Mountain Sheep in California: Perspectives on the Past, and Prospects for the Future

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Abstract: The status of mountain sheep (*Ovis canadensis*) in California is reviewed from historical, taxonomic, and political perspectives. Early conservation efforts were primarily passive, resulting in a largely unsuccessful strategy that continued well into the 20th century. In the late 1960s, the California Department of Fish and Game (CDFG) initiated formal surveys to ascertain the status of this species. As a result, recommendations were put forth regarding conservation actions believed to benefit mountain sheep. Since then, management has been proactive rather than passive, and has centered on habitat protection, habitat enhancement, and population restoration, but those efforts have been confounded by legislation and conflicting public opinion. Today, not all activities deemed appropriate for conservation purposes are well received by some members of the public, and disagreements arise frequently between conservation activities and individuals who are philosophically opposed to active intervention on behalf of mountain sheep. Unfortunately, actions of managers can be detrimental to landscape-level efforts to conserve this species if they are carried out in the absence of public support. For conservation to be successful, wildlife managers and land managers should not invoke strategies that are illogical, or appear to be founded on “beliefs” rather than on science. Future conservation successes are in the hands of those charged with that task. Bad decisions and inappropriate justifications will be detrimental to conservation activities in the future, particularly as they relate to recommendations that are perceived by the affected public to be unnecessary or otherwise without merit.

Key words: bighorn sheep, conservation, history, management, mountain sheep, *Ovis canadensis*

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Mountain sheep (*Ovis canadensis*) are endemic to North America, and occupy suitable habitat from the northern Rocky Mountains in western Canada, southward through the western United States, to northern Mexico (Trefethen 1975). In California, mountain sheep are found in the Mojave, Sonoran, and Great Basin deserts, in the transverse ranges of southern California, and in the Sierra Nevada (Weaver 1975). The number of mountain sheep in California currently is about 4,500 individuals, but precise statewide estimates are unavailable (Epps et al. 2003).

Previously, mountain sheep were more numerous in California (Buechner 1960). Based on the current distribution of mountain sheep, and the large number of extirpated populations (Wehausen et al. 1987*a*), a reasonable estimate may be 10,000 individuals at the end of the 18th century. To the best of our knowledge, those animals were distributed among approximately 100 populations, the majority in southeastern California (Wehausen et al. 1987*a*). Currently, some 63 extant populations occur in California (Epps et al. 2003). Because some mountain ranges contain multiple populations as defined by the distinct distributions of female groups, there are more populations than there are mountain ranges supporting this species (Wehausen et al. 1987*a*). Populations of mountain sheep in California have been grouped into 7 metapopulations for purposes of management and conservation planning (Torres et al. 1994, 1996; Epps et al. 2003). Those metapopulations occur in the Sierra Nevada, San Gabriel Mountains, and mountain ranges in the Mojave, Sonoran, and Great Basin deserts (Bleich et al. 1996*b*).

Throughout much of the range occupied by these native ungulates, the downward trend in numbers began with the human settlement of vast, uninhabited areas (Buechner 1960). Much attention has been given to the potential impacts of unregulated market hunting associated with the influx of gold mining during the 1850s (Buechner 1960). Another, more onerous, decimating factor likely was the introduction of livestock, primarily domestic sheep, throughout much of the range of mountain sheep (Buechner 1960). Indeed, Francisco Garces, who chronicled the expeditions of Father Anza as he traveled north and west from what is now Arizona toward the Pacific coast of California, described dead and dying mountain sheep in the Santa Rosa Mountains of southern California as early as 1776 (Bolton 1930). Moreover, a legend that describes a pestilence killing many wild sheep in northern Mexico following the arrival of the Spaniards and their livestock persists among the Kaliwa Indians of Baja California (Tinker 1978).

Following discovery of gold in California, a number of populations of mountain sheep were extirpated, but the causes of those losses remain speculative. Despite that uncertainty, the obvious losses of mountain sheep and other wildlife populations resulted in the initiation of legal protection for mountain sheep and other big game species. In 1872, the California Legislature passed a law protecting elk, pronghorn, and deer for 8 months of the year. In 1878, the Legislature amended the Act to establish a four-year moratorium on the taking of any elk, pronghorn, female deer, or mountain sheep. In 1883, the moratorium on the taking of mountain sheep was extended indefinitely, and in 1933 mountain sheep became the first species in California to receive "full protection" by the California Legislature (CDFG 2005). Despite the well-intentioned efforts of the California Legislature, however, total protection did not halt the loss of mountain sheep in California.

