal to develop additional such sources as the primary goal of an earlier conservation plan for these bighorn sheep (Sierra Nevada Bighorn Interagency Advisory Group 1984). Additional sources of translocation stock will continue to be a fundamental need.

3.2.1 **Manage wild herds as sources of stock.** Developing sources of translocation stock will depend on sufficient recovery of at least one existing herd to the point where bighorn sheep can be removed for translocation. All or most of the first available translocation stock should be used to develop one or more additional sources of such stock. However, a small fraction may be used for increasing the size of populations that will not be translocation stock, or to increase the number of herd units that are occupied. This strategy will increase the rate of recovery of these bighorn sheep.

3.2.2 **Develop criteria for and, if appropriate, implement a captive breeding program.** In addition to wild populations as a source of translocation stock, a captive breeding facility might be necessary in the future. Such a facility may produce bighorn sheep more rapidly, but it also could pose risks. Aspects of captive breeding as a potential program have been investigated and a detailed captive breeding contingency plan was developed, which can be found at: http://www.vgl.ucdavis.edu/wildlife/sheep_plan.html (see Appendix I for executive summary).

4 **Implement a genetic management plan to maintain genetic diversity of Sierra Nevada bighorn sheep. The plan must use data on genetic variation gathered in Task 6.1.** Restoration of bighorn sheep to unoccupied herd units that are needed for recovery in the Sierra Nevada will be accomplished largely through translocations. However, translocations alone may not maximize conservation of

the genetic variation that currently exists. There is a need to consider long-term genetic management in conjunction with the translocation strategy to best conserve genetic variation throughout the range of these bighorn sheep. Task 6.1 has been completed and the genetic management plan can be found in Appendix H.

5 **Monitor status and trends of bighorn sheep herds, their habitat, and threats to them.** Recovery of bighorn sheep in the Sierra Nevada will require an adaptive approach, one in which decisions made will depend on current information about key resources. Consequently, monitoring of those resources is a fundamental component of this recovery plan.

5.1 **Develop and implement a monitoring plan for population abundance and distribution of bighorn sheep herds in the Sierra Nevada.** Management actions will be dependent on the best possible data on the population status of each herd. Downlisting and delisting criteria also are dependent on that information and were developed in part with the recognition that minimum counts will be the most conservative data to use as the basis of management decisions. Appendix D considers further details of this monitoring, and provides recommendations that will form the basis for development of detailed monitoring strategies.

Recent population dynamics of Sierra Nevada bighorn sheep indicate that recovery to adequate population levels will occur only with increased use of winter ranges. Trends in the use of winter ranges need to be monitored in conjunction with population monitoring to project future population trends. They will also allow efforts to focus on herds that are reluctant to use winter ranges.

5.2 **Monitor key predators in the vicinity of winter ranges.** Efforts toward the recovery of Sierra Nevada bighorn sheep necessarily take place in a larger ecosystem context. Because management of predators, especially mountain lions, is a component of this recovery plan, careful monitoring of these predators near bighorn sheep populations is important. Such monitoring will provide data on how individual mountain lions, and mountain lions in general, use habitat in the vicinity of each population of bighorn sheep, and will allow an assessment of which mountain lions pose the greatest threats to bighorn sheep, and when those threats are greatest (see Appendix E).

5.3 **Monitor vegetation structure and composition changes likely to affect bighorn sheep population parameters.** In the absence of regular fires, vegetation succession can slowly decrease openness in bighorn sheep habitat. Vegetation structure and its concomitant effects on visibility should be monitored on a long-term basis.

5.4 **Monitor exposure to disease organisms of concern.** When bighorn sheep in the Sierra Nevada are captured for management operations, appropriate sampling and testing of those animals for disease pathogens should take place to develop a continuing database that will potentially detect changes over time. A large database already exists from captures beginning in 1979. This database will continually be updated and will be used when making decisions regarding translocations from source stock herds to recipient herds.

6 **Initiate or continue needed research.** An adaptive approach to management will require development or continuation of existing research.

6.1 **Investigate genetic population structure of existing herds.** The conservation of the gene pool of bighorn sheep in the Sierra Nevada will depend on a detailed understanding of the distribution of genetic variation and the dynamics within that genetic population structure. There is need to develop a genetic database and to use it as the foundation for a genetic management plan (see Task 4). Specific data needs: (1) current amount of genetic variation compared with other metapopulations of bighorn sheep; (2) distribution of genetic variation among the different herds; and (3) population genetic changes in each herd to determine if future erosion of genetic diversity is likely to be a problem. These studies are possible with modern laboratory techniques by using a variety of sources of DNA.

6.2 **As adequate input data become available, develop a population viability analysis (PVA) for the Sierra Nevada bighorn sheep metapopulation.** We attempted to define recovery goals and criteria that were attainable and realistic based on our current knowledge about the population ecology of these sheep. PVA sometimes can identify a key variable that is particularly influential to long-term population viability. However, as a modeling procedure, PVA results can be greatly influenced by values used for input parameters. Because some uncertainty will surround most such values, it will be particularly important to use sensitivity analyses to investigate the influences of input values on conclusions.

6.3 **Further investigate habitat use patterns of bighorn sheep herds.** A large database of sightings of bighorn sheep in the Sierra Nevada has been accumulated by researchers over the past 25 years (Figure 1). Population substructuring of female groups also has been identified and postulated based on marked bighorn sheep. However, because of sampling limitations, these data do not provide details of habitat use throughout the year or the degree of separation of female groups. Global positioning system collars may provide an efficient method of developing detailed, accurate information on the seasonal distribution and habitat selection patterns of these bighorn sheep.

6.4 Investigate and analyze human use patterns relative to habitat use patterns of bighorn sheep. Earlier investigations of hypotheses concerning human disturbance (Dunaway 1971) dismissed it as not important for the Mount Baxter herd, but possibly a factor for the Mount Williamson herd (Wehausen *et al*. 1977, Hicks and Elder 1979, Wehausen 1980). Bighorn sheep have been reintroduced to three additional areas since the earlier studies, but these new herds have not been investigated to determine the possible impacts of human disturbance. There is a need to investigate patterns of use by humans and domestic dogs including intensity, trends, and types of use in and near existing bighorn sheep habitat to identify areas of possible conflict. If areas of concern are identified, intensive studies to investigate whether human disturbance may be displacing bighorn sheep from favorable habitat can be initiated. Potential reintroduction sites also should be investigated to identify areas of possible conflict.

6.5 Investigate the potential for altering habitat use patterns of mountain lions on bighorn sheep winter ranges by aversive conditioning. Altering the behavior or distribution of mountain lions through aversive conditioning may provide an alternative to temporary management involving removal of mountain lions that may kill bighorn sheep. If effective, this approach may allow the recovery of bighorn sheep with less intervention. Aversive conditioning of mountain lions is an untested concept, and it can be investigated in situations that minimize risks to bighorn sheep.

6.6 Investigate future introduction sites relative to predator, domestic sheep or goats, and other potential conflicts. Like the genetic management plan, this investigation should be coordinated with the translocation strategy. One product of a translocation strategy will be the identification of priority for future reintroduction sites that is based on habitat characteristics and spatial relationship to existing herds. Once this priority is established, sites of top priority should be investigated for potential conflict with predators, domestic sheep, domestic goats, or other concerns.

6.7 Investigate and, if appropriate, develop a plan for decreasing the mortality of bighorn sheep remaining at high elevations in extreme winters. The bighorn sheep on Mount Warren have experienced major population declines during recent severe winters while attempting to live at high elevations year around. While an emphasis of this plan is to attempt to develop more low elevation winter range use, it also is important to maintain numbers of bighorn sheep until such changes in habitat use patterns take place. Supplemental feeding of bighorn sheep at high elevations during severe winters could be crucial to their survival. This subject should be explored in detail and an action plan developed as appropriate.

6.8 Attempt to develop long-term data to elucidate predator-prey dynamics of this ecosystem as they affect bighorn sheep. During the 1980s, bighorn sheep in the Sierra Nevada began to avoid low elevation winter ranges, a pattern of behavior that has, in turn, led to major declines in the population. This dynamic appears to reflect predator-prey processes that are not fully understood but that clearly can affect the bighorn sheep population. A better understanding of the larger predator-prey system is needed and will require long-term information. Some of the components of this system (bighorn sheep, mountain lions, and possibly other predators) will be tracked as part of the monitoring for this recovery effort. Mule deer, the primary prey of mountain lions, are a key component of this ecosystem. Monitoring the dynamics of the mule deer population is basic to developing an understanding of this predator-prey system. Other potentially important components that are not currently monitored should be identified and efforts made to add them to the monitoring scheme to understand the dynamics of this system.

6. 9 Investigate likely effects of climate change on bighorn sheep habitat. Climate change models predict changes in temperature and precipitation in the range of Sierra Nevada bighorn sheep (e.g. Knowles and Cayan 2004, Lenihan and Drapek 2006, Diaz and Eischeid 2007). In particular, these include milder winters, less precipitation falling as snow over a shorter winter period, and possibly increased total annual precipitation. These changes could potentially cause earlier seasonal drying of high-elevation meadows, conifer trees invading higher elevations, and changes in summer- and winter-range quality and accessibility in the Sierra Nevada. Additional factors may include the interaction of invasive alien plant species with climate change and increased atmospheric nitrogen fertilization from air pollution. These effects would alter the distribution of high-quality bighorn summer and winter habitats, which would influence recovery.

7 **Engage in public outreach and sharing of information.** The overriding purpose of the Sierra Nevada bighorn sheep public information and outreach effort is to foster understanding, respect, and concern for this species, and understanding of and support for conservation measures and recovery actions. A number of recovery actions outlined in this recovery plan will directly affect public use in the eastern Sierra Nevada and, conversely, human activities may affect recovery actions. It is therefore imperative that strong public information and awareness programs be implemented. Agencies working on recovery of this species should work with the public to ensure that they are informed about potential human actions that may affect bighorn sheep. The agencies should also seek to understand the publics land use needs, so that workable solutions to bighorn and human land use conflicts are developed. Conservation efforts are more likely to succeed if efforts are understood and supported by the populace. Enlisting public support for recovery efforts will require an information and outreach program on the ecology of Sierra Nevada bighorn sheep, the threats this species is currently facing, and how recovery actions will reduce those threats. Special efforts should be made to target and collaborate with private landowners near occupied herd units on the issue of disease transmission between domestic sheep or goats and bighorn sheep on their lands. This is of key importance in implementing our recommended strategy to prevent contact between domestic sheep or goats and bighorn sheep (see Section E below). Appendix F contains a detailed plan for developing an effective outreach and information program.

Public information and outreach on Sierra Nevada bighorn sheep has been occurring and is ongoing. The Sierra Nevada Bighorn Sheep Interagency Advisory Group, the Sierra Nevada Bighorn Sheep Foundation, the Inyo National Forest, and the Interagency Domestic Sheep Grazing Strategy Working Group have conducted media interviews and hosted public meetings focused on Sierra Nevada bighorn sheep ecology, management, and threats. However, additional efforts are possible and desirable. In addition, there should be a higher degree of coordination among individual programs and other recovery activities. Increased coordination would not only allow each program to present the most accurate and updated information, but it would also let the general public see that the recovery of Sierra Nevada bighorn sheep is a collaborative effort supported by multiple agencies, organizations, and individuals. Specific recovery actions to accomplish the identified goals are as follows:

7.1 **Conduct a survey of public uses of Sierra Nevada bighorn sheep habitat and public attitudes regarding Sierra Nevada bighorn sheep.** Results of the survey will be used to (1) prioritize the public information and outreach action items, (2) determine the best methods to accomplish the action items with the highest likelihood of meeting the recovery plan goals, and (3) establish a baseline from which the success of the action items in meeting the recovery plan goals can be measured by comparing to a resurvey 1 year after implementation.

7.2 Develop and distribute information related to recovery efforts. The results of the public survey (Task 7.1) should be used to determine the specific topical information and most effective method(s) of disseminating this information to target audiences. This information should be available from the key agencies involved in this recovery effort. A general brochure or information sheet should be developed that contains a brief overview of the status of Sierra Nevada bighorn sheep, as well as specific suggestions on what people can do to help the species. In addition, information on a variety of topics germane to the recovery of Sierra Nevada bighorn sheep should be summarized and made available to the public in booklet form.

During implementation of recovery efforts, the public should be fully informed as early as possible regarding actions required or restricted while in Sierra Nevada bighorn sheep habitat. Further, the finalized recovery plan, along with a cover letter, should be widely distributed to affected and interested people, including hikers and other recreationists, ranchers, ranchette owners with domestic sheep or goats, commercial packers, environmental groups, mountain lion and bighorn sheep advocacy groups, and affected local, State, and Federal agencies. Moreover, the recovery plan should reach people who would not typically be exposed to traditional programs (i.e., individuals who might not frequent visitor's centers or who do not have school-aged children). Special efforts should be made to target and inform private landowners near occupied herd units.

7.3 Continue, update, and coordinate existing informational and outreach programs and develop further programs as needed. The results of the public survey (Task 7.1) should be used to develop the most effective informational and outreach programs. However, there is an immediate need to update existing programs to provide an accurate view of our current knowledge regarding Sierra Nevada bighorn sheep. Information should strive to highlight not only how the activities of each individual agency or organization contribute to the recovery of Sierra Nevada bighorn sheep, but also how these activities complement those of other agencies or organizations. Existing bighorn sheep educational materials should be reviewed and modified to be applicable to Sierra Nevada bighorn sheep.

8 **Establish an implementation advisory team for coordination and communication.** Numerous Federal, State, and private agencies share responsibility for bighorn sheep in the Sierra Nevada along with stakeholders. Efforts to recover these bighorn sheep will require considerable coordination and communication among these different entities. This coordination will be greatly enhanced through the formation of an advisory team that meets at least twice annually. This team should include agency representatives, appropriate specialists, and key stakeholders.

E. RECOMMENDED STRATEGY FOR PREVENTING CONTACT BETWEEN DOMESTIC SHEEP OR GOATS AND SIERRA NEVADA BIGHORN SHEEP

1. Background

As discussed previously and in Appendix B, preventing contact between domestic sheep or goats, hereafter jointly referred to as "domestic sheep", and Sierra Nevada bighorn sheep is critical to recovery of this species. Given evidence described in this plan from captive studies, inoculation studies, and field observations of pneumonia related die-offs, disease contracted from domestic sheep is a potentially significant source of mortality that requires management. In November of 2006, a panel of 11 veterinarians from the Idaho Department of Fish and Game, Washington State University, University of Washington, Ministry of the Environment (British Columbia, Canada), California Department of Fish and Game (CDFG), the U.S. Geological Survey, Colorado Division of Wildlife, Nevada Department of Agriculture, and the University of Idaho's Caine Veterinary Teaching and Research Center met to review the issue of contact between domestic sheep and bighorn sheep for the Payette National Forest's *Risk Analysis of Disease Transmission Between Domestic Sheep and Bighorn Sheep* (Payette National Forest 2006). They concluded that contact between domestic sheep and bighorn sheep increases the risk of subsequent bighorn sheep mortality and reduced recruitment due primarily to respiratory disease, but they also acknowledged that the complete range of causal mechanisms that lead to die-offs in bighorn sheep herds is not fully understood. Given the conclusion that contact between bighorns and domestic sheep increases the likelihood of bighorn mortality, they recommended that management actions should seek to prevent contact between domestic sheep and bighorn sheep (Payette Science Panel 2006). Because of the potential for contact between domestic sheep and Sierra Nevada bighorn sheep and the adverse effects that such contact could have on persistence of this endangered species, we have developed a recommended strategy for preventing contact.

Singer et al. (2001) identified a buffer of 23 kilometers (14 miles) as a general guideline of separation between bighorn sheep and domestic sheep when undertaking efforts to restore bighorn populations. While we recognize the importance of this distance as a general rule, we acknowledge that it is based on a broad look at many populations of bighorn sheep and is not specific to bighorn sheep that occur in the Sierra Nevada. Therefore, a closer look at disease risk for specific bighorn sheep herds in the Sierra Nevada may arrive at somewhat different guidelines. Consequently, we have not used the Singer et al. (2001) buffer distance as a means to identify high-risk allotments or allotments that may affect bighorn sheep, but have used it to narrow the number of allotments within the scope of our analysis.

Within the historic range of the Sierra Nevada bighorn sheep there are +/- 29 domestic sheep grazing allotments within 23 kilometers of currently occupied recovery plan herd units that are managed by the Humboldt-Toiyabe National Forest, Inyo National Forest, and the Bureau of Land Management – Bishop Field Office (BLM) (Table 6). In addition, there are approximately 147,000 hectares (363,237 acres) of lands

Table 6: U.S. Forest Service and Bureau of Land Management Sheep Grazing Allotments within 23 kilometers of Sierra Nevada Bighorn Sheep Herd Units			
Agency	**Allotment Name**	**Status/Current Management**	**Nearest Herd Unit**
Humboldt-Toiyabe National Forest	Poison Creek	Active	Twin Lakes
Humboldt-Toiyabe National Forest	South Swauger	Active	Twin Lakes
Humboldt-Toiyabe National Forest	Rickey (North)	Active	Twin Lakes
Humboldt-Toiyabe National Forest	Rickey (South)	Active	Twin Lakes
Humboldt-Toiyabe National Forest	Summers Meadow	Inactive	Twin Lakes
Humboldt-Toiyabe National Forest	Cameron Canyon	Active	Green Creek
Humboldt-Toiyabe National Forest	Tamarack	Active	Green Creek
Humboldt-Toiyabe National Forest	Dunderberg	Active	Mt. Warren
Humboldt-Toiyabe National Forest	Jordan Basin	Inactive	Mt. Warren
Inyo National Forest	Horse Meadow	Vacant	Mt. Gibbs/Mt. Warren
Inyo National Forest	Bloody Canyon	Vacant	Mt. Gibbs
Inyo National Forest	Algers Lake	Vacant	Mt. Gibbs
Inyo National Forest	June Lake - West	Vacant	Mt. Gibbs
Inyo National Forest	June Lake - East	Active	Mt. Gibbs
Inyo National Forest	Mono Mills	Inactive	Mt. Gibbs
Inyo National Forest	Dexter Creek	Active	Mt. Gibbs
Inyo National Forest	Sherwin/Deadman - West	Active	Mt. Gibbs/Convict Creek
Inyo National Forest	Sherwin/Deadma - East	Active	Mt. Gibbs/Convict Creek
Inyo National Forest	McGee	Inactive	Convict Creek
Inyo National Forest	Watterson Meadow	Active	Convict Creek
Inyo National Forest	Rock Creek - East	Active	Convict Creek
Inyo National Forest	Rock Creek - West	Inactive	Convict Creek
Inyo National Forest	Rock Creek - Hilton Unit	Active	Convict Creek
Inyo National Forest	Casa Diablo	Active	Convict Creek
BLM - Bishop	Walters Ranch	Active	Twin Lakes
BLM - Bishop	Travertine Hills	Active	Twin Lakes/Green Creek
BLM - Bishop	Mount Biedeman	Active	Twin Lakes/Green Creek
BLM - Bishop	Green Creek	Active	Green Creek
BLM - Bishop	Dog Creek	Active	Green Creek/Mt. Warren
BLM - Bishop	Little Mormon	Active	Green Creek/Mt. Warren
BLM - Bishop	Rancheria Gulch	Active	Mt. Warren
BLM - Bishop	Mono Mills	Active	Mt. Warren/Mt Gibbs
BLM - Bishop	Casa Diablo	Active	Convict Creek
BLM - Bishop	Little Round Valley	Active	Convict Creek
BLM - Bishop	Volcanic Tablelands	Active	Convict Creek/Wheeler Ridge
BLM - Bishop	Mormon Ranch	Active	Green Creek

owned by private individuals, municipalities, and the Los Angeles Department of Water and Power within 23 kilometers of occupied herd units.

For the purposes of our recommendations, we have considered Highway 395 as a potential management boundary (hereafter referred to as "management boundary") as it relates to bighorn sheep movement. While it is possible that bighorn sheep will cross the highway, use of this management boundary is intended to assist in reducing the likelihood of disease transmission. Highway 395 is not an absolute barrier to bighorn sheep movement, and is therefore regarded only as a potential management boundary. Management actions to prevent bighorn sheep from occupying areas east of Highway 395 should be implemented to increase the effectiveness of this management boundary. Use of the risk assessment for analyzing disease risk on grazing allotments east of Highway 395 has been incorporated into the recommendations of Section E.

Recently, the University of California at Davis and CDFG jointly developed a risk model for disease transmission between domestic sheep and Sierra Nevada bighorn sheep (Clifford et al. 2007). The authors used 2002 to 2006 Sierra Nevada bighorn sheep location data and current modeling techniques to estimate the areas that bighorn sheep are likely to use during the spring-summer season (March through September) and the rut season (October through November). These are referred to in this section as the spring-summer and rut season utilization areas, respectively. For allotments west of Highway 395, estimated utilization areas during the spring-summer season overlap with the Tamarack, Cameron Canyon, Dunderberg, Jordan Basin, Horse Meadow, Bloody Canyon, Algers Lake, Green Creek (BLM), Dog Creek (BLM), Rickey (south), Summer's Meadow, and Rickey (north) allotments. In addition, Johnson et al. (2006) modeled bighorn sheep summer range habitat and showed areas of summer range that overlap or are immediately adjacent to the Tamarack, Cameron Canyon, Dunderberg, and Jordan Basin allotments . CDFG has also recorded bighorn sheep locations on or immediately adjacent to the Tamarack, Dunderderg, Cameron Canyon, Jordan Basin, Bloody Canyon, and Alger's Lake allotments during the spring-summer season (Clifford et al. 2007).

For allotments west of Highway 395, estimated utilization areas during the rut season overlap with the Tamarack, Cameron Canyon, Dunderberg, Jordan Basin, Horse Meadow, Bloody Canyon, Algers Lake, Green Creek (BLM), Dog Creek (BLM), Rickey (south), Summer's Meadow, Rickey (north), Rock Creek, and Little Round Valley (BLM) allotments. CDFG has also recorded bighorn sheep locations on or immediately adjacent to the Cameron Canyon, Summer's Meadow, Dunderberg, Jordan Basin, Bloody Canyon, and Rock Creek allotments during the rut season (Clifford et al. 2007).

2. Strategy

A team of veterinarians, wildlife biologists, range managers, and grazing permittees is currently developing a risk assessment that land managers can use as a tool to assess the potential risk that allotments pose under certain grazing practices. All further references to a "risk assessment" in this section refer to this pending analysis. The risk assessment will account for bighorn sheep management activities when analyzing the risk of disease transmission on certain allotments. We do not know when the team will complete the risk assessment, but the need for specific guidance remains. Consequently, we have developed an approach for management of this risk that addresses the following issues: 1) recommendations regarding some domestic sheep grazing allotments and private lands based on current knowledge of bighorn movements, range utilization, and domestic sheep grazing practices; 2) development and use of the risk assessment as a tool in the assessment of future contact risk on other allotments and private lands that are not currently close to bighorn herds and to be used in the interim period prior to the completion of recommendations regarding allotments in item one; and 3) recommendations regarding restrictions on translocations of bighorn sheep in certain locations. The details of this strategy involve recommending permanent or seasonal closures of some allotments, seeking opportunities to purchase or transfer private grazing lands, managing translocation of bighorn sheep so that the risk of contact is minimized in certain areas, managing contact between bighorn sheep and domestic sheep on allotments that remain active, using the risk assessment to annually evaluate allotments in certain areas, taking advantage of opportunities to buy-out allotments or to retire them if they are relinquished volunarily, eliminating other non-compatible uses (e.g., goat packing) in areas where they put bighorn sheep and risk, and annually assessing our efforts to prevent contact between bighorn sheep and domestic sheep. Each of these details is discussed further below.

3. Recommendations

Based on the information provided in Section E.1 (above) we recommend the following:

Recommendation 1 (Closures of High-Risk Allotments): We recommend that the Inyo and Humboldt-Toiyabe National Forests and the Bureau of Land Management – Bishop Field Office close domestic sheep grazing allotments that pose a high risk of disease transmission or consider other uses that are not potential threats to Sierra Nevada bighorn sheep. As of this writing, we believe the Dunderberg, Tamarack, Cameron Canyon, Rickey (south), Green Creek (BLM), and Dog Creek (BLM) allotments pose a relatively high risk to Sierra Nevada bighorn sheep, with Dunderberg representing the greatest current risk. Therefore, based on the best available information, such as documented bighorn sheep movement patterns and modeling of areas that bighorn sheep are likely to use, we recommend closure of these allotments to domestic sheep grazing.

We understand allotment closures require an analysis pursuant to agency procedures and other applicable Federal laws, and thus some time will be required for such closures to proceed. We recommend the Inyo and Humboldt-Toiyabe National Forests and the Bureau of Land Management – Bishop Field Office initiate such analyses in 2007 (i.e., site specific suitability analyses) pursuant to their respective land management plans to consider permanent closure of these allottments to domestic sheep. The Jordan Basin, Summer's Meadow, Horse Meadow, Alger's Lake, June Lake (west), and Bloody Canyon allotments should remain vacant or inactive, be closed, or be converted to uses that are not a potential threat to Sierra Nevada bighorn sheep.

The Service is currently participating on a subgroup of the recovery team, including scientists and stakeholders, in the development of a "risk assessment tool" to help land managers better quantify the relative risk domestic sheep pose to bighorn sheep in these various allotments. Unfortunately, this tool is not yet completed and is not available for use, but it is expected to be completed in early 2008. Once the risk assessment tool is completed, the land management agencies should incorporate its use into the analyses recommended above concerning allotment closures. In the event that information from the risk assessment or other sources indicates a high risk of contact between bighorn and domestic sheep on a given allotment, land management agencies should immediately close the allotment, on an emergency basis, while they complete their analysis. We recognize that the Forest Service is not currently permitting grazing on the Dunderberg allotment due to recent movements of bighorn sheep in that area. We recommend that this allotment remain in a non-permitted status until the Forest Service can complete its suitability analysis.

It is possible that use of the risk assessment tool may alter our future understanding of the risk of contact between domestic and bighorn sheep in these allotments. If the land management entities, through use of the risk assessment, determine that permittees can graze domestic sheep on some of the allotments listed above under certain management prescriptions that prevent contact, they may consider allowing grazing under those management prescriptions. Following such a determination, the alternative of continuing to graze domestic sheep on applicable allotments with the implementation of those management prescriptions should be fully evaluated in each agency's site-specific suitability analysis.

Rationale: Of the allotments west of Highway 395, data on known bighorn sheep locations and predicted spring-summer and rut utilization areas indicate that bighorn sheep are likely to enter the Dunderberg, Tamarack, Cameron Canyon, Rickey (south), Green Creek (BLM), Dog Creek (BLM), Jordan Basin, Summer's Meadow, Horse Meadow, Alger's Lake, June Lake (west), and Bloody Canyon allotments at any time of the year, which greatly increases the risk of contact. This may preclude the ability to implement avoidance measures such as seasonal grazing restrictions that might be successful on other allotments where the risk of contact only occurs during the rut season. Under the 2005 and 2006 domestic sheep grazing practices and allotment arrangement, the probability of an outbreak in the Northern Recovery Unit that results in significant mortality is 40 percent over the next 50 years and 50 percent over the next 70 years. In addition, an outbreak that starts in this Northern Recovery Unit has about a 7 percent (range 4.6 to 9.1 percent) chance of spreading to the Central Recovery Unit and causing significant mortality (Clifford et al. 2007). These probabilities will increase as bighorn populations increase in these recovery units. Therefore, it is prudent to begin analysis of closure of these allotments. Other allotments that fall within the spring-summer utilization areas are east of Highway 395. Because Highway 395 is considered a management boundary, it is appropriate to wait for completion of the risk assessment before analyzing risk on these allotments.

Recommendation 2 (Seasonal Allotment Closures): In contrast to the allotments identified in Recommendation 1, domestic sheep grazing on some allotments poses a risk of contact only during the bighorn sheep rut. We recommend that allotments in this category be considered for seasonal closure. In 2007, the Inyo National Forest and the Bureau of Land Management – Bishop Field Office should begin site specific suitability analyses pursuant to their respective land management plans to consider seasonal closure of the Rock Creek (west) allotment and the portion of the BLM's Little Round Valley (the portion between Rock Creek and Hilton Creek) allotment that is west of Highway 395 to domestic sheep grazing <u>during the bighorn rut</u>. If the appropriate land management entities, through use of the risk assessment, determine that permittees can graze any or all of these allotments during the rut under certain management prescriptions that prevent contact, grazing may continue during the rut season under those management prescriptions. Following such a determination, the alternative of continuing to graze domestic sheep during the bighorn rut on applicable allotments with the implementation of those management prescriptions should be fully evaluated in each agency's site-specific suitability analysis.

Rationale: Of the allotments west of Highway 395, data on known bighorn sheep locations and predicted spring-summer and rut utilization areas indicate that male bighorn sheep are likely to enter the Rock Creek (west) and the western portion of the Little Round Valley (BLM) allotments during the rut season, which greatly increases the risk of contact if domestic sheep are utilizing these allotments. Other allotments that fall within the rut season utilization areas are east of Highway 395, which is a management boundary as it relates to bighorn sheep movement. Because Highway 395 is considered a management boundary, it is appropriate to wait for completion of the risk assessment before analyzing risk on these allotments.

