

## RECONSTRUCTING THE SAN GABRIEL MOUNTAINS BIGHORN SHEEP POPULATION

STEPHEN A. HOLL  
Steve Holl Consulting  
7049 Pine View Drive  
Folsom, CA 95630  
email: steve@hollconsulting.com

VERNON C. BLEICH<sup>1</sup>  
Sierra Nevada Bighorn Sheep Recovery Program  
California Department of Fish and Game  
407 West Line Street  
Bishop, CA 93514

**The San Gabriel Mountains bighorn sheep, *Ovis canadensis nelsoni*, population has undergone substantial changes during 1976-2006 and it has been hypothesized that wildfires and predation by mountain lions, *Puma concolor*, have been responsible for the changes between 1976 and 1995. During 1995-2002 an estimated 90 bighorn sheep inhabited the San Gabriel Mountains and it was thought the population was stable. In 2006, the population estimate was  $292 \pm 69$  ( $\pm$ SE) and the population increase during 2002-2006 exceeded the intrinsic rate of increase reported for bighorn sheep. We used survey results, survival rates of adult animals, and recruitment rates to reconstruct the population. The results indicated the population had been increasing slowly since 1995. The recent population increase coincided with wildfires in 1997 and 2003 that burned 36% of winter-spring ranges occupied by bighorn sheep, and a decline in mountain lion activity, suggested a reduction in predation also played a role in the population increase.**

### INTRODUCTION

Previous investigators (Holl et al. 2004) reported the population of bighorn sheep, *Ovis canadensis nelsoni*, inhabiting the San Gabriel Mountains declined by approximately 88% between 1982 and 1995. During 1995-2002 we estimated 90 bighorn sheep inhabited that range, and the exponential rate of increase ( $r$ ) (Caughley 1977) indicated the population was stable. Furthermore, we hypothesized that the initial population decline was associated with declining habitat suitability on maturing chaparral-dominated ranges that had burned earlier, followed by an increase in predation on bighorn sheep by mountain lions, *Puma concolor*, in response to a concurrent decline in mule deer, *Odocoileus hemionus californicus*. In response to the bighorn

---

<sup>1</sup>Current address: Department of Biological Sciences, Idaho State University, Pocatello, ID 83209

sheep decline, a strategy to increase the population was prepared for the Los Angeles County Fish and Game Commission, California Department of Fish and Game (CDFG) and USDA Forest Service (Holl 2004<sup>2</sup>). The goal of that strategy was to achieve a self-sustaining population, defined by a prescribed number of females on each of six winter-spring ranges for 6 consecutive years and a minimum population of 322 sheep well distributed for 6 consecutive years.

Prior to implementing any of the management recommendations in the restoration strategy, participants in annual surveys from 2002-2006 counted 170, 148, and 167 bighorn sheep, respectively, and by March 2006 the population estimate was  $292 \pm 69$  ( $\pm$  SE). The apparent population increase during 2002-2006 exceeded the intrinsic rate of increase reported for bighorn sheep (Buechner 1960), in which case the population would double every 2.7 years.

We prepared this retrospective analysis to reevaluate and identify changes in the trajectory of the population immediately before and after 1995 and developed a hypothesis explaining why the trajectory of the population changed. This analysis is necessary to evaluate the performance of the San Gabriel Mountains bighorn sheep population relative to the goals of the restoration strategy.

## STUDY AREA

The San Gabriel Mountains are oriented on an east-west axis in eastern Los Angeles and western San Bernardino counties, California, and are a portion of the Transverse Range. The mountains are characterized by steep slopes and narrow canyon bottoms, where water usually is available. At elevations  $\leq 1,850$  m the climate is Mediterranean and the vegetation is dominated by chaparral and oak (*Quercus*) woodlands. Above 1,850 m the climate is cooler, with snow common in winter, and vegetation is dominated by montane shrubs and open stands of Jeffrey pine, *Pinus jeffreyi*, and white fir, *Abies concolor*. Lodgepole pine, *P. contorta*, and dwarf scrub vegetation occurs at the highest elevations. Fire is the major source of disturbance in this mountain range, with large conflagrations driven by hot, dry Santa Ana winds common during the fall. Approximately 95% of the mountain range is public land administered by the Angeles and San Bernardino national forests.

