February 2009

Fra Cristobal Mountains: Evaluation of an 8-year mountain lion removal management action on endangered desert bighorn sheep recovery

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Executive Summary: Desert bighorn sheep (*Ovis canadensis*; bighorn) were listed as a state endangered species in New Mexico in 1980(NMDGF 2003). As part of the recovery program, a transplant of 37 bighorn started a new herd in the Fra Cristobal Mountains in 1995, and increased statewide numbers. Through statewide bighorn radiocollaring and monitoring efforts in the 1990s, it was documented that the principle cause of mortality for adult bighorn was mountain lion (*Puma concolor*; lion) predation. Lions were not removed from 1995-1999 to protect bighorn, resulting in a period of *minimum protection*. In 1999, a study was initiated in the Fra Cristobals to investigate lion behavior and lion-bighorn interactions. Of 17 radiocollared lions, 8 were known bighorn killers, 8 were likely bighorn killers, and 1 was not a suspected bighorn killer. At the same time, a management action of removing lions was implemented in the Fra Cristobals, and in 2001 in 4 other herds (Peloncillos, Hatchets, Ladrones, and San Andres) to mitigate high lion predation rates (Rominger and Dunn 2000). Lion removal was less aggressive in the Fra Cristobals than in 4 other herds as several different management strategies, designed with greater protection for lions, were implemented. This resulted in a period of *some protection* for bighorn from 1999-2007, during which 21 lions were killed. A period of *maximum protection* was not achieved as it was in 4 other herds. To evaluate impacts of the lion removal program on bighorn, we assessed bighorn mortality rates in the different management periods using program MARK (White and Burnham 1999). The average annual mortality rate from lion predation during the period of minimum protection was 0.18 in the Fra Cristobals, and 0.17 in 4 other herds. Mortality rates decreased to 0.09 in the Fra Cristobals in the period of some protection, compared with 0.04 in 4 other herds during the period of maximum protection. The statewide bighorn population increased from <170 in 2001, to >400 in 2007 from a combination of increased survival and translocation. The Fra Cristobal population increased from approximately 66 to 80 individuals during the same time period, however the number of ewes only increased by 5-10. The less aggressive lion removal policy in the Fra Cristobals lowered lion predation mortality rates, but not as much as in 4 other herds with a more aggressive lion removal policy. In October 2006, a new management strategy for bighorn and lions was delineated in the Fra Cristobal Desert Bighorn Sheep Management Memorandum 2006-2011 (NMDGF 2006). Future analysis will allow insight into the efficacy of the new management prescription. Range-wide lion removal is recommended until bighorn populations recover to levels where less aggressive control actions can be implemented without compromising the bighorn herd.

Background of Management Action

Desert bighorn sheep (*Ovis canadensis*; bighorn) were listed as an endangered species in New Mexico in 1980 (NMDGF 2003). The Plan for the Recovery of Desert Bighorn Sheep in New Mexico (NMDGF 2003) was produced to guide management of this endangered species, and to replace the New Mexico Long-range Plan for Desert Bighorn Sheep Management 1995-2002 (NMDGF 1995) upon its expiration. Through radiocollaring and monitoring efforts in the 1990s, it was documented that mountain lion (lion) predation was responsible for ~85% of known-caused bighorn mortality. In 1999, the New Mexico State Game Commission (Commission) approved killing lions in the Peloncillo, Hatchet, and Ladron bighorn herds, with the San Andres added in 2002 (hereafter referred to as 4 other herds) as a management action to reduce mortality rates on bighorn (Rominger and Dunn 2000). Actively hunting, snaring, and killing all captured lions resulted in a period of *maximum protection* in these herds (Rominger and Goldstein 2008). The Evaluation of an 8-Year Mountain Lion Removal Management Action on Endangered Desert Bighorn Sheep Recovery (Rominger and Goldstein 2008) was completed in April 2008 at the behest of the Commission to assess the program's efficacy. Lions were also killed in the Fra Cristobal Mountains to protect bighorn using New Mexico Department of Game and Fish (NMDGF) issued permits and sport harvest licenses. The Fra Cristobals were not included in the evaluation because management strategies differed from those in 4 other herds. This evaluation serves to document lion management impacts on bighorn in the Fra Cristobals from 1995-2007, and to compare them to management strategies and results in 4 other herds.

