CAPTIVE BREEDING CONTINGENCY PLAN

A Guide for Captive Breeding of Sierra Nevada Bighorn Sheep

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Photo courtesy John Wehausen

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Executive Summary of Captive Breeding Plan

The Captive Breeding Contingency Plan (Ernest 2001), contracted by the California Department of Fish and Game's (CDFG) 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 (SNBSRT) to assist recovery planning. The concept of captive breeding in general, along with past Sierra Nevada bighorn sheep (SNBS) 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 impact 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 that further modeling with updated population estimates be conducted. One potential problem that needs further research is the translocation success of captive raised vs. wild caught sheep (see Thompson et al. 2000; 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 a must. 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 CDFG, USFWS, 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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Web site for Sierra Nevada Contingency Captive Breeding Plan 2001:
http://www.vgl.ucdavis.edu/wildlife/sheep_plan.html

Introduction to Captive Breeding

of Sierra Nevada Bighorn Sheep

This plan presents information to be used to make decisions on the captive breeding of Sierra Nevada bighorn sheep. For the purposes of this document, captive breeding is defined as confining wild Sierra Nevada bighorn sheep into an enclosed facility, and managing them for optimum reproduction, genetic viability, and health. Periodically captive sheep would be released to the wild to improve the viability of existing populations (augmentation) and/or to reintroduce animals to natural habitat within their former range. For reviews of mammal captive breeding in general, see Gipps 1991 and Griffith et al. 1989. For captive breeding in selected species, and conservation biology literature relating to captive breeding, see resources at the web sites for the International Union for the Conservation of Nature (IUCN) and Captive Breeding Specialist Group (CBSG). The United States Fish and Wildlife Service (USFWS) released a policy on encouraging judicious use of captive breeding for endangered species recovery (USFWS 2000a). The Recovery Plan (draft and final) for the Bighorn Sheep in the Peninsular Range (*Ovis canadensis*) contains an excellent set of guidelines and literature review for captive breeding, reintroduction, and augmentation developed by the Peninsular Bighorn Sheep Recovery Team (USFWS 2000c Appendix C). Ostermann et al. (2001) examined criteria used to evaluate captive breeding programs.

While several successful captive bighorn sheep facilities exist in the western United States, two remarkable failures in captive breeding and translocation in California reveal pit falls to captive breeding. In 1971 ten British Columbian California bighorn sheep were released into an enclosure at Lava Beds National Monument, Siskiyou County, California. Despite losses from poachers, bluetongue virus disease, and contagious ecthyma, by 1979 the population increased in numbers to 42. Following the removal of sheep for translocation to the Warner Mountains in 1980, the population was obliterated. The causes of the population extinction were attributed to Pasteurella pneumonia perhaps transmitted by domestic sheep and precipitated by the trapping activities associated with removals for translocation (Blaisdell 1982). Fourteen California bighorn sheep were translocated to the Warner Mountains in 1980 (including sheep from Lava Beds). By 1987, the population increased to 65 animals. However, all sheep died within a 3 week period in 1988 due to bacterial pneumonia believed to be contracted from one domestic sheep (Sleznick 1980; Weaver 1988).

Main causes of problems within captive facilities include disease, predators, and recruitment failures (skewed sex ratio, etc). Most of these factors can be greatly reduced or eliminated by careful facility planning and good management. The decision to breed Sierra Nevada bighorn sheep in captivity will not be easy. It will involve careful assessment of all information, close collaboration among many agencies, and "risk-taking, adaptive management, and research" (Stanley Price 1991). The decision should be based on a thorough review and discussion of this captive breeding contingency plan document and other resources available to the Recovery Team. If captive breeding is enacted, management should be driven by good science, not reactions to occasional set-backs, including mortalities, that are likely to happen within the facility.

This plan includes discussions of feasibility, risks, costs and benefits. The results of preliminary population modeling and conclusions in regard to captive breeding are presented in the context of current population status. Sections are provided to guide the selection and capture of founder stock and management (husbandry and veterinary care) of a captive herd. The ecology and status of Sierra Nevada bighorn sheep are reviewed in the Draft Sierra Nevada Bighorn Sheep Recovery Plan (USFWS 2000b; in prep) and Wehausen 1980, therefore are not included in this document. However, basic to understanding the potential importance of a captive herd is the concept of Geographic Conservation Unit (GCU). Three natural habitat breaks cause the current distribution of seven ewe herd areas to fall into four basic geographic units, termed Geographic Conservation Units (GCU's) by the interagency Sierra Nevada Bighorn Sheep Recovery Team (USFWS 2000b; in prep). Recovery strategies and goals are dependent on preserving genetic diversity, increasing numbers of bighorn sheep in existing herds, and reintroducing bighorn sheep within herd areas that are currently unoccupied in each of the four GCU's. A plan incorporating captive breeding may help achieve recovery goals more reliably and in a shorter time frame than strategies without captive breeding.

Captive Breeding and Research

Captive Breeding: information

Potential functions for captive breeding:

- Provide animals for augmentation release (demographic augmentation): Augment existing demes, populations, within Geographic Conservation Units (GCU's) which have low numbers by adding individuals and thereby providing increased demographic stability).
- Provide animals for reintroduction release: To produce new demes, populations (reintroduction into unoccupied habitat) within GCU's.
- Provide animals for release: Augment existing demes (genetic augmentation), populations which have low genetic variability by adding individuals of under-represented genetic types, to increase genetic stability. The demes and populations may have adequate demographic numbers but inadequate genetic variability.
- Provide safeguard and temporary safe haven against causes of population decline which cannot be immediately controlled. A number of individuals would be kept in captivity until population recovered. The captive herd would act as another population in itself to safeguard against catastrophic loss of wild populations (for example, a multiple population pneumonia epidemic; mountain lion predation that cannot be adequately controlled in the wild; etc.). These catastrophes are may be unpredictable severe events. The captive herd would be managed to increase effective population size and genetic diversity until release to wild was deemed safe. This function may be used in addition to other functions for captive breeding
- Provide research functions: a secondary function to genetic banking and providing individuals for release to wild. behavior, techniques (radiotelemetry testing), nutrition, genetics, disease, reproduction

Benefits:

- Optimize reproduction and recruitment – can expect recruitment of 70-100% (35-50% ewes recruited per year); birth rates between 90 –100 % (90-100 lambs per 100 ewes) and lamb survival to 6 months ~ 80-90%; assuming a 50/50 sex ratio (see Red Rock facility and the list of references on effects of skewed sex ratio for discussions of the potential causes and implications of skewed sex ratios).

- Increased survivorship - can expect adult survival above 90%.
- Captive herd will act as a protected additional population.
- Minimize loss of heterozygosity and genetic variability.
- Control disease exposure, predation, and breeding.
- Research and public education.

Reasons for benefits

- Exclusion of predators
- Optimization of nutrition
- Protection from extreme environmental conditions and catastrophes
- Water and food always present
- Ability to access sick or injured animals quickly
- Ability to administer medications and treatments quickly
- Ability to administer preventative medications, vaccines, dewormers, vitamin supplements and other treatments
- Managed matings for genetic benefit

Risks, Problems, and Disadvantages

The main risks and problems associated with captive breeding project failures can be attributed to poor facility planning and management. These problems may lead to diseases related to crowding and unsanitary conditions; fence problems leading to predator entry; nutrition deficits that may lead to poor recruitment or skewed sex-ratio; etc. If facility is planned, built, and managed well, these issues can be minimized or eliminated. However, high financial cost will be a consequence of a successful facility.

- <u>Potential disease risks due to location of facility or proximity to livestock</u> (ex, bluetongue virus, Pasteurella, contagious ecthyma). Minimize risks by good facility and location planning, and exclusion of domestic animals. Purchase feed (especially hay) grown on fields that have not been previously grazed by domestic animals.
- <u>Potential disease risks due to captive herd management</u>, including parasites, viral and bacterial pneumonia. Minimize by good husbandry, management of facilities and water sources, and careful screening of animals taken into captivity and released to the wild.
- <u>Potential for transmission of disease that is asymptomatic</u> in captive herd but pathogenic for wild (for example, a novel strain of Pasteurella).
- <u>Capture, handling injuries or deaths</u> – expect up to 5% (aim for <2%) for each handling effort. Minimize by good planning and experienced staff.
- <u>Fence injuries</u> (broken horns or limbs, neck caught in fence strangled) – minimize (to near zero) by building a good solid chain link fence and avoiding stressful situations that force sheep to challenge the fence.
- <u>Poaching</u> – minimize through management vigilance, facilities planning, and public education.

- Potential for habituation to humans – captive bighorn sheep may be attracted to humans (good management can reduce this).
- Potential lack of flight reaction to predators – may be able to influence through management. Do not allow dogs to roam near the captive herd because the sheep may become accustomed to the presence of predators without danger (Jim DeForge, personal communication).
- Potential loss or lack of local habitat information (ex, presence of a knowledgeable lead ewe), leading to reduced success following a release. Minimize by releasing captive-raised sheep into wild herds with existing social structure. For re-introductions, lack of local knowledge will be a risk.
- Potential for loss of genetic fitness (lack of immune system sampling of environment (see Coltman et al 1999); lack of "survival of fittest" predator pursuit and ram testing). Minimize by releasing individual animals before they have been in captivity for multiple generations, not allowing taming of sheep, by minimizing vaccination of sheep, etc.
- Potential demographic effects of small populations – possibility for ram-skewed sex ratio at birth or inbreeding. This may be related to nutrition, therefore management may help.
- Potential decrease in first year post-release survivorship and recruitment for captively bred released animals when compared to wild-caught translocated animals (personal communication, Amy Fisher and Stacey Ostermann). This area needs more research.
- Cost The funding of a captive facility could come at the expense of overall population recovery program if the facility is not funded adequately.

Growth Rate Comparison Table: Population growth rates of theoretical captive herd and wild populations

This is a very simplistic[1] example of how captive breeding *may* produce more individuals for translocation than wild populations. Successful captive herds generally have much lower mortality and somewhat higher reproduction than wild herds. Over time, this allows the "compounding of interest". This table lacks the stochasticity (random variation) that the Monte Carlo simulation program Vortex incorporates (see Population Modeling pages where stochasticity is incorporated). Lack of stochasticity means that in this table, there is no environmental variation, random chance of catastrophic mortality, or variation in mortality factors specific to each group. Therefore this table provides a simple model to characterize the potential population growth rate we may expect in a captive herd. Birth rate is defined as the probability of ewe becoming pregnant and giving birth. Each theoretical population starts with 20 adult ewes (E) and 2 adult rams (R). This model assumes a 50:50 sex ratio at birth. Deterministic values (see glossary) are supplied for birth ("birth rate") and mortality ("mort rate").

Follow table to the right to see yearly outcomes for total census and lambda (population growth rate).

[1]Simplistic, meaning lacking the complexity present in real populations. This is just a starting point way to look at population growth, using an excel spreadsheet. As we learn more about the Sierra Nevada system, complexity may be added to models to better predict what really might happen over time.

Captive Herd[2]	Year starts with these animals								Year ends with these animals - survivors after mort rate applied								End of year		
Age-sex classes	Adult Ewes(E)	2 yr E	1 yr E	E Lambs	adult Rams(R)	2 yr R	1 yr	R Lambs	Adult E	2 yr E	1 yr E	E Lambs	Adult R	2 yr R	1 yr R	R Lambs	Total census	Lambda	% growth
Mort rate	0.05	0.05	0.05	0.15	0.05	0.05	0.05	0.15											
birth rate	0.95																		
Year1	20	0	0	10	2	0	0	9	19	0	0	8	2	0	0	8	37		
Year2	19	0	8	9	2	0	8	9	18	0	8	8	2	0	8	8	52	1.41	0.41
Year3	18	8	8	9	2	8	8	8	17	8	8	8	2	8	8	7	66	1.27	0.27
Year4	25	8	8	12	10	8	7	12	24	8	8	10	9	8	7	10	84	1.27	0.27
Year5	32	8	10	15	17	7	10	15	30	8	9	13	16	7	9	13	105	1.25	0.25
Year6	38	9	13	18	23	9	13	18	36	9	12	15	22	9	12	15	130	1.24	0.24
Year7	45	12	15	21	31	12	15	22	43	11	14	18	29	11	14	19	159	1.22	0.22
Year8	54	14	18	26	40	14	19	25	51	13	17	22	38	13	18	21	193	1.21	0.21
Year9	64	17	22	30	51	18	21	31	61	16	21	25	48	17	20	26	234	1.21	0.21
Year10	77	21	25	37	65	20	26	36	73	20	24	31	62	19	25	31	285	1.22	0.22

Theoretical Wild pop#1[3]	Year starts with these animals								Year ends with these animals - survivors after mort rate applied								End of year		
	Adult E	2 yr E	1 yr E	E Lambs	adult R	2 yr R	1 yr R	R Lambs	Adult E	2 yr E	1 yr E	E Lambs	adult R	2 yr R	1 yr R	R Lambs	Total census	Lambda	
Mort rate	0.12	0.14	0.14	0.56	0.12	0.14	0.14	0.56											% growth
birth rate	0.9																		
Year1	20	0	0	9	2	0	0	9	18	0	0	4	2	0	0	4	28		
Year2	18	0	4	8	2	0	4	8	16	0	3	4	2	0	3	4	32	1.14	0.14
Year3	16	3	4	7	2	3	4	7	14	3	3	3	2	3	3	3	34	1.06	0.06
Year4	17	3	3	8	5	3	3	7	15	3	3	4	4	3	3	3	38	1.12	0.12
Year5	18	3	4	8	7	3	3	8	16	3	3	4	6	3	3	4	42	1.11	0.11
Year6	19	3	4	9	9	3	4	8	17	3	3	4	8	3	3	4	45	1.07	0.07
Year7	20	3	4	9	11	3	4	9	18	3	3	4	10	3	3	4	48	1.07	0.07
Year8	21	3	4	9	13	3	4	10	18	3	3	4	11	3	3	4	49	1.02	0.02
Year9	21	3	4	9	14	3	4	10	18	3	3	4	12	3	3	4	50	1.02	0.02
Year10	21	3	4	9	15	3	4	10	18	3	3	4	13	3	3	4	51	1.02	0.02

Theoretical	Year starts with these animals	Year ends with these animals - survivors	Total	End of year

Wild pop#2[4]									after mort rate applied								census		
	Adult E	2 yr E	1 yr E	E Lambs	adult R	2 yr R	1 yr R	R Lambs	Adult E	2 yr E	1 yr E	E Lambs	adult R	2 yr R	1 yr R	R Lambs		Lambda	% growth
Mort rate	0.1	0.1	0.1	0.25	0.1	0.1	0.1	0.25											
birth rate	0.9																		
Year1	20	0	0	9	2	0	0	9	18	0	0	7	2	0	0	7	34		
Year2	18	0	7	8	2	0	7	8	16	0	6	6	2	0	6	6	42	1.24	0.24
Year3	16	6	6	7	2	6	6	7	14	5	5	5	2	5	5	5	46	1.10	0.10
Year4	19	5	5	9	7	5	5	9	17	4	4	7	6	4	4	7	53	1.15	0.15
Year5	21	4	7	9	10	4	7	9	19	4	6	7	9	4	6	7	62	1.17	0.17
Year6	23	6	7	10	13	6	7	10	21	5	6	7	12	5	6	7	69	1.11	0.11
Year7	26	6	7	12	17	6	7	12	23	5	6	9	15	5	6	9	78	1.13	0.13
Year8	28	6	9	13	20	6	9	13	25	5	8	10	18	5	8	10	89	1.14	0.14
Year9	30	8	10	14	23	8	10	14	27	7	9	10	21	7	9	10	100	1.12	0.12
Year10	34	9	10	15	28	9	10	15	31	8	9	11	25	8	9	11	112	1.12	0.12

[2]Captive herds - mortality and reproduction figures typical for several captive herds (average of Bighorn Institute CA, Red Rock NM, Ft Collins CO, Sybille WY).

[3]Theoretical population #1 - average mortality rates from 1986-89 in Lee Vining, Chow 1991.

[4]Theoretical population #2 - Lamb mortality = half of wild population #1; other age class mortalities = 0.1

Table Interpretation:

The captive herd in this simplistic analysis grows in numbers much faster than either of the two theoretical populations - census numbers climb faster, lambda and % population growth are higher. This is due to a higher recruitment rate and lower age-specific mortality rates for the captive herd than the wild populations. Census numbers for theoretical wild population #1 remain nearly static during the last five years of the simulation, barely gaining one animal per year and with lambda values approaching 1 (no growth). With careful management of a captive facility, mortality and random demographic events can be minimized, while reproduction is maximized. See the population modeling section for more detailed and realistic models that incorporate random fluctuations in demographic rates and probabilities of catastrophic events.

Recommendations for Data Collection

For Free-ranging Populations:

Data gathering and preliminary population modeling is a continual and additive process. Every year, the following factors that may influence population recovery should be identified and estimated:

Determine current demographic information for each population: including rates for population growth, cause-specific mortality, birth rates, lamb survivorship / age-specific recruitment. Radiotelemetry of bighorn sheep and predators is very important.

Genetic monitoring, as initiated by Dr. Wehausen and Dr. Ramey, including individual identification and estimates of population- and metapopulation-level heterozygosity indices, effective migration rates, etc.

Estimate minimum viable population (MVP) size for each population. This point may be subject to debate: is it really possible to determine MVP given that variation in vital rates or frequency/degree of catastrophes is never really known? Is it really important to know what the MVP is or is it better to compare management options in a relative sense?

Estimate current habitat area and carrying capacity (K) for each extant population habitat, with and without winter range use.

Determine causes of winter range use patterns. Monitor lion, coyote, dog, bear, and human activity in proximity to bighorns and bighorn activity and movement patterns (need radiocollared bighorn).

Population Viability Analyses with modeling, at both the individual population level and metapopulation level, to predict the effects of management actions (ex, predator control, translocation and captive breeding). Initially use existing demographic data for Sierra and data from other populations living under similar conditions, then update models as more Sierra Nevada data becomes available.

Determine sustainable harvest parameters for candidate populations for source stock for translocations and captive breeding.

Decide the number of radiocollared bighorn sheep that are necessary to answer demographic and health questions.

With new monitoring data, revise current status, recovery goals and actions.

For Captive Herd:

Monitor lamb-ewe associations, age- and sex-specific survivorship and mortality rates, cause-specific mortality, reproductive rates, disease agent incidence and prevalence, genetics of herd (molecular DNA analyses, monitor for inbreeding, etc), behavioral responses to human activity and management changes.

Experimental or observational comparisons of wildlife disease surveillance methods.

Research ideas and recommendations

In addition to supplying new animals for translocation and to protect the Sierra Nevada metapopulation from extinction, the captive herd could be used for research. Until Sierra Nevada sheep were no longer endanger of extinction, the research would be a secondary function and should not interfere with the health and reproduction of the captive animals.

Included below are a few ideas:

1. Evaluate tracking methods: GPS collars, satellite collars, transponders, etc
2. Evaluate nutritional requirements, experiment with supplemental rations .
3. Test whether nutritional plane is correlated with birth sex ratio.
4. Test the stress responses of bighorn sheep to human activities.
5. Evaluate vaccinations and other treatments that may improve health of wild and captive bighorn sheep.
6. Compare genetics of captive herd with wild populations. Microsatellite, mitochondrial, and other DNA analyses conducted over time to evaluate potential for inbreeding, etc.
7. Compare short- and long-term survivorship and recruitment of captively bred animals that are translocated to the wild with wild-caught translocates.
8. Evaluate behavioral responses to proximity of predators and humans.

Decision Trees
for Augmentation and Captive Breeding of Sierra Nevada Bighorn Sheep

Introduction

Decision analysis has been used to advantage in endangered species recovery planning (Maguire et al 1988; Soule 1989). Use of decision trees is a useful component of this type of analysis. To decide whether captive breeding of Sierra Nevada bighorn sheep should be established, there are two main questions that need to be answered.

1) Is a captive herd necessary to provide sufficient translocation stock to supply projected needs to recover Sierra Nevada bighorn sheep?

2) Is a captive herd necessary to buffer against catastrophic events that could cause extinction of all Sierra Nevada populations?

These decision trees were designed to assist CDFG and the Sierra Nevada Bighorn Sheep Recovery Team in evaluating these questions. If the team finds them useful, over time, the trees should be adapted to incorporate new information and the changing needs of the team.

Use of decision tree

Assess each individual Geographic Conservation Unit (GCU) (or population, which ever unit is appropriate) at the Tree #1, by sequentially following the steps listed. Next, go to Tree #2 to assess the entire Sierra Nevada bighorn sheep metapopulation(s) unit. Prioritize each existing GCU in relation to the entire Sierra Nevada bighorn sheep unit. Prioritize potential sites and make decisions for reintroductions (locations, founder numbers, etc). Assess existing populations for source and recipient populations for augmentation, captive breeding, and reintroduction. Assess the risks/benefits of captive breeding to provide individuals for translocation and as an additional population to buffer against catastrophic events that could cause extinction of all Sierra Nevada populations. Use population modeling (see following modeling sections) where helpful to predict population viability given various management scenarios.

Recovery Goals

Step 1 Have Recovery Goals for down-listing been met?

Table 1. Recovery goals as proposed in June 2000 draft recovery plan (refer to the most current draft of recovery plan for details and updated figures, USFWS 2000):

Total # adult females in Sierra Nevada	365
Total # Herds	13
Geographic conservation units (GCU)	4
# Herds and Adult Females in each GCU	See Recovery Plan
Minimum Herd Size	See Recovery Plan

1A If all of recovery goals for down-listing have been met, then move to the de-listing recovery plan and re-evaluate steps to recovery.

1B If all of recovery goals for down-listing have not been met, go to Tree #1

Table 2. Current Status (for updated figures, see current SNBS population status report, USFWS 2000 in prep):

Total # adults in Sierra Nevada	~150
Total # adult ewes in Sierra Nevada	~40-60
Currently occupied GCU's	3
Total # herds	5-6 disjunct populations
Herd size (# adults)	1 to 50 total sheep
# of adult ewes per population	~1-20

Decision Tree #1:
Individual GCU Decision Tree
for Population Augmentation and Captive Breeding

For each Geographic Conservation Unit (GCU), proceed through the decision tree starting with Step 2 (Step 1 was on previous Recovery Goals page). For the use of this tree, "population" may be substituted for "GCU". Once all GCU's have been assessed, go to the Tree #2 and prioritize each GCU in relation to the overall Sierra Nevada unit. Values that need to be defined by the recovery team are noted by ***pink or gray X***.

Step 2

Are the past and current causes of GCU population decline known?

Can the annual rate of population increase be calculated or estimated for each GCU for each of the past 2-5 years? Decide on best indices to gauge population trend (here, lambda is used, but consider other indices including adult and lamb survivorship, total # ewes, recruitment rate, etc). Use caution if lamb survival or recruitment are used as population trend indicators. Recruitment may be high in the face of a declining pop if adult survival is low - see Peninsular Range bighorn sheep situation for an example).

2A If yes, conduct individual and Sierra-wide population modeling to predict future population viability and estimate the effects of management actions to reduce population decline; continue to gather information and monitor each GCU, and go to Step 3.

2B If no, collect basic information as quickly as possible, then go back to 2A. If any of the GCU's are declining rapidly, proceed through 2A as best as possible, even in the face of insufficient data - immediate actions may be necessary to reverse the decline and/or save individuals.

Step 3

Does the GCU contain less than the downlisting criterion number of adult ewes?

3A If yes, is the population showing signs of recovery? And is the GCU self-sustaining without augmentation, supplemental feeding, or predator control (use modeling and evaluation of population indices)? If yes to these questions, complete Tree #1 for all other extant populations, enter GCU information into the Table 3, and continue with Tree # 2.

3B If no, go to Step 4

Step 4 *~If you arrived here, then the GCU is small - has less than the minimum # adult ewes required for downlisting~*

Estimate the optimum population growth rate (lambda) in the wild that would be biologically and practically possible for each GCU.

Is the current estimate for lambda lower than optimum?

4A If yes, go to Step 5

4B If no, then the GCU is growing at the optimum rate. Consider augmentation if adult ewe numbers are much less than the downlisting criterion (***figure to be defined by recovery team***). However, the team may decide that the population is not immediately at risk, and a few years of growing may be adequate.

The GCU may serve as a source for reintroductions in a few years. Complete Tree #1 for all other extant populations, enter GCU information into Table 3, and continue with the Tree #2.

Step 5 What is the principle cause(s) of inadequate population growth (reduced lambda) for the GCU?

5A If **PREDATION** is a principle cause of decline, go to Step 6

5B If **DISEASE** is a principle cause of decline, go to Step 10

5C If **DEMOGRAPHIC STOCHASTICITY** is a principle cause of decline, go to Step 11

5D If **NATURAL CATASTROPHIC EVENTS** are principle causes of decline, go to Step 12

5E If **HUMAN-CAUSED EVENTS** are principle causes of decline, go to Step 13

5F If the principle cause of decline is **UNKNOWN** or has **NOT YET BEEN LISTED**, go to Step 14

Step 6 *~If you arrived here, then the GCU is small, and **PREDATION** is the current primary cause of reduced lambda~*

Can predation be controlled sufficiently to allow GCU to grow well (i.e., increase lambda)?

6A If yes, go to Step 7

6B If no, reassess predator control measures. Go to Step 8.

Step 7 *~If you arrived here, then predation control will improve GCU growth rate~*

Do you predict that the population will have at least the number of adult ewes listed in the downlisting goals within ***X*** years given that predation control is enacted?

7A If yes, institute and maintain predation control for ***X*** years; no augmentation should be necessary for this population at this time; go back to step 5 for secondary causes of reduced lambda (assess whether there are additional steps to improve population growth); continue to closely monitor and reevaluate population several times per year. Once the population reaches the downlisting criterion number, consider the consequences of stopping or reducing predation control. If predation control for greater than **X** years is necessary for the population to be self-sustaining, reevaluate the recovery plan, decision trees, and causes of high predation.

7B If no, reassess the primary causes of decline and predation control measures, go to Step 8.

Step 8 *~If you arrived here, then population augmentation should be considered~*

Will recovery of the population be improved by augmentation (as determined by population modeling)?

8A If yes, estimate the level and frequency of augmentation that will be needed. Population modeling will help with this; then go to Tree #2 and Augmentation Decision Tree. These populations will likely be small, less than **X** ewes.

8B If no, the primary cause is not sufficiently controlled; augmented animals may just feed the primary cause or augmented animals may not be effective for other reasons. Go to Step 9.

Step 9 *~If you arrived here, then the population is small and augmentation will not improve population growth rate~*

Will continued on-site recovery measures (see glossary; e.g. recovery measures against primary causes of population decline, predation control, etc) for a longer time than X years allow population to reach at least **X** ewes? Population modeling will help make these decisions.

9A If yes, after evaluating the GCU in the context of the entire Sierra unit, consider the following options:

9A-I Continue recovery measures and close monitoring. Once the population reaches at least *X* adult ewes, consider the consequences of stopping or reducing the recovery measure(s) (ex, predation control). If recovery measure for >***X*** ? years is necessary for the population to be self-sustaining, reevaluate the decision tree and the causes of high predation. If recovery measures can be stopped without resulting in a population decline once population reaches *X* ewes, go back to Step 3.

9A-II If the length of time required to meet recovery goal is excessive and population is too small, perhaps maintaining a bighorn sheep GCU at that location carries too much risk and individual animals within the entire GCU should be moved elsewhere. Consider emergency rescue for:

a) either to a captive refuge for genetic banking and/or breeding for translocation elsewhere; or

b) translocation to another wild location, either augmentation or reintroduction, where the sheep would be predicted to do better.

