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Surgical Sterilization of Coyotes to Reduce Predation on Pronghorn Fawns

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SURGICAL STERILIZATION OF COYOTES TO REDUCE PREDATION ON
PRONGHORN FAWNS
by
Renee Seidler
A thesis submitted in partial fulfillment
of the requirements for the degree
of
MASTER OF SCIENCE
in
Wildlife Biology
Approved:

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UTAH STATE UNIVERSITY
Logan, Utah
2009
ABSTRACT

Surgical Sterilization of Coyotes to Reduce Predation on Pronghorn Fawns

by

Renee Seidler, Master of Science

Utah State University, 2009

Major Professor: Eric M. Gese
Department: Wildland Resources

Coyote (Canis latrans) predation accounts for the majority of neonatal pronghorn (Antilocapra americana) mortality in many areas and may influence local population declines. Current techniques used to manage coyote predation on wildlife species generally focus on lethal control methods. However, these methods may be controversial to the general public. Coyote sterilization is an alternative predation control method which is more acceptable to the public and has been shown to be effective in reducing sheep predation. We hypothesized that surgical sterilization of coyotes may increase pronghorn fawn survival; in the same way it reduces coyote predation on domestic sheep. Sterilization reduces the energetic need to provision coyote pups, which may decrease the predation rate on fawns by sterile coyotes. We employed tubal ligation and vasectomy of captured coyotes to maintain pair bonds and territoriality. We monitored pronghorn fawns by radio telemetry for one year pre-treatment and coyotes and pronghorn fawns one year post-treatment. We also examined the effects of sterilization on coyote territorial
maintenance and survival. Survival of fawns captured in sterile coyote home ranges was higher than survival of fawns captured in intact home ranges ($P = 0.078$). We also found that fawn survival was consistently higher in the northern part of the study site ($P = 0.081$). A severe winter followed by a wet spring in 2007 did not reduce fawn survival and may have increased fawn survival ($P = 0.364$); however, our sample sizes did not allow us to detect significance in this relationship. Our results also supported the hypothesis that sterilization, while keeping hormonal systems intact, did not change coyote territorial behaviors. Sterile coyote packs were the same size as intact packs ($P = 0.554$). Sterile and intact coyote packs maintained similar home range sizes in all seasons tested ($P \geq 0.556$). We found differences between home range and core area overlap of sterile and intact packs in some seasons, but this trend appeared to exist before the coyotes were treated. Residency rates were similar for sterile and intact coyotes ($P = 0.406$). We recommend coyote sterilization as a tool to boost pronghorn fawn survival in areas where fawn survival is a critical factor in pronghorn population persistence. Because these techniques have been tested under few circumstances, we recommend careful monitoring in future coyote sterilization programs.
ACKNOWLEDGMENTS

This project was funded by the U.S. Department of Agriculture, Wildlife Services, National Wildlife Research Center, Logan Field Station at Utah State University. Additional logistical support was provided by the U.S. Army, Directorate of Environmental Compliance and Management (DECAM), Fort Carson, Colorado. Permits to capture animals were granted by the Colorado Division of Wildlife. I thank my field crews Jana Martinez, Jennifer Miller, Melissa Oxley, Erika Miersma, David Green, Kelly Sivy, Matthew Hatfield, and David Mallett and volunteers Jennifer Burghardt, Mead Klavetter, Barry Smart, Mary Greenblatt, Suzanne Gifford, Lisa Cross, Chris Simms, and Stacey Hollis for all their hard work and enthusiasm. Mead Klavetter (DECAM), Barry Smart (DECAM), and John Kuzmiak (U.S. Geological Survey) provided additional valuable data. My advisor, Eric Gese, provided hours of support and guidance throughout the research process and was incredibly encouraging. I owe a very gracious thank-you to all the people who helped point me down the correct path in data analysis, including Eric Gese, Mary Conner, Jim MacMahon, Kim Berger, Julie Young, Lise Aubry, and Pat Terletzky. I am grateful to my colleagues at the University who provided feedback for my ideas. My sister, Rachael Seidler, and my father, Ray Seidler, provided precious professional and emotional support through my degree. My officemates Nathan Lance, Suzanne Gifford, Kari Signor, and Jennifer Burghardt helped me keep my wit when I struggled. Finally, I thank David Perrica for his love, support, and perpetual confidence in my intellect through this adventure.

I dedicate this degree to my mother, Katherine Seidler, who knew I could do this, even before I started. 

Renee Seidler
Chapter 2, The effects of coyote sterilization on pronghorn fawn survival, will be submitted to the Journal of Wildlife Management. Coauthors will be Eric Gese and Mary Conner. Chapter 3, The effects of tubal ligation and vasectomy on coyote home range maintenance, will also be submitted to the Journal of Wildlife Management. The sole coauthor will be Eric Gese.
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>iii</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>v</td>
</tr>
<tr>
<td>PREFACE</td>
<td>vi</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>viii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>ix</td>
</tr>
<tr>
<td>CHAPTER</td>
<td></td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2. THE EFFECTS OF COYOTE STERILIZATION ON PRONGHORN FAWN SURVIVAL</td>
<td>10</td>
</tr>
<tr>
<td>3. THE EFFECTS OF TUBAL LIGATION AND VASECTOMY ON COYOTE HOME RANGE MAINTENANCE</td>
<td>54</td>
</tr>
<tr>
<td>4. SUMMARY</td>
<td>86</td>
</tr>
</tbody>
</table>
**LIST OF TABLES**

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-1</td>
<td>Models used to evaluate the influence of coyote sterilization and other covariates on pronghorn fawn survival, Piñon Canyon Maneuver Site, Colorado, May 2006-March 2008.</td>
<td>45</td>
</tr>
<tr>
<td>2-2</td>
<td>Cause-specific mortality as a percentage of total mortality in each year, area, and treatment, Piñon Canyon Maneuver Site, Colorado, May 2006-March 2008.</td>
<td>46</td>
</tr>
<tr>
<td>3-1</td>
<td>Models used to evaluate variation in sterile (n = 15) and intact (n = 12) coyote residency on the Piñon Canyon Maneuver Site, Colorado, December 2006-March 2008.</td>
<td>78</td>
</tr>
<tr>
<td>3-2</td>
<td>Models used to evaluate variation in sterile and intact coyote (n = 30) survival on the Piñon Canyon Maneuver Site, Colorado, December 2006-March 2008.</td>
<td>79</td>
</tr>
<tr>
<td>3-3</td>
<td>Tukey’s Honestly Significant Difference comparison of home range and core area overlap between sterile and intact coyote home ranges on the Piñon Canyon Maneuver Site, Colorado, December 2006-March 2008.</td>
<td>80</td>
</tr>
<tr>
<td>3-4</td>
<td>Model selection results for sterile (n = 15) and intact (n = 12) coyote residency rates on the Piñon Canyon Maneuver Site, Colorado, December 2006-March 2008.</td>
<td>81</td>
</tr>
<tr>
<td>3-5</td>
<td>Model selection results for sterile and intact coyote (n = 30) survival on the Piñon Canyon Maneuver Site, Colorado, December 2006-March 2008.</td>
<td>82</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-1</td>
<td>Coyote home ranges and fawn capture locations on the Piñon Canyon Maneuver Site, Colorado, May 2006-March 2008. Cross-hatched polygons represent coyote home ranges where at least one coyote had been sterilized, however pups were detected in the pack.</td>
<td>48</td>
</tr>
<tr>
<td>2-2</td>
<td>Model averaged pronghorn fawn survival rates (± 95%CI) in semi-monthly intervals for 79-days, (A) before treatment in 2006, and (B) after treatment in 2007, Piñon Canyon Maneuver Site, Colorado. Note in (B) that 3 survival curves are present; upper curve represents 2 survival curves, south treatment, 2007, and north, 2007.</td>
<td>49</td>
</tr>
<tr>
<td>2-3</td>
<td>Model averaged estimates of cumulative summer fawn survival for the north and south study areas in 2006 and 2007, Piñon Canyon Maneuver Site, Colorado.</td>
<td>50</td>
</tr>
<tr>
<td>2-4</td>
<td>Snowfall amounts for the winter of 2005-2006 and 2006-2007, Trinidad, Colorado (data provided by the National Weather Service).</td>
<td>51</td>
</tr>
<tr>
<td>2-5</td>
<td>Monthly precipitation averaged across 12 stations (± 95%CI) on the Piñon Canyon Maneuver Site, Colorado (data provided by the U.S. Geological Service).</td>
<td>52</td>
</tr>
<tr>
<td>2-6</td>
<td>Photos taken from similar locations on the Piñon Canyon Maneuver Site, Colorado on (A) 15 July 2006 and (B) 26 June 2007.</td>
<td>53</td>
</tr>
<tr>
<td>3-1</td>
<td>95% and 50% fixed kernel estimates of coyote home ranges, (A) winter 2006-2007, (B) summer 2007, and (C) winter 2007-2008. Sterile home ranges are represented by cross-hatch, Piñon Canyon Maneuver Site, Colorado.</td>
<td>83</td>
</tr>
<tr>
<td>3-2</td>
<td>Coyote residency rates (± 95%CI) from the top model, R{treatment+season}, in 4-month coyote season increments for sterile and intact coyotes on the Piñon Canyon Maneuver Site, Colorado, December 2006-March 2008.</td>
<td>84</td>
</tr>
<tr>
<td>3-3</td>
<td>Coyote survival rates (± 95%CI) from the second-ranked model, S{treatment+season}, in 4-month coyote season increments for sterile and intact coyotes on the Piñon Canyon Maneuver Site, Colorado, December 2006-March 2008.</td>
<td>85</td>
</tr>
</tbody>
</table>
Pronghorn (*Antilocapra americana*) are a species endemic to North America and are the sole surviving member of the family Antilocapridae (Byers 1997a). Pronghorn evolved to escape the fastest predators of the Pleistocene period and remain the fastest land mammal in North America. In addition to swiftness, pronghorn evolved complex behavioral adaptations to avoid predation (Byers 1997a). Neonates not yet fast enough to escape predators, rely on the ability to hide from predators between nursing bouts. This hiding strategy, coupled with the doe’s behavior, may fool predators regarding the location or presence of fawns; however, high mortality of fawns due to predation still occurs (Byers 1997a, Gregg et al. 2001, Dunbar and Giordano 2003).

Coyotes (*Canis latrans*) are well-adapted for searching for hidden pronghorn fawns because they are designed for tireless trotting and exhibit cooperative social behavior during hunting (Byers 1997a). Typically, pups need to be provisioned in May and June, when pronghorn fawns are born. A pronghorn fawn represents approximately 1.5-2.25 days worth of the energy requirements for a coyote (Byers 1997a). When coyotes are provisioning pups, caloric demands increase and larger prey items can provide a greater source of energy than smaller alternative prey (i.e., rodents; Bekoff and Gese 2003). Fawns can be an order of 16-120 times larger in mass than a rodent (mass estimates are based on *Neotoma* and *Peromyscus* species) and 1.3 times larger than a black-tailed jackrabbit (*Lepus californicus*). According to Byers (1997a: 54), “the annual production of pronghorn fawns represents an energy bonanza available to coyotes during a short season when additional food is essential.”
Pronghorn fawn mortality generally ranges from 40-80% in North America (Byers 1997a) with Von Gunten (1978) reporting fawn mortality as high as 90% in Montana. In Alberta over a two-year period, 67% of fawn mortality was due to predation and 78% of this predation was due to coyotes (Barrett 1984). Average yearly fawn mortality on the National Bison Range in Montana was 87% and decreases in fawn mortality were correlated with the number of coyotes removed (Byers 1997a). On the Hart Mountain National Antelope Refuge, Oregon, 60-85% of pronghorn fawn mortalities were attributed to coyote predation (Dunbar and Giordano 2003). Coyotes were responsible for at least half of the predation events in Wind Cave National Park, South Dakota (Jacques et al. 2007). In southeastern Colorado on the Piñon Canyon Maneuver Site, coyote predation accounted for 79% of fawn mortality over 4 years (Gerlach and Vaughan 1990). After coyote control in 1987 and 1988, fawn mortality was significantly reduced (Gerlach and Vaughan 1990).

High coyote-caused fawn mortality has the potential to lower recruitment of fawns into the adult population, thereby contributing to local population declines. Predator management directed at boosting fawn survival can be difficult to implement. Non-lethal coyote control techniques, i.e., husbandry practices, fencing, frightening devices, guard animals, and repellents (Knowlton et al. 1999), often used to discourage livestock depredation, are generally costly in money, time, and effort (Gese et al. 2005). Coyotes often habituate to these deterrents and their tolerance may increase with limited alternative prey or the presence of pups. In addition, because game species are usually not confined to fenced pastures, implementing non-lethal techniques in wildlife management situations can be impractical due to animal movement and dispersion.
Lethal control of coyotes has been employed as a management tool to boost native ungulate populations where the coyote is the cause of low fawn survival and potentially low fawn recruitment (Kie et al. 1979, Neff et al. 1985, Smith et al. 1986, Byers 1997b). Although short-term benefits have been documented, lethal control may not be biologically or economically effective over the long term. For instance, control efforts on Anderson Mesa, Arizona, effectively reduced the coyote population over a 3-year period from 1981-1983 (Smith et al. 1986) and resulted in a concomitant increase in the pronghorn population size by >400%. This increase was the result of greater fawn survival and recruitment and evidence suggested that the higher survival was correlated with coyote control. In addition, the year after coyote removal ceased, fawn:doe ratios declined from 0.67 in 1983 to 0.47 in 1984 and 0.26 in 1985, which suggests that continued application of lethal coyote control would be necessary to maintain this pronghorn population at management level goals. However, yearly application of lethal control could be financially costly. Wagner and Conover (1999) estimated that aerial gunning of coyotes would cost $185/coyote and trapping and killing from the ground would cost $805/coyote.