Recommendation 3 (Purchase of Lands or Conservation Easements): The Service, CDFG, and land management agencies should work with land owners to secure permanent management restriction, conservation easements, or purchase of Los Angeles Department of Water and Power, County and Municipal lands, and privately owned parcels that are suitable for domestic sheep grazing and are overlapped by all predicted utilization areas modeled in Clifford et al (2007). Conservation easements should require the elimination of domestic sheep grazing on these parcels. The Service and CDFG should give priority to parcels that currently have domestic sheep grazing on them and are within the predicted spring-summer range utilization areas.

Rationale: The rationale for this recommendation is the same as that provided above for Recommendations 1 and 2. Permanent management restrictions, land acquisitions, and conservation easements are a primary tool available for preventing contact between domestic sheep and bighorn sheep on these lands.

Recommendation 4 (Voluntary Land Transfer or Exchange): The Service, CDFG, and land management agencies should work with land owners to secure voluntary land transfer or exchange between the appropriate land management agencies and Los Angeles Department of Water and Power, County and Municipal lands, and privately owned parcels that are suitable for domestic sheep grazing and are overlapped by the predicted utilization areas modeled in Clifford et al (2007). Land transfers or exchanges should require the elimination of domestic sheep grazing on these parcels. The Service, CDFG, and land management agencies should give priority to parcels that currently have domestic sheep grazing on them and are within the predicted spring-summer range utilization areas.

Rationale: The rationale for this recommendation is the same as that provided above for Recommendations 1 and 2. Land transfer and exchanges with the appropriate land management agency may also be useful tools for preventing contact between domestic sheep and bighorn sheep on these lands.

Recommendation 5 (Translocation of Bighorn Sheep): CDFG should not perform active translocation of bighorn sheep into the Green Creek or Twin Lakes Herd Units, which the recovery plan identifies as non-essential for recovery. Populations in the Mount Warren Herd Unit should be allowed to naturally expand into the Green Creek Herd Unit over time under careful monitoring and management (see Recommendation 6 below). CDFG, the Inyo National Forest, the BLM – Bishop Field Office, and grazing permitees should coordinate with each other and utilize the risk assessment prior to any translocations into the Convict Creek Herd Unit to determine if grazing on the McGee, Little Round Valley, or Rock Creek (Hilton Unit) allotments should be eliminated or modified in any way to prevent contact between domestic sheep and translocated bighorn sheep.

Rationale: Translocations into the Green Creek and Twin Lakes Herd Units are not needed for recovery and would rapidly place bighorn sheep in close proximity to active domestic sheep grazing operations on the Poison Creek, Rickey, and South Swauger allotments, which would greatly increase the risk of contact between domestic sheep and bighorn sheep.

Translocations are the best tool for increasing population size in the essential Convict Creek Herd Unit. To prevent contact, the Service, CDFG and the appropriate land management agencies would need to evaluate and implement appropriate grazing management actions and/or restrictions for domestic sheep grazing on the McGee, Little Round Valley, or Rock Creek (Hilton Unit) allotments prior to translocations into the Convict Creek Herd Unit. Removal of bighorn sheep is not considered a viable management alternative in this area because the Convict Creek Herd Unit is essential to recovery of the species. Consequently, CDFG will actively work toward establishment of a bighorn sheep herd in this area.

Recommendation 6 (Management of Contact with Domestic Sheep on Active Allotments): CDFG, land management agencies and permittees should work cooperatively to manage bighorn sheep and domestic sheep in a manner that prevents contact between the bighorn populations and domestic sheep on the active sheep grazing allotments north of Twin Lakes (Poison Creek, Rickey (north), and South Swauger).

Although no bighorn sheep occur in the Green Creek Herd Unit as of this writing, CDFG could choose to manage bighorn sheep in the Green Creek Unit if the bighorn sheep arrive in that area through natural dispersal. However, all parties should work cooperatively to keep bighorn sheep from areas north of the non-essential Green Creek Herd Unit. If bighorn sheep wander north of this unit, the agencies should work cooperatively using all appropriate means to discourage or remove bighorn sheep from these areas. If bighorn sheep naturally expand into the non-essential Green Creek Herd

Unit, CDFG may need to manage this unit at a lower population level to reduce the likelihood of bighorns moving further north. This management approach is necessary to protect the bighorn sheep herds to the south in the recovery units. It will reduce the likelihood that bighorn will come into contact with domestic sheep in the open grazing allotments north of Twin Lakes, and potentially imperil bighorn to the south if they become diseased and return south.

For these management actions to be successful, a significant portion of the Mount Warren Herd and the Green Creek Herd will need to be radio collared and intensively monitored during the domestic sheep grazing season and regularly monitored during the non-grazing season to assess population size and individual animal movement. The frequency of data collection during the monitoring effort will be dependent on limitations in technology, but this frequency should always remain at a level that is sufficient to achieve the goal of this recommendation. Domestic sheep herds will need to be monitored daily during the grazing season to ensure that individual sheep or groups of sheep do not wander off the allotment and that all domestic sheep released on the allotment can be accounted for at all times. Land and resource managers may be able to sustain zones of no contact between wild and domestic sheep through sustained, effective levels of monitoring and removal of Sierra Nevada bighorn sheep from areas not needed for recovery. Permittees are also important participants in maintaining a zone of no contact by ensuring that they strictly adhere to their grazing permit requirements.

Similar management actions will need to occur to prevent contact of Sierra Nevada bighorn sheep and domestic sheep that are actively grazed east of Highway 395 and with domestic sheep that are kept as pets within the communities of the Mono and Owens Basins if the risk assessment determines that contact cannot be prevented through other management actions. The resource and land management agencies, grazing permittees, and the public will need to report any sightings of bighorn sheep immediately to CDFG.

Rationale: Avoiding contact between domestic sheep and bighorn sheep to prevent disease transmission is identified as a high-priority recovery action. Efforts to remove bighorn sheep from areas north of the Green Creek Herd Unit would help prevent contact between domestic sheep and bighorn sheep while eliminating the need for closure of active domestic sheep grazing allotments north of the Twin Lakes area. The Green Creek and Twin Lakes Herd Units are not needed for recovery of the Sierra Nevada bighorn sheep. Preventing contact between domestic sheep and bighorn sheep will require that all possible measures for managing domestic sheep and wild sheep are used to achieve this goal. Because bighorn sheep may naturally expand into areas north of the Green Creek Herd Unit, bighorn sheep may need to be removed from these areas to prevent contact with domestic sheep on the Poison Creek, South Swauger, and Rickey (North Unit) allotments. Removal of bighorn sheep in these areas to prevent contact is considered a viable management alternative because the Green Creek and Twin Lakes Herd Units do not need to be occupied to achieve recovery. Consequently, the removal of bighorn sheep should be considered as a method to prevent contact without compromising the recovery of the species.

Movement of bighorn sheep across Highway 395 has been documented, although to date, the known occurrences have been few. As Sierra Nevada bighorn sheep populations increase in size, the likelihood that bighorn sheep will move onto allotments east of Highway 395 may increase as well as the possible wanderings of bighorn sheep into a local ranch or community. This movement could result in contact between wild bighorn sheep and domestic sheep. Therefore, removal of bighorn sheep from these areas, to prevent contact, is considered a viable management alternative.

It must be appreciated that managing bighorn sheep dispersal under this recommendation will be a challenge and will require contributions of staff and financial resources from stakeholders. Bighorn sheep will need to be monitored, and decisions to intervene in bighorn dispersal will require close coordination among State, federal, and local entities. It also must be appreciated that it is still possible, though unlikely, that eventually bighorn sheep may successfully disperse north of the Twin Lakes into domestic sheep allotments even with aggressive monitoring and oversight by the parties.

Recommendation 7 (Outreach): A private landowner notification and outreach program should be instituted to inform landowners identified under Recommendation 6 of the potential consequences to bighorn sheep if domestic sheep grazing on their parcels make contact with bighorn sheep.

Rationale: CDFG and the Service will not be able to acquire or place conservation easements on all private lands in high-risk areas in a timely manner, if at all, so notifying and informing landowners may minimize the likelihood of domestic sheep grazing on these parcels in the interim. The success of the Sierra Nevada bighorn sheep recovery effort depends, in part, on the partnerships formed and maintained with local landowners, land users, and citizens of the eastern Sierra. These partnerships are key to ensuring the recovery of bighorn sheep through enhanced communication regarding bighorn sheep recovery needs and identification and support of compatible land use practices

Recommendation 8 (Annual Evaluations of Allotments Near Convict Creek Herd Unit and East of Highway 395): There are several allotments, that were not discussed in Recommendations 1 and 2, that may need to be assessed in the future due to translocations of bighorn sheep and/or to natural movements of bighorn sheep. These allotments fall into two general categories: (1) those near the Convict Creek Herd Unit and (2) those east of Highway 395. Following completion of the risk assessment, the Inyo National Forest and the BLM – Bishop Field Office should coordinate at least annually with the Service and CDFG to determine if recent bighorn sheep movements may require an evaluation using this assessment of domestic sheep grazing on the Rock Creek (Hilton Unit), Little Round Valley (BLM) (portion that is west of Hilton Creek), and McGee allotments which are near the Convict Creek Herd Unit. In addition, they should determine whether the risk assessment should be used to evaluate some allotments east of Highway 395. If any of these allotments requires re-evaluation, the land management entities should use the risk assessment to determine if closure or changes in grazing practices are necessary.

Rationale: Natural movement of bighorn sheep into the Convict Creek Herd Unit and potential translocations into this unit will change the level of risk posed by the Rock Creek (Hilton Unit), Little Round Valley (BLM) (portion that is west of Hilton Creek), and McGee allotments. Natural growth and expansion of bighorn sheep in some portions of the Northern or Central Recovery Unit has the potential to increase the contact risk posed by some allotments east of Highway 395. Annual evaluation of bighorn sheep movements to determine if the risk assessment should be utilized will allow for adjustment and/or restrictions in grazing practices on these allotments over time so contact is prevented.

Recommendation 9 (Grazing Buy-outs): The Service, CDFG, and land management agencies should work with non-governmental organizations to offer grazing buy-outs to permittees on the allotments discussed in Recommendation 8, and any other allotment of concern discussed in this plan. If buy-outs are successful or if the permittee voluntarily relinquishes his grazing permit, these allotments should be closed or consider other uses that are not a threat to Sierra Nevada bighorn sheep.

Rationale: In order to prevent the need for potential emergency closure of allotments in the event that bighorn sheep move into the Convict Creek Herd Unit, or any other allotment of concern discussed in this plan, buy-outs should be pursued. This would eliminate the need for expensive management actions that CDFG and land management agencies would have to implement to prevent contact in these areas.

Recommendation 10 (Voluntary Relinquishments): If any permittee agrees to voluntarily relinquish any allotment identified in this plan, the Inyo and Humboldt-Toiyabe National Forests and the BLM – Bishop Field Office should consider permanent closure to domestic sheep grazing or consider other uses that are not a threat to Sierra Nevada bighorn sheep.

Rationale: In order to prevent the need for potential emergency closure of allotments in the event that bighorn sheep move into any of the allotments identified in this plan, voluntary relinquishment should be pursued. In addition, voluntary relinquishment would allow bighorn sheep to naturally move into an allotment without risking contact with domestic sheep. This would also eliminate the need for expensive management actions that CDFG and land management agencies would have to implement to prevent contact in these areas.

Recommendation 11 (Other Non-compatible Recreation Use): The appropriate land management agencies should continue or make permanent those orders necessary to eliminate goat packing, or any other non-compatible recreation use (or any other activity not considered as grazing in this plan), within Sierra Nevada bighorn sheep herd units.

Rationale: Previous forest orders have been initiated to ensure the closure of goat packing in Sierra Nevada bighorn sheep allotments. These orders, and others which may be deemed necessary upon completion of the risk assessment, should either be regularly renewed or made permanent to prevent contact between domestic goats used for recreation (or any other activity not considered as grazing in this plan) and bighorn sheep.

Recommendation 12 (Annual Assessment): CDFG, the Service and federal land management agencies should annually assess efforts to prevent contact between Sierra Nevada bighorn sheep and domestic sheep. This assessment should be done at least annually; but may be required more frequently to enhance the effectiveness of measures implemented for preventing contact. The goal is to evaluate the effectiveness of these efforts over time and make changes, as necessary.

Rationale: As Sierra Nevada bighorn sheep populations recover, their population will increase in size and their distribution within the herd units will change. Furthermore, resource and land management agencies will better understand the effectiveness of their management actions. Therefore, it is imperative that management be adaptive to new information as it becomes available. Changes may not need to occur annually, however, because of the substantial threat disease poses to recovery of the Sierra Nevada bighorn sheep, the effectiveness of ongoing efforts should be assessed annually.

III. IMPLEMENTATION SCHEDULE

The Implementation Schedule that follows outlines actions as identified in the Narrative Outline of Recovery Actions (section II.D) and estimates costs for the recovery of Sierra Nevada bighorn sheep. It is a guide for meeting the objectives discussed in Part II of this recovery plan. This Schedule indicates task priorities, task numbers, task descriptions, duration of tasks, responsible agencies, and estimated costs. The agencies responsible for committing funds are not necessarily the entities that will carry out the tasks. The agency or agencies with the lead responsibility for each task are indicated in the table. Initiation of these actions is subject to the availability of funds.

The Implementation Schedule indicates speculative, future costs (preparation of additional plans, or research programs, etc.) as "to be determined." Indirect costs, such as those incurred by: (1) agencies and groups contributing time and materials, or (2) public agencies performing administrative or regulatory functions are not included in cost totals. Costs of continuous tasks are estimated assuming a 20-year time to recovery. Though the Implementation Schedule does not distinguish between public and private costs, no identifiable or specific expenditures by the private sector are likely to be necessary, other than voluntary efforts contributed by nonprofit conservation organizations and citizen groups. Priorities (column 1 of the following table) are assigned as follows:

Priority 1 An action that must be taken to prevent extinction or to prevent the species from declining irreversibly in the foreseeable future.

Priority 2 An action that must be taken to prevent a significant decline in species population/habitat quality or some other significant negative impact short of extinction.

Priority 3 All other actions necessary to provide for full recovery of the species.

Abbreviations used in the Implementation Schedule:

TBD	To be determined
cont.	Continuous
†	Continued implementation of task expected to be necessary after delisting.
‡	Task expected to be necessary until delisting of species.
*	Lead responsible agency

Agencies and Organizations

BLM	Bureau of Land Management
CDFG	California Department of Fish and Game
CT	CalTrans
LADWP	Los Angeles Department of Water and Power
FWS	U.S. Fish and Wildlife Service

FS	U.S. Forest Service
NPS	National Park Service
UC	University of California, White Mountain Research Station
USGS	U.S. Geological Survey, Biological Resources Division

RECOVERY PLAN IMPLEMENTATION SCHEDULE FOR SIERRA NEVADA BIGHORN SHEEP

Priority #	Task #	Task Description	Task Duration (Years)	Responsible Agencies	Total Estimated Cost ($1,000s)	Estimated Cost ($1,000s)				
						FY 08	FY 08	FY 09	FY 10	FY 11
1	2.1	Prepare and implement a management plan to temporarily protect Sierra Nevada bighorn sheep herds from predation losses, where needed, until viable herd sizes are reached.	cont.	CDFG*	7,000	350	350	350	350	350
1	2.2.1	Reduce potential predator influences on winter habitat selection where appropriate	cont.	CDFG*	1,000	50	50	50	50	50
1	2.2.2	Supplement small female groups where appropriate to attain threshold herd sizes that will encourage behavioral attributes favorable to winter range use	cont.	CDFG*	300 (estimated cost $3,000 per animal captured; number captured per year TBD)	TBD	TBD	TBD	TBD	TBD
1	2.3.1	Prevent contact between bighorn sheep and domestic sheep or goats	cont.†	FS*, FWS, BLM*, LADWP, CDFG	150	7.5	7.5	7.5	7.5	7.5

1	3.1	Develop and implement a strategy for translocations	cont.	FS, NPS, FWS, CDFG*	600	30	30	30	30	30
1	3.2.1	Manage wild herds as sources of stock	cont.	CDFG*	costs included in other tasks					
1	5.2	Monitor key predators in the vicinity of winter ranges	cont.‡	CDFG*	included in 2.2.1					
2	1.2	Maintain and/or enhance integrity of bighorn sheep habitat	cont.‡	NPS*, FS*, FWS, CDFG	TBD	TBD	TBD	TBD	TBD	TBD
2	2.2.3	Enhance bighorn sheep winter range habitat to increase visibility where appropriate	cont.	FS*, NPS*, CDFG	600	30	30	30	30	30
2	2.3.2	Develop an action plan in the event that a pneumonia outbreak occurs	1	CDFG*	10		10			
2	3.2.2	Develop criteria for and, if appropriate, implement a captive breeding program	cont.	FS, FWS, CDFG*	5,000	250	250	250	250	250
2	5.1	Develop and implement a monitoring plan for population abundance and distribution of bighorn sheep herds in the Sierra Nevada	cont.†	CDFG*, UC*	4,000	200	200	200	200	200
2	5.4	Monitor exposure to disease organisms of concern	cont.‡	CDFG*	75	3.75	3.75	3.75	3.75	3.75

2	6.1	Investigate genetic population structure of existing herds	5	CDFG, UC*	200	40	40	40	40	40
2	8.	Establish an implementation advisory team for coordination and communication	cont.‡	CDFG*, FWS, FS, BLM, NPS	20	1	1	1	1	1
3	1.1	Identify and acquire important habitat not in public ownership from willing landowners.	cont.	FS*, FWS, CT, CDFG	TBD	TBD	TBD	TBD	TBD	TBD
3	2.4	Manage human use locally where it is found to cause bighorn sheep to avoid important habitat and, thereby, compromises survivorship or reproductive success.	1	FS*, NPS*, FWS, CDFG	5					
3	4	Implement a genetic management plan to maintain genetic diversity of Sierra Nevada bighorn sheep. The plan must use data on genetic variation gathered in Task 6.1.	cont.‡	CDFG*	20 Implementation costs included in 3.1			20		
3	5.3	Monitor vegetation structure and composition changes likely to affect bighorn sheep population parameters	10	FS*, NPS*, CDFG	100	10	10	10	10	10

3	6.2	Develop a population viability analysis (PVA) for the Sierra Nevada Bighorn Sheep	2	CDFG*, UC	100				50	50
3	6.3	Further investigate habitat use patterns of bighorn sheep herds	cont.	CDFG*	200	10	10	10	10	10
3	6.4	Investigate and analyze human use patterns relative to habitat use patterns of bighorn sheep	cont.	FS, NPS, CDFG*	100	5	5	5	5	5
3	6.5	Investigate the potential for altering habitat use patterns of mountain lions on bighorn sheep winter ranges by aversive conditioning	10	CDFG*	100	10	10	10	10	10
3	6.6	Investigate future reintroduction sites relative to potential predator and domestic sheep problems and other potential conflicts	cont.	FS, NPS, CDFG*	200	10	10	10	10	10
3	6.7	Investigate and, if appropriate, develop a plan for decreasing mortality of bighorn sheep remaining at high elevation in extreme winters	1	FS, CDFG*	30			30		

3	6.8	Attempt to develop long term data that will help elucidate predator-prey dynamics of this ecosystem as they affect bighorn sheep	cont.	FS, NPS, UC, CDFG*	1,550	30	80	80	80	80
3	6.9	Investigate effects of climate change on bighorn sheep habitat	TBD	FS, NPS, USGS*, CDFG	120	TBD	TBD	TBD	TBD	TBD
3	7.1	Conduct a survey of public uses of bighorn sheep habitat and public attitudes regarding bighorn sheep	1	FS*, NPS*, FWS, CDFG	40		40			
3	7.2	Develop and distribute information related to recovery efforts	cont.‡	FS, NPS, FWS*, CDFG*	110	10	10	5	5	5
3	7.3	Continue, update, and coordinate, existing informational and outreach programs and develop further programs as needed	cont.‡	FS, NPS, FWS*, CDFG*	100	5	5	5	5	5

Total estimated cost (over 20-year timeframe): $21,730,000 + additional costs that cannot be determined at this time.

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V. APPENDICES

A. Pack llamas as potential sources of diseases for Sierra Nevada bighorn sheep
B. Sierra Nevada bighorn sheep and domestic livestock: Preliminary risk assessment of disease transmission in the eastern Sierra
C. Translocation considerations for Sierra Nevada bighorn sheep
D. Considerations for developing a monitoring plan for bighorn sheep in the Sierra Nevada
E. Considerations for a predator management plan
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G. Summary of threats and recommended recovery actions
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I. Captive Breeding Contingency Plan, Executive Summary
J. Comments received on the draft plan

APPENDIX A PACK LLAMAS AS POTENTIAL SOURCES OF DISEASES FOR SIERRA NEVADA BIGHORN SHEEP

Abstract: The interspecies transmission of infectious pathogens is dependent on characteristics of the two species, the disease agents, and the environment and requires effective contact between the host species. The requirements for transmission of diseases potentially shared by pack llamas and Sierra Nevada bighorn sheep are not satisfied in the context of the epidemiology of known diseases of new world camelids in the United States, the management of pack llamas in the back country, and the ecology and natural history of free ranging Sierra Nevada bighorn sheep. Current scientific evidence suggests that llamas utilized as pack animals present minimal risk of transmission of known pathogens to Sierra Nevada bighorn sheep and does not support the exclusion of llamas from Sierra Nevada bighorn sheep habitat due to the risk of disease transmission. Prevention of overuse of trails by llama packers, requirement of evidence of preventive health programs in llama herds for issuance of trail use permits, and good sanitation and husbandry practices by llama packers on the trail will further reduce the already very small risks and further protect the endangered Sierra Nevada bighorn sheep.

Literature Review: The transmission of infectious disease agents from one species to another depends on characteristics of the host species, (susceptibility and infectiousness), characteristics of the pathogen (infectivity, virulence and environmental stability), and effective contact between the host species (Thrusfield 1995). In order for a llama (*Llama glama*) to transmit a pathogenic virus, bacterium, or parasite to a bighorn sheep, the agent must be present in the llama in a form and quantity adequate for successful transmission, the disease agent must be infective enough to be passed between species either by direct contact or indirectly via a vector or inanimate physical vehicle, and there must be effective contact with the bighorn sheep adequate to allow transmission. The agent must be able to survive environmental conditions during the transmission and the bighorn sheep must in turn be susceptible to the pathogen.

A literature review (Thedford and Johnson 1989) and a standard text (Fowler 1998) on the infectious diseases of new world camelids indicated that most llamas in the United States are healthy and most medical problems are related to management or environment. Many disease agents that are infectious to both new world camelids and bighorn sheep are rare in llamas in the United States, are more easily acquired from the environment or sympatric wildlife than from the llama, are not present at adequate levels in the environment to infect bighorn sheep, or are unlikely to survive environmental conditions during indirect transmission.

Due to their economic value, pack llamas are generally tethered or otherwise kept close to their owners on the trail (Fowler 1998). In the unlikely event that a llama would escape into a free ranging situation, it would be unable to keep up with Sierra Nevada bighorn sheep in the steep, rocky terrain they frequent. In addition, Sierra Nevada bighorn sheep naturally keep a wide flight distance from humans, making direct physical contact between pack llamas and bighorn sheep highly unlikely and reducing the opportunity for transmission of infectious disease. Depending on the number, size, and distribution of llama pack strings, indirect transmission of disease agents from contaminated pastures, artificial feed, and/or standing water sources is theoretically possible. A few disease agents warrant individual discussion as they have demonstrated pathogenicity in bighorn sheep: *Pasteurella* hemolytic pneumonia; Mycobacterium paratuberculosis (Johne's disease); Contagious ecthyma virus (CE, soremouth); and *Psoroptes* spp. (Scabies).

Pasteurella hemolytica pneumonia

Pasteurella pneumonia is a major cause of epizootic disease outbreaks in captive and free ranging bighorn sheep populations resulting in high adult mortality with poor lamb survivorship in subsequent years. In separate trials, Rocky Mountain bighorn sheep were placed in direct contact with llamas, domestic sheep, exotic mouflon sheep (*Ovis musimon*), domestic goats, mountain goats (*Oreamnos americana*), domestic cattle (Foreyt 1994), elk (*Cervus elaphus*), and deer (*Odocoileus virginianus and Odocoileus hemionus hemionus*) (Foreyt 1992) and domestic horses and cattle (Foreyt and Lagerquist 1996) to determine if contact with other wild and domestic ungulate species exposed bighorn sheep to *Pasteurella* pneumonia. Except for the llamas and horses, essentially all the ungulates including the bighorn sheep were pharyngeal carriers of isolates of *Pasteurella hemolytica* when the experiment started. Foreyt tested 17 llamas to use as *Pasteurella* carriers in the trials but found none that were culture positive. All bighorn sheep exposed to the domestic sheep and the mouflon (Foreyt 1994), and one exposed to domestic cattle (Foreyt and Lagerquist 1996), succumbed to *Pasteurella* pneumonia while those exposed to the other ungulates including the llamas remained normal. *Pasteurella multocida* infection can cause a hemorrhagic septicemia-like disease in old world camels (Thedford and Johnson 1989). However, *Pasteurella* pneumonia in new world camelids has not been reported in the literature. Based on available data, there is no scientific evidence that contact with llamas will result in respiratory disease from *Pasteurella spp*. in bighorn sheep (Foreyt 1994).

Mycobacterium paratuberculosis (Johne's Disease)

Much controversy surrounds the potential for transmission of Johne's disease (*Mycobacterium paratuberculosis*) from llamas to free ranging bighorn sheep (Fowler 1998). Johne's disease is considered a disease of confinement, usually requiring intense sustained exposure to feces of infected, shedding animals as seen in domestic livestock and captive wild ungulates. Generally, adult ungulates are much less susceptible to infection and require greater exposure than juveniles. *Mycobacterium paratuberculosis* infection has been documented in several species of free ranging ungulates in the United States (Chiodini and Van Kruiningen 1983, Shulaw *et al*. 1986, Riemann *et al*. 1979, Jessup 1981). Williams *et al*. (1979) reported on cases of Johne's disease in bighorn sheep and in a mountain goat (*Oreamnos americana*) in the Mount Evans area of Colorado. The source and epizootiology of the disease were not clear in these cases. In a follow-up study, M. *paratuberculosis* was isolated from tissues and/or feces from nine of nine bighorn sheep/domestic sheep hybrids experimentally inoculated with an *M.*

paratuberculosis isolate from the Mount Evans cases and two of three bighorn sheep hybrids exposed to runoff from contaminated animal pens (Williams *et al*. 1983).

Johne's disease has been documented in new world camelids in England (Fowler 1998) and in Australia (Ridge *et al*. 1995) but is rarely diagnosed in llamas in the United States, with only four cases documented in Colorado (2), Oklahoma (1) and Minnesota (1) (Fowler 1998). Casual contact with the feces from a subclinically infected pack llama shedding *Mycobacterium paratuberculosis* is considered unlikely to provide adequate exposure to infect a bighorn sheep. The rare occurrence of this disease in llamas in North America makes it highly unlikely that any exposure will occur. There is no scientific evidence that llamas present a risk of transmission of Johne's disease to bighorn sheep.

Contagious ecthyma virus (CE, soremouth)

Contagious ecthyma is a cause of painful scabs and lesions on the mouths and faces of bighorn lambs and on the teats of bighorn females, and can result in difficulty in nursing and stunted growth of lambs. Clinical cases of contagious ecthyma have been diagnosed in bighorn sheep in Nevada, New Mexico, Colorado, Canada and California (Jessup and Boyce1993) and serologic evidence of exposure is not uncommon in desert bighorn (*Ovis canadensis nelsoni*) and Peninsular bighorn sheep (*Ovis canadensis cremnobates*) in California (California Department of Fish and Game, unpublished data). Clark *et al*. (1993) surveyed Sierra Nevada bighorn sheep sera retrospectively for contagious ecthyma exposure and found 2 of 14 (14 percent) seropositive accessions. More recent data from five Pine Creek animals captured in 1999 showed one of five negative and four of five inconclusive results on contagious ecthyma complement fixation tests (California Department of Fish and Game, unpublished data).

Transmission can be direct or indirect, as contagious ecthyma virus can be transmitted by insect vectors and may survive for years in scabs and soil. Contagious ecthyma is seen in camelids in Peru, and at least one case is documented in the United States. The natural reservoir for contagious ecthyma infecting llamas is probably the domestic sheep (Fowler 1998). Direct transmission of contagious ecthyma virus is highly unlikely due to lack of physical contact with bighorn sheep. While the contamination of pastures with contagious ecthyma virus is theoretically possible, the rare occurrence of contagious ecthyma in llamas in the United States makes it highly unlikely. Closely managed pack llamas, kept under good husbandry and sanitation conditions and with no evidence of clinical contagious ecthyma, present little or no risk to Sierra Nevada bighorn sheep.

Psoroptes spp. (Scabies)

Psoroptes scabies is an ectoparasitic disease that has caused declines in bighorn sheep populations throughout the west from the late 19th century to the present. Serologic evidence of exposure is not uncommon in desert bighorn sheep in California (Clark *et al*. 1993), and clinical cases have been observed in several desert mountain ranges in California (California Department of Fish and Game, unpublished data). Of 110 Sierra Nevada bighorn sheep tested retrospectively, none showed evidence of previous exposure to *Psoroptes spp*. (Clark *et al*. 1993). Two llamas, a cria and his dam (offspring and mother), are the only documented cases of Psoroptes in new world camelids in the United States. Based on morphological and epidemiological studies, the authors determined that the potential for transmission of Psoroptes from llamas to other hosts is present (Foreyt *et al*. 1992). Considering the rarity of this disease in llamas in the U.S. and the unlikely nature of direct contact between llamas and Sierra Nevada bighorn sheep, the risk for interspecies transmission of this disease is extremely low.

