Sierra Nevada bighorn sheep in 2006

Few wildlife conservation programs have engendered as much public interest as the restoration of the Sierra Nevada bighorn sheep. These unique ungulates (hoofed mammals) occur only in the Sierra Nevada and are endemic to California. Early in 1999, Sierra Nevada bighorn sheep were afforded protection as an endangered species by the U.S. Fish and Wildlife Service (USFWS),

Photo © P. McGrath

Mule deer are the primary prey of mountain lions in the eastern Sierra Nevada. Scientists working on the restoration of bighorn sheep have emphasized the importance of understanding relationships between climate, forage production, predator densities, and deer population dynamics, all of which have important implications for the conservation of large mammals in the Sierra Nevada. .

and the California Department of Fish and Game (DFG) agreed to lead the effort to recover bighorn sheep populations so to stave off extinction. At the time of the listing, there were approximately 125 bighorn sheep in the Sierra Nevada. Today, the number of bighorn sheep approaches 350.

The Sierra Nevada Bighorn Sheep Recovery Plan has been prepared, and USFWS has circulated it for final review by interested parties and stakeholders. Stakeholders include agencies that are partners in the restoration effort (U.S. Forest Service, Los Angeles Department of Water and Power, Bureau of Land Management, National Park Service), and a number of non-governmental conservation organizations. The plan recognizes a number of necessary actions for restoring bighorn sheep in the Sierra Nevada, such as decreasing mortality rates from predation, minimizing the potential for diseases to impact bighorn sheep, and translocating bighorn sheep to vacant but historical ranges.

The common philosophy among the agencies charged with restoration efforts not only emphasizes the protection and management of bighorn sheep, but also includes a strong investigative component. Understanding why bighorn sheep declined to precipitously low numbers is as important as developing ways to reverse that downward trend.

Personnel working actively to restore bighorn sheep are also working to better understand the interrelationships between bighorn sheep, mule deer, and the primary predator of both of those animals, the mountain lion. In addition, they place strong emphasis on understanding diseases and their effects on bighorn sheep populations, as well as developing an understanding of the genetic structure of the various populations of bighorn sheep in the Sierra Nevada.

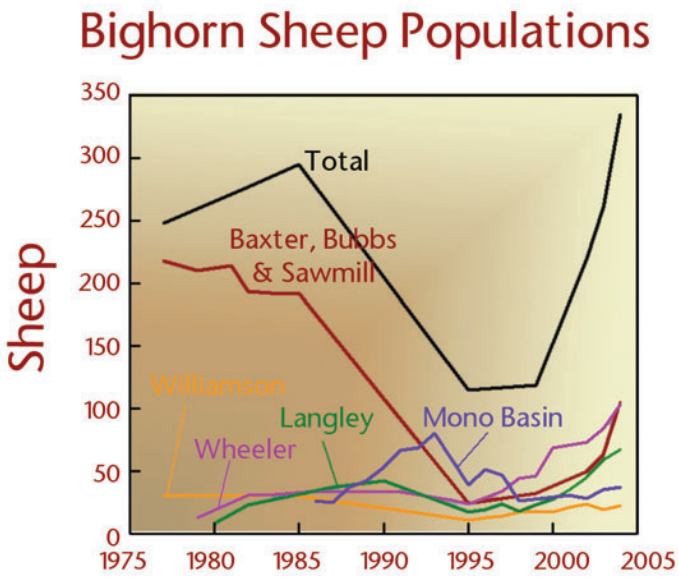
If the opportunity to restore these magnificent animals to the Sierra Nevada failed to yield a better understanding of their ecological relationships, the Sierra Nevada Bighorn Sheep Recovery Program would fall short of its objective of providing a basis from which future conservationists can implement recovery strategies. The Sierra Nevada Bighorn Sheep Program staff provide annual reports on the recovery effort to keep the public informed of the progress.

