AN ANALYSIS OF TRANSLOCATION OPTIONS FOR THE RECOVERY OF SIERRA NEVADA BIGHORN SHEEP

Prepared by
John D. Wehausen, Ph.D.
White Mountain Research Station
June 1998

I. Introduction

Bighorn sheep inhabiting the central and southern Sierra Nevada of California have recently been found to be a unique variant of bighorn sheep (Ovis canadensis) deserving of their own subspecific status. They are listed as threatened under the California Endangered Species Act. Recent population declines attributed to a high mountain lion density that developed in the 1980's resulted in a 1996 low of only 120-125 bighorn remaining in the Sierra Nevada, distributed among five populations (Wehausen and Chang 1997). This population decline resulted substantially from a change in winter habitat selection by all five populations in which they avoided use of low elevation ranges where most mountain lion predation occurred. In 1997, the Sierra Nevada Bighorn Sheep Interagency Advisory Group produced a Conservation Strategy that was the recommendation of that group of biologists for the recovery of bighorn sheep in the Sierra Nevada. That document made eight recommendations. One of these was the development by 1998 of a second document concerned with translocation of sheep either to new locations or to augment existing populations. It also called for a new analysis of bighorn sheep habitat as part of that translocation plan. This is that plan. Like the Conservation Strategy, this analysis does not include the very southern Sierra Nevada south of Olancha Peak.

II. Background and Problem

A reintroduction program during 1979-88 used one of two surviving native populations to create three additional populations of bighorn sheep in the Sierra Nevada. These new populations showed initial success, although removal of one mountain lion in each of three consecutive winters was necessary for the success of the last population that was initiated in 1986 in Lee Vining Canyon. The first two reintroduced populations are known to have reached sizes of around 40 sheep or more, while the Lee Vining Canyon population exceeded 80. Major declines were documented for a couple of the populations over the winter of 1995. That winter produced wet thick snow that did not blow off high slopes that sheep were depending on apparently to avoid the threat of lion predation at lower elevations. Many avalanches also occurred in that winter and 12 sheep from the Wheeler Ridge population were documented to die in a single avalanche. Not all population declines occurred in 1995. The Mount Baxter population had been declining since it began occupying high elevation sites throughout winter in 1987. The timing of decline of the Mount Langley and Mount Williamson populations is not known, but the Mount Langley population was known to contain at least 42 sheep in 1990.

From south to north, these populations and 1996 sizes are: (1) Mount Langley (4 ewes, 2 lambs, 11 rams; reintroduced); (2) Mount Williamson (2-3 ewes, 3 rams; native); (3) Mount Baxter (17 ewes, 4 lambs ≥ 6 rams; native); (4) Wheeler Ridge (9 ewes, 5 lambs, 7 rams; reintroduced); (5) Lee Vining (and Bloody) Canyon (16 ewes, 14 lambs, 18 rams; reintroduced). Of these, the Mount Baxter population was the source of all past reintroduction stock and contained as many as 220 sheep in recent decades.

There is evidence that the mountain lion population has declined substantially in the past half decade, especially since 1995. In response, there has been a discernible increase in the use of former low elevation winter ranges by some members of the Mount Langley and Mount Baxter populations beginning in 1997.

III. Overview of this Analysis

This document has four basic components. First is an analysis of the problem in terms of goals, issues, constraints, and strategies for use of available translocation stock. Second is a discussion of habitat and potential locations to which these sheep might be moved. Research needs constitute the third section, and some general overall recommendations conclude this plan.

IV. Goals, Constraints, and Strategies

The ultimate goal of translocation of bighorn sheep in the Sierra Nevada is long term conservation of this unique gene pool within its native habitat. Translocation is one of several tools outlined in the Conservation Strategy toward that end. Long term conservation of Sierra Nevada bighorn will be effected through the development of four metapopulations of sheep that have long term viability. Long term viability involves both demographic and genetic considerations. Demographically, this simply involves the numbers and sizes of demes within each metapopulation, and the initial short term goal is a minimum of 100 sheep in each metapopulation. However, from a long term viability perspective at least a couple of these metapopulations should exceed 200 sheep. While demographic health may usually imply genetic health, this may not be so on a long term basis. Thus, in addition to developing suitable metapopulations in terms of overall sizes, an attempt should be made to maximize the genetic diversity within each to best ensure viability. This will best serve the ultimate goal of gene pool conservation. The four metapopulations proposed within the Sierra Nevada are as follows from north to south: (1) from Mount Wood north as far as is feasible (possibly Robinson/Victoria Peaks above Twin Lakes); (2) from the west side of the Bishop Creek Drainage to Mount Laurel (just south of Mammoth Lakes; (3) Olancha Peak to Big Pine Creek and Coyote Ridge; and (4) west of the Kern River with winter range concentration areas in Laurel Creek, Rattlesnake Creek, and Big Arroyo. Except for the last one, each of these metapopulations currently contains at least one population that can be built on by establishing neighboring populations. While it is possible that rams might occasionally move between these metapopulations, they will be sufficiently separated, at least for many years, that it is highly unlikely that a disease epizootic that might develop in one of them would spread to others.

Major constraints on reaching metapopulation recovery goals are: (1) availability of translocation stock; (2) domestic sheep allotments which threaten viability of demes via disease transmission potential that can lead to pneumonia epizootics; and (3) predators, notably mountain lions. Because the future success of a program to translocate bighorn sheep is highly dependent on these factors, it has been necessary to consider them as part of this analysis.

A. Management of Populations for Translocation Stock

The Lee Vining Canyon population offers the best prospect for a source of females for translocation in the near future. Prior to the severe winter of 1995, it showed large population increases while wintering at high elevations in contrast to other populations. However, on a longer term basis other sources should be considered. First is the possibility of reestablishing the Sand Mountain herd as a large productive source. Second is the possibility of captively breeding these bighorn. Third might be a highly successful reintroduction.

In the 1970's, the threat facing the future of Sierra Nevada bighorn was that only a single population existed that could produce reintroduction stock. This was a primary concern of the Sierra Nevada Bighorn Sheep Recovery and Conservation Plan. An unanticipated ecosystem change in the 1980's in the form of a substantial increase in mountain lion predation eliminated the one source of translocation stock before any other sources existed. It is a matter of luck that (1) a reintroduction program for these sheep came into being when it did, and (2) the third and last location to which these sheep were reintroduced became the one reasonably successful population under the changed wintering patterns that apparently resulted from high lion densities. Had those reintroductions not occurred, Sierra Nevada bighorn would undoubtedly now be desperately close to extinction, probably totaling about 40 animals. What cannot be predicted now is what unforeseen catastrophe might befall the Lee Vining Canyon population, such as one stray domestic sheep. As such, the sooner that population is used to create or augment other populations that might serve as future sources of translocation stock, the sooner some resolution to this precarious situation will be achieved.