9B If no, consider removal of animals from that site for translocation to a safer site (see 9A-II)

Step 10 *~If you arrived here, then the primary cause of decline is **DISEASE**~*

Consult with the CDFG bighorn sheep wildlife veterinarian. Consider options for recovery, depending on specific disease (*Pasteurella* pneumonia, contagious ecthyma, Psoroptic mange, toxic plants, etc). Consider capture for captive rehabilitation; treatment in the wild; removal of toxic plants; vaccination; no action and let disease run course; temporary supportive care in the wild (such as supplemental feeding); etc. Prevent contact with livestock, especially domestic sheep. Also, go to Step 8 (caution - depending on timing of disease course and treatment, augmentation may help or just feed the disease). If disease is the cause of decline in one or more GCU's, avoid mixing individuals coming from different populations (in captivity or via translocations).

See also Emergency Rescue.

Questions to consider: Can the animals be treated effectively in captivity? Can the treated animals be released back to the wild without threat of transmission to other bighorn sheep in the wild or to other wildlife species? If not, can the offspring of the treated animals be released to the wild? What is the cost-benefit of treating the diseased animals? Would effort be better placed with other populations not experiencing the disease? What is the risk (to other populations) of leaving the diseased animals in the wild?

Step 11 *~If you arrived here, then the primary cause of decline is **DEMOGRAPHIC STOCHASTICITY**~*

Consider whether there are any recovery measures (ex, supplemental feeding to correct skewed sex ratio) other than augmentation alone. Go to back to Step 8

Step 12 *~If you arrived here, then the primary cause of decline is high level of mortality and/or morbidity from **NATURAL CATASTROPHIC EVENTS**, such as avalanches (death and injury), severe drought (poor forage leading to malnutrition and poor recruitment), prolonged rain (predispose lambs to pneumonia), etc~*

Consider recovery actions to reduce the risk of natural catastrophic events. Examples: predict high risk avalanche sites and ask agency with land jurisdiction to mitigate to reduce risk of avalanches; set out supplemental food and water during severe drought; etc. Improve habitat (prescribed burns, etc) and prevent further habitat loss. Evaluate the risks and benefits of mitigation vs. no action, in relation to the GCU and entire Sierra Nevada bighorn sheep unit. Also go to Step 8 expect to plan these catastrophes into recovery. If recovery criteria are not high enough to allow the GCU to withstand these types of catastrophes, then need to refigure recovery criteria

Step 13 *~If you arrived here, then the primary cause of decline is high level of mortality* *and/or morbidity from* ***HUMAN-CAUSED EVENTS****, including vehicle strikes, poaching, harassment, etc~*

Prevent all human-caused events as much as possible. Warden patrols, road signage, hiker education, etc. Improve habitat (prescribed burns, etc) and prevent further habitat loss. Also go to Step 8. Augmentation should not be a substitute for good habitat management / human disturbance control.

Step 14 *~If you arrived here, then the primary cause of decline is* ***UNKNOWN*** *or has* ***NOT YET BEEN LISTED****~*

Go to Recommendations for data collection and look further for a cause. Reduce the effects of suspected causes if possible (do risk assessment and cost-benefit analysis on recovery actions first) and go to Step 8.

Decision Tree #2: for Entire Sierra Metapopulation (Multiple GCU's) for Captive Breeding

After completing Tree #1, fill out the Table 3 for each Geographic Conservation Unit (GCU). If information is not available for specific GCU's, then use available information from similar Sierra Nevada populations, and apply population modeling. Values noted by ***pink or gray*** represent values to be defined by the recovery team. Then go to Step 1 of this tree.

Step 1 *~If you arrived here, then* ***bighorn sheep numbers in the Sierra Nevada are below downlisting (or delisting) level~***

From Table 3, is the total # of ewes in the Sierra Nevada below the ***critically low number*** (as defined by the Recovery Team; the number at which population extinction is an imminent threat)? Is there an overall ***decreasing trend*** in total number (as defined by the Recovery Team; a sustained decrease in population number)?

1A If yes to either of the questions above, consider emergency captive breeding

1B If no, go to Step 2

Step 2

From Table 1, are more than *X* of the GCU's showing declining trend in lambda?

2A If yes, consider emergency captive breeding

2B If no, go to Step 3

Step 3

From Table 1, determine the total # of individuals (ewes, rams) needed each year for:

3A Augmentations each year? ______

3B Reintroductions each year? ______

3C Total each year ______

Step 4

From Table 1, determine the total # of individuals (ewes, rams) that could be sustainably harvested each year from existing SNBS populations to provide individuals for:

4A Augmentation? ______

4B Reintroduction? ______

4C Total each year ______

Step 5 Is 4C greater or equal to 3C?

5A If yes, then there are currently enough wild individuals available for all augmentation and reintroduction needs. Reevaluate several times per year. Continue with decisions based on recovery plan; if desired, construct Augmentation Decision Tree and Reintroduction Decision Tree.

5B If no, there aren't currently enough wild individuals available for all augmentation and reintroduction needs. Go to step 6

Step 6 *~If you arrived here, then there are not enough wild individuals available for reintroduction~*

Is 4A greater or equal to 3A?

6A If yes, then there are currently enough wild individuals available for augmentation needs, but not enough wild individuals available for reintroduction.

Can reintroduction wait for a couple years? Will there soon be more wild individuals available for reintroduction? If not, consider captive breeding.

6B If no, there are currently not enough wild individuals available for augmentation needs. Are there enough wild individuals available for some augmentation? If so, set the priorities for augmentation.

Do you predict that within ***X*** years, there will be enough wild individuals available for all augmentations? If not, consider captive breeding.

Table 3. Sierra GCU / population status and translocation plan

Fill in and use this table to help prioritize populations for recovery actions.

GCU or population name	Priority for conser-ation1	# adult ewes present	List recovery actions	Trends in Lambda[2]				Augmentation Requirements[3]		
				monthly trend for current year	3-4 year trend	Primary factor causing decline	secondary factors causing decline	# Ewes	#Rams	Time interval
Langley										
Williamson										
Baxter-Black										
Baxter-Sand										
Baxter-Sawmill										
Wheeler										
Lee Vining-Tioga/Gibbs										
Lee Vining-Warren										
Reintroduction Site(s) as determined by recovery team - to be listed here		N/A		N/A	N/A	factors that may cause loss of transplants				

[1] Priority for conservation needs to be defined by recovery team. Modeling may help to determine where recovery effort is best spent (see Rubin et al in review)

[2] Lambda = annual rate of population increase.

[3] Augmentation Requirements: enter negative value if sustainable harvest is possible from the population; enter a positive value if the population needs augmentation. Positive values are the Recovery Team's estimates for number of bighorn sheep that are needed for augmentation in populations that are not growing fast enough to reach recovery goal within a specified time. Negative values are Recovery Team's estimates for number of bighorn sheep that can safely (without incurring increased extinction risk) be removed from a population that is doing well (estimated to approach recovery goals within a specified time) and be translocated to populations in need of augmentation, reintroduction, or to a captive herd.

CAPTIVE BREEDING FOR EMERGENCY RESCUE For Preservation - Salvage

Values to be defined by the SNBS Recovery Team are noted in ***pink or gray*.**

Reasons to initiate an emergency captive herd:

1. All or most GCU's/populations are in ***serious decline***, as defined by the Recovery Plan.
2. Total # of ewes in the Sierra is less than the ***critically low number*** (as defined by the Recovery Team; the number at which population extinction is an imminent threat).
3. When a ***high priority GCU*** is in danger of extinction. (see Tree #2)

In any case, an emergency captive herd should be founded when the cause(s) of decline can not be managed or decline is so rapid that management cannot take effect fast enough to recover the population.

Refer to the Facilities section of Captive Breeding Contingency Plan for details of starting and maintaining a facility.

How and when to take wild animals into captivity:

Step A Go to Table 3 and Step 2 of Tree #2 to assess which GCU's need emergency rescue.

From Table 3, is the total # of ewes in the Sierra <***X*** and/or is there an ***overall decreasing trend*** in total number?

That is, did you answer "yes" to Step 1 in Tree #2

A-1 If yes, the entire metapopulation may be collapsing. Consider immediate capture of representative individuals for captivity. If there are some GCU's/populations that are less affected by the cause of decline, consider leaving those individuals in the wild and increasing mitigation efforts there.

If the rate of decline is rapid, a large number of animals (>***20***), or large proportion of wild animals, may need to be taken into captivity very quickly. This management action will likely hasten extinction in the wild (by disrupting social structure, removing reproductive individuals, etc), leaving only the captive herd(s) as the last hope. Also, if the captive facility has not yet been tested using an initial small number of sentinel animals, there could be significant risk of failure of the capture herd.

If the decline is not rapid, a small number of animals (6-20) may be taken into captivity, over an extended period of time. By taking a smaller number into captivity, there will be less negative impact on social structures of animals left in the wild, and therefore the action may not hasten extinction in the wild. Also, if the captive facility has not yet been tested, then the first captive animals could serve as trial animals, and the facility improved as needed before additional animals were added. However, increasing numbers of introductions of bighorn sheep to the facility will increase the chance for disease introduction to the captive herd.

Proceed to Step B.

A-2 If you answer no to Step A, go to Step C

Step B *~If you arrived here, then the entire Sierra bighorn system is in immediate jeopardy~*

What are the causes and progression of population and metapopulation decline? Are different causes acting on different GCU's (independent dynamics)? Can any of the causes be reduced by management actions? See Step 5 of Tree #1 and Table 3 of Tree #2 to answer.

If disease is the cause of decline in one or more populations, avoid mixing individuals coming from different populations (in captivity or via translocations). More than one facility may be needed to prevent the spread of disease and to quarantine animals.

Additional questions to consider: Which sheep to take into captivity? Which to leave in the wild (at high risk of extinction)? Number of sheep to take into captivity, and at what frequency? Is detailed individual genetic and demographic data available?

Step C *~If you arrived here, then total # of ewes is not seriously low and there is not an overall decreasing trend in total number. However there is still a threat of extinction to the entire Sierra Nevada unit (metapopulation) because one or a few critical GCU's/populations are in severe decline~*

An example of this situation would include a rapid decline of the Wheeler Crest population (currently the only population of approaching >25 ewes), but the rest of the GCU's (all currently < 25 ewes) not declining.

Return to Tree #1 to explore the causes of rapid decline. If the decline cannot be rapidly reversed, consider capturing all members of the declining population for immediate translocation to another wild population; for reintroduction to a safer region; or take them into captivity for captive breeding or treatment (depending on the cause of decline). If the cause of decline is disease, consider capturing affected members of the declining population for treatment in captivity. Depending on the disease etiology, rehabilitated sheep could be released if treatment was effective and eliminated the cause.

Population Modeling

Introduction to Population Modeling for Sierra Nevada bighorn sheep

Strategies for the conservation of Sierra Nevada bighorn sheep using captive breeding were preliminarily examined using Vortex (version 8.41, Lacy 2000), a Monte Carlo simulation software program. Vortex helps to predict the viability of populations and illustrate the effects of forces that shape the dynamics of wildlife populations. These dynamics are driven by both deterministic (not random), as well as stochastic (random) forces that shape demographic, environmental, and genetic events.

To learn more about the Vortex program, visit the following web site: http://home.netcom.com/~rlacy/vortex.html.

Since this pilot set of models detailed is very preliminary and simplistic, they should be used only for initial guidance in decision-making. Models of the Sierra Nevada bighorn sheep populations should be reexamined and expanded periodically (at least once a year) to include more data as it becomes available. The Sierra Nevada bighorn sheep recovery team may consider running a set of models with input parameters decided by the group, and perhaps in more detail than the models presented here (see Model Ideas). The workshop should be lead by a person experienced in Vortex or other population viability program. The team may also consider inviting Dr. Ulysses Seal and Dr. Phillip Miller of the Captive Breeding Specialist Group (CBSG) of the IUCN to conduct a Population Health and Viability Assessment (PHVA) workshop for Sierra Nevada bighorn sheep. The CBSG PHVA program was used by the New Mexico Department of Fish and Game to plan desert bighorn sheep recovery, and also about 50 other endangered species teams.

Vortex is an excellent program, however, it does have some limitations on input and output parameters for population viability modeling. Additional modeling using programs written specifically for the Sierra Nevada bighorn sheep population may be useful for finer scale prediction and planning.

Wheeler Crest has been identified by the recovery team as the most likely wild population to serve as a source for translocation stock because it is the largest population and apparently is growing well (however data is limited). Using Vortex, the Wheeler population was examined the potential for population growth, genetic preservation, and population viability, with and without removal of varying numbers of sheep for translocation and/or captive breeding. Next, these factors were examined for the Baxter population (as a model recipient population) with and without augmentation. Augmentation was modeled as sheep translocated from either the Wheeler or captive population. Finally, a theoretical captive herd was modeled the viability, genetic preservation, and growth potential with varying levels of removals.

Model output variables included probability of extinction within 50 years, mean population size over time, inbreeding coefficient, loss of heterozygosity, and intrinsic population rate of growth (r). Data for Sierra Nevada bighorn sheep was not available for all necessary demographic input parameters for the models. Therefore, input parameters for the models were developed using advice and unpublished data from Dr. John Wehausen, Chow 1991, and estimates based on other populations of bighorn sheep (Fisher et al. 1999). For input parameters that lacked solid data, analyses were conducted to determine the sensitivity of the model to a range of input values. Input parameters are detailed in Model Input Page. The models were run for 1000 iterations, with population projections extending 50 years. Output results were summarized at 2 year intervals for use in tables and figures. For model output summary, see Model output summary. A deterministic comparison of wild vs. captive population growth rates, that was calculated independently of the Vortex models, is also presented in the Growth Rate Table.

Vortex Model Input Summary

The following input parameters were common to all modeled populations:

50 year simulations were run, with 1000 iterations run for each simulation. Vortex uses a random number generator to simulate random events in the life cycle of each animal, therefore no two iterations will be identical. Baseline models were run first - as the simplest model, with no removals or supplementations. Extinction was defined as only one sex remaining. To simplify, populations were modeled individually, therefore migration was ignored. Polygynous mating system was assumed. The age at first breeding was 3 years for females and 5 for males. The maximum breeding age was 14 years. The birth sex ratio was set at 50%. The maximum number of young per year was one. Reproduction is not assumed to be density dependent, however, density dependence trials were also run in preliminary trials not presented. Fifty percent of males were assumed to be in the breeding pool.

Initial models were run with and without incorporation of inbreeding depression and compared for outcome parameters. Inbreeding depression tended to slightly worsen the outcome results (decrease intrinsic population rate of growth (r), decrease mean population size at 50 years, etc). For this reason and because Sierra Nevada bighorn sheep exist in very small numbers that may be impacted by inbreeding depression, all of the models presented in the results here incorporate inbreeding depression. However, an unpublished study by Kalinowski and Hedrick (in review 2000; Hedrick personal communication) provided no evidence of inbreeding depression for captive bighorn sheep populations that were examined.

When inbreeding depression was incorporated, the number of lethal equivalents per diploid genome was input as 3.14. This value is unknown for bighorn sheep, therefore we used the average of mammals tested (Ralls et al. 1988). The percent of genetic load due to lethal alleles was 50%. Again this figure is unknown for bighorn sheep and most animals, 50% is representative of fruit flies (Simmons and Crow 1977) and considered by conservation geneticists (Miller and Lacy 1999) to be a first best estimate.

Environmental variation (EV) in reproduction was assumed to be concordant with EV in survival. The baseline models (01) were run assuming no catastrophic events occurred. Additional models (02) added a 5% probability (effectively once every 20 years) that a catastrophe that would reduce reproduction by 50% and survival by 25% for one year. Such an event could include an avalanche (as experienced by Sierra sheep populations) or disease epidemic (ex, Pasteurella pneumonia in wild or captive populations; bluetongue virus in captive herd). Future models could incorporate catastrophic events with more than one year of detrimental effects, such as loss of quality winter range for multiple years. In these preliminary models, we assumed no migration in or out of the population.

The Wheeler population was examined as the source for translocation and captive breeding stock. The Baxter population (with Sand, Sawmill, and Black lumped as one population) was modeled as the recipient of translocation stock either from Wheeler directly or from the captive herd. These models assumed that sheep translocated to Baxter from the captive herd or directly from Wheeler will survive and reproduce at the same rate as native Baxter sheep. Preliminary work from California (Steve Torres unpublished data), New Mexico (Fisher unpublished data) and the Bighorn Institute (Ostermann and DeForge unpublished data) indicate that there may be different survival and reproduction rates for wild bighorn sheep that are not translocated, sheep that are translocated among wild populations, and captive animals that are translocated to the wild. Future models and plans for translocation should incorporate data on survival and reproduction of translocated individuals. Also, these models do not incorporate a scenario where translocated animals caused health or demographic decline of the native population. Very careful planning, testing, and quarantine procedures should minimize that possibility. These models do not address social interactions (ewe group structure, lead ewe, etc) among native and translocated animals. These components should be factored into any management actions.

First set of models (-01 models):

	Models with optimistic mortality and reproduction rates[1]		
Parameter	Wheeler-01	Baxter-01	Captive-01
Starting pop size	48 (24F:24M)	34 (23F:11M)	8 (4F:4M)[2]
% Females breeding each year (SD[3])	90(5)	90(5)	95(5)
Mortality % (SD[3]) 0-1 year	25(5)	25(5)	15(3)
Mortality % (SD[3]) all other ages	10(2.5)	10(2.5)	5(1)
Carrying capacity[4] (SD[3])	150(10)	300(20)	100(10)
Catastrophe	None	None	None
For captive herd only, every 2 years from years 3-15, add 2 Females and 2 males (total founder stock = 36 animals).			

[1] These mortality and reproduction (% females breeding) rates represent "good years" for bighorn sheep dynamics in the wild. Mortality and reproduction rates for captive population was taken from an average of 3 existing captive bighorn sheep facilities.

[2] Starting population of captive herd was based on preliminary Wheeler population model runs that incorporated removal of 4 females and 4 males every 3 years.

[3] SD = standard deviation

[4] Carrying capacity values based on personal communication with Dr. John Wehausen.

Second set of models (-02 models):

These models incorporated a 5 % probability that a catastrophic event would reduce reproduction by 50% and survival by 25% for one year. Otherwise model inputs were the same as -01 models.

Third set of models (-03 models):

The mortality rates were doubled for 0-1 year olds and decreased % females breeding by 5%. Otherwise model inputs were the same as -02 models.

Each of the three sets of models were run with and without augmentation and/or removals. Wheeler-01, -02, and -03 models were run first without removal of any animals for translocation elsewhere. Then models were run with 4 adult females and 4 adult males removed once every 3 years for years 3-15. Baxter-01, -02, and -03 models were run first without any augmentation (translocation from Wheeler or a captive herd, for example). Then the models were run with addition of 4 adult females and 4 adult males once every 3 years from years 4-15. The Captive -01, -02, and -03 models were run first without removal of any animals. Then models were run with 6 adult females and 6 adult males removed once every 2 years for years 7-50. Equal numbers of rams and ewes were modeled for removal, augmentation, and foundation of the captive herd to avoid problems with ram-skewed sex ratios.

Vortex Output Summary

See Vortex Model Input Page for details on input parameters.

All of the model results presented below incorporated inbreeding depression. When these models were compared to models that did not incorporate inbreeding depression, the outcome variables listed below varied slightly (slightly more pessimistic outcome with inbreeding depression). Therefore, since Sierra Nevada bighorn sheep exist in very small numbers and may be subject to inbreeding depression, that parameter was incorporated. Results listed are the means and standard deviations (SD) of 1000 iterations.

Negative prognostic indicators (predicting a worse outcome) for population viability include lower intrinsic population rate of growth (r), increased standard deviation (SD) in r, increased % populations going extinct, decreased mean time to extinction (TE) increased % populations dropping below 30 animals, decreased mean population size, increased SD in mean population size, decreased retained heterozygosity over 50 years, increased year that the average population reached at least 80 animals, and increased year that the average population reached carrying capacity. Note that % populations going extinct was an *insensitive* indicator relative to the others, being one of last indicators to change when a modeled population was in trouble.

If the Wheeler population follows the trends of the Wheeler-01 or -02 models, it may be able to withstand a modest removal of bighorn sheep for translocation elsewhere. One disadvantage of the current Vortex program is that it does not allow a variable removal of animals over time. Management of this herd should incorporate an initial minimal removal of animals (for example, 4 ewes and 4 rams every 3 years) when deemed to present a minimal risk to the population. Following the initial removal, yearly evaluation of population growth rates, census sizes, and other population indices would help estimate the next safe time and number of animals to remove. If the Wheeler-03 model closely approximates the true Wheeler population trend, then removal of any animals may jeopardize future population viability.

With the Baxter-01 and -02 models, augmentation produced modest increases in population viability. In these cases, however, perhaps the populations would have grown well on their own, and augmented animals could have been more effectively used elsewhere. With the Baxter-03 model, augmentation was critical in reducing the threat of extinction.

Captive-01 and -02 model populations withstood removals well. The Captive-03 model showed reduced population viability due to removals. However, in a real well-managed situation, yearly reevaluation of the population viability of the herd would allow adjustment of timing and numbers of animals removed for translocation.

Dr. Philip Miller of the Captive Breeding Specialist Group (CBSG) of IUCN, recommended that heterozygosity should not drop below 90-95% of the original heterozygosity over about 100 years (personal communication; Ballou and Lacy 1995; Soule et al. 1986). The averages for captive herd models hover just over 90% after simulations of 50 years. This may indicate that the foundation herd of 36 animals, under the model conditions, is a minimum, and perhaps insufficient. Animals from the wild may be needed to supplement and preserve genetic diversity over the long term. Additional models and more data (particularly genetic data) from the Sierra Nevada may help define optimum number of animals to preserve genetic diversity. Programs such as the GeneDrop and Capacity segments of SPARKS (ISIS 1991) can be used to calculate the captive population size needed to maintain desired amounts of heterozygosity.

Table. Vortex model output results. Numbers in **red** **(or gray)** indicate extreme danger of extinction for modeled populations.

Model	# F:M[1] removed	# F:M[1] added	Frequency of removals(R) or additions(A)	r [2]	SD[3] of r	% pop going extinct[4]	Mean TE[5]	% pop <30 within 50 year[6]	Mean pop size at year 50 (extant)[7]	SD[3] mean pop size year 50	Mean % retained heterozyg at year 50[8]	Year avg pop size reached 80[9]	Year avg pop reached K[10]
Wheeler-01 No removals	0	0	0	0.091	0.060	0	>50	0	145*	9	94	6	14
Wheeler-01 Removals	4:4	0	(R) at year 3,6,9,12,15	0.077	0.070	0.2	25.5	3	145*	11	94	8	25
Wheeler-02 No removals	0	0	0	0.072	0.107	0	>50	0	139	18	94	6	>50
Wheeler-02 Removals	4:4	0	(R) at year 3,6,9,12,15	0.053	0.122	3.2	20	7	133	28	94	13	>50
Wheeler-03 No removals	0	0	0	**-0.002**	0.123	**5.9**	37.5	**34**	**62**	**41**	90	**>50**	**>50**
Wheeler-03 Removals	4:4	0	(R) at year 3,6,9,12,15	**-0.047**	0.185	**55.6**	**22.9**	**82**	**34**	**31**	**72**	**>50**	**>50**
Baxter-01 No Augmentation	0	0	0	0.093	0.061	0	>50	0	292*	16	95	10	25
Baxter-01 Augmentation	0	4:4	(A) at year 4,7,10,13	0.105	0.063	0	>50	0	292*	17	96	5	19
Baxter-02 No Augmentation	0	0	0	0.074	0.107	0	>50	0	277*	41	93	9	>50
Baxter-02 Augmentation	0	4:4	(A) at year 4,7,10,13	0.088	0.107	0	>50	0	282*	30	96	7	29
Baxter-03 No Augmentation	0	0	0	**-0.005**	0.134	**14.5**	**38.5**	**45**	**55**	**48**	**87**	**>50**	**>50**
Baxter-03 Augmentation	0	4:4	(A) at year 4,7,10,13	0.021	0.117	0.6	43.3	10	120	74	92	12	**>50**
Captive-01 No Removals	0	**	0	0.180	0.068	0	>50	0	98*	10	91	10	11
Captive-01 Removals	6:6	**	(R) every 2 years; years 4-50	0.138	0.090	0	>50	0	98*	9	92	11	13
Captive-02 No Removals	0	**	0	0.161	0.115	0	>50	0	96*	11	91	11	13
Captive-02 Removals	6:6	**	(R) every 2 years; years 4-50	0.118	0.130	0	>50	0	93*	14	92	13	16
Captive-03 No Removals	0	**	0	0.119	0.118	0	>50	0	92*	12	92	13	16
Captive-03 Removals	6:6	**	(R) every 2 years; years 4-50	0.059	0.137	1.0	39.7	**14**	**72**	**28**	91	**>50**	**>50**

* Population at or near carrying capacity, K

** 2F:2M added every 2 years from years 3-15

[1] F:M = Females:Males

[2] r = intrinsic population rate of growth. K = carrying capacity. "r for years prior to K truncation" = population growth rate, r, calculated only for years before the population reached carrying capacity.

[3] SD = standard deviation

[4] "% pop going extinct" = Percent of the iterations in which the population went extinct (had individuals of only one sex left).

[5] "Mean TE" = mean time to extinction in years.
[6] "% pop <30 within 50 years" = Percent of the iterations in which the population size declined below 30 total individuals at any time within 50 years. For the model conditions presented here, a population below about 30 total individuals (about 15 ewes) was highly susceptible to extinction.
[7] "Mean pop size at year 50 (extant)" = the mean population size at year 50 for only populations that are still extant (have not gone extinct).
[8] "Mean % retained heterozyg at year 50" = The percent remaining (mean of 1000 iterations) of the heterozygosity that a population started with.
[9] "Year avg pop size reached 80" = the number of years before the average population, of 1000 iterations, reached a total population size of 80. For the model conditions presented here, a population of at least 80 total individuals (about 40 ewes) is relatively resilient to forces of extinction, compared to populations of lesser sizes. Note that a certain number of populations in the models do not reach 80 within 50 years (data not shown).
[10] "Year avg pop reached K" = the number of years before the average population, of 1000 iterations, reached K. K = carrying capacity.