Management agencies choosing to employ lethal coyote control to boost ungulate numbers also run into political and social resistance. The general public contends that lethal control of coyotes is an unacceptable strategy for predation management (Knowlton et al. 1999). In 1996 and 1998, the Predator Defense and the Oregon Natural Desert Association legally prevented Hart Mountain National Antelope Refuge from using lethal control of coyotes to boost pronghorn fawn survival (Belsky 1999). The U.S. Fish and Wildlife Service was attempting to solve the 29% decline in
pronghorn numbers coupled with a <1:100 fawn:doe ratio in July, 1995 (Dunbar et al. 1999). Similarly, Friends of Animals and Predator Defense halted lethal control of coyotes on the Julia Butler Hansen Refuge, Washington, in 1998 (U.S. Fish and Wildlife Service 1998). The goal on this refuge was to boost Columbian white-tailed deer (*Odocoileus virginianus leucurus*) fawn survival, which is a federally-listed endangered species. In 2002, after being denied the ability to remove coyotes, fawn survival was considered too low to contribute to overall increases in the population (Ricca et al. 2002).

As an alternative to lethal control of coyotes, Bromley and Gese (2001a) focused on biological mechanisms to alter predatory behaviors of coyotes. They followed the vein of Till and Knowlton (1983) who explored the possibility of reducing domestic sheep depredations by removing coyote pups from the dens of sheep-killing coyotes. In the week following treatment (pup removal), they found the total number of predation incidents decreased by >87% when pups were removed from dens of sheep-killing adult pairs. No changes in predation incidents were seen in the control group where sheep-killing coyotes did not have their pups removed from the den. Although data were collected for only a short period following treatment, the results suggest that adult coyotes killed fewer sheep when they did not have pups to feed.

Consequently, Bromley and Gese (2001a) sterilized coyotes to prevent reproduction. They hypothesized that without pups, the energetic demands of the alpha pair would decrease and, hence, so would depredations on domestic sheep. They used tubal ligation and vasectomy to sterilize coyotes, leaving hormonal systems intact. Over the 3-year study, non-sterile coyote packs with pups killed 6 times more sheep than sterile packs without pups. In addition, the surgically sterilized coyotes had higher
survival rates, remained pair-bonded and territorial, and sterile dyads had a significantly higher association score than sham-operated dyads in the second year (Bromley and Gese 2001b). Given sterile coyotes retained their territorial behavior, it is likely they will exclude non-sterile, reproductive coyotes through territory defense. In a comparison of costs versus benefits, this study suggested that surgical sterilization of coyotes is a cost effective means of reducing domestic lamb loss due to coyote depredation, even after one year of application (Bromley and Gese 2001a, b).

We hypothesized this same sterilization technique could increase pronghorn fawn survival where coyote predation is a significant contributor to fawn mortality. Because surveys have shown fertility control is more acceptable among the general public than traditional lethal techniques (Arthur 1981, Kellert 1985, Andelt 1987, Messmer et al. 2001), we believed this to be an important non-lethal alternative to explore. We conducted our study on the Piñon Canyon Maneuver Site in southeastern Colorado, where coyote predation on fawns was historically high in the absence of coyote control (Firchow 1986, Gerlach and Vaughan 1990). Our questions were twofold: 1) Do tubal ligation and vasectomy of coyotes increase pronghorn fawn survival? and 2) Do surgically sterilized coyotes exhibit normal social behaviors and biology; specifically, do sterilized pairs associate the same as intact pairs and do sterilized coyotes remain members of a pack at the same rate as intact coyotes? If evidence confirms increases in fawn survival and no change in coyote behaviors when coyotes are sterilized, then surgical sterilization could be an effective option for wildlife managers. Sterilization offers the advantages of biological and economical effectiveness as well as public acceptance.


CHAPTER 2

THE EFFECTS OF COYOTE STERILIZATION ON PRONGHORN FAWN SURVIVAL

Abstract. Sterilization of coyotes (Canis latrans) has been shown to reduce predation of domestic sheep. We investigated whether sterilizing coyotes would similarly reduce predation on pronghorn (Antilocapra americana) neonates in southeastern Colorado. In a study from May 2006 to March 2008, we radio-collared 71 pronghorn fawns to determine survival rates and causes of death. During the first year of the study, all coyotes were intact. During the second year, we captured and sterilized coyotes in the southern half of the study area, while coyotes in the northern half were given sham sterilizations. In addition, we surveyed the availability of alternative prey and examined the influence of snowfall and precipitation on fawn survival and small mammal detection. Using the known fate model in Program Mark, we constructed models that included a treatment effect, plus year, area, alternative prey, and individual covariates to estimate fawn survival. Fawn survival was higher for fawns captured in sterile coyote home ranges than for fawns captured in intact coyote home ranges (P = 0.078). Subtle differences in locale affected fawn survival; fawn survival was higher in the north than in the south in both years (P = 0.081). Lagomorph abundance was not influential on fawn survival (P = 0.293) nor was rodent abundance (P = 0.264), but increased vegetation may have impaired prey detection probabilities. We did not detect any relationship between fawn survival and fawn gender, fawn birth weight, fawn birth date, fawn age, or coyote density.

1 Co-authored by Eric Gese and Mary Conner.
Although in the second year of the study we experienced record winter conditions, this did not reduce fawn survival and may have contributed to increased fawn survival \((P = 0.364)\). Our results indicate that sterilization of coyotes may be a useful tool for wildlife managers to reduce coyote predation on pronghorn fawns.

**INTRODUCTION**

Coyotes \((Canis latrans)\) are considered an abundant and expanding native species in much of North America (Garrott et al. 1993, Goodrich and Buskirk 1995). Their population expansion has been enhanced by altered landscapes and the loss of top carnivores (Gompper 2002, Berger and Gese 2007). Coyotes can have considerable effects on prey populations and in particular, the effects of coyote predation on ungulate neonate survival can be significant (Linnell et al. 1995). Where ungulate populations are declining or critically low, limited fawn recruitment can affect the persistence of local populations (Bright and Hervert 2005, Berger et al. 2008). Under these circumstances, coyote management may be required to sustain ungulate populations. For instance, in Grand Teton National Park, Wyoming, a tenuous balance exists between a declining pronghorn \((Antilocapra americana)\) population and development along their migration corridor (Berger 2003). Mitigation in the form of immediate coyote control may help to preserve this population while conservation efforts address long-term stability. However, traditional control methods cannot be used in a national park. As another example, Sonoran pronghorn \((A. a. sonoriensis)\) in Arizona face an estimated 23% probability of extinction in <100 years (Bright and Hervert 2005). In 2002, only 21 animals were
estimated to occur. Coyote control in areas of fawn birthing could increase chances of fawn recruitment into the population (Smith et al. 1986, Bright and Hervert 2005).

Predation of North American ungulate neonates can be the primary cause of mortality in many ungulate populations, on average accounting for 67% of total mortality (Linnell et al. 1995). Coyotes are especially adapted for pronghorn fawn predation (Byers 1997). Studies have shown coyote-caused mortality of pronghorn neonates to exceed 75% of total mortality (Gerlach and Vaughan 1990, Dunbar and Giordano 2003). The latter population had fawn:doe ratios in mid-July of <1:100 (Dunbar and Giordano 2003). Losses such as these may not sustain declining pronghorn populations, despite efforts in habitat preservation or ecosystem restoration (Goodrich and Buskirk 1995).

Management of coyote predation is complex and generally involves employment of several techniques (Knowlton et al. 1999). In the wild where protection of game species or species of concern is the goal, management becomes a greater challenge due to unrestricted animal movements, extent of the landscape, cost of the effort, and lack of public support. Management techniques that gain more public acceptance (such as animal husbandry, guard animals, repellents, or aversive conditioning; Mitchell et al. 2004) are impractical and often impossible in these settings. Lethal control of coyotes is frequently the only method available for managers to cope with predation. However, lethal control is a source of controversy to the public (Arthur 1981, Kellert 1985, Andelt 1987, Messmer et al. 2001) and in some cases may not be biologically effective (Ballard et al. 2001).

Till and Knowlton (1983) showed removing coyote pups from a den reduced predation on domestic sheep over a short-time interval. They hypothesized that the lack of pups reduced the energetic needs of the pack, thus reducing predation on larger food
Corroborating evidence from Sacks et al. (1999) showed the offending coyotes responsible for sheep predation were breeding, territorial animals and recommended control efforts be focused on these individuals. After Zemlicka (1995) demonstrated sterilization of captive coyotes did not affect social or territorial behaviors, Bromley and Gese (2001a) introduced coyote sterilization as an alternative method to coyote removal for protection of domestic sheep. They found surgical sterilization of coyotes reduced predation on domestic lambs by up to eightfold. In addition, Conner et al. (2008) simulated several management scenarios for lethal and non-lethal control of coyote-livestock predation. They determined that coyote sterilization was the most effective strategy to reduce coyote numbers and so may be the most practical method to reduce predation.

Surgical sterilization is less objectionable to the public and has the potential to be more successful biologically because it can persist for several years. Lethal control has to be applied annually. The surgical technique used in previous studies kept the endocrine systems intact (ovaries and testes remained in the animals) and preserved social behaviors. Sterilized wild coyote pairs continued to defend their territory against neighboring coyotes (Bromley and Gese 2001b). In addition, they showed this management technique to be economically feasible (Bromley and Gese 2001a).

If predation can be reduced on domestic lambs with this technique, then it may have the potential to work in a wildlife application as well. We tested the hypothesis that surgical sterilization of coyotes would reduce predation on pronghorn fawns in southeastern Colorado. We evaluated baseline pronghorn fawn survival and cause-specific mortality during the first year, and then sterilized coyotes during the second year.
on approximately half the study site. Subsequently, we compared fawn survival and cause-specific mortality in the treatment area and the control area where coyotes were given sham surgeries. Survival estimates of fawns were also compared between the first (pre-treatment) and second (post-treatment) years. We examined levels of alternative prey availability and relative coyote density in addition to other individual fawn covariates in the survival analysis.

**METHODS**

*Study site*

We conducted this research on the 1,040-km$^2$ Piñon Canyon Maneuver Site (PCMS) in Las Animas County, Colorado. The study area encompassed the home-range boundaries of radio-collared coyotes and the locations of radio-collared fawns involved in the study (approximately 350 km$^2$). Average elevation on the PCMS was 1520 m, average temperatures ranged from 1ºC in January to 24ºC in July (Shaw and Diersing 1990), and mean annual precipitation was 305 mm at the nearest long-term weather station in Delhi, Colorado (Milchunas et al. 1999). Harvest of coyotes was not permitted for the duration of the study.

Nearly 60% of the PCMS was identified as shortgrass prairie dominated by blue grama (*Bouteloua gracilis*), galleta (*Hilaria jamesii*), and western wheatgrass (*Agropyron smithii*) (Shaw et al. 1989). Many shrub communities occurred within the grassland communities along alluvial fans, waterways, and slopes. These included black greasewood (*Sarcobatus vermiculatus*), fourwing saltbush (*Atriplex canescens*), Bigelow sagebrush (*Artemisia bigelovii*), winterfat (*Krascheninnikovia lanata*), small soapweed
(Yucca glauca), and tree cholla (Opuntia imbricata). Woodland communities were composed primarily of one-seeded juniper (Juniperus monsperma) and pinyon pine (Pinus edulis) mixed with grassland or shrubland species. Woodlands dominated the canyons and breaks. Areas that had been burned were defined as natural or prescribed fires occurring either during or after 2004.

**Capture and monitoring of fawns**

We observed solitary pronghorn does during the fawning season with spotting scopes in order to locate hidden fawns (Autenrieth and Fichter 1975). Newborn fawns were permitted to bond with their mother for >4 hours before capture. We captured fawns by hand or with a long-handled salmon net, then blindfolded and handled them with latex gloves. We outfitted fawns with ≤75 g expandable radio-collars with a 6-hour mortality mode and precise event transmitter (Advanced Telemetry Systems, Isanti, Minnesota). The transmitter was programmed to convey the amount of time elapsed post-mortality mode. We measured fawn mass with a spring scale and sling, and noted the presence and state of the umbilicus (Byers and Moodie 1990), sex, and health of fawns. Research protocols were approved by the Institutional Animal Care and Use Committees at the USDA/National Wildlife Research Center (QA-1350) and Utah State University (IACUC #1269).

We monitored fawns daily from the ground with telemetry through July, weekly through August, and monthly through March of the following year. We located mortalities immediately and the body, if present, and surrounding area was carefully examined. We classified predation events as coyote, eagle, or unknown, based upon
tracks, scat, hair, hemorrhage patterns, and caching characteristics (O’Gara 1978, Wade and Bowns 1984, Acorn and Dorrance 1998). We collected DNA evidence from fatal puncture wounds on carcasses that had evidence of hemorrhaging (Blejwas et al. 2006). When doubt remained about the species of predator responsible for the mortality, we attempted to identify the species through genotyping (Wildlife Genetics International, Nelson, BC, Canada). Unless otherwise noted, all statistics were calculated in SPSS 10.0.5 (SPSS Inc., Chicago, IL).