Conclusion

Scientific evidence suggests that llamas utilized as pack animals present minimal risk of transmission of known pathogens to Sierra Nevada bighorn sheep. Diseases reported in new world camelids but not discussed here (e.g., tuberculosis, brucellosis) are rare or nonexistent in the United States in llamas, are environmentally related (anthrax, clostridial diseases), or require conditions of contact that do not exist in the context of Sierra Nevada bighorn sheep and llama management. Due to the endangered status of the Sierra Nevada bighorn sheep, land managers may desire a conservative approach to further reduce the already small risk of disease introduction from llamas. The following measures could be implemented:

Prevent overuse by private and commercial llama packers. This measure will limit contamination of pastures, pens, and standing water sources. Limitations placed on numbers due to potential forest and trail impacts may be adequate to address disease considerations.

Require evidence of adequate herd health care before issuance of permits. Evidence of herd examinations by a licensed veterinarian, regular diagnosis and treatment of gastrointestinal parasites, and exclusion of animals showing signs of infectious disease from the pack string can be reflected in a health certificate that is renewed on a periodic (annual) basis.

These additional precautions impose little if any additional burden on either land managers or llama packers, and will further protect the small and endangered populations of Sierra Nevada bighorn sheep.

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APPENDIX B SIERRA NEVADA BIGHORN SHEEP AND DOMESTIC LIVESTOCK: PRELIMINARY RISK ASSESSMENT OF DISEASE TRANSMISSION IN THE EASTERN SIERRA

Epidemiology

Domestic livestock grazing allotments are commonly located within or adjacent to bighorn sheep habitat in some areas of the eastern Sierra Nevada. In addition, feral, abandoned, or lost domestic cattle, goats, and sheep may become sympatric with bighorn sheep. The proximity of domestic livestock to bighorn sheep raises concerns for the transmission of diseases to bighorn sheep.

Cattle

The impacts of domestic cattle (*Bos taurus*) grazing within bighorn sheep habitat have not been well documented. Bighorn sheep may avoid areas where cattle are grazed and not return to those areas for long periods after cattle are removed (King and Workman 1984). The potential for cross species transmission of diseases between cattle and wild ungulates may vary with local environmental conditions. Bovine viral diarrhea causes a complex of respiratory diseases, gastrointestinal diseases, and reproductive failure and may be transmitted between species. Hemorrhagic disease and pneumonia resulting from bluetongue virus (BTV) infection have been reported in bighorn sheep (Robinson *et al* 1967, Noon *et al* 2002). Because of prolonged viremia, cattle may be an important reservoir of BTV for *Culicoides* vectors (Osburn 2000) and, thus, a potential source of infection for other wild and domestic ungulates in areas climatically suitable for *Culicoides*. Singer *et al* (1997) studied cattle, bighorn sheep and mule deer (*Odocoileus hemionus*) in an area where the three species were known to utilize common areas. Only cattle were seropositive to BTV but deer and bighorn sheep were seropositive to *Babesia sp*. and *Psoroptes* mites were found only on bighorn sheep. Singer *et al*. (1997) concluded that cattle, deer, and bighorn sheep did not share similar patterns of exposure to the three pathogens and, thereby, proposed that cattle did not constitute a health risk for bighorn sheep in that area. Foreyt (1994) reported no adverse effects on healthy bighorn sheep in one co-pasturing study with domestic cattle. In a follow-up study, however, one of five bighorn sheep co-pastured with cattle developed a fatal pneumonia and died on day 6 post introduction (Foreyt and Lagerquist 1996). Although cattle may carry *Pasteurella* spp. that are pathogenic to bighorn sheep, those authors hypothesized that "the nose to nose contact required for transmission of *P. haemolytica* (renamed *Mannheimia haemolytica*) is less likely to occur between bighorn sheep and cattle" than with domestic sheep because the social interactive behavior between bighorn sheep and cattle is less likely to result in nose to nose contact. They recommended that further studies be conducted to determine the compatibility of bighorn sheep and domestic cattle. Based on the limited information currently available, there is insufficient evidence to exclude cattle grazing in or near bighorn sheep habitat based on disease considerations. However, if cattle grazing increases in proximity to bighorn sheep, disease considerations should be reconsidered.

Goats

Domestic goats (*Capra hircus*) are occasionally proposed for use as pack animals or for brush control in or near bighorn sheep habitat. Goats can be unapparent carriers of various pathogens. A recent outbreak of disease in bighorn sheep in Arizona provides strong evidence that contact with domestic goats presents a significant disease risk for bighorn sheep (Heffelfinger 2004). In October 2003, 4800 domestic goats were legally imported into Arizona from Texas to an unfenced state land grazing allotment about 5 miles north of bighorn sheep habitat in the Silver Bell Mountains, Pima County. In early November, a number of stray goats were confirmed within bighorn range. Despite efforts to remove the goats, by December, contact between the two species had resulted in an outbreak of infectious keratoconjunctivitis (inflammation of the eye) resulting in complete blindness in 33 bighorn sheep. During capture and treatment of these bighorn, contagious ecthyma (CE or soremouth) was also detected in 19 animals. Of 81 bighorn sheep thought to inhabit the Silver Bell Mountains, there were 14 known mortalities from malnutrition, predation, and other factors that were exacerbated by blindness. In addition, there were three stillborn lambs and three lambs that died post-partum from infected ewes. Thirteen bighorns are known to have recovered, but five remain unaccounted for. Heffelfinger (2004) provided the following links that implicated contact with goats as the cause of the bighorn disease outbreak:

- Neither disease had ever been seen before in bighorn in the Silver Bell Mountains.
- All bighorn observed were healthy during surveys on October 8, 2003.
- Goats arrived in October and were confirmed to be in bighorn habitat in November. Blindness and CE lesions in the bighorn appeared in early December.
- Both diseases are common in goat operations.
- Cowboys reported some of the goats came off the trailer blind and later recovered.
- One goat collected from sheep habitat was recovering from blindness.
- Genetic sequences from the bacterium, (*Mycoplasma conjunctivae)* found in the eyes of the collected goat were identical to those isolated from a blind Silver Bell bighorn.

Domestic Sheep

Bighorn sheep are closely related to domestic sheep (*Ovis aries*) and share many diseases with them, including pneumonias of viral and bacterial origin, contagious ecthyma, psoroptic scabies, bluetongue virus infection, and others. Chronic sinusitis in bighorn may result from infestation by the domestic sheep nasal bot fly (*Oestrus ovis*) (Bunch and Allen 1981) but can be avoided in domestic sheep with routine use of ivermectins. This may be a more significant risk from poorly managed, backyard sheep operations.

Introduction of domestic sheep grazing into the Rocky Mountains and southwestern states in the late 1800s and early 1900s coincided with widespread, all-age losses of bighorn sheep (Buechner 1960). There is substantial, albeit circumstantial, evidence from outbreaks in free-ranging bighorn sheep indicating that diseases introduced by domestic sheep likely played an important role in the reductions of bighorn sheep populations throughout their range (Goodson 1982, Martin *et al* 1996). Experimental data support this view. Numerous independent trials in which bighorn sheep that were well adapted to captivity and on an excellent plane of nutrition developed respiratory disease and died after direct contact with domestic sheep provide compelling evidence of the incompatibility of the two species (Onderka and Wishart 1988; Foreyt 1989, 1990, 1994; Callan *et al*.1991). Inoculations of bighorn sheep with *Pasteurella* isolates or fluids from the respiratory tract of healthy domestic sheep (Onderka *et al*. 1988, Foreyt *et al*. 1994, Foreyt and Silflow 1996) usually have resulted in respiratory disease and death of the bighorn sheep, but not of domestic sheep treated identically. By eliminating many of the environmental stressors that complicate field outbreaks of pneumonia in bighorn sheep, the aforementioned experimental studies have established a direct link between domestic sheep contact and respiratory disease in bighorn. In these studies, the domestic sheep remained free of clinical symptoms of disease while bighorn sheep succumbed to pneumonia. Further, in numerous additional pen trials in which a variety of other wild and domestic ungulate species were mixed with bighorn sheep, respiratory disease did not occur in bighorn sheep, except for the case cited above involving cattle (Foreyt 1992, 1994; Foreyt and Lagerquist 1996). Thus, the hypothesized stress on bighorn sheep of mixing of other species with them in pens does not explain the results of the pen trials with domestic sheep. The alternative explanation is that healthy domestic sheep frequently carry strains of pneumophilic bacteria that are fatal to bighorn sheep.

Outbreaks of respiratory disease from *Pasteurella* infections also may occur in bighorn sheep herds without known contact with domestic livestock (Miller *et al*. 1991). The respiratory disease complex of bighorn sheep is multi-factorial, and environmental and anthropogenic stressors likely allow opportunistic microorganisms to become pathogenic in bighorn sheep herds. The lungworm, *Protostrongylus stilesi*, is an important cause of verminous pneumonia and summer lamb mortality in overcrowded bighorn herds (Spraker and Hibler 1982) and is specific to bighorn sheep. Heavy infestations predispose bighorn lambs to severe, sometimes fatal parasitic pneumonias (Hibler *et al*. 1972, Hibler *et al*. 1974, Woodard *et al*. 1974) but such infestations have not been observed in less mesic ranges such as the Sierra Nevada (Wehausen 1980). Some bighorn herds are asymptomatic carriers of types of *Pasteurella* that are considered potentially pathogenic to other populations of bighorn sheep (Sandoval *et al*. 1987). Transmission of bacteria can result in acute disease, long-term carrier status, or nothing. A high percentage (84-100%) of bighorn sheep typically test positive for *Pasteurella* spp. when pharyngeal swabs are cultured properly and promptly (Wild and Miller 1991, 1994, Ward *et al*. 1997).

Some contacts between bighorn sheep and domestic sheep may not result in transmission of respiratory disease to bighorn; the outcome likely depends on a variety of factors including the exposure history and immune status of both the bighorn sheep and the domestic sheep. However, current technology does not allow us to predict which particular contact will result in disease transmission. Further, the onset of pneumonia in affected bighorn sheep may be delayed by days, weeks or months following contact with domestic sheep, and disease in isolated herds may not be detected for months after infection. In addition, surviving bighorn, especially wandering rams, may transmit pathogens to adjacent populations.

Currently there is no vaccine that will protect bighorn sheep against the many types of *Pasteurella haemolytica* (now *Mannheimia haemolytica)* or *P. multocida* prevalent during pneumonia outbreaks. In the event that an effective vaccine were to be developed, the logistics of effectively vaccinating a bighorn sheep population at risk would not be feasible, especially in the rugged Sierra Nevada. Vaccines generally protect from disease but not from infection. As a result, vaccinated ewes could continue to pass pathogenic bacteria to their lambs, possibly resulting in high juvenile mortality for 3 to 5 years following an outbreak.

Current evidence strongly suggests that domestic sheep and bighorn sheep are incompatible. Policies to maintain separation between the two species have been adopted by wildlife departments, as well as land management agencies (Bureau of Land Management 1992, 1998; Schommer and Woolever 2001). When attempting to find management solutions to the incompatibility between domestic and bighorn sheep, Schommer and Woolever (2001) concluded, "the most essential step in this sheep-specific process is to reach common understanding among all involved that incompatibility between domestic sheep and bighorn sheep exists and mixing the two species will eventually result in a bighorn sheep die-off. Without this fundamental understanding of the problem, collaborative efforts to develop potential solutions will probably not occur."

<u>Risk Assessment and Behavior</u>

Domestic Goats

The potential for contact between domestic goats and bighorn sheep exists in the eastern Sierra Nevada through the use of pack goats, as well as goats that are raised for meat. Pack goats are a concern because they are used to carry supplies into the backcountry, particularly high elevation areas in Wilderness. Current Forest Service policy prohibits the use of pack goats within herd unit areas occupied by Sierra Nevada bighorn sheep; this policy should continue. Owners of goat herds should be informed about the risks associated with contact with bighorn sheep and the need to keep animals confined. The use of weed control goats has been suggested but particularly should be avoided in the eastern Sierra Nevada because such goats are often of auction origin and tend to carry numerous diseases. Goats are not strong herd animals and the potential for animals to stray is great.

Domestic Sheep

Given the potential for disease transmission that may occur following contact between bighorn and domestic sheep, maintaining a zone of no contact between the two species is essential (Martin *et al*. 1996, Schommer and Woolever 2001, Gross *et al*. 2000). Suggested separation distances between domestic sheep and bighorn sheep ranges, but a minimum distance of 23 km has been recommended as a general rule when performing translocations of bighorn sheep near domestic sheep grazing allotments (Singer *et al*. 2000, Singer *et al*. 2001). Implicit in these recommendations is the concern that the two species will come into contact through straying of domestic sheep or long distance movements by bighorn sheep. The propensity for contact is exacerbated further by the interest in and ability of bighorn rams to mate with domestic ewes (Young and Manville 1960).

Previous recommendations for conserving Sierra Nevada bighorn sheep were based on limited knowledge of bighorn behavior and movements (U. S. Fish and Wildlife Service 2001). Consequently, assumptions made when assessing risk of disease transmission must be reevaluated. Previously, risk was assessed largely on concern about domestic sheep straying into bighorn habitat. That concern is real, as exhibited by at least three examples in this region in the last decade: 1) 23 domestic sheep wandered from the Bloody Canyon allotment into Dana Fork in Yosemite National Park and were discovered in November 1995 (U.S. Fish and Wildlife Service 2001), 2) $\geq$ 27 domestic sheep wandered off private land and into bighorn habitat in Jeffrey Canyon in the White Mountains in June 2004 (T. Stephenson, California Department of Fish and Game, unpublished observation), and 3) on 17 November 2004, 7 domestic sheep were observed wandering on the north side of Conway Summit along Highway 395 after the grazing season (T. Taylor, California Department of Fish and Game, unpublished observation). In addition, husbandry and grazing practices on some allotments are inadequate to either prevent or respond to contact between domestic and bighorn sheep (California Department of Fish and Game 2005).

Equal importance must be given to the potential for forays by bighorn sheep, particularly males, to result in contact with domestic sheep. The timing and extent of such forays are particularly relevant such as when and where they occur relative to adjacent domestic sheep grazing. Movements of female bighorn sheep in the Sierra Nevada are characterized by seasonal philopatry. Specific females use the same winter and summer ranges year after year. Movements of males also are characterized by a tendency to use the same winter and summer ranges repeatedly; however, there are frequent exceptions.

Since 2002, six instances of adult male bighorn traveling at lower elevations in or near the eastern Sierra have been documented. In November 2002, a male was observed crossing Bridgeport Valley east to west and disappeared in Buckeye Canyon (Tim Taylor, California Department of Fish and Game, unpublished observation). On 30 June 2003, a young male was observed and captured along highway 6 just north of Hamill Valley (T. Stephenson, California Department of Fish and Game, unpublished observation). On 29 November 2003, a radio-collared adult male (S21) was struck by a vehicle on highway 395 at the mouth of Lundy Canyon while crossing from east to west (T. Stephenson, California Department of Fish and Game, unpublished observation). On 6 August 2004, a bighorn sheep was reported traveling west across highway 395 just north of Conway Summit (Kathy Lucich, U.S. Forest Service, personal communication). During November 2005, a bighorn male (estimated age - 4 years) was observed on the floor of the Owens Valley, east of highway 395 and adjacent to the Black Rock Hatchery

(Los Angeles Department of Water and Power, personal communication). Finally, from November 3 to 6, 2005, a radio-collared adult male (S20) traveled north from Lundy Canyon, through the Cameron Canyon allotment, to the south end of Bridgeport Valley and then returned to Lundy Canyon. It cannot be assumed that bighorn sheep, and in particular males, will remain entirely at high elevation during summer, especially as the rut approaches. Domestic sheep graze public and private land in the eastern Sierra Nevada from June into November and use elevations ranging from <7,000 feet to > 10,500 feet.

Considerable data from telemetered bighorn in the Sierra Nevada reveal a tendency for some males to make long-distance movements beyond their normal home range. It is notable that all radio-collared bighorn rams that made extralimital movements returned to their core home range within 8 months of their departure; as yet, none resulted in permanent colonizations of new areas. The significance of their initial departure and movement is surpassed only by their subsequent return, which has important implications when evaluating the potential for widespread disease transmission. Of the 25 bighorn rams collared and with sufficient data as of May 2006, seven (28 percent) have made substantial movements beyond their core home ranges. The movements of three males that traveled north from the Mt. Warren area (Figures B-1 and B-2) illustrate their potential to act as carriers of disease if exposed. S12 and S60 were observed on the north end of Kavanaugh Ridge directly above Green Creek. S20 traveled north on two separate occasions in 2005 (Figure B-2); during July he was in the Dunderberg allotment and during 2-7 November 2005, he traveled through the Cameron Canyon allotment and beyond. Over a span of only a few days in late October and early November 2002, S10 circumnavigated Mount Tom while making a foray southward from Wheeler Ridge (Figure B-3). The most extensive movements observed were by S13, who traveled >33 air miles (53 km) south of Lee Vining Canyon to Laurel Mountain (Figure B-4). S13's departure occurred during December 2002 and he returned the following August.

Home range extent provides one measure of the extremes in distances traveled by bighorn and includes movements that result from migrations and forays. Sixty-one Sierra bighorn had data that encompassed winter and summer ranges and were used in the analysis. Maximum extent of female movements ranged from 7.0 to 22.6 km. In comparison, maximum extent of male movements varied from 11.4 to 59.4 km. Berger (2004) noted that migration distances of bighorn ranged between 7 and 74 km. DeCesare and Pletscher (2006) observed bighorn rams moving >30 km beyond their core home range.

Home ranges of male and female bighorn differed in size ($t = -3.05$, $n = 61$, $P = 0.005$); male ranges were almost twice as large on average. Mean minimum convex polygon home range of ewes was 53.0 km^2 (SD = 24.3). Mean size of home ranges for rams was 100.4 km^2 (SD = 75.0).

The movements of radio-collared bighorn sheep in the Sierra Nevada, in combination with observations of rams crossing adjacent valleys, illustrate the possible role that bighorn may play in contracting and spreading disease from the numerous domestic sheep herds in the area. The potential for bighorn rams to move into and through domestic sheep allotments and then return to their herd of origin are reasons to be concerned about potential for disease transmission. Questions remain as to what behavioral and ecological factors may precipitate long distance movements by specific rams. Social status, age, nutritional status, herd size, population density, predation risk, and habitat availability may be factors affecting the propensity of an animal to make forays.

The proximity of bighorn sheep locations and domestic sheep allotments translates to a non-trivial risk of contact between the two species, and the consequent potential for disease transmission (Figure B-5). Of the three occupied Recovery Units, only the Southern Recovery Unit no longer exhibits significant risk of contact (Figure B-5). In the Northern Recovery Unit, bighorn sheep were located immediately adjacent to active allotments during 2004 (Figure B-6). In the Central Recovery Unit, the Wheeler Ridge Herd currently supports the largest concentration of bighorn sheep within the Sierra Nevada and lies within 5 kilometers of domestic sheep grazing allotments (Figure B-7). The 10- and 20-kilometer distances used to illustrate the zones of epidemiologic risk are less than some recommendations in the literature for avoiding contact. Further, they are less than movements observed for some rams in the Sierra Nevada. Nevertheless, such distances reduce the likelihood of contact. Included, at least in part, within the 20-kilometer zones of risk are 31 federal domestic sheep grazing allotments totaling over 350,000 acres.

The focus here has been on the negative aspects of long distance movements by bighorn sheep relative to domestic sheep, but these movements have essential benefits to populations. Considered in an ecological and evolutionary context, such movements have profound genetic benefits, such as reduction of the potential for inbreeding (Mills and Allendorf 1996), and function to maintain metapopulation structure through the potential for colonization to occur (Bleich *et al*. 1990).

Disease threats in the eastern Sierra Nevada also are posed by the prevalence of domestic sheep and goats on private land; these include larger flocks on farms, as well as individual animals and smaller flocks in small pastures and back yards. In many cases, non-commercial or hobby animals may pose a greater threat because there may be less awareness by their owners of the risk to bighorn. Efforts to inform these owners are needed to reduce the risk and ensure that agencies are notified if animals are lost or if contact with bighorns occurs.

For recovery of Sierra Nevada bighorn sheep to succeed, there should be no contact between Sierra Nevada bighorn sheep and domestic sheep. There may be various actions that can be taken to achieve this goal; one of those is to evaluate risk and encourage resource management agencies to take actions to prevent contact.

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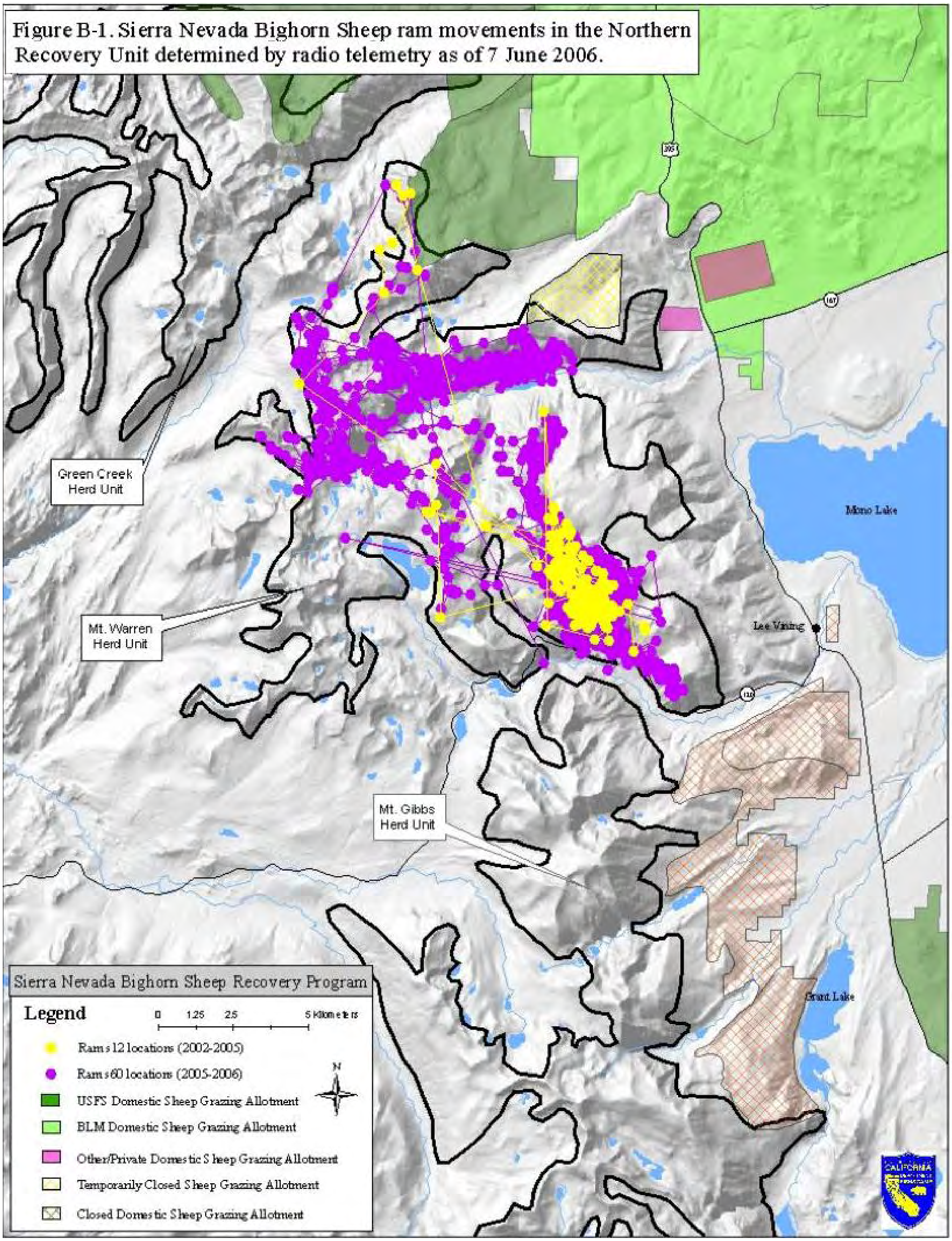


Figure B-1. Sierra Nevada Bighorn Sheep ram movements in the Northern Recovery Unit determined by radio telemetry as of 7 June 2006.

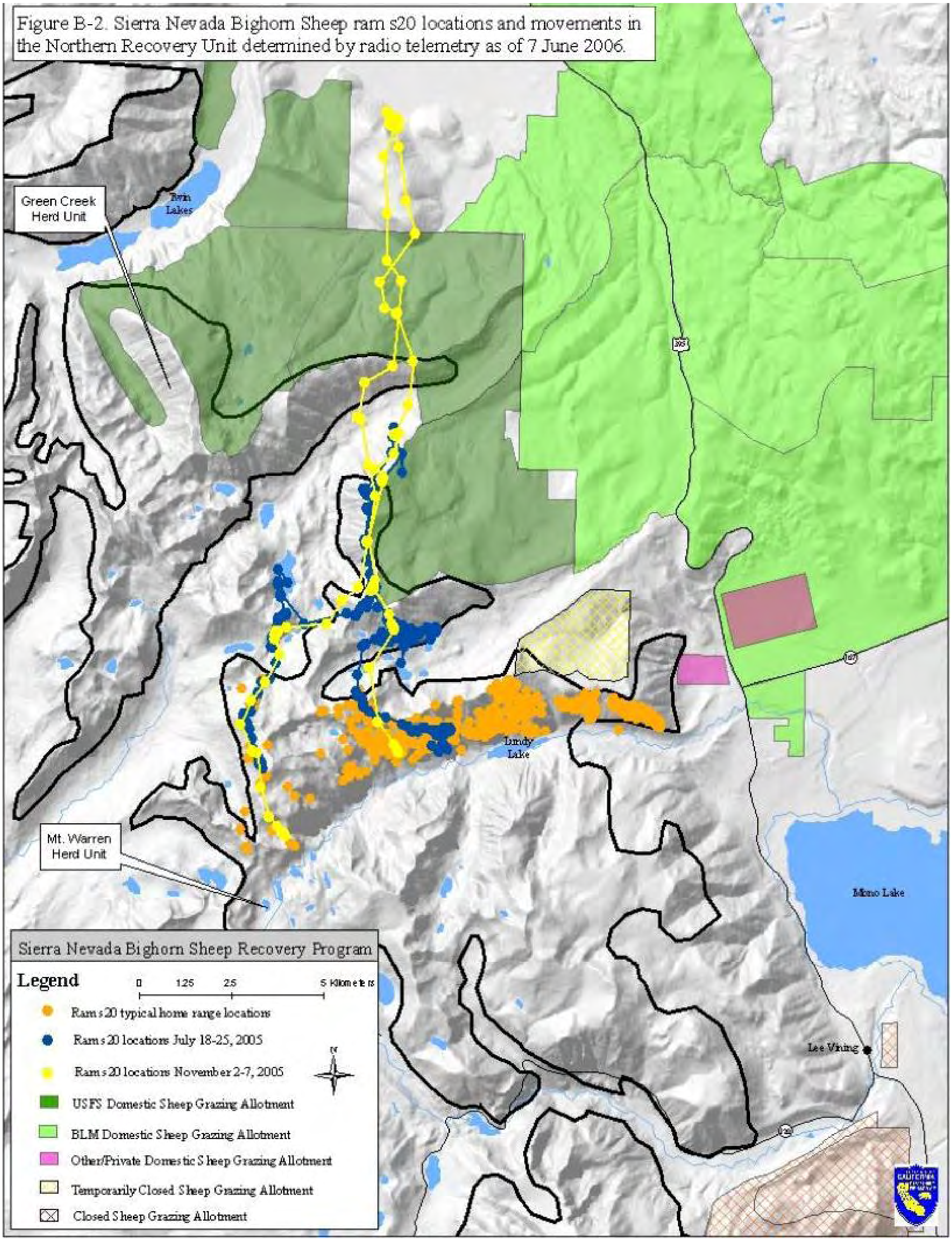


Figure B-2. Sierra Nevada Bighorn Sheep ram s20 locations and movements in the Northern Recovery Unit determined by radio telemetry as of 7 June 2006.
Green Creek Herd Unit
Twin Lakes
Lundy Lake
Mt. Warren Herd Unit
Mono Lake
Lee Vining
Sierra Nevada Bighorn Sheep Recovery Program
Legend
0 1.25 2.5 5 Kilometers
Ram s20 typical home range locations
Ram s20 locations July 18-25, 2005
Ram s20 locations November 2-7, 2005
USFS Domestic Sheep Grazing Allotment
BLM Domestic Sheep Grazing Allotment
Other/Private Domestic Sheep Grazing Allotment
Temporarily Closed Sheep Grazing Allotment
Closed Sheep Grazing Allotment