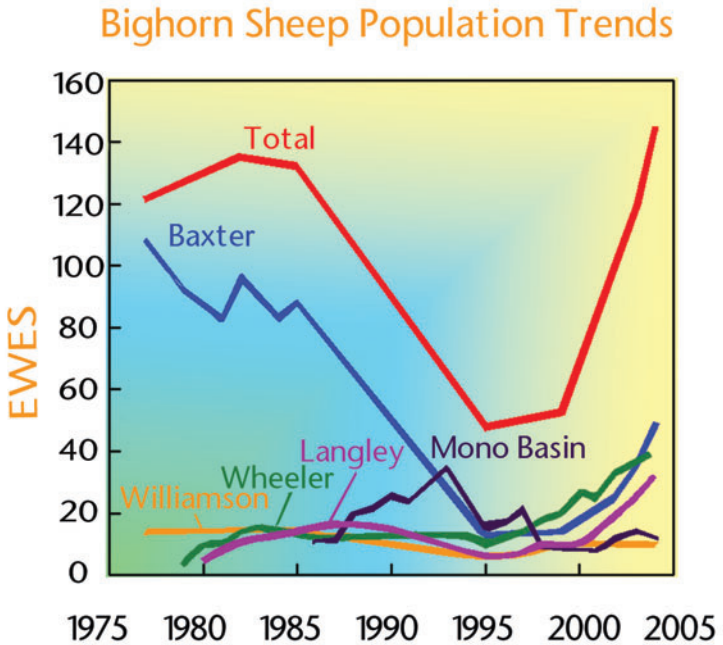
Bighorn sheep population status

The population of Sierra Nevada bighorn sheep continued to grow during 2004-2005. Since experiencing a low estimate of 125 total bighorn (including only about 50 ewes) during 1995 - 1999, the population has exhibited a steady increase.

A minimum of 146 adult ewes were estimated to inhabit eight herd units in the Sierra Nevada during 2004-2005. Bighorn numbers in the central and southern recovery units exhibited particularly strong growth, with lamb to ewe ratios as high as 63 to 100. Despite experiencing a severe winter with snowfall that fell early and was heavy, bighorn sheep occupying the northern recovery unit (that winter in alpine habitats) largely survived the winter. Counts in summer and autumn 2005 indicated that a minimum of 35 bighorn, including four lambs, reside in the northern recovery unit.

Although numbers of Sierra Nevada bighorn continue to increase, it is imperative that we are able to further expand the geographic distribution to be able to meet recovery goals. Sierra Nevada bighorn sheep currently are distributed among eight herd units, but the majority of animals exist in only three of these units (Wheeler Ridge, Mt. Baxter, and Mt. Langley). To meet recovery goals, bighorn must exist in five additional herd units. Geographic recovery goals will be met primarily through translocations of animals from herd units that support large numbers of sheep to vacant units. Successful augmentations, such as the five ewes moved to the Mt. Baxter unit last winter, are also important in attaining the numerical recovery goals of a minimum of 280 ewes in the Sierra Nevada.



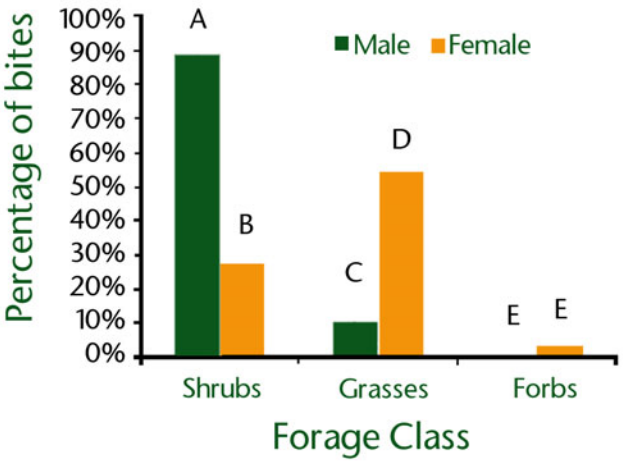


Foraging ecology of bighorn sheep

The ability of a population to persist depends, in part, on available food resources. Winter forage is a critical component of food resources for bighorn sheep. Sierra Nevada Bighorn Sheep Program (SNBS) staff is investigating the quality and abundance of forage to determine carrying capacity (the number of animals a habitat can support) and identify key habitats for bighorn sheep. Specifically, they sample vegetation to examine the amount of food available on a number of winter ranges. These evaluations will be important for determining the number of bighorn sheep each winter range can support, and for determining sites for future translocations.

In addition to knowing the availability of winter feed, SBNS staff examine how bighorn sheep forage. In order to fully understand winter habitat, it may be necessary to consider males and females separately because of differences in diet selection. Staff study bighorn feeding habits by direct observation and collecting fecal pellets.

To accomplish this, the SBNS team watches bighorn through high powered scopes and record the number of bites of each plant species taken during foraging bouts. They also collect fecal samples from observed sheep feeding sites for analysis of diet composition and to estimate the amount of protein in the diet. The SBNS team is also studying bighorn sheep foraging behavior to investigate the effects of group size and distance to escape terrain to gain a better understanding of factors that affect foraging efficiency.