The Lee Vining Canyon population initially increased at 24% per year under the aid of mountain lion control (Chow 1991). At a population of 25 ewes, this would produce a sustainable harvest of about 6 ewes per year for translocation. Increasing the population to 30 ewes gains only 1 additional ewe for harvest per year. At 35 and 40 ewes, the sustainable harvest increases to 8.5 and 9.5 ewes per year, respectively, if productivity is not compromised by density. Since 6 ewes and a few rams may be an appropriate group size for translocations (see below), initiation of use of the Lee Vining Canyon populations as translocation stock when it reaches 25 ewes is a viable strategy. Waiting 2 extra years to begin transplants will increase annual harvest potential by about 50%; but, in the interim, 2 small translocations might have taken place. The question reduces to the tradeoff between yield and time and the associated risk of another severe winter, a stray domestic sheep, or some other factor reducing the harvest temporarily or permanently to zero. It is recommended that the Lee Vining Canyon population be used as reintroduction stock as soon as it exceeds 25 ewes at least 1 year old, and that removals for reintroductions maintain a minimum of 25 ewes. Setting a minimum of 25 ewes in Lee Vining Canyon will commonly result in larger numbers of ewes in that population because of logistical constraints in capturing them for translocations. Whether this population again increases at around 24% per year will depend on various factors.

As long as the Lee Vining Canyon population shows high increase rates, removing sheep should not be a threat to its future and may actually help survival in a severe winter. Because snow reduces forage availability, heavy winters are effectively a temporary reduction in population carrying capacity. As populations increase, intraspecific competition for choice forage is likely to cause a decline in individual nutrient intake, a resultant decline in body condition, and eventually a decline in reproductive success. When a particularly stressful winter hits, survivorship of sheep will be higher if (1) they carry optimal body reserves, and (2) there are not too many sheep trying to feed on a limited amount of available forage.

Data from the Lee Vining Canyon population prior to its 1995 crash did not give any indications of whether intraspecific competition was yet a factor. Nevertheless, a smaller population size at that time might have had higher rates of overwinter survival. The poor condition of the sheep that survived that winter and their very low reproductive output that spring suggested that available forage was a factor in losses that winter. However, density independent losses from snow avalanches may have been a major factor.

Should another heavy winter similar to 1995 occur with wet snow that cannot blow off high slopes, an attempt should be made to supplement the diet of these sheep with grass hay. In general, increasing survival and productivity of a wild population via supplemental feeding may be a much better strategy than doing the same in a captive situation because (1) the sheep produced will have wild behaviors that are likely to aid survival when translocated, and (2) it should be much less expensive.

Should an unforeseen calamity occur to the Lee Vining Canyon population that threatens the ability of this population to reach 25 ewes and thereby provide translocation stock, immediate capture of some of the remaining sheep should be implemented to place them in a captive breeding facility in order to preserve this gene pool and establish a captive breeding program. The capture of a small number of additional sheep from other populations to augment this captive population should also be considered at that time. A program to maximize representation of genetic diversity in this captive population should then be developed.

B. Translocation Strategies

There are two possible goals for translocating bighorn sheep. One is to build populations through reintroductions and augmentations. The other is to increase genetic diversity within populations. These are not exclusive approaches, but in some cases involve quite different constraints. The first involves the translocation primarily of females, while the second may in some cases be accomplished largely by translocating rams. Any of the existing populations might be used for the latter (i.e. exchange of rams), but currently only one population, the Lee Vining Canyon population, offers a possible source of females for translocation in the near future. While the Lee Vining Canyon population only slightly exceeds the Mount Baxter population in its reproductive base, some of the females in the Mount Baxter population are now part of a subpopulation unlikely to be available for translocation stock due to location. Also, because the Mount Baxter population consists of three separate females demes (designated here as "herds"), each is small relative to the Lee Vining Canyon population. Most sheep removed for translocations from the Mount Baxter population in the past came from the Sand Mountain herd, which then contained as many as 76 ewes, but has had only 4 ewes in it for the past 7 winters. Unless augmented, it will not be a source of translocation stock for many years.

As discussed above, the Lee Vining Canyon population cannot be expected to produce large numbers of sheep for translocation. This makes these available sheep a particularly precious resource that should be used most effectively toward the overall recovery of this subspecies. The following is a discussion of factors involved and options available.

C. Genetics, Metapopulations, Uncertainties, and Composition of Translocations

It is important to recognize the metapopulation structure that is common in bighorn sheep. This consists of separate demes of females defined by different home range patterns connected genetically by rams that move among these demes to breed (Bleich et al. 1996). This means that establishing additional female demes within metapopulations will have the effect of accomplishing simultaneously genetic and population goals, and may represent a particularly efficient use of translocation stock. Because such demes will be connected genetically to other demes, considerably fewer sheep can be translocated than are needed to establish isolated populations through reintroductions. It has been recommended that reintroduced populations of bighorn sheep be created with at least 20 sheep (Wilson and Douglas 1982), and this has been the common practice, including past reintroductions in the Sierra Nevada. Establishing sufficient genetic variation in isolated populations has been one reason for this approach. In contrast, a new deme of females established within a metapopulation where rams will find them might be created with only a few females and perhaps one ram to assure breeding until other rams discover them. There is evidence that this practice better mimics the natural colonization in bighorn sheep, where demes may sometimes arise from a single dispersing female (Bleich et al. 1996). Rams explore nearby habitat considerably more than females and find suitable habitat patches before females in general.

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. Even for a reintroduction, the initial translocation of a relatively small number of sheep 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 sheep due to unforeseen circumstances will be an unretrievable loss of a rare resource. This should be considered for future translocations. Also considered should be the advantages that sheep obtain from group living, including better predator detection and feeding efficiency. Groups sizes of 5-6 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 5 sheep if possible.

In the absence of detailed data on genetic structure and processes of existing populations, it will be necessary to err conservatively and assume that: (1) each of the five populations is currently genetically isolated; and (2) that maximizing genetic variation within each population will require induced gene exchange. A small telemetry data set of interest exists only for relocated sheep, but shows that rams can move large distances. One ram returned within one year from Mount Langley to the Sawmill Canyon winter range where he was captured (linear distance of 30 miles). Another ram caught on Sand Mountain and released at Wheeler Ridge returned to San Mountain three years later, after first spending the life of his radio collar on Wheeler Ridge (linear distance of 40 miles). Another ram released at Mount Langley was last recorded at Mount Williamson (linear distance of 12 miles). Finally, a ewe released at Mount Langley moved at least as far as Mount Williamson where her collar fell off after the attachment failed. Because these were all translocated sheep, they may not reflect normal movement patterns; but, if they do, the three southern extant populations may already exist as a metapopulation in terms of genetic exchange via rams. If so, attempts to move rams among them may be entirely unnecessary and thus only an unnecessary risk to the animals moved and the people involved. Given that possibility, it may be best to exchange rams mostly between the more distant populations which are much less likely to be linked genetically already.