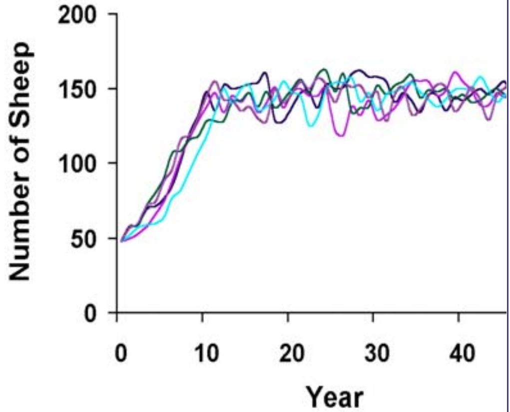
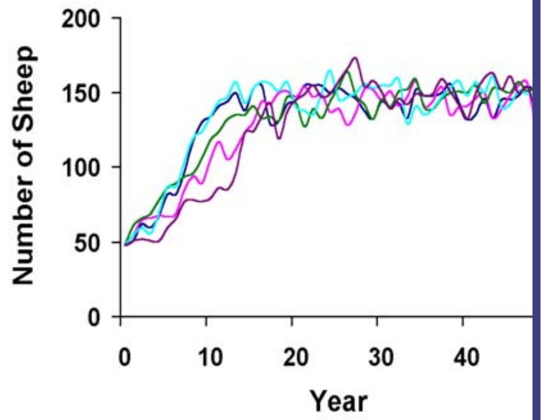
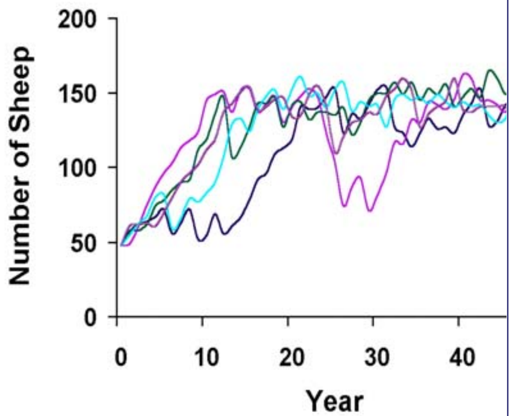
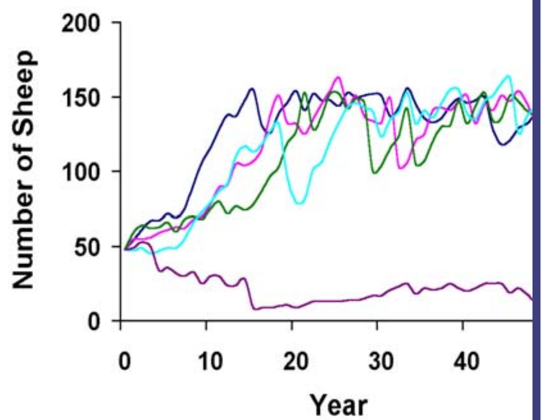
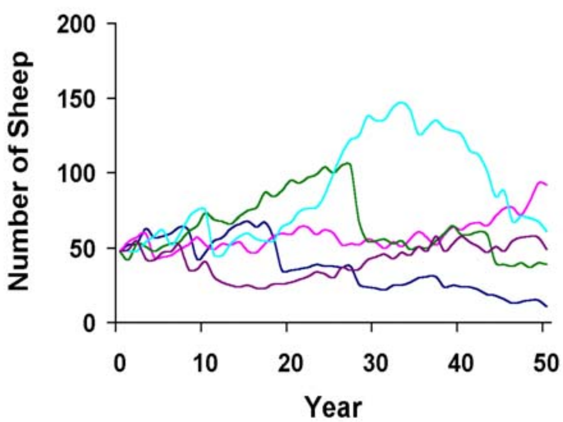
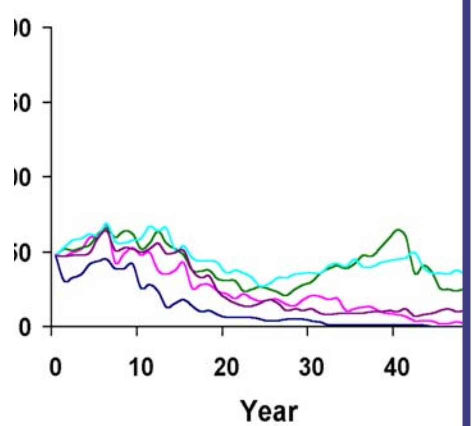
Vortex Charts-Wheeler

Population size prediction over 50 years

5 random iterations are shown (of the 1000 iterations that were run for each model simulation). These random iterations help to illustrate the general trends exhibited by each model. Since these graphs show only 5 out of 1000 possible outcomes, they do not illustrate the entire range of variation that occurred.

See table below.

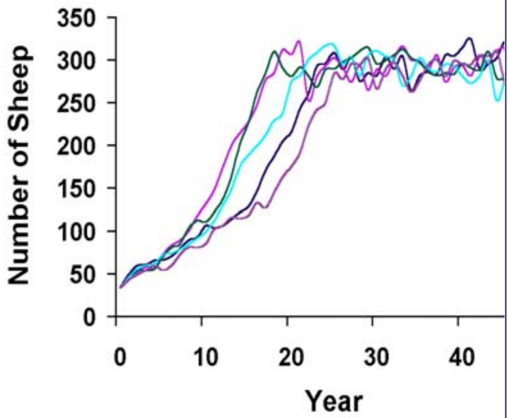
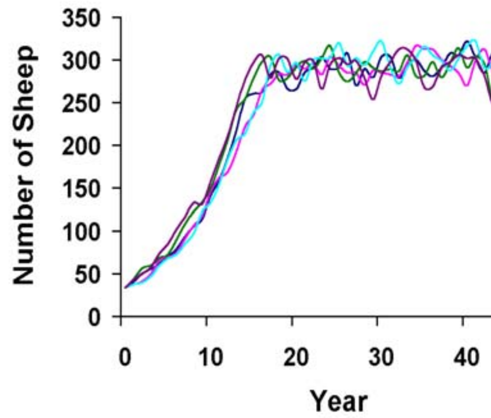
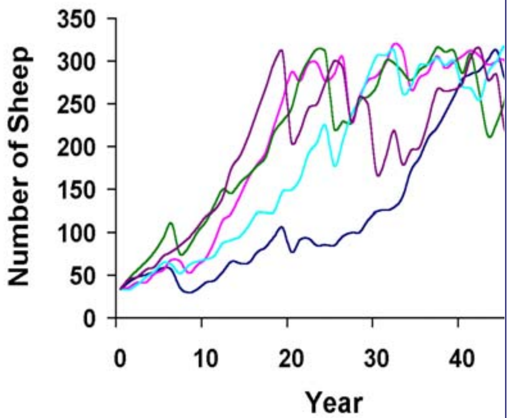
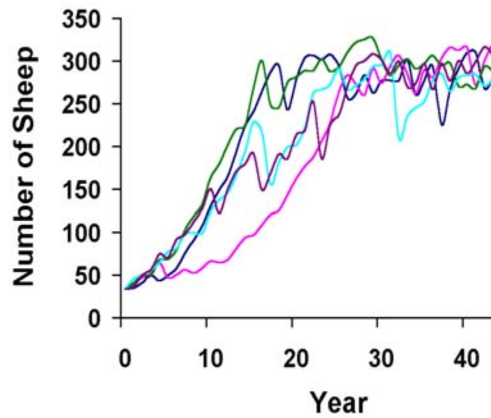
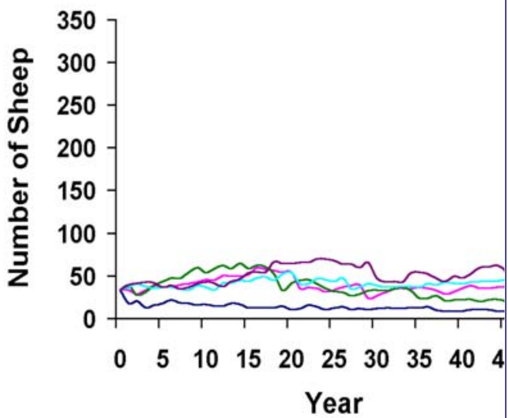
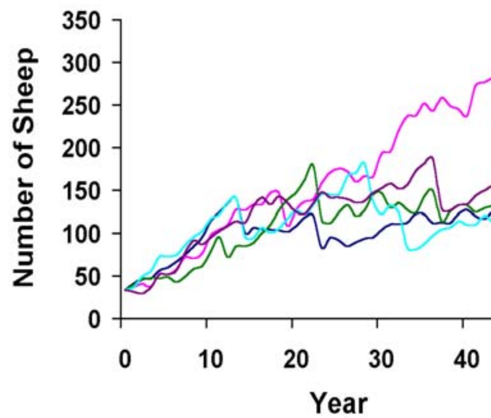
Population size at year 0 = 48; no augmentation

Model	No removals	Removals 4 adult F & 4 adult M Every 3 years from year 3-15 Except as noted by *
Wheeler-01 Model No catastrophes 75% first year survival 90% females breed each year		
	No removals	**Removals**
Wheeler-02 Model 5% probability of catastrophe 75% first year survival 90% females breed each year		
	No removals	**Removals**
Wheeler-03 Model 5% probability of catastrophe 50% first year survival 85% females breed each year		 *Removal year 7-15 every 3 years

Vortex Charts-Baxter

Population size prediction over 50 years
5 random iterations shown (of the 1000 iterations run)
Population size at year 0 = 34

See table below

Model	No augmentation	Augmentation 4 adult F and 4 adult M Every 3 years - from year 4-15
Baxter-01 **No catastrophes** **75% first year survival** **90% females breed each year**		
	No augmentation	**Augmentation**
Baxter-02 **5% probability of catastrophe** **75% first year survival** **90% females breed each year**		
	No augmentation	**Augmentation**
Baxter-03 **5% probability of catastrophe** **50% first year survival** **85% females breed each year**		

Vortex Charts:
Captive Herd

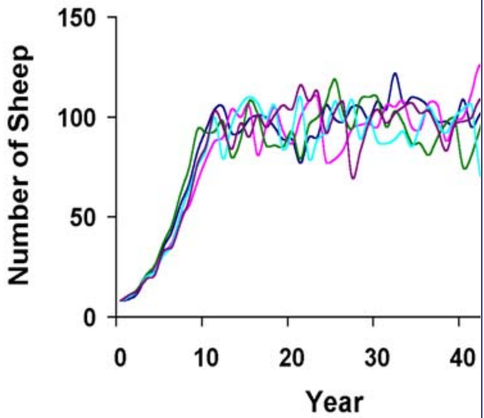
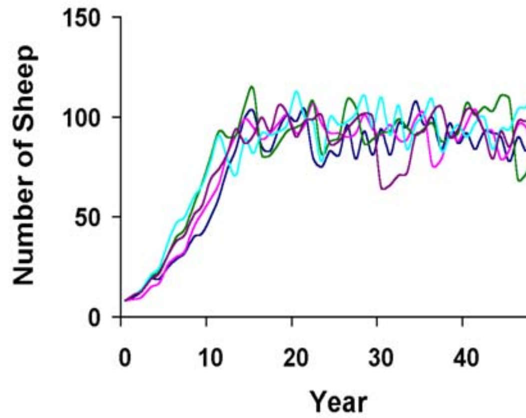
5 random iterations shown (of the 1000 iterations run).
Population size at year 0 = 8

See table below.

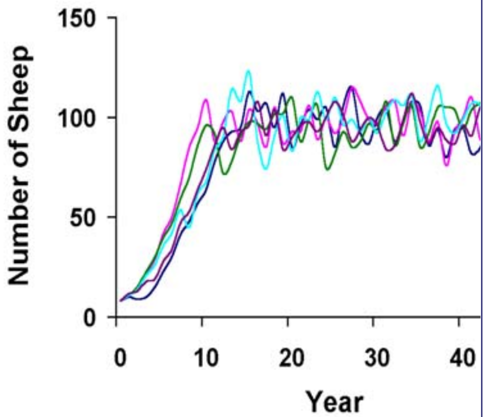
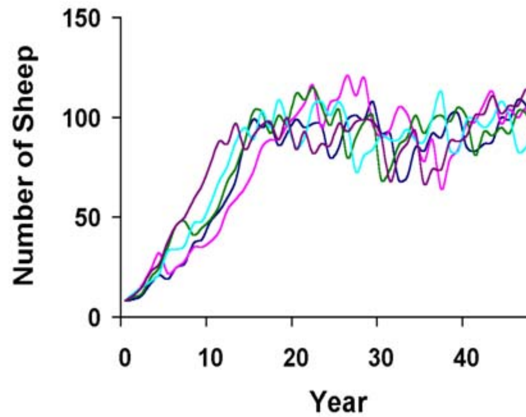
<table>
<tr><th>Model</th><th>No Removals</th><th>Removals
6 yearling F and 6 yearling M
Every 2 years from year 7 to 50</th></tr>
<tr><td>Baseline model

No catastrophes

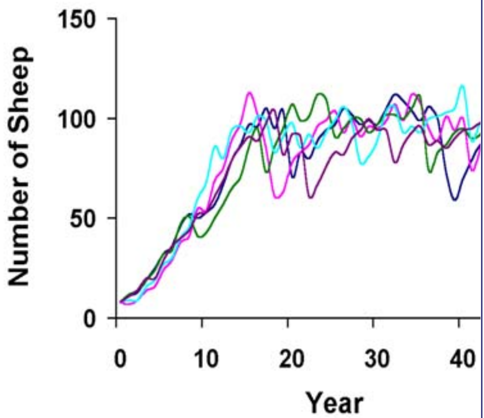
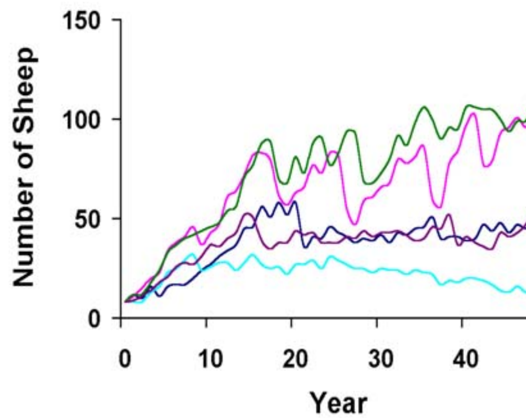
85% first year survival

95% females breed each year</td><td>
</td><td>
</td></tr>
<tr><td></td><td>No removals</td><td>Removals</td></tr>
<tr><td>5% probability of catastrophe

85% first year survival

95% females breed each year</td><td>
</td><td>
</td></tr>
<tr><td></td><td>No removals</td><td>Removals</td></tr>
<tr><td>5% probability of catastrophe

70% first year survival

85% females breed each year</td><td>
</td><td>
</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

Population Modeling Conclusions

The main points demonstrated by this modeling exercise are:

1) Data for Sierra Nevada bighorn sheep are needed to provide accurate predictions of outcomes with and without management actions. These data include rates for age-specific and cause-specific mortality, reproduction and recruitment; reproductive and survival success of translocated and captive bred animals; population genetics; long term information on climate and potential catastrophic events; risk assessments for disease transmission among bighorn sheep populations and domestic and wild animals.

2) Although much data is lacking to accurately predict population viability for Sierra Nevada bighorn sheep populations, these preliminary models give an indication of a range of management options that may be available to increase population viability.

3) The Wheeler population has been identified by the Sierra Nevada Bighorn Sheep Recovery Team as perhaps the only current possible wild source of translocation stock. However, even though this is the largest of the Sierra Nevada populations, this population has been shown by these models to have a potentially tenuous future. When the population is modeled with moderate probabilities of catastrophes, realistic mortality and reproduction rates (such as with Wheeler-02 and -03 models), significant proportions of modeled populations decline even without removal of animals. When even the modest removal of 8 animals every 3 years is added, there is a serious risk of population extinction in the modeled population.
Population managers should examine the population dynamics of the Baxter population(s) from 1970's-80's in relation to bighorn sheep removal for translocation. In that case, removals were conducted for translocations (Bleich et al 1990; Wehausen 1984). Perhaps concurrent with removals was an increase in mountain lion predation. The Baxter population proceeded to decline sharply (Status of Bighorn Sheep in California, Desert Bighorn Council Transactions 1989, 1994, 1996). Whether or not lion predation was the proximate cause of decline, the translocation removals may have been a strong precipitating factor. Although the situation for the Baxter population(s) was likely different twenty years ago that it is for the Wheeler population today, valuable lessons may be learned that may help prevent a population decline that coincides with removals.

4) The Baxter population has been identified by the Sierra Nevada Bighorn Sheep Recovery Team as a potential candidate population for augmentations. As modeled here, the Baxter population may (Baxter-03 model) or may not (Baxter-01 and -02) benefit greatly from the amount of augmentation that would be allowed through removals from the Wheeler population. If the Baxter population is shown to be growing rapidly without intervention, animals added via translocation may not help population viability. This may be particularly true considering that the Wheeler animals were translocated from the Baxter group and therefore are close genetic relatives. In that case, perhaps the augmented animals could have been more effectively used elsewhere. With the Baxter-03 model, even the modest amount of augmentation was critical in reducing the threat of extinction. The augmentation used in these models assumes that all of the translocated animals function the same as native animals. As mentioned on Model Input Page, there is evidence to indicate that animals that are

translocated into a population may have poorer reproductive and survival success than animals native to the population.

5) A captive herd is likely to provide a larger, more stable source of translocation stock than the Wheeler population by itself. Because a captive herd, as modeled, is protected from high levels of environmental variation, it may withstand an increased level of removal for translocation than can the Wheeler population. Removing a few animals from the wild every few years to found a captive herd early in the recovery program may remove the dependence on the Wheeler population as the sole provider of translocation stock. However, if wild populations in the Sierra Nevada experience stable and favorable conditions over the next 10-20 years, a captive herd would not be needed. That set of conditions, unfortunately, cannot be predicted.

6) Care should be taken to avoid creating a skewed sex ratio through translocation of animals. When removing animals from a population for translocation elsewhere, the number of rams added and ewes removed should not greatly increase the ram:ewe ratio in the source or recipient populations. Similarly for the captive herd, rams should be released regularly along with ewes to prevent excessive numbers of rams in the facility.

Wheeler Model Update
October 4, 2000

With an updated estimate of the Wheeler bighorn sheep population (perhaps 31 ewes, personal communication, Dr. John Wehausen, September 10, 2000), preliminary stochastic models were run to examine extinction probability, population size, and maintenance of genetic variability over time. The VORTEX models were run with the same inputs as listed on the Model Input Page with the exceptions noted. Again, noting the many assumptions that these models incorporate, largely due to lack of data and environmental variability, the Wheeler population may not safely support sustained removal of sheep for translocation. If conditions are highly favorable over decades, removal of 6 ewes per year every 2 years for the first 10 of 50 years may not incur a significant extinction risk. However, if conditions are variable and recruitment is less favorable (more realistic for many bighorn sheep populations with small population sizes), this amount of removal will likely incur a significant risk of extinction, loss of genetic variability, and reduction in population growth. Two sets of models are used to illustrate these effects:

Highly favorable conditions:

The first model (Wheeler -04A) was run as in Wheeler -01. Initial population size was set at 62 (31 ewes, 31 rams, assuming a stable age distribution). The percent of breeding females was set at 95% with 5% standard deviation (SD) and lamb (age 0-1 year) mortality set at 21% with 5% standard deviation, no catastrophes, no inbreeding depression, and no removals (very optimistic values - may not be realistic). The modeled population grows very well over 50 years (r = 0.115, SD=0.056, reaches carrying capacity within 10 years) with no extinctions noted in 1000 iterations. Ninety-five percent of the initial heterozygosity is retained over 50 years.

When this optimistic -04A model was run with removal of six ewes (2 ewes each of ages 1 and 2 years, and adults) once every 2 years for the first 10 years, the modeled population experiences a slower and more variable growth in numbers (r=0.99, SD=0.064). The average modeled population does not reach carrying capacity until after 20 years.

Less favorable, but realistic conditions:

A series of models was run, each adding an additional element of less optimistic demographic value or environmental stochasticity to the base Wheeler04A model. Model Wheeler -04P was run with a 5% probability of a catastrophe (as in Wheeler-02 models), 85% (SD=5%) of the adult ewes giving birth each year, lamb mortality of 30% (SD=10%), and no removals. Population growth declined and was much more variable in the average iteration (r=0.059, SD= 0.107), when compared with the -04A optimistic model. Ninety-four percent of the initial heterozygosity was retained by the average population after 50 years, and none of the 1000 iterated populations went extinct. However, removal of 6 ewes every 2 years for the first 10 years increased the risk of extinction from 0 to 7% (73 extinctions out of 1000 iterations), the average population did not reach carrying capacity, retained heterozygosity dropped to 89%, and growth rate slowed dramatically (r=0.031, SD=0.124).

Ideas for additional models to assist evaluation of alternative management strategies

1. Update the models presented here with latest demographic data.
2. Perform more detailed sensitivity analyses on input parameters.
3. Construct metapopulation models with migration.
4. Incorporate models with mountain lion predation and predation control incorporated.
5. Incorporate the latest genetic data on Sierra bighorn sheep.
6. Incorporate data on reproductive and survival success of translocated animals.
7. Write models specific to the Sierra Nevada metapopulation, rather than using an existing program such as Vortex.

Facility & Site Information

Captive Breeding Site Selection

The captive breeding site and facility should allow optimum maintenance of behavior, physiology, nutrition, health, and reproduction in the captive herd of bighorn sheep. A primary purpose of a facility is to enhance survival by preventing predation and exposure to domestic livestock, while maintaining natural behaviors, to allow expression of high natural reproductive potential in bighorn sheep. A large (hundreds of acres) facility is more likely than small (less than 100 acres) to provide all the nutritional (native vegetation, water, etc) and behavioral (escape terrain, lambing habitat, etc) elements necessary for successful captive breeding of bighorn sheep for release to the wild. Once the facility is constructed and functional, it will likely be needed for decades (i.e. long term commitments are needed). However, the responsible agency (likely CDFG) should consider and write a contingency plan for decommissioning the facility when it is no longer needed for recovery of Sierra Nevada bighorn sheep.

The following elements should be evaluated and integrated.

1. Terrain that will allow bighorn sheep to express behaviors that are as normal as possible for escape, thermoregulation, reproduction (lambing sites), and social function.
2. Approximated natural habitat for Sierra Nevada bighorn sheep (SNBS).
3. High quality forage and minerals that are available year-round
4. Reliable and clean water sources
5. Safety from predators and poachers.
6. Minimal disease risks
7. Facilitated safe capture and transport of animals

8. Minimal human disturbance
9. Minimal factors that may impose genetic selection not found in the wild

The site should be assessed for the following:

- toxic/poisonous plants
- insect vectors, including proximity to potential *Culicoides* habitat
- plant, soil, and forage analyses, including natural sources of dietary minerals (salt licks)
- proximity to domestic animals, particularly domestic sheep, but also cattle, goats, llamas, etc.
- proximity to habitat and migratory routes of deer, mountain lions, bears, etc.
- presence of other threatened or endangered plant and animal species
- feasibility of fence, road, and facility construction and maintenance, including an assessment by the contractor
- surveys for archaeological and Native American sites of importance

Please refer to references to review bighorn sheep biology and requirements to maintain health, behavior, physiology, nutrition, and reproduction.

1. Terrain for escape, thermoregulation, reproduction, and social function

Bighorn sheep require open steep "escape terrain" for normal behavioral function (Geist 1971). The basic social unit is the "ewe group", which may average about 5 ewes in size (Dr. John Wehausen and Dr. Esther Rubin, personal communication; Geist 1971). Berger (1978) found that 5 ewes was the minimum number to effectively maintain vigilance against predators while optimally foraging. When the sheep are frightened, they tend to run uphill, jumping among boulders that would be difficult for a predator to maneuver. Providing escape terrain in a captive facility is important for several reasons. Habitat for the captive animals should preserve behavioral and physiological responses that may then be carried with them upon release to the wild. Stress prevention is important for health maintenance. If the captive sheep are startled, access to escape terrain will relief stress by allowing them to run away (usually uphill to safe rocky bluffs) from a threat, then assess it from a safe vantage point.

Provision of escape terrain may make facility construction, maintenance, and capture of animals a challenge. However, knowledge of the escape behavior of the animals will minimize stress during capture and handling. High rocky bluffs are also important for lambing sites. When a ewe prepares to give birth, she will often separate from the ewe group and seek a safe secluded site to have her lamb. Topographic relief is also important so that sheep can thermoregulate: seek shade from the heat, or move into the sun for additional warmth.

2. Site that closely approximates natural habitat for SNBS.

The captive facility should have vegetation, climate, sunshine/lighting patterns, geography that are as similar to that experienced by SNBS as possible. This way, captively bred sheep are less likely to lose natural adaptations necessary for survival in the wild. Facilities built on the eastern scarp of the central Sierra Nevada are most likely to accomplish these goals (but see "Minimal Disease Risk" section below). For example, sites on the western slopes of the White-Inyo Ranges may be similar in many respects, however, light incidence patterns will be altered from that experienced in the eastern Sierra Nevada, with relatively decreased morning sun and increased afternoon sun. This may have effects on reproductive or seasonal migration cycles, or the behavior of captive sheep once released to the wild. Sites distant to the wild populations (sites located in other mountain ranges within or outside California, or at a zoo), may offer a measure of security from the risk that the same catastrophic event will severely impact both captive and wild populations. However, that risk is likely small in comparison to the risks and disadvantages of locating the captive herd at a distant location. See Table of Location Risk/Benefit Comparison

3. Forage / vegetation

Sierra Nevada bighorn sheep forage on a wide variety of plants, especially in the summer (Wehausen 1983). Some of plants found in the Sierra Nevada accumulate compounds that are toxic to domestic sheep and potentially bighorn sheep. For example, plants found on Paoha Island, *Sarcobatus vermiculatus* (greasewood) and *Grayia sp.*, accumulate oxalates (see Paoha Island Assessment). During summer months in the Sierra Nevada, bighorn sheep typically forage at higher alpine elevations. In winter months, snow forces the sheep to move down in elevation (Wehausen 1983), except when predator pressure is hypothesized to drive them back to higher elevations (Wehausen 1996). The migration down to lower elevations in the winter allows access to better forage (Wehausen 1996). Periods of poor forage lead to poor body condition and decreased lamb recruitment. Vegetation should be surveyed for nutritional composition and toxic plants. References for plants that are toxic to animals include Fowler 1998, Fowler 1999, Murphy 1996, and Whitson et al 1996. The captive herd facility should have the capability of providing supplemental forage to provide nutritional support during periods when vegetation quality declines within the enclosure (see Husbandry). Because there are certain husbandry advantages to feeding the sheep on a regular basis, providing hay and or pellets daily is a consideration. Sheep have been observed using mineral licks in the wild (Wehausen 1983). A balanced ration of minerals should be supplied, such as salt-mineral blocks.

4. Water

Sierra Nevada bighorn sheep are closely allied genetically with desert bighorn (Ramey 1993; Wehausen and Ramey 2000) and have physiologic adaptations to survive with little water. However, reproduction and survival will be optimized by providing abundant clean water sources. These sources may be natural riparian areas or installed water troughs. The advantage to a properly installed artificial water system is that it will reliably supply water at all times, while a natural stream may dry up seasonally. Installed drinkers can be kept clean and disease-free, while natural water sources may be difficult to control, sanitize, and may be breeding grounds for insect vectors of disease (for example, the bluetongue virus biting midge *Culicoides*). Flooding of riparian areas may wash out or undercut fences (see Red Rock, NM facility). Riparian areas can provide good stalking cover for mountain lions ("Death Row" riparian area in Round Valley, near Bishop, CA, personal communication Dr. Becky Pierce and Dr. Vernon Bleich), Riparian areas within a facility could encourage mountain lion entry, even with the best attempts at fence construction and maintenance.

Nevertheless, riparian areas constitute a normal component of bighorn sheep habitat and the surrounding ecosystem, therefore may be important to maintain within an enclosure.

5. Safety from predators and poachers.

One of the main purposes of a captive facility in the Sierra Nevada is to protect breeding stock from predation. Bighorn sheep enclosed by a fence are easy prey for any predators that may enter a facility (as experienced at Red Rock). Unless extensive escape terrain is provided within a facility, the sheep no longer have the ability to elude predators and may be chased up against the fence. Adequate fence construction and maintenance is absolutely critical and should not be compromised. With proper planning, construction and maintenance, predation within the facility should not be a common problem.

6. Minimal disease risk

See also Diseases. The captive facility should allow safe distances (preferably miles; for specifics, refer to Sierra Nevada Bighorn Sheep Recovery Plan) from domestic animals, particularly domestic sheep and goats. Any riparian areas located within the facility should be evaluated for parasite habitat and managed to minimize parasite and vector-borne disease transmission. Fecal (ex, intestinal parasites) and urine (ex, Leptospirosis) contamination of natural water courses by captive bighorn sheep and other animals should be prevented. Increasing elevation may reduce exposure to *Culicoides* biting midges that may carry bluetongue virus. The facility should not be located in areas subject to saline or silica dust (such as Paoha Island or near the Owens Lake bed). Excessive exposure to dust storms may predispose bighorn sheep and facility staff to respiratory ailments. Human disturbance near the site should be minimized (see "Minimum Human Disturbance: below) to reduce stress that may predispose to disease. Enclosures should be large enough and designed to prevent crowding and stress. Crowding of animals may lead to increased internal and external parasite loads and may reduce immunity to disease (Jessup 1993). If a captive facility is located in the same region as wild populations (vs. distant from wild populations), there may be some risk of disease transmission between wild and captive animals (ex, wild rams attracted to captive ewes, leading to fence line contact). Although likely a remote probability, a range wide catastrophe could impact both wild and captive populations.