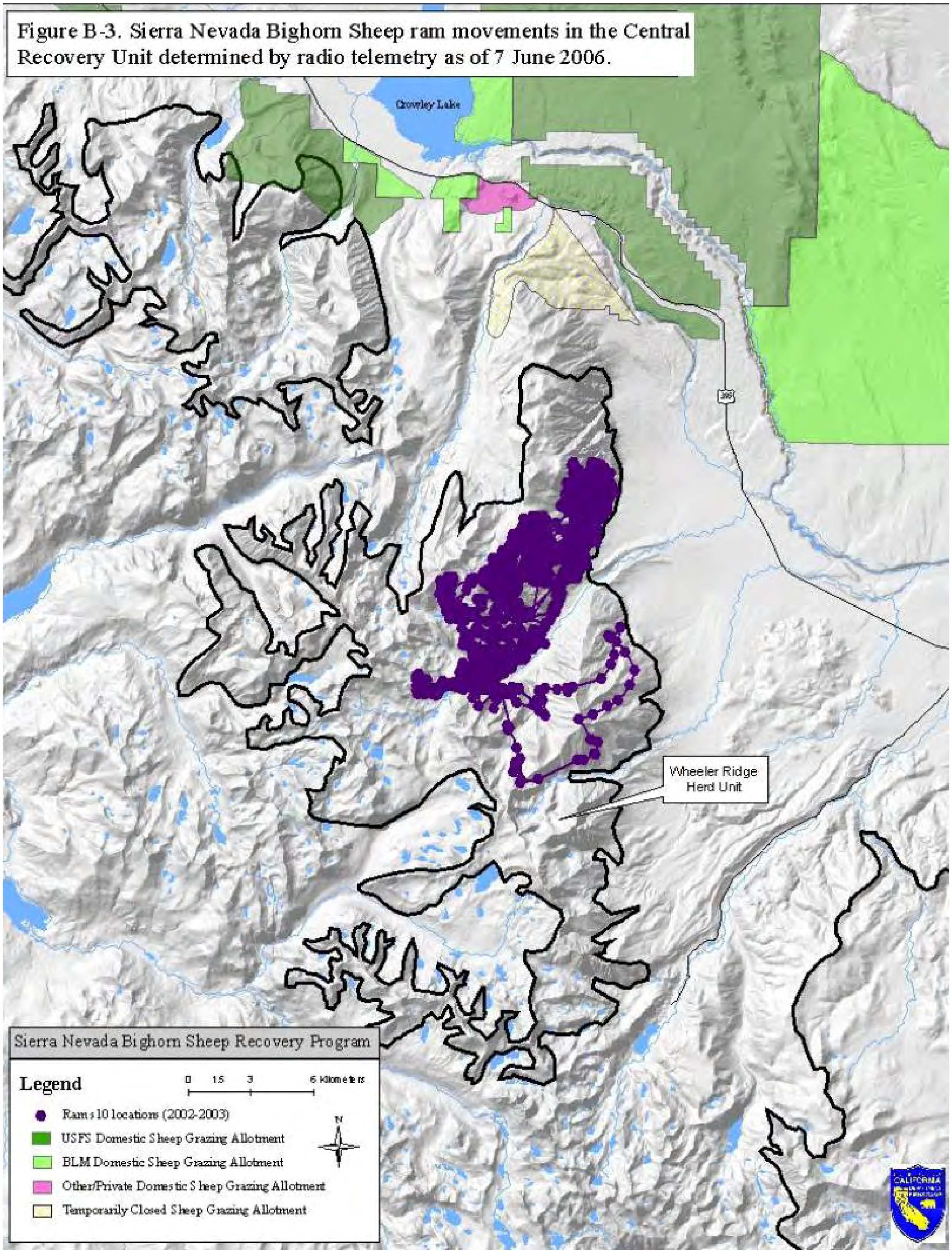
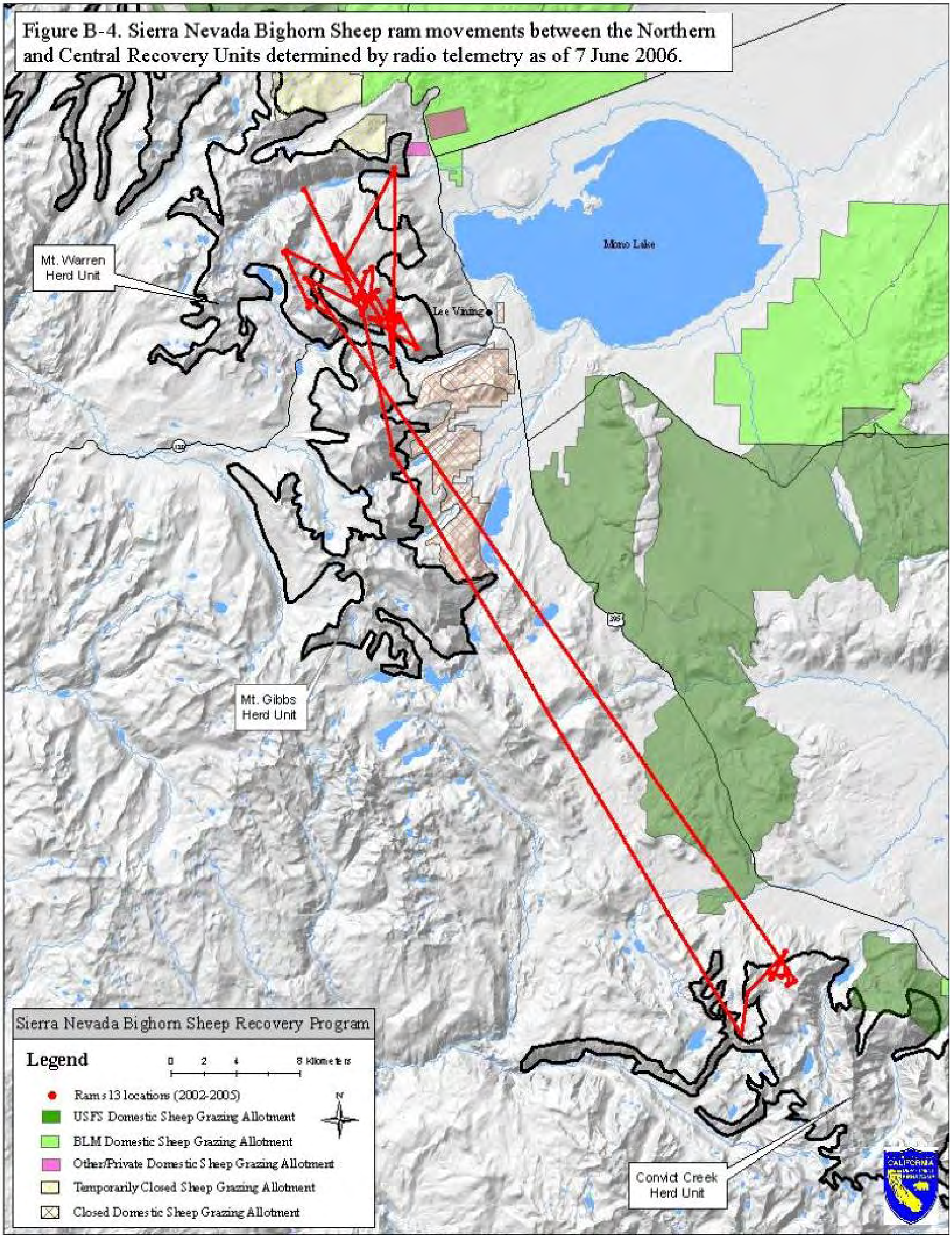


Figure B-3. Sierra Nevada Bighorn Sheep ram movements in the Central Recovery Unit determined by radio telemetry as of 7 June 2006.

Figure B-4. Sierra Nevada Bighorn Sheep ram movements between the Northern and Central Recovery Units determined by radio telemetry as of 7 June 2006.



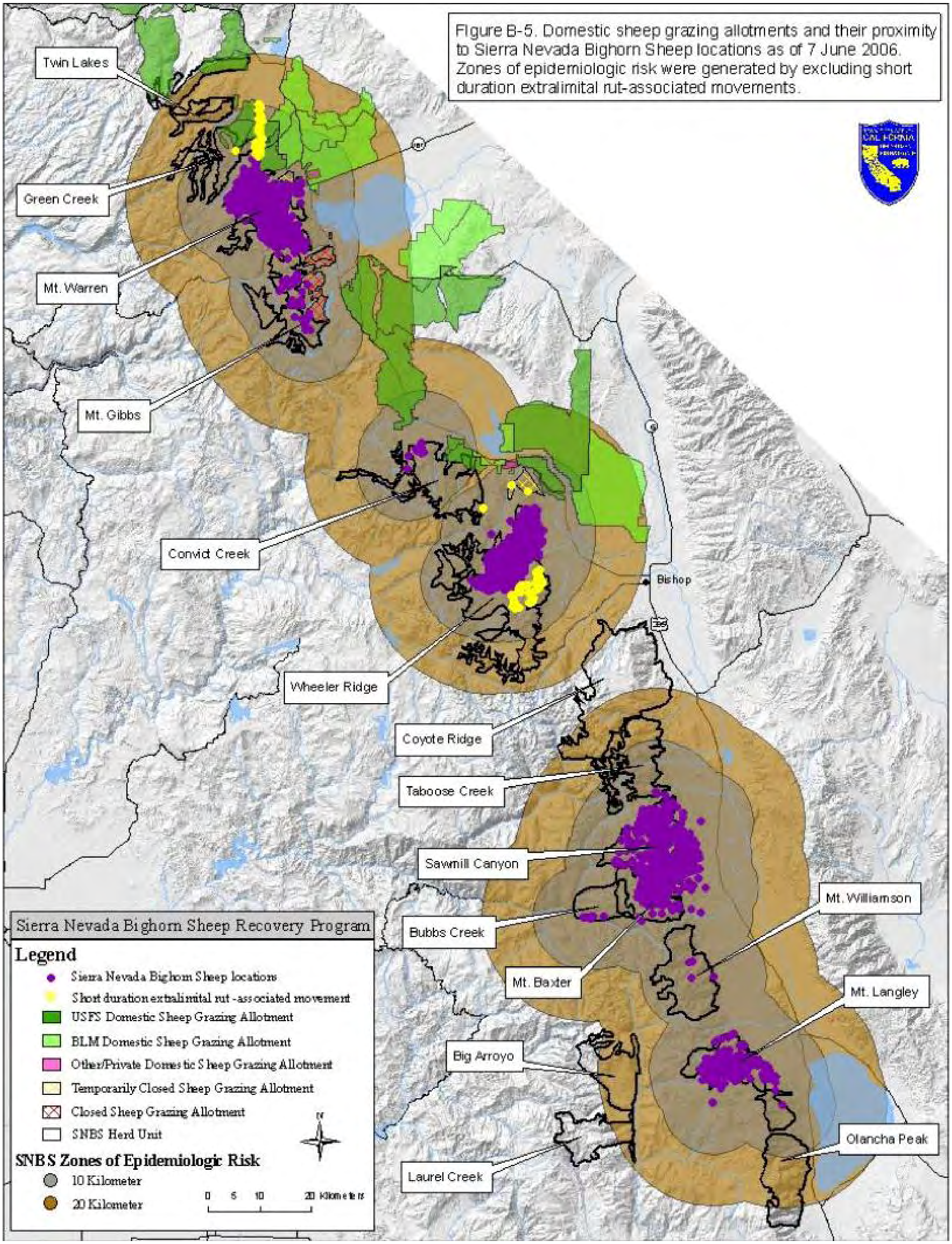


Figure B-5. Domestic sheep grazing allotments and their proximity to Sierra Nevada Bighorn Sheep locations as of 7 June 2006. Zones of epidemiologic risk were generated by excluding short duration extralimital rut-associated movements.
Twin Lakes
Green Creek
Mt. Warren
Mt. Gibbs
Convict Creek
Wheeler Ridge
Bishop
Coyote Ridge
Taboose Creek
Sawmill Canyon
Bubbs Creek
Mt. Williamson
Mt. Baxter
Mt. Langley
Big Arroyo
Olancha Peak
Laurel Creek
Sierra Nevada Bighorn Sheep Recovery Program
Legend
Sierra Nevada Bighorn Sheep locations
Short duration extralimital rut-associated movement
USFS Domestic Sheep Grazing Allotment
BLM Domestic Sheep Grazing Allotment
Other/Private Domestic Sheep Grazing Allotment
Temporarily Closed Sheep Grazing Allotment
Closed Sheep Grazing Allotment
SNBS Herd Unit
SNBS Zones of Epidemiologic Risk
10 Kilometer
20 Kilometer
0 5 10 20 Kilometers

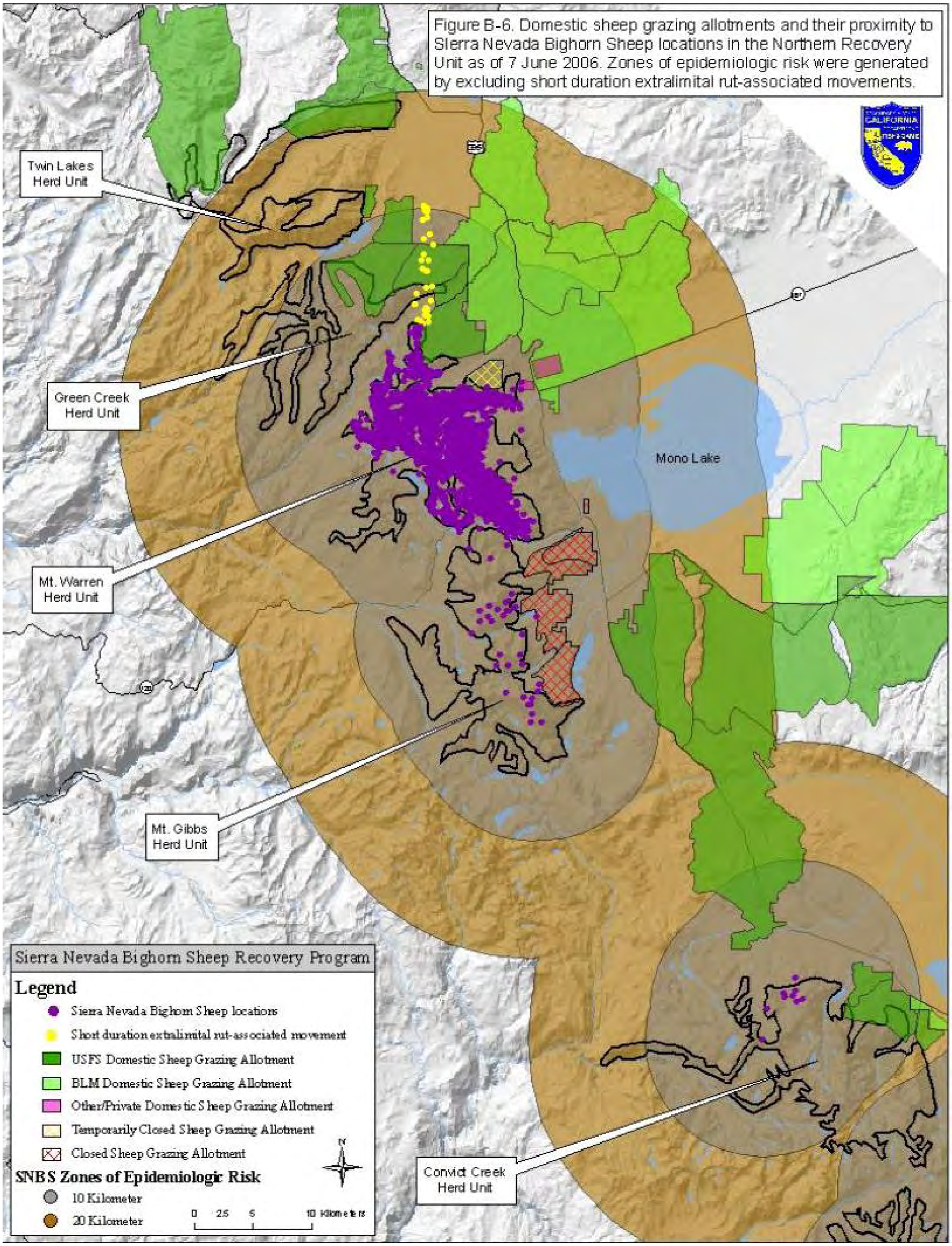


Figure B-6. Domestic sheep grazing allotments and their proximity to Sierra Nevada Bighorn Sheep locations in the Northern Recovery Unit as of 7 June 2006. Zones of epidemiologic risk were generated by excluding short duration extralimital rut-associated movements.

APPENDIX C TRANSLOCATION CONSIDERATIONS FOR SIERRA NEVADA BIGHORN SHEEP

The future of bighorn sheep in the Sierra Nevada hinges on the use of translocations for reintroductions and herd augmentations, and possibly for genetic management. The translocation plan called for in Task 3.1 is therefore critical to the recovery effort for these bighorn sheep. This appendix lays out some of the elements and issues that should be in that plan and a discussion of both occupied and unoccupied bighorn sheep habitat in the southern and central Sierra Nevada.

A. Sources of translocation stock

In the 1970s and 1980s, only a single herd existed in the Sierra Nevada that was large and productive enough to be tapped for reintroduction stock. That vulnerable situation was a primary concern addressed in the Sierra Nevada Bighorn Sheep Recovery and Conservation Plan (Sierra Nevada Bighorn Sheep Interagency Advisory Group 1984). The same vulnerable situation exists today. Solving this problem has to be one of the key elements of the translocation strategy. Among the options that need to be explored are the establishment and maintenance of one or more wild source herds and the conditions under which a captive herd should be developed in parallel to produce stock for translocation needs to be addressed as well. The advantages of captive breeding lie with being able to control factors affecting survivorship and reproductive output. A captive herd could be managed to have optimum reproduction and survivorship without the environmental variation that is present in wild populations, thereby maximizing production of bighorn sheep.

A captive breeding contingency plan will need to be developed to facilitate decisions relating to the captive breeding of bighorn sheep. The final product of a captive breeding herd should be healthy, behaviorally normal individuals capable of surviving and reproducing in the wild. The concept of captive breeding in general, along with the history of bighorn sheep captive breeding attempts, will need to be reviewed. A theoretical decision tree should be constructed to help facilitate captive breeding decisions and identify the point at which captive breeding is considered essential to prevent extinction and accelerate recovery.

Selection guidelines for a captive breeding site need to be developed, and potential sites should be identified and evaluated. Also, guidelines and recommendations for constructing and maintaining a facility for captive breeding, selection of founder breeding stock, husbandry, veterinary care, and a summary of diseases that may affect a captive herd needs to be carefully developed. Development of this information prior to an actual decision to enter into a captive breeding program will greatly expedite the development of such a facility if it is needed.

Population models can help in evaluating how captive breeding may facilitate recovery goals. The integrity of these models will depend on the input of demographic data on age- and cause-specific mortality, reproductive success, and census numbers. Such models also can help assess the effects that the bighorn sheep removal and augmentation associated with captive breeding could have on extinction probabilities in populations. These initial models may help guide decision-making and the construction of future models.

B. Management of wild herds for translocation stock

Issues that should be addressed in a translocation plan are: (1) how such herds are to be managed differently from other herds; (2) what demographic criteria will be used to determine when and how many bighorn sheep will be removed from a herd; (3) what tradeoffs and benefits are associated with waiting until a herd has grown larger before removing bighorn sheep for translocation; and (4) what potential behavioral implications for the source herd may be associated with frequent captures, and how these may relate to logistical difficulties of capturing bighorn sheep.

C. Translocation strategy

The optimal use of bighorn sheep available to translocate is a complex question. While a short-term plan can be developed based on current population information, it is important to recognize that it will need to change as the status of herds change, recovery goals are met, and new information on habitat is developed. Ideally, the plan will incorporate needed flexibility. The alternative will be to revise the plan as needed. Below are some of the key issues to be addressed in the plan.

1. <u>Prioritization of locations to receive available stock</u>

Should available stock be used only for augmentations to assure recovery to all existing herds before unoccupied ranges are considered?

Should the first bighorn sheep available for translocation be used only to create at least one more source of translocation stock, or should a mixed strategy be considered?

Should the goal of the translocation strategy be to minimize the time to downlisting? Does such an optimization have any associated risks? In developing a long-term strategy, it will be important to estimate the minimum number of bighorn sheep that will need to be moved for reintroductions to meet recovery goals.

How does the proximity of domestic sheep grazing allotments and the grazing practices implemented on those allotments affect prioritization of translocation sites?

<u>Translocation group size</u>

Minimum numbers that will be moved for augmentations versus reintroductions need to be established. Moving smaller numbers will risk fewer bighorn sheep and may be desirable for some reintroductions, with the idea that the initial group can be augmented later. Because herd augmentations can generally be accomplished with far fewer individuals than reintroductions, it may be difficult to justify engaging in reintroductions until existing herds have reached sizes that afford some comfort in terms of viability.

It has been recommended that reintroduced herds of bighorn sheep be created with at least 20 individuals (Wilson and Douglas 1982), and this approach has been the common practice, including past reintroductions in the Sierra Nevada. Establishing sufficient genetic variation in isolated herds has been one reason for this approach. In contrast, a new group of females established within a metapopulation where males will find them might be created with a small number of females and perhaps one male to assure breeding until other males discover them. This practice will better mimic natural colonization in bighorn sheep, where new female groups sometimes arise from a single dispersing female (Bleich *et al*. 1996). Males explore nearby habitat considerably more than females and in general find suitable habitat patches before females.

There are other considerations regarding numbers of females to translocate. Regardless of how much research may be allocated to choosing release sites, uncertainties will always remain. Therefore, it will be important to proceed with an experimental approach to translocations so that different scenarios can be evaluated to optimize future efforts. Even for a reintroduction, an initial translocation of a relatively small number of individuals will allow an assessment of site suitability. An augmentation can follow if deemed appropriate to boost numbers and assure sufficient genetic diversity, but the failure of a reintroduction of many bighorn sheep due to unforeseen circumstances will be an irretrievable loss of a rare resource. Also considered should be the advantages that bighorn sheep obtain from group living, including better predator detection and feeding efficiency. Group sizes of five to six are common, and feeding efficiency shows little gain beyond that size (Berger 1978, Risenhoover and Bailey 1985). Thus, releases in new areas should attempt to provide a group of at least five bighorn sheep if possible.

3. <u>Timing of translocations</u>

The intent of most or all translocations will be the establishment or augmentation of herds using low elevation winter ranges. Since the peak in such use of this habitat historically has been in late winter and early spring, this period (especially March) would be the ideal time to translocate bighorn sheep to these sites. There are several reasons for this assessment. First, these bighorn sheep have a natural tendency to descend to such sites at that time of year. Second, forage quality will be high during this period, which may help hold translocated bighorn sheep near the release site. Third, for augmentations, there are likely to be herds present on these winter ranges that translocated animals can join, which should also serve to help hold translocated bighorn sheep near the release site. Finally, bighorn sheep can be caught most readily at this time of year. The translocation strategy should consider whether there is any other time of year at which translocations might be successfully done.

4. Potential areas to receive bighorn sheep

Below is a discussion of locations that might support herds of bighorn sheep. It combines habitat attributes with historical data. These locations are grouped by recovery units and by herd units within recovery units. The following attributes were considered in developing a list of potential areas that might support female groups (Table C-1): (1) known past use by bighorn sheep; (2) extent of high elevation snow-free winter habitat; (3) availability of lower elevation south or east-facing habitat and its lowest elevation and quality in terms of visual openness; and (4) availability of high elevation summer habitat. Winter habitat is the most limited habitat available in general and was the primary focus.

Recent herd histories have indicated that some use of low elevations in late winter and spring is essential for herds to maintain viable sizes. Table C-1 lists minimum elevations for each area. Lower elevations are correlated with warmer temperatures, earlier initiation of forage growth, and potentially higher overall nutrient intake by bighorn sheep. Wehausen (1980) found that each 17.8-meter (58.4-foot) increase in elevation equated to a 1-day delay in initiation of forage growth and associated increases in diet quality. This relationship translates to a 17-day delay per 1,000 feet, or 28 days per 500 meters. The large size attained by the Mount Baxter herd prior to changes in winter habitat use apparently resulted from high nutrient intake obtained on its low elevation winter range; this herd declined to about 15 percent of its former size while avoiding low elevation winter range habitat (Wehausen 1999). While lower minimum elevations allow greater nutrient intake by bighorn sheep herds using them, it is not known what the upper limit of this minimum elevation is relative to supporting a viable herd.

Northern Recovery Unit

Bighorn sheep were recorded historically as far north as the Sonora Pass region (Grinnell and Storer 1924). Some patches blown free of snow exist near and east of Sonora Pass. However, these patches included little rocky escape terrain and were not considered suitable for reintroduction. It is not yet evident what sort of habitat use patterns the native bighorn sheep in this area might have had, but viable habitat may have included the Walker River Gorge and even the Sweetwater Mountains.

Nine areas were considered to have potential habitat for bighorn sheep in this recovery unit (Table C-1). Three of these currently are inhabited by both sexes, and three more receive at least occasional use by males. Two areas are not suitable for translocations due to the proximity of active domestic sheep grazing operations (Green Creek and Twin Lakes). These areas are not included as potential areas for translocation.

Mount Warren Herd Unit: The Mount Warren area north of Lee Vining Canyon has a good combination of high elevation and low elevation winter habitat and supported a large concentration of bighorn sheep prior to 1995. Tioga Crest is included in the herd unit because of close connectivity. However, since 1995 data have suggested that a separate female group occupies Tioga Crest.

Table C-1. Potential sites for bighorn sheep wintering groups in the central and southern Sierra Nevada grouped by Recovery Unit.

Location	Current Bighorn Sheep Use	Minimum Winter Habitat Elevation (m)	Winter Range Visual Condition
Northern Recovery Unit			
Twin Lakes (Victoria Peak)	No	2,200	open
Green Creek (Crater Crest)	No	2,750	open
Dunderberg Peak	No	3,050	open
Lundy Canyon	Males	2,450	mixed
Lee Vining Canyon (Mount Warren)	Yes	2,300	mixed
127 Tioga Crest	Yes	2,900	open
Bloody Canyon (Mount Gibbs)	Yes	2,775	open
Parker Canyon (Mount Lewis)	Males	2,700	open
Alger Creek (Mount Wood)	Males	2,300	open
Central Recovery Unit			
Convict Creek (Laurel Mountain)	Isolated male use	2,400	open
McGee Creek (McGee Mountain)	No	2,450	open
Nevahbe Ridge	No	2,600	open
Wheeler Ridge	Yes	1,700	open
Mount Tom	Males	1,950	open

Southern Recovery Unit			
Shannon Canyon (Coyote Ridge)	No	1,700	open
Birch Mountain/Kid Mountain	No	2,800	open
Taboose Creek	No	1,950	open
Goodale Creek	No	2,100	open
Sawmill Canyon	Yes	1,500	open
Thibaut Canyon-Sand Mountain	Yes	1,525	open
Onion Valley (Kearsarge Peak)	Yes	2,300	open
Bubbs Creek	Yes	2,075	mixed
Shepherd Creek-Pinyon Creek	Yes	2,075	mixed
George Creek - N. Bairs Creek	No	1,900	mixed
128 Lone Pine Creek-Hogback Creek	No	2,075	mixed
Carroll Creek -Tuttle Creek	Yes	1,750	mixed
Cottonwood Creek - Slide Canyon	Males	1,450	open
Falls Creek - Ash Creek	No	1,450	open
Kern Recovery Unit			
Big Arroyo	No	2,100	mixed
Rattlesnake Creek	No	2,075	mixed
Laurel Creek	No	2,075	mixed

Immediately to the north, Lundy Canyon has good low elevation south-facing winter range that rivals Lee Vining Canyon in its lowest elevation (Table C-1). In contrast, Lundy Canyon has very little high elevation winter habitat. Farther north, much of Dunderberg Peak is substantially blown free of snow in winter, but it does not connect to low elevation winter range. It is, however, connected to the Lundy Canyon range in summer.

Mount Gibbs Herd Unit: South of Lee Vining Canyon, the region from Mount Wood to Mount Dana has high potential for expansion of bighorn sheep range in this recovery unit. There is considerable high elevation habitat blown free in winter, which connects well to south-facing slopes that drop to lower elevations. Males are already known to move between Mount Warren and this area. With the recruitment of a yearling female in the Mount Gibbs herd in 1997, its known reproductive base increased to two females. Beginning in 1999, a third female has been documented in this group (Wehausen 2000). It is possible that, left alone, this little group will grow and eventually expand south to Mount Wood. This process could be greatly accelerated by translocating some females into this area. It is noteworthy that just west of Parker Peak lies Koip Peak, which means bighorn sheep in the Paiute language.

While many details on seasonal habitat use are lacking, the current herd in the region apparently uses only Mount Gibbs and part of Mount Dana during summer. Mount Lewis has habitat that appears to receive use only by males currently. The south-facing side of this mountain is steep and holds little snow in winter. It may be capable of supporting a small group of females. The Mount Wood area appears to be the best habitat in this unit. The slopes above Silver Lake provide low elevation east-facing winter range down to 2,316 meters (7,600 feet) that probably once received use by bighorn sheep, perhaps including birthing in spring in some years.

<u>Central Recovery Unit</u>

Wheeler Ridge Herd Unit: The Central Recovery Unit currently has one herd on Wheeler Ridge, which had grown to about 70 individuals in 2000. In the winter of 1998, there was a reported sighting of three females above Wells Meadow, the first known use of this low elevation winter range in many years. In subsequent years, this excellent winter range showed a steep increase in use by that herd in late winter. The herd is increasing very rapidly and is the one prospect for a source of translocation stock in the near future.