Bighorn sheep occur in four subgroups (Cucamonga Peak, Mt. San Antonio, Iron Mountain, and Twin Peaks), and the Cucamonga subgroup occupies five winter-spring ranges (Middle and South Forks Lytle Creek, Deer Canyon, Cucamonga Canyon, and Barrett-Cascade Canyons). All other subgroups occupy one winter-spring range each (Cattle Canyon, East Fork San Gabriel River, and San Gabriel Wilderness, respectively). All of these winter-spring ranges vary in elevation from  $\approx 1,000$  to 1,900 m, and are used following the first snows in early winter until late May (Weaver

---

<sup>2</sup>Holl, S. A. 2004. Implementation strategy to restore the San Gabriel Mountains bighorn sheep population. Prepared for the Los Angeles County Fish and Game Commission, Los Angeles, California, USA; California Department of Fish and Game; and Angeles and San Bernardino National Forests.

et al. 1972<sup>3</sup>, Holl and Bleich 1983<sup>4</sup>). During summer and fall some bighorn sheep migrate to higher elevation ( $\approx 2,000 - 3,300$  m) ranges (Weaver et al. 1972<sup>3</sup>, Holl and Bleich 1983<sup>4</sup>), presumably to take advantage of more nutritional forage. Other large mammals that occur on bighorn sheep seasonal ranges include mule deer, mountain lions, and black bears, *Ursus americanus*.

## METHODS

### Population Surveys

Annual helicopter surveys of bighorn sheep in the San Gabriel Mountains have been conducted since 1976 during March, when bighorn sheep concentrate on winter-spring ranges (Holl et al. 2004). At that time young were approximately 10-11 months old and we assumed they would be recruited into the population. We recorded the location, sex, and age class of individual bighorn sheep, and the number of bighorn sheep observed per hour of helicopter survey time (catch-per-unit effort), on each winter-spring range. Although dense chaparral cover could affect observability of bighorn sheep during aerial surveys, available evidence is to the contrary (Bleich et al. 2008). During the 30 year period different methods were used to calculate population estimates using the best available data. From 1976 to 1978 population estimates were calculated from the helicopter surveys and a model, POP50 (Holl and Bleich 1983<sup>4</sup>); from 1979-1989, population estimates were calculated from double samples (Magnusson et al. 1978) obtained during concurrent aerial and ground surveys. The ground surveys were discontinued after 1989 because maturing chaparral limited access to observation areas. No other population estimates were available until 2006, when the population estimate was calculated using radio-collared animals in a Peterson index as corrected by Bailey (Caughley 1977).

### Bighorn Sheep Demography

#### *Exponential Rate of Increase*

We calculated an  $r$  during each of four time periods (1976-1982, 1982-1989, 1989-1995, and 1995-2006) using the population estimates, total number of animals counted, and catch-per-unit effort (Caughley 1977). We established the four time periods by evaluating changes in the number of animals counted and the trajectory of population indices (Holl et al. 2004).

---

<sup>3</sup>Weaver, R. W., J. L. Mensch, W. Timmerman, and J. M. Hall. 1972. Bighorn sheep in the San Gabriel and San Bernardino Mountains. Wildlife Management Administrative Report 2-2, California Department of Fish and Game, Sacramento, California, USA.

<sup>4</sup>Holl, S. A. and V. C. Bleich. 1983. San Gabriel mountain sheep: biological and management considerations. San Bernardino National Forest, San Bernardino, California, USA.

### *Adult Survival and Recruitment*

Personnel from CDFG captured 35 adult bighorn sheep with a hand-held net gun fired from a helicopter (Krausman et al. 1985) during September 2003-January 2006. Each animal was fitted with a radio telemetry collar that included a mortality sensor (Telonics, Inc; Mesa, AZ<sup>5</sup>). CDFG estimated the location of all collared animals once monthly from an airplane, and telemetry signals were monitored from the ground 3-5 times each week. All mortality signals were investigated; however, the cause of mortality could not always be determined.