The amount of such exchange that might be necessary to maximize genetic variability within each population will be something of a guess in the absence of detailed data on the existing distribution of genetic variation and gene pool dynamics. Schwartz et al. (1986) made a crude analysis of the question of inbreeding prevention for a desert metapopulation of bighorn sheep in California. They concluded that low levels of gene migration were necessary with a maximum of .08 migrants per generation for their smallest population, which had a genetic effective size of 12. This was based on a simple equation involving effective population size and migration rate ($N_e * m = 1$), which if satisfied will approximate panmixis. For the very small Mount Williamson population (N_e about 5), this would require only one migrant every 5 generations, i.e. about 1 every 35 years). However, assumptions such as random mating, which underlie the equation used by Schwartz et al. (1986), do not accurately represent the biology of bighorn sheep; thus it is not clear that recommendations on induced migration can be made from the equation they used. It is also possible that natural migration is already occurring, e.g. that rams from the Mount Langley and/or Mount Baxter populations may be mating with Mount Williamson ewes. This underlines the need for detailed genetic analyses as the basis of recommendations on induced migration to maximize genetic diversity.

D. Development of Additional Future Sources of Translocation Stock

An additional important variable in finding the most effective use of anticipated translocation stock concerns the potential for translocated sheep to contribute to additional future sources of such stock. This includes both captive and wild populations. Clearly, the more that translocated sheep can contribute to such populations, the more sheep there will be to move in the future, much like compounded interest. Development of a second source of translocation stock will greatly reduce overall vulnerability of this resource to catastrophic losses. Weight must be given to this consideration in choosing release sites. Specifically, in addition to the option of a captive population, reestablishment of the Sand Mountain herd as a large productive population should be considered, especially given its known history of such capability. However, this end might also be accomplished if a highly successful population west of the Kern River can be created via reintroduction.

Recent history and research has shown that high use of low elevation winter ranges results in larger populations, presumably due to differences in nutrient intake. If the mountain lion population remains low enough for bighorn to increase winter range use, this should be encouraged. Recent history also suggests that the alternative migratory behavior of strong winter range avoidance may not produce long term viability of bighorn sheep within much of the Sierra Nevada. The recent increase in winter range use by the Mount Baxter and Mount Langley populations is indicative of the potential to reestablish this former habitat use pattern. Bighorn sheep find both safety and greater feeding efficiency in numbers. Current surviving herds offer too few sheep to develop the large group sizes once seen on winter ranges. Instead, it is common now to see groups of only 1-3 sheep occupying winter ranges. During the peak in mountain lion densities, these small sheep groups would visit low elevations on the Sand Mountain winter range for only 1-2 days following severe storms. Beginning in 1997 this has increased to periods of 1-5 weeks. Winter range use in these areas is likely to increase as a function of population size and related available group sizes. Greater winter range use in turn can be expected to increase population growth through greater nutrient intake. There is likely to be a threshold in population size above which this winter range use may increase substantially.

In summary, an important potential strategy for the use of translocation stock is to augment some existing populations, with the goal of increasing winter range use. Augmenting increasing populations also has the simple numbers advantage that a larger population base produces a higher yield. This has particular advantages if applied to the Sand Mountain and Sawmill Canyon winter ranges. Because of the particularly good quality of these winter ranges, it is doubtful that any other location has the population potential of the Mount Baxter population. Currently, it is the second largest remaining population. Use of translocation stock to reestablish it as a large productive population brings with it the development of a second source of translocation stock. This in turn will greatly accelerate the long term recovery of Sierra Nevada bighorn. The Sand Mountain herd previously constituted 70% of the Mount Baxter population, thus has the highest population potential and should be given priority.

Because there is considerable uncertainty about the future influences of mountain lions in the Owens Valley region, attempting to build the Sand Mountain herd as a future source of reintroduction stock may be a risky use of translocation stock. A second options to develop a future wild source of translocation stock may be historic ranges west of the Kern River, where mountain lions may be absent in winter.

An alternative or addition to development of a wild population as a second source of translocation stock is a captive population. This might best be accomplished using existing zoo facilities, and those in the Rocky Mountain region might be best due to a better climate match with the Sierra Nevada. There are advantages to developing the Sand Mountain herd rather than a captive one. First, bighorn sheep translocated to Sand Mountain will accomplish the fundamental goal of population recovery in the wild while also developing a source of translocation stock. Second bighorn sheep reared in captivity are unlikely to be wise to treats in the wild and may have much lower survivorship when released in the wild. However, there is the alternative possibility that wild sheep caught from the Lee Vining Canyon population will not remain on the Sand Mountain winter range, but instead will adopt high elevation wintering areas. Translocating mostly young sheep may solve this problem, but the use of captive bred sheep may be an effective means to reestablish low elevation wintering patterns. Captive reared sheep would presumably follow wild sheep to summer ranges or naturally migrate elevationally. Only after some sheep from the Lee Vining Canyon population are moved to Sand Mountain and closely monitored can this question be adequately investigated. Historic ranges west of the Kern River do not present this potential translocation problem because there are no high elevation sites that wild caught sheep can inhabit in winter.

If a captive breeding approach is chosen, a useful strategy would be to initiate multiple small herds in different locations (e.g. Rocky Mountain region zoos) with rams exchanged among the locations to prevent inbreeding. This would minimize the frequency of efforts necessary to exchange rams between these facilities and the Sierra Nevada to avoid inbreeding.

E. Population Augmentation, Metapopulation Expansion, and Reintroduction

Because population augmentation and metapopulation expansions can generally be accomplished with far fewer sheep than reintroductions, it may be difficult to justify engaging in reintroductions until existing populations and metapopulations have reached sizes that afford some comfort in terms of viability. However, the opposite will be true if it is found that environmental factors do not favor the recovery of some existing populations. This was the case only a few years ago when the effects of mountain lions precluded many options. Should mountain lions show a rebound to a similar level with no control options for bighorn sheep available, the best use of any available translocation stock will be reintroduction to a new site lacking or minimizing this problem. Historic range west of the Kern River is the primary candidate in this regard because deer migrate out of this area in the winter, leaving the possibility that lions will also be absent in that season. Reintroduction to this area should be considered once sufficient comfort exists about the viability of the existing metapopulations, or sooner if conditions do not favor recovery of these metapopulations. Potential areas north of Owens Valley should also be considered if mountain lion threats preclude viability of populations in Owens Valley. Like the Kern River ranges, these sites also lack deer in winter (see habitat discussion below).