Percentage of bites (± SE) taken of 3 forage classes (shrubs, grasses, and forbs) by male (N = 5) and female (N = 8) bighorn sheep. Different letters indicate significant differences between percentage of bites taken by males and females for three different forage categories.

By collecting detailed information on foraging behavior, SBNS can better understand the relationship between food resources in the environment and how bighorn sheep use these resources in winter and, ultimately, their implications for the conservation of this rare animal.

Minimizing contact between domestic and bighorn sheep

Domestic sheep can carry a variety of pathogens, and those pathogens have the potential to trigger disease outbreaks in bighorn sheep. Diseases acquired from domestic sheep are one of the primary threats to recovery of Sierra bighorn. Recovery of bighorn sheep in the Sierra Nevada requires preventing contact between bighorn and domestic sheep to eliminate the potential for disease transmission. Past recommendations for minimizing contact have focused largely on distance as a barrier to contact. Movements by bighorn males are unpredictable and may occur over long distances (e.g., more than 30 kilometers in the Sierra Nevada), and the current scale of domestic sheep grazing in the eastern Sierra Nevada makes closure or modification of grazing allotments in proximity to bighorn range problematic. Based on these considerations, during 2005 Department of Fish and Game (DFG) conducted intensive monitoring to determine risk of contact and evaluated current husbandry practices through frequent monitoring of bighorn sheep and domestic sheep as a means to prevent disease transmission.

In an effort to understand the potential of bighorn movements to result in contact with domestic sheep, we have attempted to deploy GPS collars on a large percentage of bighorn males that use habitat adjacent to domestic sheep allotments. In addition, DFG conducted repeated ground surveys of herd units in proximity to allotments to quantify bighorn use of those areas. Members of the Sierra Nevada Bighorn Sheep Recovery Program also observed domestic sheep operations on a daily basis to help minimize the potential for contact between the two species. Locations of bighorn sheep did occur within 3 miles of domestic sheep, but radio-collared bighorn sheep did not wander into adjacent domestic sheep allotments.

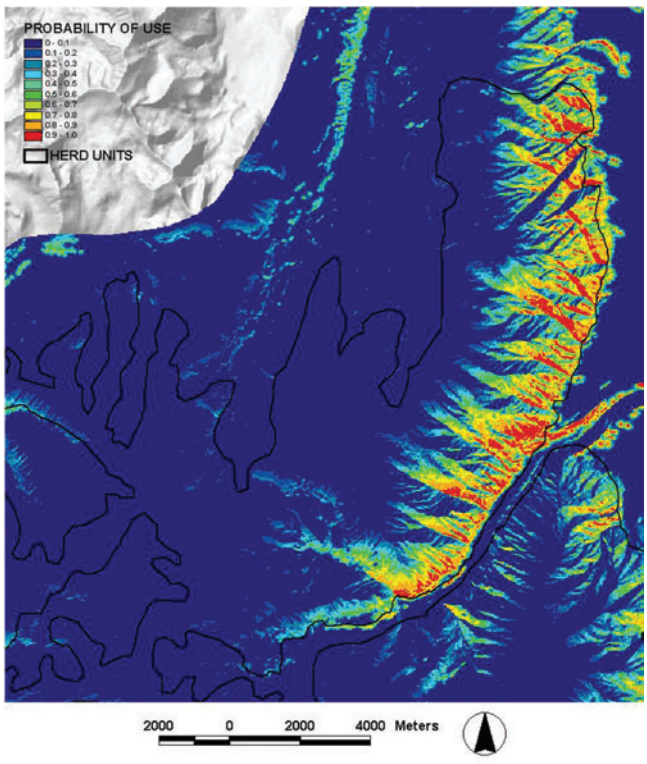
SBNS staff determined that some husbandry methods were inadequate to minimize the probability of contact or to enable a rapid response if contact had occurred. Factors such as the elevation grazed, the density of vegetation used by domestic sheep, levels of predation, and oversight by herders and guard dogs were such that risk of contact was unacceptably high on some allotments given proximity to occupied bighorn sheep habitat. We are currently working with land management agencies and grazing interests to develop recommendations that will minimize the risk of contact with domestic sheep and, subsequently, the transmission of pathogens to bighorn sheep in the Sierra Nevada