History of Bighorn Sheep and Mountain Lion Management in the Fra Cristobal Mountains

In 1995, 37 bighorn were transplanted from the captive breeding facility in the Red Rock Wildlife Area (RRWA) to the privately owned Fra Cristobal Mountains to establish a new herd. The transplant was done in collaboration with the land owner, Turner Endangered Species Fund, and the land manager, New Mexico Ranch Properties, Inc. A full time ground monitor was hired to track bighorn for 5 months post-release (Mabe 1996). Bighorn have been monitored from approximately monthly fixed-wing flights since October 1996, and a full time biologist has monitored the bighorn herd almost continuously since July 1997. In 1997, an additional 7 rams were transplanted from RRWA to augment the herd. In an effort to gather lion movement pattern and bighorn-lion interaction data, lions were captured, radiocollared, and monitored beginning in 1999 in collaboration with Hornocker Wildlife Institute. There was no management regime of killing lion to protect bighorn from 1995-April 1999, resulting in a period of *minimum protection*. A policy of killing lions in bighorn range was initiated in May 1999 in an attempt to mitigate high documented lion predation rates on bighorn. Two graduate students studied bighorn habitat characteristics and causes of adult and lamb mortality from January 2000-August 2002. The lion removal policy was modified to kill only lions that had preyed on 3 ewes or 5 bighorn total, in deference to the second graduate student who was studying causes of bighorn mortality.

Following the graduate students' departure, a bighorn population decline precipitated hiring snaremen to re-implement the policy of removing lions to protect bighorn. In March 2003, an attempt was made to test the hypothesis that male lions remain in an area only if female lions are present. All captured female and offending lions were euthanized, and all captured non-offending male lions were radiocollared and monitored. In July 2004, this was modified to incorporate euthanizing male lions that remained in bighorn habitat for > 48 hours, or were otherwise likely hunting bighorn. However, attempts were not always made to kill male lions meeting these criteria, and female lions often remained on the mountain due to difficulties in removing them. The turnover rate for snaremen was high with 6 different snaremen employed from 2003-2007, and expertise ranged from retired professional lion snaremen to students who had recently graduated. Ultimately, implementation of the lion removal policy from 2003-2007 was highly variable. The management actions were less aggressive than in 4 other herds, and resulted in a period *some protection* for bighorn.

In October 2006, a new management strategy for bighorn and lions was delineated in the Fra Cristobal Desert Bighorn Sheep Management Memorandum 2006-2011 (NMDGF 2006), with varying prescriptions for lion removal based on the size of the ewe component of the bighorn population. If $\leq$ 30 ewes are in the population, any lion captured in bighorn range will be killed. If 31-75 ewes are in the population, any female lion captured in bighorn range will be killed, and attempts will be made to capture and kill any male lion that has killed a bighorn. Attempts will be made to capture and kill any radiocollared male lion remaining in bighorn range for greater than 96 hours, as he will be considered a threat to bighorn. Finally, if there are $\geq$ 76 ewes in the population, attempts will be made to capture and kill offending lions only. This management strategy has been in place for 1 year, therefore it is too early to evaluate it separately.

In 2006, NMDGF established a lion management matrix which puts forth the maximum lion mortality allowed per management zone due to all human activities in order to maintain stable lion populations throughout the state (NMDGF 2008). Sustainable mortality is defined as <20-30% of the total lion population, and is dependant on the proportion of adult female lions harvested (Ross et. al 1996, Anderson and Lindsey 2005). In Management Zone H, which encompasses the White Sands Missile Range and most of the area west to I-25, including the Fra Cristobal Mountains, the annual stable harvest is no more than 22 lions annually, based on 20% total mortality of an estimated lion population of 110, as long as no more than 6 are adult females (NMDGF 2008). The number of lions removed in Zone H since 1999 has always been lower than these thresholds, with the exception of the initial year of the lion removal program in the San Andres Mountains in the 2002-2003 season when 7 females were harvested with the goal of reducing the lion population. As mandated by the lion management matrix, the number of lions removed to protect bighorn does not exceed the total harvest allowed to maintain a stable lion population within the management zone.