We calculated annual survival rates of radio-collared adults using the Kaplan-Meier procedure as modified for staggered entry by Pollock et al. (1989). Each biological year started April 1, just before young were born and ended March 31 the following year, when all young surviving to that date were presumed to be recruited into the population.

We calculated the mean adult survival rate from annual adult survival rates during 2004-2005 and 2005-2006. We also estimated the female survival rate by an iterative process that maintained a male to female ratio of approximately 0.66 (the mean adult sex ratio observed from 1976-2006) during 1995-2006. Only one yearling (1.5 years old) was fitted with a radio collar and it was alive at the end of 2006. Survival rates of yearling bighorn sheep generally are higher than are those of older animals (Geist 1971, Leslie and Douglas 1979, Hansen 1980, Festa-Bianchet 1989), except in declining populations (Festa-Bianchet 1989, Rubin et al. 2002). Therefore, yearling survival rates were always assumed to be 0.98, the mean derived from other bighorn sheep populations (Festa-Bianchet 1989), and an equal sex ratio was assumed. We did not use yearling survival rates from desert populations because the San Gabriel Mountains are a mesic range, unlike the xeric ranges occupied by other populations of bighorn sheep in southeastern California. Observed recruitment rates (lambs:ewes) derived from survey data were used to estimate annual recruitment into the adult cohort, assuming an even sex ratio. Additionally, we used monthly precipitation from Mount Wilson, Los Angeles County to test for relationships between rainfall and lamb recruitment.

### *Population Estimates*

We developed population estimates for missing individual years from 1979-1989 and for all years from 1990-2006 using the exponential growth equation,  $N_t = N_0 * e^{rt}$ . During those four time periods,  $N_0$  was the population estimate obtained from POP50 in 1976; the estimates obtained from the double survey in 1982 and 1989; and the estimate from 1995 that had been calculated from the exponential growth equation. Rates of increase were calculated from the population estimates and again from the mean of the number of animals counted and the catch-per-unit effort data.

We also calculated population estimates for 1995-2006 using adult survival and

---

<sup>5</sup>The use of trade names does not imply endorsement by the California Department of Fish and Game.

recruitment rates. An initial population estimate ( $N_0$ ) of 130 animals in March 1995 was calculated from the exponential growth equation. The number of adult males and females and young in  $N_0$  was calculated using an adult sex ratio of 0.66 males:females and the observed recruitment rate in 1995. The numbers of adult males and females the following March ( $N_t$ ) were calculated with a simple deterministic time model similar to that used by Logan and Sweanor (2001):

$$N_t = (A_m * s) + ((Y/2) * s) + (A_f * s) + ((Y/2) * s) + (L)$$

where  $A$  was the number of adult males ( $m$ ) or females ( $f$ ) estimated the previous year,  $Y$  was the number of yearlings (young recruited the previous year),  $L$  was the number of young that will be recruited (adult females plus half the yearlings multiplied by the observed recruitment rate) and  $s$  was the sex- or age-specific survival rate. No survey was conducted in 2003; therefore, we used the mean recruitment rate (0.31) from the previous 7 years in the modeling effort for that year.

### Area Burned and Mountain Lion Abundance

We determined the area of bighorn sheep winter-spring range burned during 1995-2006 by comparing Forest Service maps of large fires and the perimeters of winter-spring ranges, as described by Holl (2004<sup>2</sup>). Changes in mountain lion activity were determined by evaluating the number of depredation permits issued annually by the CDFG in Los Angeles and San Bernardino counties. In these counties, mountain lions are confined to the San Gabriel and San Bernardino Mountains (Torres et al. 1996).

## RESULTS

### Rate of Increase

Exponential rates of increase varied during each of the four time periods (Table 1), with a population increase during 1976-1982 and 1995-2006 and a population decline during 1982-1995. During 1982-1989,  $r$  derived from the population estimates (-0.046) was similar to the mean  $r$  (-0.052) calculated from the number of bighorn sheep counted (-0.038) and the catch-per-unit effort (-0.067). Although this is the only period where  $r$  calculated from different samples could be compared, the close agreement among those values (Table 1) suggests the mean  $r$  would produce results similar to those calculated directly from population estimates.