Applying habitat modeling to bighorn sheep recovery

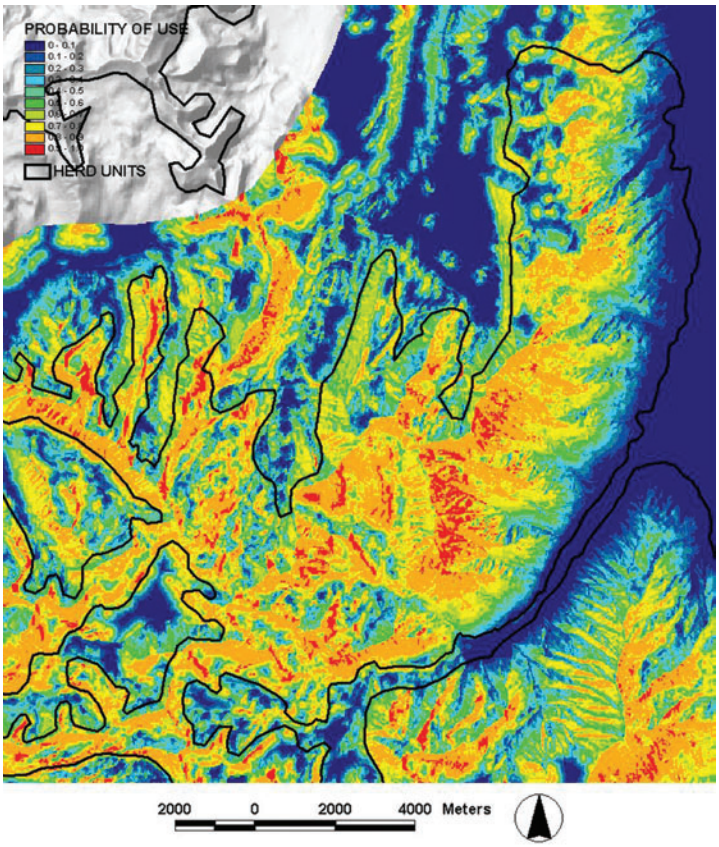
The Sierra Nevada Bighorn Sheep Recovery Program is developing habitat models to assist with population recovery objectives. SBNS researchers have been able to describe winter and summer habitat used by bighorn sheep in the Sierra Nevada, and apply those habitat use patterns to areas not currently occupied by bighorn sheep.

To date, research efforts have focused primarily on acquiring, deriving, and digitizing GIS data layers for habitat modeling, and generating preliminary habitat models for Sierra Nevada bighorn sheep. Sierra Nevada habitat models will be finalized after acquiring additional location data in spring 2006. For all areas of the Sierra Nevada that currently are occupied by bighorn sheep or have potential to support bighorn sheep, researchers developed digital layers describing elevation, slope, aspect, hillshade relative to sun exposure, terrain ruggedness, distance to escape terrain, and vegetation. Using about 5,000 GPS radio-collar locations from Sierra Nevada bighorn in the Wheeler, Sawmill, and Baxter herd units, scientists built models that describe winter and summer habitat use. These models identify specific topographic and vegetative characteristics that bighorn select during different times of the year. Applying those models to the entire Sierra Nevada, scientists quantitatively predicted areas that could provide good seasonal habitat for bighorn sheep. These models, known as Resource Selection Models, are powerful tools for quantifying suitable habitat. SBNS researchers use the models to rank the suitability of geographic areas that have been proposed for translocations and augmentations of bighorn sheep. Using the models, scientists determine the amount of winter and summer range available in each of the herd areas, and evaluate the connectivity of those ranges. The models have also been useful for identifying additional translocation areas that may have been overlooked. Recent northward range expansions by Sierra Nevada bighorn have caused concern because it places them close to extensive areas open to grazing by domestic sheep, which increases the potential for exposure to disease. Modeling allows SNBS staff to assess the likelihood of further range expansion, and to anticipate in which areas contact between domestic sheep and bighorn sheep is most likely to occur. Researchers also anticipate using the models to evaluate how habitat enhancement projects, like prescribed fires, may change the probability of bighorn sheep using certain areas.

Ultimately, modeling will allow the SNBS team to evaluate relationships between habitat quality and population performance, including recruitment, survival, and nutritional condition. With increased understanding of the habitat requirements of bighorn sheep in the Sierra Nevada, the SNBS team will be better equipped to develop management strategies that will support the recovery and conservation of this unique group of bighorn sheep.