7. A site that facilitates safe capture and transport of animals

A captive facility that is located short distance from capture and release sites will reduce travel time, effort, cost, and stress for animals that are moved. The topography of the site should allow construction of capture and quarantine facilities, along with good access for animal trailers and helicopters.

8. Minimal human disturbance

The captive facility should have minimal disturbance from human activities such as mining, construction, road traffic, recreation, housing developments, and excessive aircraft over flights (Dunn 1996). Noise from these and other human sources may cause abandonment of bighorn habitat (DeForge and Scott 1982; MacArthur et al. 1982) and increase stress that may be associated with disease problems.

9. Minimal factors that may impose genetic selection not found in the wild

The captive sheep should not be exposed to long-term conditions that may drastically alter the course of natural genetic selection. For example, presence of certain diseases or treatments in a captive herd may artificially select certain genetic types (genotypes) that would not have been selected in the wild (Coltman et al 1999). This may be a nebulous concept, but one that should be kept in mind during captive breeding.

10. Environmental Assessment (EA) and permit requirements;

Land provided by federal agencies will require at least an Environmental Assessment (EA; consult with the agency biologists), compliance with National Environmental Protection Act (NEPA) and California Environmental Quality Act (CEQA) regulations. Also permits may be required by federal and state agencies overseeing humane captive propagation of animals. Check with U.S. Department of Agriculture (USDA) and California Department of Food and Agriculture (CDFA).

Risk/Benefit Comparison for Site Location:

Local Vs. Distant Site of Captive Facility

Criterion	Local Site Within Sierra Nevada	Distant Site Other mountain ranges within or outside CA, zoos, etc)
Habitat	Most closely approximates SNBS habitat (including climate, diurnal cycles, etc)	Not likely to as closely approximate SNBS habitat, therefore may impose different evolutionary selection forces on herd.
Transport	Close proximity to wild populations = less stress, cost, management effort and mortality/morbidity risk at transport	Increasing distance from wild populations = increased stress, cost, management effort and mortality/morbidity risk at transport
Management	Can use resources of closely adjacent Sierra Nevada Bighorn Sheep Project; less cost and effort required	Increasing distance from Sierra Nevada = increased costs; additional management staff necessary
Proximity to domestic animals	A potential risk, but with interagency and local cooperation, likely to be reduced to minimal risk	Variable. A zoo-based facility may be very risky due to proximity to other ungulates and disease transmission. Some zoos have such chronic widespread problems with diseases such as Johnes Disease, that animals cannot be released from the zoo. Other mountain ranges may offer less risk of domestic animal exposure than the Sierra Nevada
Diseases and Sierra Nevada Range-wide catastrophes	Captive herd may experience range-wide diseases and catastrophes that also strike wild populations, leading to loss of both captive and wild animals (example Pasteurella pneumonia)	Distance from the Sierra Nevada may provide buffer against diseases and catastrophes that negatively impact Sierra Nevada populations
Cost	Likely much less than distant sites unless funding contingent on maintaining a site outside of Sierra Nevada Mountains	Variable. Likely to be much more costly unless an agency or organization offers land and facilities outside of the Sierra Nevada for captive breeding

Site Availability	With interagency cooperation, there are several good site options within the Sierra Nevada	Good sites are likely to be very limited, if available at all.

Captive Breeding Facilities Recommendations

Fencing

Basic recommendation: predator proof perimeter fence of 12' chain link of at least 9 gauge, with concertina/razor wire on top and 30" apron on bottom (either underground or fastened securely to the ground) to exclude predators, discourage human entrance, and prevent entry by other ungulates (free-ranging rams, deer, livestock, etc). Interior fences of at least 10' chain link (no concertina/razor wire; no aprons).

Strong, predator-proof fencing is imperative for safe captive husbandry of bighorn sheep. Money, effort, and time spent properly planning and constructing the enclosure is well-spent and will prevent many serious problems in the future. In addition, continual fence patrol is critical to quickly repair holes or washouts, and to detect predator tracks or scats along the outside perimeter. Fence construction and maintenance should basically be patterned after a high-security prison - but in this case, more to keep predators *out*.

The ideal enclosure will be large (hundreds of acres), predator-proof, prevent bighorn sheep from escaping, and prevent any other animals (including wild rams) from entering. The enclosure should prevent the entry of predators, particularly mountain lions (can kill lambs and adults), bears, dogs, and coyotes (usually kill only lambs). One type of ideal enclosure would be double fenced (perimeter fence plus interior fences) to prevent nose-to-nose contact between captive sheep and all other animals. However, if the enclosures are larger than 50-100 acres, double fencing may be prohibitively expensive and/or impractical. One consideration would be to construct a 12' predator-proof and ungulate-proof perimeter fence, with 10' bighorn sheep-proof interior fences.

The total fence height of the outside perimeter fence should be at least 12 feet. The height and construction is particularly important to exclude mountain lions. Other captive bighorn sheep facilities have had serious predation problems with lions that enter the enclosures and kill sheep. Mountain lions have been reported to jump over 5.5 meters (>16 feet; Anderson 1983). Lions may climb up mesh and are especially known for climbing up wood posts (personal communication, Dr. Eric Rominger, Red Rock, NM). Despite the recorded vertical leaping ability, well-maintained fences of at least 12 feet and topped by razor wire seem to keep lions out. The gauge of the wire must be thick enough to withstand gnawing by predators and rodents (dogs can gnaw through 9 gauge wire, personal experience). Coyotes and other animals may try to dig under a fence. Coyotes may use tunnels dug by innocuous species (ex, rodents) to access the enclosure. Lions may climb wooden posts, therefore all posts should be metal and not allow a good claw-grip.

The outside perimeter fence should be constructed to exclude coyotes, bobcats, domestic dogs, and other predators and also to maintain separation between captive ewes and wild rams. Lamb predation by golden eagles probably cannot be prevented directly (except by providing an environment which the ewes can optimally protect their lambs). An underground mesh apron of 12-30" and/or an apron laid on the ground and securely fastened down is highly desirable to prevent digging animals from entering. A razor wire or concertina wire top to the fence will help prevent climbing lions, bears, and poachers from entering. Washouts from floods need to be prevented or immediately repaired. If riparian areas are crossed by the fence, flood gates should be constructed and well-maintained.

If snow accumulation may occur adjacent to the fence, the fence should be made higher in that area to accommodate snow drifts, or any snow drifts should be quickly removed. Heavy gauge (at least 9 gauge) chain link is best, to withstand butting, weathering, and the mesh should be small enough to prevent horns and heads from getting caught. The fence must be able to withstand full-charge strike by rams in rut and frightened ewes, along with outside wildlife and livestock that may try to enter. The fence should discourage heads and horns from being caught in wire mesh (again, chain link is best). Fatalities and broken horns due to getting caught in fence have been reported at other facilities (ex, Fort Collins, CO facility; personal observation at a temporary bighorn sheep facility in the San Andres Mountains, NM). Sharp corners in the fence should be avoided - whenever possible corners should be rounded to avoid animals from feeling trapped, or getting crowded into a corner. Rounded edges of the fence will allow animals to herd into and out of a corner more easily.

Electric or electronic fencing could be considered for some portions of the enclosure, however, it may not be as practical or cost-effective as the basic perimeter predator-proof fence described above. Electric or electronic fences may not be effective at containing heavy-coated animals or lambs. For more information on electronic fencing, see Tiedemann et al 1999.

Livestock, particularly domestic sheep and goats, should not be allowed within several miles of the captive facility (see Sierra Nevada Bighorn Sheep Recovery Plan). For guidance on livestock-bighorn sheep separation, refer to the current Recovery Team recommendations and interagency agreements concerning livestock grazing in the eastern Sierra Nevada.

Rams should be fenced in a separate enclosure from ewes to prevent excessive harassment of ewes (see Red Rock NM facility). Preferably, this enclosure would not allow fence line sight or nose-to-nose contact between ewes and rams. Visual barriers between ram and ewe facilities may help prevent stress, fence-testing, and conflicts. If the facility houses only a few rams, separation may not always be necessary, however, the facility should be constructed to allow separation when it is deemed necessary. During breeding season, rams can be herded into ewe pens.

Gates should have sturdy latches that don't slide easily, and that open both in and out. Gates should be at least 8-10 feet wide to prevent congestion of animals and accommodate vehicles.

They should not create corners in which animals may become trapped, but designed diagonally across a corner.

Intensive handling area should be designed with bighorn sheep behavior in mind. It should be located such that sheep may naturally herd to the area, perhaps at the top of a hill. Squeeze chutes, scales, funnel-shaped pastures, handling stalls, drop net sites may be incorporated to ease capture. Drop net areas may be planned at feeding stations or other areas where captive bighorn sheep will be expected to visit daily.

Fenced areas should be accessible for fence construction and maintenance. Dirt roads should be graded along fence lines to allow access by heavy machinery

Enclosures at existing facilities

The Bighorn Institute in Palm Desert has a 11.5 foot exterior fence (10' high plus 1.5' barb wire on top and a 3' apron held to the ground by rocks) and 8' interior fences. The facility has no rocks adjacent to the fence that lions could use to jump. They have not had a problem with intruding animals, although lions have traveled through the property (but not into the enclosure) several times. The 10-15 ewes are maintained in a 30 acre fence separate from the seven acre enclosure for 2 rams and four isolation pens. Sheep are fed hay daily.

The New Mexico Red Rock facility, 1100 acres for 70-140 bighorn sheep, has wooden posts, lack of regular fence maintenance patrol, and no aprons. Coyotes and mountain lions have entered and killed a number of bighorn sheep. Javelinas (pig-like animals not present in the Sierra Nevada) commonly dig under the Red Rock fence, allowing coyotes to follow. Red Rock also has a large creek (Ash Creek) flowing through the enclosure. The river rises during the monsoon season, then dries completely. Flood gates have been constructed which float up on the water, then drop down to block entry when the river is dry. During a visit to the Red Rock facility in February 2000, the flood gates were observed to contain holes that a coyote could squeeze through. Also, at that time there was major renovation of the flood gates - they require continual vigilance against problems (washouts, mechanical breakdown) and frequent potentially expensive maintenance. For these reasons, ideally, the fence should not cross areas subject to floods. During the April 2000 census at Red Rock, several bighorn sheep deaths attributed to predation were discovered, along with fresh lion scat within the enclosure (Fr. Eric Rominger, personal communication). Rams are currently fenced in with ewes, although tend to maintain separate groups except during rut. For several years, sheep were not offered supplemental feed, however within the past year, feed pellets have been offered every few days.

The Fort Collins, CO facility, located in the foothills of the Rocky Mountains, has several 3-hectare (about 7.5 acres) pastures, each enclosing 10-15 sheep with 12' perimeter fences, and rams separate from ewes. Electric fencing is used successfully there with tame rams, however wild sheep will challenge it. Hay and grain is supplied daily. They have not had problems with predators for over eight years (no lions nearby, but dogs entered facility then).

The Sybille, WY facility in the Laramie Mountains, about 70 miles north-east of Laramie, is maintained on 235 acres, with bighorn sheep confined to a 40 acre pasture on a hill side. Perimeter fences are 8' high. Hay and grain is supplied daily. No predator problems were reported.

The United States Fish and Wildlife Service (USFWS) San Andres National Wildlife Refuge, located in south-central New Mexico, contains temporary pens constructed to enclose up to 6 bighorn sheep temporarily for 2-4 weeks. The pens were constructed like a wagon wheel, with a 35' diameter hexagonal handling/feed pen at the center, and 3 trapezoidal 50' X 50' X 50' X 10' pens (0.29 acres each). Fence is 10-foot high with 6' non-climbing horse fence, topped with 47" field fence. There is a top and mid rail for support. There is double fence between pens to reduce risk of transmission of disease between pens. Covering the wire with 6' tall black shade cloth helped to calm and indicate location of fence to animals.

Quarantine and Sick Sheep Facilities

The CDFG Bighorn Sheep Wildlife Veterinarian should be consulted on quarantine facilities and procedures. At least one quarantine enclosure pen (preferably at least two of different sizes) should constructed to allow 30+ day quarantine of new animals entering the facility. Other pens should be constructed to allow separation and treatment of sick adult animals and orphan or sick lambs from the main captive herd. Both the quarantine and sick pens should have capture facilities and be located distant from healthy animals enclosures, with no fence line contact possible. Quarantine and sick facilities should be downwind of the prevailing winds from healthy sheep pens; and not have common riparian areas that could transfer water among pens.

Water Troughs, Feeders and Buildings

Preferably, the enclosure would be large enough and designed so that water toughs and feeders would not be necessary (except for baiting in to drop net stations, or extreme weather situations.

WATER: If continuous clean water cannot be provided through natural sources, water troughs should be constructed. The troughs should be planned to prevent fecal, parasites, and bacterial contamination. The water should be changed and troughs scrubbed frequently. Float controls and heaters (therefore plumbing from a water source and electricity) are necessary to prevent freezing. For an example and picture of a successful watering setup, see Ft Collins facility.

FEEDERS: Feed should never be left on the ground to avoid fecal and parasite contamination. Feed bins should be designed to minimize waste, reduce fecal contamination, allow lamb access, and protect feed from weather. For an example of feeder designs, see Sybille, WY facility.

Hay feeders may be designed with the following specifications: rack to hold hay with trough underneath to catch uneaten hay; drain holes in trough; on skids to move easily; sufficient space for each animal (at least 2 feet per animal).

Grain pellet feeders - shallow trough about 2' high; with roof to exclude rain or snow; kept clean of feces and urine.

OUTBUILDINGS: will be needed to store feed, for the facility manager, for veterinary supplies, necropsy area, treatment area (including intensive treatment of sick or orphan lambs). Because the eastern Sierra Nevada region has had cases of Hanta Virus disease in humans, special precautions should be taken to exclude rodents and their dropping from buildings. Any buildings that will house bighorn sheep should have ceiling and fixture heights of at least 9 feet. Sheep can easily jump lesser heights. All light bulbs and other fixtures should have sturdy protective coverings.

SCALE: an accurate scale should be installed so that animals may be lead through a chute, or transported via litter or wheelbarrow and weighed.

Poisonous plant control

During the site planning stage, the grounds should be surveyed for plants that may be potentially poisonous to bighorn sheep. Following construction, the facilities should be regularly inspected for poisonous plants. Captive bighorn sheep grazing may cause changes in the local plant community and may predispose to changes in densities of certain plants, including those that may be toxic. Refer to the following references for poisonous plant information: Fowler 1998, Fowler 1999, Whitson et al 1996, Murphy 1996.

Preliminary Cost Estimates and Worksheet for Sierra Nevada Bighorn Sheep Captive Facility Costs

These estimates are very rough, guestimates, and hopefully "ballpark".
Edit and add to this work sheet as new information is gained about intended facility.
Please contact contractors for accurate estimates when site location is decided.

Category	Item	Total cost	cost per unit	unit
Fence: estimate not inclusive, only the basics. Contact several contractors with Sierra Nevada fencing experience to obtain a more accurate and up-to-date estimate. Recommend chain link fence for predator exclusion and safety to bighorn sheep. It is the most expensive. Use of hog wire instead may lead to predator incursions and deaths due to bighorns catching horns in wire and strangling	Estimate from Builders Fence Co,8548 Unsworth Ave, Sacramento, CA 95828-1009 (916) 381-4065. Assume 4 linear miles exterior fence, 1 linear mile interior fence. Total 26,400 feet			
	Chain link fence 9 gauge, schedule 40 post 12', 1 5/8"-1 7/8" OD for exterior fence	$220,000-$270,000	$10.57-12.67	foot
	+/-Razor ribbon/wire for exterior fence,18-24" high, loop every 18" coil, 50'	$21,000	$40-51	50' roll
	+/-Barb arms on top of post to hold up razor wire, 45 degree angle, 1 7/8"	$8000	$2-15	each
	+/-Underground wire for exterior fence, 3', 9ga	$21,000	$0.85-1.00	foot
	Corners, 1 5/8", 21-24" length pipe	Depends on fence profile	0.54-0.92	foot
	Subtotal, materials, for exterior fence above:	$220,000-$320,000		
	+/-One mile interior fencing	$42,240+		
	Subtotal interior and exterior fences supplies only	$262,000-362,000+		

	Fence construction labor costs – very rough estimate for 4 mi exterior + 1 mile interior fencing	$130,000+/-	+/-$5	foot
	Total Fence Cost – very rough estimate	$300,000-$500,000		
	+/- Electric fence if used exterior fence	add $40,000-$100,000	Add $2-5	foot
Facility construction: plumbing, electrical, buildings, dirt road construction, etc. Consider pole barn bldg or pre-fabricated trailer, TGR container, or other modular unit.	Bighorn sheep exterior handling facilities: fencing, gates, dropnet construction, etc. (see Bighorn Institute for example of good handling facilities)	$20,000+		Per handling facility
	40' X 60' insulated pole barn bldg: 1000 sq ft for basic living quarters for one caretaker; kitchen, bathroom, office; 1400 sq ft for animal inside intensive handling facilities	$60,000 +/- $20,000, depending on needs	$60,000 +/- $20,000, depending on needs	Per bldg
	Propane furnace	$7500	$7500	each
	100+ gal water heater	$1000	$1000	each
	room-size A/C unit	$500	$500	each
	Kitchen and living facilities: stove, microwave, bed, etc	$2000+		
	2 refrigerators (one for personnel, one for animal care)	$1000	$500	each
	animal care chest freezer (tissues samples, etc)	$500	$500	each

	200 amp electrical svc, exterior and interior electrical wiring	$10,000	$10,000	Per bldg
	Running electrical svc 2000' (distance depends on site) from nearest power poles – transformer, poles, high voltage wire, etc	$10,000	$10,000	Per bldg
	Plumbing to bldg	$10,000	$10,000	Per bldg
	Dig well, water pump	$10,000	$10,000	Per bldg
	Grade dirt roads for access to bldg and fences	?	? depends on location and whether CDFG personnel can do this	Per foot
Facility Caretaker	Live-in Facility Manager/Biologist	$50,000 +/-$10,000	$50,000 +/-$10,000	Per year per person
USDA-WS services for predator control around facility	1/10-1/2 time of predator control specialist	$3000-$15,000		Per year
Facility supplies	ATV-All terrain vehicle	$6000-8000		each
	Special pens (3+) - quarantine, sick lambs	$1500+	$500	each
	Sheep shade shelters if needed	0-$1000	$200	each
	Feeders, hay racks, buckets	$500-1,000		
	Waterers if needed, Ritchie brand, 120V, 250W, 21 amp Model 2AC double	$500-1000	$250+	each

	Plumbing svc, supplies for Waterers	$1000		Once during installation
	Electrical svc supplies, for other than bldg above	$1000		Once during installation
	Trailer for supplies, feed (ex TGR container)	$3500	$3,500+	each
	4 WD Vehicle for facility manager	$30,000+	$30,000+	each
	Sheep transport trailer	$10,000+	$10,000+	each
	Chutes - metal, squeeze	$1,000+	$1,000+	each
	Hay storage cover or shade structure	$1.000+	$1.000+	each
	Computer	$3,000.00	$3,000.00	each
	Software (pedigree (ISIS-SPARKS), etc)	$3,000.00	$3,000.00	each
	Diagnostic lab - yearly health screens for all sheep (assume 30 sheep), sick animals (assume 20 tests)	$15,000	$300	Per test per bighorn sheep

	Capture specialists for bighorn sheep founding herd and periodic handling (WIL, USDA-WS, etc).	Provided by CDFG?		
	Helicopter time and capture costs for capture of founding herd (assume 30 sheep)	$30,000	$1000	Per bighorn sheep
	Helicopter time – once herd established (assume 2 days 2 times per year (28 hours @ 7 hr per day)	$14,000	$500	hour
	Veterinary care - WIL vet (travel costs, etc), contracted local vet, etc. Assume 12-20 "events"	$6000-20,000	$500-1000	Per Event
	Contracted researchers	?		
	Repair/Handy person - fence, plumbing, etc	Provided by CDFG?		
	Fence and dirt road maintenance	Provided by CDFG?		
	Snow removal (roads, fences)	Provided by CDFG?		
	Flood control	Provided by CDFG?		
Animal Supplies	Vet drugs (capture drugs, vaccinations, antibiotics, etc)	$1000-2000		Initial stock and per year

	Vet equipment and supplies if needed (+/-centrifuge, minor lab equipment, etc)	+/-$2000		
	Bighorn sheep walk on weighing scale	$500-1000		
	Drop nets	Provided by CDFG?		
	Capture equipment (dart gun, pole syringe)	Provided by CDFG?		
Animal crates for transport		Provided by CDFG?		
Supplemental Feed if needed	Hay - 1.5 kg (3.3 #) per head per day	$3000 Depends on local costs	~$100 for hay and pellets estimated by Dr. Margaret Wild	Per sheep per year
	Pelleted ration 0.5-1.6 kg (1-3.5 #) per head per day			
	Mineral blocks	$100	$5	Per block
TOTAL ESTIMATE START-UP AND FIRST YEAR	**$600,000-1,000,000**			

Personnel for Captive Breeding Facility

Captive herd manager(s)

The candidates for herd manager should be experienced with bighorn sheep, field biology, and captive management techniques. They should have strong scientific and observation skills and a biology background. A good solid work ethic, ability to work under harsh conditions, ability to work well with people and animals, and persistence are critical. The manager will need to travel by foot and vehicle to check sheep and fences on a daily basis. They may need to help with facility repair as needed. The manager should either live on-site or very nearby.

Predator Control Specialist(s)

While the captive herd manager and predator control specialist may be the same person(s), past experience by other facilities indicates that these positions should be filled separately. The predator control specialist should have extensive experience in preventing and controlling predator entry to a facility. The position may require humane euthanasia of animals. Personnel from USDA-Wildlife Services and/or CDFG may be well suited for this position.

On-call Facility Repair Staff

While the captive herd manager will maintain vigilance against fence breaks, plumbing, electrical, and facilities problems, specialists are needed to repair these problems on a timely manner.

Veterinary and Rehabilitation Staff

The CDFG Bighorn Sheep Veterinarian should be consulted for all routine veterinary care and problems. An experienced and qualified local veterinarian should be identified and contracted for on-call duty in the event that the CDFG veterinarian is not available for emergencies. Zoos and wildlife rehabilitation facilities should be identified that would be willing to adopt bighorn sheep not fit for breeding or release.

CDFG Bighorn Sheep Biologist

The CDFG bighorn sheep biologist may be involved (along with the other people listed above) in coordinating captures and releases of captive breeding stock, along with design and implementation of research studies conducted on captive animals. The biologist will be useful in providing advice for management issues.

Licenses, Permits

Check that all necessary licenses and permits are secured before bighorn sheep are captured and brought to the facility, preferably before land is secured and construction started. Some requirements may include: Memoranda of Understanding (MOU) with agencies entrusted with the property on which the facility would be located; Animal Welfare Act research facility licensing (check with Dr. Margaret Wild, National Park Service Wildlife Veterinarian, Fort Collins, CO.

Bighorn Institute Bighorn Sheep Facility

Palm Desert CA

For information, visit their web site at www.bighorninstitute.org

The Bighorn Institute, a nonprofit organization, was founded in 1982 to investigate causes of bighorn sheep declines in the Peninsular Ranges of southern California. Located near Palm Desert, it consists of several buildings, a 30 acre pen for 10-15 ewes, 7 acre pen for 2 rams, and four isolation pens. It is staffed several biologists who care for the captive animals and conduct ecological research observing wild bighorn sheep. The enclosure is constructed of a 11.5 foot exterior 2.5" chain link fence (10' high plus 1.5' barb wire on top and a 3' apron held to the ground by rocks) and 8' interior fences. The fence was constructed by the All About Fence Company (760) 775-4404. The 30 acre pen encloses a complete hill that ewes use for escape terrain and lambing. The facility has no rocks adjacent to the fence that lions could use to jump in. They have not had a problem with intruding animals, although lions have traveled through the property (but not into the enclosure) several times. Sheep are fed alfalfa hay and pellets daily.

Recommendations and notes from the Bighorn Institute

In general, the staff at the Bighorn Institute believe that smaller enclosures and intensive management lead to more control over sheep and predictability of conditions. However, excessive handling, bottle feeding is believed by the staff to cause increased morbidity and mortality. Even in these relatively small enclosures, sheep can be difficult to find. The staff have good luck handling sheep that have become accustomed to a regimented and limited presence of keepers. The animals are acutely aware of any changes in the daily routine and will react by becoming uneasy and difficult to handle. Dogs should not be allowed anywhere near the facility.

Sheep are hand captured when they enter the feeding pen (photograph above) using a hand net (photograph above). The sheep are not marked with ear tags or collars - the staff knows them individually. The staff uses disinfectant boot baths when stepping in or out of enclosures. They shower and change clothes before working at facility. Alfalfa hay and pellets (horse feed) are fed daily into clean rubber bowls in the feed pen. Salt and mineral blocks are available. The feeding pen is raked and cleaned out at night and sliding gates are closed so that ewes can not enter from the 30 acre pen. Water and feed bowls are turned over at night to prevent contamination.

The Bighorn Institute has had the best experience bringing young lambs (they feel 2 months age is best, with yearlings at the oldest) into captivity rather than adults. The young apparently adapt better to captivity and are less likely to challenge the fence (run up against it full force and possibly break horns or neck). Wild animals brought in for captivity are isolated and quarantined for 30 days.

Sheep are not vaccinated while in captivity - the Institute has not had Clostridial disease problems (unlike the Ft Collins facility). Sheep are given selenium injections at release to the wild. Historically, the following diseases were noted at times in the captive animals: *Pasteurella*, bluetongue virus, contagious ecthyma, Para Influenza 3, Epizootic Hemorrhagic Disease (see Disease section). Captive sheep have tested positive to Bovine Respiratory Syncytial Virus (BRSV) antibodies (meaning exposure, not necessarily disease). Cattle are pastured nearby.

Nearly all ewes bred at the Bighorn Institute become pregnant. Occasional dystocia (difficult birth) occurs. Lamb recruitment is usually 80-90%. However, there was concern that the stress caused by local heavy helicopter and road-grader traffic for a construction site may have precipitated a *Pasteurella* pneumonia outbreak in lambs during 1999.

Careful medical and pedigree records are maintained. The ISIS program SPARKS (International Species Information System, Single Population Analysis and Records Keeping System) is used for parentage and pedigrees. There are no reports of inbreeding problems within the facility.

Thank you very much to Jim DeForge and Stacey Ostermann for tour of the facility and their very helpful advice.

PHOTOGRAPHS:
Fence
Pen
Capture Net

Bighorn Institute Fence

Bighorn Institute pen enclosure:
Feeding pen with shade tree in foreground; 30 acre ewe pen with hill side (for escape terrain) in background.

Capture Net

Jim DeForge holding the capture net. It is basically a tuna net, with flexible Plexiglas loop holding the net, that can be used to hook the horns (careful with tender lamb horn buds).

Red Rock

New Mexico Department of Game and Fish Bighorn Sheep Facility

Red Rock is a large facility of 1100 acres, about 110 bighorn sheep, and without intensive management (quite the opposite of the Bighorn Institute). Over 450 lambs have been born at the facility since foundation. It is located in Chihuahuan high desert/grassland in the southwestern corner of New Mexico. The facility was begun in 1972 following a steep decline in the only remaining population of desert bighorn sheep in New Mexico, the San Andres Mountains population. A very small number (<10) of founder sheep from the San Andres and Mexico were brought into a 600 acre facility at Red Rock. For a history of the facility, see (Hoban 1990, Jessup and Clark 1992, Desert Bighorn Council Transactions New Mexico Status reports each year).