Capture and monitoring of coyotes

Coyotes were sterilized in December 2006 in half the study site in a Before-After, Control-Impact (BACI) study design (Stewart-Oaten et al. 1986, Gotelli and Ellison 2004). We attempted to capture all coyotes present in the study area with a net-gun fired from a helicopter (Barrett et al. 1982, Gese et al. 1987). We sterilized animals captured in the southern portion of the study area, while animals captured in the northern portion of the study area were sham-operated. We transported captured animals by vehicle or helicopter to a central processing location. A veterinarian sterilized females by tubal ligation and males by vasectomy. All animals otherwise received the same treatment: they were given a combination of a sedative and dissociative, incised and sutured, radio-collared, allowed to recover, and released at the capture site within 24 hours.

To determine with greater certainty that treated coyote packs were indeed sterile, we conducted howling surveys and searched for dens and pups of radio-collared individuals. Howling surveys were conducted regularly from 4 June 2007 to 13 August 2007, with 1-2 teams going to high points, howling, and recording whether the response
included pups or not. Concurrently, all radio-collared individuals from the pack were
detected with telemetry. Packs with pups were considered intact.

Visual observations of radio-collared individuals allowed us to gain information
on pup presence as well as minimum group sizes. We conducted these surveys 8 June
2007 to 5 December 2007. One to two people would home in on a radio-collared coyote
on foot. We attempted to approach animals from downwind in a stealthy manner to
reduce disturbance of potential additional pack members that may have been present. We
noted coyote group size, location, and the presence of pups. We estimated pre-whelping
coyote density by dividing the minimum pack size observed by the pack’s home-range
size (Gese 2001).

Home range analysis

We monitored coyotes with telemetry from December 2006 to March 2008,
primarily at dawn and dusk to obtain locations during the highest activity periods (Andelt
and Gipson 1979). Telemetry was performed using a hand-held antenna and receiving
unit from a vehicle. Locations were attempted every two days. We calculated locations
using ≥3 bearings in Program LOCATE (Pacer, Ltd., Truro, N.S.). To reduce estimation
errors when assigning fawn capture locations to specific coyote home ranges, we only
used locations with 95% error areas ≤0.10 km² and we did not include extra-territorial
forays as part of the home range. The mean telemetry error was 328 ± 97.133 (95%CI) m
based on 14 blind tests on randomly placed radio-collars. The average 95% error area
estimated for reference collars was 26,419 m². We used data locations gathered from
April 2007 to September 2007 to define seasonal pack home ranges used in assigning
pronghorn fawns to sterile or intact coyote packs. We chose this time period to include the coyote pup-rearing season when energetic needs for the pack were highest and pronghorn fawns were vulnerable to predation.

We used observation-area curves (Odum and Kuenzler 1955) to determine whether we had enough locations to adequately estimate seasonal home ranges for radio-collared coyotes. The curves reached an asymptote at an average of 22 locations (for curves which reached an asymptote). Since some curves (7/17) had not reached an asymptote with all locations gathered that season, some home range boundaries may have been underestimated.

We plotted home ranges of coyote packs with the ArcMap (ArcGIS 9.2-Environmental Systems Research Institute, Inc., Redlands, CA) extension, Hawth’s Tools 3.27. We used the fixed kernel density estimator (Worton 1989) with point locations to describe resident pack home ranges because it is less biased to small sample sizes and outliers (Millspaugh and Marzluff 2001). We used a 95% contour to describe a pack’s home range (Shivik and Gese 2000). To determine bandwidths, we adapted an ad hoc method which prevents undersmoothing, is relatively unaffected by sample size, and reduces Type I errors (J. G. Kie, unpublished data). Initially, we plotted home ranges using $h = 1000$ and then incrementally reduced the bandwidth by 10% until we had the smallest bandwidth that did not create disjoint polygons and did not contain lacuna. Additionally, because we wanted home ranges to not only be contiguous but also reflect ground-truthed observations, we up-smoothed the bandwidth if long, narrow channels persisted in the home range that were not justified by topographic or anthropogenic features. We also up-smoothed the bandwidth if an unjustified gap was amid two
contiguous home ranges. In this case, we used the same methods as before, but increased each home range bandwidth involved in the gap by 10% until the gap was closed with minimal overlap.

We calculated the amount of each habitat type present in each coyote pack home range to compute indices for alternative prey available to each coyote pack. Vegetation layers were provided by the Directorate of Environmental Compliance and Management (DECAM), Fort Carson, Colorado, as geospatial data. These layers were merged into four habitat types: grassland, shrubland, woodland, or burn. Coyote pack home ranges were clipped over the habitat layers in ArcGIS to estimate the amount of each habitat type present within each pack’s home range.

*Estimation of available alternative prey*

We conducted surveys to determine the relative abundance of rodents and lagomorphs available within each coyote pack home range. We used small mammal trapping grids and spotlight surveys in June and July of both years. We used 7.6 x 7.6 x 25.4 cm Sherman live traps baited with chicken-scratch-grain mix and peanut butter to catch small mammals. Traps were set in a 5 x 7 grid design with 10 m spacing across all four different habitat types in a nested design of three replicates per habitat in the north half and south half of the study area. Traps were run for three consecutive nights. We checked the traps each morning and captured animals were marked, recorded, and released. To calculate the rodent index, all catchable species were grouped by genus and the median mass for each species (Fitzgerald et al. 1994) was then averaged across all species captured in that genus. The average mass was then multiplied by the total number
of unique individuals of that genus captured on each grid. A rodent index value was assigned to each habitat type as rodent kg/km$^2$. We then extrapolated the rodent index to each coyote home range based upon the amount of each habitat type in the home range (Bromley and Gese 2001a).

Lagomorph spotlight surveys (Smith and Nydegger 1985) were conducted in replicates of three per habitat type over three consecutive nights. Cottontail ($Sylvilagus$ $audubonii$) and black-tailed jackrabbit ($Lepus$ $californicus$) numbers were counted per kilometer for each habitat type and replicates were averaged together. The mean number of lagomorphs/km was multiplied by the average mass of the species and used to assign a lagomorph index value to each habitat type. These index values were then extrapolated into each coyote home range.

_Fawn survival analysis_

We estimated semi-monthly fawn survival rates over five time intervals (14 May to 31 July) using known fate models in Program MARK (White and Burnham 1999). This program estimates model parameters using the numerical maximum likelihood techniques of Akaike’s Information Criterium (AIC, Akaike 1973). We compared differences between models using the change in AIC corrected for small sample size bias ($\Delta$AICc, Burnham and Anderson 2002). We used the logistic (logit-link) function when running our models in order to express the probability of survival as a linear function of the explanatory variables.

Due to small sample sizes, _a priori_ models were carefully designed to avoid detection of spurious correlations (Burnham and Anderson 2002). Survival rates for
unequal time intervals (18, 15, 15, 15, 16 days, sequentially) were standardized to semi-monthly rates for comparison (White and Burnham 1999) and encounter histories were censored for the year the fawn was not monitored (i.e., fawns captured in 2006 had encounter history formats of LDLDLDLDLD0000000000 and fawns captured in 2007 had encounter history formats of 0000000000LDLDLDLDLD). We then grouped the data by area (north or south). Our models included eight covariates: fawn sex, birth weight (kg), estimated age at capture (days), birth date, treatment (intact or sterile), relative coyote density, lagomorph relative abundance index, and rodent relative abundance index. We assigned values for the last four covariates based upon the coyote home range in which the fawn was captured. If a fawn was captured outside of any known coyote home range, then it was assigned an average coyote, rodent, and lagomorph index value.

Because the primary goal of our study was to evaluate the effect of coyote sterilization on pronghorn fawn survival, we included the sterilization treatment effect in every model. This allowed us to determine a parameter estimate for treatment using model averaging (White et al. 1999). The sterilization treatment effect was modeled by the covariate called treatment which separated fawns captured in the south into sterile and intact treatments. To minimize the number of models, we constructed models of fawn survival in a 3-phase process. First we constructed models with just temporal effects. Survival of fawns over a 79-day period should show variance between semi-monthly intervals as the fawns’ vulnerability to predation changes (Barrett 1978, Von Gunten 1978). To model hypothesized temporal differences in survival, we ran the following 4 models: a linear time trend model based on the hypothesis that fawn survival increases
after birth, a non-linear time trend model (i.e., a threshold model using the natural logarithm) based on the hypothesis that fawn survival increases to a maximum value then plateaus, a model which held the first three and the last two time intervals equal based on the hypothesis that survival increases in stages as fawns age, and a model which allowed the first 3 time intervals to vary but held the last two intervals constant based on the hypothesis that survival is variable when fawns are the youngest and most vulnerable to predation (Table 2-1, models 3 - 6).

Once we had established the appropriate temporal component of the models, we combined the best time model of fawn survival with area and year effects (Table 2-1, models 7-9). The area effect was considered different from treatment because, although we attempted to capture and sterilize coyote packs throughout the entire southern portion of the study site, some fawns in the south were not captured within a radio-collared coyote home range and so could not be assigned to the treatment regime.

For the last phase of model building, we added all other covariates to the best model from phase 1 and 2. We included the fawn covariates sex, birth weight, age, and birth date to address important variation known to occur in other fawn survival studies (Fairbanks 1993, Byers 1997, Gregg et al. 2001; Table 2-1, models 10-13). Estimated age at capture was calculated using a constant for growth rate derived from Byers (1997). We used the formula:

\[
\text{estimated age at capture} = \frac{(\text{weight at capture} - \text{mean of known birth weights})}{0.2446}.
\]

Known birth weights were taken from fawns known to have been born the day of capture. We knew <1-day old fawns because either we witnessed their birth or they had a wet
umbilicus (Byers and Moodie 1990). Birth weight was then estimated using the fawn’s estimated age. Lastly, because fawn survival could be related to predator-prey factors, we also added coyote density, lagomorph abundance index, and rodent abundance index (Table 1, models 14-16) covariates to the best model from phase 1 and 2. Due to a significant difference between alternative prey index estimates in the two years, we always included year in models with an alternative prey covariate. Using real and derived model averaged estimates, we performed a z-test for differences in survival rates to compare significance between areas and years. A Wald’s test (Agresti 1990) was used to determine significance of covariates.

Weather

Weather patterns may influence fawn production and survival. Maternal condition has been shown to be an important correlate with fawn survival in many ungulate species and severe winters may reduce maternal condition (Verme 1977, Guinness et al. 1978, Andersen and Linnell 1998). Due to record snowfall events in the second winter of our study, we compared weather parameters between the two years. Estimates of precipitation in the north and south were compared within each year to investigate potential influences on fawn survival. We used data from the U.S. Geological Survey weather stations on the PCMS to compare 2006 and 2007 spring precipitation; monthly totals from 12 meteorological stations were averaged. The nearest recorded snowfall data to the PCMS were from the National Weather Service in Trinidad, Colorado (50 km southwest of the PCMS). These data were used to compare monthly snowfall amounts between the two winters.
RESULTS

Coyote home ranges and densities

We captured 30 coyotes and outfitted them with transmitters. Nine coyotes from 7 resident (areas <35 km$^2$) home ranges in the north were captured and sham sterilized (Figure 2-1). We captured and sterilized 15 coyotes from 10 resident home ranges in the south; 2 of the sterile packs were later assigned to the intact treatment regime due to suspected presence of pups (Figure 2-1). In one of these packs, 2 males were captured and sterilized, but pups were later heard during June howling surveys. In another pack, a single female had been captured and upon sterilization she was found to be senescent. Her age was approximated to be 7+ years both by tooth wear and because she had a friable uterus. Although she remained a resident in her home range for the duration of the study, the potential for another reproductive female in her pack prompted us to treat the home range as intact. While most of our pup-presence efforts were focused on the sterilized coyote packs, we occasionally surveyed the sham packs for pups as well in order to validate our methods. Coyote pups were confirmed in 3 of the 7 intact sham-operated packs.

Four radio-collared coyotes (two intact and two sterile) were transient (their home range encompassed multiple resident home ranges) and one sterile and two intact resident coyotes began dispersals in the summer of 2007. One intact coyote could not be accurately tracked due to her home range being off the study area. Four radio-collared coyotes died during the study. Three mortalities were due to gunshot and one was due to unknown causes during dispersal.
We used 485 locations ($\bar{x} = 28.53 \pm 5.00$ (95%CI) per home range) to define seasonal pack home ranges. The total area considered sterile was 125.1 km$^2$. Mean home range area of all radio-collared coyotes was $16.13 \pm 3.38$ (95%CI) km$^2$ and the mean minimum pack size was $2.19 \pm 0.20$ (95%CI) coyotes. Coyote densities were not different in the north ($0.15 \pm 0.05$ (95%CI) coyotes/km$^2$) and south ($0.18 \pm 0.04$ coyotes/km$^2$), $t_{14} = -0.816$, $P = 0.428$) areas of the study site.

*Alternative prey indices*

Alternative prey indices decreased in the second year. Lagomorph relative abundance index was $22.70 \pm 4.69$ (95%CI) kg/km in 2006 compared to $4.96 \pm 1.56$ kg/km in 2007 ($t_{20} = 7.034$, $P \leq 0.001$). Rodent relative abundance index was $1235.18 \pm 228.12$ kg/km$^2$ in 2006 and $282.22 \pm 70.82$ kg/km$^2$ in 2007 ($t_{20} = 7.819$, $P \leq 0.001$). We detected no difference in overall availability of alternative prey between the north and south (lagomorph index, $t_{32} = -0.349$, $P = 0.730$; rodent index, $t_{32} = 0.038$, $P = 0.970$).