Example of a winter habitat model for the Wheeler Ridge herd unit. The various colors represent different probabilities of the habitat being used by Sierra Nevada bighorn sheep.



Example of a summer habitat model for the Wheeler Ridge herd unit. The various colors represent different probabilities of the habitat being used by Sierra Nevada bighorn sheep.

Sierra Nevada bighorn sheep a

Few animals stir as much emotion as do cougars, catamounts, or pumas; these are large felids most commonly called mountain lions. In California, mountain lions hold special interest with a long and varied management history. That history includes the entire spectrum of management strategies, ranging from year-round open hunting seasons with no limit on take, to persecuted predator, nonprotected predator, carefully regulated game animal and, now California's only "specially protected mammal."

During the early part of California's history, mountain lions had no legal status. Following cessation of the bounty period in 1963, the Department of Fish and Game (DFG) managed mountain lions as nonprotected, nongame animals, and no records of take were maintained. Anyone with a hunting license could pursue these large carnivores in unlimited numbers on a year-round basis.

Mountain lions first received protection under modern wildlife management regulations in 1969, when they were classified as game animals by the California Fish and Game Commission. They retained that status until 1972, when a moratorium on take was enacted. From 1969 to 1972, 4,953 tags were issued, and 118 individuals were harvested. After the moratorium was in place, DFG established a system for recording incidents involving livestock or pets and mountain lions which has been kept with painstaking consistency, and depredation permits are issued to affected property owners and allow them to "take" the offending mountain lion.

Following extensive investigations, mountain lions were again classified as a game mammal in 1986, but recommendations for limited harvests were challenged in court. As a result, no hunting season ever occurred and, in 1990, the voters of California passed Proposition 117, which afforded mountain lions the status of specially protected mammal. A subsequent ballot measure, Proposition 197, would have modified the specially protected status, but suffered defeat in 1996 and reaffirmed total protection as the primary management strategy for mountain lions in California. In 1999, the Legislature passed a law that gave the DFG limited management authority over mountain lions for the purpose of protecting bighorn sheep populations.

Populations of mountain lions were thought to be self-regulating for many years, but research on mountain lions in the eastern Sierra Nevada through the 1990s has demonstrated that mountain lion populations are regulated by their food supply (that is, population levels were determined by the nutritional carrying capacity of their environment), and not primarily by "social mechanisms." Further research in the eastern Sierra Nevada also demonstrated that the movements of mountain lions were often closely tied to the migratory patterns of their primary prey, mule deer.

With Global Positioning System (GPS) technology now being applied to wildlife biology, DFG's ability to more finely describe the behavior and movements of mountain lions has greatly improved. Since the onset of the Sierra Nevada Bighorn Sheep Recovery Program, 45 mountain lions have been captured. Of those, eight males and eight females have been fitted with GPS collars capable of providing accurate locations of individuals multiple times in a single day.

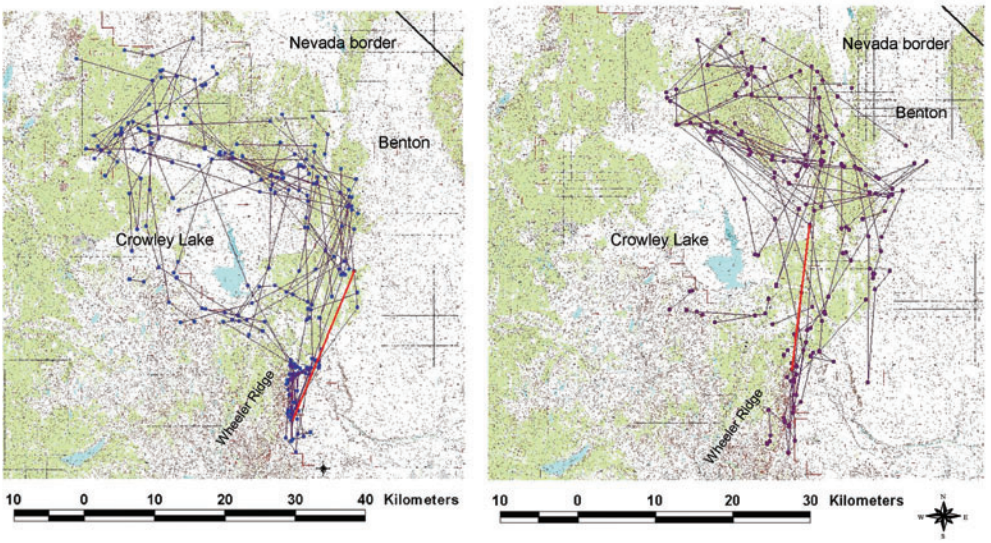
The identification of predation events on bighorn sheep also has been greatly facilitated with the use of GPS technology. Behavior of mountain lions, which includes killing, covering, and returning to feed on kills several nights in a row, often reveals a pattern of movements that pinpoints the location of cached prey. This information makes it easier and safer for project personnel to climb to the location of a probable kill site, and increases the chances of determining when a bighorn has been preyed upon. Bighorn sheep have been killed by mountain lions at a wide range of elevations, confounding the question of whether movements by bighorn sheep to high elevations are a response to minimize risk of mountain lion predation.