Immediately south of Wheeler Ridge is Mount Tom, which had a native herd of bighorn sheep that persisted into the 1930s. Ober (in litt. 1911) said of them: "on Mount Tom, twenty miles west of the city of Bishop, there ranges in winter and summer a beautiful herd numbering forty head; they course from Mount Tom on over the summit to the west and around the head waters of Pine Creek". Three years later Ober also noted that this herd numbered "about forty or fifty head; they follow the snow line in winter, and, as a matter of fact come very close to the little farming community of Round Valley (Ober

1914)." Males from Wheeler Ridge have been known to visit Mount Tom occasionally since they were reintroduced in 1979, and Mount Tom is the likely first site for range expansion in this region via translocation. Mount Tom offers multiple habitat options. Low elevation winter-spring habitat extends down to 1,950 meters (6,400 feet) in Elderberry Canyon. High elevation winter habitat is extensive on the west side of the north ridge of Mount Tom, and there are even some narrow ridges that can be blown free of snow on the south side of the mountain. Further, the summit plateau between Basin Mountain and Mount Humphreys remains snow free in winter and is accessible to bighorn sheep traversing ridgelines from Mount Tom via Four Gables and along the crest. Early sighting records indicate that the bighorn sheep that inhabited this area used the crest in summer at least as far as Mount Emerson, and males certainly ranged farther. Reestablishment of this herd might go a long ways toward increasing total numbers of bighorn sheep in this recovery unit and thereby enhancing its viability.

Convict Creek Herd Unit: Farther north are three areas that were probably all used historically by bighorn sheep to some degree: Nevahbe Ridge, McGee Mountain, and Convict Creek. A native herd inhabited the Convict Creek area into the 1950s (Jones 1950). Traditional south-facing winter-spring habitat that melts off quickly after winter storms occurs above Convict Lake down to 2,407 meters (7,900 feet). That area is connected to extensive high elevation wind swept patches on Laurel and Bloody Mountains. Of these three northern sites, Convict Creek is the most favorable due to this combination. McGee Mountain has excellent south-facing winter habitat down to about 2,438 meters (8,000 feet) that is equivalent to the slope above Convict Lake, but has only a small amount of high elevation winter habitat. Nevahbe Ridge has more windblown habitat than McGee Mountain, but the low elevation habitat is east facing and occurs down to only 2,590 meters (8,500 feet); thus it is much more delayed in snowmelt.

In 1989, 11 males from Wheeler Ridge were photographed by a hiker near Rosy Finch and Laurel Lakes, which is a considerable distance northwest from Wheeler Ridge and indicative of the potential for gene exchange with the northern portion of this recovery unit if it can be established via translocation. There was probably also once some gene exchange between this recovery unit and the Northern Recovery Unit via San Joaquin Ridge. In 2002-2003 a radio-collared male from the Mt. Gibbs herd unit temporarily moved south from the Mt. Warren herd unit to Laurel Mountain in the Convict Creek herd unit before returning (Figure B-4), as discussed above in Appendix B. As of 2006, the Convict Creek herd unit is unoccupied by bighorn sheep.

Numerous sightings of bighorn sheep on San Joaquin Ridge were recorded between 1954 and 1957 including a male killed by a deer hunter. Connectivity across this region is less likely in the future because of human developments.

There are currently U.S. Forest Service domestic sheep grazing allotments in close proximity to the Convict Creek area. Prior to translocations into these areas, these allotments should be analyzed to determine if measures need to be instituted to prevent contact between domestic sheep and bighorn sheep (see Section II.E above).

<u>Southern Recovery Unit</u>

As many as 13 or more distinct female groups may have once occupied the area from Olancha Canyon to Coyote Flat. Of those areas listed on Table C-1, five currently contain female groups and another four are known to have been visited by males. These areas are discussed below as six general herds.

Coyote Ridge Herd Unit: East above the south fork of Bishop Creek there are multiple high elevation patches of habitat on Coyote Ridge and the Inconsolable Range that remain snow-free in winter. There is a paucity of historical evidence that bighorn sheep occupied this area, but this lack of evidence could reflect an incomplete record. Bighorn sheep using this area might have used low elevation habitat along Bishop Creek and/or crossed over Coyote Flat to excellent south and east-facing winter range as low as 1,706 meters (5,600 feet) in the Shannon Canyon area. Bishop Creek is currently treated as a break between the Central and Southern Recovery Units because of uncertainty about former use of the region of Coyote Ridge and the Big Pine Creek drainage. A Coyote Ridge herd would serve substantially as a link between these two recovery units. It is likely that historically there was gene flow through the bighorn sheep herds along the entire east side of the Sierra Nevada. It is noteworthy that a number of recent reported sightings on Coyote Ridge, the Inconsolable Range, and the west side of the Palisades region suggest the possibility of a small number of bighorn sheep currently occupying this area.

Taboose Creek Herd Unit: Jones (1950) listed a Birch Mountain herd just south of Big Pine that he estimated at 15 bighorn sheep. His evidence for these bighorn sheep was tracks of six animals. Clyde (*in litt*. 1971) noted that he had never seen bighorn sheep sign on Birch Mountain in numerous ascents but had once seen deer (does and fawns) well above timberline on its slopes. Nevertheless, Ober (1914) mentioned bighorn sheep living from Birch Creek to Big Pine Creek, and Clyde (in litt. 1971) noted evidence on a variety of occasions of bighorn sheep in the upper Big Pine Creek drainage. Whether females were present is unknown. There are some significant areas of high windblown habitat on Birch and Kid Mountains that might have supported bighorn sheep. However, available low elevation south or east-facing habitat to complement these sites is limited to relatively high elevations unless the animals moved farther south to Red Mountain and Taboose Creeks. Alternatively, they might have dropped as low as 2,194 meters (7,200 feet) on the northeast side of Kid Mountain.

The Inyo National Forest Fish and Game Reports in 1921 and 1923 listed a Goodale-Birch Mountain herd; the 1921 report described it as "A considerable number ranging from Goodale Mountain to Birch Mountain, and wintering along the foothills in the Black Rock region during heavy snow." Ober (in litt. 1911) noted, "In the winter season they range low on Taboose Creek and along the snow line to Goodale and Red Mountain." Coincident with increasing mountain lion predation on bighorn sheep in the early 1980s, bighorn sheep were found wintering in Goodale Creek, where they had not been recorded for decades. As numbers of bighorn sheep wintering in Sawmill Canyon declined, the number wintering in Goodale Creek increased to a peak of 25 in 1981 and 24 in 1982, but then declined steadily. It is possible that members of the Sawmill Canyon herd were attempting to find a new safer area to winter. Lion predation on these bighorn sheep was also recorded at Goodale Creek in this period, which may have accounted for the decline in use there also. No use of this winter range has been known for some years. This area offers some patches of high elevation winter habitat, and excellent south-facing low elevation habitat, especially in Taboose Creek, where it occurs as low as 1,950 meters (6,400 feet).

Mount Baxter and Sawmill Canyon Herd Units: What was once referred to as the Mount Baxter herd is now known to be multiple herds. The northernmost is the Sawmill Canyon herd, which ranges as far north as Mount Pinchot. South of Sawmill Canyon is the Mount Baxter herd proper. South of Oak Creek there appears to be a third independent female group that developed after abandonment of winter range use in the late 1980s. Its range extends south to Kearsarge Peak and Mount Gould. The herd that utilized the ridges and drainages of Mount Baxter in the 1970s and 1980s was large and productive, and it provided most of the reintroduction stock used in the Sierra Nevada. Bighorn sheep removed from the Sawmill Canyon herd made up the remainder. Of existing herds currently in the Sierra Nevada, the Mount Baxter herd has the highest prospect for becoming a second wild source of translocation stock in addition to the Wheeler Ridge herd, due to its history. Augmentation of this herd with members of the Wheeler Ridge herd could accelerate that prospect.

Bubbs Creek Herd Unit: There is no historical evidence of bighorn sheep inhabiting Bubbs Creek, but a small herd was documented there in 2002 following a report from a climbing guide. Habitat in lower Bubbs Creek is a steep south-facing canyon wall about 6 kilometers in length that terminates at the junction with the Kings River. Sheep habitat drops as low as 2075 meters in elevation near the Kings River and consists of steep slabs with considerable tall shrubby vegetation where soil permits. There are also numerous spring areas that support stringer meadows, as well as open talus slopes along the base of the slabs. Bighorn sheep appear to occupy the lower canyon year round, but also visit alpine habitat around Mount Gardiner in summer. Habitat in upper elevations of lower Bubbs Creek is limited by forest and shrub habitat on slopes that mostly lack adequate escape terrain for bighorn. Consequently, suitable habitat consists of a narrow elevational band of only about 350 meters.

Mount Williamson Herd Unit: Females from the Mount Williamson herd ranged from Georges Creek to Shepherd Creek prior to its recent decline (Wehausen 1980) associated with avoidance of winter ranges. Of the four canyons previously used as winter range, only Shepherd Creek is currently used. Males were previously known to use the Symmes Creek and Pinyon Creek drainages in addition during summer, as well as areas west of the crest. Clyde (*in litt.* 1971) recorded considerable use farther south on Mount Russell, where he once encountered four males. This greater range of use may have reflected a much larger herd at that time, which Jones (1950) estimated subjectively at 125. Recent surveys of the herd have suggested that its range is currently farther north than it was up to 1985 when all winter range areas were used (Wehausen 2000). Any attempts to expand its current range through augmentation should attempt to reestablish South Bairs

Creek as a winter range. Females established there will likely use Georges Creek as well. A small amount of historic evidence suggests that females may have once used Symmes and Pinyon Creeks to the north, where only males could be found in the 1970s (Wehausen 1979).

Mount Langley Herd Unit: Prior to its recent decline, females from the Mount Langley herd used the area from Carroll Creek to Lone Pine Peak. It is not clear whether Tuttle Creek currently receives other than occasional use by females. South of Carroll Creek are Slide Canyon, which contains the road to Horseshoe Meadows, and then Cottonwood Creek, the top of which is also traversed by that road. Both of these canyons offer excellent low elevation open winter range, with Cottonwood Canyon notably more extensive. These winter ranges are better than those currently used from Carroll Creek to Diaz Creek, but would require greater distance traveled to connect them to alpine ranges. From Slide Canyon and the top of Cottonwood Canyon, it would be natural for bighorn sheep to cross a short stretch of open south-facing forest via Wonoga Peak to reach the large open plateau country currently used by this herd. It is hard to imagine that Cottonwood Canyon did not once support a large bighorn sheep herd. Males have begun using Cottonwood Canyon. The carrying capacity of this herd could probably increase dramatically if a female group used Cottonwood Canyon every winter. An alternative home range pattern for bighorn sheep using Cottonwood Creek would be a summer range to the south immediately east of the Kern Plateau at top elevations of only about 3,048 meters (10,000 feet). While this habitat would not provide the vast open expanses of higher alpine habitats in the Mount Langley area, it would be nutritionally quite suitable and likely to support a large bighorn sheep herd.

Olancha Peak Herd Unit: South of Cottonwood Creek, from north to south, are Ash, Braley, Cartago, Olancha, and Falls Creeks, all of which are potential bighorn sheep habitat. The southern three of these creeks are more favorable because they readily connect to Olancha Peak, which reaches 3,695 meters (12,123 feet) and provides some alpine summer habitat (the southernmost alpine habitat in the Sierra Nevada). Olancha Canyon is the most direct connection to this alpine habitat. The Olancha Peak herd would be the most southern herd in this recovery unit. Winter range would be traditional low elevation south-facing slopes, of which there is an abundance of excellent habitat reaching low elevations that will ensure high winter and spring diet qualities. Jones (1950) considered this region part of his Mount Langley herd, presumably because of reported sightings in that region at that time.

Kern River Recovery Unit

There is good historical evidence of bighorn sheep on the Great Western Divide. They occurred in the Mineral King and Kaweah Peaks area, with notable concentrations on Red Spur and in Big Arroyo (Jones 1950). A die-off was reported in the Kaweah Peaks in the 1870s that was attributed to scabies (Jones 1950).

Big Arroyo and Laurel Creek Herd Units: Bighorn sheep would have moved readily along the east-facing cliff areas of the Kern River Canyon in winter, but Big Arroyo, Rattlesnake Creek, and Laurel Creek would have been particularly attractive due to south-facing exposures on which snow melts faster and forage grows earlier. These sites are probably the best ones for reintroductions. Since there are no high elevation wind-swept areas west of the Kern River, the issues in comparing these three winter range sites are: (1) elevation; (2) visual openness; (3) amount of south-facing range; and (4) access to alpine ranges. Minimum elevations differ little among the sites (Table C-1). Big Arroyo may have the largest amount of low open habitat, but there appears to be ample habitat at each site, and all three are substantially open with some scattered trees. The Chagoopa Plateau largely blocks access to alpine habitat from Big Arroyo, but bighorn sheep can be expected to find access to the Kaweah Peaks at the upper end of the drainage. Alternatively, Red Spur can be immediately accessed from the Kern River canyon. In contrast, Rattlesnake and Laurel Creeks provide immediate access to summer ranges. One alternative would be to release bighorn sheep along the Kern River near Red Spur and let them ultimately find Big Arroyo as a preferred winter range. Laurel Creek has the potential advantage of having no trails and, thus, probably the least human use.

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APPENDIX D CONSIDERATIONS FOR DEVELOPING A MONITORING PLAN FOR BIGHORN SHEEP IN THE SIERRA NEVADA

The recovery plan for Sierra Nevada bighorn sheep calls for an adaptive management approach where timely decisions are made based on data collected on key resources. The bighorn sheep population is the most fundamental of those resources, and section II.D.5.1 calls for development of a plan to monitor the basic status of that resource. Specifically, it calls for the monitoring of distribution and abundance, and the use of low elevation winter ranges. The recovery plan recognizes that winter ranges are an important source of nutrients and thereby significantly affect carrying capacities of herds. Those carrying capacities figure importantly in recovery criteria, which are formulated in the currency of minimum herd sizes; thus, monitoring herd sizes is essential relative to those criteria.

Good information on herd sizes is also critical for management actions needed to reach recovery criteria. Range expansion into unoccupied habitat will occur primarily through translocations. The use of herds as translocation stock will require detailed monitoring of their sizes and trends. The elucidation of density-dependent patterns of population growth may allow the determination of the approximate population density where maximum sustained yield occurs. This would potentially allow optimization of harvesting strategies for translocation stock. At the other end of the spectrum, monitoring will allow the identification of populations that are failing to attain adequate sizes. Those populations, in turn, can be targeted for research needed to better understand limiting factors and to develop appropriate management actions.

The Recovery Plan distinguishes research from monitoring. The latter concerns variables that undergo temporal changes that are population parameters or may have large effects on sheep population parameters that might be mitigated through management actions. In addition to the bighorn sheep population, the resources identified in the Recovery Plan for monitoring are: 1) key predators, notably mountain lions; 2) disease exposure; and 3) vegetation structure. Of those entities, only the bighorn sheep population was singled out to have a monitoring plan. While this appendix discusses subjects appropriate to that plan, it might be appropriate to expand the scope of that plan to include the other resources listed for monitoring, and additional ones that might be identified as potentially important, e.g., genetic monitoring (see Appendix H), or detailed climatic data. This discussion touches on some other topics for which data can be collected in conjunction with basic monitoring efforts.

History of Efforts to Monitoring Bighorn Sheep Herds

Monitoring the sizes of bighorn sheep herds in the Sierra Nevada always has posed a challenge because of the difficulty of accessing most of the habitat these sheep inhabit, coupled with high elevations occupied much of the year. Prior to the late 1970s, most information consisted of subjective population estimates that used unclear methods to derive estimates from very limited data (Wehausen 1980).

A different approach to population monitoring began in 1976 in an attempt to develop more reliable information. That approach relied on understanding the behavior of different herds and attempting to make direct counts when the sheep were most concentrated in regions that are most accessible, either low-elevation winter ranges or along the crest in summer. This approach provided minimum counts that accounted for a high proportion of the sheep present. Initially, direct counts were made for the native herds when sheep were most concentrated on low-elevation winter ranges, usually in February and March. When possible, multiple such counts were made each year when sheep numbers on winter ranges appeared highest, and the highest number counted for each sex/age class was used for the minimum population size (Wehausen 1980, 1981, 1982, 1983, 1987, 1996).

No independent estimate of actual population size was used to evaluate the completeness of those counts. Instead, they were compared across time within and between years for consistency in the context of dynamics expected based on recruitment rates. In years of more complete counts, it was possible to correct previous counts for uncounted sheep (reconstructed populations). For instance, if two more 3-year old males were seen one year than 2-year old males the previous, those two could be added to the count from the previous year; and that reconstructed number of 2-year old males similarly could be compared with the number of yearling males counted the previous year.

Wehausen (1987) evaluated numerous years of winter counts for the Mount Baxter, Sawmill Canyon, and Mount Williamson herd units prior to winter range abandonment. He found counts were generally more complete in winters of particularly heavy snowfall (1978, 1983, and 1986) and only in such winters was it conceivable that essentially every sheep may have been accounted for in the Mount Baxter and Sawmill Canyon herds. Wehausen (1987) treated those three years as complete counts to develop an algebraic model that predicted population changes of the Mount Baxter herd unit based on lamb recruitment rates. Predictions from that model were used to evaluate the completeness of minimum counts in years of less snowfall. The results indicated that minimum counts varied from a low of about 70% of the population in drier years to >90% in heavier winters. A recent application of mark-resight estimation to evaluate a winter minimum count for the Wheeler Ridge herd unit supported the concept that good winter counts may account for every sheep in the population, and that counts in other years still account for a very high proportion of the sheep (Wehausen and Stephenson 2004).

After sheep herds in the Sierra Nevada began avoiding winter ranges in the mid 1980s (Wehausen 1996), data on population size became considerably more difficult to obtain and required efforts at high elevations during summer, where sheep are typically more dispersed. Nevertheless, predictable patterns of habitat use in summer also can be used to develop good counts with sufficient persistence in some situations. For the Mount Langley, Mount Warren, and Mount Gibbs herd units, summer counts always have produced the best data (Brown and Ramey 1987, Moore and Chow 1990, Hammett and Thompson 1992, Jensen 1994, Chang 1993). For most herds, attempts to develop regular data on population size were resumed in 1995 due to (1) concern about widespread herd declines, and (2) better counting opportunities provided by small herd sizes (Wehausen and Chang 1995, 1997, 1998; Wehausen 1999).

During the low ebb in herd sizes in the Sierra Nevada during 1995-99, summer counts in some herds were supplemented with interpretation of sign left by sheep where this suggested that some sheep had not been counted. This provided an assessment of possible additional sheep present (Wehausen 1999). That was possible only because of small herd sizes, and relied on information such as sizes of lamb fecal pellets to indicate that the sign probably represented additional sheep. Genotyping of sheep from fecal samples was then added as a less subjective data source to help assess population sizes and trends in some herds (Wehausen 2001, 2002).

Monitoring of all herds has depended on knowing seasonal habitat use patterns and attempting to interact spatially and temporally with those patterns in a way that maximizes the probability of finding the most females and associated sheep. Persistence and some luck have often been critically important to success. Habitat use patterns in the Sierra Nevada have shown notable changes over the past 30 years. It will be necessary for monitoring efforts to recognize this potential and respond to such changes. A fixed monitoring protocol has the potential to produce data that may be misinterpreted as population dynamics when they instead reflect changing sheep behavior. The decline in winter range use in the second half of the 1980s is a prime example.

Past Population Monitoring Approaches

Mount Baxter and Sawmill Canyon Herds, 1976-1990

During the 15 years beginning in 1976, these two herds were counted when they were most concentrated on winter ranges, mostly in February and March. Counts were done usually over three consecutive days. Once it was recognized that the Sawmill Canyon herd was demographically a separate herd, one or more days occasionally intervened between the counts of these two herds, e.g., if weather disrupted counts.

Initially, the Sawmill Canyon herd was counted from two strategic positions on rocks high on the south side of Sawmill Creek. This was supplemented with counts made from the north road that leads to the canyon mouth to account for sheep on the rocks at the mouth of the canyon and the north-facing habitat not visible from survey points south of the creek. The two survey points south of the creek were chosen because most of the south-facing winter range was clearly visible.

This census approach had a shortcoming in that the western-most part of the Sawmill Canyon winter range, where the first Jeffrey pines begin, was not sufficiently visible. Consequently, a second approach was developed that involved walking through the winter range in a pattern that maximized the likelihood of seeing all sheep there. This approach also began with glassing (remote observation using binoculars and spotting scopes) the north side of the ridge from the north road leading to the canyon mouth. It then involved climbing through the front rocks and traversing the south-facing winter range about mid elevation to the most western sandy slope where the Jeffrey pines begin. From there, further elevation was gained so that return was via the ridge top. This method had the advantage that sheep at the westernmost area of the winter range were readily found while the descent of the ridge top increased the likelihood of finding sheep to the north, and allowed rechecking of the sheep that had been seen in the canyon. The success of this census approach was illustrated well in 1982. During that winter, multiple counts of Sawmill Canyon showed a decline in the number of lambs from 13 to 10, while numbers of females and yearlings remained unchanged. All three missing lambs eventually were found as lion kills.

Two days were allocated to counting the Mount Baxter herd – one for Sand Mountain and one for Sand Canyon to Thibaut Canyon. Sand Canyon is the short drainage midway between Sawmill Canyon and Black Canyon. Sand Mountain is the area between Sand Canyon and Sawmill Creek. Counts of Sand Mountain began with a search from below with binoculars and a spotting scope in an attempt to find most of the sheep groups prior to hiking. Hiking routes were then chosen relative to the locations of those groups. Those routes began either at the base of Sand Canyon or at the mouth of Sawmill Canyon and generally consisted of a loop that allowed all potential habitat to be surveyed, including upper Sand Canyon.

Efforts to count sheep south of Sand Canyon always began by counting and classifying sheep in the region between Sand Canyon and Black Canyon ("Black Canyon front range"). Once that was completed, sheep were counted further south. That involved climbing to Big Ram Mine to survey the south- and north-facing rocks in Black Canyon and walking over to Thibaut Canyon. An area of important sheep use was the rocky drainage north of Thibaut Canyon ("Thibaut Gulch"). During that time, most sheep entered the winter range from Thibaut Canyon and worked their way north to Sand Mountain. It was possible to track the progress of sheep groups day by day. Many sheep also used that same route to leave the winter range. Thus, Thibaut Gulch was an important stopover location for sheep moving to or from the lower winter range

Critically important to counts of the Mount Baxter herd was not double-counting sheep near the boundary between the two census polygons. This was accomplished by keeping careful track of sheep groups on either side of Sand Canyon during both days involved, particularly late the first day and early the second day. If sheep crossed that boundary between the two days, it was highly likely that this would be detected using the size and composition of the group(s) in question to identify them.

These census methods ceased after 1990 because so few sheep continued to use those low elevation winter ranges. Instead, areas that sheep continued to use were checked less often in winter and spring during times most likely to produce sheep, notably following major winter storms.

Mount Williamson Herd 1976-1986

Counts of the Mount Williamson herd were made on escarpment base winter ranges between 1976 and 1985. Strong avoidance of those winter ranges developed after 1985, with only a few sheep seen in 1986 and none since then. Compared with the Mount Baxter and Sawmill Canyon herds, the Mount Williamson herd has only a few small patches of suitable escarpment base wintering habitat. What limits this habitat is poor visibility, primarily due to pinyon pine woodland.

Three escarpment base patches were found to receive most use by the Mount Williamson herd during 1976-86: the rocky ridge and connected small point of rock between South Bairs Creek and Georges Creek, the south-facing slope at the mouth of South Bairs Creek, and the south-facing rocks near the mouth of North Bairs Creek. The best counts occurred following major snowstorms. Snow conditions when those good counts took place commonly precluded driving across Foothill Road. The Georges Creek road was driven as far as snow allowed and the sites preferred by sheep were visited on skis. However, in years of continued heavy snows, sheep remained low for numerous weeks, well after Foothill Road became passable.

Of the three sites, the one between South Bairs Creek and Georges Creek was most preferred, followed by South Bairs Creek, and North Bairs Creek. By tracking sheep in snow and following groups over time, it appeared that sheep frequently descended to winter ranges at the north end of Mount Williamson and then worked their way south to the more preferred wintering sites. A lion-killed 3-year old female was once found at the mouth of Shepherd Creek, suggesting that they sometimes began that far north. Sheep also occasionally made forays to the mouth of Georges Creek from the preferred site a short distance to the north. Thus, while there were preferred sites, the entire escarpment base from Georges Creek to Shepherd Creek apparently was used as a travel corridor at times.

Future Population Monitoring

Problem Analysis

A clear definition of populations is requisite to the development of meaningful population statistics. Bighorn sheep populations can be substructured into separate home range patterns that constitute separate subpopulations. Understanding that structure is important to how demographic data are obtained and interpreted. An adequate understanding of spatial patterns of habitat use by sheep is thus an important aspect of future monitoring. It is particularly important for certain herd units that appear to have substructuring that is not fully understood.

One important use of population monitoring data concerns when and how populations will be used as translocation stock to meet restoration objectives. Fundamental to the question of population management for translocation stock is the nature of density-dependent relationships involving demographic processes, including reproduction and recruitment. Such relationships will best be elucidated where measurements of the number of female sheep and sheep of young age classes are made with the least error. The development of such data needs to be a fundamental goal of the monitoring program for Sierra Nevada bighorn sheep.

Minimum counts have served well in the past as a basis for management decisions, because those counts appear to have accounted for a high proportion of the herds in question, especially in some years, and those key years have served as baselines to interpret counts from intervening years. There is a need to develop periodic independent estimates of female numbers as an added evaluation of the completeness of minimum counts. Although minimum counts form a conservative basis for measuring progress toward recovery, as populations grow those minimum counts may represent a decreasing proportion of the total number, possibly increasing the value of point estimates with confidence intervals. In addition to determining population sizes, the distribution of bighorn must be quantified; in part, this may be accomplished by implementing additional systematic surveys to more comprehensively identify distribution. Such methods might include ground-based surveys or aerial telemetry, as well as the use of collars employing Geographic Positioning System (GPS) technology.

The finite populations correction factor is a statistical procedure that collapses the variance around sample means as the sample approaches the population total (Steel and Torrie 1960). The reason for this correction factor is simple -- little variance is possible when samples are that complete, with the extreme being no variance when the total population is sampled. The same concept holds for minimum and reconstructed counts of bighorn sheep that approach or reach the population total. Such samples will have high resolution in tracking population dynamics relative to estimators that may incur relatively wide confidence intervals. Bayesian statistical procedures are potentially more efficient than alternative independent estimators because they use prior information (Gill 2002). There is a need to explore the possible development of a Bayesian statistical approach for survey data.

Future monitoring of bighorn sheep population parameters in the Sierra Nevada should utilize as many tools as possible to develop the best possible data. Below is a discussion of some methods that may be useful as supplementation to past procedures to better meet the goals of the recovery plan.

Helicopter Counts

Because of the remoteness and ruggedness of much of habitat, there are limitations on methods that can be employed. For instance, some previous attempts to use a helicopter at high elevations in the Sierra Nevada have found no sheep or only a small proportion of those known to exist. Because of the atmospheric conditions at high elevations and related high speeds and elevations AGL that helicopters must fly for safety under conditions existing at high altitudes, it may be difficult to obtain reliable data on sex and age composition of sheep located by this method.

In 1981, a helicopter census took place on the low elevation winter ranges of the Mount Baxter and Sawmill Canyon herds. It was carried out with simultaneous ground observers to produce a double survey estimate (Magnusen *et al*. 1978) and evaluate the utility of such helicopter counts (Wehausen 1981) in the Sierra Nevada, a methodology that had been highly successful elsewhere in California (Holl and Bleich 1983, Holl *et al*. 2004). This approach was never repeated in the Sierra Nevada, because the results were poor compared with data that a single experienced investigator could produce with repeated ground surveys.

Nevertheless, helicopter surveys recently have been useful as a supplement to winter ground data. In 2001, under conditions of optimal early March snow cover, a helicopter survey of numerous potential winter ranges was particularly effective in finding sheep via tracks and in verifying the absence of tracks and, presumably, bighorn sheep. This method allowed ground surveys to be focused where sheep were known to be present. Helicopter surveys of Wheeler Ridge have been used to look for sheep in areas not accessible during winter ground counts. On a couple of occasions, such aerial surveys have found no further sheep, which contributed to the evaluation of the completeness of winter ground counts.

For winter range counts, helicopter surveys will frequently be most effective in late winter when sheep are likely to be at low elevations. However, a helicopter survey of Bubbs Creek on the west side of the Sierra Nevada located a key group of sheep on that range in January of 2003 and January 2005. Remote areas like Bubbs Creek that currently lack sheep (e.g., Kern Recovery Unit) may prove difficult to access by other means when conditions are optimal for counting sheep (e.g., winter).

Helicopters should continue to be used where they prove to be effective or might add some key additional data (e.g., sheep not counted on the ground because of lack of access). Moreover, the use of helicopters, in combination with marked animals (see below), provides a method of covering large expanses without huge investments of time by ground observers. Results may have wide associated confidence intervals, but as the distribution of sheep expands, the need to cover more ground may necessitate the use of additional methodologies.

Telemetry Collars

Radio collars have been used to great effect in the past to aid in monitoring the three reintroduced herds in the Sierra Nevada and similarly can aid future population monitoring. Radio collars can be added to herds through the capture of existing members or by translocating sheep to populations from a larger and more productive herd. Capture opportunities will be limited largely to low-elevation winter ranges because of logistical constraints. Consequently, the option of translocating sheep to add radio collars will have the advantage of not putting members of small herds through the major disturbance of capturing them during brief visits to winter ranges that these sheep may be hesitant to utilize. If efforts to capture members of such small groups cause winter range avoidance, those efforts may trade off population recovery for easier and better information.