The enclosure fence is 10' mesh, supported by vertical wooden posts, an upper strand of barb wire, and no aprons. In recent years, the facility has lacked frequent fence maintenance patrol. Coyotes and mountain lions have entered and killed a number of bighorn sheep. Javelinas (pig-like animals not present in the Sierra Nevada) commonly dig under the Red Rock fence, allowing coyotes to follow. Red Rock also has a large creek (Ash Creek) flowing through the enclosure. The river rises during the monsoon season, then dries completely. Flood gates have been constructed which float up on the water, then drop down to block entry when the river is dry. During a visit to the Red Rock facility in February 2000, the flood gates were observed to contain holes that a coyote could squeeze through. Also, at that time there was major renovation of the flood gates - they require continual vigilance against problems (washouts, mechanical breakdown) and frequent expensive maintenance. For these reasons, ideally, the fence should not cross areas subject to floods. During the April 2000 census at Red Rock, several bighorn sheep deaths attributed to predation were discovered, along with a fresh lion scat within the enclosure.

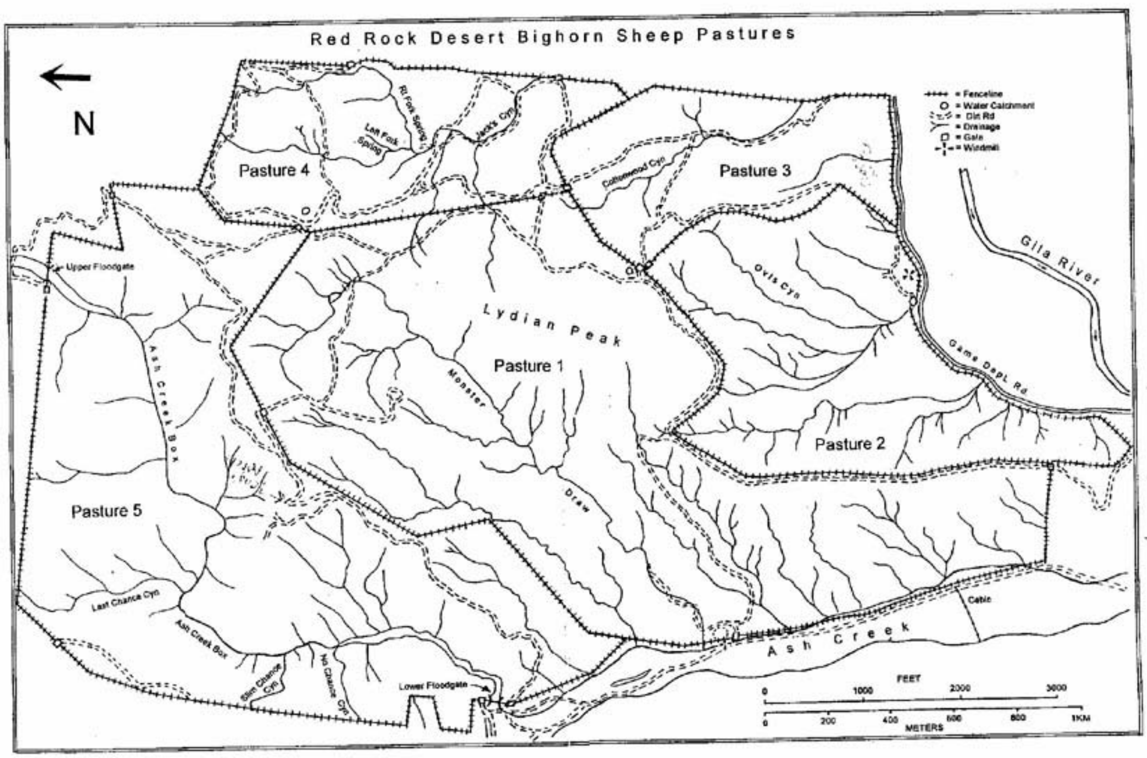
Red Rock has had disease problems. The founder sheep from the San Andres Mountains were brought to the facility because of a severe psoroptic mange mite (scabies) epidemic causing population decline. Bluetongue virus circulated in the Red Rock herd 1989-1993 and caused a die-off in 1991 (Singer et al 1998). The bighorn sheep share a fence line with cattle. Riparian areas, that can support the biting midge insect vector, are present: Ash Creek flows within the facility and Gila River flows adjacent.

Over the past decade the facility has experienced an excess of rams, leading to excessive ewe harassment and decline in ewe condition. Potential causes of the skewed sex ratio include removals of more ewes than rams for translocations, inbreeding, and possibly a nutrition-related ram-skewed sex ratio at birth, however data is lacking. Bighorn were fed horse-pellets as a supplement to native forage from 1980-1992. During one of those years, as an example, the herd had a sex ratio of about 80 males/100 females. In 1992 the pen size was doubled and supplemental feeding ceased. However reproduction was high and the density was back to the same level within 2 years. Since that time the sex ratio at 1 year has become 158 males/100 females. This includes 15 males and 2 females recruited in April 1999 (Dr. Eric Rominger personal communication). Dr. Eric Rominger, biologist studying the herd, hypothesized that a nutritional decline may have be responsible for ram-skewed sex ratio (White 1995). As of the facility tour during spring 2000, horse pellets were fed out on the ground.

Thanks to Dr. Eric Rominger for a tour of the facility and good discussions of bighorn sheep management. Thanks also to Bill Dunn, Dr. Dan Beck, Dr. Kristina Ernest, and Amy Fisher for their very valuable advice and help.

PHOTOGRAPHS / DIAGRAMS
Map
Flood gate
Guzzler

Red Rock, New Mexico
Department of Game and Fish Bighorn Sheep Facility
Map. Courtesy Dr. Dan Beck



Red Rock, New Mexico
Department of Game and Fish Bighorn Sheep Facility

Flood gate

Constructed in a riparian area to allow rise and fall of water flows while preventing animals from moving in or out of enclosure. Note width of wooden slats (4-5") - may allow small carnivore access to pen. Flood gates require continual vigilance against fence-breaks and regular maintenance.

Red Rock, New Mexico Department of Game and Fish Bighorn Sheep Facility:

Guzzler Water catchment and delivery system.

Ft. Collins Bighorn Sheep Unit
Foothills Wildlife Research Facility

Colorado Division of Wildlife

The Colorado Division of Wildlife facility is located in foothills just west of the town of Ft Collins. For details of the facility, feeding regimen, and descriptions of research conducted there, see Wild et al 1998; Miller et al 1998).

Bighorn sheep, along with elk and deer, are held in captivity for disease research (including chronic wasting disease in deer and elk and *Pasteurella* in bighorn sheep). Thirty-three sheep are maintained in several 3-hecatare pastures, with ten 10 confined separate from 23 ewes. The enclosure includes a 10' perimeter fence and interior fences, including an electric fence (constructed by Waterford Corp, (970) 482-0911). A caretaker lives on site.

Sheep are fed daily (see Nutrition/Husbandry section for details). Lambs are bottle-raised so that they become tame, so tame that caretakers believe that humans have become part of the sheep social system. Sheep are handled 1-2 times per month by herding them from pastures, down wood alleys to a scale and treatment area, blood samples are collected and hooves trimmed. Tame rams can be dangerous and head-butt people. Birth rate is 80-85% annually, with about 80% lamb survival. There may be one trauma death per year: collar or horn caught in fence, aggressive ewes killing lambs, broken legs, etc.

Thanks to Dr. Margaret Wild and Dr. Michael Miller for an informative tour of the facility and very helpful discussions.

PHOTOGRAPH
Watering Trough

Ft. Collins, CO Bighorn Sheep Facility

Watering Trough

Electric watering trough at Ft Collins facility, supported on concrete pad. Provides a reliable water source and prevents water from freezing. Ritchie model (Iowa) 2AC, 120V, 250 W, 21 A, Cost is about $250.

Sybille Bighorn Sheep Facility
Wyoming Department of Game and Fish

The Wyoming Department of Game and Fish Sybille Wildlife Research and Conservation Unit was founded in 1952 to collect data on wildlife diseases, capture and marking techniques, and life history. For details about the facility, including wildlife husbandry, see Blunt and Myles 1998. Just adjacent to the Sybille facility is the USFWS black-footed ferret captive breeding enclosure.

Bighorn sheep have been maintained at Sybille for over 40 years. At the time of the tour (April 2000), fifteen sheep (7 ewes, 4 lambs, 4 rams) were contained in a semi-free-ranging state within one 40 acre enclosure - rams run with ewes year-round. The Sybille sheep don't sexually segregate as in the wild. Occasionally, ram aggression toward people has been a problem. The fence is 8 foot woven wire, with 3 strands of barb wire. Mountain lions and coyotes can enter, however that has not been a problem for them. Wild bighorn rams have jumped into the enclosure.

Currently there is no preventative medicine protocol (i.e., no vaccines or preventative treatments), other than basic husbandry. They are fed alfalfa hay and grain twice daily. Dr. Kreeger reported no disease problems. The animals are quite acclimated to humans, allowing people to touch them. Dr. Kreeger estimated the pregnancy rate was 85-90%, with 90% lamb survival. Of the animals housed at Sybille (including deer, elk, mountain lions, moose), he felt that sheep were the easiest to maintain in a healthy state. At the time of the facility tour, there was no bighorn sheep research protocol in place. They were just being maintained in case future research was desired. In the past they had been used for nutrition and disease (including *Pasteurella*) research.

Address:
Wyoming Department of Game and Fish
Sybille Wildlife Research and Conservation Unit
2362 Highway 34
Wheatland, WY 82201
(307)322-2571

Thanks to Dr. Terry Kreeger and Dr. David Zeiler for an informative tour of the facility and very helpful discussions.

PHOTOGRAPHS
Fence / Feeder / Handling board

Wyoming Department of Game and Fish
Sybille Bighorn Sheep Facility Fence

Wyoming Department of Game and Fish Sybille Bighorn Sheep Facility: Hay Feeder

Wyoming Department of Game and Fish Sybille Bighorn Sheep Facility

Handling board. Dr. David Zeiler stands beside a handling board used for bighorn sheep and elk at the facility. The handler stands behind the board for protection while hazing animals through a chute.

USFWS San Andres Mountains, New Mexico

Temporary Bighorn Sheep Enclosure at Little San Nicholas Camp

The San Andres National Wildlife Refuge, located in south-central New Mexico, is the home of the last native "population" (only one ewe left, translocations from Red Rock in progress) of desert bighorn sheep in New Mexico. In 1999, the United States Fish and Wildlife Service (USFWS) constructed pens to enclose up to 6 bighorn sheep temporarily for 2-4 weeks, while tested for *Psoroptes* mites. Following negative findings for mites, sheep were released to the wild and monitored. The pens were constructed like a wagon wheel, with a 35' diameter hexagonal handling/feed pen at the center, and 3 trapezoidal 50' X 50' X 50' X 10' pens (0.29 acres each). Fence is 10-foot high with 6' non-climbing horse fence, topped with 47" field fence. There is a top and mid rail for support. There is double fence between pens to reduce risk of transmission of disease between pens. Gates are 4' X 8' for each larger pen to the outside and to the handling/feeding area. A squeeze chute extends as an exit from the handling area. When first released into the pen, the sheep tend to panic and run full-force up against the wire. Covering the wire with 6' tall black shade cloth helped to calm and indicate location of fence to animals.

Thanks to Mara Weisenberger, USFWS; Dr. Eric Rominger, Bill Dunn, and Darryl Weybright, New Mexico Department of Game and Fish for useful advice.

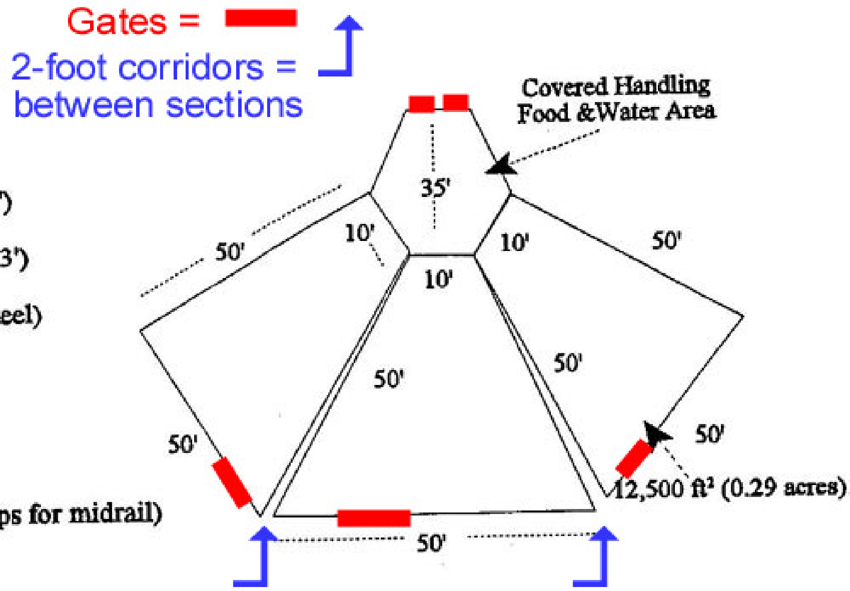
Pen diagram

USFWS San Andres Mountains, NM
Temporary Bighorn Sheep Enclosure at Little San Nicholas Camp

Diagram courtesy Mara Weisenberger

List of materials

Top-rail (1 5/8 OD x 21')
Eye tops 2 7/8 x 1 5/8
T-40 12 ga. (2 3/8 OD x12')
Ball caps 2 7/8
T-40 13 ga. (2 7/8 OD x 13')
Top rail ties
Rail ends (1 5/8 Pressed Steel)
Fork latch 2 7/8 x 1 7/8
Brace Bands
Gate hinges 1 7/8 x 5/8
Post hinges 2 7/8
Tee clamps 1 5/8
Zip ties
Boulevards (line rail clamps for midrail)
Gate frames (4' x 8')
Shade cloth



Assessment of Paoha Island, Mono Lake

as a Potential Sierra Nevada Bighorn Sheep Breeding Site

**Report to the
California Department of Fish and Game**

November 30, 1999

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Summary

This report is an assessment of the Paoha Island ("island") as a potential site for captive breeding of Sierra Nevada bighorn sheep ("sheep"). The site chosen for breeding should optimize conditions for maximum reproductive success. The main reason for considering the island was that it had a water barrier that might obviate a perimeter fence to exclude predators and contain the sheep. Based on information reviews, plant and water evaluations, and island surveys conducted to date (11-30-99), my assessment is that Paoha Island is not an appropriate location for bighorn sheep breeding. Coyotes and deer are present on the island, indicating that the water surrounding the island is not likely to be an impermeable barrier for ungulate and carnivore migration. There are major potential toxicity problems with plants and water. The plant species composition is not optimum bighorn forage. The soil is extremely fine and saline-silica dust storms are common. Weather (fog over the lake, especially in the winter; heavy wind storms, etc) can prevent island access.

For these and other reasons detailed below, I recommend that other alternatives, including land-based sites, such as those in the Baker Creek region, be considered as primary potential sites and that Paoha Island be removed from consideration unless extenuating circumstances prevent consideration of a non-island site. I recommend that the Sierra Nevada Bighorn Sheep Scientific Advisory Team discuss these findings and determine whether to pursue

National Environmental Protection Act (NEPA) Environmental Assessment (EA) for the island or whether to initiate evaluation and EA process for an alternate site. Three main options may be available for the island site: 1) pursue full EA and continue with it as primary site (including placement of trial Ovis canadensis nelsoni sheep); 2) realize that it may not be ideal, but still pursue EA and see how trial sheep do, while pursuing EA for land site (expensive in time and effort); 3) discontinue consideration of the island (my recommendation).

Detailed Information

An initial island survey trip was made 2-23-99 by John Wehausen, Larry Ford, and others. On June 9 and 10, 1999, John Wehausen, Karl Chang, Ben Gonzales, Vern Bleich, Diana Craig, and Steve Torres traveled to the island to evaluate water and plant resources and sample the rodent fauna, plants and water. Plants were identified by John Wehausen, Jim Richards (University of California Davis (UC Davis) professor and plant ecologist) and Ellen Dean (UC Davis herbarium botanist). Plants and water samples collected on 6-10-99 were analyzed for toxicology by California Veterinary Diagnostic Laboratory Services (CVDLS) on 10-26-99. Based on these results, Dr. Birgit Puschner (CVDLS toxicologist), Dr. John Maas (UC Davis School of Veterinary Medicine Extension Veterinarian with expertise in ruminant nutrition), and Dr. Jim Richards provided advice on forage quality and plant toxicology issues. On November 9, 1999, the island was evaluated for plant community abundance and distribution and survey was continued for available water sources and habitat suitability for bighorn sheep. Rodent livers (n=14) that were collected 6-10-99 were tested by CVDLS for selenium and heavy metal concentrations 11-17-99.

The water "barrier" around the island appears to be permeable to mammals. Coyotes and deer are present on the island, perhaps permanently or as seasonal migrants. Sign from both species was observed on 6-10-99 and 11-9-99, and has been noted by other biologists. On 11-9-99, several coyote scats and tracks were observed (two scats were collected). We also observed an abundance of deer sign - both tracks and feces. In some areas (fumarole hill and marsh), feces were so numerous that we could not avoid walking in it. John Wehausen and Karl Chang noted that there was much more deer sign on 11-9-99 than on 6-10-99. We are suspicious that deer frequently swim on and off the island. Perhaps this is true of coyotes also. Mountain lions and bighorn sheep are documented swimmers (Graham 1980; Hansen 1993) and the distance from Paoha to Negit Island (~500 meters +/-), and then to the mainland is short. Although Mono Lake water will not freeze due to salinity, apparently, flumes of fresh water occasionally flow over the top of lake water and freeze. Dr. Scott Stine (biologist; personal communication with John Wehausen) reported seeing coyotes walking out on a frozen fresh water flume. For these reasons, the water surrounding the island should not be assumed to be capable of containing bighorn sheep and excluding predators.

Paoha Island is a volcanic island that arose from Mono Lake 300 years ago. It is covered with fine salty, alkaline lake sediments and has a mixed vegetation community. There are multiple fresh water springs, hot springs, and an artesian well (nonfunctional, but with water tens of feet down) from an old goat ranch site. The island does not contain escape terrain (high rocky bluffs), but a small area of exposed volcanic rocks is located on the north-east side, but they provide limited topographic relief. Lack of escape terrain could interfere with normal behavior, including lamb developmental behavior. Additionally, lack of rocky bluffs on which to escape may increase dangers from predators that may swim onto the island. Topographic relief may be insufficient for sheep to evade the full force of saline-silica dust storms, predisposing them to compromised respiratory health.

The most widespread plant community, particularly on the lower elevation perimeter of the island, is a mixed shrub community of *Sarcobatus vermiculatus* (greasewood), *Atriplex confertifolia* (shadscale), *Grayia spinosa* (spiny hopsage), and *Tetradymia spinosa* (cotton-thorn or spiny horsebrush). *Sarcobatus* is a known oxalate-accumulator and exists in thick monocultural stands on low elevation terraces (<6460 foot elevation) and mixed communities throughout the island. Oxalate toxicity from leaf-ingestion can cause a variety of very serious diseases in ruminants, including bighorn sheep: acute death, kidney damage, a variety of problems related to calcium deficiency, including osteodystrophy (bone thinning and abnormal growth; Radostits et al. 1999). Toxicology analysis on plant samples collected 6-10-99 indicate that both Sarcobatus and *Grayia* on the island contain oxalate levels that exceed safe levels for ruminants.

Another area of concern is relative levels of molybdenum (Mo), copper (Cu), and sulfur (S) in plants and water. Copper deficiency can cause severe pathologies in sheep, including a lamb defect called swayback, and hair, bone, and anemia problems in adults. Copper levels were generally low for plants that were tested, while molybdenum and sulfur were high in certain samples. One water sample tested extremely high in sulfur. The combination of low CU, high MO and S can exacerbate copper deficiency syndromes in sheep. Calcium and phosphorus of several tested plants (3 out of 8 samples, including the grasses *Elymus* and *Bromus*) exhibited ratios less than 2:1 Ca:P, the optimum level for sheep forage (references, Dr. Birgit Puschner, CVDLS; Dr. John Maas, UC Davis School of Veterinary Medicine). *Elymus* and *Bromus* were identified to be among the most important species for bighorn sheep forage on the island. Dr. John Wehausen has observed that Sierra Nevada bighorn sheep can survive on Ca:P less than 2:1. Should it be deemed necessary, supplemental feed and mineral blocks could be balanced to minimize mineral imbalances.

One water sample and one plant sample contained significant arsenic concentrations (5.1 and 5 ppm respectively, with levels <0.2 ppm considered satisfactory). Arsenic is a general tissue poison, and acute clinical findings can include death, abdominal pain, severe gastroenteritis, seizures, dehydration, circulatory collapse. Chronic cases can present with unthriftiness, poor growth, indigestion, decreased lactation, stillbirths, and abortions. Lower elevation terraces are extremely salty, with salt crust on soil. One water sample (fumarole spit) contained extremely high salt (potassium and sodium), and sulfur levels. Other water samples (marsh water from springs and fumarole hill water did not test out of normal range for salts. However, except the fumarole hill water sample (sampled through the rusty pipe that was embedded in rock) tested acidic (pH4.51) on the 6-10-99 sample. Water was collected again (through a PVC pipe inserted into the rusty pipe) on 11-9-99 and was not found to be acidic using pH paper (if deemed important, the 11-9-99 sample can be submitted for more precise analysis). Toxic water sources could be fenced off and guzzler water sources be developed.

For the 14 rodent samples submitted to CVDLS, there was no evidence of elevated levels of selenium, arsenic, cadmium, copper, iron, lead, manganese, mercury, molybdenum, and zinc. That indicates no obvious toxic levels for these metals in rodents. This is a positive indicator for the use of Paoha Island for bighorn breeding. However, the results in rodents may or may not extrapolate to levels in bighorn sheep, particularly if the rodents tested graze on different plants - or different parts of plants - than bighorn, and if rodents metabolize metals and selenium differently than bighorn sheep. Water and plant samples that were collected 11-9-99 from the island have been banked, but not submitted for testing. If the island is considered for bighorn breeding, these samples are available for further testing if necessary.

Paoha Island is littered with debris that could be dangerous to bighorn sheep. There are remnants of a goat ranch that was present in the 1920's-40's, including barbed wire fences, run down buildings with decaying roofs on the west shore. On the east shore, is wire, debris and decaying buildings from bath houses from a failed spa project started about 50 years ago. Sheep could become tangled in the wire and debris, therefore all of it would need to be removed.

From the 1994 Mono Lake ruling, the lake level is scheduled to rise to just under 6400 feet elevation. Available land area on the island will decrease from that which is currently visible. The water barrier separating Negit Island from Paoha would widen. Assuming a 6400 foot shore line, the island area is roughly 3.5 sq miles (9 sq km). Water availability and vegetation distribution may change with increasing lake level. Being an island, access is limited to boat or helicopter. Mono Lake is subject to sudden high winds that can make travel on the lake extremely dangerous. The lake is extremely salty (2-4 times saltier than ocean water) and alkaline (pH 10), which can quickly corrode metal on boats, docks, and other infrastructure improvements that may be needed for a sheep project. These factors will impact the efficacy of monitoring and feeding the sheep.

Other factors that will be important in considering the island for bighorn sheep breeding include: the Mono Basin Scenic Area designation of Mono Lake and its islands; migrating water bird nesting and feeding sites; cultural heritage of the island for the Kuzedika tribe of Paiute people; access of the island for kayakers, hikers, and other researchers (such as NASA Jet Propulsion Laboratory microbiologists that we met on the island on 11-9-99). While bird (California gulls and other species) nesting on Paoha Island may be limited currently, natural history indicates nesting locations are dynamic, and the island may become a preferred site for nesting in the future.

Domestic goats, which then became feral, existed on Paoha Island in abundance for decades (1920's-1960's). Deer are currently present. This information indicates that ungulates can survive and reproduce on the island. However, for bighorn sheep captive breeding, the question should not merely be, can they survive? Instead, we should ask, are the conditions optimum for reproduction, providing healthy lambs to later translocate to augment Sierra Nevada bighorn sheep herds in the wild. Bighorn sheep are likely to survive on Paoha Island, however, the combined effect of the factors listed above would likely result in suboptimal reproduction rates, and perhaps long-term health consequences. For these reasons, I advise that Paoha Island should not be a primary location option for captive breeding of Sierra Nevada bighorn sheep.

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Richards, James. 1999. Vegetation assessment and plant species identification during 11-9-99 Paoha Island trip - see attached.

USGS 7.5 minute topographic maps of Paoha Island.

Appendices

Appendix 1. Dr. Jim Richards' Vegetation assessment and plant species identification on Paoha Island, Mono Lake, CA.

Appendix 2. Table of relative advantages and disadvantages of island vs. land sites.

Appendix 3. Topographic map identifying locations of island features.

Appendix 4. Summary of abnormal findings in California Veterinary Diagnostic Laboratory Services (CVDLS) Plant and Water toxicology reports.

Appendix 5. Topographic map of potential alternate sites located between Baker Creek and Fuller Creek, just west of Big
Pine, CA.

Appendix 6. Aerial View of Paoha Island in Mono Lake

Appendix 7. View from Paoha Island in Mono Lake

Mono Lake web sites of interest:

http://www.monolake.org/index.html
http://www.monolake.org/naturalhistory/chem.htm

Paoha Report Appendix 1.

Dr. Jim Richards' Vegetation assessment and plant species identification on Paoha Island, Mono Lake, CA

1. At fumarole hill, soils between volcanic outcrops are dominated by Bromus tectorum. I collected a couple of other species there. I've put these in campus mail to you. Perhaps Ellen Dean can confirm my tentative ID's. There are many weedy species growing under and among the cheatgrass. One appears to be Polygonum sp? Erodium sp (filaree) was also observed. I expect that spring collecting will find many other herbaceous weedy species. Near and on the volcanic rock outcrops is Antennaria luzuloides (check ID), in addition to the Agrostis spp you collected.

2. The most widespread community on the island appears to be a mixed shrub community of Sarcobatus vermiculatus (greasewood), Atriplex confertifolia (shadscale), Grayia spinosa (hop sage), and Tetradymia spinosa (cotton-thorn or spiny horsebrush). These typical shrubs of clayey saltdesert sites throughout the Great Basin have approximately equal dominance over the majority of the island with clay soils (derived from lacustrine sediments) above 6480 or 6500 ft elev. This community also includes a low density, patchy understory of the perennial grass Elymus elymoides (bottlebrush squirreltail). I wouldn't call this community a grassland. What I saw was a mixed shrub community with a sparse understory of the native perennial grass. In areas where there is fumarole activity the shrub community may be absent (as around fumarole pipe) or of much lower density.

3. The lower elevation terraces (less than 6460 ft. elev. but mostly between 6400 and 6420 ft. elev) with clay soils are dominated by dense, nearly monocultural stands of Sarcobatus vermiculatus. Note that the lake level was above 6400 ft elev from 1850 (beginning of record) until 1959, with a maximum of 6427 ft elev. in 1919. These communities have developed naturally in the last 40 years. Extremely salty areas on these terraces, where the soil has a salt crust, have lower densities of this shrub. Localized areas of the Sarcobatus community, apparently near areas of previous disturbance (plowing, grazing), include weeds such as Bassia hyssopifolia, Descurania sp, other Cruciferae among others

(collections needed in spring or summer).

On these lower terraces where freshwater springs or seeps are present there are wetlands dominated by Scirpus pungens, Scirpus acutus var occidentalis (check ID) (tule), Carex spp., Distichlis spicata (saltgrass), and Typha sp (cattail). I also noticed remants of Thelypodium sp and remnants of plants that looked like either Atriplex serenana or Chenopodium chenopodies (sp need ID's checked when fresh material available). Again, these communities have developed naturally in the last 40 years.