Number and Fates of Radiocollared Bighorn

Between 1995 and September 1999, 44 radiocollars were deployed on bighorn released from RRWA. In October 1999, 2 radiocollars were still active, and an additional 32 collars were deployed on extant bighorn over the next 8 years. Thirteen of 32 collars were replacements for old or failed collars. Between 1999 and 2007, the number of radiocollared bighorn was between 8 and 19 annually. Radiocollared individuals comprised 11-34% (average=23%) of the estimated population, which is less than the average of 36% in 4 other herds. This is primarily due to almost all transplanted adult bighorn in 4 other herds being radiocollared in each of 5 large transplants between November 2002 and October 2006. There were no bighorn releases in the Fra Cristobals during this time to provide a large increase in radiocollar numbers.

Of 63 bighorn that received radiocollars, 27 were killed by lions and 7 died of other or unknown causes. Six radiocollars went off the air due to failure or expired batteries, 18 collars fitted with drop-off tabs fell off of the animal, and 5 were still active on live animals at the end of the study.

Number of Lions Killed

No lions were harvested in the Fras Cristobals from the October 1995 bighorn release to February 1998, despite 11 of 44 (25%) radiocollared bighorn being killed by lions. The first lion harvested to protect bighorn occurred in spring 1998 with a sport harvest license, with no additional lions killed the following year. With implementation of lion control in spring 1999, NMDGF issued kill permits and 3 lions were removed in the next 10 months. Only 1 lion was killed, after he had killed 5 bighorn, from February 2000-November 2002 while a graduate student studied causes of lamb mortality. A more aggressive lion removal policy was implemented following the graduate student's departure and a bighorn decline in autumn 2002. Lions killed since 2002 have been taken under an NMDGF scientific and educational collection permit. All lions were taken with the specific intent of protecting bighorn; therefore they are included in the category of lions taken by "contractors" in Table 1. From the time lion removal was implemented in spring 1999 through September 2007, 21 adult and 2 juvenile lions were killed to protect bighorn (2 of these were removed from livestock depredations). This averages 2.1 adult lions/year, which is less than the average of 3.3 in 4 other herds under the lion removal program (Table 1).

The sex ratio of lions removed was near parity (8 males, 10 females). This was also true in other ranges where lions were less aggressively removed, either because of hound-hunting only (Peloncillos=9 males, 8 females), or because NMDGF did not convert from hound-hunting to snares until 2005 (Hatchets=5 males, 6 females). A higher proportion of male lions were killed in the most intensively trapped ranges, particularly in later stages of the control program (San Andres =17 males, 11 females; and Sierra Ladron=17 males, 6 females; Red Rock=19males, 12 females).

Of 11 bighorn killed by lions from May 1999-2007 when bighorn were monitored full time and lion removal to protect bighorn occurred, all 5 offending radiocollared lions were killed Only 1 of 5 (20%) uncollared offending lions was able to be killed, which is similar to the 15% average in 4 other herds.

Radiocollared lions

Individual lion predation behavior appeared varied throughout the state, with both incidental and specialist bighorn killers. In the Fra Cristobals, a total of 17 lions was radiocollared from March 1999 to September 2007, with the total number of lions collared at any time ranging from 1-4. These were the only radiocollared lions in any bighorn range in New Mexico, and although sample sizes are too small to merit statistical evaluation, they allow some insights into interactions between lions and bighorn. Eight radiocollared lions were known bighorn killers, 8 were likely bighorn killers based on their geographic and temporal movements, and 1 was not suspected of killing bighorn. Fifteen of 17 radiocollared lions were euthanized, but in most, if not all, cases it was only after the loss of one or more bighorn.

Table 1. Numbers of lions killed in 5 mountain ranges October 1999-September 2007 by NMDGF contractors; additional lions removed by sport harvest/road kill in parentheses.