Populations continued to disappear up to the present (Epps et al. 2003). At least 45 populations disappeared in California since 1850 (Wehausen et al. 1987*a*); 50% of them since 1920. About 30% of the populations in 1920 no longer exist. These figures suggest that the rate of population loss declined little, if any, despite effective wildlife law enforcement since about 1920 (Wehausen et al. 1987*a*).

Persistent losses suggested that legislative protection did not affect factors primarily responsible for the extirpation of mountain sheep in California. Indeed, assumptions inherent in the concept of total protection likely revolved around the notions that (1) over-hunting was a cause of extirpations, and (2) that protected populations would increase in size and expand into unoccupied habitat. Both of these assumptions were faulty (Wehausen et al. 1987*a*): the first failed to consider the potential role of diseases and habitat destruction, and the second was erroneous, because mountain sheep are notoriously slow to disperse from occupied ranges (Geist 1971). Nonetheless, conservation actions continued to focus on total protection and, with minor exceptions, these specialized ungulates retain "fully protected" status.

Nomenclature

Until recently, taxonomists recognized three subspecies of mountain sheep in the state, including *O. c. californiana* (which was thought to occur throughout the Sierra Nevada and historically in northeastern California), *O. c. nelsoni* (which occurs throughout the majority of the Mojave and Sonoran deserts and in the transverse ranges of southwest California), and *O. c. cremnobates* (which occupied the peninsular ranges located primarily near the border with Mexico) (Cowan 1940). In a recent taxonomic revision (Wehausen and Ramey 2000), animals in the Sierra Nevada were designated *O. c. californiana* and are the only representative of that taxon; at the same time, all other wild sheep formerly designated as *californiana* were synonymized with *O. c. canadensis*, and are now recognized as the Rocky Mountain subspecies. Mountain sheep in the peninsular ranges, formerly the subspecies *cremnobates*, were synonymized with *O. c. nelsoni*, and no longer are considered a distinct subspecies (Wehausen and Ramey 1993). To further complicate nomenclature, assignment by Wehausen and Ramey (2000) of sheep in the Sierra Nevada to the subspecies *californiana* was in error. Joseph Grinnell (1912) assigned the subspecific epithet *sierrae* to animals he described from the Sierra Nevada before Cowan (1940) published his revision of the taxonomy of North American mountain sheep. Because Wehausen and Ramey (2000) synonymized *californiana* with *canadensis*, and because sheep in the Sierra Nevada warrant subspecific recognition, judicious application of the rule of priority as it appears in the International Code of Zoological Nomenclature dictates they are once again assigned to the subspecies *sierrae* (Wehausen et al. 2005).

Legal Status

There were a number of legislative attempts to change the status of mountain sheep to that of a game animal. One such attempt occurred in 1922, when Senate Bill 527 proposed an open season, with a $100 license fee and tag system; the legislation was unsuccessful. In 1979, Senate Bill 83 proposed that the Nelson subspecies be classified as a game animal, while maintaining threatened status for the other two subspecies then recognized, but the legislation also was defeated. In 1983, Assembly Bill 1548 proposed the same changes as Senate Bill 83, but also emphasized the need for a statewide study of the status of populations, effects of competition and disease, and reintroduction needs in accordance with a study plan prepared earlier by the Department of Fish and Game; Assembly Bill 1548 also failed to gain approval. The Legislature did, however, allocate monies for the investigations called for in the failed legislation. Resulting research yielded important information related to capture methods (Kock et al. 1987*a*, *b*, *c*), status of diseases among mountain sheep populations (Clark et al. 1985, 1993), importance of nutrition and effects of cattle grazing on mountain sheep (Wehausen 1989), and long-term syntheses of behavioral (Bleich et al. 1997) and demographic phenomena (Wehausen 2005).

In 1986, the Legislature passed Assembly Bill (AB) 3117, which reclassified mountain sheep as game animals in two geographic areas but retained fully protected status for all other populations. In part, passage of AB 3117 occurred because both reclassified populations had provided large numbers of animals for translocation stock, circumventing arguments that limited sport hunting would jeopardize them (Wehausen et al. 1987*a*). The bill also provided that one sheep hunting tag could be made available for fund raising on an annual basis, and stipulated that the number of permits offered would not exceed 15% of the mature males counted annually in each population. Assembly Bill 3117 also contained a sunset clause, perhaps making it more palatable to legislators concerned about potential impacts of hunting on the targeted populations.