4. On the lava and gravelly substrates we visited on the north end of the island Artemisia tridentata (sagebrush) and Chrysothamnus nauseosus (rubber rabbitbrush) join the other major shrubs. At least Chrysothamnus also occurs in small patches within the mixed shrub community. Subspecies id of these two widespread Great Basin species were not confirmed. However, the palatability for bighorn of Artemisia cannot be ascertained without actual trials since populations within subspecies differ greatly in palatability for other ungulates (see extensive studies by Welch, B and MacArthur D).

5. On the black gravel terraces of the north shore of the island we saw Mentzelia laevicaulis (check ID) (blazing star), Cammisonia boothii ssp. desertorum (check ID) (sun cups), and Psathyrotes ramossima (turtleback). On checking I noticed that Psathyrotes appears to be our of it's range, but I have also collected it on my study site on the NE shore of Mono Lake. I believe that I deposited a voucher specimen in the UCD herbarium. We might want to confirm this ID and see if a range extension needs to be documented. Ellen Dean could best advise on this.

6. Achnatherum hymenoides (Indian ricegrass) was observed among shrubs on gravelly slopes due north and above the fumarole spit.

As stated in his email, these notes are the result of Dr. Richards single visit and may need to be modified as more information surfaces.

Appendix 2 of Paoha Assessment Report

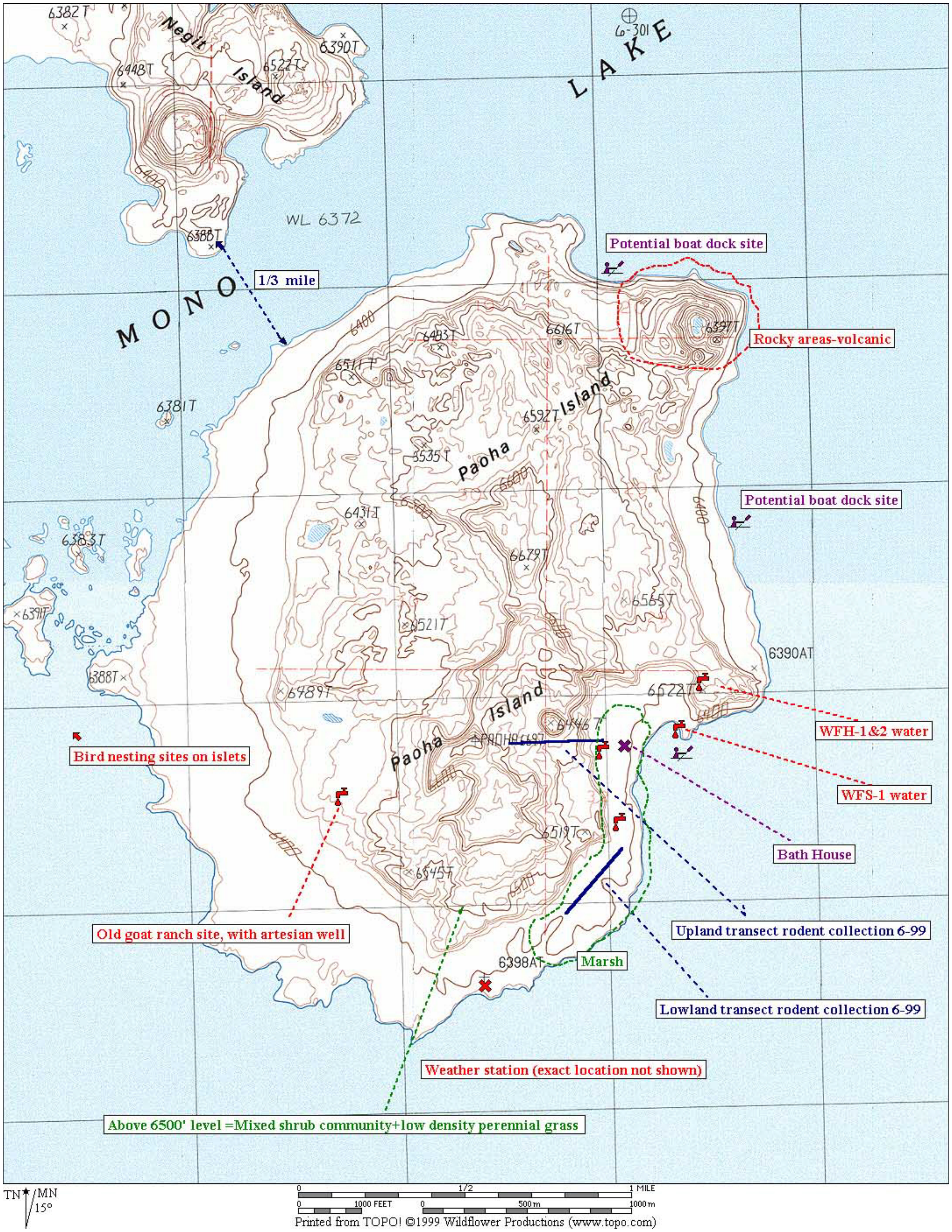
Site Comparisons for Paoha Island Site and Baker Creek-Fuller Creek for Sierra Nevada Bighorn Sheep Captive Breeding Sites

Location	Mono Lake	See Appendix 5 topographic map. West of Big Pine, south of Warren Bench, ~118�22'30" west and 37�07'30" north latitude, bounded by Baker Creek to north, Inyo Heights school to east, Fuller Creek to south. Site#1 that Vern and I drove around (including on 4WD dirt road to west) was about 1 sq km; additional sites (#2, 3, 4) to south identified with John Wehausen on 11-11-99.
Area	~9 sq km; =3.5 sq mi; assuming 6400' level shoreline (projected level for Mono Lake restoration by ~ year 2020) 2.25 km wide (E-W) X 4 km long (N-S)	Each site as identified on topo map ranges from just under 1 sq mile to nearly 2 sq miles;
Land jurisdiction agencies	Northern half= National Forest; southern half=City of LA Land (LADWP); shores=state land?	Eastern half= City of LA Land (LADWP); western half= National Forest, adjacent to private land and school which leases land from LADWP
Major disadvantages	Poorer habitat; accessible only by boat; storms; toxic plants, water	Predator-proof fence ($$) and active vigilance required (personnel)
Major advantages	No major fencing (may not be true if animals can swim on/off); lower predator problem likely	Good BHS habitat, road accessibility on perimeter (some road = rough 4WD dirt road)

Sheep carrying capacity	? depends on supplemental feeding, etc	To be determined depending on land area, etc.
Potential time to sheep introduction	Likely not before spring 2001 at earliest for Sierra BHS, at least one year (maybe 2+) after sentinel Nelsoni placed, Nelsoni placed Feb-Mar 2000, if EA completed, etc.	Likely not before spring 2001. Need major allocation of money ($millions for fencing) and time to build fence (likely 1+ year).
Fencing requirements	may be necessary-to exclude BHS from nesting, possibly toxic water and/or plants, prevent migration of BHS, deer, coyotes, etc.	major effort and expense at least~ 4 miles of predator-proofing
Quality of BHS habitat	Fair-poor: minimal escape terrain, soft substrate (hoof health)	Good-Excellent
BHS Forage Quality	Fair-poor: oxalate-accumulating plants, at least one species with significant arsenic; likely will need to supplement feed	Good-excellent but no diagnostic plant analysis done; may need to supplement feed, but less than Paoha
Water sources	Present, but some toxic; surrounded by saline-alkaline lake	Present, but at least 2 are choked with vegetation so that BHS are unlikely to enter; no diagnostic water analysis done
Air quality	Saline-silica-alkali dust toxic storms periodically	?Frequency of dust storms? Likely much less frequency and less toxicity than Paoha
Predators	Coyotes likely, need to swim across, vigilance needed, but perhaps less than Baker	Major problem. Good lion, bobcat, coyote habitat, even with best fencing, will need constant vigilance

Contact with other ungulates	Likely - abundant deer sign on island; goats in past history (none noted for 2+decades)	Deer are there, cattle and sheep grazing nearby, but maybe not directly adjacent
Accessibility for personnel and infrastructure	By boat or helicopter only: inaccessible during storms; flat sites for feeding stations, drop-netting, guzzlers, etc (will evaluate on 11-9-99)	Probably better than Paoha overall. good roads on 2+ sides; 4WD dirt road on one side, power line right of way on one side; can truck supplies, sheep into site
Access for helicopter-capture	Good, need consider migratory birds	Fair; likely more dangerous than island -risk of running BHS into fence or helicopter into mtn
Good ability to set drop net	Probably	maybe
Poaching and human disturbance	Less likely; humans excluded April-August for birds	More likely - near roads, more visible to public, more likelihood of poaching
Human safety	Severe lake or wind storms; boat required (water safety), toxic dust storms	Precipitous terrain, fencing dangers (getting pinned by ram in rut, running helicopter into fence, etc), steep 4WD roads, mtn lions
Historical, ecological, human aspects of site	Historic native Kuzedika tribe (Paiute) site, migratory bird staging area, CA gull, eared grebes, phalaropes nesting; part of Mono Lake ecosystem	Near Inyo HS children and a few residences, deer range through region (therefore mtn lions) otherwise none known yet.

Appendix 3
Topographic map identifying locations of island features



Negit Island
LAKE
MONO
WL 6372
1/3 mile
Potential boat dock site
Rocky areas-volcanic
Paoha Island
Potential boat dock site
6390AT
WFH-1&2 water
WFS-1 water
Bath House
Bird nesting sites on islets
Old goat ranch site, with artesian well
Upland transect rodent collection 6-99
Marsh
6398AT
Lowland transect rodent collection 6-99
Weather station (exact location not shown)
Above 6500' level =Mixed shrub community+low density perennial grass
TN MN 15°
0 1/2 1 MILE
0 1000 FEET 0 500m 1000m
Printed from TOPO! ©1999 Wildflower Productions (www.topo.com)

Appendix 4

California Veterinary Diagnostic Laboratory Services (CVDLS) Plant and Water toxicology reports

Summary of Abnormal Findings

Heavy Metal Screen: Plants

Arsenic high (5ppm) at FH-1 site
Molybdenum high (14.3 ppm) at UP-1 Site
Copper - plants at all sites generally low
(less than 10 ppm at M-1, FH-1, Fh-2, NV-1, UP-1, UP-3)

Heavy Metal Screen: Water

Arsenic high (5.1 ppm) at WFS-1 Site
Molybdenum high (0.12 ppm) at WFS-1 Site

Oxalate Screen: Plants

High at UP-1 (35,200 ppm wet weight) and UP-2 (26,100)

Salt Screen: Plants

Ca:P ratio in ppm
FH-1 (2210:1550)
FH-2 (1000:1800)
NV-1 (14,200:2200)
NV-2 (3040:2370)

Sulfur (ppm)

NV-1 (11,400)
UP-1 (8800)

Salt Screen: Water

Potassium high WFS-1 (158 ppm)
Sodium high WFS-1 (6730 ppm)
Sulfur high WFS-1 (905 ppm)

pH: Water

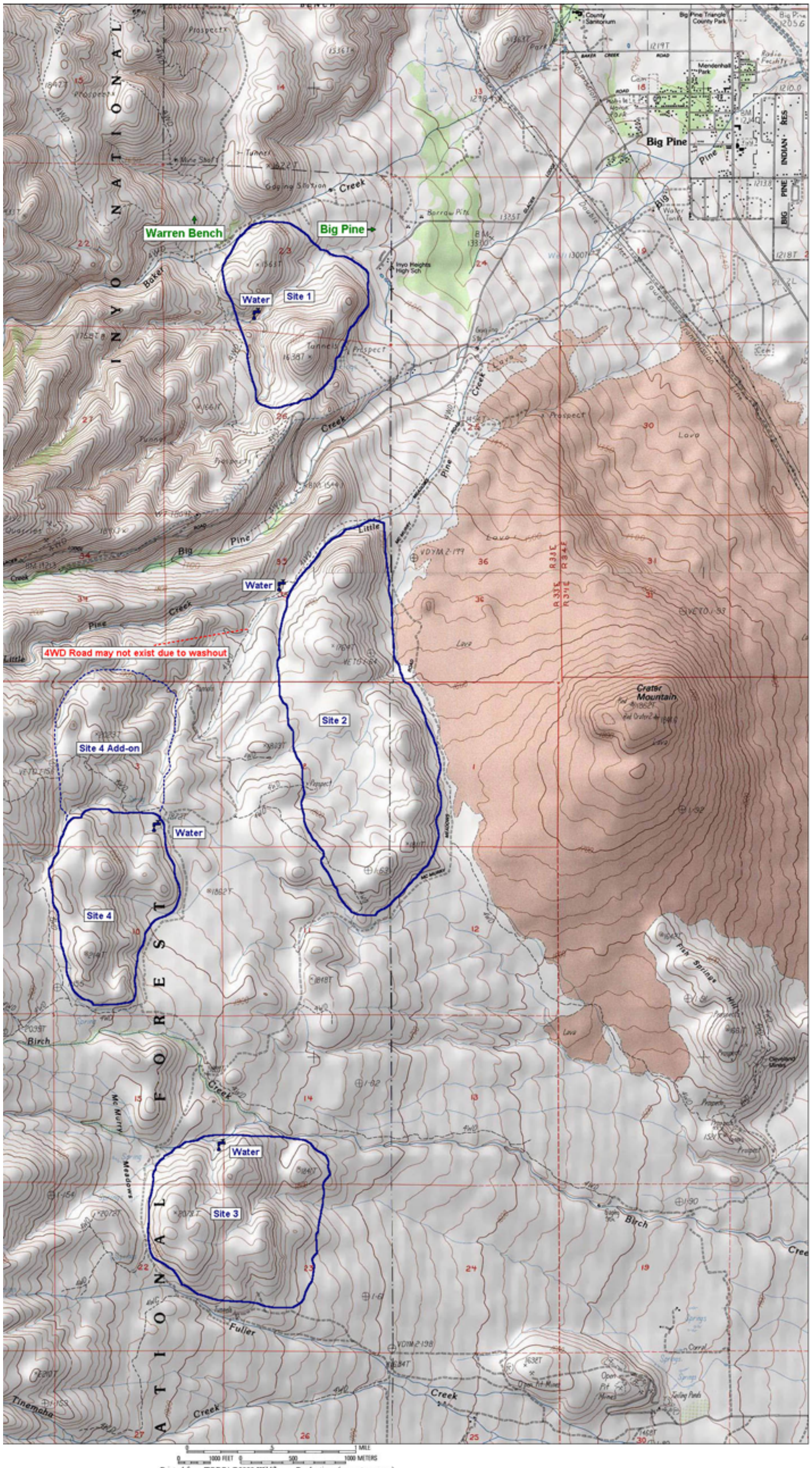
Acid at WFH-1 through rusty pipe (pH 4.51)
but neutral pH through PVC pipe inserted in rusty pipe

Alkaline at WFS-1 (pH 9.42)

Appendix 5

Topographic map of potential alternate sites located between Baker Creek and Fuller Creek, just west of Big Pine, CA.

Elevations in meters. Thanks to Dr. Vernon Bleich, Dr. John Wehausen, Steve Torres, and Dr. Ben Gonzales for assistance with initial examinations of these sites.


Warren Bench
Big Pine
Water
Site 1
Water
Site 2
4WD Road may not exist due to washout
Site 4 Add-on
Water
Site 4
Water
Site 3
Crater Mountain
Printed from TOPO! ©2000 Wildflower Productions (www.topo.com)

Appendix 6

Aerial view of Paoha Island in Mono Lake looking from the west

Paoha is the largest island located on the farthest right (south), with the smaller black Negit island to the middle left and a sand land bridge farthest left. The town of Lee Vining Tioga Pass, Highway 120, Mt Gibbs, and Mt Warren are located off the lower edge of the picture.

Appendix 7

View from Paoha Island in Mono Lake

Looking southwest from the Paoha Island bluff at area labeled "WFH - 1&2 Water" on the Paoha Topo Map Appendix 3. Snow covered Tioga Pass area of Sierra Nevada at top of photo.

"Baker Creek" Sites

The Baker Creek region sites, west of Big Pine, between Baker and Fuller Creeks, (see the topographic map in the Paoha Appendix 5) may be viable alternatives for a captive breeding facility site. On preliminary survey, the habitat appeared to be good for bighorn sheep (consultations with Dr. John Wehausen and Dr. Vernon Bleich), providing abundant escape terrain and nutritious native vegetation. Several of the "Baker Creek" sites have good dirt road access. Fencing an enclosure appeared practical. Water is available either naturally, through riparian areas, or possibly through existing water structures or guzzlers that could be built. These sites will not allow captive Sierra Nevada bighorn sheep to seasonally migrate, as they do in the wild.

Elevations range from 1400-2100 meters (4600-6900 feet). There are cattle allotments within 3 miles in the McMurray Meadows, Shannon Canyon, and the Coyote Allotments (see US Forest Service, Resource Data Management map of Cattle and Sheep Allotments on the Inyo National Forest, January 2000). As with most sites in the eastern Sierra Nevada, bluetongue virus is a large concern, particularly for captive sites that are near cattle and riparian areas (breeding grounds for the biting midge vector) and with elevations lower than 7000 feet (midges are more likely to occur).

Most of the land is federal - US Forest Service (see Inyo National Forest Map R33E T9S sections 22-23 near Baker Creek, south to R33E T10S sections 22-23 near Fuller Creek)- and therefore use is contingent on interagency agreements and Environmental Assessments. There are small sections of City of Los Angeles Department of Water and Power (LADWP) land also. If LADWP land (private land) was proposed to be included, agreements with that body would also be needed. Depending on the site, enclosures of less than 1 square mile to over 2 square miles could be constructed. The region may contain important mule deer travel routes, therefore surveys conducted before final site selection should assess the impact of a facility to deer movements. See Captive Facility Site Selection for additional considerations.

Figures:
Topographic map (same as Paoha Appendix 5 - see above)
Aerial view
Site comparison with Paoha (same as Paoha Appendix 2-see above)

Aerial view of Baker Creek Site
courtesy Dr. Ben Gonzales

Herd Health and Care

Capture & Transport
Selection Criteria for Herd
Husbandry
Raising lambs
Diseases
Veterinary Care
Blood Reference Values

Capture and transport techniques

The CDFG Wildlife Investigations Lab (WIL) Capture Specialists and Wildlife Veterinarians, and Dr. Vernon Bleich, and Dr. John Wehausen are excellent resources for these procedures. Also, refer to the CDFG WIL Restraint Handbook, Jessup 1993, and Jessup 1999.

While capturing, moving, or releasing animals, know and plan for bighorn sheep behavior: response to danger, natural curiosity (to explore new fences and gates), instinct to test fences (usually hitting them full force - watch for broken necks, limbs, horns), etc. Gentle, slow, and quiet movements by staff will reduce stress and risk of injuries to animals and people.

Specific protocols should be in place before any animal is captured, transported, or released into the captive facility. Consider specific instances, including the capture and transportation of lambs, use of airline and surface transport, etc.

Special attention is required during capture and transportation to prevent injuries, including limb fractures and capture myopathy. For transportation of lambs, airline transport of bighorn sheep, and other special cases, consult with bighorn sheep biologists with experience (see references and acknowledgements for a partial list).

Chemical immobilization should be avoided in bighorn sheep if at all possible. Drug-based captures are likely to increase capture-related mortality rates. Successful capture methods in the wild include netgun, drive net, and drop net. Netgun techniques may be dangerous for animals and people within a captive facility. Therefore, techniques of choice will include driving animals through a series of chutes then individual crates, pole net capture within a feeding pen, or drop net (see below). Avoid chasing bighorn sheep for more than 5 minutes to reduce the risk of death and injury from capture myopathy and fractures. Animals should be quickly processed (measured, blood samples, tagged, etc), then driven to their destination. Animals may be crated individually or loosely within a darkened truck. If a helicopter is used, bighorn sheep may be slung beneath and flown to their destination.

Notes from experts:
Dr. Vernon Bleich: Discussed a study of soft release (holding pen) vs. hard release (directly from truck to new area) in Chuckwalla Mtns (Thompson et al. in review). Hard released animals had much better survival rates. Mortality during capture may range around 4%, more if chemical immobilization is used, slightly less with netgun captures. Trucking sheep for up to 30 hours may not cause much additional mortality.

Stacey Ostermann and Jim DeForge of Bighorn Institute recommend the system that they use: providing a small feed pen which the sheep can be accustomed to. Sliding gates are used to trap animals inside the pen, then pole nets used to capture individuals. The capture pen should not be located near lambing areas. See Bighorn Institute section for more information.

Dr. Dave Jessup (personal communication 2-17-00) recommended that bighorn ewes be trucked loose, not crated, kept in the dark. Rams may be crated if necessary to keep them from harassing ewes or each other.

Doug Humphreys (Texas Department of Parks and Wildlife and prior work at Red Rock New Mexico, personal communication February 2000) recommended that one pasture in the facility be dedicated as a trap with a fence line that sheep could be hazed down to progressively smaller chutes. The chutes could end at a crate of 10' X 10' covered by a drop cloth to maintain darkness and prevent sheep from viewing personnel. He felt that would produce less stress than with helicopter capture within the facility. Doug stressed to keep personnel down to the minimum number needed - avoid photographers and non-essential personnel to reduce stress to sheep. For capture from the wild and translocation to the captive facility, he stressed the importance of using an experienced bighorn sheep netgunner to select out the lead ewe and her ewe group, to maintain intact social structure within the facility.

Selection of Foundation Stock and Pedigree Management of Captive Bighorn Sheep

Determination of number of bighorn sheep to take into captivity for breeding

Initially, a small number of bighorn sheep (one ewe group) should be released into the captive breeding facility. These first sheep will act as sentinels to test that the facility will function properly to safely contain the breeding stock. The initial number should consist of about five or more ewes (to constitute one ewe group) and 1-2 rams. If there is no urgency to the captive breeding plan, these sheep should be maintained for at least one year and monitored for health problems. All problems with fencing and facilities should be worked out before introducing more sheep the following year.

Selection of Founder Stock

Many factors will come into play for the selection of the foundation stock of a captive herd. Very different selection criteria may be involved depending on the reasons that the captive herd is founded (See Captive Breeding General Information). In general, genetic diversity and strong healthy bighorn sheep are important selection criteria. If possible, breeding stock should represent the range of variation present in the wild. This means that if possible, sheep from multiple populations should be selected. As genetic data becomes available, more specific selections are possible. Keep in mind that the current Wheeler, Langley, and Lee Vining populations contain Baxter genotypes, since they were reintroduced from the Baxter population.

Although juvenile ewes and young adult ewes would provide breeding potential for a longer time than older ewes, selection of one or more mature lead ewes may be important to instill behavioral stability to the captive herd. However, the mature lead ewes may be deemed to have a more important in the wild and therefore not selected for captive breeding. Juvenile sheep (<1 year age) may adapt better to captivity and have calmer behavior than older adults brought to captivity from the wild. If available, genetic and/or kinship information should be used to select foundation stock to maximize genetic diversity and to avoid close inbreeding of relatives. Once sheep are in captivity and have completed their quarantine period, they should be observed for behavior. If individual animals are observed to be continually agitated and disrupt the behavior of the rest of the captive herd, they should be returned to the wild (following an individual quarantine period). Kinship should be minimized (see Montgomery et al 1997; recommendations from the Captive Breeding Specialist Group and IUCN).

Captive rams and ewes

All healthy ewes that are brought into captivity should be bred. One ram can potentially breed a large number of ewes (30-50), however an optimum ratio may be lower, one ram to 6-10 ewes (personal communication, Stacey Ostermann, Bighorn Institute and Doug Humphreys, Texas

Department of Parks and Wildlife). The number of rams used in the breeding program should be maximized for genetic reasons, but may be limited by aggressive behavior and facility capacity. In nature, adult rams and ewes generally form separate groups except during the rut (breeding season). Some existing captive bighorn sheep facilities maintain ewes and rams together throughout the year (Sybille, WY facility of the Wyoming Dept of Game and Fish, for example). However, other facilities keep rams and ewes separate except during the rut (the Bighorn Institute and the Ft Collins, Colorado Division of Wildlife facility, as examples). The Red Rock facility of NM Dept of Game and Fish has reported serious problems with ram harassment of ewes, leading to ewe condition decline, when rams and ewes were fenced together (personal communication, Dr Eric Rominger, Bill Dunn, Amy Fisher, New Mexico Department of Game and Fish. This problem was particularly acute when the facility had too many rams. For this reason, and to maintain control over breeding, separate ewe and ram pastures should be constructed. When an initial small number (<10) breeding stock are brought to the facility, a trial period of maintaining ewes and rams together may be attempted. Having just one herd initially, may facilitate care and observation of the sheep, may provide the safety in numbers that sheep require. If the herd dynamics are not stable (ex, rams harass the ewes), then rams should be separated. Once the herd expands in number (<20), rams should probably be separated except during the rut.

Mature (>4 years of age), gentle rams should be selected for breeding. Immature or aggressive rams can excessively harass ewes causing decline in their condition and undue stress which may interfere with reproduction. The behavior of rams may only be determined after they are released to the ewe pasture. Aggressive rams should be returned to the wild. Rams should be rotated in from the wild periodically to maximize genetic diversity of offspring. The frequency of ram rotation will depend on many factors, including the ability to capture unrelated rams from the wild, the behavioral qualities of captive rams, number of offspring (i.e., the amount of the ram's genetic contribution to the population), risk of introduction of disease, etc. A captive ram exhibiting good breeding behavior and few offspring may be a good candidate to maintain as breeding stock longer than an overly aggressive ram with many offspring. Similarly, ewes that don't adapt well to captivity may be good candidates for release back to the wild.

Dr. Ben Gonzales adds the following: Cycling wild rams in and out of the enclosure must be considered very carefully in the context of genetic diversity. Wild mature rams may introduce behavioral instability into the captive herd. Consider potential for introducing weaned wild lambs or yearling rams to maintain genetic diversity.

Pedigree information and planned matings

If available, genetic and/or kinship information should be used to plan matings of the founder stock. If this information is not available, matings should be planned to maximize genetic diversity in accordance with the recovery plan. Genetic samples from all captive sheep and their offspring should be collected and analyzed. Very stringent record keeping should be maintained, and from this a pedigree of the captive herd developed. The pedigree will insure that close relatives are not mated. It will also help to plan releases of captive sheep to the appropriate mountain ranges / Genetic Conservation Units (GCU's).

Assisted Reproduction and Contraception

Currently, the best option for breeding captive bighorn sheep is the most natural - allowing mating as in the wild. However, techniques of assisted reproduction for captive species are improving and should be monitored for future consideration. Also, permanent or temporary contraception of selected ewes or rams may be desired in the future. The following references will provide an introduction to these subjects:

Pope and Loskutoff 1999
Liu et al 1999

EXAMPLES OF RECORD KEEPING SYSTEMS

ISIS SPARKS

An example of a pedigree record keeping system is the ISIS SPARKS (International Species Information System, Single Population Analysis and Records Keeping System) computer record keeping system that many zoos and the Bighorn Institute use. If more than one ram is used to mate captive ewes, samples should be collected from lambs for genetic analysis to determine paternity. ISIS charges an annual fee to access their services. Click here to go to the ISIS web site: http://www.isis.org/services.htm

PEDSYS

Another system that is available is PEDSYS, a database system developed as a specialized tool for management of genetic, pedigree and demographic data. As of this report, PEDSYS and associated programs are free. Click here to go to their web site: http://www.sfbr.org/sfbr/public/software/software.html

Husbandry of Captive Sierra Nevada Bighorn Sheep

Health and General Care
Disaster Planning
Handling
Nutrition
Reproduction

Health and General Care

HUMANE CARE: Captive bighorn sheep should be treated humanely, not only for ethical reasons but also to maintain the least possible stress level in the herd. A review of humane care may be found in McManamon 1993 and Williams 1993.