Year	Peloncillo	Ladron	Hatchets	San Andres	Fra Cristobal	Total
1999-2000	0	0 (1)	0 (1)	0	1	**1 (2)**
2000-2001	0 (1)	1	0	0	1[b]	**2 (1)**
2001-2002	4 (2[a])	4	1 (1)	0	2[b]	**11 (3)**
2002-2003	5 (2)	8[b] (1)	4[c] (1)	16[d] (1[e])	5	**38 (5)**
2003-2004	5	0	0 (2)	3	3 (1[f])	**11 (2)**
2004-2005	0	4	1 (3)	3	3	**11 (3)**
2005-2006	0	2	6	3	3	**14 (0)**
2006-2007	3	4	1	4	3[g]	**13 (0)**
Total	**17 (5)**	**23 (2)**	**13 (8)**	**29 (1)**	**21**	**103[c,d,g] (16[h])**

[a] includes 1 lion road-kill on Interstate 10
[b] includes 1 lion taken on livestock depredation
[c] includes 2 female juveniles killed by hounds
[d] includes 1 male <40 lbs. snared and died during transport
[e] includes 1 lion road-kill at San Augustine pass
[f] includes 1 lion train-strike
[g] includes 2 female juvenile kittens in attendance with an adult female
[h] includes 4 lions taken by lion contractors guiding clients and therefore attributed to sport harvest

Assessing Cause of Bighorn Mortality

Bighorn mortalities were investigated to evaluate causes of death. Lion predation was determined by kill-site characteristics including: a dragline from kill-site to cache-site, lion tracks at kill-site or cache-site, lion scat at cache-site, canine puncture wounds in neck or face, canine punctures or claw slices in radiocollar, rumen extracted and uneaten or buried, carcass partially or completely buried (i.e., rocks, sticks, grass, raked over

carcass), broken neck, (generally at cervical vertebrae 1 or more rarely 2), rostrum bones eaten back >10 cm, braincase cracked in females (never males), long bones i.e., humerus and/or femur cracked, lion hair present at kill-site or cache-site, lion scrapes at or near cache-site, hair plucked from carcass, and/or multiple cache-sites.

If lion sign was documented at the kill site, predation was assumed unless evidence of scavenging was detected. The potential for misidentifying a lion kill for a scavenging event existed and 2 lion-scavenged bighorn have been documented in >250 bighorn mortalities in New Mexico since 1995 (NMDGF files). The inherent difficulty in differentiating scavenging from predation events has led to a lack of data in the literature on lion scavenging rates. In a 10-year lion study conducted in collaboration with the Hornocker Institute in the San Andres Mountains, a scavenging rate of 2% on all deer carcasses found during the study (*Odocoileus hemionus*) was documented (Logan and Sweanor 2001). Koehler and Hornocker (1991) reported a lion scavenging rate of 4% on 100 large ungulate carcasses. We concur with Anderson and Lindzey (2003) that the error due to misidentifying a lion scavenge event as a lion predation event creates an "unknown but likely small bias".

Mortality Rates Calculated Using Program MARK

We used the nest-survival model in program MARK (White and Burnham 1999) to calculate mortality rates for bighorn. This computer program uses data collected from monitoring radiocollared bighorn to extrapolate mortality rates for individual herds and the statewide population. We examined average annual mortality rates from all causes of mortality and from lion predation only, for all bighorn, and for rams and ewes. For the Fra Cristobals, we divided mortality data in 2 main time periods: 1) a period of *minimum protection* which includes the period when one lion was removed to protect bighorn (Oct. 1995-May 24, 1999); and 2) a period of *some protection* when enough lions were removed to decrease bighorn mortality rates (May 25, 1999-Sept. 2007), but sufficient numbers of lions were not removed to establish a period of *maximum protection* (as defined below).

For 4 other herds, we also divided mortality data into 2 time periods: 1) a period of *minimum protection* when no or few lions were removed to protect bighorn (dates vary according to herd); and 2) a period of *maximum protection* that occurred after a sufficient number of lions were removed to decrease predation rates on bighorn to 0 for at least 6 months with a concomitant decrease in the amount of lion sign observed by contract hunters. This period continued as long as NMDGF attempted to remove lions, and includes periods when 1 or more bighorn were killed by lions.

The mortality rate from lion predation in the Fra Cristobals decreased from 0.18 during the period of minimum protection to 0.09 during the period of some protection. In 4 other herds, the mortality rate decreased from 0.17 during the period of minimum protection to 0.04 during the period of maximum protection. During the same periods, mortality rates from all causes of mortality decreased from 0.18 to 0.16 in the Fra Cristobals, and from 0.24 to 0.09 in 4 other herds (Table 2). By subtraction, mortality

rates from other and unknown causes increased from 0.00 to 0.07 in the Fra Cristobals, and decreased slightly from 0.07 to 0.05 in 4 other herds in the same time periods.