### Recruitment and Adult Survival Rates 1995-2006

During 1995-2006, recruitment rates ranged from 18 to 53 young/100 females, with a mean of 34 ( $\pm 3.0$ ). There was no relationship ( $P > 0.05$ ) between lamb recruitment rates and monthly precipitation or aggregates of months, during November-March

Table 1. Rates of increase for bighorn sheep in the San Gabriel Mountains, Los Angeles and San Bernardino counties, California, 1976-2006.

Population statistic used to calculate rate of increase	Rate of increase			
	Time period			
	<u>1976-1982</u>	<u>1982-1989</u>	<u>1989-1995</u>	<u>1995-2006</u>
1. Population estimate	0.015	-0.046		
2. Number sheep counted		-0.038	-0.258	0.087
3. Catch-per-unit effort		-0.067	-0.195	0.061
Mean (2+3)/2		-0.052	-0.226	0.074

of the preceding year when precipitation would have affected forage quality during gestation.

Nine (5 males, 4 females) of 35 adult bighorn sheep died between September 2003 and March 2006. During 2004-2005 and 2005-2006 adult male survival rates were 0.909 ( $n = 12$ ) and 0.732 ( $n = 17$ ), respectively, with a mean of 0.82. Adult female survival rates for the same periods were 0.79 ( $n = 10$ ) and 0.83 ( $n = 16$ ), respectively, with a mean of 0.81. An adult female survival rate of 0.915 was necessary in the modeling to maintain a mean adult sex ratio of 65:100, similar to that observed 1976-2006.

### Population Estimates

The similarity in  $r$  calculated during 1982-1989 described above, is supported by the population estimates. In 1989, the population estimate obtained from the double survey was  $501 \pm 30$ ; the estimate from the exponential growth equation was 491 that same year using  $r$  calculated from all double survey results, and 496 using the mean  $r$  calculated from the number of animals observed (Fig. 1). Using the mean  $r$  calculated from the number of animals observed we calculated that the population had declined to 130 bighorn sheep in 1995 and then increased to 291 sheep in 2006. That value essentially is identical to the Peterson estimate of  $292 \pm 69$  obtained from the survey data. Using observed recruitment rates and adult male survival rates, estimated adult female survival rates, and an initial population of 130 bighorn sheep in 1995, the 2006 population was estimated to be 287, a value very close to the estimates obtained from the mark-recapture survey that year (292) and exponential growth equation (291) (Fig. 1).

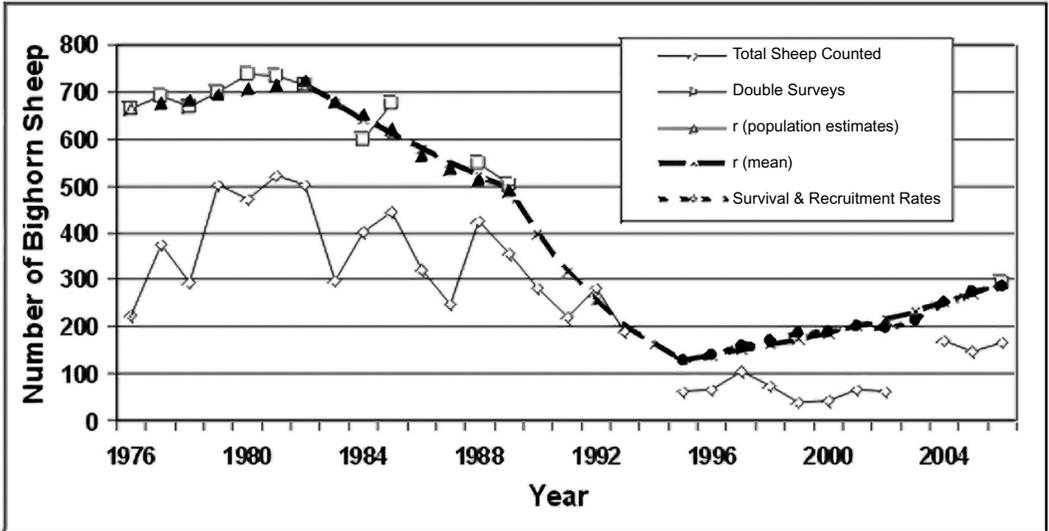


Figure 1. Total number of bighorn sheep counted and population estimates developed from those surveys and calculated population estimates using rates of increase ( $r$ ) calculated from the double survey, the mean of total number counted and catch-per-unit effort, and adult survival and recruitment rates of young, San Gabriel Mountains, Los Angeles and San Bernardino counties, California, 1976-2006.