LONGEVITY: Bighorn sheep, particularly ewes, may survive in captivity up to 16+ years.

IDENTIFICATION: All captive sheep should be individually and permanently identified with ear or neck tags that are visible from a distance. Permanent Implantable Transponder (PIT) tags and/or ear tattoos are a good idea in case external tags are lost. The Captive Breeding Specialist Group of the IUCN has recommended PIT tags as a global standard for zoo animal identification (Loomis 1993). Lambs should be tagged as soon as possible after birth (see below). Placement of mortality-sensing radiocollars on all captive sheep will allow the facility manager to more effectively monitor the herd.

AVOID DISEASE TRANSMISSION: After handling wild bighorn sheep or any other animals, personnel should completely change clothes and disinfect boots before handling captive bighorn sheep and visa versa. It is best to avoid working with captive bighorn sheep immediately after working with wild bighorn sheep or any other animals. Foot baths of disinfectant provided before entering pastures may reduce spread of contagious disease agents. No dogs or other pets should be allowed in the facility.

Disaster Planning

The occurrence of natural (fires, avalanches, predators, etc) and human-caused disasters (captive escapes, disease introductions, etc) within the facility should be anticipated. Procedures should be prepared in advance outlining how to care for the animals. Instructions should outline when and if animals should ever be released from the facility, euthanized, or transported elsewhere, in the event of an emergency such as a fire. See Harwell 1993 for a discussion of disaster planning and Rafael 1993 for escaped animals.

See also Disease Outbreaks section.

Handling

Although captive, the bighorn sheep maintained at the facility will not be truly domesticated. They will exhibit defensive behaviors at unfamiliar situations. The best policy may be one of minimal handling. However, by moving slowly, quietly, predictably, and in small numbers of people, the sheep may become accustomed to daily activities around the facility. The manager should be consulted before people other than facility staff are allowed near the facility. Always handle sheep in a gentle, quiet, and consistent manner. Bighorn sheep will recognize characteristics of individual people, including clothing, odors, mannerisms, vehicles, and time of day. Occasional slight change (not too abrupt or drastic) in feeder locations, daily schedule will help exposure lambs to variety of situations.

Taming of animals to make them easier to handle is likely to be counterproductive to producing stock for release to the wild. However, in the event that taming is considered essential for some animals, it is best to begin while animals are young (less than 6 months age). Many older animals may also become tamed. This may be facilitated by handling adults once weekly by moving through chutes, weighing them, etc. However, this type of activity is more likely to stress animals than to provide a great benefit with tame sheep.

A variety of capture techniques should be available to capture and handle sheep with the least amount of stress to animals and people. Do not rely on one single method to work most effectively each time. These methods may include drop net, net gun, hand net, darting with tranquilizers, chutes, etc (see CDFG WIL Wildlife Restraint Manual). Robbins (1993) recommends providing free choice selenium salt blocks at least one month prior to capture to reduce cell damage that may occur during capture myopathy (see Diseases section below on capture myopathy).

ZOONOTIC DISEASES: Humans working or visiting the facility may be at risk for diseases passed from animals to humans. These may include diseases carried by bighorn sheep (contagious ecthyma for example) or by other animals living at the facility (Hanta virus from rodents). See Diseases.

Nutrition

Ideally, the enclosure would supply native plants year-round to provide good nutrition to the captive bighorn sheep. Native forage will likely be closer to vegetation that with which the sheep have evolved than hay and pellets (assuming the facility is located in the eastern Sierra Nevada. Therefore native forage is less likely to cause digestive upsets, will be nutritious, and will prepare captive animals for eventual release to the wild. However, preparations to supply supplemental feed should be readied in case native forage is not optimum or for reasons listed below.

SUPPLEMENTAL FEED: Regular daily supplemental feeding can accomplish several goals. Drought years or changes in vegetation may require supplementation. If there is insufficient forage within the enclosure, sheep that were previously acclimated to hay and pellets by regular supplementation will more likely accept the artificial food than sheep not so prepared. Optimum nutrition may be provided by supplementation for reproduction. Feed may be used as bait during capture. Regular supplemental may accustom captive sheep to drop net sites. Regular feeding may allow the sheep to become acclimated to the handlers, so that animals may be less stressed during capture and handling. There are anecdotal (Red Rock) and research data (White et al 1995) to indicate that poor nutritional plane may lead to a ram skewed sex ratio at birth. Supplemental feed is likely to improve nutritional status during drought years.

Hay should not be harvested from fields previously grazed by livestock (there is a risk of disease transmission, contagious ecthyma, for example). I recommend the hay recipe provided by Dr. Margaret Wild and used at the Fort Collins facility: hay - 80% grass, 20% alfalfa, fed at about 1.5 kg (3.3 lb) per head per day; and the pellet ration as listed in Baker et al. (1998). All feed should be supplied in feeders that protect the ration from the elements, fecal and urine contamination. Unused feed should be picked up daily to prevent molding and degeneration. Pregnant, lactating, and geriatric bighorn sheep may require modifications in the basic ration.

MINERALS: Trace mineral blocks should be formulated based on local and supplemental forage composition. If forage is selenium deficient, supplemental selenium should be provided. Selenium deficiency can cause white muscle disease in domestic sheep, and may worsen the pathology caused during capture myopathy. Robbins (1993) recommends providing free choice selenium salt blocks at least one month prior to capture to reduce cell damage that may occur during capture myopathy (see Diseases section below on capture myopathy).

WATER: Fresh clean water should be available on a daily basis.

HAND-REARING ORPHAN LAMBS:
Refer to the hand-rearing recommendations by Karla Michelson, Lead Keeper, San Diego Wild Animal Park, Margaret Wild DVM (next section), and Charles T. Robbins book, Wildlife Feeding and Nutrition (see references).

Reproduction

MATING: For selection of animals to be bred, see Captive Breeding Selection Criteria. If determination of pregnancy is desired, the following methods may be used: ultrasound (Bunch et al 1986), blood, fecal, urine tests, rectal palpation, observing behavioral signs of heat and pregnancy, and udder development.

PREGNANCY: For techniques to assess pregnancy status, refer to Lasley and Shideler 1993 and Borgesson et al 1996.

LAMBING: Preparation should be made for lambing season. Trained personnel, pens, and equipment should be available to manage problems with lamb delivery. Handling young lambs may lead to lamb abandonment and interruption of colostrum intake. In a zoo environment, Dr. Ben Gonzales has observed delayed intake of colostrum (> 12 hours) in some ungulates. If the ewes are in a large pen, it will be difficult to locate the newborn lambs and capture may introduce hazards to the lamb. The benefit of capture and processing of newborn lambs should be weighed against these dangers. Perhaps the best measure is close and regular observation by the facility manager using binoculars. "Processing" would involve hand-capture of lambs within 12 hours of birth for examination, tagging, sexing, blood samples, treatment of umbilical cord with iodine (or other disinfectant), and administration of vaccines if desired. Healthy lambs older than 12 hours are likely to be difficult to capture. Depending on parasite status and disease of the captive herd, deworming and vaccination may be desired. Ewes should be observed to make sure that they do not have a retained placenta, are lactating normally, and have recovered well. If weak, rejected, and non-nursing lambs are to be saved, they should be captured and assisted. However, these lambs may have been naturally selected out of the gene pool in nature - consider that they may not be the best stock to reproduce or release to the wild, that saving weak and sick lambs will likely reduce genetic fitness of the herd. Strongly consider not assisting weak and sick lambs.

Orphan Lamb Hand-Rearing Recommendations

Handrearing Recommendations
for the San Diego Wild Animal Park's Infant Isolation Unit
by Karla Michelson, Lead Keeper

Formula

Table 1. Composition of caprinae milk samples (mean values from multiple samples) and composition of artificial milk formulas.

See table below.

Milk type or formula	% Solids	% Fat	% Protein	% CHO	Source
Bighorn Sheep (n=4)	22.00	46.55	31.50	18.25	
Dall Sheep (n=3)	22.50	36.60	33.60	24.60	
Tahr (n=?)	18.90	51.90	30.70	17.50	Jenness and Sloan (1970)
Ibex (n=?)	23.30	53.00	24.00	19.00	Oftendal (1984)
Formula A	19.78	41.55	31.62	17.56	
Formula B	19.00	34.00	22.00	31.00	
Formula C	21.33	34.00	22.00	31.00	
Formula D	22.30	34.00	22.00	31.00	
Formula E	21.44	34.00	22.00	31.00	

A = Whole goats milk/cream/whey (Calpro 75 whey protein concentrate), 15:2:1 by weight.

B = Evaporated goats milk/whole goats milk 1:1

C = Evaporated goats milk/whole goats milk 2:1

D = Evaporated goats milk/whole goats milk 3:1

E = Whole goats milk/powdered goats milk 8:1 by weight

Notes: Karla recommends Formula E due to the higher digestibility and availability of the components. We have used this formula with good success on Urial sheep.

Colostrum

Bovine colostrum (from Johnes disease-free herds) or a colostrum substitute (such as "Colostrum Plus") is fed at full strength for the first 24 hours of life, then as 50% of formula for second day, than as 10% of the regular formula through one month of age. If a colostrum substitute is used, it should be derived from colostrum, not serum.

Dr. Ben Gonzales noted that cow colostrum used for neonatal bighorn sheep may introduce Johne's Disease into the captive herd. Certification of a cattle herd as "Johne's Disease Free" is very difficult. "Heat treated" cow colostrum was not adequate to eliminate *Mycobacterium paratuberculosis,* the Johnes agent.

Feeding Schedule

Age	Minimum # of feedings	Suggested feeding times
1-3 days	6	6am, 9am, noon, 3pm, 6pm, 9pm
3-7 days	6	6am, 9am, noon, 3pm, 6pm, 8pm
8-21 days	5	6am, 9am, noon, 3pm, 6pm
3 weeks	4	6am, 9am, 1pm, 5pm
6 weeks	3	6am, 11am, 4pm
10 weeks	3 (with decreasing volume in middle bottle)	6am, 11am, 4pm
11 weeks	2 (with decreasing volume in both)	6am, 4pm
12 weeks	weaned	

Feeding amounts

The goal is to have the animal consume at least 15% with a maximum of 20% of its body weight per day (for ex., 525 ml to 700 ml for a 3.5 kg neonate) for the first 2 weeks, and then 12-15% during weeks 2-4. Feedings are typically of equal volumes but young animals sometimes benefit from having a slightly larger feeding in the morning and for the last feeding of the day, and the volume of some bottles is decreased during weaning (see table above).

Increases/Decreases

Increases are based on two criteria: appetite and weight gain. Usually, appetite is the best indicator for increases. Increases are made in small daily increments until neonate shows signs of satiation. Increases should be approximately 10% of the daily total. If a neonate's appetite can not be satiated (ex. if it is taking 20% of its body weight) and is not showing a good weight gain, then the diet may need to be changed (it may be too dilute). If appetite decreases or animal is refusing at least one feeding a day then daily total should be decreased by 2-4%, the frequency of feedings should be decreased, or (in the case of a very young animal) the formula needs to be diluted slightly. Appetite is often used to guide the weaning process.

Weaning age

Caprinae are typically weaned at 3 months.

Routine medical treatment

All newborn animals receive umbilical treatment with 3% iodine for three days. Other treatments to consider are a one-time injection of vitamin E and selenium, and three days of preventative penicillin injections (a previous protocol at Wild Animal Park which has been discontinued).

Miscellaneous information

Dietary additives: regardless of species or formula, the formula (through weaning) is fortified once daily with “Visorbin”, a vitamin and iron preparation with sorbitol, at a dosage of 0.15ml/lb. “Probios”, a source of lactobacillus, is added to every bottle for the first week of life and then to one bottle a day until weaning (1/4 tsp/5 lbs).

Types of nipples/bottles: Caprinae neonates do well on human preemie nipples/bottles. Change to pritchard or soft lamb nipple if necessary. Due to their enthusiastic nursing behavior, use a small cross-cut to prevent aspiration. Enlarge as needed.

Solid foods: Solid foods should be offered as early as 2-3 days of age. Young animals will start sampling foods earlier if they are housed with older animals. If housed in a larger pen with adult animals, the neonate may be “clicker” trained to approach the caretaker for bottle feeding.

Supplemental fluids: The projected fluid needs of a young lamb total 15-20% of its body weight daily. These needs must be met orally with formula or with subcutaneous fluids (usually 2.5% dextrose in 1/2 strength Lactated Ringers). If a neonate does not take in adequate formula, the typical nursery protocol is to make up the deficit with subcutaneous fluids. This is only applicable for animals that have not started eating solids or drinking water. In addition, this need may increase for dehydrated animals or those with diarrhea.

Evaluating the neonate’s immune status: After the age of 24 hours, a blood sample can be drawn to confirm whether or not the neonate has acquired and absorbed the necessary immunoglobins from the colostrum or colostrum substitute. There are two tests available: a gluteraldehyde test and a sodium sulfite test (the “Bova-S” test kit is commercially available for cattle). If the neonate has not acquired immunoglobins orally it may be possible to give it plasma (intravenously) from an adult animal.

Normal temperatures: Range 101-104°F

Products mentioned above:

Bova-S test kit: VMRD, Inc. Pullman WA. 1-800-222-8673

Calpro 75 Whey Protein Concentrate: Calpro Ingredients, 1787 Pomona Road, Suite D, Corona, CA 91720-6912. (909) 735-5921.

Colostrum Plus: Jorgensen Laboratories, Inc. Loveland, CO 80538 1-800-525-5614

Powdered goat milk: whole Meyenberg powdered goat milk is whole goat milk which has been pasteurized, spray-dried, and supplemented with folic acid. Meyenberg Products, Jackson-Mitchell Inc. P.O. Box 934, Turlock, CA 95381, http://meyenberg.com/prod4.htm

Probios: CHR Hansen Biosystems, 9015 West Maple Street, Milwaukee, WI, 53214-4298, www.chrhansen.com

Visorbin: manufactured by Pfizer.

Whole goat milk: Meyenberg Ultra-Pasteurized Goat Milk, fortified with vitamin D. http://meyenberg.com/prod2.htm

Literature Cited

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Oftedal, O. 1984. Milk composition, milk yield and energy output at peak lactation: a comparative review. Symp. Zool. Soc. London 51:33-85.

For Handrearing Recommendations by Margaret Wild DVM, Colorado Division of Wildlife See Wild et al 1994.

Diseases of Note for Sierra Nevada Bighorn Sheep

Bluetongue virus
Capture Myopathy
Contagious Ecthyma
Pasteurella pneumonia
Protostrongylus lungworm
Psoroptes mange mite
Additional diseases
Zoonotic diseases
Reportable diseases
Disease references

As noted by Ballou 1993, "Disease risks are an inherent part of captive breeding, translocation, and reintroduction programs...". One of the keys to success if captive breeding plan is implemented in the Sierra Nevada, is to assess and minimize disease risks at every step of the program.

Below are listed a few of the diseases that may have the greatest potential for problems in a captive breeding program. This list is not comprehensive and includes only some diseases that may be of major importance to bighorn sheep and the people who care for them in the Sierra Nevada. Please consult with the CDFG Bighorn Sheep Wildlife Veterinarian and the Sierra Nevada Bighorn Sheep Recovery Plan on all disease related issues.

Bluetongue virus & Epizootic hemorrhagic Disease

Blue tongue virus (BTV) and Epizootic hemorrhagic Disease (EHD) are of potential importance to all bighorn sheep populations, and of particular concern for captive populations existing near water sources and at elevations that may harbor high numbers of the insect vector. The viruses are spread by biting midge species (*Culicoides sp.)* and can cause a severe vasculitis (blood vessel inflammation) disease. BTV tends to afflict domestic and wild sheep species; while EHD is particularly pathogenic in deer. Acute mortalities attributed to BTV occurred in Lava Beds National Monument bighorn sheep translocated from the Sierra Nevada, and populations in other regions, including Red Rock, NM. EHD caused mortalities in British Columbian bighorn sheep in 1987 and 1999 (Canadian Ministry of Environment, Lands and Parks). BTV and EHD viruses are closely related and may cause indistinguishable disease in bighorn sheep. Cattle and elk generally, and sometimes sheep, can harbor the BTV and EHD viruses without signs of disease (Jessup and Boyce 1993). Cattle are viremic for about 30 days, then remain serologically positive for life (Dr. John Maas, personal communication).

Culicoides sp. midges are present and blue tongue is endemic in cattle herds (exists continually) in valleys just east of the eastern Sierra Nevada Mountains, including the Owens Valley (Personal communication, Dr. N.J. MacLachlan, UC Davis School of Veterinary Medicine; Dr. J. Corbett and Dr. Jeff Davidson, California Department of Food and

Agriculture) Native wild Sierra Nevada bighorn sheep have tested serologically positive to both BTV and EHD (see Table 1 below), however there is no known history of acute mortalities (however, cause-specific mortality has not been studied in any detail in the Sierra Nevada). Wild Sierra bighorn sheep may have escaped acute disease epidemics because they may have some level of herd immunity, or mortalities have just not been identified. While midges are less likely to exist above about 7000 feet elevation (Dr Brad Mullens, personal communication), both the vector and the virus have been found at high elevations (Rocky Mountains) and cold temperatures (Dr. N. James MacLachlan, personal communication). BTV and EHD are endemic in Owens Valley cattle (ref) and elk (see Table 2 below). Fewer than 4% of over 550 samples from Inyo and Mono County mule deer 1979-98 tested serologically positive for BTV or EHD; none were positive by virus isolation.

Because of the potential for catastrophic disease in a captive herd, potential enclosures should be surveyed for midges during multiple seasons and if possible, the midges tested for BTV and EHD viruses (contact Dr. Brad Mullens). However, even with negative finding, the recovery team should be prepared for the possibility that BTV or EHD may cause problems in a captive herd.

Table 1. Sierra sheep serological history: BTV and EHD results for samples from 113 Sierra Nevada bighorn sheep tested between 1979 and 1999 are shown below (n=104 for years 1979-88; n=2 for 1995; n=7 for 1999). Not all tests were run on all samples (ex, BTISO and EHDSN were not run in years after 1982). Diagnostic test database courtesy of CDFG Wildlife Investigations Lab and Karen Jones.

	BTAGID	BTISO	EHDSN	EHDAGID	EHDISO
Total Positive	4	0	11	3	0
Total Run	109	59	55	51	104
Proportion Positive	0.04	0	0.2	0.06	0

BTAGID = Blue tongue agar gel immunodiffusion; all of 4 positives occurred in 1986.

BTISO = Blue tongue virus isolation

EHDSN = Epizootic hemorrhagic disease serum neutralization; all of 11 positives occurred during 1980.

EHDAGID = Epizootic hemorrhagic disease agar gel immunodiffusion; all of 3 positives occurred in 1986.

EHDISO = Epizootic hemorrhagic disease virus isolation

Table 2. BTV and EHD results for samples from 421 Owens Valley Elk tested between 1977 and 1998 are shown below (diagnostic test database courtesy of CDFG Wildlife Investigations Lab and Karen Jones).

	BTAGID	BTISO	EHDSN	EHDAGID	EHDISO
Total Positive	305	6	31	200	0
Total Run	387	110	77	249	3
Proportion Positive	0.79	0.05	0.40	0.80	0

Elk positives for both BTV and EHD were found in all years tested.

For expertise in *Culicoides*, contact Dr. Brad Mullens 909-787-5800 bradley.mullens@ucr.udu; and Dr. Nancy Hinkel, UC Riverside.

For Sierra Nevada and Owens Valley livestock blue tongue information: California Department of Food and Agriculture veterinarians, Dr. N. James McLaughlin (University of California Department of Veterinary Pathology, Microbiology, and Immunology; email: <njmaclachlan@ucdavis.edu>), Dr. Randy Singer (University of Illinois School of Veterinary Medicine; email: rsinger@staff.uiuc.edu); University of California School of Veterinary Medicine extension veterinarians including Dr. John Glenn and Dr. John Maas.

For a general disease description of BTV, see the OIE (Office International des Epizooties (World organization for animal health) web site: http://www.oie.int/eng/maladies/fiches /A_A090.HTM

Capture myopathy

Capture myopathy is of great concern to bighorn sheep managers. This often fatal syndrome has been observed following prolonged chase times during capture and/or when animals become hyperthermic. For details see Spraker 1993; the WIL Wildlife Restraint Manual. Prevention is key: avoidance of capture chase times over 5 minutes, preventing hyperthermia (check temperatures of animals that are handled often and apply water and other cooling procedures when needed); and consider administering providing selenium supplementation via free-choice Se + salt blocks at least one month before capture (Robbins et al. 1986; Robbins 1993). Injections of selenium and vitamin E given at the time of captures may *not* help reduce muscle degradation because selenium conversion to the glutathione peroxidase which assists cell repair takes weeks. Peak glutathione peroxidase levels occur 20-30 days following selenium supplementation (Robbins et al. 1986).

Contagious ecthyma (Orf)

Contagious ecthyma (CE), also called orf, causes painful lesions on teats and oral mucosa of domestic and wild sheep. It is a zoonotic disease that can be readily spread from sheep to humans, causing itchy, painful lesions at the point of contact (usually hands). Hay grazed by domestic sheep is implicated with transmitting CE to bighorn sheep and subsequently to human handlers of the sheep. Domestic sheep or goats can transmit the disease to wild bighorn sheep. Every time a bighorn sheep is handled, the mouth, teats, and mucosal surfaces should be inspected visually. If there are any vesicular (blister-like) lesions, handlers should wear gloves and all items that contacted the animal should be carefully disinfected. See Gonzales 2000; Jessup and Boyce 1993.

Pasteurella pneumonia

Pneumonia caused by *Pasteurella sp.* is one of the most important diseases limiting the success of bighorn sheep programs. Some strains of *Pasteurella* may exist as normal flora in bighorn sheep airways. Dangerous strains of the bacteria may be contracted from other bighorn sheep or domestic sheep and goats (ex, Hell's Canyon bighorn sheep die-off (Hunter 1997). Both adults and lambs may be affected. The taxonomy of the *Pasteurella* species is complicated and in flux. All captured bighorn sheep should be tested for Pasteurella infection, and those that test positive should be typed (contact Dr. Alton Ward, Caine Veterinary Teaching and Research Center, Caldwell, Idaho email: award@uidaho.edu). At the time of this report, there was not an effective and currently recommended vaccination for bighorn sheep, but it is a topic of research.

Pasteurella infected animals may be difficult to exclude from the captive herd due to the presence of different strains, pathogenic and nonpathogenic. Since there is a lack of data indicating which strains are dangerous and which are normal, Dr. Gonzales, Dr. Boyce, and Dr. Ernest suggest that funding be supplied to culture and identify *Pasteurella* strains in all bighorn captured in California, including Nelson’s sheep. This will provide a baseline data base to evaluate animals for captivity and for release. The identification of pathogenic Pasteurella vs. normal flora is still not an exact science. This baseline will allow us to identify pathogenic strains during an outbreak and or evaluate vaccination of captive animals if Pasteurellosis becomes a threat. Once data is provided, bighorn sheep infected with pathogenic *Pasteurella* (who may become persistent carriers of the organism), may be excluded from breeding herds.

There is a rich supply of published literature on the subject (start with references listed below), including work toward vaccines (not yet of practical use for wildlife application).

Protostrongylus lung worm

Protostrongylus is a nematode lungworm that may cause lung disease directly or predispose bighorn sheep to bacterial pneumonia (Jessup and Boyce 1993; Festa-Bianchet and Samson 1984). Lungworms have been documented in fecal samples from Sierra Nevada bighorn sheep (Wehausen 1980) and CDFG WIL database. However there has been no observation of obvious disease in the Sierra Nevada populations. For treatment and details, see (Jessup and Boyce 1993); Miller et al 1987; Green et al 1999).

Psoroptic mange

Mites of the species *Psoroptes ovis*, cause scabies mange in domestic and wild sheep. Bighorn sheep inhabiting the Great Western Divide of the Sierra Nevada may have suffered a scabies die-off in the 1800's (Wehausen 1980). Some populations of bighorn sheep can maintain mite populations without severe lesions (Kofa Mountains in Arizona, for example), however other populations have been severely impacted (San Andres, NM (Clark and Jessup 1992), Cushingbury Mountains, CA (Dr. Ben Gonzales personal communication). The mites most often cause crusty lesions with bleeding in the ears. In severe cases, lesions extend over large areas of skin of the animal's body. All animals captured for translocation to captivity or the wild should be examined carefully for mites. A *Psoroptes* ELISA test of the blood is very sensitive and specific for the mite (Mazet et al 1992; contact Dr. Walter Boyce, University of California Davis). Treatment may include ivermectin injections and/or Amitraz collars (personal communication Dr. Ben Gonzales). See also Gonzales 2000, Jessup and Boyce 1993.

A Few Additional Diseases

Four animal diseases were newsworthy at the time this report was compiled (years 2000-2001): Anthrax (terrorist actions and threats), Chronic Wasting Disease of deer and elk (a prion disease similar to Mad Cow Disease, but not yet documented in Caprinae), Foot and Mouth Disease (epidemic in cows, sheep, and pigs in the United Kingdom – no wildlife FMD documented in UK, at the time of this report), and West Nile Virus (documented in humans, birds [especially crows], and horses). In the past, these diseases were not considered a significant threat to bighorn sheep, however vigilance is warranted.

Included here are just a few of the diseases that may impact wild and captive bighorn sheep. Many of the diseases of domestic cattle and sheep may cause problems in bighorn sheep. The facility manager should communicate with the CDFG WIL Wildlife Veterinarians, CDFA Veterinarians, and local veterinarians to learn local prevalence of diseases such as tuberculosis, brucellosis, bovine viral diarrhea, infectious bovine respiratory virus, bovine respiratory syncytial virus, parainfluenza-3, scrapie and other prion disease of livestock, coccidiomycosis, etc (see Radostits 1999 for a comprehensive list of livestock diseases).

Anaplasmosis is a blood borne parasite disease that may cause severe anemia. The disease may be present in the Owens Valley, according to California Department of Food and Agriculture (CDFA) veterinarians, however, it is not reportable to CDFA. For a general disease description, see Jessup and Boyce 1993; Consult with Dr. Will Goff 509-335-6003 at Washington State University, Pullman; Dr. Walter Boyce wmboyce@ucdavis.edu; and Dr. Paul Crosbie, California State University, Fresno pcrosbie@csufresno.edu.

Anthrax is a fatal disease of mammals that has serious zoonotic potential. CDFA veterinarians report that anthrax spores may be present in the eastern Sierra Nevada, as with most other areas in the state. Spores can lay dormant for decades, then cause sudden disease (Jensen 1999; Radostits 1999). Anthrax may be used as a terrorist weapon against people and animals, as events of Autumn 2001 point out.

Clostridial diseases have caused mortality in captive bighorn sheep (personal communication, Dr. Margaret Wild). Clostridial diseases (Radostits 1999, pages 753-777), including over-eating disease (enterotoxemia) of sheep (p 773), may present special problems with lambs. To avoid outbreaks, prevention of sudden diet changes (particularly when increasing diet quality and quantity via supplementation) is critical and vaccination can be instituted (Jensen 1999).

Coccidiosis - a protozoan diarrheal disease afflicting lambs (Radostits 1999).

Eleophora - see Boyce et al 1999.

Johnes Disease - see Jessup and Williams 1999 for a review.

Nasal bot fly (*Oestrus ovis*) larvae can infest nasal passages and frontal sinus (Jessup and Boyce 1993). Dr. Margaret Wild, Colorado Division of Wildlife, reported that nasal bots can cause problems in captive bighorn sheep. Ivermectin and insecticides can eliminate the problem.

Selenium deficiency (see also Capture myopathy, above). See
http://cahfs.ucdavis.edu/publications
/copperselenium.pdf

Trichostrongyle parasites - see Isaza and Kollias 1999.