Lion predation was the only documented cause of mortality during the period of minimum protection in the Fra Cristobals, and was higher for rams (0.43) than for ewes (0.10). The strikingly high mortality rate on rams during the period of no protection was not observed in the any of the other herds studied in New Mexico. No rams were radiocollared from 1999-2002, and few rams were collared relative to the number of ewes through 2007. Therefore, mortality rates for rams are not reported during the period of some protection. For ewes, the mortality rate from lion predation was 0.10, and from all causes was 0.17 (Table 2).

Table 2. Average annual bighorn morality rates from all causes of mortality and from lion predation only during the periods of minimum and some protection in the Fra Cristobal Mountains, New Mexico, 1995-2007, and during the periods of minimum and maximum protection in 4 other herds (Peloncillo, Hatchet, Ladron, and San Andres) in New Mexico, 1992-2007. For all values, SE≤0.01.

Category	Average Annual Mortality Rate			
	Fra Cristobals		4 Other New Mexico Herds	
	All Causes	Lion Predation	All Causes	Lion Predation
Minimum protection	0.18	0.18	0.24	0.17
Some protection	0.16	0.09	N/A	N/A
Maximum protection	N/A	N/A	0.09	0.04
Males – Minimum protection	0.43	0.43	0.20	0.12
Some protection	N/A	N/A	N/A	N/A
Maximum protection	N/A	N/A	0.07	0.03
Females – Minimum protection	0.10	0.10	0.27	0.20
Some protection	0.17	0.10	N/A	N/A
Maximum protection	N/A	N/A	0.10	0.05

It is interesting to note that the lion predation rate in the Fra Cristobals was similar to 4 other herds during the period of minimum protection and higher than 4 other herds during the period of some protection, despite the highest observed deer/hour rate in any bighorn range in NM (Table 3).

Table 3. Observation rate of deer/hour during bighorn helicopter surveys in the Peloncillo, Hatchet, Ladrones, and Fra Cristobals during the periods of minimum, some (Fra Cristobals only), and maximum protection.

Time Period	Deer/hour			
	Peloncillo	Little Hatchet	Ladrones	Fra Cristobals
Minimum protection	4.2	6.2	4.9	13.7
Some/maximum protection	8.1	N/A	6.9	11.8

In 1999, a population habitat and viability assessment workshop (PHVA) was conducted in New Mexico to model bighorn extinction rates and probabilities, with experts in population modeling from around the country in attendance (Fisher et al. 1999). Model results predicted a 100% probability of extinction within 13 years (11 years in the Fra Cristobals) with an additive lion predation mortality rate of 0.20, a 100% probability of extinction within 27 years (25 years in the Fra Cristobals) with a lion-caused mortality rate of 0.10, and a 53% probability of extinction within 94 years in the San Andres and an 82% probability of extinction within the next 65 years (60 years in the Fra Cristobals) in the other 3 herds with a lion-caused mortality rate of 0.05. Some population sizes have increased, including the Fra Cristobals, and others have decreased since 1999, therefore the exact probabilities and number of years to extinction may be different today. However, the results indicate that population persistence is very sensitive to small changes in lion predation mortality rates.

Population Trends

The Fra Cristobal population increased from an initial 37 (including 24 ewes) in 1995 to approximately 53 (including 23 ewes) by fall 1999, although the number of ewes decreased by 1. Following implementation of lion control, the population expanded to 75-80 (including approximately 35 ewes) by 2004, with a similar population size (75-85 including 29-34 ewes) by fall 2007. The ewe population increased by only 5-10 ewes during the 8 ½ year period of some protection (Figure 1). The statewide population trend increased from <170 in 2001 to >400 in 2007, following effective implementation of the lion control program, in combination with continued transplants out of Red Rock.