Because females are the basis of recovery goals and central to population monitoring, a greater return in population monitoring can be expected by radio collaring that sex.

Radio collars will have the extra benefit of adding data on habitat use patterns and causes of mortality where mortality signals can be detected and investigated in a timely manner, while quantifying survivorship rates (Pollock *et al*. 1989). Survivorship statistics will be limited by the number of radio collars that can be placed in each herd. However, this information can be increased notably by configuring collars to transmit for as long as possible. Longer transmitter life will be beneficial to other uses of telemetered animals as well and should be a standard consideration.

While the recovery plan calls for the monitoring of habitat use patterns only relative to winter ranges, telemetry collars placed on sheep to aid in population monitoring also can provide considerable other important information on home range patterns and changes in the distribution of bighorn sheep. That information will be important for proper definition of populations and development of sampling strategies. Detailed data on movements of bighorn sheep also are important relative to understanding potential for disease transmission from contact with domestic sheep and among herd units (Gross *et al*. 2000, Zeigenfuss *et al*. 2000, Singer *et al*. 2001) and metapopulation questions regarding potential for gene flow and natural colonization (Schwartz *et al*. 1986, Bleich *et al*. 1990, 1996, Mills and Allendorf 1996). Monitoring of bighorn movements relative to diseases is particularly pertinent to the Northern and Central Recovery Units, which continue to have domestic sheep grazing in the vicinity. Data from GPS collars placed on rams in those areas will allow a more quantitative assessment of risk of contact with domestic sheep.

Detailed information from GPS collars also can be used to research questions of habitat use by sex and season (White and Garrott 1990) at varying levels of detail relative to resource selection: home range delineation, habitat selection within home ranges, and use of foraging patches (Johnson 1980). Habitat suitability modeling using resource selection probability functions (Manly *et al*. 2002, Johnson *et al*. 2005) should help refine understanding of bighorn habitat in the Sierra Nevada. Those models should be useful in identifying important movement corridors, areas where natural range expansions are most likely to occur, and more quantitative assessment of areas for translocation, while better understanding factors determining carrying capacities (DeYoung *et al* 2000).

Capture of animals for placement of telemetry collars can yield additional data not directly associated with the collars themselves, such as ultrasonography and serum assays to assess pregnancy status (Stephenson *et al*. 1995, Drew *et al*. 2001), ultrasonography to measure fat deposits (Stephenson *et al*. 1998, 2002), and serum assays of disease exposure. Radio-collared females can be monitored to determine birthing dates, lamb production, and lamb survival and recruitment to provide additional data on reproduction.

Mark-Resight Estimation

Telemetry collars also can be used to generate mark-resight population estimates if an adequate percentage of the herd is collared and the herd can be sampled in a random manner. The latter requirement precludes the use of telemetry signals from radio collars to influence which sheep are sampled. In the Sierra Nevada, this will eliminate the primary benefit of radio telemetry for herd monitoring: greater efficiency in finding sheep and an aid in finding otherwise missed sheep. This will lead to a difficult tradeoff in the allocation of sampling effort, given that the time when the best sampling for mark-resight estimates occurs frequently also will coincide with the time when the best minimum counts can be obtained. Where minimum counts include essentially all of the population, mark-resight estimates will contribute little, if any, additional population information. Additionally, Wehausen and Stephenson (2004) reported evidence that random sampling of the Wheeler Ridge herd in winter might not be possible, and that somewhat biased mark-resight estimates can result. Despite those potential problems, periodic mark-resight estimates provide important evaluations of minimum counts and should be pursued where results will provide estimates of meaningful precision and accuracy.

There are multiple mark-resight estimators that result in part from different sampling approaches (Bailey 1951, Chapman 1951, Caughley 1977, Minta and Mangel 1989, Neal *et al.* 1993), but all have the advantage of providing measures of precision in the form of confidence intervals. Mark-resight estimates typically require the capture and marking of some proportion (typically 5-20%) of the bighorn herd in question; however, in some situations it may be possible to generate such estimates using naturally marked animals.

Animals may be captured using a combination of methods, including drop net, helicopter net gun, drive net, and ground darting (Kock *et al*. 1987). Animals can receive colored, numbered ear tags to facilitate recognition of individuals, and a primary VHF radio collar, or a GPS collar that can be remotely downloaded and triggered to drop off. Animals that receive a GPS collar that will drop off also should be fitted with a secondary VHF collar that will remain with the individual to facilitate longer-term sampling.

The precision of mark-resight estimates is a function of the percentage of the population collared and the total size of the random sample(s). The latter will be critical to estimates of sizes of bighorn sheep herds in the Sierra Nevada and may require numerous sampling episodes for each estimate to narrow the precision to a meaningful level. Sample sizes can be increased using both sampling with and without replacement approaches. The joint hypergeometric estimator (Neal *et al*. 1993) uses the latter and is well suited to the development of population estimates in the Sierra Nevada where enough marked sheep are present. This approach involves repeated ground surveys within a specified geographic region (e.g., winter or summer range) using multiple observers equipped with binoculars and spotting scopes to survey the range in a systematic fashion, classifying all sheep seen by sex and age categories and marked status. Data can be analyzed using the program NOREMARK (White 1996), which offers multiple potential estimators. Two of those estimators require reliable individual identification of marked sheep; thus, it is important to develop an appropriate visual marking system.

Large sample sizes also can be developed using a sampling with replacement approach that approximates binomial sampling. One advantage of this approach is that a Bayesian statistical method can be incorporated using the beta distribution as a close approximation of the binomial distribution (Gill 2002). Ananda (1997) showed that this approach can significantly narrow the confidence intervals for mark-resight estimates of bighorn sheep populations.

Genotyping from Feces

Individual sheep can be identified genetically from DNA extracted from fecal samples (Taberlet *et al*. 1996, 1997, 1999). This tool has been applied to some bighorn sheep herds in the Sierra Nevada to help develop more complete minimum counts. This method is particularly useful for small populations like the Mount Williamson herd, where neither aerial monitoring nor ground surveys have been very successful. Indeed, when populations do not possess sufficient marked animals for mark-resight sampling, a combination of directed searches and fecal DNA sampling may be the most reasonable way to arrive at minimum herd sizes. With further refinement of fecal DNA technology (Wehausen *et al*. 2004), it has proven to be an important tool for monitoring some bighorn sheep herds in the Sierra Nevada.

Frequency and Intensity of Population Monitoring

Annual monitoring of all herds is a desired but, perhaps, unrealistic long-term goal. The intensity of monitoring applied to the various bighorn herds in the Sierra Nevada will depend on a variety of factors including herd size, risk of decline (e.g., from disease, predation, or severe weather), use as translocation stock, personnel, and financial resources. As long as a population remains small, monitoring should remain intensive so that immediate action may be taken to mitigate population declines. As populations become self-sustaining, increase in numbers, and are exposed to a lowered risk of extinction, the frequency and intensity of monitoring might decline.

Because survey results can vary across years in their completeness, it is important to maximize the probability of getting excellent counts when conditions are favorable. Developing an understanding of what factors underlie the completeness of counts (e.g., winters of heavy snowfall for low elevation winter ranges) will allow a more focused approach that maximizes data return for effort. What follows is a recommendation of minimum monitoring frequencies for herds in different categories if available funds do not allow annual monitoring of all herds.

A. Herds considered potential sources of translocation stock. Determine minimum numbers of females, yearlings, and lambs yearly to provide data on recruitment and herd size. Any population to be used as translocation stock likely will make concentrated use of low elevation winter habitat where the best population data will probably be obtained. Data on population parameters should be developed on winter ranges unless opportunities for better data occur in a different season. An attempt should be made to develop data on number of males, including age distribution, every 1-2 years.

B. Herds not used as translocation stock containing 1-15 females. Gather yearly data on size and recruitment. Attempt to count males every 2-3 years.

C. Herds not used as translocation stock containing 15-25 females. Attempt to assess size and recruitment every 1-2 years for each female group. Count males every 2-4 years.

D. Herds not used as translocation stock containing more than 25 females. Attempt to assess size and recruitment every 2-3 years and every 3-5 years for males if possible until delisting. After delisting, attempt to develop population data every 5 years or more often if severe environmental conditions (e.g., a very severe winter) occur that raise concerns about the status of the population.

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APPENDIX E CONSIDERATIONS FOR A PREDATOR MANAGEMENT PLAN

Predators are an integral ecological component of the community occupied by Sierra Nevada bighorn sheep. Sierra Nevada bighorn sheep will not be recovered until population objectives are attained, at which point Sierra Nevada bighorn sheep will be able to withstand naturally occurring predation without intervention. Coyotes and bobcats are known to prey on bighorn sheep; however, mountain lions, because of their larger size, are better adapted to kill larger prey, such as deer and bighorn sheep. Predation is a natural component of the system. However, predation, like disease, represents another vehicle of bighorn sheep mortality, and all mortality must be minimized until full recovery is attained. The goal of the predator management plan is to temporarily protect bighorn sheep from adverse effects of predators while preserving an intact ecosystem.

A predator management plan (Task 2.1) should be prepared that ties together the multiple tasks concerning predators called for in section II.D of this recovery plan and lays out specifics of how they will be accomplished and when they will be ended. These tasks include monitoring, research, and selective, humane predator removal where needed. Of potential predators, mountain lions have been implicated as the primary predator of Sierra Nevada bighorn sheep, and they may affect population dynamics of those bighorn sheep through direct losses or by influencing habitat selection by the bighorn sheep. Below is a brief discussion of some of the elements that should be included in this plan.

1. Experimental approaches in an ecosystem context.

The primary objective of the predator management plan should be to protect small herds of bighorn sheep to prevent further extirpations and to restore populations to a level at which the natural predator-prey interactions can be allowed to occur without human intervention. Predators, and their potential direct and indirect effects on these bighorn sheep, are part of the ecosystem inhabited by these bighorn sheep, and management of predators needs to recognize the role of these species in an ecological system.

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 in the vicinity of bighorn sheep herds. There is little question that such a control program would also result in the unnecessary removal of some predators that had little or no influence on the population dynamics of bighorn sheep. Further, such a program would undoubtedly have unforeseen effects on other aspects of the ecosystem that might ultimately negatively affect bighorn sheep. Therefore, this approach is undesirable in that it has unacceptable consequences.

Finding a balance in which the minimum of predator management is practiced will take creative and experimental approaches. Management prescriptions will evolve as they are tried and evaluated and conditions change. Balanced predator management will entail using different approaches for different bighorn sheep herds and will take into account the vulnerability of each herd to extirpation. Finding the optimal prescription(s) for minimal predator management while still recovering bighorn sheep will entail risk to some individual bighorn sheep. At the same time, though, those risks will be allowed only where the bighorn herds are large enough to be able to withstand such a loss.

2. Protection of bighorn sheep translocation stock.

The ultimate success of population recovery hinges on the development and use of sources of translocation stock. Past reintroduction efforts occurred only because of the prior size and productivity of the Mount Baxter and Sawmill Canyon herds. The decline and inability of those herds to serve as further sources of translocation stock was associated with widespread changes in winter habitat use patterns that Wehausen (1996) suggested were linked to increased predation pressure from mountain lions during the 1980s. Predation pressure from mountain lions that developed in the 1980s may have been exceptional, and differed substantially from the current situation of lower lion densities. Nevertheless, the predator management plan should address how herds serving as sources of translocation stock might be treated, given their key role in the recovery of these bighorn sheep.

3. Protection of translocated bighorn sheep.

Bighorn sheep may be translocated to augment existing herds or to create new ones. Translocation stock has been, and will likely continue to be, a rare and precious resource. The predator management plan needs to address questions of how translocated bighorn sheep will be treated relative to predators compared with other herds, and why. Among the tasks to be considered will be investigations of potential predator conflicts at sites considered for reintroductions (Task 6.6). Results of such investigations may influence decisions on where available translocation stock will be used. For instance, reintroduction sites that have higher potentials for predator problems may be a lower priority for translocation projects. Those areas may be stocked later when, presumably, greater numbers of bighorn sheep will be available and that will allow larger initial releases to compensate for potential losses to predators.

4. Monitoring of mountain lions in the vicinity of winter ranges (Task 5.2).

It is well known that mountain lions vary in their behavior toward different prey species. Research in Canada, New Mexico, and California (Ross *et al*. 1997, Logan and Sweanor 2001, H. Ernest, unpubl.data) indicates that one or a small number of individual mountain lions often are responsible for a disproportionate number of bighorn sheep kills. Radio collaring of lions in the vicinity of winter ranges will allow the details of habitat use patterns to be elucidated, thereby identifying potential problem animals.

In the Sierra Nevada, mountain lions range long distances as a response to the availability of prey (Pierce *et al*. 1999). Radio-collaring lions will allow predator management teams to monitor their locations precisely in relation to areas used by bighorn sheep. Although physical evidence of the presence of mountain lions is important when evaluating degree of threat to bighorn sheep, tracks of individual lions are not always distinguishable from each other (Grigione *et al*. 1999). Collared lions will remove most guesswork in reading sign (i.e., distinguishing individual lions via track measurements), provide more reliable data on which lions are of concern, and allow predator management specialists to be most efficient in the use of their time. In the absence of the use of radio collars on lions, efforts to protect bighorn sheep in the Sierra Nevada will likely result in the deaths of some lions that might have been spared if telemetry data were available. It is possible to collar most lions near bighorn sheep winter ranges, but it is unlikely that more than a small proportion of the bighorn sheep population can be collared. Monitoring of collared lions can provide considerable data regarding bighorn sheep and predator dynamics. The success of this approach ultimately will lie with the schedule of monitoring of collared and uncollared lions in conjunction with monitoring of populations of bighorn sheep.

Through the collaring of mountain lions, detailed information also can be gathered on lion population dynamics, allowing assessment of the impacts of removals of mountain lions on their populations and, thereby, helping to put recovery efforts for these sheep in a larger ecosystem context.

5. Attempting to alter habitat use patterns of mountain lions on bighorn sheep winter ranges by aversive conditioning (Task 6.5).

Aversive conditioning has not been attempted before with mountain lions. It is a potentially useful tool that, if successful, could afford a reduction of mortality for both Sierra Nevada bighorn sheep and mountain lions. Experiments should be carried out when and/or where they do not jeopardize bighorn sheep. To be effective, these efforts will need to occur during fall and early winter, prior to the usual appearance of bighorn sheep on winter ranges. These experiments will require the development of data on activity patterns of the subject mountain lions that will allow an adequate evaluation of the effectiveness of this intervention.

6. Development of long-term data to elucidate predator-prey dynamics of this ecosystem as they affect bighorn sheep (Task 6.7).

The predator-prey situation that unfolded in the eastern Sierra Nevada during the 1980s was unexpected and is not sufficiently understood. Those dynamics are not likely to be adequately explained unless similar circumstances recur and key elements are monitored over many years. Of primary interest will be the dynamics of deer herds, which are the primary prey of mountain lions, and the distributions and densities of which are important factors determining the abundance of lions (Pierce *et al*. 2000). Monitoring of mesopredators, such as coyote or bobcat, to ascertain population fluctuations relative to mountain lion populations should also be considered. Careful monitoring of key elements of this ecosystem will help elucidate whether the events of the past two decades were simply part of a cyclical phenomenon, or whether these events constitute an exceptional circumstance that is not likely to be repeated; in either situation, however, future efforts to conserve wild sheep will be enhanced through the acquisition of such knowledge.

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APPENDIX F PUBLIC INFORMATION AND OUTREACH PLAN

Abstract

The Sierra Nevada bighorn sheep Public Information and Outreach Program is based on the overarching principle that understanding and appreciation of the natural history and ecology of the Sierra Nevada bighorn sheep and concern for its future are vital to building public support for conservation measures and recovery actions. A number of recovery actions will directly affect the public using the eastern Sierra Nevada. Conversely, human activities may affect recovery. Knowing how Sierra Nevada bighorn sheep live and survive and the threats they face will help people understand the need for regulatory actions.

Delegating Public Information and Outreach Plan responsibilities to one agency and one or two individuals within that agency will eliminate confusion and ensure that a uniform and timely message gets out to the public.

An initial survey to assess the present level of public understanding of Sierra Nevada bighorn sheep and the situation threatening the survival of the species can be used as a tool to create the most effective public information and outreach program. The survey data will be used to establish and prioritize the steps that are needed to inform the public and build support. The program will not only seek to build an appreciation and understanding of the species, but also to make the public aware that the Sierra Nevada bighorn sheep recovery effort is a collaborative effort supported by multiple agencies, organizations, and individuals.

A second survey will be taken 1 year later and compared to the initial survey in order to measure the success of the program and to identify areas where the program needs to be strengthened or otherwise modified.

Certain information projects should be initiated concurrently with the activities to design a Sierra Nevada bighorn sheep Public Information and Outreach Program. The public needs to be made aware as soon as possible about required actions and restrictions while in Sierra Nevada bighorn sheep habitat. The recovery plan will also be released to the public, and wide distribution should be ensured. Funding to support future programs and broadened public information campaigns should be sought.

1. INCREASING AWARENESS

Using Understanding as a Foundation for Support

The public needs to have a foundation upon which to build concern for the situation facing the Sierra Nevada bighorn sheep and an interest in its recovery. The words "endangered species" frequently carry a negative connotation for a significant segment of the public. In the absence of more information, the public may interpret the words to mean that a rather hopeless situation exists that will limit human activities in order to save a remote species of unknown importance. The Public Information and Outreach Plan should provide information about the unique qualities of the Sierra Nevada bighorn sheep, its historic significance to American Indians, its decline with the settlement of the west, its ecology, and its natural history. This information will offer the public an alternative picture to conceptualize when hearing about the Sierra Nevada bighorn sheep, the threats to the survival of the species, and the recovery program underway.

Assigning Program Duties

To be optimally effective, an information campaign needs to be coordinated, accurate, timely, and consistent in the message it delivers. Deliberate steps need to be taken to ensure that a uniform message reaches the public. Numerous agencies have been and will continue to be involved in the recovery efforts. The responsibility for overseeing the Sierra Nevada bighorn sheep Public Information and Outreach Program should be delegated to one agency or organization and a single or small number or persons within the organization. Restricting oversight of outreach efforts will ensure that a consistent message is delivered to both the public and agency personnel who are not directly involved in the recovery effort. It will also ensure that a message is getting out to the public, rather than setting up a situation that could lead to misunderstandings and confusion about which agency is undertaking a given information or outreach activity. Finally, it will provide some assurance that the importance of communicating with the public and building public support will not be forgotten or minimized amid the urgent and intriguing biological questions attendant to the recovery of Sierra Nevada bighorn sheep.

2. DESIGNING A PUBLIC INFORMATION AND OUTREACH PLAN

Objectively Assessing Current Public Perceptions

An objective assessment of current public knowledge and attitudes toward the Sierra Nevada bighorn sheep needs to be made. Identifying the target audience and a baseline use of Sierra Nevada bighorn sheep habitat, key messages, and methods for disseminating information can all be achieved using a survey. The survey should be conducted simultaneously with the effort currently underway for Peninsular bighorn sheep and could be conducted by one of the partner agencies or a university.

Surveying for Target Audiences

The survey will be used to identify target audiences. Recreationists, commercial packers, local residents, range allotment permittees, and domestic sheep and/or goat owners all conduct activities that take place in or near Sierra Nevada bighorn sheep habitat. Other target audiences need to be identified as part of the process of determining how people receive their information (see Methods of Disseminating Information below). The identification of target audiences includes information about how these individuals and businesses use Sierra Nevada bighorn sheep habitat and important surrounding areas.

Defining and Prioritizing Key Messages

The survey will establish public knowledge of the natural history and ecology of Sierra Nevada bighorn sheep. It will also provide insight into the public perception of the threats to Sierra Nevada bighorn sheep and the seriousness of the situation, as well as attitudes about conservation efforts related to Sierra Nevada bighorn sheep. The data, in turn, will provide direction for defining key messages. Specific information should include: an overview of the ecology of Sierra Nevada bighorn sheep, current threats to population viability, and recovery actions; effects of mountain lion predation on recovery of Sierra Nevada bighorn sheep and the larger role of predators in ecosystems; threats to Sierra Nevada bighorn sheep due to disease transmission from domestic sheep and goats; threats to bighorn sheep recovery from domestic dogs in bighorn sheep habitat; threats to bighorn sheep from disturbance by human recreational activities; actions needed to achieve recovery objectives; and opportunities to learn more about Sierra Nevada bighorn sheep. This approach will encourage the full spectrum of business people, recreationists, students, seniors, and local residents to behave in ways that promote the recovery of Sierra Nevada bighorn sheep populations.

Disseminating Information

The survey will provide data that identify the most effective means of conveying information. The survey could query individuals about how they receive their information, and media outreach efforts could then be channeled through the media that are most effective at delivering the message. The survey will also be used to identify other target audiences, including opinion leaders such as local elected officials and national and local media. The means and methods of distributing information include but are not limited to: printed material (press releases, handouts, brochures, newspaper articles, signage); electronic media (radio and television interviews, public service announcements, web sites); person to person delivery (presentations for service organizations, elected officials, as well as school programs and field trips, interpretive programs, campfire talks); and the merchandising of consumer goods with an educational theme (t-shirts, posters, postcards, notepaper). The information should be updated regularly and kept current regarding the status of Sierra Nevada bighorn sheep and recovery actions.

Distributing Information

Identifying the most effective method of message delivery also guides the identification and prioritization of points of distribution. Printed matter could be distributed at a variety of locations, including visitor’s centers, agency offices, chambers of commerce, web sites, email, and conventional mail. Links to a single web site would assure that the information is up-to-date and would eliminate duplicative efforts.

Information should be specifically distributed to members of the general public that are directly affected by recovery actions, such as hikers, ranchers, ranchette owners with domestic sheep or goats, commercial packers, and off-road vehicle users.

3. ASSESSING THE EFFECTIVENESS OF AND MODIFYING THE PLAN

Second Survey

Approximately 1 year after the initial survey is undertaken and a formal Sierra Nevada bighorn sheep Public Information and Outreach campaign is launched, a second survey should be undertaken. Comparisons of the results with the initial survey would provide the basis for modifying the information and outreach efforts.

Recovery Plan Advisory Team Meeting

A meeting of the Recovery Plan Advisory Team (section II.D.8) should be convened to critique the Sierra Nevada bighorn sheep Public Information and Outreach Plan. Broadening the outreach should also be considered. Interviews on national radio and television should be considered to maximize the number of people reached. Videotapes or audio tapes of the programs could be used as tools for further outreach.

4. USING CONCURRENT INFORMATION PROJECTS

Disseminating Information on Multiple Fronts

Certain information projects should be initiated concurrently with the activities to design a Sierra Nevada bighorn sheep Public Information and Outreach Program. The public needs to be made aware as soon as possible about required actions and restrictions while in Sierra Nevada bighorn sheep habitat. The recovery plan will also be released to the public, and broad distribution should be ensured. Existing outreach programs need to be updated to incorporate the most current information.

During implementation of recovery efforts, the public should be fully informed as early as possible regarding actions required or restricted while in Sierra Nevada bighorn sheep habitat. For example, signs or flyers explaining trail closures (in such places as the Zoological Area) or restrictions (such as areas where dogs or pack goats are not allowed) should be located so that users are aware of these restrictions while planning their trip and/or when they are still able to modify their visit.

Affected members of the public should be contacted in other ways, such as through presentations to commercial packers or campers. Information regarding restrictions and requirements while in Sierra Nevada bighorn sheep habitat should also be included in sources of information that attract visitors to the area, such as commercial advertising, chamber of commerce publications, and web sites.

A master calendar that lists all specific recovery actions requiring public involvement should be developed (such as seasonal trail closures). This calendar should indicate the dates that publicity should begin, as well as the outreach message and method.

Distributing the Recovery Plan

The final recovery plan, along with a cover letter, should be widely distributed to affected and interested people, including hikers and other recreationists, ranchers, ranchette owners with domestic sheep or goats, commercial packers, environmental groups, mountain lion and bighorn sheep advocacy groups, and affected local, State and Federal agencies. Distribution of the recovery plan can be facilitated through the Recovery Plan Stakeholders Working Group. At a minimum, recovery plans should be distributed to everyone on our mailing list of people interested in the Endangered Species Act listing of Sierra Nevada bighorn sheep as well as the local news media.

Updating and Coordinating Existing Informational and Outreach Programs

There is an immediate need to update existing programs to provide an accurate view of our current knowledge regarding Sierra Nevada bighorn sheep. Information should strive to highlight not only each agency or organization's contributions to the recovery of Sierra Nevada bighorn sheep, but how these activities complement those of other agencies and organizations.

The bighorn sheep exhibit at the Mono Basin Scenic Area Visitor's Center should be updated and upgraded.

The California Watchable Wildlife Viewing Guide site at Lee Vining/Tioga Lake should include interpretive information on bighorn sheep.

National Park Service, U.S. Forest Service, Bureau of Land Management, and California Department of Fish and Game interpretive talks at visitor centers and campgrounds should include segments on bighorn sheep.

Using Educational Programs for Students

If an educational program targeting local schools is developed, the goals of the program should be for students to: understand the ecology of Sierra Nevada bighorn sheep; develop a respect, appreciation and concern for this species; become aware of the threats this species is currently facing and how recovery actions will reduce these threats; understand the role of Sierra Nevada bighorn sheep within the ecosystem and the value of bighorn sheep recovery to the ecosystem; become aware of specific actions they must take while in Sierra Nevada bighorn sheep habitat and why they are important to recovery; and become aware that the Sierra Nevada bighorn sheep recovery effort is a collaborative effort supported by multiple agencies, organizations, and individuals.

Existing bighorn sheep curricula should be reviewed and modified as needed to be applicable to Sierra Nevada bighorn sheep. Existing activities or curricula include:

"Murder Ewe Wrote" (level: Grades 6-8)
(http://www.sd5.k12.mt.us/glaciereft/wild8-12.htm)

“Bringing bighorn into the classroom” (Cunningham, S. C. 1993. Desert Bighorn Council Trans. 37:33-36).

In addition, a variety of educational materials on bighorn sheep exist that target school-aged children and that could be incorporated into a Sierra Nevada bighorn sheep curriculum. They could be incorporated as is or modified to be made specific to Sierra Nevada bighorn sheep. These materials include:

National Bighorn Sheep Center's Traveling Trunk Exhibit
(http://www.bighorn.org/exhibit.html)

National Bighorn Sheep Center's A Year in the Life of the Whiskey Creek Bighorn Sheep
(http://www.bighorn.org/Exhibit.html)

Foundation for North American Wild Sheep's Wild Sheep Journal

5. IDENTIFYING FUNDING AND PARTNERSHIPS TO SUSTAIN SIERRA NEVADA BIGHORN SHEEP PUBLIC INFORMATION AND OUTREACH PROGRAMS

Finding New Partners and New Funding

An effort should be made to identify new partners in the Sierra Nevada bighorn sheep Public Information and Outreach Plan such as the Paiute Shoshone Tribes, The Independence Civic Club, the Yosemite Association, and others. Funding to support future programs and broaden public outreach campaigns should be sought. In addition to grants, a partnership with the Eastern Sierra Interpretive Association might be explored. As referred to in section 2 above, marketing t-shirts, posters, and other informational consumer goods would not only raise awareness about the Sierra Nevada bighorn sheep program but could also provide a source of income to sustain or augment the program.

Conclusion

An effective Sierra Nevada bighorn sheep Public Information and Outreach Plan will enhance the success of recovery efforts for the Sierra Nevada bighorn sheep. The program needs to celebrate the uniqueness and majesty of the species along with delivering a message about the threats facing the Sierra Nevada bighorn sheep and how recovery efforts are addressing those threats. With opportunities for innovative partnerships, the Sierra Nevada bighorn sheep campaign can be the source of regional pride not only for residents of the eastern Sierra Nevada but also the agencies that are collaborating on the recovery plan.

APPENDIX G SUMMARY OF THREATS AND RECOMMENDED RECOVERY ACTIONS

Listing Factor	Threat	Recovery Criteria	Task Numbers
A	Habitat loss [considered a minor threat]	B4	1.1, 1.2, 6.3
B	Hunting [historical in 19th century; not currently considered a substantial threat]	N/A	N/A
C	Disease (pneumonia and other epizootics contracted from domestic sheep)	A2	2.3.1, 2.3.2, 5.4, 7.1, 7.2, 7.3
C	Disease (lungworm infestation) [considered a minor threat]		5.4
C	Direct mortality from predation (by mountain lions and other predators)	A1, B1	2.1, 5.2, 6.5, 6.6, 6.8, 7.1, 7.2, 7.3
C	Reduced nutritional condition and lamb survival due to use of poor-quality winter range at high elevations, perhaps indirectly resulting from excessive predation	A1, B1	2.1, 2.2.1, 2.2.2, 2.2.3, 5.1, 5.2, 5.3, 6.3, 6.5, 6.6, 6.7, 6.8, 7.1, 7.2, 7.3
D	Limited effectiveness of management by State and Federal agencies	B3	1.2, 2.3.1, 2.3.2, 7.1, 7.2, 7.3, 8
E	Random variation in population characteristics (e.g., sex ratio) due to small population size	A1, B1, B2, B3	2.2.2, 3.1, 3.2.1, 3.2.2, 5.1, 6.6, 6.7
E	Loss of genetic variability due to small population size	A1, B1, B2, B3	2.2.2, 3.1, 3.2.1, 3.2.2, 4, 5.1, 6.1, 6.6, 6.7

E	Increased vulnerability to naturally occurring environmental events (avalanches, prolonged or severe winters) due to small population size	A1, B1, B2, B3	2.2.2, 3.1, 3.2.1, 3.2.2, 5.1, 6.6, 6.7
E	Competition with elk or deer for winter range resources [considered a minor threat]	B4	6.8
E	Disturbance from recreational use [not currently considered a substantial threat; may be reevaluated if warranted in future]†	B4	1.2, 2.4.1, 2.4.2, 6.4, 7.1, 7.2, 7.3
E	Mortality from automobile strikes	B4	7.3
E	Vegetation succession decreasing openness in habitat†	B4	1.2, 2.2.3, 5.3, 6.3
E	Broad environmental factors (climate change, acid rain, mining wastes)[potential threat, needs research]†	B4	1.2, 6.9

† Not identified as a threat in the original listing rule.