*Fawn survival*

We captured and radio-collared 31 fawns in 2006 and 40 fawns in 2007 (Figure 2-1). Coyote predation was the primary cause of death in both years. In 2006, 26 fawns died or lost their collars by July. In the north, most deaths were due to coyote predation, followed by unknown predation, then eagle predation (Table 2-2). In the south, most deaths were also due to coyote predation, followed by unknown predation, then unknown causes. DNA analysis attributed the cause of death to coyote predation in one out of two questionable mortalities.
In 2007, 25 fawns died or lost their collars by July. In the north, most deaths were due to coyote predation, followed by unknown causes (Table 2-2). In the intact area in the south, most deaths were due to coyote predation and a few to unknown causes. In the sterile area, most deaths were due to coyote predation, followed by unknown causes. DNA analysis attributed cause of death to coyote predation in four out of five questionable mortalities. We failed to detect a difference in the frequency of fawns killed by coyotes when analyzed by year ($\chi^2 = 0.579, P = 0.447$, Pearson’s chi-square), area ($\chi^2 = 0.002, P = 0.963$), or treatment ($\chi^2 = 0.019, P = 0.889$).

The best model of fawn survival, $S_{(t4=t5)+area+treatment}$, was only slightly better than many other models tested (Table 2-3, model 7). Based upon a criterion of $\Delta$AICc < 2 (Burnham and Anderson 2002), five models were competitive (Table 2-3, models 7, 9, 10, 11, and 13). Not counting treatment, which was in every model, all competing models included area and semi-monthly time interval (modeled as varying in the first three intervals but constant in the last two; Table 2-3).

Based on model averaged values (White et al. 1999), the probability of a fawn surviving the duration of the study in the north (0.183, 95%CI = 0.071-0.396) was higher than the probability of a fawn surviving the duration of the study in the south (0.034, 95%CI = 0.008-0.139, $z = 1.744$, 2-sided $z$-test, $P = 0.080$). This pattern was consistent between the years (Figure 2-2A, B). Model averaged parameter estimates for year showed fawn survival in 2006 to be the same as fawn survival in 2007 ($\beta = 0.110 \pm 0.635$, 1-sided Wald test, $P = 0.364$).

Model averaged fawn survival was higher for fawns captured in treated (sterile) coyote home ranges when compared to fawns captured in untreated (intact) coyote home
ranges in the south ($\beta = 0.904 \pm 1.247$, 1-sided Wald test, $P = 0.078$). To more thoroughly evaluate the effect of treatment using model averaged values, we ran our set of models with user-specified treatment values of zero and one (Figure 2-2A, B). Overall, survival was higher in the north control area than in the south control area. In spite of this difference, increased survival on the treatment area was evident; that is, survival on the south treatment area increased substantially more than on the south control area in 2007 (Figure 2-2B). None of the other covariates tested were statistically significant ($P > 0.110$, 1-sided Wald test).

We also calculated model averaged cumulative summer survival rates of fawns in each area for 2006 and 2007 by treatment (Figure 2-3). After declining over the first 2 time intervals, the probability of fawn survival stabilized in the third week of June. In 2006 at the end of the 79-day period, cumulative summer survival rates of fawns were 0.16 in the south and 0.39 in the north. In 2007, cumulative summer survival rates of fawns were 0.18 for southern control fawns, 0.43 for northern control fawns, and 0.44 for southern treatment fawns.

**Weather**

During severe winter weather, pronghorn malnutrition and fetal resorption can increase (Martinka 1967, Barrett 1982) which may lead to low fawn survival for neonates born to does that survive to parturition the following spring. Because weather patterns were remarkably different in the two years of this study, the covariate year, which showed an insignificant yet increasing fawn survival trend between the years, could be viewed as a proxy for weather in our fawn survival analysis. In the winter of 2005-06, the
highest recorded monthly snowfall in Trinidad was 35.56 cm in January with a total snowfall of 78.74 cm over the winter (Figure 2-4). In the winter of 2006-07, snowfall in Trinidad peaked in December with 125.73 cm and total winter snowfall was 205.99 cm. This was the highest snowfall amount recorded in December and the second highest total winter snowfall on record since 1947 (Western Regional Climate Center, Reno, NV). In the spring of 2006, 21.59 cm of snow fell in March. In spring 2007, the latest snowfall recorded was 20.32 cm in April.

Precipitation in the spring and summer months on the PCMS also showed variation between the two years (Figure 2-5). In 2006, heavy rain did not fall until July, well after the peak of fawning season. From our survival estimates, this was also beyond the period of fawns’ vulnerability to mortality. In 2007, heavier rain patterns occurred in April, May, and June contributing to a subsequent increase in vegetative cover across the study area (R. Seidler, personal observation; Figure 2-6). However, we found no difference in mean precipitation amounts between the north (1.21 ± 0.10 (95%CI) cm) and south (1.16 ± 0.16 cm) in 2006 ($t_{10} = 0.462$, $P = 0.654$) nor in 2007 (north = 0.99 ± 0.11 cm, south = 1.13 ± 0.15 cm, $t_{10} = 1.573$, $P = 0.147$).

**DISCUSSION**

*Was sterilization of coyotes correlated with increased fawn survival?*

Coyote predation on domestic sheep was reduced up to 8-fold when coyotes were experimentally sterilized (Bromley and Gese 2001a). Given the success of Bromley and Gese’s study (2001a), we hypothesized that sterilized coyotes would prey less on pronghorn fawns than intact coyotes. Thus, we designed an experiment to evaluate
whether pronghorn fawn survival could be increased via experimental sterilization of coyotes. The applicability of such a tool could alleviate pressures on pronghorn populations that are at critical thresholds while reducing public concerns about lethal management of coyotes. In the face of the many factors that influence fawn survival, we found a significant treatment effect. Over the course of a summer, cumulative fawn survival was 2.4 times higher for fawns captured in treatment areas compared to fawns captured in control areas.

There are undoubtedly many factors influencing fawn survival on the PCMS. We investigated the variables we believed would be most influential on coyote predation rates. Since the predator-prey relationship between coyotes and pronghorn is potentially quite different than between coyotes and domestic sheep, it was important to quantify the influence of intrinsic and extrinsic factors such as fawn sex, birth weight, birth date, age at capture, coyote density, alternative prey abundance, and weather. We found local area and coyote sterilization (treatment) to be the most influential covariates on fawn survival rates. We found no significant correlations between the other covariates and fawn survival rates.

Pronghorn have been present in North America since the Pleistocene and have likely been sympatric with coyotes since the evolution of *Canis latrans* (Kurtén and Anderson 1980). Because coyote predation on pronghorn reflects an evolved relationship unlike the predatory relationship with domestic sheep, we had concern that sterilization of coyotes may not change ungulate neonate predation. Coyotes also may have different hunting strategies dependent upon the behavioral response of the prey which could influence management efforts. Sheep have been bred to be docile and may even flee in
the presence of coyotes, stimulating an attack response from the predator (Connolly et al. 1976, Lehner 1976). In contrast, pronghorn neonates remain bedded and motionless in the threat of coyote predation (Byers and Byers 1983). Does with fawns are observant of nearby coyotes until the coyote comes too close to their fawn’s bed site, at which point she will defensively charge the coyote (Byers 1997; R. Seidler, personal observation). Given the vastly different predatory strategies employed with these prey, it is an important finding that coyote sterilization can increase fawn survival.

The significance level of our results suggests that our conclusions should be interpreted cautiously. More importantly, our study represents only one replicate and it could be that we sampled an unusual population. However, given that we observed a substantial effect (Fig. 2-2 and 2-3) and that treatment was significant at $\alpha = 0.10$ even with the number of parameters included in our models and the relatively low number of fawns in the analysis, it is our opinion that this result is biologically significant. In addition, our estimates of fawn survival reflect biologically relevant population changes (i.e., cumulative fawn survival rates in the south more than doubled from 0.18 to 0.44 for fawns captured in sterile coyote home ranges); an increase which could influence fawn recruitment and provide important demographic changes for pronghorn populations considered critical. We evaluated whether the changes in fawn survival on the PCMS were reflected in fawn recruitment. At the end of our semi-monthly fawn survival analysis (31 July), 8/22 southern fawns captured in 2007 were alive; 9/18 fawns were alive in the north. In December of 2007, 6/22 fawns captured in the south were still alive and 6/18 fawns captured in the north were still alive (2 northern animals were censored due to collar failure). In February 2008, all 6 fawns were still alive in the south. All but 1
animal in the north was censored due to collar failure; the remaining fawn was still alive in February.

*The influence of other variables*

Although the relationship was not significant, we found a positive correlation between fawn survival and alternative prey abundance; specifically, lagomorph abundance. We were only able to see this relationship by modeling prey abundance with year present in the same model because overall prey indices dropped from 2006 to 2007 while fawn survival rates increased. By modeling these variables together, we found higher alternative prey abundance was correlated with higher fawn survival rates. The lack of significance in these results may be due to small sample sizes of small mammals or differences in detection probability in the second year.

The observed decreases in alternative prey abundance may be due to the severe winter in 2006-07. Stoddart (1985) described severe winter conditions (unusually low temperatures, high snow accumulation, high wind velocities) over a <3-day period, which resulted in the mortality of 34% of 59 instrumented jack rabbits. Many of the carcasses were still intact, suggesting the cause of death was related to the weather.

Alternatively, severe winter weather may have created *apparent* decreases in alternative prey abundance on the PCMS in 2007 due to decreased detectability during our surveys. Increased vegetation height and density on the PCMS was noted after heavy winter snows and a wet spring. Tall, dense vegetation could make it difficult to detect small mammals during surveys. Dense vegetation can make it difficult for some rodent species to travel (Rowland and Turner 1964, Rosenzweig and Winakur 1969). If rodents
are moving shorter distances, their trap-ability will decrease during surveys. This would be reflected in mark-recapture studies as decreased density estimates. In addition, spotlight surveys for lagomorphs can also be compromised by issues of visibility.

Lagomorphs may have been easier to detect in 2006 because the vegetation was lower in height and less dense. If alternative prey abundances were actually higher in 2007 (and went undetected), increases in alternative prey abundance might then act as a buffer for pronghorn fawns (Stoddart et al. 2001, Bartel and Knowlton 2005). Hamlin et al. (1984) found that coyote populations were highest when fawn mortality was lowest.

Of the covariates we tested, fawn birth weight, birth date, and age at capture, none were statistically important in our models. We found that subtle differences in local areas (i.e., between the north and south) influenced fawn survival. We attempted to account for these differences by comparing average precipitation amounts between the north and south, but found no differences. Although both the north and south were comprised primarily of grassland species, the distributions of vegetation types within the grasslands in the two areas were different (B. Smart, personal communication). Predominant species in the north (i.e., western wheatgrass and needle-and-thread (\textit{Stipa comata})) tend to grow taller than predominant species in the south (i.e., grama species) potentially influencing fawn survival. In addition, a recent burn regime had been used in the south part of the study area in 2004-2006, and not in the north. Although fires are often used to improve shortgrass prairie habitats to benefit species such as pronghorn (Yoakum 1979, Wright and Bailey 1982, Courtney 1989), recent burns could compromise immediate fawn survival by reducing canopy cover. Canopy cover has been shown to be an important correlate in fawn survival (Barrett 1984, Alldredge et al. 1991). We attempted to compare
fawn survival between fawns which were captured in burn areas and fawns which were not. The sample size of fawns captured in burn areas was small (n = 6) and we were not able to detect a difference in 115-day survival rates ($t_{69} = 0.647, P = 0.520$), however the means indicated a trend toward lower survival for fawns captured in burned areas (burn: mean = 0.17 ± 0.33 (95%CI); non-burn: mean = 0.29 ±0.11).

We found that fawn survival was lowest in the second semi-monthly time interval and that after the first 6 weeks of life, the probability of fawn survival increased to 100%. This is supported by previous studies which have shown fawn mortality to be highest at ages 11-20 days (Von Gunten 1978, Barrett 1978, Byers 1997). We found no difference in survival between male and female fawns. This is similar to other studies which reported no difference between the sexes (Fairbanks 1993, Byers 1997). In the Greater Yellowstone Ecosystem, female fawn survival was higher than male fawn survival (Berger et al. 2008).

Although extreme winter weather can adversely affect fawn survival by affecting the condition of the doe (Verme 1977), the extreme snowfalls of 2006-07 in southeastern Colorado did not reduce fawn survival on the PCMS. In fact, fawn survival following the winter of 2006-07 was higher in both the north and south than fawn survival in the same areas the previous year (although not statistically significant). Because the effect of treatment was of most importance to us, we concentrated our capture efforts on treatment animals and focused our analyses on the effect of treatment. This focus probably masked a real influence of weather changes over the years. The winter snowfall and spring precipitation likely boosted fawn survival in 2007 directly by increasing vegetation biomass. Coyotes probably initially use visual cues to detect pronghorn fawns (Wells
1978) and high vegetation would make it difficult for them to find fawns (Barrett 1981). Increased vegetation would also provide important forage for lactating does (Smyser et al. 2005), subsequently increasing fawn survival.