GPS technology has made it possible for predator management personnel in the SNBS Recovery Program to detect lion-caused mortality among Sierra Nevada bighorn sheep and selectively remove only those individuals that pose a threat to the endangered bighorn. Over the last six years a total of 15 Sierra Nevada bighorn sheep that were killed by mountain lions have been located. Since the beginning of the program, six mountain lions have been removed because they were determined to be a threat to Sierra Nevada bighorn sheep. In addition, two others that were identified as predators of Sierra Nevada bighorn sheep died of other causes.

Because of the rugged and steep terrain that Sierra Nevada bighorn sheep occupy, and because of the tremendous distances that mountain lions can travel, the use of radio collars is essential. Without the radio collaring program, this ability to determine and capture the mountain lions responsible for preying on bighorn sheep would be extremely difficult, if not impossible. As an example, we have illustrated the movements of two of the six male mountain lions responsible for killing bighorn sheep on Wheeler Ridge. The home ranges of those two individuals encompassed more than 12,000 square kilometers and 14,000 square kilometers, respectively, and included areas near the Nevada border where those lions spent a large part of their time. Identifying, tracking, and capturing those individuals while they occupied the steep rocky face of Wheeler Ridge would have been extremely difficult and exceedingly dangerous for the houndsmen and their dogs. However, when those individual lions left Wheeler Ridge, DFG located them in safer terrain away from the bighorn sheep winter range. Without the radio collars staff would never have extended the search to the Nevada border, and would not have been able to selectively remove the offending mountain lions. Interestingly, those lions did not simultaneously occupy the illustrated ranges at the same time. After the first male was removed for killing bighorn sheep on Wheeler Ridge the second male quickly replaced it; that individual occupied almost an identical home range and also killed Sierra Nevada bighorn sheep.

DFG's analysis of the movements of four male mountain lions that have worn GPS radio collars in the vicinity of Wheeler Ridge indicates that their movement patterns overall were very similar in terms of distances moved on a daily basis. Staff examined the distance each individual moved over 24 hour periods and determined that the average daily movement by males was six kilometers, and the maximum daily movement was nearly 29 kilometers. DFG also examined those movements by season, and results indicate that male mountain lions make signifi-

nd mountain lions



GPS locations of two separate male mountain lions responsible for killing bighorn sheep on the Wheeler Ridge winter range. The lines represent the shortest distance between two locations 24 hours apart. Red lines illustrate the tremendous distances mountain lions can move in one day to reach Wheeler Ridge and become a threat to Sierra Nevada bighorn.

Mountain lion and hounds in habitat typically occupied by Sierra Nevada bighorn sheep.

cantly shorter daily movements during the winter than during the deer migration or during summer. This result is not surprising, considering the greater concentrations of deer during the winter.

The management of predators is an emotionally charged issue. The Sierra Nevada Bighorn Sheep Recovery Program strives to minimize the number of mountain lions killed while simultaneously maximizing the chances for bighorn recovery. Furthermore, staff hopes to learn more about the dynamics of the unique ecosystem that both the SNBS and mountain lions share during the recovery process, in order to lessen the odds that bighorn will face the threat of extinction again in the future.

Bleich earns State Statesman honor for bighorn sheep

The Foundation for North American Wild Sheep named the Department of Fish and Game's (DFG) Dr. Vernon C. Bleich "State Statesman" for his conservation efforts on behalf of bighorn sheep in California.

The prestigious award, the highest honor the Foundation gives, is presented annually to an individual who has contributed in meaningful ways to the conservation of wild sheep.

Bleich, who began working for the DFG in 1973, has spent his entire career in the deserts of southeastern California working largely on issues germane to the conservation and restoration of bighorn sheep. He currently supervises DFG's Sierra Nevada Bighorn Sheep Recovery Program.