Three populations or subpopulations (herds) warrant consideration for augmentation with females to boost reproductive bases. Top priority for such augmentation should be populations that will benefit from such action, but are unlikely to recover without this boost in numbers. The tiny Mount Williamson population fits this criterion. Augmentation there should attempt to reestablish the use of the South Bairs Creek drainage via translocation of ewes to that canyon after prescribed fire has improved it as a winter range relative to lion predation. Introduction of ewes to this population will also enhance genetic variability.

Second priority for augmentation should be populations that may recover without it, but have potential themselves to produce future translocation stock sooner if augmented. The Sand Mountain and Sawmill Canyon herds of the Mount Baxter population fit this criterion as discussed above. Of these two, the Sand Mountain herd is smaller, thus is in more need of help, and has a higher potential to develop into a large population. It is not clear whether augmentation of either or both of these herds would provide any genetic benefit for the Mount Baxter population, given that the Lee Vining Canyon herd is derived from it.

Third priority for augmentation should be populations that may recover more quickly for it, but may recover without it and have less potential to become future sources of translocation stock. With a current reproductive base of only four ewes (plus a yearling), the Mount Langley population fits this criterion. With its current large number of rams of varying ages, this population may not need any genetic input. As such, the option exists to leave this population to recover on its own (an experimental control), monitor it carefully, and augment only if deemed necessary.

F. Maximizing Home Range Pattern Diversity

A variety of studies have found that the natural structure of many bighorn sheep populations involves substructuring in which the larger reproductive base is the sum of multiple female demes defined by separate home range patterns (Bleich et al. 1996). For instance, the Mount Baxter population formerly consisted of two such demes, but now has developed a third one since winter migratory patterns changed. Separate home range patterns can overlap to varying degrees and these demes are the basic units of metapopulations. With this definition the distinction between population augmentation and metapopulation expansion becomes somewhat blurred. There may be benefit in trying to establish a variety of home range patterns in the process of augmenting populations and expanding metapopulations. First, this will increase the overall use of available habitat. Second, this greater variety will provide more opportunity for a particularly productive pattern of habitat use to develop that may greatly increase overall population size. Third, under adverse circumstances, this variety may similarly provide more opportunity for persistence. Bighorn sheep in the Sierra Nevada show considerable plasticity in life history features like growth rates, age at sexual maturity, and even lambing time to some extent. This plasticity allows a variety of home range patterns to persist. Some will be more successful under certain environmental situations. The most successful home range patterns will tend to dominate in terms of sheep numbers in populations, and these will be the populations that are best known, because of concentrations of animals in certain locations and seasons, notably winter ranges. However, other less successful patterns can coexist. It is possible, that a much greater variety of home range patterns once existed than those that survived to be recorded. For instance, there once may have been some degree of winter use in all or most canyons in the Owens Valley region, resulting in a relatively continuous metapopulation, but including some fairly small demes. This should be considered in trying to expand and better connect populations into metapopulations after higher priority uses of translocation stock have taken place.

G. Predators and Domestic Sheep

Reintroduction of the Lee Vining population was successful only after augmentation was accompanied by a focused mountain lion removal program (Chow 1991). To have augmented this population without this limitation of predation losses would have amounted to a very expensive program to feed rare sheep to mountain lions and most likely would have failed to establish that bighorn sheep population, which is now the largest in the Sierra Nevada. Sierra Nevada bighorn sheep are now considerably rarer than they were then, and translocation stock is accordingly in much less supply. This makes it all the more imperative that mountain lion activity near areas that receive translocated bighorn be closely monitored, and that a clear policy on predator removal be in place. Whether or not this is possible should figure into the choice of where sheep are moved. In short, this limited translocation stock should not be moved to locations where there is a potential for uncontrollable loss to predation. It may also be crucial to establish a couple of priority levels for limiting predation losses to mountain lions. Top priority would be populations used for translocation stock and those that are very vulnerable to extinction due to small numbers. Currently, this would include all populations. Once sufficient recovery has occurred, this level would be limited to sources of translocation stock, where bighorn populations should grow unimpeded by lions or other predators deemed a threat until this is no longer needed. While currently a crucial tool for the recovery of Sierra Nevada bighorn sheep, predator control should be exercised as little as possible, with the goal of no such control once sufficient recovery is achieved.

Similarly no translocations should be made to locations where there is other than a negligible probability of contact with domestic sheep. A primary purpose of this plan is to identify potential sites for translocation and identify conflicting land management uses that can be ameliorated by the time that bighorn might be available to restock these ranges.

H. Timing of Translocations.

The intent of most or all translocations will be the establishment or augmentation of populations using low elevation winter ranges. Since the peak in such use of this habitat historically has been in late winter and early spring, this would be the ideal time to translocate sheep to these sites, notably March. There are a number of reasons for this. First, these sheep have a natural tendency to descend to such sites in that period. Second, forage quality will be high, which may help hold them there after release. Third, for augmentations, there are likely to be sheep on these winter ranges that can be joined, which should also serve to help hold translocated sheep on these sites. However, fall translocations may also work in some cases. For instance, west of the Kern River there is an absence of high wind swept areas which bighorn might occupy in winter. If released on low elevation winter ranges in fall, they can be expected to return there during winter. This may also work elsewhere, but will only be known through careful monitoring of sheep translocated at different times.

V. <u>Potential Areas to Receive Bighorn Sheep</u>

A. Habitat Considerations

The following attributes were considered in considering potential areas that might support bighorn sheep populations: (1) known historical use; (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. It would be very desirable if viable bighorn sheep populations could persist in the Sierra Nevada living year round at high elevation, thereby largely eliminating mountain lions as an issue. This was a primary purpose in investigating the distribution of high snow-free habitat in winter. However, even under earlier conditions of low mountain lion predation pressure in winter, this habitat was used a great deal in early winter (Wehausen 1996), thus has always been an important part of the winter ecology of these sheep.

The Lee Vining Canyon population grew to substantial size while wintering primarily at high elevations prior to 1995. However, it also relied on low south-facing winter range in Lee Vining Canyon for short periods in spring during that rapid population growth. While this spring period was considerably later than the winter range use previously exhibited by the Mount Baxter and Mount Williamson populations, it is presumed to be a crucial variable in nutrition and population growth rate and carrying capacity. As such, it is important in evaluating habitat to consider both high and low elevation winter habitat.