Our study results were not as clear as Bromley and Gese’s (2001a) study in Utah (i.e., they reported a significance level of $P = 0.026$ when comparing kill-rates between intact and sterile packs). This may be due to sample size variation or it may be due to the differing dynamic of coyote predation and different prey types (e.g., domestic versus native). Further research may be able to elucidate the relationship between coyotes and native prey and determine if there is a more tightly coupled dependency between coyotes and neonatal ungulates versus domestic sheep. Future studies should focus on differences in coyote behaviors given different prey types.

**Study limitations**

We chose not to randomize our treatment area based on coyote home ranges. Instead, we selected one contiguous area to treat. We believe this was the best way to test our hypothesis because if the treatment had been randomly applied we would have been presented with the issue of fawns moving across the landscape through treated and non-treated areas. In addition, a broad spectrum application of coyote sterilization best simulated what would be conducted in a true management setting. We also did not use a fawn’s mortality location in order to test the effects of the covariates because not all fawns died in this study. If we had used mortality locations (instead of fawn capture locations), then all the fawns that had survived would have been assigned average values for covariates, biasing our sample.
Our statistical power could have increased with a larger sample size and longer study duration but we were limited by our ability to capture coyotes and fawns. And although the extraordinary winter in 2006-07 provided important insight into pronghorn ecology in southeastern Colorado, it may have influenced our ability to interpret the effects of coyote sterilization on pronghorn fawn survival. Because fawn survival rates changed between the 2 years, there may have been an interaction between some of the covariates that we were not able to detect (i.e., the severe winter may have influenced our ability to accurately assess alternative prey abundances).

Management implications

We recommend coyote sterilization be considered as a tool to boost pronghorn fawn survival in areas where fawn survival is a critical factor in pronghorn population persistence. This non-lethal tool is especially applicable in situations where lethal management of coyotes is controversial, unacceptable, or not an option. Costs to perform this technique (helicopter captures + sterilization = $900/coyote) are not very different from estimates made to trap and kill coyotes ($805; Wagner and Conover 1999). The fact that sterilization lasts the lifetime of the coyote offers promise of lower costs than lethal control over the long-term.

We do not recommend the use of coyote sterilization alone to boost pronghorn numbers where populations are critically low. The importance of multiple or concurrent management strategies in reducing coyote predation or increasing prey survival has been demonstrated many times. Management should also continue to use the current successful
tools to boost fawn survival, such as habitat enhancement. Careful monitoring of any program which uses these techniques will be insightful for future management.

**LITERATURE CITED**


Table 2-1. Models used to evaluate the influence of coyote sterilization and other covariates on pronghorn fawn survival, Piñon Canyon Maneuver Site, Colorado, May 2006-March 2008.

<table>
<thead>
<tr>
<th>Model Structure</th>
<th>Model Hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. {GLOBAL+treatment}</td>
<td>Survival varied by an interactive effect of area and time.</td>
</tr>
<tr>
<td>2. {S(treatment)}</td>
<td>Survival varied only by treatment.</td>
</tr>
<tr>
<td>3. {S(T+treatment)}</td>
<td>Survival varied by a linear trend in time.</td>
</tr>
<tr>
<td>4. {S(ln(T)+treatment)}</td>
<td>Survival varied by a nonlinear trend in time.</td>
</tr>
<tr>
<td>5. {S(t1=t2=t3, t4=t5)+treatment)}</td>
<td>Survival was constant in time intervals 1, 2, and 3 and constant in intervals 4 and 5.</td>
</tr>
<tr>
<td>6. {S(t4=t5)+treatment)}</td>
<td>Survival was constant in time intervals 4 and 5.</td>
</tr>
<tr>
<td>7. {S(t4=t5)+area+treatment)}</td>
<td>Survival was constant in time intervals 4 and 5 but varied by area (north and south).</td>
</tr>
<tr>
<td>8. {S(t4=5)+year+treatment)}</td>
<td>Survival was constant in time intervals 4 and 5 but varied by year (2006 and 2007).</td>
</tr>
<tr>
<td>9. {S(t4=t5)+area+year+treatment)}</td>
<td>Survival was constant in time intervals 4 and 5 but varied by area and year.</td>
</tr>
<tr>
<td>10. {S(t4=t5)+area+sex+treatment)}</td>
<td>Survival was constant in time intervals 4 and 5 but varied by area and fawn gender.</td>
</tr>
<tr>
<td>11. {S(t4=t5)+area+birth weight+treatment)}</td>
<td>Survival was constant in time intervals 4 and 5 but varied by area and fawn birth weight.</td>
</tr>
<tr>
<td>12. {S(t4=t5)+area+age+treatment)}</td>
<td>Survival was constant in time intervals 4 and 5 but varied by area and fawn age.</td>
</tr>
<tr>
<td>13. {S(t4=t5)+area+birth date+treatment)}</td>
<td>Survival was constant in time intervals 4 and 5 but varied by area and fawn birth date.</td>
</tr>
<tr>
<td>14. {S(t4=t5)+area+coyote+treatment)}</td>
<td>Survival was constant in time intervals 4 and 5 but varied by area and coyote density.</td>
</tr>
<tr>
<td>15. {S(t4=t5)+area+year+lago+treatment)}</td>
<td>Survival was constant in time intervals 4 and 5 but varied by area, year, and lagomorph density.</td>
</tr>
<tr>
<td>16. {S(t4=t5)+area+year+rodent+treatment)}</td>
<td>Survival was constant in time intervals 4 and 5 but varied by area, year, and rodent density.</td>
</tr>
</tbody>
</table>

*All models include survival varying by treatment.
Table 2-2. Cause-specific mortality as a percentage of total mortality in each year, area, and treatment, Piñon Canyon Maneuver Site, Colorado, May 2006-March 2008.

<table>
<thead>
<tr>
<th>Year</th>
<th>Treatment</th>
<th>Area</th>
<th>n&lt;sup&gt;a&lt;/sup&gt;</th>
<th># of mortalities</th>
<th>Coyote</th>
<th>Eagle</th>
<th>Unknown Predation</th>
<th>Unknown Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>None</td>
<td>North</td>
<td>14</td>
<td>10</td>
<td>60</td>
<td>10</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>South</td>
<td>17</td>
<td>16</td>
<td>56</td>
<td>0</td>
<td>38</td>
<td>6</td>
</tr>
<tr>
<td>2007</td>
<td>Intact</td>
<td>North</td>
<td>18</td>
<td>9</td>
<td>67</td>
<td>0</td>
<td>0</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Intact</td>
<td>South</td>
<td>13</td>
<td>10</td>
<td>70</td>
<td>0</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Sterile</td>
<td>South</td>
<td>9</td>
<td>6</td>
<td>67</td>
<td>0</td>
<td>0</td>
<td>33</td>
</tr>
</tbody>
</table>

<sup>a</sup> n = # of fawns captured

<table>
<thead>
<tr>
<th>Model</th>
<th>K</th>
<th>AICc</th>
<th>Delta AICc</th>
<th>AICc Weight</th>
<th>Model Likelihood</th>
<th>Deviance</th>
<th>Evidence Ratio (w₁/wᵢ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. {S((t₄=t₅)+area+treatment)}</td>
<td>6</td>
<td>185.932</td>
<td>0.000</td>
<td>0.187</td>
<td>1.000</td>
<td>173.468</td>
<td>1.000</td>
</tr>
<tr>
<td>9. {S((t₄=t₅)+area+year+treatment)}</td>
<td>7</td>
<td>186.197</td>
<td>0.260</td>
<td>0.164</td>
<td>0.876</td>
<td>171.575</td>
<td>1.142</td>
</tr>
<tr>
<td>10. {S((t₄=t₅)+area+sex+treatment)}</td>
<td>7</td>
<td>186.588</td>
<td>0.660</td>
<td>0.135</td>
<td>0.721</td>
<td>171.965</td>
<td>1.388</td>
</tr>
<tr>
<td>11. {S((t₄=t₅)+area+birth weight+treatment)}</td>
<td>7</td>
<td>187.330</td>
<td>1.400</td>
<td>0.093</td>
<td>0.497</td>
<td>172.707</td>
<td>2.011</td>
</tr>
<tr>
<td>13. {S((t₄=t₅)+area+birth date+treatment)}</td>
<td>7</td>
<td>187.452</td>
<td>1.520</td>
<td>0.087</td>
<td>0.468</td>
<td>172.830</td>
<td>2.138</td>
</tr>
<tr>
<td>16. {S((t₄=t₅)+area+year+rodent+treatment)}</td>
<td>8</td>
<td>187.978</td>
<td>2.050</td>
<td>0.067</td>
<td>0.360</td>
<td>171.173</td>
<td>2.781</td>
</tr>
<tr>
<td>12. {S((t₄=t₅)+area+age+treatment)}</td>
<td>7</td>
<td>188.053</td>
<td>2.120</td>
<td>0.065</td>
<td>0.346</td>
<td>173.431</td>
<td>2.887</td>
</tr>
<tr>
<td>15. {S((t₄=t₅)+area+year+lago+treatment)}</td>
<td>8</td>
<td>188.079</td>
<td>2.150</td>
<td>0.064</td>
<td>0.342</td>
<td>171.274</td>
<td>2.925</td>
</tr>
<tr>
<td>14. {S((t₄=t₅)+area+coyote+treatment)}</td>
<td>7</td>
<td>188.086</td>
<td>2.150</td>
<td>0.064</td>
<td>0.341</td>
<td>173.463</td>
<td>2.935</td>
</tr>
<tr>
<td>8. {S((t₄=t₅)+area+year+treatment)}</td>
<td>6</td>
<td>189.162</td>
<td>3.230</td>
<td>0.037</td>
<td>0.199</td>
<td>176.698</td>
<td>5.028</td>
</tr>
<tr>
<td>6. {S((t₄=t₅)+treatment)}</td>
<td>5</td>
<td>189.879</td>
<td>3.950</td>
<td>0.026</td>
<td>0.139</td>
<td>179.549</td>
<td>7.194</td>
</tr>
<tr>
<td>5. {S(t₁=12+t₃, t₄=t₅)+treatment)}</td>
<td>3</td>
<td>191.422</td>
<td>5.490</td>
<td>0.012</td>
<td>0.064</td>
<td>185.292</td>
<td>15.570</td>
</tr>
<tr>
<td>3. {S(T+treatment)}</td>
<td>3</td>
<td>207.403</td>
<td>21.470</td>
<td>0.000</td>
<td>0.000</td>
<td>201.273</td>
<td>NA</td>
</tr>
<tr>
<td>1. {Global+treatment}</td>
<td>21</td>
<td>212.872</td>
<td>26.940</td>
<td>0.000</td>
<td>0.000</td>
<td>165.305</td>
<td>NA</td>
</tr>
<tr>
<td>4. {S(ln(T)+treatment)}</td>
<td>3</td>
<td>213.505</td>
<td>27.570</td>
<td>0.000</td>
<td>0.000</td>
<td>207.375</td>
<td>NA</td>
</tr>
<tr>
<td>2. {S(treatment)}</td>
<td>2</td>
<td>218.725</td>
<td>32.790</td>
<td>0.000</td>
<td>0.000</td>
<td>214.660</td>
<td>NA</td>
</tr>
</tbody>
</table>

*Number of estimable parameters
Figure 2-1. Coyote home ranges and fawn capture locations on the Piñon Canyon Maneuver Site, Colorado, May 2006-March 2008. Cross-hatched polygons represent coyote home ranges where at least one coyote had been sterilized, however pups were detected in the pack.
Figure 2-2. Model averaged pronghorn fawn survival rates (± 95%CI) in semi-monthly intervals for 79-days, (A) before treatment in 2006, and (B) after treatment in 2007, Piñon Canyon Maneuver Site, Colorado. Note in (B) that 3 survival curves are present; upper curve represents 2 survival curves, south treatment, 2007, and north, 2007.
Figure 2-3. Model averaged estimates of cumulative summer fawn survival for the north and south study areas in 2006 and 2007, Piñon Canyon Maneuver Site, Colorado.
Figure 2-4. Snowfall amounts for the winter of 2005-2006 and 2006-2007, Trinidad, Colorado (data provided by the National Weather Service).
Figure 2-5. Monthly precipitation averaged across 12 stations (± 95% CI) on the Piñon Canyon Maneuver Site, Colorado (data provided by the U.S. Geological Service).
Figure 2-6. Photos taken from similar locations on the Piñon Canyon Maneuver Site, Colorado on (A) 15 July 2006 and (B) 26 June 2007.
CHAPTER 3
THE EFFECTS OF TUBAL LIGATION AND VASECTOMY ON COYOTE HOME RANGE MAINTENANCE\textsuperscript{2}

Abstract. Sterilization of wild canids is being used experimentally in many management applications. Few studies have clearly demonstrated that vasectomized and tubal ligated canids will retain pair-bonding and territorial behaviors. We tested whether behaviors of surgically sterilized coyote packs were different from sham-sterilized coyote packs. We captured and radio-collared 30 coyotes in December 2006. Sixteen of these animals were sterilized via vasectomy or tubal ligation, 14 were given sham-surgeries. We monitored these animals using telemetry and visual observations through 2 breeding seasons from December 2006-March 2008. Pack sizes were the same for sterile and intact coyotes (\(P = 0.554\)). We found no difference in home range size between sterile and intact coyotes (\(P \geq 0.556\)). We found differences in home range and core area overlap between sterile and intact coyote packs in some seasons, however it is likely this difference was pre-existing before treatment. Home range fidelity was the same for sterile and intact coyotes (\(P = 0.406\)). All coyotes had higher residency rates during the breeding season, with no differences between sterile and intact coyotes. Survival rates were correlated with biological season, but may have been confounded by human presence on the site; there were no differences between sterile and intact coyote survival rates. We conclude that surgical sterilization of coyotes did not affect pair-bonding or home range maintenance.