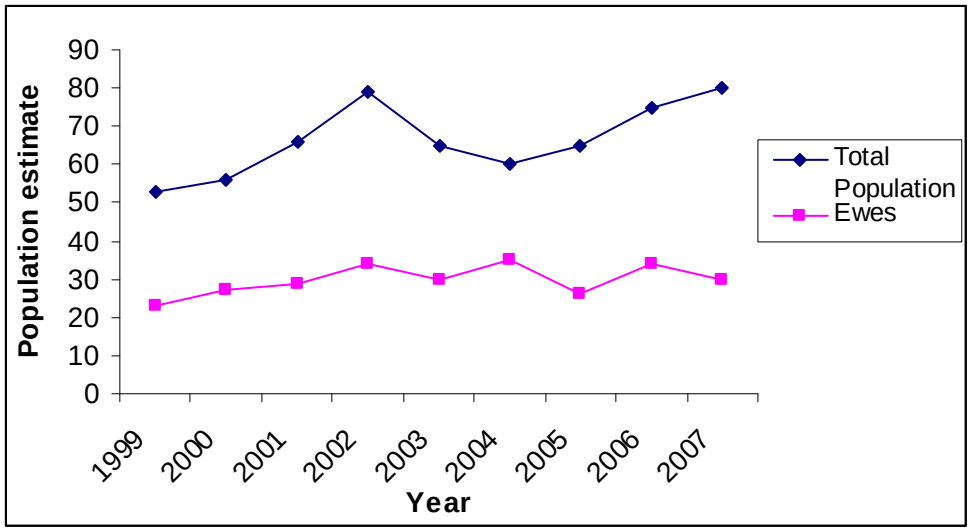

Figure 1. Total bighorn population and ewe population trends in the Fra Cristobal Mountains, New Mexico, 1995-2007.

Two population declines were observed in the Fra Cristobals. First, there was a decline from an estimated 79 in 2002 to 65 in 2003, which coincided with the first reliable sightings of bighorns in the adjacent Caballo Mountains. Immigration to this mountain range, located adjacent to and south of the Fra Cristobals, likely explains part of the decline as only 14 rams were observed in 2003 compared with 24 in 2002. However, only 7 of 19 lambs from the 2002 cohort were recruited to yearlings in 2003, and only 1 of the 7 was female. It is possible that some of the female lambs went to the Caballos as 2 ewes were observed there in 2006. While no adult radiocollared bighorns were killed by lions during this time, 4 lions were removed from the range. It is possible that the low recruitment rate was related in part to high lion density on the mountain.

Second, from May 2004 – May 2005, the population apparently decreased from approximately 70-75 to 60-65. No radiocollared bighorn were killed by lions, however 2 lions were removed from the mountain. In addition, bighorn hair was found in 3 fresh scats collected during this time period, indicating that lion predation had occurred. The majority of the decline was due to a reduction in ewes from 32 to 17, while there was no decline in the number of rams observed, and only a small decline in lambs (16 to 12). Two of 12 (17%) radiocollared ewes died from disease, while none of 6 radiocollared rams died. The disproportionately high mortality rate on ewes further impacts the herd as it reduces reproductive potential. It is hypothesized that the decline was due to a combination of disease and lion predation.

Numbers of Radiocollared Bighorn Killed by Lions

Between October 1995 and September 2007, a total of 63 radiocollared bighorn was present in the Fra Cristobals, and 27 (43%) were killed by lion predation. Eighteen of 44 (41%) radiocollared bighorn were killed by lion predation during the approximately 3 1/2 year period of minimum control, and 9 of 36 (25%) were killed by lions during the approximately 8 1/2 year period of some control. The sum of the number of collared

bighorn on the mountain during the two time periods is greater than the total number because some individuals were alive, and therefore counted, during both time periods.

From October 1999-September 2007, in the 3 herds without a disease outbreak (Peloncillo, Hatchets, Sierra Ladron) 30 of 40 (75%) radiocollared bighorn that died were killed by lions. In the San Andres, where disease outbreaks were documented, 17 of 46 (37%) radiocollared bighorn mortalities were from lion predation. In the Fra Cristobals, where one small disease outbreak was suspected, 12 of 18 (67%) radiocollared bighorn mortalities were from lion predation.

During the period of minimum protection, an average of 16.1% of radiocollared bighorn per year were killed by lions in the Fra Cristobals, compared with 15.5% in 4 other herds. During the period of some protection, an average of 8.8% of radiocollared bighorn per year were killed by lions in the Fra Cristobals, compared with 3.8% during the period of maximum protection in 4 other herds.