One of the attributes of potential low elevation winter ranges listed on Table 1 is the minimum elevation. Lower elevations mean warmer temperatures, earlier initiation of forage growth, and potentially higher overall nutrient intake. The large size attained by the Mount Baxter population prior to changes in winter habitat use apparently resulted from a very high nutrient intake obtained on low elevation winter range. However, the Lee Vining Canyon population exhibited rapid population growth using a low elevation winter range whose minimum elevation was almost 3,000 feet higher than the Mount Baxter population. This is a reflection of the physiological plasticity of these sheep. What is not clear is what the upper limit of the lowest elevation is in terms of supporting a viable deme of ewes relative to nutritional requirements for reproduction. It was previously found that each 17.8m (58.4 ft.) of elevation equated to a one day delay in forage growth and associated diet quality (Wehausen 1980). This represents a 17 day delay per thousand feet.

A fundamental tradeoff that occurs with declining elevations of winter ranges is the potential to overlap or abut deer range and thus greatly increase the potential for problems with mountain lion predation.

Except in unusual winters, deer do not inhabit the base of the Sierra Nevada north of Toms Place (Sherwin Grade) and begin migration into this northern region in mid April from various distant winter ranges. This means that the potential bighorn ranges in this region may have considerably less risk of lion predation problems prior to spring. However, at the time when the Lee Vining ewes appear at lower elevations the Mount Baxter ewes would have already left the winter range in the 1970's and early 1980's. Thus, the timing of this risk could simply be shifted later for these more northern ranges and perhaps only slightly decreased. However, the use of low elevation habitat in Lee Vining Canyon in spring has varied from use by all ewes to years of almost no use, despite high lamb output. Where ewes feed and what their diet quality levels are during springs when Lee Vining Canyon is not used are not known. Until some of these details are better understood, it will not be possible to determine the limits of habitat that can support bighorn sheep in the Sierra Nevada.

Numerous flights were made in a fixed wing aircraft during the 1996-97 and 1997-98 winter to investigate high elevation winter habitat. The 1998 winter was particularly useful in having very high snow fall. The primary purpose of these flights was to map patches kept largely free of snow in winter by wind and I tried to represent the extreme of 1998 to the extent possible. Because the Lee Vining Canyon population was able to thrive while spending much of winter at high elevations prior to 1995, this area was used as a model for comparison. In February of 1995 two ewes inhabiting lower elevations in Lee Vining Canyon received radio collars. Those collared sheep have been used as much as possible to verify that wind swept patches are the high elevation habitat used in winter. In one instance, we actually spotted the group of sheep containing one of these collars in such habitat on Mount Warren.

The region most comparable to the Mount Warren area lies immediately south of Lee Vining Canyon from Mount Dana to Mount Wood. A small group of sheep from Lee Vining Canyon dispersed to Mount Gibbs the first year they were reintroduced (1986). Only a few sheep have persisted in this area due to earlier influences of mountain lion predation (Chow 1991). The availability of high elevation winter habitat in this area has important implications for the potential establishment of viable metapopulation in this region. However, the idea that a number of such viable metapopulations might be established that rely largely on high elevations in winter to avoid predation is very questionable. For instance, the spur of the Sierra Nevada west of the Kern River had no wind swept areas free of snow; thus the native sheep there would have used only low elevations near the Kern River in winter, as will reintroduced ones.

Nevertheless, there are some important patches free of snow at high elevations in winter south of the Yosemite area that figure importantly in some potential sites for translocation. High elevation winter habitat patches were mapped on a GIS system (Figures 1-4) and the area of each patch was determined. Low elevation winter habitat was also mapped and coded as to its degree of visual obstruction (trees, mixed, or open).

B. Potential Locations for Populations

Below is a discussion of potential sites for populations. These are discussed by metapopulation, which allows a discussion of relative quality within metapopulations based on a comparison of attributes.

1. Northern Metapopulation

Bighorn were historically recorded as far north as the Sonora Pass region (Manly 1916). During flights some patches blown free of snow were photographed 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 sheep in this area might have had, but it may have included the Walker River Gorge and even the Sweetwater Mountains. It is questionable whether that bighorn will ever be returned to this area.

Seven areas were considered to have potential habitat for sheep in this metapopulation. Two of these currently are known to be inhabited by females, and two more are known to receive use only by rams at this time. The Mount Warren area has a particulary good combination of high elevation and low elevation winter habitat and currently supports the largest concentration of bighorn in the Sierra Nevada. Adjacent Lundy Canyon has excellent low elevation south facing winter range that rivals Lee Vining Canyon in its lowest elevation. However, Lundy Canyon is almost lacking in high elevation winter habitat. Further north, Dunderberg Peak is substantially blown free of snow in winter, but does not connect to low elevation winter range. Crater Crest has some high areas free of snow and connects to excellent low elevation habitat, but with a minimum elevation of 9,000 ft. Immediately north of Twin Lakes there are south-facing slopes that are actually blown free of snow, as is a region around Victoria Peak. It is not clear whether there would be a connection between these sites for sheep except in late winter and spring when snow firms up. The south-facing slopes above Twin Lakes, while steep and open, appear to lack areas rock outcroppings, which Crater Crest provides in the Green Creek drainage. Dunderberg Peak, Crater Crest, and Victoria Peak probably all had bighorn sheep use historically, but should be considered for translocations only after all other more suitable areas have been filled.

South of Lee Vining Canyon, the region from Mount Wood to Mount Dana has high potential for expansion of this metapopulation. There is considerable high elevation habitat blown free in winter, which connects well to south-facing slopes that drop to lower elevations. Rams are already known to move between Mount Warren and this area. With the recruitment of a yearling female on Mount Gibbs in 1997, the reproductive base there increased to 2 ewes. It is possible that left alone this little deme will grow and eventually expand south to Mount Wood. This process could be greatly accelerated by translocating some ewes into this area. It is noteworthy that just west of Parker Peak lies Koip Peak, which means bighorn sheep in the Piute language. It is also noteworthy that the slopes above Silver Lake provide good low elevation east-facing winter range down to 7,600 ft. which probably once received much use by bighorn in this region, including spring lambing.

There are conflicts with domestic sheep throughout this region. Because rams have expanded north across Lundy Canyon, there is vulnerability there from domestic sheep grazed in the Copper Mountain area, and two allotments south of Lee Vining Canyon pose constraints on bighorn expansion to the south. Efforts should be made to solve these conflicts in order to develop a viable metapopulation at least from Lundy Canyon south to Mount Wood. This metapopulation currently appears to be crucial to the future of these sheep.