Subsequently, additional legislation eliminated the sunset clause and provided the Fish and Game Commission the authority to consider additional hunting opportunities for mountain sheep, required the Department to prepare management plans necessary for the conservation of subpopulations, and authorized an additional fund-raising tag to be issued if a minimum number of permits was available to the general public on a drawing basis during any particular year. This action did not occur without protest; nonetheless, it is law in California, and mountain sheep inhabiting 6 geographic areas will be game animals during the legal hunting season in 2006. They will retain fully protected status for the remainder of the year.

Threatened or Endangered Status

During the early 1970s, the Legislature enacted the California Endangered Species Act, and two of the subspecies of mountain sheep then recognized were listed as “rare” by the California Fish and Game Commission (CDFG 2005). Indeed, *O. c. californiana* and *O. c. cremnobates* were limited in distribution and presumed to be distinct (Cowan 1940). As a result of State listing, recommendations were made for the development and implementation of recovery plans for each subspecies. Both of these listings subsequently were revised to threatened, and mountain sheep in the Sierra Nevada eventually were uplisted to endangered by the Fish and Game Commission (Epps et al. 2003).

Mountain sheep in the peninsular ranges, formerly recognized as *O. c. cremnobates*, were listed in 1998 as an endangered population segment by the U. S. Fish and Wildlife Service, and sheep in the Sierra Nevada similarly were listed by the federal government a year later (Epps et al. 2003). With federal involvement, conservation of mountain sheep in California became more complicated. A recovery plan was completed for sheep in the peninsular ranges, and the recovery plan for sheep in the Sierra Nevada is underway (Epps et al. 2003); both plans are being implemented. In the case of sheep in the peninsular ranges, the U.S. Fish and Wildlife Service remained the lead agency for recovery, but no funding to implement recovery actions became available as a result of the listing process. Recovery efforts in that range are being implemented by a number of governmental and non-governmental organizations. A primary rationale for listing these animals as endangered was the threat of continued loss or modification of habitat (USFWS 2000). Disease(s) may have been a factor in the depression of recruitment rates beginning in the late 1970s (Wehausen et al. 1987*b*) and, as a result, could have contributed to a population decline prior to listing (USFWS 2000), but subsequent investigations (Boyce 1995) did not yield evidence that disease resulted in a demographic consequence. The most important source of mortality in the peninsular ranges was identified as predation (Hayes et al. 2000).

In the Sierra Nevada, the California Department of Fish and Game was asked by the U.S. Fish and Wildlife Service to serve as the lead agency with respect to recovery of mountain sheep (Bleich 2001). Substantial funding was made available by the California Legislature, and currently 6 employees work full time on the recovery effort. Nonetheless, funds could be reduced at any time due to the fiscal crisis currently facing California. Predation by mountain lions, and resultant affect on habitat use by mountain sheep (Wehausen 1996) are suggested as primary factors in the decline in the Sierra Nevada. Although viable, the hypothesis is not universally accepted as the single causative factor. Objectives of the recovery effort include minimizing mortality of mountain sheep and restoring sheep to historically occupied ranges (Sierra Nevada Bighorn Sheep Recovery Program [SNBS] 2004). Recently, the potential risk of domestic sheep to wild sheep again surfaced as an important issue, and controversy surrounding grazing privileges on public lands is increasingly apparent (SNBS Recovery Program 2006).

Management History

Until recently, management of mountain sheep in California centered largely around an active water development program in desert areas, ongoing since about 1950 (Weaver et al. 1959). Modern management and conservation efforts began in 1968, following passage of Senate Resolution 43, which resulted in the most detailed statewide survey of the species ever conducted. Until then, basic inventory data consisted of information gathered during cursory statewide surveys that occurred in 1940, 1946, and 1957 (Buechner 1960, Berger 1990, Wehausen 1999). Senate Resolution 43 provided funding to conduct the survey during 1968 through 1972. The population was estimated at 3,700 mountain sheep (Weaver 1975), and for the first time the management needs of mountain sheep, including land-use conflicts, habitat acquisition, water development needs, and translocations were addressed comprehensively (Weaver 1972).