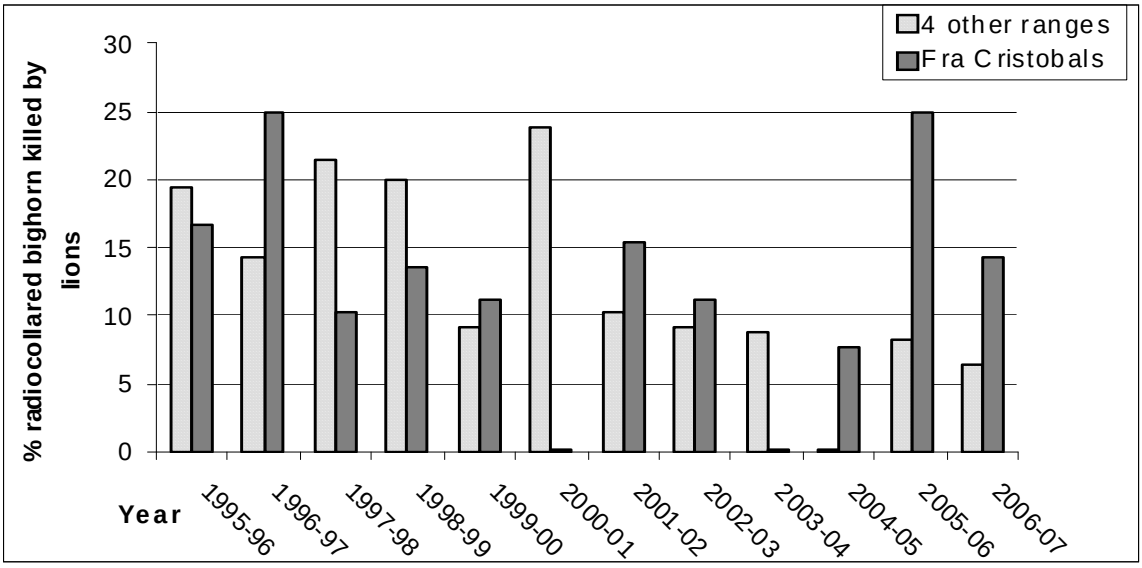

Figure 2. Percentage of radiocollared bighorn killed by lions in 4 mountain ranges (Peloncillos, Hatchets, Ladrones, and San Andres) and in the Fra Cristobals, New Mexico from October 1995-2007.

Lamb:Ewe Ratios

In 2001 and 2002, a total of 21 lambs were captured and radiocollared. Eleven of the lambs died: 5 from lion predation, 3 from golden eagle predation, 1 from disease, 1 from an accident, and 1 from an unknown predator (Parsons 2007). In an ongoing effort to monitor recruitment, spring and fall lamb:ewe ratios were derived from a combination of helicopter surveys and ground monitoring. Collection of accurate lamb:ewe ratio data is difficult, and multiple biological factors contribute to the numbers. We consider this the least well understood metric, however data from the Fra Cristobals are likely more accurate than in any other herd due to intensive monitoring, and easier observations due to topographical considerations.

Lamb:ewe ratios in the Fra Cristobals were higher than those observed in 4 other herds, however the growth rate remained slow (Table 4). In order for the Fra Cristobals population to increase, the female yearling:ewe ratio must be greater than the 0.17 average annual mortality rate for ewes. This was observed in only 2 of 8 years. The sample size of radiocollared rams was too small to calculate an average annual mortality rate, therefore the male yearling:ewe ratio needed for population growth is unknown.

Table 4. Bighorn lamb:ewe and yearling:ewe ratios in the Fra Cristobal Mountains, NM from 2000-2007; yearling females are included in ratio denominator for L:E, but not Y:E.

Year	L:E		Y:E		
	Spring	Fall	Y:E	Female	Male
2000	44	22	57	29	29
2001	80	48	23	12*	12
2002	66	56	56	36	20
2003	40	?	24	3*	21
2004	48	71	16	9*	6
2005	71	50	48	24	24
2006	62	?	48	17*	31
2007	38	?	33	17*	42

*Y:E ratio is equal to or below the average of 17 ewes necessary for a stable population

Conclusions

NMDGF documented high lion predation rates on state-listed endangered bighorn throughout New Mexico. Small populations of wild ungulates are more vulnerable to impacts of predation (Compton et al. 1995, Rominger and Weisenberger 2000, Wittmer et al. 2005), therefore lion removal to mitigate high predation was deemed necessary to reduce the risk of extinction of this faunal component in the desert mountain ranges of New Mexico.