2. Central Metapopulation

This metapopulation currently has one population on Wheeler Ridge which had grown to about 25 sheep in 1997. In the winter of 1998 there was a reported sighting of 3 ewes above Wells Meadow, which is the first known use of this part of their range in many years. This may reflect the same response to the decline in mountain lion density that has been seen further south. If this condition persists, this population has the potential to grow to considerable numbers, given a very large expanse of excellent low elevation winter range. If, alternatively, use continues to be concentrated at higher elevations as it has in the recent past, this population may not exceed 40 sheep.

Immediately south of Wheeler Ridge is Mount Tom, which had a native population of bighorn sheep that persisted into the 1930's. Ober (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 he also noted that this population 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). Rams from Wheeler Ridge have been known to visit Mount Tom since they were reintroduced in 1979, and Mount Tom would be unquestionably the first site for expansion of this metapopulation via translocation.

Mount Tom offers multiple habitat options. Low elevation winter-spring habitat extends down to 6,400' 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 sheep traversing ridgelines from Mount Tom via Four Gables and along the crest. Early sighting records indicate that the bighorn that inhabited this area used the crest in summer at least as far as Mount Emerson, and rams certainly ranged further. Reestablishment of this population would go a long ways toward increasing total sheep in this metapopulation and thereby enhancing its viability.

Further north are three areas that were probably all historic bighorn ranges: Nevahbe Ridge, McGee Mountain, and Convict Creek. A population inhabited the Convict Creek area into the 1950's (Jones 1950). Traditional south-facing winter-spring habitat occurs above Convict Lake down to 7,900', which melts off quickly after winter storms. This is connected to extensive high elevation patches on Laurel and Bloody Mountains. Of the three northern sites this is the most favorable due to this combination. McGee Mountain has excellent south-facing winter habitat down to about 8,000' that is equivalent to the slope above Convict Lake, but has only a little high elevation winter habitat. Nevahbe Ridge has more wind blown habitat than McGee Mountain, but the low elevation habitat is east-facing and only down to 8,500, thus is much more delayed in snow melt.

In 1989, 11 rams from Wheeler Ridge were photographed 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 the metapopulation if it can be established via translocation. There was probably also once some gene exchange between this metapopulation and the one further north via San Joaquin Ridge. Numerous sighting of bighorn sheep were made on San Joaquin Ridge between 1954 and 1957, including a ram killed by a deer hunter. This may be less likely in the future because of human developments in these region.

C. Southern Metapopulation

As many as thirteen (or more) demes of females might have once occupied the area from Olancha Canyon to Coyote Flat. Of those areas listed on Table 1, five currently support such demes and another four are known to have been visited by rams. These are discussed below as six general populations.

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 snowfree in winter. There is a paucity of historical evidence that bighorn occupied this area, but this could reflect an incomplete record. Bighorn sheep using this habitat 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 5,600' in the Shannon Canyon area. Bishop Creek is currently treated as a break between the central and southern metapopulation because of uncertainty about former use of the region of Coyote Ridge and the Big Pine Creek drainage. A Coyote Ridge population would serve substantially as a link between these two metapopulations and it is possible that historically the entire east side of the Sierra Nevada was one long metapopulation with gene flow throughout. 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.

Jones (1950) listed a Birch Mountain population estimated at 15 sheep as persisting in mid century. His evidence was less than convincing. Clyde (1971) noted that he had never seen bighorn sign on Birch Mountain, but had once seen does and fawns well above timberline on its slopes. Jones (1950) postulated the existence of bighorn sheep there entirely on the basis of tracks of six animals he believed to be sheep, which may have been deer. Nevertheless, Ober (1914) mentioned bighorn living from Birch Creek to Big Pine Creek, and Clyde (1971) noted evidence on a variety of occasions of bighorn sheep in the upper Big Pine Creek drainage. There are some significant areas of high wind blown habitat on Birch and Kid Mountains that might have supported bighorn. However, available low elevation south or east-facing habitat to complement these sites is limited to relatively high elevation unless they moved further south. Alternatively, they might have dropped as low as 7,200' on the northeast side of Kid Mountain.

The 1921 and 1923 Inyo National Forest Fish and Game Reports listed a Goodale-Birch Mt. population of which the 1921 report describes 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 (1911) noted "In the winter season they range low on Taboose Creek and along the snow line to Goodale and Red Mountain". As mountain lion predation rose in the early 1980's bighorn sheep were found wintering in Goodale Creek, where they had not been recorded for decades. As numbers wintering 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 likely that this was an attempt by members of the Sawmill Canyon herd to find a new safer area to winter. However, lion predation was also recorded at Goodale Creek in this period, which likely 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 6,400' ft.

As discussed above, the Mount Baxter population currently consists of three females demes, of which the Sand Mountain herd is smallest and the best candidate for augmentation. The Sawmill Canyon herd ranges as far north as Mount Pinchot, and the Black Mountain herd ranges south to Kearsarge Peak.

Females from the Mount Williamson population ranged from Georges Creek to Shepherd Creek prior to its recent decline (Wehausen 1980). Rams were known to use the Symmes Creek and Pinyon Creek drainages in addition, as well as areas west of the crest. Norman Clyde (1971) recorded considerable use further south on Mount Russell, where he once encountered four rams. This greater range of use may have reflected a much larger population that Jones (1950) estimated subjectively at 125, with this range shrinking continually as the population declined. The recent decline in this population has left the few remaining females occupying only the north ridge of Mount Williamson. The first attempt at range expansion should be to South Bairs Creek. Ewes established there will almost certainly also use Georges Creek.

A small amount of historic evidence suggests that ewes may have once used Symmes and Pinyon Creeks to the north where only rams could be found in the 1970's (Wehausen 1979). This may also have been the case for Hogback and Lone Pine Creeks to the south. All of these areas have some high elevation winter habitat associated with them. Female demes that might be established in some of these drainages would serve as connecting links in this metapopulation. These four drainages should be contemplated for translocations once all major areas have established populations. Prescribed fire would greatly improve habitat in these canyons.

Prior to its recent decline, ewes from the Mount Langley population 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 notably better than those currently used from Carroll Creek to Diaz Creek, but would require greater distance traveled to reach them from alpine ranges. It is hard to imagine that Cottonwood Canyon did not once support a large bighorn population.