The first effort to reestablish mountain sheep on historically occupied ranges in

California occurred in 1971 when 10 animals were captured in British Columbia and placed in an enclosure at Lava Beds National Monument, Siskiyou County (Blaisdell 1972). The population persisted until 1980, when a die-off wiped out the entire population (Weaver 1983), perhaps a result of diseases contracted from domestic sheep (Foreyt and Jessup 1982). Prior to the die-off, 4 sheep from Lava Beds were translocated to the Warner Mountains, Modoc County, in an effort to establish a population in extreme northeastern California (Sleznick 1980); those sheep were supplemented in 1980 with 10 from the Sierra Nevada (Camilleri and Thayer 1982). Mountain sheep seemingly did well in the Warner Mountains until 1988, when the entire population died as a result of disease thought to be associated with direct contact with domestic sheep grazed legally in the area (Weaver and Clark 1988).

In 1979, efforts to reestablish mountain sheep on historical ranges in the Sierra Nevada were initiated, and 102 individuals were translocated to 3 formerly occupied areas. Animals were moved from the Mount Baxter winter range at Sand Mountain to Wheeler Ridge (1979, 1980, 1982, 1986), Mount Langley (1980, 1982), and Lee Vining Canyon (1986, 1988) (Bleich et al. 1990*b*, 1996*a*). Additionally, more than 400 mountain sheep were translocated in efforts to establish populations in 9 vacant mountain ranges in the Mojave Desert, and in the transverse ranges of southwest California (Bleich et al. 1990*b*). Sources of animals were Old Dad Peak and the Marble Mountains, both of which figured prominently in the passage of AB 3117, and the San Gabriel Mountains, once recognized as the largest population of *O. c. nelsoni* (Holl and Bleich 1983, Holl et al. 2004). There have been translocations to establish additional populations of wild sheep in California since 1992, although several populations were augmented.

Other Management Challenges

The majority of mountain sheep in California are not categorized as endangered, but conservation efforts were severely affected by recent federal legislation. In 1994, Congress passed the California Desert Protection Act (CDPA) that established more than 70 new wilderness areas in the Sonoran, Great Basin, and Mojave deserts of California, elevated the status of Death Valley National Monument and Joshua Tree National Monument to national parks and expanded their boundaries, and created a new National Park Service unit known as Mojave National Preserve. Proponents argued that the legislation was necessary to protect the desert from future threats, despite the intensive efforts of the Bureau of Land Management (Bleich 2005). Indeed, the California Desert Conservation Plan had established some wilderness areas, identified areas with emphasis on special uses, and provided for the aggressive and productive management of mountain sheep and their habitats (Bureau of Land Management [BLM] 1980). Moreover, BLM had been an important cooperator in the management of sheep habitat for many years.

The California Desert Protection Act resulted in many changes in conservation activities for mountain sheep, and how and where those efforts occur. The Act provided for the use of motorized equipment within the newly established wilderness areas for purposes of conservation activities on lands managed by BLM, but individual opinions expressed by agency staff frequently complicated conservation efforts (Bleich 1999). A lack of consistency in interpretation of legislation and regulations was identified as an onerous aspect of wilderness management affecting conservation of mountain sheep (Bailey and Woolever 1982).

The CDPA did not specifically authorize construction or development of additional water sources in wilderness areas, but did indicate they may occur pending compliance with the National Environmental Policy Act. Nonetheless, there were no new developments since the CDPA, largely because of actions by wilderness advocacy groups and despite the existence of hundreds, if not thousands, of kilometers of roads, widespread evidence of historical mining activity, and many anthropogenic structures distributed among nearly all of the recently designated wilderness areas (Bleich 2005). Lawsuit after lawsuit has been filed to prevent the construction or development of any water source that would benefit mountain sheep conservation. As a result, conservation activities for mountain sheep in California declined dramatically both numerically and spatially.

The California Desert Protection Act stated plainly, "Nothing in this act shall be construed as usurping the responsibility of the state agency with respect to wildlife management decisions within the preserve." Remarkable progress has been made with respect to conservation issues between the state agency having responsibility for wildlife management decisions and the National Park Service. Nonetheless, the first translocation of mountain sheep from the Mojave National Preserve occurred > 8 years after passage of the CDPA, and after > 3years of negotiations. It is possible that resolution to the question of stewardship responsibilities for wildlife within the preserve will be fully resolved only through the legal system.