### Areas Burned and Mountain Lion Abundance

Two wildfires occurred after 1995, one in 1997 that burned 920 ha (47%) in the East Fork San Gabriel winter-spring range and one in 2003 that burned 2,880 ha (75%) of winter-spring range in the Cucamonga subunit. During 1983-1990 the mean number of depredation permits issued annually in Los Angeles and San Bernardino counties was 0.38 (range = 0-2) (CDFG files). The number of depredation permits issued then increased and reached its peak in 1995 and 1996 ( $n = 5$  each year) and then declined to a mean of 1.2 (range 0-2) annually during 2003-2006.

## DISCUSSION

### Adult survival

The estimated survival rate of 0.915 for adult females during 1995-2006 was similar to the annual survivorship ( $\approx 0.90$ ) necessary for that cohort to increase in the Granite Mountains of southeastern Californian (Wehausen 1996). Overall, the annual adult survival rate was 0.867 in the San Gabriel Mountains, which is higher than mean annual adult survival rates of 0.81 and 0.80 reported for declining bighorn sheep populations elsewhere in southern California (Hayes et al. 2000, Schaefer et al. 2000).

## Population Estimates

This analysis provided population estimates for all missing years between 1983 and 2005. In an earlier analysis of this population, Holl et al. (2004) used a population estimate of 90 animals during 1995-2002, compared to 130 in 1995 and 216 in 2002 that we calculated for that same period in this analysis (Fig. 1). The earlier estimate (Holl et al. 2004) was conservative because not all of the winter-spring ranges were surveyed each year. Unlike the previous analysis (Holl et al. 2004), our results suggest the population had been increasing slowly since 1995. In this analysis we estimated there were 130 bighorn sheep present in 1995; when we used that as the initial population estimate in two different models, the resulting population estimates were nearly identical with the estimate obtained from the survey results (Fig. 1). Assuming  $r$  does not change substantially in the immediate future, the population should exceed the recovery goal of 322 animals in 2008; unfortunately the annual survey was not completed in 2008 because of extremely poor weather conditions that substantially reduced the amount of flight time available.

## Factors Affecting the Population

The San Gabriel Mountains bighorn sheep population has undergone significant changes during 1976-2006 and it has been hypothesized that wildfires and predation by mountain lions have been responsible for the changes between 1976 and 1995 (Holl et al. 2004). From 1976-1982 the population was stable; however, a slow decline occurred during 1982-1989. The decline was initiated 7-14 years after approximately 22% of the habitat on winter-spring ranges had burned in wildfires that occurred in 1968, 1970, and 1975. After being initially attracted to newly burned areas, the number of sheep using those burned areas progressively declines, until their distribution is negatively associated with habitat that is more than 15 years post-fire (Holl et al. 2004, Bleich et al. 2008). By 1989 all of the areas burned between 1968 and 1975 were at least 14 years post-fire and habitat suitability had decreased substantially.

Between 1989 and 1995 the population declined rapidly, characterized by a loss of adult bighorn sheep and a concurrent decline in mule deer (Holl et al. 2004). Because of the sudden loss of adult bighorn sheep, a similar decline in mule deer, and an increase in the number of depredation permits issued for mountain lions in Los Angeles and San Bernardino counties Holl et al. (2004) hypothesized that mountain lion predation was, in part, responsible for the rapid decline in bighorn sheep. Mountain lions are confined largely to the Transverse Range in Los Angeles and San Bernardino counties, and the number of depredation permits provides an index of mountain lion activity (Torres et al. 1996). In the Sierra Nevada, the number of mountain lion depredation permits increased during 1986-1991, as mule deer and bighorn sheep populations declined (U. S. Fish and Wildlife Service 2008). Following the decline in mule deer and bighorn sheep in the Sierra Nevada, the mountain lion population index declined

by 50 percent during 1993-1997 (Pierce et al. 2000) and the number of depredation permits issued also declined during 1993-2000, at which point the bighorn sheep population recovery began (U. S. Fish and Wildlife Service 2008).