Listing Factors:
A: The Present or Threatened Destruction, Modification, or Curtailment Of Its Habitat Range
B: Overutilization for Commercial, Recreational, Scientific, Educational Purposes (not a factor)
C: Disease or Predation
D: The Inadequacy of Existing Regulatory Mechanisms
E: Other Natural or Manmade Factors Affecting Its Continued Existence

Recovery Criteria
Downlisting
A1: A minimum total of 305 females at least 1 year of age, distributed among the Kern (50), Southern (155), Central (50), and Northern (50) Recovery Units
A2: The measures to prevent contact between domestic sheep/goats and bighorn sheep have been implemented and are successful.

Delisting
B1: Downlisting population levels maintained for 7 years without intervention.
B2: Bighorn sheep of both sexes present in 12 herd units, distributed among the Kern (2), Southern (6), Central (2), and Northern (2) Recovery Units (Mount Warren and Mount Gibbs for the Northern Recovery Unit).
B3: A population viability analysis projects that all recovery units are viable.
B4: Regulatory mechanisms and management commitments have been established to protect bighorn sheep and their habitat.

APPENDIX H GENETIC MANAGEMENT OF SIERRA NEVADA BIGHORN SHEEP

Abstract

Genetic diversity develops slowly in populations but can erode rapidly when populations decline to and remain at small sizes (population bottlenecks) for numerous generations. Bighorn sheep in the Sierra Nevada exhibit strong evidence of a recent population bottleneck, which is consistent with their demographic history in the past 150 years. Additionally, the three reintroduced herds show the lowest genetic diversity resulting from founder effects. However, relative to a variety of bighorn sheep herds whose genetic diversity has been sampled in the southwestern states, genetic diversity in the Sierra Nevada simply falls at the lower end of natural variation among populations. Additionally, recent strong population gains in the Sierra Nevada indicate that existing genetic diversity currently is not a limiting factor for the demographic recovery of this taxon. Thus, there is no justification for induced gene migration from populations outside of the Sierra Nevada.

Attempts to increase genetic diversity in existing herds by moving sheep between herd units within the Sierra Nevada mostly will not be effective because of large population sizes and overall similarity in allele frequencies between source and recipient herds. Genetic diversity can be influenced most effectively when populations are small. Consequently, actions to maximize genetic diversity need to occur during reintroductions or when populations go through bottlenecks. Genetic management for bighorn sheep in the Sierra Nevada needs to focus on minimizing the loss of existing genetic diversity. This will be accomplished by actions that enhance herd sizes and natural gene migration among herds in this metapopulation: habitat manipulations in herd units, restoration of bighorn sheep to vacant habitat, and conservation/enhancement of habitat in corridors connecting herd units. The following actions are recommended: (1) use fire and other methods to enhance habitat within herd units to increase carrying capacities where appropriate; (2) translocate sheep to vacant habitat within occupied recovery units as quickly as possible using the genetically most diverse stock available, and attempt to expand habitat use within herd units with translocations; (3) identify key habitat connecting herd units and recovery units and take actions to improve and conserve that habitat to promote gene flow; (4) where new herds are established in isolated locations not likely to receive gene flow from nearby populations, use at least 40 sheep to initiate the new herd, and use the genetically most diverse stock available; (5) monitor genetic diversity in herds containing fewer than 40 sheep at least every 14 years and every 35 years for all herds; and (6) where herds undergo population bottlenecks, assess genetic diversity and take actions to enhance it where appropriate.

Dynamics and Importance of Genetic Diversity

Loss of genetic diversity due to genetic drift in small isolated populations has been a concern of conservation biology (Soulé 1980, Hedrick *et al*. 2001) and has resulted in suggested minimum population goals and population structures to minimize this loss

(Franklin 1980, Templeton and Read 1983, 1998). The loss of genetic diversity in small, isolated populations may be exacerbated by "cryptic genetic bottlenecks" when few individuals contribute to subsequent generations, but census size of the population does not signal immediate concern (Luikart *et al*. 1998, Ramey *et al*. 2000). In these and very small isolated populations, inbreeding (mating between relatives) is a concern.

Reduced genetic diversity results in higher levels of homozygosity in individual organisms. This can lead to increased phenotypic expression of deleterious recessive alleles (Soulé 1980). It also can lead to reduced fitness where heterozygosity translates to more varied physiological functions that effectively buffer individuals better against challenges such as novel pathogens. Extreme inbreeding and loss of genetic diversity can lead to overt fitness effects with demographic consequences that may hasten extinction (Ralls and Ballou 1983). However, because of different time scales involved in demographic and gene pool dynamics, Lande (1988) suggested that demographic problems associated with small populations most likely will preempt genetic problems in importance. Nevertheless, an important consideration in endangered species management is the retention of as much genetic diversity as possible under the expectation of recovery of the population in question. In addition to reducing potential deleterious effects of inbreeding, this diversity is considered important for populations to be able to respond to selection from future environmental changes (Franklin 1980). There is growing evidence that genetic diversity manifested as heterozygosity levels of individuals can be important for disease resistance, including in sheep (Carrington *et al*. 1999; Coltman *et al*. 1999). Indeed, novel disease pathogens are one form of environmental change. However, at what point lowered genetic diversity is detrimental to population fitness varies among organisms as a function of demographic history, and cannot be predicted (Williams *et al*. 2004).

Although not always obvious, endangered species management ultimately concerns conservation of diversity of a unique gene pool. Endangered species typically represent unique gene pools, and their endangered status implies a significant past population decline, which is likely to be associated with loss of genetic diversity (Frankham 1995a, 1996). In extreme situations, improving genetic diversity requires bringing in outside sources of genetic material, and thereby somewhat diluting the uniqueness of the gene pool in question (Varvio *et al*. 1986, Mills and Smouse 1994). Thus, genetic management of endangered species can be a balancing act between preserving uniqueness and preventing extinction (Hedrick 1995).

While immigration can be an important source of increased genetic diversity, the initial source of all genetic diversity is mutations. New mutations necessarily begin at very low frequencies in populations and generally disappear quickly. However, occasionally they persist and become established in gene pools, increasing in frequency through genetic drift and/or selection. Because mutation rates are generally low, genetic diversity builds slowly in populations over hundreds and thousands of generations. While mutations are the source of genetic diversity, and genetic drift causes some new mutations to become established in gene pools, genetic drift also results in the loss of existing genetic variants. In time, equilibrium can be reached between the addition of new genetic variation from mutations and the loss of variation from genetic drift. When that theoretical equilibrium is reached, genetic diversity is a function of population size and mutation rate according to the following equation (Hartl and Clark 1997):

$$H = 4N_e \mu/(1 + 4N_e \mu) \qquad (1)$$

where H is heterozygosity, a measure of genetic diversity (the probability that two alleles randomly drawn from the gene pool are different by state), N_e is the genetically effective population size, and μ is the mutation rate. A fundamental conclusion from this equation is that at large population sizes mutation rate has the dominating effect on H, while at low population sizes, drift dominates and H is lower (Gillespie 1998). Bighorn sheep tend to fall at the low end of population sizes. However, gene flow among populations within metapopulations will counter the effects of genetic drift on individual populations (Schwartz *et al*. 1986), as will selection that favors more heterozygous individuals. While genetic diversity accumulates slowly in populations, it can be lost relatively quickly when populations go through bottlenecks. Genetic diversity, as measured by heterozygosity, declines at a rate of $1/2N_e$ per generation, i.e.

$$H' = (1 - ½\ N_e)H \qquad (2)$$

where H and HN are heterozygosity in successive generations, and N_e is genetically effective population size (Gillespie 1998). The effect of a population bottleneck on genetic diversity depends on the severity of the bottleneck (N_e) and how many generations it lasts. During population bottlenecks, the drift-mutation equilibrium of equation (1) is disrupted and leads to a transient heterozygosity excess relative to what would be expected at equilibrium from the surviving numbers of alleles per locus. That pattern is the basis of a test for recent population bottlenecks (Cornuet and Luikart 1996, Luikart and Cornuet 1998, Luikart *et al*. 1998).

Genetic Diversity in Sierra Nevada Bighorn Sheep Herds

Wehausen and Ramey (2004) measured genetic diversity on a relative scale for all extant bighorn sheep herds in the Sierra Nevada. The recovery plan defines those herds on a demographic basis as eight different herd units. From a genetic standpoint it is more meaningful to combine herd units that are geographically contiguous with no barriers to male-mediated gene flow. Consequently, Wehausen and Ramey (2004) defined five different genetic populations (Mount Langley, Mount Williamson, Mount Baxter, Wheeler Ridge, and Mono Basin) for analyses, with each separated from others by unoccupied habitat.

Wehausen and Ramey (2004) used twelve microsatellite loci to measure genetic diversity. DNA was obtained from fecal samples, blood from captured sheep, and tissue from recently dead sheep using silica-based methods (Wehausen *et al*. 2004) to develop large sample sizes ($\geq$ 35 individuals) for each population, with >200 total different sheep sampled. In addition, data were developed for the Mount Baxter population from around 1980 prior to the recent bottleneck using dried tissue from skulls. Comparative data were developed also for four bighorn sheep populations immediately east of the southern Sierra Nevada (White Mountains, Inyo Mountains, Last Chance Range, and Hunter Mountain) using the same methods. Gutierrez-Espeleta *et al*. (1998, 2000) developed data on a variety of bighorn sheep populations in southwestern United States using nine of the same microsatellite loci. Those data also were used for further comparisons.

Historical data summarized in the recovery plan indicate that about fourteen herds of bighorn sheep disappeared from the Sierra Nevada between 1850 and 1970, leaving only three surviving native herds. That loss alone would be expected to reduce genetic diversity. It is probable, however, that the surviving herds also went through significant population bottlenecks during that time period that would diminish genetic diversity further. During 1979-88, 93 bighorn sheep were captured from the Mount Baxter and Sawmill Canyon herd units and used to restock historic ranges in three areas (Bleich *et al*. 1990a). The founder effects associated with those reintroductions would be expected to produce herds with genetic diversity yet lower than the native source herds. Additionally, all bighorn sheep herds in the Sierra Nevada went through population bottlenecks lasting about two generations beginning in the 1980s (Wehausen 1996), where a generation is about 7 years. The effects of 150 years of demographic perturbations are apparent in strong genetic evidence of past bottlenecks in all herds in the Sierra Nevada (Wehausen and Ramey 2004; Table H-1).

The effects of those bottlenecks on genetic diversity also are apparent, with Sierra Nevada bighorn sheep exhibiting among the lowest genetic diversity levels for bighorn sheep populations sampled (Table H-2). Only a captive herd (Red Rock NM), expected by its history to show low genetic diversity, is as low. Within the Sierra Nevada, the reintroduced herds exhibit the lowest diversity, as expected (Table H-2). Additionally, the relative level of genetic diversity of those reintroduced herds follows expectations based on differences in founder size and severity of recent bottlenecks (Wehausen and Ramey 2004).

Similar to other measures of diversity, genetic diversity is determined by the number of different states (alleles) and the frequency distribution among those states. Expected heterozyogosity similarly reflects those two parameters: the more alleles and the more even the frequency distribution among them, the higher the heterozygosity. Genetic diversity differences among herds in the Sierra Nevada reflect both parameters. For the 12 loci examined by Wehausen and Ramey (2004), 27 different alleles were recorded in the Sierra Nevada. Only the Mount Williamson herd has all of them. The Mount Baxter, Mono Basin, and Wheeler Ridge herds each have 26, while the Mount Langley herd has 24.

Comparative results that fit expectations from demographic histories (e.g., Table H-2) provide some confidence in the measures of genetic diversity used. However, those measures apparently are meaningful only on a comparative basis. Mitton and Pierce (1980), Chakraborty (1981), and DeWoody and DeWoody (2005) have pointed out that samples of small percentages of loci in the genome will not correlate with genetic diversity of the entire genome. For example, microsatellite loci (mostly neutral markers) in vertebrates yield mean heterozygosities an order of magnitude higher than do allozymes (markers under selection; DeWoody and Avise 2000). DeWoody and DeWoody (2005) noted that at least 10% of the genome would have to sampled to develop a meaningful estimate of average heterozygosity.

Given (1) inability to predict the level at which inbreeding is important for different species, and (2) the inability to develop a genetic diversity measure for the overall genome, population performance is the best assessment of whether reduced genetic diversity might limit the ability of bighorn in the Sierra Nevada to recovery to sufficient numbers. For instance, Kodiak brown bears exhibit extremely low genetic diversity as measured by microsatellite loci (Petkau *et al*. 1998), yet the population is demographically healthy with large bodied bears. Large mammals in general appear able to recover as populations after severe bottlenecks that greatly reduce genetic diversity (McCullough *et al*. 1996; Amos 1999; Weber *et al*. 2000, 2004; Williams *et al*. 2004). Sierra Nevada bighorn sheep appear to fit that pattern. Recent strong population gains in most herds beginning in the late 1990s indicate that genetic diversity is not hindering their potential to recover as a population. Within the Sierra Nevada, the Mount Langley herd unit has the lowest measured genetic diversity (Table H-2), yet recently exhibited essentially maximum rate of increase (30% per year) while making minimal use of low elevation winter ranges.

While microsatellite heterozyogosity levels in Sierra Nevada bighorn appear reduced relative to some other bighorn sheep populations, it is not known from what level they have declined. There is considerable variation in genetic diversity among native bighorn sheep populations (Table H-2), much of which is probably natural variation reflecting differences in long-term population dynamics and gene migration. Other than the captive population at Red Rock, New Mexico, the lowest measured genetic diversity outside of the Sierra Nevada is the Old Dad Peak population in the eastern Mojave Desert of California. . Its level of genetic diversity is comparable to the native herds in the Sierra Nevada (Table H-2); it also clearly has not been compromised by lower genetic diversity. It appears that the current level of genetic diversity in the Sierra Nevada may simply fall at the lower end of natural variation in genetic diversity of bighorn sheep populations.

Genetic Management

The conclusion that genetic diversity currently is not a limiting factor indicates that there is no apparent reason to bring in outside genetic variation; thus, this situation is not a balancing act between extinction and uniqueness. Consequently, genetic considerations for Sierra Nevada bighorn sheep need to focus on minimizing future losses of genetic diversity.

Equation (2) describes the rate at which genetic diversity will be lost in the absence of gene flow between populations. In polygynous (breeding system in which a male mates with several females) species like bighorn sheep, N_e is considerably smaller than actual population size (N) and may approach N/10 (Frankham 1995b). Wehausen and Ramey (2004) noted that the maximum numbers of translocated sheep that could have contributed genes to the 3 reintroduced populations in the Sierra Nevada ranged from 21 to 26, thus N_e levels for those founding populations may have been <10. Currently, the most isolated population is in the Mono Basin, with the total population recently varying between 35 and 40. Assuming an N_e of 20 for this population, it will lose about 2.5% of its variation per generation due to genetic drift in the absence of immigration, which translates to about a 7.3% loss in 20 years (3 generations). However, if N_e is 10, that loss increases to 5% per generation and 14.3% in 3 generations.

Unfortunately, effecting a change in genetic diversity via induced migration between populations may be difficult. In the 1970s a rule of thumb was developed from the population genetic model of Wright (1931) that about one migrant per generation (Nm=1, where m is migration rate and N is population size) would substantially counteract the negative effects of genetic drift on heterozygosity in otherwise isolated populations (Spieth 1974, Lewontin 1974). This rule has found its way into conservation biology, including for bighorn sheep (Schwartz *et al*. 1986) and would indicate that few sheep may need to be moved between populations in the Sierra Nevada to counteract losses of genetic diversity. However, Mills and Allendorf (1996) pointed out that this rule of thumb is greatly influenced by a number of unrealistic model assumptions and thereby underestimates the number of migrants needed in many situations. One such assumption is that migrants originate randomly from any of many widely diverging populations that consequently differ considerably in gene frequencies. When the source population instead is closely related, with mostly the same alleles, considerably more migrants may be needed. That is the current situation in the Sierra Nevada, where reintroduced herds are naturally closely related to their source herd in alleles present and their frequencies, as are the two native herds to each other, perhaps due to close proximity.

The one-way migration model (mainland to island migration model) is

$$p_t = p^* + (1-m)^t(p_0 - p^*), \qquad (3)$$

where p_t is allele frequency at generation t, p* is allele frequency of migrants, and p_0 is the initial allele frequency in the island population receiving migrants (Hartl and Clark 1997). Under this model, allele frequency in the island population approaches that of the mainland over time at a rate equal to the migration rate (m). This model assumes that some proportion (m) of the alleles in the island population is replaced by alleles from migrants each generation; the higher that proportion, the more rapid the convergence.

The difficulty of altering allele frequencies in Sierra Nevada populations can be illustrated by applying equation (3) to data from existing populations. The Mount Langley herd is the only reintroduced population that lacks some alleles present in its source herd. One of those is the 106bp allele of microsatellite locus MAF36. That allele is present in the Wheeler Ridge herd at a frequency of 0.171. Table H-3 lists expected frequencies of the 106bp allele in the Mount Langley herd from equation (3) for different levels of induced migrations from the Wheeler Ridge herd under the assumption that the Mount Langley herd size is about 100 (a reasonable carrying capacity suggested by analysis of its population trajectory). For a migration of 2 sheep per generation, the frequency of the 106 bp allele would be only 0.016 at 5 generations, and 0.031 at 10 generations. For 10 sheep moved per generation those frequencies increase to 0.070 and 0.111 respectively.

The latter frequency is still well below the frequency of that allele in the Wheeler Ridge herd, yet took a total induced sheep migration of 100 over approximately 70 years (7 years per generation) to reach that frequency. That total induced migration represents the number of sheep that successfully replaced themselves in the Mount Langley gene pool via reproduction. The actual number of sheep that would have to be moved to achieve that might be considerably higher due to animals that died, did not remain in the population, or failed to reproduce due to dominance status (males). Given the polygynous mating system of bighorn sheep (Geist 1971), a male that achieved dominance status would accelerate the rate of gene migration, especially if dominance was related to level of heterozygosity. However, given the higher variance in reproductive success of male sheep (Coltman *et al*. 2001), females might be the better choice for such an effort to induce gene migration. Females would be especially preferable if they also increased the population carrying capacity through expansion of the habitat used and thereby increased N_e.

The numbers of sheep that would need to be moved to effect a notable change in gene frequencies essentially preclude consideration of this approach for most situations in the Sierra Nevada. For numerous years to come, most sheep available for translocation will be needed to increase total population size by restocking vacant herd units and expanding habitat use of existing herds. The one exception might be small populations, where changes in gene frequencies could be effected with translocation of fewer sheep.

Management Implications and Recommendations

The most important lesson from the previous section is that the initial reintroduction is when genetic diversity best can be maximized. Two variables are important for reintroductions: total founding numbers and genetic diversity of the source herd(s) used. The former may be less important where reintroductions are contiguous to existing herds and will attract male-mediated gene flow from the existing herd (e.g., Taboose Creek). Where herds are re-established in more isolated situations, planning should include early augmentation(s) to maximize genetic diversity. The Mono Basin herds resulted from a total of 38 sheep reintroduced there, but only a maximum of 26 of those might have contributed genes (Wehausen and Ramey 2004). Initial mortality rates associated with reintroductions are typically somewhat elevated, but were more so in the Mono Basin. While that effort has produced the highest level of genetic diversity of the three reintroduced populations, despite the lowest current population size, it is nevertheless lower than its source herd. Based on analysis of success of numerous reintroductions of bighorn sheep in the Rocky Mountain region, Singer *et al*. (2000) suggested a minimum of 41 sheep for reintroductions. A total founding population of 40-50 is a reasonable goal to maximize genetic variability where populations are isolated.

With the relative ineffectiveness of using induced migration to alter genetic diversity, it will be necessary to rely on natural dispersal to link bighorn sheep herds genetically in the Sierra Nevada. What the extent of that gene flow will be is not known. Presumably, such linkage between herds once served to connect them sufficiently to counteract losses of genetic diversity that otherwise occur in isolated populations of limited sizes. Known movements of translocated males that returned to their native herds (Mount Langley to Mount Baxter and Sawmill Canyon, and Wheeler Ridge to Mount Baxter) and of males not translocated (Mount Warren to Mount Gibbs and to Laurel Mountain in the Convict Creek herd unit, Wheeler Ridge to Mount Tom and Mount Izaak Walton in the Convict Creek herd unit) suggest a large potential for gene flow among herds.

Re-establishing herds in habitat gaps is the primary management tool that will conserve genetic diversity by enhancing dispersal. This needs to be coupled with the appropriate conservation of migration corridors that link herd units and recovery units (Bleich *et al* 1990b). Additionally, habitat manipulations that will minimize habitat gaps, and thereby enhance gene flow, also will be beneficial. Early photographs indicate that taller vegetation that obstructs vision increased substantially in the eastern Sierra Nevada during the twentieth century, and thereby reduced the quality of some potential bighorn sheep habitat. Prior to that vegetation succession, habitat favorable to bighorn sheep apparently was considerably more continuous. This would have enhanced genetic diversity through more gene flow, as well as through higher overall population size. In short, as Lande (1988) concluded, enhancing demographic potential for these sheep will enhance retention of genetic diversity.

Trends in genetic diversity should be monitored periodically where appropriate. Loss of genetic diversity from genetic drift is a relatively slow process unless populations undergo extreme and prolonged bottlenecks. It would be appropriate to repeat the genetic diversity measurements of Wehausen and Ramey (2004) for smaller herds (< 40 sheep) every 1-2 generations to develop a measure of the actual rate that genetic diversity is declining. As long as larger populations maintain herd sizes, there is no reason to expect detectable changes in genetic diversity for numerous generations. This is illustrated by the lack of evidence of any loss of genetic diversity in the Mount Baxter population between the period around 1980 and 20 years later, despite a short bottleneck in those two decades (Table H-2). Because conservation of genetic diversity in this entire metapopulation depends on gene flow among populations that is poorly understood, genetic diversity of all populations in the Sierra Nevada should be monitored over a time scale of 5 generations (35 years) to better understand the extent of gene flow. Finally, where major population declines occur, genetic diversity should be reassessed and appropriate actions taken to restore it via induced migration if appropriate. As with founding populations, small populations offer the best opportunity to effect such changes.

Specific recommendations are:

1. Use fire and other methods to enhance habitat within herd units to enhance carrying capacity and connectivity with adjacent herd units.

2. Translocate sheep to vacant habitat within occupied recovery units as quickly as possible using the most genetically diverse stock available. Also, attempt to expand habitat use within herd units with translocations.

3. Identify key habitat connecting herd units and recovery units and take actions to improve and conserve that habitat to promote gene flow.

4. Where new herds are established in isolated locations not likely to receive gene flow from nearby populations, use at least 40 sheep to initiate the new herd, and use the most genetically diverse stock available.

5. Monitor genetic diversity in herds containing fewer than 40 sheep at least every 2 generations (14 years) to determine the actual rate at which genetic diversity is declining and for all herds on a time scale of 5 generations (35 years).

6. Where herds undergo population bottlenecks, assess genetic diversity and take actions to enhance it with translocation where appropriate.

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Table H-1. Bottleneck test results (one-tailed Wilcoxen probabilities that the data came from an unbottlenecked population at drift-mutation equilibrium) based on variable microsatellite loci for the infinite allele model (IAM), stepwise mutation model (SMM), two-phased models (TPM; #1 = 70% SMM, variance=30; #2 = 90% SMM, variance=4). MODE is an assessment of the overall allele frequency distribution pattern. Data from Wehausen and Ramey (2004). Asterisk identifies Sierra Nevada bighorn sheep populations.

POPULATION	LOCI	IAM	SMM	TPM #1	TPM #2	MODE
Last Chance Range	12	0.0104	0.409	0.059	0.402	normal
Hunter Mountain	12	0.0320	0.661	0.190	0.545	shifted
Inyo Mountains	12	0.00012	0.604	0.0012	0.102	normal
White Mountains	12	0.0067	0.339	0.088	0.170	normal
*Mount Baxter (1980)	10	0.00049	0.00049	0.00049	0.00049	shifted
*Mount Baxter (2001)	10	0.00049	0.00049	0.00049	0.00049	shifted
*Mount Williamson	10	0.00049	0.00049	0.00049	0.00049	shifted
*Mount Langley	10	0.00146	0.0420	0.00146	0.0420	shifted
*Wheeler Ridge	10	0.00049	0.00244	0.00098	0.00146	shifted
*Mono Basin	10	0.00098	0.00146	0.00098	0.00098	shifted

Table H-2. Expected heterozygosity (H_e; Nei 1987) calculated from data for 12 microsatellite loci and 9 of those also run by Gutierrez-Espeleta *et al*. (1998, 2000). Sample size (N) is number of sheep. Data from Wehausen and Ramey (2004). Asterisk identifies Sierra Nevada bighorn sheep populations.

POPULATION	N	H_e (12 loci)	H_e (9 loci)
Eagle Mountains, CA	22		0.612
Last Chance Range, CA	21	0.629	0.602
Hunter Mountain, CA	20	0.600	0.586
Inyo Mountains, CA	31	0.606	0.571
Castle Dome, AZ	20		0.564
White Mountains, CA	25	0.485	0.483
San Ysidro Mountains, CA	22		0.466
San Gorgonio, CA	22		0.452
Mount Nutt, AZ	28		0.444
*Mount Baxter, CA (current)	62	0.468	0.434
Old Dad Peak, CA	23		0.427
*Mount Baxter, CA (1980s)	46	0.454	0.412
*Mount Williamson, CA	37	0.446	0.390
*Mono Basin, CA	42	0.430	0.384
*Wheeler Ridge, CA	35	0.420	0.389
*Mount Langley, CA	40	0.404	0.335
Red Rock (captive), NM	25		0.324

Table H-3. Modeled effects of moving sheep from the Wheeler Ridge herd to the Mount Langley herd (N = 100) on the frequency of the MAF36 106bp allele using equation (3). Migrants per generation represent sheep translocated that were successful in replacing themselves genetically through reproduction.

migration	migrants per	106bp allele frequency	
rate (m)	Generation	generation 5	generation 10
0.02	2	0.016	0.031
0.04	4	0.032	0.057
0.06	6	0.046	0.079
0.08	8	0.058	0.097
0.10	10	0.070	0.111

APPENDIX I CAPTIVE BREEDING CONTINGENCY PLAN, EXECUTIVE SUMMARY

Prepared by Holly Ernest, DVM, PhD

The Captive Breeding Contingency Plan (Ernest 2001), contracted by the California Department of Fish and Game's Sierra Nevada Bighorn Sheep Population Recovery Program, includes several tools to facilitate decisions relating to the captive breeding of bighorn sheep. This analysis was also provided to the multi-agency Sierra Nevada Bighorn Sheep Recovery Team to assist recovery planning. The concept of captive breeding in general, along with past Sierra Nevada bighorn sheep captive breeding attempts were reviewed in the Introduction. A model for decision tree analysis was presented in a dichotomous format: a series of questions requiring yes or no answers to lead to specific recommendations for captive breeding.

Next, to assess the impact that captive breeding-associated sheep removal and augmentation would have on extinction probabilities in populations, population modeling was conducted. Preliminary models for the populations at Wheeler Ridge, Mt. Baxter region, and a theoretical captive herd were run under three different scenarios representing a range of mortality and survival values. Since this pilot set of models detailed is very preliminary and simplistic, they should be used only for initial guidance decision-making and construction of future models. Perhaps most importantly, these models demonstrate the conspicuous need for age- and cause-specific mortality, survivorship, and census data. Although the models were run with limited available data, they revealed that the potential for Wheeler population to serve as a reliable source of transplantation stock may be limited and tenuous due to small population size. Using data available at the time of writing from the Sierra Nevada and existing captive bighorn sheep facilities, models indicated that a captive herd would produce a more reliable source of translocation stock than Wheeler Crest alone. Depending on factors specific to the contemporary populations, well planned and conducted captive breeding and translocation of animals may facilitate recovery goals by increasing the rate of population growth and achieving population numbers to reduce likelihood of extinction.

Captive breeding site selection guidelines were presented, along with a detailed assessment of a site (Paoha Island in Mono Lake) that had been under consideration by the California Department of Fish and Game. Preliminary assessments were made for potential sites west of Big Pine between Baker and Fuller Creeks. The Plan includes information (including strengths and weaknesses) on existing captive breeding facilities in southern California and other states collected by site visits and communications with facility managers, veterinarians, and biologists. Most of the problems experienced in the past would be eliminated or at least greatly reduced with proper facility planning and management. Also included are guidelines and recommendations for constructing and maintaining a facility for captive breeding, selection of founder breeding stock, husbandry, and veterinary care, along with a summary of diseases that may affect a captive herd. A preliminary cost estimate worksheet for start-up and first year is provided. Start-up and first year costs range from $600,000-1,000,000 (roughly estimated, since there are many unknowns).