From Slide Canyon it would be natural for bighorn to cross a short stretch of open south-facing forest to reach the large open plateau currently used by the Mount Langley population via Wonoga Peak. Because of the geographic connection of the tops of these two canyons, this might easily also happen for sheep translocated to Cottonwood Creek. The alternative for bighorn using Cottonwood Creek would be a summer range east of the Kern Plateau at peak elevations just over 10,000'. While this habitat would not provide the vast open expanses of higher alpine habitats, it would be nutritionally quite suitable and likely to support a large bighorn sheep population. Expansion of the range of the Mount Langley population further south to these two drainages will probably substantially increase is potential size. This could be attempted through an augmentation or by moving some of the existing Mount Langley sheep once they have shown sufficient recovery in numbers.

South of Cottonwood Creek from north to south are Ash, Braley, Cartago, Olancha Creeks, and Falls Creeks, all of which are potential bighorn sheep habitat. The southern three of these are more favorable because they readily connect to Olancha Peak (12,123'), which will provide some alpine summer habitat (the southernmost alpine in the Sierra Nevada). Olancha Canyon is the most direct connection to this alpine habitat. This would be the most southern population in this metapopulation. 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. It is likely that nutritionally this range can support a large population.

D. Kern River Metapopulation

There is good historical evidence of bighorn sheep in this area. Bighorn sheep 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 1870's that was attributed to scabies (Jones 1950). Bighorn would have moved readily along the east-facing cliffy 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 may be the best sites 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. 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 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. In contrast, Rattlesnake and Laurel Creeks provide immediate access to summer range. One alternative would be to release bighorn 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 no trails and thus probably least human use. An investigation of winter mountain lion use of this area is needed.

VI. Research Needs

A. Population Monitoring

It will be necessary to make yearly decisions on potential translocation actions on the basis of the most recent information on source and recipient populations. The entire recovery program for these sheep hinges on the development of good demographic information on every population as often as possible. This is particularly the case for the Lee Vining Canyon population, which may serve as a source of translocation stock. Development of continuing good demographic data should be the first priority for research.

B. Genetics and Metapopulation Processes

Recent severe population declines are likely to have resulted in loss of genetic variation for at least some of the populations of Sierra Nevada bighorn sheep. The potential for further losses of genetic diversity through inbreeding due to small population sizes raises genetic questions to a prominent position. As noted above, any translocations that take place for the purpose of maximizing genetic variation will do on the basis of untested assumptions in the absence of research on the distribution of genetic variation.

With recent advances in the use of feces to extract and amplify DNA, detailed information can be obtained noninvasively on the amount and distribution of genetic variation and potential genetic linkages between demes of Sierra Nevada bighorn. For instance using maternity and paternity exclusion procedures, it will be possible to determine whether rams from the Mount Langley or Mount Baxter population are fathers of any lambs at Mount Williamson. Such information is critical to the definition and understanding of these metapopulations, as well as to potential remedial actions to prevent inbreeding.

It will also be possible to compare the current genetic structure of each population with earlier such structures using archived serum samples from all sheep moved to create three of the existing populations and archived fecal samples from the Mount Williamson population. Additionally, by sampling each yearly lamb cohort in the future, it will be possible to detect whether increases in levels of homozygosity are occurring due to inbreeding. Implication of results from this research could vary from conclusions that no or little action is necessary to assure genetic integrity of the overall gene pool and this aspect of long term viability of populations, to the other extreme -- that a great deal of induced gene migration is critical to maximize genetic variation in each metapopulation. Research on genetic structure of all Sierra Nevada bighorn populations should be a high priority.

C. Mountain Lion Populations

The mountain lion population in the eastern Sierra Nevada has had by far the greatest negative influence on the demographic status of Sierra Nevada bighorn sheep in recent years. The future status of the mountain lion population will also potentially have a large influence on choices for the use of translocation stock. It will be very important to develop regular data on this predator in the vicinity of bighorn sheep populations. This would most likely be done via a comprehensive track count transect. The detailed study of the mountain lion population adjacent to the Wheeler Ridge population has been particularly useful in producing a sound mountain lion population index that may index lion numbers over a much larger area. This index should be continued as part of a larger ecosystem monitoring. Finally, there is an urgent needs for data on mountain lion activity near potential winter ranges west of the Kern River.

D. High Elevation Winter Range Forage Resources

This study mapped high elevation snow-free patches in winter, but was not able to investigate these in terms of forage resources. Such patches are environmentally the most extreme conditions for plant growth in the alpine. Alpine plant communities in the Sierra Nevada are alpine desert because the Mediterranean climate of California means that precipitation is scant and unpredictable during the summer season when temperatures are favorable for plant growth. Snow melt provides the moisture for many alpine plant communities. However, those that are blown free of snow in winter are largely lacking in this moisture source and commonly support very sparse vegetation. Before any locations are chosen as translocation sites in part due to high elevation winter ranges, these patches should be investigated on the ground to evaluate forage availability. What bighorn sheep eat and exactly where they forage in winter at high elevations remains a question worthy of investigation.

VII. Synthesis and General Recommendations

The greatest mistake that could be made in the recovery effort for Sierra Nevada bighorn sheep would be to set a rigid prescription in this or any document to be followed to the letter. Instead, the strongest recommendation of this document is to engage in adaptive management whereby analyses and decisions are made year by year based on input of sound information on all aspects of this recovery problem. The purpose of this document is to outline the issues, possible approaches, and options that should be considered in those yearly decisions; and it is purposefully not called a "plan".

The reason that this approach is necessary is that population ecology is not a precise predictive science for the simple reason that cause-and-effect relative to population dynamics is multifactorial and many of these factors vary unpredictably, such as weather. Under the most optimistic scenario, all existing bighorn sheep populations in the Sierra Nevada will recover on their own unaided and with no genetic problems. Under this scenario, translocations would be needed only to fill in the existing metapopulations and create the fourth one. The history of bighorn sheep in general does not favor such an optimistic outlook, and points to the probable need for intervention to aid in the most rapid development of viable metapopulations. Translocation will be a primary tool for this.

It cannot be overemphasized that the lack of availability of translocation stock is the major obstacle limiting this recovery program. Thus, the foremost objective should be the development of a source, taking whatever measures are necessary. Even the initiation of a captive breeding program requires an initial source. While a captive breeding population is an attractive option, including undoubtedly the highest rate of gain in numbers, my recommendation is that captive breeding be initiated only if wild production of sufficient numbers of translocatable sheep does not appear to be a viable option, or if the constraints of mountain lions and domestic sheep do not support the use of any wild release sites when sheep are available. It should be evident within a couple of years whether the Lee Vining Canyon population will be an adequate source of sheep that can be translocated.