Poisonous plants - see Captive Breeding Facilities - Poisonous plant section

Reportable Diseases

Refer to lists prepared by the California Department of Food and Agriculture (CDFA) and World Organization for Animal Health (OIE). See web sites below.

CDFA reportable list: http://www.cdfa.ca.gov/animal/animal_
health/ahweb/reportab.htm

Disease information publications http://www.cdfa.ca.gov/animal/animal_
health/ahweb/publications.htm

OIE (www.OIE.int) List A and B reportable diseases:

Definitions of List A and B:
http://www.oie.int/eng/maladies
/en_mal.htm

Disease Lists: http://www.oie.int/eng/maladies
/en_fiches.htm#Liste A

Zoonotic Diseases of Note

Zoonotic diseases are those that can be contracted by people. This is a partial list of zoonotic diseases. Refer also to the CDFG WIL Wildlife Restraint Manual and these web sites: Centers for Disease: www.cdc.gov and California Department of Health Services: www.dhs.ca.gov

Anthrax - see above.

Contagious ecthyma: See above.

Hanta Virus: Fatal Hanta virus infections in humans have occurred in Inyo and Mono

Counties. This severe respiratory syndrome is caused by exposure to the virus through rodent feces or urine. Case histories often include exposure to dusty rodent-infected buildings. Care should be taken to keep all outbuildings at the bighorn sheep facility free of rodent infestations. Staff should take extra precautions to avoid exposure to rodents or their excretions. For more information visit the following web sites:

California Department of Health Services: http://www.dhs.ca.gov/ps/dcdc/
html/disbindex.htm
for disease reports and information.

Centers for Disease: www.cdc.gov http://www.cdc.gov/ncidod/diseases
/hanta/hps/index.htm

Leptospirosis: should be assumed to be present in cattle, other livestock and wildlife (including deer) in the eastern Sierra (personal communication, CDFA veterinarians). Kidney and serious systemic disease can result from infections in mammals including humans and bighorn sheep.

Plague: A serious bacteria disease, sometimes including lung infections, that is transmitted through exposure to fleas that live on rodents. see the following web sites:
http://www.dhs.ca.gov/ps/dcdc/html
/disbindex.htm
or
http://www.dhs.ca.gov/ps/dcdc/html
/publicat.htm

Rabies: Seven bats have tested positive for rabies in Inyo County over the past 8 years (1992-1999; California Department of Health Services data, courtesy Dr. Bruce Hoar). Since any mammal may contract and transmit rabies, bighorn sheep project personnel should take precautions. Bighorn sheep probably present a very low risk for rabies transmission to people, while work with mountain lions may present more risk. Refer to the CDFG WIL Wildlife Restraint Manual and see the following web sites: http://www.dhs.ca.gov/ps/dcdc/html
/disbindex.htm
or
http://www.dhs.ca.gov/ps/dcdc/html
/publicat.htm

General disease references:
Ballou 1993
Beck et al 1993
Clark et al 1993
Fowler 1993
Fowler and Miller 1999
Griffith et al 1993
Gonzales 2000

Jessup and Boyce 1993
Munson and Cook 1993
Radostits et al. 1999
Wobeser 1994
Web site for the OIE: www.oie.int
Web site for USDA APHIS VS Centers for Epidemiology and Animal Health:
http://www.aphis.usda.gov/vs/ceah/

Veterinary Care

Medical Records

All aspects of veterinary care should be coordinated with the CDFG bighorn sheep wildlife veterinarian. As with all stages of a captive breeding program, medical care should be carefully documented. Recording of medical data is very important for several reasons: to track disease and management problems, to evaluate and improve treatment protocols, in the event of change in management staff, for publication of results of research, and to assist other captive breeding programs.

All animals should be permanently and individually identified with tags that are visible from a distance and also some type of permanent mark or transponder that cannot be removed or lost (see Husbandry). Every treatment given to an animal should be recorded on an individual animal record with date, time, dosage and site of any drugs, details, and person administering the care. A computer data base should be maintained and backed up onto storage media that is stored off-site to protect against data loss in the event of computer hard drive failure. A well-recognized computerized animal medical record-keeping system should be employed. For example, many zoos routinely use a program called MedArks (available through the International Species Information System (ISIS) at www.isis.org. A good reference for this subject is Wobeser 1994, pages 103-115.

Routine Care

See also Husbandry section.
PHYSICAL EXAMINATIONS: Periodic physical examinations are important to quickly determine individual and herd-wide health problems. However, the frequency of capture and examination should be weighed against the stress and risk of injury that the sheep may suffer. In a large enclosure, capture for annual exams may be very difficult and possibly hazardous to the occupants. Drop net sites or corral trap sites must be planned into the design of the enclosure and the sheep must be accustomed to coming into the trap site on a routine basis. Advance planning and preparation must be thorough before any captures or handling occurs. Helicopter net gun capture and chemical immobilization of sheep are probably excessively hazardous to justify for routine physical examinations.

Whether or not sheep are captured periodically for exams, using binoculars and close approach, the facility manager should very closely count and observe each individual as frequently as possible (minimum of once weekly, preferably, every day). This will allow early detection of newborn, missing, sick, injured, or dead sheep.

If captures can be accomplished with minimal stress and risk to animals and personnel, sheep should be completely examined by an experienced wildlife veterinarian at least once yearly, more often if there are problems or the opportunity due to capture for another reason.

See Radostits et al 1999 pages 3-23 for recommendations on animal examination. In addition to a thorough exam from head to hoof, the animal should be weighed, and samples of feces and blood collected for diagnostic testing. Temperature, pulse and respirations should be measured and recorded at least every 5 minutes while the animal is restrained. Watch diligently for increasing temperature signaling the threat of capture myopathy.

Results from the examination should be entered on data forms and the medical data base. Procedures that may be included during an examination include: injections (selenium if necessary-see below, etc), vaccinations (if indicated), hoof exam and trim, treatment of wounds, collection of samples (blood, feces, skin biopsy, ectoparasites, etc) for diagnostic and research tests, and special tests of pregnant ewes (pregnancy ultrasound, etc) and rams (exam of reproductive organs).

Unless selenium levels are very high in soil and vegetation at the facility, Vitamin E and selenium should be administered whenever sheep are handled. This may help reduce the risk of capture myopathy. Sheep can be monitored for selenium by blood test.

Diagnostic Tests

At least once yearly, all members of the captive herd should be health-screened by collection of blood, feces, skin biopsy, and examination for ectoparasites. Recommended tests are provided here, but consult with the CDFG-WIL bighorn sheep wildlife veterinarian for the most current recommendations. Collect purple-top (EDTA anticoagulant) tubes of blood for a complete blood count (CBC) with visual examination of the blood smear. This tests for anemia (low red blood count), abnormalities of white blood cell levels (sometimes indicative of bacterial, parasitic, and viral diseases), abnormal cell types (such as cancerous cells), and blood parasites (e.g., *Anaplasma*, *Babesia*, etc). At least one purple top tube of blood may be used for DNA analysis (the buffy coat [white blood cells] will be separated for immediate analysis or frozen for preservation). Collect red top tubes (with serum separator) of blood to separate serum from the clot. Serum should be tested for blood electrolytes and disease titers (antibody levels). See section below: Hematology and Serum Chemistry Blood Reference Values for Desert Bighorn Sheep.

The following disease titers should be tested (blood serum): *Pasteurella*, Infectious Bovine Rhinotracheitis (IBR), Bovine Viral Disease (BVD), Parainfluenza-3 (PI_3), bluetongue virus (BTV), Epizootic Hemorrhagic Disease (EHD), *Brucella*, *Leptospira* (with individual serotypes), Bovine Respiratory Syncytial Virus (BRSV), Ovine Progressive Pneumonia (OPP), Caprine Arthritis Encephalitis (CAE), *Anaplasma*, *Toxoplasma*, *Chlamydia*, and Contagious Ecthyma. Virus or bacterial isolation and DNA typing procedures, as appropriate, should be initiated on any samples that test titer-positive for disease agents.

Fecal samples should be screened by direct smear, flotation (to screen for nematodes [Trichostrongyles]) and Baermann (to screen for lungworms [*Protostrongylus*]). McMaster's fecal technique may be used on fecal samples to quantify eggs of parasites.

Collect pharyngeal swabs for *Pasteurella* testing per current recommendations by the CDFG-WIL bighorn sheep wildlife veterinarian and Dr. Alton Ward, Caine Veterinary Center, University of Idaho, 1020 E. Homedale Road, Caldwell, Idaho 83607, (208) 454-8657, award@uidaho.edu.

Examine ear canals for mite and tick infestations; swab ear canals and submit samples for microscopic analysis. Consider submitting blood tests for *Psoroptes* ELISA testing (laboratory of Dr. Walter Boyce, UC Davis School of Veterinary Medicine, (530) 752-4629). If any skin lesions are detected that may be suspicious for ectoparasites, including *Psoroptes*, submit skin scraping for microscopic examination.

Quarantine Procedures

Refer to Miller 1999 and Jensen 1999. All animals that are sick, enter or exit the captive breeding facility should be quarantined. For facility entry or exit of apparently healthy bighorn sheep, a quarantine period should extend 30 days. No animal should be released from quarantine until it has been observed as healthy for at least 30 days. If the animal(s) exhibit any signs of disease, the period should be extended 30 days beyond the time when the animal appears healthy on full veterinary exam. Sick animals may need to be quarantined for longer periods, depending on the disease. If any animals are added to the quarantine pen, the entire lot should be observed for at least the 30 day period. Any animals with chronic conditions, including *Pasteurella* (pneumonia or asymptomatic), may need to be removed permanently from the facility, due to risk to the herd. Of the causes of failure of captive facilities, the introduction of disease into the herd is near the top of the list.

Waste material generated by quarantined animal(s) should be properly disposed (following guidelines of the county, CDFG, California Department of Health Services, etc). The disposal method (deep burial, incineration, etc) should prevent any animal or person from contacting the waste.

Vaccines and Injectable Supplements

My current vaccination recommendation is not to vaccinate the captive herd, given that the other recommendations in this report are followed. Preventative measures other than vaccinations will be most important in maintaining health: avoidance of stress and crowding of animals, providing complete isolation from domestic animals, etc. However, vaccination may become prudent under certain circumstances (e.g., the health of the herd is endangered by a disease that is preventable by vaccination) and as vaccination technology improves (e.g., *Pasteurella* and bluetongue virus vaccines may become efficacious in the future).

One vaccine that may be considered is a multivalent clostridial vaccine (see Clostridia in disease section), particularly if conditions become crowded and/or supplemental feeding is provided. Several of the captive herds visited for this report did not receive the vaccine and did not report problems. However, enterotoxemia clostridial disease can have a major impact on lamb survival, most often when supplemental feed is provided and during intensive management (i.e. crowding). Multivalent Clostridial vaccines may be administered upon capture for introduction to facility and opportunistically whenever an animal is handled. In addition, the vaccination should be administered at least one month prior to diet supplementation. Prior to planning vaccination, the CDFG wildlife veterinarian should be consulted to evaluate potential hazards related to the use of this killed bacterin. The veterinarian in charge of the Colorado Division of Wildlife Foothills bighorn sheep facility should also be consulted for most current experience with Clostridial vaccination, since that facility (with sheep under intensive management and crowded conditions) has had experience with the disease and vaccination.

Whether or not to vaccinate captive bighorn sheep is a more difficult decision than would seem at the outset. Vaccinations against common domestic cattle and sheep diseases may prevent an outbreak in the bighorn sheep herd. However, such vaccinations may also affect evolutionary potential of host-parasite relationships particularly once animals are released to the wild. Maintenance of natural immunity without human intervention would be ideal; however, captively bred bighorn sheep maintained at lower elevations and closer to domestic animals will be more likely to encounter pathogens that they would not in the wild. Ideally, the captive herd should be maintained at least several miles from domestic animals, with strict procedures for preventing exposure to domestic animal diseases. Prevention of disease by avoiding dense congregations of animals is the best measure against respiratory and parasitic diseases.

Disease Outbreaks

The outbreak of disease is always a possibility within a captive herd. Assume it will happen and be prepared. The best option is always prevention - that is one of the main purposes of this guide - however if a disease problem occurs, rapid intelligent action will minimize the impact on the herd and on wild Sierra Nevada bighorn sheep. Be prepared by maintaining stocks or easy access to medications, sample collection supplies, and communication with experts.

Institutions (zoos, rehabilitation facilities, etc) that will accept Sierra Nevada bighorn sheep on a permanent basis should be identified in advance in case a disease event that may permanently prevents the maintenance and/or release of individual bighorn sheep.

Refer to Wobeser 1994.

Necropsy Procedures

Necropsies on all bighorn sheep that die within the facility should be performed at CAHFS (formerly CVDLS) by qualified pathologist whenever possible. If it is necessary to perform the necropsy in field, an experienced wildlife veterinarian should perform per specific protocol as below.

Every effort should be made to establish a specific cause of death and to enter the details in the medical database. This information will be critical for identifying problems with the facility or management. Necropsy protocols established by the CDFG Wildlife Investigations Laboratory should be followed. Since collection of appropriate samples is critical, each case should be discussed with the CDFG Wildlife Veterinarian before the necropsy is conducted. Keep in mind that special necropsy and carcass disposal procedures are needed if anthrax and certain other diseases are suspected.

For additional information on necropsy procedures and sample collection, see the following web site: http://www.vetmed.ucdavis.edu/whc/Necropsy/TOC.html, for protocols written by Dr. Linda Munson, Veterinary Pathology, Microbiology, and Immunology, University of California Davis. Dr. Munson's manual provides practical guidelines for performing necropsies on mammals, birds, and reptiles while in the field. Munson walks the examiner through the necropsy procedure with the aid of detailed illustrations. Also included are equipment lists, cautionary tips, sample storage directions and forms that can be printed out to ensure thorough and complete tissue sampling procedures. Also review Wobeser 1994.

Proper disposal of carcasses and waste material to eliminate disease transmission risks. The disposal method (burial, incineration, etc) should prevent any animal or person from contacting the waste.

Euthanasia

Refer to the report by the AVMA Panel on Euthanasia 2000 (reprint attached; web site is http://www.avma.org/resources/euthanasia.pdf; check www.avma.org for updates), CDFG WIL Restraint Manual, Andrews et al. 1996, current publications from the American Association of Wildlife Veterinarians (AAWV), and American Association of Zoo Veterinarians (AAZV) for guidelines for humane methods of euthanasia. Injectable euthanasia drugs, such as pentobarbital, may provide a humane death, but may remain potent in the carcass. Scavenging animals have died after consuming carcasses of animals euthanized by pentobarbital. Therefore animals killed with such drugs should be incinerated to prevent consumption by people or animals. The most practical and humane method of euthanasia may be gunshot to the head (following recommendations by AVMA [2000]). Gunshot is considered humane, is inexpensive, and will allow carcasses to be disposed without concern for harm to scavengers. Gunshot to the neck is not currently considered humane according to the AVMA 2000 report, however the American Association of Wildlife Veterinarians (AAWV) recommends that the AVMA reconsider gunshot to the neck to be humane. Until the AVMA accepts the AAWV position, I recommend following the AVMA-recommendations for gunshot sites.

Follow local ordinances and CDFG protocols for carcass disposal. Depending on the site of the facility, burial, incineration, or delivery to a landfill or rendering plant may be options. The main reason that a captive bighorn sheep would need to be euthanized is disease. There will be concerns about placing the carcass out for consumption by scavengers, including disease transmission and public perception.

Hematology and Serum Chemistry
Blood Reference Values
for Desert Bighorn Sheep

Courtesy Dr. Dori Borjesson

Veterinary Clinical Pathology, School of Veterinary Medicine, University of California, Davis

Reference: Borjesson, DL; Christopher, MM; Boyce, WM. Biochemical and hematologic reference intervals for free-ranging desert bighorn sheep. Journal of Wildlife Diseases, 2000 Apr, 36(2):294-300.

See tables below.

Note: these reference ranges were calculated for *desert* bighorn sheep, not specifically for Sierra Nevada bighorn sheep (SNBS). SNBS may be genetically allied with desert sheep (Wehausen and Ramey 2000). Until reference ranges are calculated specifically for SNBS, reference ranges noted below by Borjesson et al 2000 may be useful in assessing laboratory values, with recognition that there may be differences among populations for some blood parameters.

Table 1. Reference intervals and median value for hematologic parameters for free-ranging desert bighorn sheep.

Variable	n	Reference Interval[a,b]	Median
Hematocrit (%)			
Females	159	44.3- 56.2	50
Males	43	33.2- 56.3	46
Young	15	43.6- 59.2	53
RBC (x 106 / ml)			
Adults	192	10.54- 14.31	12
Young	15	11.30- 17.20	14
Hemoglobin (g/dl)			
Females	159	14.4- 18.2	16
Males	43	10.8- 17.6	15
Young	15	14.4- 19.3	17
MCV (fl)	207	35.3- 43.7	40
MCH (pg)	207	11.3- 14.1	12.8
MCHC (g/dl)	207	30.3- 34.3	31.9
WBC (/ ul)	207	3,500 -15,400	7,100
Neutrophils (/ml)	207	250 - 9,700	2,506
Lymphocytes (/ml)	207	1,200 - 6,900	3,650
Eosinophils (/ml)	207	0 - 2,500	406
Monocytes (/ml)	207	0 - 600	114
Basophils (/ml)	207	0 - 70	0

[a] Reference intervals calculated with nonparametric analysis using the central 90th percentile.

[b] Range of values (minimum to maximum) are reported for the young sub-class rather than true reference intervals due to the low number of animals included in the sample.

Table 2. Reference intervals and median value for biochemical parameters for free-ranging desert bighorn sheep.

Variable		n	Reference	Median
Alkaline Phosphatase (IU/L)	Adults	184	73- 575	166
	Young	16	184- 627	411
g Glutamyl-transferase (IU/L)		200	20- 130	36
Lactate Dehydrogenase (IU/L)		200	409- 788	534
Aspartate aminotransferase (IU/L)		200	78- 312	137
Creatine Kinase (IU/L)		200	175- 2300	392
Blood Urea Nitrogen (mg/dl)		200	5- 28	14
Creatinine (mg/dl)		200	1.6- 2.6	2
BUN/ Creatinine ratio		200	2.5- 14.8	7
Glucose (mg/dl)		200	95- 185	151
Total Bilirubin (mg/dl)		200	0.0- 0.1	0.1
Direct Bilirubin (mg/dl)		200	0.0- 0.0	0
Indirect Bilirubin (mg/dl)		200	0.0- 0.1	0.1
Total Protein (g/dl)	Adults	184	6.0- 9.3	7.4
	Young	16	6.0- 7.8	6.8
Albumin (g/dl)		200	2.8- 3.7	3.3
Globulin (g/dl)	Adults	184	2.8- 6.1	4
	Young	16	2.7- 4.2	3.4
Albumin/Globulin ratio	Adults	184	0.5- 1.2	0.9
	Young	16	0.8- 1.3	1
Calcium (mg/dl)		200	9.3- 11.5	10.3
Phosphorus (mg/dl)		200	4.0- 9.3	6.5
Sodium (mmol/L)		200	145- 160	153
Chloride (mmol/L)		200	89- 107	99
Potassium (mmol/L)		200	3.8- 6.3	4.7

[a] Reference intervals calculated with nonparametric analysis using the central 90th percentile.

[b] Range of values (minimum to maximum) are reported for the young sub-class rather than true reference intervals due to the low number of animals included in the sample.

Partial List of Helpful Contacts

Dr. Vernon Bleich, CDFD, Bishop CA. predators@telis.org, (760) 872-1137 Bighorn sheep and mountain lion biology.

Dr. Walter Boyce UC Davis (530) 752-1401 wmboyce@ucdavis.edu. Wildlife health, bighorn sheep biology and genetics; wildlife parasites and diseases.

Dr. Paul Crosbie, California State University, Fresno pcrosbie@csufresno.edu. (559) 278-2074. Wildlife ectoparasites.

Jim DeForge, Bighorn Institute BighrnInst@aol.com (760) 346-7334 Bighorn sheep captive breeding.

Amy Fisher (505) 989-8261 Bighorn sheep captive breeding and biology.

Dr. Will Goff, Washington State University, Pullman. 509-335-6003. Bighorn sheep diseases.

Dr. Ben Gonzales, CDFG, Rancho Cordova, CA. BGonzale@dfg.ca.gov (916) 358-1464, Wildlife health, bighorn capture and diseases.

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Glossary and Abbreviations

Glossary

Augmentation - movement of individuals to a small existing population, with the purpose of speeding recovery of that population to a greater self-sustaining population size.

Causes of population decline - may include predation, disease, demographic effect (small population, by chance high % ram lambs born, by chance high % of certain age class of ewes die), catastrophic events cause increased mortality and/or decreased recruitment (avalanches, excess rain).

Carrying capacity - as used in VORTEX, the maximum number of individuals that an area may support.

Deme = ewe group = subpopulation; a group of bighorn sheep, with minimum number of ewes to provide protective vigilance against predators and having local knowledge of habitat (with lead ewe) to safely maneuver to foraging and escape terrain.

Demographic stochasticity - variability in demographic variables (percent females, number of ewes, number of rams, population size, skewed sex ratio at birth, variation in birth, survival rates, etc).

Deterministic variable - a fixed number, not affected by random variation. Sometimes used in modeling for simplicity, but most values in nature have some randomness (stochasticity). For example, in modeling, the birth rate could be set deterministically at 0.9, meaning that every year 90% of the ewes give birth.

Downlisting criteria - the guidelines for re-categorizing Sierra Nevada bighorn sheep from federally listed "endangered" to "threatened" and "threatened" to non-listed , as set by the Recovery Team. See Sierra Nevada Bighorn Sheep Recovery Plan (USFWS 2000 in prep).

Entire Sierra Metapopulation - all populations of bighorn sheep living within the Sierra Nevada. This term may be replaced with any that the recovery team feels are appropriate.

Geographic conservation unit (GCU). Basic to understanding the potential importance of a captive herd is the concept of Geographic Conservation Unit (GCU). Three natural habitat breaks cause the current distribution of seven ewe herd areas to fall into four basic geographic units, termed Geographic Conservation Units (GCU's) by the interagency Sierra Nevada Bighorn Sheep Recovery Team (USFWS 2000; in prep). Recovery strategies and goals are dependent on preserving genetic diversity, increasing numbers of bighorn sheep in existing herds, and reintroducing bighorn sheep within herd areas that are currently unoccupied in each of the four GCU's. A plan incorporating captive breeding may help achieve recovery goals more reliably and in a shorter time frame than strategies without captive breeding.

"Harvest" - in VORTEX modeling, means the removal of bighorn sheep from a source population for translocation to a wild population or captive herd or reintroduction of unoccupied historic range; in this case, the term does not mean hunting of bighorn sheep.

Heterozygosity - The frequency of heterozygotes in a population. Heterozygotes are genotypes that contain two different alleles (variants of a genetic site or gene) at a locus (genetic site or gene). Homozygotes contain one allele type at a locus. For mathematical details of the heterozygosity, see Gillespie 1998.

Inbreeding coefficient - a measure of inbreeding. Inbreeding occurs when an individual mates with a relative. The offspring of inbreeding are more likely to be homozygous at their genetic sites than the offspring of animals that are not inbred. For mathematical details of the inbreeding coefficient, see Gillespie 1998.

Lambda and r, rates of population increase:

Lambda = finite (annual) rate of population increase. Lambda is a positive number that measures the proportional change in population size from one year to the next. Lambda $=e^r$, where e is the mathematical natural exponent. Lambda = 1 means no population growth. Lambda > 1 = pop growth. Lambda < 1=no pop growth. Multiply the number of sheep in the beginning of the year by lambda to obtain the estimate (deterministically) for the beginning of the next year.

The term "r", is the intrinsic (instantaneous rate of population increase). r = 0 means there is no change in population size; r > 0 = pop growth; r < 0 = pop decline. Correlated with lambda through natural log function. For the r values we are working with for Sierra bighorn sheep (-0.1 to + 0.2), you can approximate lambda by r + 1. Refer to Gotelli 1998.

Loss of genetic diversity - means a decline in number of alleles (variants of a gene); change in allelic frequencies with tendency toward fixation (some alleles go extinct, others become the only type remaining).

On site recovery measures - predation control (see below); habitat improvement through (possibly) burning, clearing brush, restoring water sources, etc.; reduction of human impacts (reduce disturbance near salt lick, dogs on trails, hunting near lambing areas, etc.

Predation control - should consider all methods of decreasing the predation of bighorn sheep by predators (mountain lions, coyotes, eagles, bears, dogs, etc). Includes removal of predators by killing or translocating them; indirect methods of reducing predation, such as habitat modification to decrease stalking cover; may include deer management (deer are the usual primary prey of North American mountain lions) and/or management of alternate prey populations such as feral horses (especially foals), etc. For immediate relief of predation and for the short term, predator removal may be the primary method, while indirect methods are evaluated and/or started. Evaluate whether predator control measures will cause harm to other T/E species or threaten predator populations or other species which interact with them. Assess the risks/benefits of predator control on predator populations, and other elements of ecosystem, as well as prey.

Reintroduction - movement of individuals to an unoccupied habitat within the species' historic range.

Self-sustaining population - With respect to approaching stable demography, maintenance of census size without on-site recovery measures (see above). See downlisting requirements for recovery plan criteria (USFWS 2000b).

Signs of recovery - for recovery team to decide. May include some combination of the following: a certain population growth rate specific to each population; strongly increasing annual trends in population size, minimum total numbers, minimum ewe #'s , minimum lamb recruitment (adequate lamb:ewe ratios for birth and recruitment to 12 months (see Wehausen 1983, 1984)), maximum age-specific mortality rates, minimum ewe body condition, optimum ram:ewe ratios (fewer rams than ewes, such as 70 rams per 100 ewes (Wehausen 1983, 1984), use of winter range without heavy predation, etc.

Stochastic variable - values with a component of variation; in the case of computer simulations, the model will randomly select a value within a probability distribution that is assigned to that value. For example, birth rate may be a random value selected within the normal distribution from 0.85-0.95.

Sustainable harvest - removal of individuals from a population or region such that the population or group does not decline in number over time. The removed individuals are replaced by natural recruitment (births, immigration, increased survivorship).

Translocation - movement of free-ranging individuals among populations or regions.

Valuable alleles may include rare alleles, that are not common in population, and that are likely to be lost through genetic drift if not reproduced; and alleles that are important for fitness.

Viable population - subject to debate and rules of thumb assigned by theory or work with other taxa; a regional group of animals that is not declining in number and is not likely to decline or go extinct over a specified time period.

Abbreviations

BHS = bighorn sheep

CAHFS (formerly called CVDLS)
California Animal Health & Food
Safety Laboratory System
University of California, Davis
School of Veterinary Medicine
P.O Box 1770
Davis, CA 95617-1770
Phone: (530) 752-8700
Fax: (530) 752-6253
http://cahfs.ucdavis.edu

CBSG = the Captive Breeding Specialist Group of the IUCN.

CDFA = California Department of Food and Agriculture

CDFG = California Department of Fish and Game

CVDLS = California Veterinary Diagnostic Laboratory Services, now called California Animal Health & Food Safety Laboratory System (CAHFS).

DHS = California Department of Health Services

GCU = Geographic conservation unit

IUCN = International Union for the Conservation of Nature. [ ] include web site.

OIE = OFFICE INTERNATIONAL DES EPIZOOTIES (World organization for animal health).

SNBS = Sierra Nevada bighorn sheep

SNBSRT = Sierra Nevada bighorn sheep Recovery Team

USFWS = United State Fish and Wildlife Service

USDA = United States Department of Agriculture

- WS (formerly Animal Damage Control - ADC) Wildlife Services
- APHIS Animal and Plant Health Inspection Service
- VS Veterinary Services

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