In the San Gabriel Mountains, the peak in mountain lion activity (1995-1996) coincided with the nadir of the decline of bighorn sheep (Fig. 1) and, presumably, after the mule deer population had reached its lowest level. Thus, the largest number of mountain lion depredation permits was issued when prey populations were at very low levels, as in the Sierra Nevada. The decline in the number of mountain lion depredation permits issued after 1996 (CDFG files) suggests the mountain lion population had decreased, and a lower rate of predation would be consistent with an increase in the sheep population. The increase in bighorn sheep also coincided with wildfires that burned 36% of their winter-spring range habitat in 1997 and 2003. Fires improve forage quality for 2 years in chaparral (Taber and Dasmann 1958) and they remove visual obstructions that allow bighorn sheep to detect predators; as a result the distribution of bighorn sheep in these mountains is positively associated with areas that have burned < 15 years ago (Bleich et al. 2008).

## MANGEMENT IMPLICATIONS

The annual helicopter survey and efforts required to coordinate the ground surveyors in the San Gabriel Mountains are expensive. The resultant long-term data set produced by these efforts has proven to be an invaluable resource to monitor population changes and state and federal agencies should include these costs as a line item in future budgets to ensure financial resources are available for the survey. Similar to lessons learned from another long-term data set (Pelton and van Manen 1996), conclusions about the status of this population have changed, depending on what data are available when those conclusions were reached. In response to the dramatic decline in the San Gabriel bighorn sheep population, one analysis demonstrated the population was eligible for listing as a distinct population segment under the federal Endangered Species Act (Holl 2002<sup>6</sup>). That determination facilitated funding for additional studies of adult survival that contributed to the current analysis and our conclusion that the population had been increasing since 1995. Thus, long-term data sets are essential for adaptive management processes that increase the ability to identify the mechanisms that affect populations and allow managers to make informed decisions. Although little is known about the historic or current distribution of mountain lions or mule deer in the San Gabriel Mountains, recent observations indicate some additional monitoring may be warranted when the current trajectory of the bighorn sheep population changes to understand the relationship between bighorn sheep and other large mammals.

The recent population increase coincided with a decline in mountain lion activity and serendipitous wildfires in 1997 and 2003 that improved habitat suitability. The habitat benefits of the 1997 fire will soon be lost (Bleich et al. 2008); therefore,

---

<sup>6</sup>Holl, S. A. 2002. Conservation strategies for bighorn sheep in the San Gabriel Mountains, California. Los Angeles Fish and Game Commission, Los Angeles, CA.

additional prescribed burns identified in the restoration strategy (Holl 2004<sup>2</sup>) should be implemented to increase habitat, improve habitat suitability on unburned ranges, and increase the number of bighorn sheep.

### ACKNOWLEDGMENTS

CDFG biologists R. Barboza, C. Davis, J. Davis, P. Swift, R. Teagle, S. Torres; Forest Service biologist K. Meyer; and volunteers J. Aziz, S. Crew, T. Glenner, J. Hybarger, C. Kearns, and the Society for the Conservation of Bighorn Sheep assisted with recent surveys and captures. Landells Aviation provided helicopter support for surveys and captures and we thank T. Evans (CDFG) for monitoring locations of radio-collared sheep. The San Bernardino National Forest has been a major source of funding for the restoration effort, with additional funding provided by the USFS Full Curl Program, Los Angeles County Fish and Game Commission, Quail Unlimited, Safari Club International, Society for the Conservation of Bighorn Sheep, and the California Chapter of the Foundation for North American Wild Sheep. Lastly, we thank 2 anonymous reviewers for their constructive comments on this paper. This is a contribution from the CDFG Mountain Sheep Conservation Program, and is Professional Paper 063 from the Eastern Sierra Center for Applied Population Ecology.