This analysis largely concerns possibilities for the use of translocation stock once it is available. Optimal use of this precious stock will hinge substantially on the future dynamics of the mountain lion population in the eastern Sierra Nevada and whether focused lion control is an option, which it currently is not. Because this predation factor so strongly influences translocation options, pursuit of legislation to provide the option of focused mountain lion control for the recovery of Sierra Nevada bighorn sheep cannot be separated from the subject of translocation.

Where the first wild released bighorn should go revolves around the question of mountain lion influences. This reduces to the question of translocating to areas adjacent to or overlapping deer winter ranges (Owens Valley) versus to those lacking nearby deer in winter. I suggest that choice of the former should be made on the basis that mountain lion effects (1) will remain low enough on their own to allow high productivity of translocated sheep and (2) can and will be controlled sufficiently to assure this, if necessary. At this point in time there is great uncertainty as to the future dynamics of the mountain lion population in the eastern Sierra Nevada. The recent apparent decline is of too short a duration to provide confidence about the future. A number of additional years at low density would instill considerably more confidence in the wisdom of translocating bighorn to the Owens Valley. In the absence of the ability to manipulate mountain lion populations for the recovery of Sierra Nevada bighorn, I recommend against translocating bighorn to Owens Valley populations for at least a few years, other than perhaps rams to Mount Williamson.

This leaves two options: ranges north of Owens Valley or west of the Kern River. Of those north of Owens Valley, I would place priority on the region immediately south of Lee Vining Canyon from Mount Dana to Mount Wood on the basis that it will expand an exiting metapopulation. Unfortunately, this is currently not advisable due to conflicts with domestic sheep allotments along the base of the mountains. In fact, all potential ranges north of Owens Valley are currently limited by domestic sheep grazing conflicts.

Kern River ranges are left as the best area to receive the first available sheep because of the absence of domestic sheep. However, this conclusion must remain tentative until more is learned about seasonal mountain lion distribution in that region. If it is learned that mountain lions are unlikely to be a factor in winter, these Kern River ranges have the highest probability of producing the most sheep from available translocation stock of all locations in the Sierra Nevada under the current ecological and land use situation. Investigations of mountain lions in that region should be given very high priority.

When it is decided to begin translocations to the Owens Valley that include ewes, I would put as top priority sites the existing populations where augmentation are warranted, and Olancha Canyon, Cottonwood/Slide Canyon, Taboose Creek, and Mount Tom. Other sites listed in Table 1 should be considered as lower priority sites. In the absence of (1) genetic data that dismiss the need for genetic management for existing populations and (2) any prospect of translocations of ewes to Mount Williamson or Mount Tom in the next half decade, I recommend that Mount Williamson and Wheeler Ridge each receive a couple of rams from Lee Vining Canyon in the next five years.

VIII. Literature Cited

Berger, J. 1978. Group size, foraging, and antipredator ploys: an analysis of bighorn sheep decisions. Behav. Ecol. and Sociobiol. 4:91-99.

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

Chow, L. S. 1991. Population dynamics and movement patterns of bighorn sheep reintroduced in the Sierra Nevada, California. M. S. Thesis, Univ. of Calif., Berkeley. 157 pp.

Clyde, N. 1971. 23 March letter to game warden Vernon Burandt titled "The bighorn in the Southern Sierra. Mostly half a century of casual recollections".

Jones, F. L. 1950. A survey of the Sierra Nevada Bighorn. Sierra Club Bull. 35(6):29-76.

Manly, W. M. 1916. Sierra mountain sheep in the Mono National Forest. Calif. Fish and Game 2:111.

Ober, E. H. 1911. 20 November letter to the California Fish and Game Commission.

Ober, E. H. 1914. Fish and game conditions in the "land of little rain". Biennial Report of the State of California Fish and Game Commission. 23:123-126.

Risenhoover, K. L., and J. A. Bailey. 1985. Foraging ecology of mountain sheep: implications for habitat management. J. Wildl. Manage. 49:797-804.

Schwartz, O., V. C. Bleich, and S. A. Holl. 1986. Genetics and the conservation of mountain sheep Ovis canadensis nelsoni. Biol. Conserv. 37:179-190.

Wilson, L. O., and C. L. Douglas. 1982. Revised guidelines for capturing and re-establishing desert bighorns. Trans. Desert Bighorn Counc. 26:1-7.

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

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

Wehausen, J. D. 1996. Effects of mountain lion predation on bighorn sheep in the Sierra Nevada and Granite Mountains of California. Wildlife Soc. Bull. 24:471-479.

Wehausen, J. D., and K. D. Chang. 1997. Sierra Nevada bighorn sheep: 1995-97 status. Sierra Nevada Bighorn Sheep Foundation Tech. Report No. 2.

Table 1. Potential sites for bighorn sheep population in the central and southern Sierra Nevada separated by metapopulations.

Location	Current Bighorn Use	Known Historic Habitat	Minimum Low Winter Habitat	Domestic Sheep Conflict	Visual Condition
NORTHERN METAPOPULATION					
Twin Lks.			7,200	yes	open
Crater Crest			9,000	yes	open
Dunderberg			10,000	yes	open
Lundy	rams only		8,000	yes	mixed
Mt. Warren	yes	yes	7,600	yes	mixed
Tioga Crest	yes	yes	9,500	yes	open
Mt. Dana/Gibbs	yes	yes	9,400	yes	open
Mt. Lewis	rams only		8,800	yes	open
Mt. Wood/Parker Pk.			7,600	yes	open
CENTRAL METAPOPULATION					
Laurel Mt.		yes	7,900	yes	open
McGee Mt.		yes	8,000	yes	open
Nevahbe Ridge			8,500	yes	open
Wheeler Ridge	yes	yes	5,600		open
Mt. Tom-Mt. Emerson	rams only	yes	6,400		open
SOUTHERN METAPOPULATION					
Coyote Flat			8,600/5,600		mixed/open
Kid Mt./Birch Mt.			9,200		open
Goodale Cr-Tinemaha Mt.	rams only	yes	6,400		open
Sawmill Cyn.	yes	yes	5,000		open
Sand Mt.	yes	yes	5,000		open
Kearsarge Pk.	yes	yes	7,500		open
Symmes/Pinyon Cr.	rams only		6,800		mixed
N. Bairs	yes	yes	6,200		mixed
S. Bairs/Georges	rams only	yes	6,400		mixed
Lone Pine/Hogback Cr.	rams only		6,800		mixed
Carroll-Tuttle Cr.	yes	yes	5,700		mixed
Cottonwood/Slide Cyn.			4,800		open
Falls-Ash Cr.		yes	4,800		open
KERN RIVER					
Big Arroyo		yes	6,900		mixed
Rattlesnake Cr.		yes	6,800		mixed
Laurel Cr.		yes	6,800		mixed