All New Mexico bighorn populations, including the Fra Cristobals, are considered below carrying capacity and thus are not limited by habitat. The Fra Cristobals currently support the highest density of bighorn in New Mexico at 1.2 bighorn/km^2, based on a habitat evaluation by Dunn (1994), and the 2007 population estimate. This is lower than densities observed in other herds not only in the Chihuahuan desert, but also the Sonoran and Mojave deserts where lower rainfall supports lower maximum bighorn densities. It is estimated that the Fra Cristobals can support a population of 100-150 bighorn based on size of available bighorn habitat, compared with the current population estimate of 75-85 bighorn. Increasing the Fra Cristobal population is important to the statewide recovery effort as this population could be used as a source herd for transplants to other mountain ranges once the population exceeds 100 bighorn with a minimum of 50 ewes (NMDGF 2006).

Based on model results from both the PHVA and MARK, decreased mortality rates from lion predation in the periods of some protection in the Fra Cristobals and maximum protection in 4 other herds should decrease extinction risk in all herds. However, the lion

predation mortality rate in the Fra Cristobals was more than twice that observed in 4 other herds during these periods, and extinction risks remain high. All documented lion predation in the Fra Cristobals during the period of some control has been on ewes, which exacerbates the problem by resulting in lower natality. In 4 other herds, population numbers have increased only slightly following augmentations, demonstrating that even low rates of lion predation inhibits population growth. Low lamb recruitment also contributes to low growth rates. Causes of lamb mortality are not well understood, but based on data gathered in the Fra Cristobals, and continued lion presence in bighorn ranges in New Mexico, it is hypothesized that lion predation is a contributing factor.
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The policy of range-wide removal, until populations recover to levels where less aggressive control actions can be implemented without compromising the bighorn herd is the most efficacious method to protect bighorn. This strategy was found to be superior in reducing extinction risk compared to less aggressive strategies (Ernest et al. 2002), and is supported by findings in New Mexico (Rominger and Goldstein 2008). An offending lion removal only policy is not likely to effectively lower mortality rates on bighorn because it is difficult to capture lions at kill sites. This is reflected in the low success rate of capturing uncollared offending lions in the Fra Cristobals (20%) and 4 other herds (15%), despite intensive ground monitoring. The strategy of removing offending lions and a portion of the lions using bighorn range, as in the Fra Cristobals, was more effective than offending lion removal only. Mortality rates from lion predation in the Fra Cristobals were reduced by 50% from 0.18 to 0.09 when this strategy was employed. The policy of removing almost all lions that use the mountain resulted in a 76% reduction in the lion predation rate from 0.17 to 0.04. Therefore, the more aggressive lion removal policy should further decrease extinction risk, and help populations grow more quickly than the less aggressive policy.

With the completion of the Management Memorandum (NMDGF 2006), a tiered lion removal policy was implemented, with more aggressive removal when the ewe population is small, and less aggressive removal as the ewe population increases. The goal in the Fra Cristobals is to have a bighorn herd in excess of 100 animals, including 50 ewes, so that it may be used as a source herd for other populations. A statewide population of 500, with 3 populations or metapopulations ≥100, is required to delist this state-endangered species (NMDGF 2003). The Fra Cristobal-Caballo metapopulation is one of these metapopulations, and therefore critical to recovery of the species. Impacts of the lion control management action on the Fra Cristobals bighorn herd will continue to be evaluated and modified to minimize lion predation. It is hoped that the Fra Cristobal population increases, and the status of bighorn progresses from endangered species, to threatened species, to once again becoming a game animal in New Mexico.

Acknowledgements

We acknowledge K. Kunkel, M. Phillips, T. Turner, and T. Waddell, for their dedication to recovering desert bighorn sheep in the Fra Cristobal Mountains. We also thank the lion and bighorn sheep field biologists for their dedication in the field.

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