### LITERATURE CITED

- Bleich, V. C., H. E. Johnson, S. A. Holl, L. Konde, S. G. Torres, and P. R. Krausman. 2008. Fire history in a chaparral ecosystem: implications for conservation of a native ungulate. *Rangeland Ecology and Management*: 61:571-579.
- Buechner, H. 1960. The bighorn sheep in the United States, its past, present, and future. *Wildlife Monographs* 4:1-174.
- Caughley, G. 1977. Analysis of vertebrate populations. John Wiley and Sons, New York, NY.
- Festa-Bianchet, M. 1989. Survival of male bighorn sheep in southwestern Alberta. *Journal of Wildlife Management* 53:259-263.
- Geist, V. 1971. Mountain sheep: a study in behavior and evolution. University of Chicago Press, Chicago, IL.
- Hansen, C. G. 1980. Population dynamics, pp. 217-235 in G. Monson and L. Sumner, editors. The desert bighorn, its life history, ecology, and management. University of Arizona Press, Tucson, AZ.
- Hayes, C. L., E. S. Rubin, M. C. Jorgensen, R. A. Botta, and W. M. Boyce. 2000. Mountain lion predation of bighorn sheep in the Peninsular Ranges, California. *Journal of Wildlife Management* 64:954-959.
- Holl, S. A., V. C. Bleich, and S. G. Torres. 2004. Population dynamics of bighorn sheep in the San Gabriel Mountains, California, 1967-2002. *Wildlife Society Bulletin* 32:412-426.
- Krausman, P. R., J. J. Herver, and L. L. Ordway. 1985. Capturing deer and mountain sheep with a net-gun. *Wildlife Society Bulletin* 13:71-73.
- Leslie, D. M., and C. L. Douglas. 1979. Desert bighorn sheep of the River Mountains, Nevada. *Wildlife Monograph* 66:1-56.
- Logan, K. A., and L. L. Sweanor. 2001. Desert puma: evolutionary ecology and conservation of an enduring carnivore. Island Press, Washington, D.C.

- Magnusson, W. E., G. J. Caughley, and G. C. Grigg. 1978. A double survey estimate of population size from incomplete counts. *Journal of Wildlife Management* 42:174-176.
- Pelton, M. R. and F. T. van Manen. 1996. Benefits and pitfalls of long-term research: a case study of black bears in Great Smokey Mountains National Park. *Wildlife Society Bulletin* 24:443-450.
- Pierce, B. M., V. C. Bleich, and R. T. Bowyer. 2000. Social organization of mountain lions: does a land-tenure system regulate population size? *Ecology* 81:1533-1543.
- Pollock, K. H., S. R., Winterstein, C. M. Bunck, and P. D. Curtis. 1989. Survival analysis in telemetry studies: the staggered entry design. *Journal of Wildlife Management* 53:7-15.
- Rubin, E. S., W. M. Boyce, and E. P. Caswell. 2002. Modeling demographic processes in an endangered population of bighorn sheep. *Journal of Wildlife Management* 66:796-810.
- Schaefer, R. J., S. G. Torres, and V. C. Bleich. 2000. Survivorship and cause-specific mortality in sympatric populations of mountain sheep and mule deer. *California Fish and Game* 86:127-135.
- Taber, R. D., and R. F. Dasmann. 1958. The black-tailed deer of the chaparral: its life history and management in the north Coast Range of California. *California Department of Fish and Game, Game Bulletin* 8:1-163.
- Torres, S. G., T. M. Mansfield, J. F. Foley, T. Lupo, and A. Brinkhaus. 1996. Mountain lion and human activity in California: testing speculations. *Wildlife Society Bulletin* 24:451-460.
- U. S. Fish and Wildlife Service. 2008. Recovery plan for the Sierra Nevada bighorn sheep. U.S. Fish and Wildlife Service, Sacramento, CA.
- Wehausen, J. D. 1996. Effects of mountain lion predation on bighorn sheep in the Sierra Nevada and Granite Mountains of California. *Wildlife Society Bulletin* 24:471-479.

Received: 20 May 2008

Accepted: 6 August 2008