\textsuperscript{2} Co-authored by Eric Gese.
Sterilization of canids is being tested for various management purposes including population control of native and non-native species, predation control, and to reduce genetic introgression with other canids (Haight and Mech 1997, Kelly et al. 1999, Spence et al. 1999, Bromley and Gese 2001a, Saunders et al. 2002). Surgical sterilization in particular is a promising approach because hormonal systems remain intact with vasectomy and tubal ligation. Canid reproductive strategies (e.g., monogamy and pseudopregnancy in subordinate pack members) and physiology (e.g. monestrum and prolonged proestrus and estrus) favor pair and pack cohesion (Asa 1997). Without hormonal signals, these characteristics may not be preserved (Asa 1995). For most management purposes, retaining social structure of the pack is critical. If the social structure of a sterilized pack fails, then a vacant territory becomes open to colonization by intact animals (Till and Knowlton 1983, Asa 1995, Mech et al. 1996, DeLiberto et al. 1998, Gese 1998).

In 1987 and 1988, Mech et al. (1996) vasectomized 5 wolves (Canis lupus) to determine if sterilization of wolves was a viable method for controlling population sizes. They determined that the vasectomized wolves’ social behaviors were not altered. Subsequently, state management agencies predicted that wolf control may be necessary where wolves colonize close to human settlement. Due to the success of this study, wolf sterilization is one of several proposed methods to control populations in the Lake Superior region (Haight and Mech 1997).

In the Yukon, Canada, wolves had been implicated in the decline of caribou (Rangifer tarandus) and moose (Alces alces) calf survival (Spence et al. 1999). Due to
the economic costs, effort, and public concern of the use of lethal control, fertility control was tested as an alternative tool to manage wolves (Spence et al. 1999). In studies to determine the applicability of such a tool, territorial behaviors were again examined. Using aerial telemetry, the study reported that the sterilized wolves maintained pair bonds and remained in their territories (Spence et al. 1999).

Red foxes (*Vulpes vulpes*) in Australia are an introduced species from Europe and have had destructive impacts on native fauna (Saunders et al. 1995). Native mammals lack the appropriate anti-predator behaviors and, hence, are susceptible to fox predation (Kinnear et al. 1988). In addition, the foxes may pose a threat to livestock producers (Saunders et al. 2002). Consequently, female foxes were experimentally sterilized. The sterile vixens retained pair-bonding and territorial behaviors, although they became more tolerant of home range overlap (Saunders et al. 2002).

The sheep industry in the western United States has a long history of conflict with coyote (*Canis latrans*) predation (Wagner 1988). When warranted, ranchers and wildlife management agencies utilize various lethal methods to control coyote predation on livestock and wildlife species (Knowlton et al. 1999). The public, concerned with animal rights, continually voices concern over the use of lethal management (Arthur 1981, Kellert 1985, Andelt 1987, Messmer et al. 2001). One alternative method being considered to reduce predation on sheep is surgical sterilization of coyotes (Knowlton et al. 1999). Bromley and Gese (2001a) sterilized coyotes in Utah and found that they could reduce coyote predation on domestic sheep by up to eight-fold. This technique is thought to be effective because it reduces the energetic needs of the pack (Till and Knowlton
1983, Bromley and Gese 2001a). Bromley and Gese (2001b) further demonstrated that the sterile coyotes’ territorial and pack affiliative behaviors were not modified.

Coyote sterilization is also being used as part of an endangered species recovery program in the eastern United States. In North Carolina, red wolf (Canis rufus) recovery is being threatened by genetic introgression with coyotes. Coyotes and red wolves can hybridize (Nowak 1992) which jeopardizes the persistence of the red wolf gene pool (Fredrickson and Hedrick 2006). After consideration by the U.S. Fish and Wildlife Service and The Conservation Breeding Specialist Group (Kelly et al. 1999), coyotes were sterilized in various areas across the recovery zone (Beck 2005). Sterilization has reduced the incidences of coyotes breeding with red wolves, while maintaining a space for the future placement of newly released red wolves (Beck 2005).

Although sterilization has been used in many canid species, only Bromley and Gese’s (2001b) study has demonstrated that free-ranging coyotes will maintain territorial and breeding-pair behaviors. If coyote sterilization continues to be used as a management tool, it is important to validate that territorial maintenance and pair-bonding behaviors are retained across different circumstances (Asa 1995). Without this assurance, intact animals can displace sterile packs and threaten the success of the management practice (Till and Knowlton 1983, Asa 1995, Mech et al. 1996, DeLiberto et al. 1998, Gese 1998). As part of a study to test whether coyote sterilization could increase pronghorn fawn survival (Chapter 2), we tested the hypothesis that coyote sterilization will not affect home range maintenance. We examined similar behavioral criteria as Bromley and Gese (2001b). We compared pack size of sterilized coyotes to intact coyotes. We also evaluated home range size and overlap as well as home range fidelity. We used the home range as our
measurement of space use instead of the territory because we did not collect any data that we believed would constitute a territorial analysis (i.e., we did not make visual observations of coyote behaviors such as urinating, defecating, or howling at territory boundaries) and the methods we used were designed to match previous studies. Finally, we made a comparison of survival rates between sterile and intact animals. We were not able to compare association indices between treatment groups due to a small sample size of intact coyote pairs.

**METHODS**

**Study site**

We conducted this study on the 1,040 km$^2$ Piñon Canyon Maneuver Site (PCMS) in Las Animas County, ~50 km northeast of Trinidad, Colorado. The study area within the PCMS encompassed the home range boundaries of radio-collared coyotes involved in the study. Average elevation on the PCMS was 1520 m, average temperatures ranged from 1°C in January to 24°C in July (Shaw and Diersing 1990), and mean annual precipitation was 305 mm at the nearest long-term weather station in Delhi, Colorado (Milchunas et al. 1999). Harvest of coyotes was not permitted for the duration of the study.

Nearly 60% of the PCMS was identified as shortgrass prairie dominated by blue grama (*Bouteloua gracilis*), galleta (*Hilaria jamesii*), and western wheatgrass (*Agropyron smithii*) (Shaw et al. 1989). Many shrub communities occurred within the grassland communities along alluvial fans, waterways, and slopes. These included species of black greasewood (*Sarcobatus vermiculatus*), fourwing saltbush (*Atriplex canescens*), Bigelow
sagebrush (*Artemisia bigelovii*), winterfat (*Krascheninnikovia lanata*), small soapweed (*Yucca glauca*), and tree cholla (*Opuntia imbricata*). Woodland communities were composed primarily of one-seeded juniper (*Juniperus monsperma*) and pinyon pine (*Pinus edulis*) mixed with grassland or shrubland species. Woodlands dominated the canyons and breaks.

**Capture and monitoring of coyotes**

We captured coyotes in December 2006 using a net-gun fired from a helicopter (Barrett et al. 1982, Gese et al. 1987). Animals captured in the southern portion of the study area were sterilized, while animals captured in the northern portion of the study area were sham-sterilized. We used this clustered experimental design in an effort to swamp a single area with the treatment and to simulate actual management practices (Chapter 2). We transported captured animals by vehicle or helicopter to a central processing location. A veterinarian sterilized females by tubal ligation and males by vasectomy. All animals otherwise received the same treatment: they were given a combination of a sedative and dissociative, incised and sutured, radio-collared, allowed to recover, and released at the capture site within 24 hours. Research protocols were approved by the Institutional Animal Care and Use Committees at the USDA/National Wildlife Research Center (QA-1350) and Utah State University (IACUC #1269).

To determine with greater certainty that treated coyote packs were indeed sterile, we conducted howling surveys and searched for dens and pups of radio-collared individuals. Howling surveys were conducted regularly from 4 June 2007 to 13 August 2007, with 1-2 teams going to high points, howling, and recording whether the response
included pups or not. Concurrently, all radio-collared individuals from nearby packs were detected with telemetry. Visual observations of radio-collared individuals allowed us to gain information on pup presence as well as minimum group sizes. We considered packs with pups as intact.

**Pack size**

We compared pack sizes between sterile and intact packs using the minimum pack size observed. We made multiple visual observations of radio-collared individuals to count associated pack members. Packs were surveyed from 8 June 2007 to 5 December 2007. One or two people would track a radio-collared animal on foot. We attempted to approach animals from down wind in a stealthy manner to reduce disturbance of potential additional pack members that may have been present. Group size, location, and pup presence were noted. We did not include pups in pack size estimations; we used pre-whelping pack size estimates.

**Home range size and overlap**

We performed telemetry primarily at dawn and dusk to obtain point locations during the highest activity periods (Andelt and Gipson 1979) using a hand-held antenna and receiving unit. We attempted to locate animals every 2 days. We calculated locations using ≥3 bearings in Program LOCATE (Pacer, Ltd., Truro, N.S.). All home ranges were computed using locations with error <0.10 km². We calculated home range size using the 95% fixed kernel (FK) density estimator and core area with the 50% FK density estimator in ArcGIS 9.2 (Environmental Systems Research Institute, Inc., Redlands, CA) with the
Hawth’s Tools extension (Hawth’s Analysis Tools). Bandwidths were set to $h = 1000$ for consistency and each home range and core area was calculated separately. Due to limited location sample sizes, we calculated estimates for 3 seasons: first winter (December 2006-March 2007), summer (April 2007-September 2007), and second winter (October 2007-March 2008).

We compared percent overlap among adjacent packs for the 95% and 50% FK contours using analysis of variance (ANOVA). We used only adjacent packs to calculate percent overlap, including adjacent packs with zero overlap. Packs were considered adjacent if their home range boundaries were <2 km apart. This figure represents the radius of the smallest home range and was the minimum area we used to exclude the potential presence of a home range in which the pack members were not radio-collared. We made comparisons of home range overlap among adjacent sterile-sterile packs, intact-intact packs, and sterile-intact packs. Tests for differences between each pair were performed with a Tukey’s honestly significant difference (HSD) test. All statistical tests were performed using SPSS 10.0.5 (SPSS Inc., Chicago, Illinois, USA).

Because availability of alternative prey could affect the percentage of tolerated overlap between coyote home ranges, we monitored rodent and lagomorph abundance and applied an index for each to all coyote home ranges. We used small mammal trapping grids run for three consecutive nights in four different habitat types (grasslands, shrublands, woodlands, and burned areas) to estimate rodent abundance. An average mass was calculated based upon the unique individuals captured and the median mass for each species (Fitzgerald et al. 1994). These estimates were then extrapolated to each coyote home range given the amount of habitat types in that home range. Lagomorphs
were surveyed using spotlight surveys conducted in replicates of three per habitat type over three consecutive nights. An average mass was calculated using the number of lagomorphs seen/km times the mean mass of the species. These estimates were then also extrapolated to each coyote home range given the amount of habitat types in that home range. A regression was then performed using the amount of available alternative prey (rodents or lagomorphs) and the amount of coyote home range overlap.

Home range fidelity

We tested home range fidelity of resident coyotes using known fate models in Program MARK (White and Burnham 1999). Animals were censored after dispersal. We compared models of residency rates between sterile and intact coyotes with Akaike’s Information Criterium (AIC, Akaike 1973) corrected for small sample size bias (ΔAICc, Burnham and Anderson 2002).

We grouped coyotes by treatment (sterile or intact) and encounter occasions were expressed as 15 1-month intervals. Because treatment was of primary interest, all models included this variable. Hypotheses tested included residency varying by treatment alone, treatment and 4-month season, or treatment and 1-month time interval (Table 3-1, models 1, 2, and 3). We based 4-month seasons on biological changes in coyote behavior, including the breeding season (December-March), pup-rearing season (April-July), and dispersal season (August-November; adapted from Gese and Ruff 1998). We also tested a model which examined the interactive effect between treatment and time (the most parameterized model, Table 3-1, model 4). We censored animals which were transient
when captured from the analysis unless and until they resettled as residents later in the
study.

Survival

We compared estimates of survival rates between sterile and intact coyotes in
Program MARK using the numerical maximum likelihood model approach and known
fate analysis (White and Burnham 1999). We compared models of survival rates using
\[ \Delta AIC_c \] (Akaike 1973, Burnham and Anderson 2002). Coyotes were grouped by treatment
and models included 3 covariates: gender, age, and weight. We analyzed survival over 15
1-month occasions. We created models based on gender, age, weight, coyote season, or
monthly time interval and always included the variable treatment since this was our
variable of interest (Table 3-2, models 1-6). Except a global model (Table 3-2, model 7),
all hypothesized models were restricted to additive models due to a limited sample size.

RESULTS

Pack size

We captured and radio-collared 30 coyotes across the PCMS. We sterilized 16
animals from the southern portion of the study area and sham-operated 14 from the
northern portion. Defined home ranges contained 1-2 radio-collared individuals because
we were not consistently able to capture pairs. The first winter and summer seasons we
defined 8 sterile home ranges. After the dispersal season, we defined 6 sterile home
ranges in the second winter. We defined 10 intact home ranges in the first winter, 9 in the
summer, and 8 in the second winter. Most of the control (intact) coyote home ranges
contained sham-operated coyotes. Two of the control home ranges contained sterilized coyotes but due to the detection of pups in these packs, we considered them intact. Mean pack size of sterile coyotes (2.3 ± 0.3 (95%CI)) was similar to the mean pack size of intact coyotes (2.10 ± 0.3; \( t_9 = 0.607 \), 2-sided t-test, \( P = 0.554 \)).