Bleich watched the precipitous population decline of bighorn sheep to their lowest point in 1995 – only about 125 sheep in five eastern Sierra herds were left. One of the most magnificent animals in California was on the verge of extinction.

Sierra bighorn sheep were listed as endangered by California and the federal government. Following implementation of the Sierra Nevada Bighorn Sheep Recovery Program, the sheep rebounded to the current population estimate of 350.

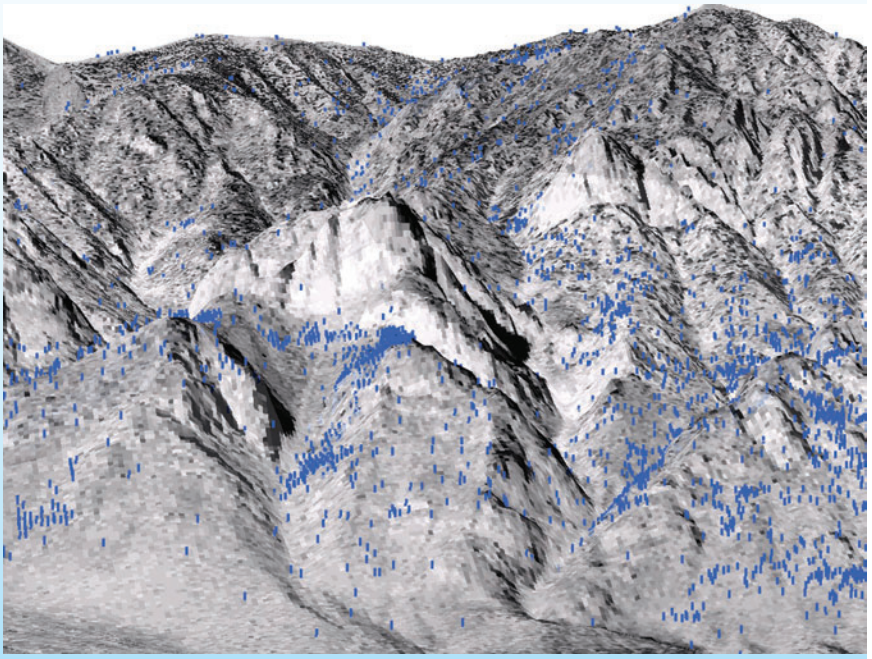
Bleich has placed a strong emphasis on recovery and restoration, and on understanding the causes of the decline. Without this understanding, future managers will not benefit from all of the efforts put forth to conserve those wild sheep.

Vern Bleich

Technology takes Sierra Nevada

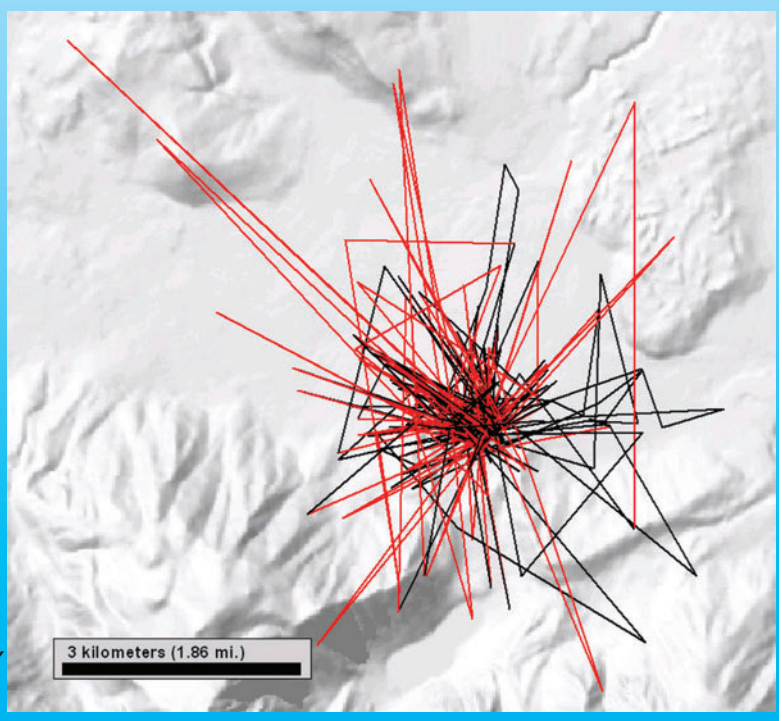
Making use of the latest spatial technology