My general conclusion at the time of writing, from literature review, consultation with captive breeding and bighorn sheep experts, and preliminary population modeling was that establishment of a well-managed captive herd would reduce the risk of extinction of Sierra Nevada bighorn sheep, given the year 2000 population estimates. The captive herd should consist of a minimum of 30-40 founder animals, collected over at least fifteen years, from the Wheeler population (and other populations, as available) to preserve a minimum level of genetic diversity (at least 90-95% of original heterozygosity). Well-planned breeding, and pedigree and genetic analyses should be conducted under consultation of a geneticist experienced in ungulate captive breeding. The captive herd would provide a new population (estimated to be 50-100 animals) as a safeguard against wild extinctions. Based on models, within 4-7 years, reliable translocation stock should be available for translocation and reintroduction to Sierra Nevada populations. Simulation models specific to the Sierra Nevada metapopulation should be constructed and further modeling with updated population estimates should be conducted. One potential problem that needs further research is the translocation success of captive raised vs. wild caught sheep (see Thompson *et al*. 2001; Clark *et al*. 1988). Other issues for further research include detailed examinations of the risks of pathogen exposure and infection in a captive herd and transmission to wild sheep.

The final products of a captive breeding herd should be healthy, behaviorally normal individuals capable of surviving and reproducing in the wild. A large enclosure with an abundance of natural forage, escape terrain and protection from predation is required. Disease may be an unavoidable occurrence in a captive herd, especially an intensively managed herd in a small enclosure. Prevention will be the key to minimizing and delaying this event. In the case of a disease event in the captive herd, the eventual release of captive animals into the wild must be managed very conservatively. It is within the realm of possibility that disease could totally prevent the release of any captive animals into the wild. *A long-term commitment (i.e. greater than 10 years) by California Department of Fish and Game, U.S. Fish and Wildlife Service, and the Recovery Team for high-quality facility planning, construction, and management will be critical to the success of a captive breeding program.*

Reduced adult survival and high environmental variation in reproduction and lamb survival are likely to be important factors driving Sierra Nevada populations toward extinction. A captive population can be managed to have optimum reproduction and survival without the high environmental variation that is present in wild populations. Without the potential stability of captive herd, the Wheeler population, as currently modeled, may have a limited potential to supply translocation stock for augmentation of existing Sierra Nevada populations and for reintroduction of new populations, and therefore, population recovery goals may not be achieved in the desired time frame.

Finally, as the Sierra Nevada metapopulation of bighorn sheep and their ecosystems are dynamic, so should be captive breeding contingency planning. This document is meant as a starting point, and as a living document it should be revised and supplemented as new science becomes available.

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APPENDIX J COMMENTS RECEIVED ON THE DRAFT PLAN

In July 2003, we released the Draft Recovery Plan for the Sierra Nevada bighorn sheep (Draft Plan) and initiated a 90-day comment period. This comment period was re-opened in October of 2003 for an additional 60 days. During both comment periods, we received comments from Federal agencies, State and local governments, and members of the public. Marco Festa-Bianchet, Michael Oehler, and Frances Cassirer were asked to provide peer review of the draft plan. We received comments from all three peer reviewers.

This section provides a summary of general information including the total number of letters received from various affiliations. It also provides a summary of the major comments. All letters of comment on the draft plan are kept on file in the Ventura Fish and Wildlife Office at 2493 Portola Road, Suite B, Ventura, California 93003.

We received 47 letters during the two open comment periods. Many of these letters simply voiced support or opposition to the recovery plan with no reason provided; these letters are on file but have not been specifically addressed. Some letters included new information or suggestions for clarity. In these cases, the information has been incorporated into the final version of the recovery plan. Some letters requested an explanation of the scientific basis for various points made in the draft plan. In these cases, the final recovery plan has been revised to include an expansion or clarification of the particular section. Most comments resulted in revisions to the draft recovery plan. Information and comments not incorporated into the final version of the recovery plan were considered, noted, and are on file with the entire package of agency and public comments. Major comments that were not incorporated or that require clarification in addition to their incorporation are addressed in the summary below.

The following is a breakdown of the number of letters received from various affiliations:

Federal agencies	3
State agencies	2
Local governments	1
Environmental/conservation organizations	7
Academia/professional	5
Business/industry	13
Individual citizens	15
Recreation groups	1

Summary of comments and our responses

Comment: One commenter stated that the Forest Service is designated as the lead agency responsible for "eliminating the risk of contact between bighorn sheep and domestic sheep or goats." However, the Forest Service has no authority to influence contact between bighorn sheep and domestic sheep on lands other than those managed by the National Forest System, and this should be clearly explained in the plan.

Response: Although we agree with the commenter that the authority of the Forest Service is limited, recovery plans do not obligate cooperating or other parties to undertake specific tasks, but delineate reasonable actions required to recover and/or protect listed species. The Forest Service was included as the lead agency for this task because the vast majority of areas where risk of contact between domestic and Sierra Nevada bighorn sheep remains is on lands administered by the Forest Service. Most of the tasks listed in the plan will require cooperation among various agencies, but at no time would the plan recommend or expect any agency to carry out an action outside of its jurisdiction.

Comment: One commenter recommended that the word “should” in the narrative outline of recovery actions (section D) be replaced with “shall" for all necessary protective measures.

Response: Changing the wording of the narrative for recovery actions as recommended by the commenter would imply that the tasks are mandatory. Recovery plans are guidance documents and are not regulatory documents. No agency or other entity is required by the ESA to implement the recovery strategy or specific recommended actions in a recovery plan.

Comment: One commenter believed that the plan is based on the incorrect assumption that, since the bulk of Sierra Nevada bighorn sheep habitat is on Federal land, it is protected.

Response: All proposed Federal actions that may affect Sierra Nevada bighorn sheep must be analyzed, and consultation must be initiated with the U.S. Fish and Wildlife Service. This ensures that Federal projects, projects carried out on Federal land, or projects with some type of Federal nexus will not jeopardize bighorn sheep.

Comment: One commenter recommended that the plan should include measures to prevent mortality of bighorn sheep by vehicles.

Response: Data indicate that the number of bighorn sheep being struck by vehicles is so small that it is an insignificant factor affecting population levels. Accordingly, this has not been identified as a threat to recovery. As population numbers increase, we anticipate there may be a small increase in the number of collisions, but the rate of collisions and level of population impacts is not expected to change.

Comment: One commenter faulted the plan for not including the economic impacts to livestock operators.

Response: Recovery plans are guidance documents only and do not create new regulations. No agency or other entity is required by the ESA to implement the recovery strategy or specific recommended actions in a recovery plan, and therefore recovery plans are categorically excluded from NEPA and not required to incorporate economic impact analyses.

Comment: One commenter recommended that existing land and forest management plans be reviewed to identify allowed uses that would have an adverse effect on bighorn sheep and that the plans be amended as appropriate.

Response: Under section 7(a)(2) of the Endangered Species Act, Federal agencies are required to consult with the Service on any action that may affect a listed species. Because the law requires land management agencies to consult on any actions that they determine to have an effect on Sierra Nevada bighorn sheep, we felt that identifying the review of authorized uses, as a recovery action would be redundant. The Service has not reviewed the broad effects of the land and forest management plans for the Humbodlt-Toiyabe National Forest, Inyo National Forest, and BLM-Bishop Field Office. However, the land management agencies review all site-specific actions taken under the authorization of these plans, and they consult with the Service on any actions that may affect the Sierra Nevada bighorn sheep.

Comment: Some commenters were concerned that the study of human/recreational impacts, including impacts from dogs, is only a low priority.

Response: Actions to ameliorate the effects of human/recreational use were not given high priority in this plan because we do not currently consider recreational use, including the activities of dogs, a significant threat to Sierra Nevada bighorn. If information indicating recreational use is having an effect on recovery becomes available, appropriate actions will be recommended.

Comment: Some commenters disagreed with the assumption that the Sierra Nevada bighorn sheep were near their historic carrying capacity in the past 25 years and believed that the numbers have actually been declining since the mid-1880s.

Response: The overall historic carrying capacity of the Sierra Nevada is not known. The plan refers to the specific areas (Mt. Baxter and Sawmill Canyon herds) that were likely near their historic carrying capacity in the late 1970s. These two areas are used as a point of reference for comparisons with nearby herd units.

Comment: One commenter believed that the generation time for bighorn sheep is 3 years rather than 6 years as given in the plan.

Response: A generation time is how long it takes the population to replace itself. Given the age at which female bighorn sheep reach sexual maturity (2-3 years) in the Sierra Nevada, a 3-year generation time would not be sufficient for population replacement via natural reproduction. Ramey (1995) also used 7 years for the generation time when performing genetic analysis.

Comment: One commenter questioned the validity of the "natural breaks" which are used to separate the four recovery units. The commenter concluded that the boundaries of the Southern Recovery Unit and the Kern Recovery Unit seemed appropriate, but the breaks separating the Southern, Central, and Northern Recovery Units appear more arbitrary in light of several recent sightings.

Response: The breaks in the recovery units are based on current knowledge of Sierra Nevada bighorn sheep distribution and movement. Their distribution consists of a series of subpopulations, represented by herd units, which occupy patches of suitable habitat within a matrix of unsuitable habitat. These subpopulations interact intermittently through the movement of males between them. The recovery units are comprised of those herd units that are more likely to be connected by males moving between them to a greater degree than those in other recovery units. Males may also move between recovery units, but movement between recovery units is much less common that movement within them.

Comment: One commenter believed that, if the Sierra Nevada bighorn sheep is truly a separate population from the bighorn sheep to the east, then the plan should include techniques to ensure that any sheep traveling from the east are intercepted to prevent hybridization.

Response: Although there have been occasional observations of bighorn rams on the floor of Owens Valley, we have no evidence that Sierra Nevada bighorn sheep are mating with other bighorn sheep subspecies from ranges to the east. The morphological uniqueness of the Sierra Nevada bighorn sheep indicates that gene flow from mountain ranges to the east is limited at best.

Comment: One commenter believed there is no justification for eliminating sheep grazing on all areas west of Highway 395 for the recovery of Sierra Nevada bighorn sheep.

Response: Because the transmission of disease from domestic sheep to bighorn sheep is the greatest threat to recovery of Sierra Nevada bighorn sheep, preventing contact between domestic sheep and Sierra Nevada bighorn is a critical strategy highlighted in this plan. However, we are not recommending elimination of domestic sheep grazing in <u>all</u> areas west of Highway 395. We are recommending closing certain allotments to sheep grazing where the risk of contact between domestic sheep and bighorn sheep is high (see also section II.E).

Comment: One commenter recommended that the California Department of Fish and Game should capture any bighorn sheep that wander off or vaccinate them for disease.

Response: There is currently no vaccine available for the *Pastuerella* strains that are of concern. We have incorporated a strategy for preventing contact between bighorn sheep and domestic sheep (Section E) that addresses the concept of removing bighorn sheep if they move into the Twin Lakes Herd Units. We have also indicated the need to remove

Sierra Nevada bighorn sheep from areas east of Highway 395. We have addressed these areas specifically because current conditions with regard to bighorn population size and distance from potential disease sources make this concept logistically feasible. We have not included other areas for implementation of this measure because they are too close to potential sources of disease transmission, which makes them inappropriate due to the logistical difficulties of monitoring and managing bighorn sheep movements. However, given the logistical difficulty of monitoring and capturing wild sheep and likelihood of expanding populations in the future we cannot provide an absolute guarantee that all bighorn sheep that wander away from essential herd units will be captured and removed in perpetuity.

Comment: One commenter recommended that the California Department of Fish and Game control bighorn sheep to the south of Lundy Canyon, thereby preventing conflicts with domestic sheep and protecting bighorn sheep from the hard winters that occur in northern areas.

Response: We disagree that bighorn sheep would benefit from being protected from hard winters in northern areas. The south-facing slopes in Lundy Canyon provide high quality winter and spring habitat, which is particularly important during winters with heavy snowfall. In addition, there are some areas to the north of Lundy Canyon that are still within the Mount Warren Essential Herd Unit. However, the concept of removing bighorn sheep from areas in the Twin Lakes region has been incorporated into Section E of the recovery plan. Because the Twin Lakes Herd Unit is not needed for recovery, the occupation of this area by bighorn sheep would pose a risk due to the presence of active domestic sheep grazing allotments to the north. Consequently, we have recommended that bighorn sheep be monitored and managed intensively in the Northern Recovery Unit to allow removal of any bighorn sheep that wander that far north. However, based on the data that we currently have on bighorn sheep locations and movements it is not logistically feasible to prevent bighorn sheep from moving into areas that are between Lundy Canyon and Twin Lakes.

Comment: One commenter pointed out that the recovery plan identifies the Forest Service and National Park Service as the lead agencies for implementing a habitat improvement program, yet fails to outline any specifics.

Response: In the case of the Forest Service, National Park Service, and other land management agencies, the recovery plan prescribes general management concepts only; development of specific applications to address the general concepts in the plan are under the purview of the responsible agencies.

Comment: One commenter stated that the use of the northern part of the Mono Basin area by bighorn sheep should be reevaluated, especially in light of recent sightings and high recreational use of the area.

Response: A spatial model of bighorn sheep habitat suitability in the Sierra Nevada is in preparation, and recreational use relative to bighorn sheep will be monitored.

Comment: One commenter stated that the Sierra Nevada bighorn sheep are the same species as the desert bighorn and should never have been listed.

Response: It is correct that Sierra Nevada bighorn sheep are the same species as desert bighorn; all bighorn sheep are the same species. However, Sierra Nevada bighorn sheep are a separate subspecies that is supported by objective analyses of morphometric and genetic data, as published in the scientific literature (Wehausen and Ramey 2000). The ESA states that a species is endangered when it is in danger of extinction throughout all or a significant portion of its range and that the term species includes any subspecies of wildlife and any distinct population segment of any species of vertebrate wildlife that interbreeds when mature. Sierra Nevada bighorn sheep were listed as a distinct vertebrate population segment. All of this information is reviewed in the recovery plan.

Comment: One commenter stated that critical habitat should be designated for the Sierra Nevada bighorn sheep, including travel corridors. The critical habitat designation would then provide the rationale for developing a recovery plan prior to completion of other portions of section 4 of ESA.

Response: The designation of critical habitat and the preparation of recovery plans are two separate processes, and critical habitat is not necessarily synonymous with recovery plans or recovery units. However, we are currently in the process of preparing a proposed rule to designate critical habitat for the sheep; we expect to publish this rule in 2007.

Comment: One commenter stated that the appropriate distances between bighorn sheep and grazing allotments should be determined by section 7 consultations.

Response: The distances given in the recovery plan are guidelines only. The entity that issues grazing permits, such as the Forest Service, determines which allotments will be permitted. If an agency determines that a permit it intends to issue is likely to affect a listed species, they are subsequently required to consult with the Fish and Wildlife Service pursuant to section 7 of the ESA to determine whether that action will jeopardize the continued existence of the listed species. The distance allowed for a specific grazing permit would be determined through the section 7 consultation process for that permit. It should be noted, however, that the agency issuing the permit also has the authority to use a greater distance if it believes it is appropriate.

Comment: One commenter stated that the Fish and Wildlife Service should not tell the Forest Service how and where to graze cattle or sheep.

Response: The U.S. Fish and Wildlife Service does not determine where the Forest Service allows cattle or sheep grazing. Congress has outlined procedures for Federal interagency cooperation to conserve listed species in section 7 of the Endangered Species Act. Section 7 makes it clear that all Federal agencies should participate in the conservation and recovery of listed threatened and endangered species and that any action they authorize, fund, or carry out is not "likely to jeopardize the continued existence of a listed species…" The issuance of a grazing permit is a Federal action that must be analyzed for any effects to endangered or threatened species. Through that consultation process, the Fish and Wildlife Service has an obligation to advise the Forest Service on measures it should take to minimize take of a listed species, but the Fish and Wildlife Service cannot suggest substantial changes to their proposed action unless that action will jeopardize the continued existence of the species.

Comment: One commenter recommended that the recovery plan include a review of the listing of the Sierra Nevada bighorn sheep.

Response: Under the Endangered Species Act (Act) (16 U.S.C. 1531 et seq.), we maintain a List of Endangered and Threatened Wildlife and Plants at 50 CFR 17.11 (for animals) and 17.12 (for plants). Section 4(c)(2)(A) of the Act requires that we conduct a review of listed species at least once every 5 years. Then, based on such reviews under section 4(c)(2)(B), we determine whether or not any species should be removed from the List (delisted), or reclassified from endangered to threatened or from threatened to endangered. Reviews consider the status of threats to the species, including: 1) the present or threatened destruction, modification, or curtailment of its habitat or range; 2) overutilization for commercial, recreational, scientific or educational purposes; 3) disease or predation; 4) the inadequacy of existing regulatory mechanisms; and 5) other natural or manmade factors affecting its continued existence. These reviews are not part of the recovery planning process. A recovery plan is a guidance document that includes specific actions that, if implemented, should lead to the recovery of the listed species (i.e., bring the species to the point where the protections of the ESA are no longer necessary).

Comment: One commenter believed that the plan requires a full economic and environmental analysis before it can be considered for approval.

Response: The development and approval of recovery plans are categorically excluded from National Environmental Policy Act (NEPA) requirements and are not required to incorporate economic impact analyses because recovery plans are guidance documents only. No agency or other entity is required by the ESA to implement the recovery strategy or specific recommended actions in a recovery plan. Management tasks identified in the plans are subject to NEPA, and therefore a full economic and environmental analysis, if they are proposed for implementation. In these cases, public involvement would be sought through the development of Environmental Assessments or Environmental Impact Statements.

Comment: One commenter stated that Forest Service permits for domestic sheep grazing within the Bloody Creek and Dunderberg allotments are eligible for exemptions in accordance with ESA section 7 and that these exemptions should be granted immediately. The commenter requested that these exemptions be included in the recovery plan.

Response: Recovery plans are guidance documents only and are not appropriate for regulatory issues such as exemptions. Exemption refers to exemption from take prohibitions defined in section 9 of the Endangered Species Act. Take is defined as "to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct." After formal consultation with the Fish and Wildlife Service, an action agency may be allowed exemption from take through the incidental take statement of a biological opinion. Incidental take statements exempt action agencies and their permittees from the ESA's section 9 prohibitions if they comply with the reasonable and prudent measures and the terms and conditions of the incidental take statements. To be considered in an incidental take statement, any taking associated with an agency's action must meet the following three criteria. The taking must not be likely to jeopardize the continued existence of listed species or destroy or adversely modify designated critical habitat, result from an otherwise lawful activity, and be incidental to the purpose of the action.

Comment: One commenter faulted the plan because it ignores the findings of veterinarians who have studied the transmission of disease between domestic and wild animals and have documented the presence of disease in bighorn sheep populations that have had no contact with domestic sheep.

Response: We acknowledge in the plan the fact that bighorn sheep have died from disease where there was not contact with domestic sheep (Section I.D.3). However, there is compelling scientific evidence to support the conclusion that exposure to domestic sheep greatly increases the risk of fatal pneumonia in bighorn sheep.

Comment: One commenter criticized the plan for failing to cite scientific evidence that domestic sheep caused the decline in bighorn sheep populations.

Response: A number of factors may have contributed to the decline of bighorn sheep in the western United States. Refer to Section I.C.1 and Section I.D.3 for a full discussion of disease die-offs in bighorn sheep.

Comment: One commenter recommended that the plan include climatological data concurrent with existing population information.

Response: Long-term temperature and precipitation data series from weather stations in the region are readily available from a number of sources, including the National Weather Service. Similarly, snowpack data are available from the California Snow Survey. Where we believe that weather and/or climate are factors in population regulation, these are noted.

Comment: One commenter suggested that more deer be provided for mountain lions.

Response: Deer population numbers in the eastern Sierra Nevada are determined by precipitation and forage. Mountain lion populations are determined by deer populations. A large increase in the number of deer would likely cause an increase in the mountain lion population, an increase in competition between deer and sheep for forage resources, and an increase in the use of sheep winter range by deer with a correlated increase in mountain lion use of those areas. Therefore, it is doubtful that an increase in the deer population would benefit bighorn sheep.

Comment: One commenter stated that aversive conditioning of mountain lions is untested and that it is irresponsible to use on untested methodology with an endangered species.

Response: Aversive conditioning has been tested in a limited manner with some success. Allowing mountain lions that do not show a predilection for killing bighorn sheep to maintain a home range may be an effective tool for preventing immigration by mountain lions that do kill sheep. The use of aversive conditioning to limit use of bighorn sheep winter ranges by known mountain lions could be a useful tool for enhancing bighorn sheep recovery efforts.

Comment: One commenter stated that the removal for translocation of 103 individuals from 1979-1987 should not be dismissed as a factor in the use of lower quality habitats by bighorn in some areas and the subsequent decline in abundance observed in those areas. The removal of bighorn for translocation may have resulted in a loss of "knowledge," which in turn may have been one reason for the problems mentioned above.

Response: More than 30 years ago, Valerius Geist proposed the concept that bighorn sheep can lose knowledge of important habitats when populations are extirpated. That concept emerged from research in Canada where bighorn sheep must cross through considerable amounts of forested habitat that separate important seasonal ranges, and for various reasons probably does not apply to the Sierra Nevada. First, because of the rain shadow and precipitous nature of the eastern slope of the Sierra Nevada, forested barriers between summer and winter ranges are not an issue for the herd units in question; the sheep can simply follow steep, open ridges that connect the two. Second, the harvesting of sheep for translocations in no way approached extirpations. To the contrary, those removals were intentionally very conservative. Thus, more than 75% of the population remained after each translocation, and the knowledge of different habitats available for use was embodied in those individuals, all of whom had used those habitats over the previous year. For instance, following the removal of 32 sheep from the Sand Mountain winter range in 1986 for translocations, 109 bighorn were observed there 3 weeks later.

Comment: One commenter stated that translocations are not always successful and wanted to know what criteria would be used for both conducting translocations and determining whether or not they are successful.

Response: Bighorn sheep are well documented to be relatively slow colonizers because of strong philopatry (tendency to remain in home locality), especially among females. Therefore, reintroduction has been the primary tool, and will continue to be the primary tool, used to re-establish bighorn sheep in areas where they have been extirpated. Each translocation will be evaluated, but criteria have not yet been established. A variety of factors, including long-term persistence and genetic diversity, will likely be evaluated for all future translocations; these factors will be included in future translocation plans (see Appendix C).

Comment: One commenter recommended that a protocol be developed for sampling live and dead bighorn sheep.

Response: Fecal DNA methodologies have been established. Sampling of live bighorn is standardized on field data sheets filled out during collection of samples from live animals. Examinations of dead bighorn sheep are conducted by the San Bernardino and Davis branches of the California Animal Health and Food Safety Lab System according to their standard necropsy protocols for ruminants and with consultation from California Department of Fish and Game veterinarians. Formalized sample collection and disease testing protocols for live and dead bighorn sheep are currently under development.

Comment: One commenter noted that the management strategy for domestic sheep has always focused on domestic sheep straying into bighorn sheep areas. The commenter recommended that there should also be a strategy for bighorn sheep moving onto domestic sheep allotments.

Response: This document incorporates a strategy for preventing contact between domestic sheep and bighorn sheep (Section E) that identifies actions that should be taken to prevent bighorn sheep from moving onto some domestic sheep grazing allotments in areas where such a program is logistically feasible and meets our recovery objectives.

Comment: One commenter suggested that mountain lion predation should be the focus of the recovery plan.

Response: Although mountain lion predation is one factor in bighorn recovery, we disagree that it should be the focus of the plan. Predator control is just one part of a strategy for increasing survival of bighorn sheep and meeting recovery objectives, which are outlined in the plan.

Comment: One commenter recommended that the recovery plan should also address other predators, including coyotes and golden eagles.

Response: We are not aware of any data that suggest predators other than mountain lions have had a substantial impact on bighorn sheep in the Sierra Nevada. Predation in general is discussed in Section I.D.3 of the recovery plan.

Comment: One commenter was concerned that the recovery plan will negatively affect domestic sheep grazing.

Response: Recovery plans do not obligate cooperating or other parties to undertake specific tasks, but delineate reasonable actions required to recover and/or protect listed species. We acknowledge that some grazing operations may be modified in response to our recommendations. However, if an agency were to undertake a task outlined in the plan that would affect domestic sheep grazing, the agency would continue to work with all affected parties to accommodate the needs of the permit holders while working to achieve the goals outlined in the recovery plan.

Comment: One commenter was concerned that the plan indicates the potential need for future restrictions on recreational users, but fails to specify what those actions might be.

Response: The recovery plan states that any actions limiting recreational use will take place only if research results in a recommendation to limit human use in some areas. At present, there appear to be few locations where recreational disturbance has the potential to significantly affect sheep. Because the research needed to address this issue has not been completed, it would be premature to speculate about these actions.

Comment: One commenter believed the potential effects of off-trail recreation and mountain climbing on new herds that have become established and proposed future herd ranges have not been adequately addressed in the plan.

Response: Although we recognize the potential of recreation to impact bighorn sheep, these impacts seem to be minor. However, the recovery plan calls for continued monitoring of the compatibility between recreational use of bighorn sheep habitat and bighorn sheep recovery (see Task 6.4).

Comment: One commenter recommended that a PVA should be done prior to the issuance of the final plan.

Response: The California Department of Fish and Game's Sierra Nevada Bighorn Sheep Recovery Program is initiating an in-depth, spatially explicit population viability analysis. For such an analysis to be meaningful, it is essential that we incorporate detailed and accurate values for model parameters. Data for all recovery units are being collected and compiled to ensure that modeling is representative across the range of the species. Long-term viability will be examined using demographic, habitat, and genetic data. To understand population trajectories, our detailed analysis will include factors as varied, but interrelated, as vital rates, forage conditions, climate, habitat suitability, and inbreeding.

Comment: One commenter stated that the plan does not provide protection for critical migration corridors between proposed recovery units despite the fact that they are threatened by development.

Response: Recovery plans are guidance documents only. Recovery plans do not create reserves or restrict development. However, recovery plans are dynamic documents, and as more information on migration corridors becomes available, this information will be incorporated into the plan. This information may result in additional action items as necessary.

Comment: One commenter recommended that the plan should include objective, measurable criteria for determining whether reasons for avoidance of winter range have been addressed.

Response: We use the best available science in preparing recovery plans. If new scientific information on winter range avoidance becomes available, we will incorporate that information into the next version of the plan. New information may result in the addition of new action items to the plan or changes in existing ones.

Comment: One commenter believed that the Fish and Wildlife Service should recommend permanent mineral withdrawal on all lands in bighorn sheep habitat.

Response: We are not aware of any information that indicates mining activities are incompatible with the recovery of the Sierra Nevada bighorn sheep. Those mines on Federal lands or that have a Federal nexus are subject to section 7 of the ESA.

Comment: One commenter suggested periodic sampling of the closest herds of domestic sheep and goats to look at changes in time of both wild and domestic populations. These data could be important for determining the source of pathogens in the event of a disease outbreak in bighorn sheep.

Response: When captured, Sierra Nevada bighorn sheep receive a physical examination and a bank of diagnostic tests. Blood is collected for a complete blood count and chemistry panel, trace mineral analysis, and serology for potential viral and bacterial sheep pathogens. Pharyngeal swabs are taken for *Pasteurella* isolation and identification. No similar effort is being made at this time for domestic sheep and goats. Currently, there are no serology or microbiology techniques that could definitively tie a die-off to a specific band of domestic sheep.

Comment: One commenter encouraged a review of what has been done in other areas subsequent to a pneumonia outbreak.

Response: Various responses to ongoing pneumonia outbreaks have proven ineffective. During the Hell's Canyon pneumonia epizootic in 1996, 72 live bighorn sheep were removed from the outbreak area and placed into captivity for treatment. All 72 sheep developed pneumonia and died. Various strategies for antibiotic treatment of sick bighorn sheep have been developed. Single treatments of individual, free-ranging bighorn sheep with antibiotics may suppress bacterial growth temporarily, but infection will usually run its course despite treatment. Treatment may also prolong the shedding period, thus exposing more bighorn sheep. There are currently no vaccines that will prevent infection or disease from *Pasteurella* pneumonias in bighorn sheep. These unsuccessful efforts to stop ongoing outbreaks dictate the cautious approach to proximity of domestic and bighorn sheep, and lead us to conclude that prevention is more appropriate than reaction.

Comment: One commenter was concerned with the emphasis of the plan being research. With fewer than 250 individuals, this population does not lend itself to being a test bed for theoretical management.

Response: The focus of the recovery program is to conserve the Sierra Nevada bighorn sheep. We do not agree with the commenter that the focus of this recovery plan is research, but we acknowledge that research is one component of the plan. The California Department of Fish and Game's Sierra Nevada Bighorn Sheep Recovery Program collects data on population status and trends and the underlying factors that influence them in an effort to ensure the long-term persistence of Sierra Nevada bighorn sheep. We believe that gathering information to improve our understanding of Sierra Nevada bighorn sheep and the factors that limit them, will contribute to their conservation and recovery.

Literature Cited

Ramey, R. R. 1995. Mitochondrial DNA variation, population structure and evolution of mountain sheep in the southwestern United States and Mexico. Molecular Ecology 4:429-439.

U.S. Fish and Wildlife Service and National Oceanic and Atmospheric Administration. 1996. Policy regarding the recognition of distinct vertebrate population segments under the Endangered Species Act. Federal Register 61:4722-4725. February 7, 1996.