*Home range size and overlap*

Home range sizes were not different between sterile and intact coyotes in any season. In the first winter season, mean home range size of intact (n = 10) and sterile (n = 8) coyotes was 24.0 ± 3.8 (95%CI) km\(^2\) and 22.3 ± 3.9 km\(^2\), respectively (\( t_{16} = 0.601 \), 2-sided t-test, \( P = 0.556 \); Figure 3-1A). In the summer, home range size of intact (n = 9) coyotes was 26.4 ± 6.8 km\(^2\) and sterile (n = 8) coyotes was 24.7 ± 4.4 km\(^2\) (\( t_{15} = 0.405 \), 2-sided t-test, \( P = 0.692 \); Figure 3-1B). In the second winter season, home range size of intact (n = 7) and sterile (n = 6) coyotes was 20.6 ± 4.9 km\(^2\) and 22.0 ± 4.0 km\(^2\), respectively (\( t_{11} = -0.421 \), 2-sided t-test, \( P = 0.682 \); Figure 3-1C). Equal variances were assumed in all cases by Levene’s test (\( P \geq 0.082 \)).

All overlaps of home ranges were expressed as a proportion of total home range area, not an area *per se*. In the first winter season, mean overlap between adjacent sterile home ranges was 0.251 ± 0.081 (95%CI) and mean overlap between adjacent intact home ranges was 0.139 ± 0.076. Mean overlap between adjacent sterile and intact home ranges was 0.060 ± 0.069. During the first winter season, core areas of adjacent sterile home ranges had an average overlap of 0.033 ± 0.032 (SD). Core areas of adjacent intact home ranges overlapped by 0.001 ± 0.001 and core areas of adjacent sterile-intact home ranges had no overlap. We found differences in overlap of adjacent sterile core areas compared
to adjacent intact core areas ($P = 0.020$). This relationship appears to be mainly due to the overlap of core areas between only 2 sets of sterile home range pairs (Figure 3-1A). We did not find any other differences in overlap in the first winter season (Table 3-3A).

Mean summer home range overlap among adjacent sterile home ranges ($0.266 \pm 0.073$ (95%CI)) was different from the mean overlap among adjacent intact home ranges ($0.113 \pm 0.061$; $P = 0.006$). Differences in overlap among adjacent sterile home ranges and adjacent sterile-intact home ranges were also significant ($0.057 \pm 0.074$, $P = 0.007$). However, there was no evidence of difference in the overlap among adjacent intact home ranges and adjacent sterile-intact home ranges ($P = 0.639$). Core area overlaps in the summer were also different among adjacent sterile home ranges ($0.028 \pm 0.030$) and adjacent intact home ranges (no overlap, $P = 0.043$). No other differences in core area overlap were found in the summer (Table 3-3B).

Mean overlap of adjacent sterile home ranges ($0.208 \pm 0.074$ (95%CI)) in the second winter season was different from adjacent intact home ranges ($0.012 \pm 0.017$, $P < 0.001$). We also found a difference among mean overlap of adjacent sterile home ranges and adjacent sterile-intact home ranges (no overlap, $P = 0.011$). No other differences in overlap in the second winter season were found (Table 3-3C).

Because age differences may influence dispersal which could affect apparent overlap, we also tested for differences in age between sterilize and intact coyotes. We found no difference in age between sterile and intact coyotes ($t_{28} = -0.976$, $P = 0.337$) nor did we find a difference between sample sizes used to define home ranges for sterile and intact coyotes (first winter: $t_{16} = -0.429$, $P = 0.674$, summer: $t_{15} = -0.249$, $P = 0.807$, second winter: $t_{13} = -0.147$, $P = 0.885$) which may also influence home range overlap.
We also found no correlation between home range sample size and percent overlap of home ranges (first winter: $R^2 = 0.013$, $F_{53} = 0.676$, $P = 0.415$, summer: $R^2 = 0.013$, $F_{45} = 0.601$, $P = 0.442$, second winter: $R^2 = 0.017$, $F_{29} = 0.480$, $P = 0.494$).

In order to better determine what may have caused differences in overlap between sterile and intact home ranges, we performed a regression of alternative prey availability against home range overlap. Relative rodent abundance was not strongly correlated with home range overlap ($R^2 = 0.135$, $F = 2.340$, $P = 0.147$), nor was relative lagomorph abundance ($R^2 = 0.000$, $F = 0.001$, $P = 0.974$).

*Home range fidelity*

Six coyotes (20%) dispersed during the study. Three of these dispersals occurred during the pup-rearing season and 3 during the dispersal season. No dispersals occurred during the breeding seasons.

The best fit model for coyote residency was $R\{\text{treatment+season}\}$ (Table 3-4, model 2). This model was 2.2 times as plausible as the second-best model $R\{\text{treatment}\}$ (Table 3-4, model 1). Models 3 ($R\{\text{treatment+time}\}$) and 4 ($R\{\text{treatment*time}\}$) were not very likely candidates (evidence ratios = 927.04 and NA, respectively, Table 3-4).

Residency was highest during the breeding seasons and dropped during the pup-rearing and dispersal season (Figure 3-2). Model averaging showed that derived residency rates (the probability of remaining a resident through the duration of the study) were not different between sterile ($\hat{r} = 0.779$, 95%CI = 0.496-0.927) and intact ($\hat{r} = 0.738$, 95%CI = 0.432-0.913) coyotes ($z = 0.239$, 1-sided z-test, $P = 0.406$).
Coyote survival rates

We analyzed survival rates of 17 male and 13 female coyotes. Eight of the males and eight of the females were sterilized. Ages (as assessed by tooth-wear; Gier 1968) ranged from 1-7 years old and weights ranged from 8.16-16.33 kg. Four coyotes perished during the study: 3 due to gunshot wounds, 1 due to unknown causes.

Many of the models used to analyze coyote survival rates were competitive. The first 5 models were within <2.016 ΔAICc values from each other, indicating that all 5 were plausible (Burnham and Anderson 2002). The best-fit model, S{treatment} (Table 3-5, model 1), suggested that sterile coyotes had lower survival rates than intact coyotes, but statistics did not support this hypothesis (sterile: $\hat{s} = 0.805$, 95%CI = 0.540-0.936, intact: $\hat{s} = 0.923$, 95%CI = 0.608-0.989, $z = -0.940$, 1-sided z-test, $P = 0.174$). The second-ranked model, S{treatment+season} (Table 3-5, model 5), showed an increasing trend in survival over the seasons and higher survival in intact coyotes, but the confidence intervals between the groups overlapped (Figure 3-3). Model averaged derived estimates of survival rates (i.e., the probability of surviving the duration of the study) of sterile and intact coyotes were not different (sterile: $\hat{s} = 0.809$, 95%CI = 0.544-0.938; intact: $\hat{s} = 0.924$, 95%CI = 0.611-0.990; $z = -0.926$, $P = 0.177$). When we calculated statistics for the third-, fourth-, and fifth-ranked models, S{treatment+age}, S{treatment+weight}, and S{treatment+sex}, we found the covariates were not significant ($P > 0.280$). Other models had ΔAICc values > 2.016.
As surgical sterilization becomes more widely used in canid research and management practices, we must confirm that territorial maintenance and pair-bonding behaviors are retained. Without these behaviors, the social structure of the pack will dissolve leading to an unguarded, open territory and management efforts would fail. We found no evidence to suggest that territorial behaviors among coyotes were altered by sterilization. Pack size, home range size, home range fidelity, and coyote survival rates were the same for sterilized and sham-operated coyotes. We did find that sterile packs exhibited greater home range overlap than intact packs, but it is questionable whether this was due to the effects of sterilization.

Similar to our results, sterile red fox vixens also displayed increases in home range overlap when compared to non-sterile vixens (Saunders et al. 2002). In contrast, coyotes in Utah did not display differences in home range overlap between sterile and intact packs (Bromley and Gese 2001b). Average overlap between coyote territories in Utah was 21%, greater than the overall average overlap in our study (13.8%). It appeared that sterile coyote packs on the PCMS were more tolerant of home range overlap than intact coyote packs. However, the degree of home range overlap that we found within the sterilized coyote packs appears to have existed at the time the animals were sterilized.

Overlap in the sterilized home ranges was greatest during the first winter and summer seasons. It then declined in the second winter season, but there were no real differences between any of the seasons ($F_{2,47} = 0.426$, $P = 0.656$, ANOVA). This consistent temporal trend implies that greater overlap was typical for the treatment area before we captured and sterilized coyotes. We also tested for age and location sample
size differences between the sterile and intact packs to try and account for the differences in overlap. Younger, low-ranking pack members disperse when resources are not abundant (Gese et al. 1996). If coyotes in the sterile group were younger than coyotes in the intact group and location sample sizes were not large enough to accurately detect pre-dispersal forays then we might mistake these forays for home range overlap. However, we did not detect differences in dispersal rates between the groups. Further, we found no difference in age between the groups nor did we find a difference between sample sizes used to define home ranges for the 2 groups suggesting that pre-dispersal forays were not occurring differentially between sterile and intact coyotes. Varying home range sample sizes also did not account for differences in overlap of home ranges.

Potentially, food resources were better in sterile home ranges (Atwood and Weeks 2003), however we found no correlation between alternative prey availability and coyote home range overlap. Perhaps kinship was higher (Kitchen et al. 2005) in the sterilized area allowing for greater home range overlap, but we did not test for this. Additionally, two dispersals in the second winter of previously resident coyotes in the intact area may account for differences observed between home range overlap in this season. One of the dispersers was an adult male coyote that was located in the center of the intact part of the study area. His initial home range had contributed to overlap in previous seasons. His dispersal was associated with the expansion of adjacent coyote pack home ranges into his previous home range area and may have been the result of displacement (Carbyn 1981, Gese et al. 1996). However, the expansion of the neighboring pack’s home range was not enough to compensate for the lost overlap. Given consistently high overlap in the sterile home ranges and dispersal events which reduced overlap in the intact home ranges, we
believe that the disparity in home range overlaps was not prompted by sterilization, but most likely had high pre-existing overlap among home ranges in that area.

Home range fidelity of coyotes varied by season and declined during the pup-rearing and dispersal seasons. This is not surprising; pack sizes gradually decline after whelping due to dispersals of non-breeding associated pack members (Bekoff and Gese 2003). We found no evidence that dispersals were influenced by sterilization. This corroborates with Bromley and Gese’s (2001b) results; they found no difference between residency rates of sterile and sham-operated animals.

Although our results suggested many variables were important to coyote survival, sterilization had no significant influence. In addition, a post hoc analysis using the model S{.} (coyote survival rate was not influenced by any of the variables), ranked this model at the top when run with the previously described models, further suggesting none of the other variables captured the true effects. Indeed, the Wald’s test confirmed them as insignificant. Season, as modeled as a coyote biological interval, may have been influential on coyote survival. A further post hoc analysis ranked this model (S{season}) as second only to S{.}. However, we must also consider confounding variables such as human persecution. Three of four coyote mortalities were caused by gunshot and the fourth mortality suggested human involvement. This mortality was discovered >12 km from its home range and >2 km off the PCMS. This death was recorded as “unknown causes” because the carcass was too decayed, but it was discovered <4 m from a gravel road, implicating human-related causes. Although shooting of coyotes was not permitted during the study, 3 of the 4 mortalities were detected during or shortly after military maneuvers involving armed personnel.
Results from this study add to the small body of knowledge that we have regarding the effects of sterilization on wild canids. We did not find any results that were in contradiction to other studies on coyotes or wolves. One component that is lacking in all peer-reviewed studies of coyote sterilization is an assessment of the long-term stability of territorial and social behaviors following sterilization. Mech et al. (1996) monitored vasectomized wolves for seven years, but their sample size was small and females were not sterilized. Zemlicka (1995) monitored sterilized captive coyotes for 1 year and Bromley and Gese (2001b) followed their sterilized coyotes for 3 years. Despite functioning endocrine systems, it is possible that after multiple, sequential years of no reproductive success sterile coyotes could sever their pair-bond and search for a more successful mate. Hence, we recommend a study of sterilized, free-ranging, male and female coyotes which follows treated and untreated animals into senescent years. With this method, dispersals by “breeding” individuals (dominant animals which had been sterilized) due to a lack of reproduction may be detected. Also, by following sterile and intact coyotes to senescence, changes in survival rates may be detected. Because home range overlap of red fox vixens was reported (Saunders et al. 2002) and this study found apparently pre-existing home range overlap in sterile coyotes, disruption of territory boundaries may be an important avenue to explore further. Tolerance of trespassers into territories may complicate interpretation of experimental results and could result in failed measures for canid management.


Wagner, F. H. 1988. Predator control and the sheep industry, the role of science in policy formation. Regina Books, Claremont, California, USA.

Table 3-1. Models used to evaluate variation in sterile \((n = 15)\) and intact \((n = 12)\) coyote residency on the Piñon Canyon Maneuver Site, Colorado, USA, December 2006- March 2008.