The Sierra Nevada Bighorn Sheep Recovery Program is employing the latest available remote sensor data to complement global positioning system collars in evaluation of bighorn sheep movements. Visual observations are matched with features visible in satellite imagery to determine an accurate location and elevation for each ground observation. With the support of the Department of Fish and Game's Geographic Information Systems (GIS) unit, the SNBS team is deploying innovative 3D spatial tools that allow a satellite or aerial image to be displayed in three dimensions when "draped" over a digital elevation model (DEM). The precision of these tools will be greatly enhanced in spring 2006 when new imagery becomes available. DFG teamed with state and federal agencies under the National Agricultural Imagery Program (NAIP) to acquire 1-meter-resolution color air photos flown in summer 2005 to aid in observation, field sampling, and habitat characterization.



A technological fix to technology failure

Analysis of data from collars containing Global Positioning System receivers deployed on mule deer, Sierra Nevada bighorn sheep, and desert bighorn sheep showed a problem with a particular model of GPS collar. While most locations seemed reasonable, a portion (some 5 percent) of locations were clearly flawed, with errors of up to 17 kilometers. When staff tested collars at known locations, the problem was verified and the search for a solution began. The manufacturer offered no remedy for problems with the collars, so SNBS staff sought an alternative method of salvaging useful data. SNBS personnel developed an algorithm that identifies likely false movements that display an "out-and-back" pattern. This algorithm was incorporated in a software add-on, or "extension," to the ArcView GIS program. The "BadFix" extension is available for download by other researchers having the misfortune of deploying some of the hundreds of the defective GPS collars that have been used by wildlife scientists over the past several years.



BadFix links
http://www.dfg.ca.gov/region6/snbsrp/

BadFix ArcView extension
http://arcscripts.esri.com/details.asp?dbid=14434

bighorn sheep studies to new levels

Investigating the use of infra-red (IR) photography to quantify forage growth

Project personnel are exploring the use of low-cost digital infra-red (IR) photography to evaluate the timing and spatial distribution of the nutritious "green-up" of forage on bighorn sheep winter range. Plants undergoing rapid growth and photosynthesis reflect IR radiation while absorbing visible red waves. In a conventional photograph, we see the reflected green in a growing plant (as the red portion of the light spectrum is absorbed by chlorophyll).

An IR photo shows growing plants in light colors, as IR radiation is reflected by water in the growing leaves. When IR images are paired with images containing visible red color, the mathematical difference between infra-red and red reflectance allows plant growth to be quantified as "Normalized Difference Vegetation Index" (NDVI). Remote sensing experts use sophisticated software to analyze NDVI from satellite images.

The SNBS program has obtained a Section 6 grant from the U.S. Fish and Wildlife Service to investigate the "analysis of spatial and temporal patterns of forage and phenology" using Landsat satellite imagery. Project personnel are also investigating whether a low-cost, ground-based assessment can provide similar information. The satellite remote sensing approach made possible by the grant will provide a reference against which to check the information gathered in the experiment in inexpensive, fine-scale ground based evaluation.

Sierra Nevada bighorn sheep program personnel

Dr. Vern Bleich (DFG Program Leader), Dr. Becky Pierce (DFG Predation Ecologist), Dr. Tom Stephenson (DFG Bighorn Sheep Ecologist), Dr. John Wehausen (University of California Bighorn Sheep Population Biologist), Jeff Davis (USDA Wildlife Services Predator Detection Specialist), Jeff Ostergard (USDA Wildlife Services Predator Detection Specialist), Jeff Villepique (Graduate Student, Idaho State University), Heather Johnson (Graduate Student, University of Montana), Cody Schroeder (Graduate Student, Idaho State University), Maya Leonard-Cahn (Graduate Student, Yale University), Dennis Jensen (DFG Field Technician), Vicki Davis (DFG Field Technician), David German (DFG Field Technician), and Amy Stephenson (DFG Office Technician).

Acknowledgments: We are indebted to the many individuals, including numerous volunteers and agency personnel, that have participated in this recovery program. In particular, we acknowledge the contributions of the numerous agencies, and their dedicated employees, who are cooperating in the restoration and recovery of Sierra Nevada bighorn sheep. Among these are the USDI Fish and Wildlife Service, USDI Bureau of Land Management, Los Angeles Department of Water and Power, USDA Forest Service, USDA Wildlife Services, and the National Park Service.