<table>
<thead>
<tr>
<th>Model no.</th>
<th>Model Structure</th>
<th>Model Hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>{R{treatment}}</td>
<td>Residency varied only by treatment (sterile and intact).</td>
</tr>
<tr>
<td>2</td>
<td>{R{treatment+season}}</td>
<td>Residency varied by treatment and 4-month season (breeding, pup-rearing, or dispersal).</td>
</tr>
<tr>
<td>3</td>
<td>{R{treatment+time}}</td>
<td>Residency varied by treatment and monthly time interval.</td>
</tr>
<tr>
<td>4</td>
<td>{global R{treatment}*time}\</td>
<td>Residency varied by an interactive effect of treatment and monthly time interval.</td>
</tr>
</tbody>
</table>
Table 3-2. Models used to evaluate variation in sterile and intact coyote (n = 30) survival on the Piñon Canyon Maneuver Site, Colorado, December 2006-March 2008.

<table>
<thead>
<tr>
<th>Model no.</th>
<th>Model Structure</th>
<th>Model Hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>{S(treatment)}</td>
<td>Survival varied only by treatment (sterile or intact).</td>
</tr>
<tr>
<td>2</td>
<td>{S(treatment+sex)}</td>
<td>Survival varied by treatment and coyote gender.</td>
</tr>
<tr>
<td>3</td>
<td>{S(treatment+age)}</td>
<td>Survival varied by treatment and coyote age.</td>
</tr>
<tr>
<td>4</td>
<td>{S(treatment+kg)}</td>
<td>Survival varied by treatment and coyote weight.</td>
</tr>
<tr>
<td>5</td>
<td>{S(treatment+season)}</td>
<td>Survival varied by treatment and 4-month season (breeding, pup-rearing, or dispersal).</td>
</tr>
<tr>
<td>6</td>
<td>{S(treatment+time)}</td>
<td>Survival varied by treatment and 15-month time interval.</td>
</tr>
<tr>
<td>7</td>
<td>{global S(treatment*time)}</td>
<td>Survival varied by an interactive effect of treatment and 15-month time interval.</td>
</tr>
</tbody>
</table>
Table 3-3. Tukey's Honestly Significant Difference comparison of home range and core area overlap between sterile and intact coyote home ranges on the Piñon Canyon Maneuver Site, Colorado, December 2006-March 2008.

<table>
<thead>
<tr>
<th>Group Comparison</th>
<th>95% Home Range:</th>
<th>50% Core Area:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. First Winter</strong></td>
<td>Sterile-Intact 0.118</td>
<td>Sterile-Intact 0.020</td>
</tr>
<tr>
<td></td>
<td>Sterile-Both 0.181</td>
<td>Sterile-Both 0.343</td>
</tr>
<tr>
<td></td>
<td>Intact-Both 0.734</td>
<td>Intact-Both 0.999</td>
</tr>
<tr>
<td><strong>B. Summer</strong></td>
<td>Sterile-Intact 0.006</td>
<td>Sterile-Intact 0.043</td>
</tr>
<tr>
<td></td>
<td>Sterile-Both 0.007</td>
<td>Sterile-Both 0.200</td>
</tr>
<tr>
<td></td>
<td>Intact-Both 0.639</td>
<td>Intact-Both 1.000</td>
</tr>
<tr>
<td><strong>C. Second Winter</strong></td>
<td>Sterile-Intact &lt;0.001</td>
<td>Sterile-Intact 0.312</td>
</tr>
<tr>
<td></td>
<td>Sterile-Both 0.011</td>
<td>Sterile-Both 0.733</td>
</tr>
<tr>
<td></td>
<td>Intact-Both 0.982</td>
<td>Intact-Both 1.000</td>
</tr>
</tbody>
</table>
Table 3-4. Model selection results for sterile (n = 15) and intact (n = 12) coyote residency rates on the Piñon Canyon Maneuver Site, Colorado, December 2006-March 2008.

<table>
<thead>
<tr>
<th>Model no.</th>
<th>Model Structure</th>
<th>AICc</th>
<th>Delta AICc</th>
<th>AICc Weights</th>
<th>Model Likelihood</th>
<th>K&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Deviance</th>
<th>Evidence Ratio (w&lt;sub&gt;1&lt;/sub&gt;/w&lt;sub&gt;i&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>{R(treatment+season)}</td>
<td>62.583</td>
<td>0.000</td>
<td>0.686</td>
<td>1.000</td>
<td>5</td>
<td>14.630</td>
<td>1.00</td>
</tr>
<tr>
<td>1</td>
<td>{R(treatment)}</td>
<td>64.151</td>
<td>1.568</td>
<td>0.313</td>
<td>0.457</td>
<td>2</td>
<td>22.344</td>
<td>2.19</td>
</tr>
<tr>
<td>3</td>
<td>{R(treatment+time)}</td>
<td>76.242</td>
<td>13.659</td>
<td>0.001</td>
<td>0.001</td>
<td>16</td>
<td>4.761</td>
<td>927.04</td>
</tr>
<tr>
<td>4</td>
<td>{global R(treatment*time)}</td>
<td>103.889</td>
<td>41.306</td>
<td>0.000</td>
<td>0.000</td>
<td>30</td>
<td>0.000</td>
<td>NA&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> Number of parameters.

<sup>b</sup> Evidence ratios could not be calculated because model weight was = 0.
Table 3-5. Model selection results for sterile and intact coyote (n = 30) survival on the Piñon Canyon Maneuver Site, Colorado, December 2006-March 2008.

<table>
<thead>
<tr>
<th>Model no.</th>
<th>Model</th>
<th>AICc</th>
<th>Delta AICc</th>
<th>AICc Weights</th>
<th>Model Likelihood</th>
<th>K&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Deviance</th>
<th>Evidence Ratio (w&lt;sub&gt;1&lt;/sub&gt;/w&lt;sub&gt;i&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>{S(treatment)}</td>
<td>47.907</td>
<td>0.000</td>
<td>0.336</td>
<td>1.000</td>
<td>2</td>
<td>43.876</td>
<td>1.00</td>
</tr>
<tr>
<td>5</td>
<td>{S(treatment+season)}</td>
<td>48.377</td>
<td>0.471</td>
<td>0.266</td>
<td>0.790</td>
<td>5</td>
<td>38.224</td>
<td>1.27</td>
</tr>
<tr>
<td>3</td>
<td>{S(treatment+age)}</td>
<td>49.536</td>
<td>1.629</td>
<td>0.149</td>
<td>0.443</td>
<td>3</td>
<td>43.474</td>
<td>2.26</td>
</tr>
<tr>
<td>4</td>
<td>{S(treatment+kg)}</td>
<td>49.871</td>
<td>1.965</td>
<td>0.126</td>
<td>0.374</td>
<td>3</td>
<td>43.810</td>
<td>2.67</td>
</tr>
<tr>
<td>2</td>
<td>{S(treatment+sex)}</td>
<td>49.923</td>
<td>2.016</td>
<td>0.123</td>
<td>0.365</td>
<td>3</td>
<td>43.861</td>
<td>2.74</td>
</tr>
<tr>
<td>6</td>
<td>{S(treatment+time)}</td>
<td>65.058</td>
<td>17.151</td>
<td>0.000</td>
<td>0.000</td>
<td>15</td>
<td>33.795</td>
<td>5606.83</td>
</tr>
<tr>
<td>7</td>
<td>{global S(treatment*time)}</td>
<td>94.335</td>
<td>46.429</td>
<td>0.000</td>
<td>0.000</td>
<td>30</td>
<td>29.239</td>
<td>NA</td>
</tr>
</tbody>
</table>

<sup>a</sup> Number of parameters.
Figure 3-1. 95% and 50% fixed kernel estimates of coyote home ranges, (A) winter 2006-2007, (B) summer 2007, and (C) winter 2007-2008. Sterile home ranges are represented by cross-hatch, Piñon Canyon Maneuver Site, Colorado.
Figure 3-2. Coyote residency rates (± 95%CI) from the top model, \( R\{\text{treatment+season}\} \), in 4-month coyote season increments for sterile and intact coyotes on the Piñon Canyon Maneuver Site, Colorado, December 2006-March 2008.
Figure 3-3. Coyote survival rates (± 95%CI) from the second-ranked model, $S\{\text{treatment+season}\}$, in 4-month coyote season increments for sterile and intact coyotes on the Piñon Canyon Maneuver Site, Colorado, December 2006-March 2008.
Coyote (*Canis latrans*) management in the U.S. has a long and contentious history that began with the settling of the West (Reynolds and Tapper 1996). Initial efforts to reduce predation on livestock focused on lethal control of canid populations (Reynolds and Tapper 1996). Today, public outcry challenges the use of lethal control and solicits more humane management practices (Arthur 1981, Kellert 1985, Andelt 1987, Messmer et al. 2001). However, methods which are used in confined agricultural settings such as animal husbandry, guard dogs, and aversive conditioning (Mitchell et al. 2004) are not practical with wild, free-ranging ungulates. Recently, coyote predatory behaviors toward sheep have been changed using surgical sterilization (Bromley and Gese 2001a). This approach is more acceptable to the public (Arthur 1981, Kellert 1985, Andelt 1987, Messmer et al. 2001) and has the potential to be more effective than lethal control (Conner et al. 2008) because it leaves territorial coyote packs essentially guarding a pup-less, sterile home range (Bromley and Gese 2001b). The lack of pups in sterile coyote packs is believed to be the mechanism which has reduced predation on domestic sheep (Till and Knowlton 1983, Knowlton et al. 1999, Bromley and Gese 2001a).

Key to the implementation of sterilization is that the coyotes’ hormone systems remain viable. Without functional physiological stimuli, coyotes are likely to lose motivation to maintain pair-bonds and territorial behaviors (Asa 1995). If these behaviors are not maintained, then intact coyotes are likely to displace the pup-less pack, defeating

Surgical sterilization of canids is being contemplated under several management scenarios. Studies have focused on population reduction, sterilization as a model for immunocontraception, prevention of genetic introgression, and reducing predation on livestock (Haight and Mech 1997, Kelly et al. 1999, Bromley and Gese 2001a, Saunders et al. 2002). In some of these situations, the goal was a simple reduction in population size (Haight and Mech 1997, Saunders et al. 2002). But there is also evidence that surgical sterilization can change the predatory behaviors of canids. In Utah, sterile coyote packs killed 8-fold fewer sheep than intact coyote packs (Bromley and Gese 2001a). The results of this study led us to hypothesize that surgical sterilization of coyotes may also reduce predation on ungulate neonates; a circumstance where management typically has only been able to practice lethal control. We chose to focus our efforts on pronghorn (Antilocapra americana) fawn survival due to high fawn mortality rates associated with coyote predation (Gerlach and Vaughan 1990, Linnell et al. 1995, Byers 1997, Dunbar and Giordano 2003).

Our study was designed in such a way as to compare not only changes in pronghorn fawn survival between a treatment and control group, but to also compare changes in fawn survival between years before and after treatment. This approach allowed us to detect a difference in fawn survival rates that existed between the north (0.183, 95%CI = 0.071-0.396) and south areas (0.034, 95%CI = 0.008-0.139) and was apparent in both years (z = 1.744, P = 0.080). Knowing that one area (the south) had lower survival rates, we applied treatment there. Additionally, we accounted for
variability in the system (fawn gender, fawn birth weight, fawn age, fawn birth date, coyote density, and alternative prey abundance) in an attempt to find the most parsimonious model to represent ecological reality.

Since our experiment was conducted in a free-range setting (i.e., not in captivity), we had to account for variables which could not be controlled. In fitting data to a set of models, a balancing act is played between reducing bias and reducing variance (Burnham and Anderson 2002). The most parsimonious model will fall somewhere in between. The number of parameters included in our suite of models affects the fit of our data. As we increased the number of parameters (variables), we decreased the bias in our estimates. However, this comes at the cost of increasing variance in our estimates. It is perhaps the case that we struck the balance in favor of low bias, as our level of confidence in our estimates was marked with some uncertainty. However, given the amplitude of the difference in estimates (cumulative survival of fawns captured in intact coyote home ranges was 0.18 and cumulative survival of fawns captured in sterile coyote home ranges was 0.44), we believe that coyote sterilization has a relevant effect on pronghorn fawn survival. If coyote predation on fawns generates additive mortality in a pronghorn population that is struggling to persist, then this technique holds important prospects.

In addition to the importance of treatment effects, it is critical to test that coyotes maintain their territorial behaviors. Without this, packs likely will not defend a home range and the area will fall to occupation by intact coyotes. Because only one study has previously shown that sterile coyotes will maintain a home range, the importance of confirming the retention of pair-bond and territorial behaviors was apparent. Some of our findings did not clearly demonstrate the maintenance of home ranges in sterile coyotes:
we found greater home range and core area overlap between sterile packs than intact packs in some seasons. However, we do not believe these results were the effects of sterilization. The home range and core area overlaps in the sterile packs were consistent from the beginning of the study, indicating that this pattern likely existed before experimental treatment was applied. Hence, we believe that these differences between sterile and intact packs were characteristic of the packs before they were sterilized. Other than these discrepancies, all other measured characteristics between the treatment and control group were the same. Pack sizes were the same for sterile and intact coyotes and home range sizes remained consistent through all 3 seasons and were the same between the sterile and intact packs. Residency and survival rates for sterile and intact coyotes were also similar.

Our results suggest that sterilization of coyotes could be a useful tool to reduce predation on free-ranging pronghorn fawns. Trends in public opinion demonstrate a need for non-lethal alternatives when managing wildlife. Currently, the only practical non-lethal method to reduce predation in these situations is through reproductive interference. When ungulate populations are low or persistence is threatened, several management techniques may be needed to preserve the local population. Careful analysis of the situation may conclude that predation management is necessary. When lethal control is unacceptable or ineffective, surgical sterilization is a practical alternative.

**LITERATURE CITED**