What the Future Holds

Mountain sheep in California benefited from a diverse and ambitious conservation program (Bleich and Torres 1994). Nonetheless, the future of mountain sheep conservation in California is uncertain, and conservation activities may become more and more difficult to implement. Indeed, recent legislation complicated working relationships among agencies that formerly worked cooperatively to conserve these magnificent ungulates (Bleich 2005). Further, designation of some 70 wilderness areas complicated efforts to manage these herbivores on a landscape level and facilitate the persistence of metapopulation processes (Bailey 1982). Failure to adequately protect areas outside designated wilderness has implications for the long-term persistence of mountain sheep in the metapopulation structure (Schwartz et al. 1986, Bleich et al. 1990*a*, 1996*b*, Krausman 1997, Epps 2005) in which they presumably exist. Indeed, development associated with roads, agriculture, and urbanization has major implications for recolonization of vacant habitat (Bleich et al. 1996*b*) and gene flow (Epps et al. 2005) and, ultimately, for the persistence of small populations that will become increasingly isolated as a result of human actions (Bleich 1999, 2005). Moreover, interagency competition and bureaucratic inertia resulted in failure of efforts to translocate mountain sheep to vacant habitat, cancellation of augmentations to small populations seemingly faced with extinction, and even failure to manage exotic species, such as feral asses, that are problematic for native wildlife yet are deemed appropriate components of wilderness (Bleich 2005). I believe it incongruous that seemingly well-intentioned legislation actually precludes implementation of conservation actions designed to benefit large, native mammals eliminated from so many areas as a result of human actions.

Similarly, efforts to enhance the persistence of small populations of mountain sheep are questioned because they are deemed inappropriate activities within wilderness. The majority of those areas in the deserts of California include a single mountain range coincidentally occupied by a (sometimes tiny) population of mountain sheep, and those ranges are separated from other populations by many kilometers of desert flats subject to many anthropogenic modifications.

My concerns about the conservation of mountain sheep in the future are confounded further by issues beyond the control of individual management agencies. For example, Epps et al. (2004) used modeling to infer the probable extinction of additional populations of mountain sheep as a consequence of global warming. Consequences include decreased availability of water sources and changes in vegetation characteristics, both of which have important implications for the persistence of mountain sheep in arid environments. Indeed, other investigators suggest major changes in vegetation composition and structure at the landscape level (Bachelet et al. 2001, Root et al. 2003). Such changes cannot be good for mountain sheep, nor for other species (including our own) inhabiting this planet called Earth.

Conservation actions on behalf of mountain sheep will, I believe, have important implications for the continuation of the Endangered Species Act (ESA) if they are unwise, economically damaging, or not based on credible science. Mountain sheep conservation efforts have the potential to affect real estate development worth billions of dollars, much of which is owned by politically well-connected individuals who have no desire to incur economic hardship on behalf of "some animal". As a result, implementation of recovery efforts and recommendations for habitat protection should be well founded and cooperative. In my opinion, anything less could jeopardize the ESA as currently written. The effects of mountain sheep conservation on economic development, and vice-versa, will be increasingly important in the future.

Current proposals to modify livestock grazing on lands managed by the U.S. Forest Service and BLM in the eastern Sierra Nevada, no matter how well intentioned, should include some guarantee no threat to the livelihoods of those with grazing privileges. Further, evidence accumulating rapidly in the Sierra Nevada suggests that conservationists must not only be concerned with husbandry of domestic sheep, but also with the behavior of wild sheep (SNBS Recovery Program 2006). Conservation actions should consider the ramifications of restoration efforts relative to other land uses. Indeed, movements by wild sheep in the Sierra Nevada potentially place grazing privileges on hundreds of thousands of hectares of federal land at risk. Those risks have ramifications for grazing of domestic sheep throughout the west and, ultimately, for the ESA. Recognition of impacts to private enterprise, cooperative approaches to resolving conflicting uses, and some level of compromise will be necessary components of future conservation efforts.

Endangered species advocates should ensure that their recommendations are credible and well-founded. The public and, I suspect, politicians in particular have difficulty tolerating illogical decisions or recommendations. For example, some individuals advocate use of trails in the peninsular ranges be curtailed, or even eliminated, to enhance recovery of mountain sheep. Yet, many of the same individuals strongly advocate research activities that are highly dangerous to individual animals (Turner et al. 2005). I don't believe one can argue that an individual who has been riding a horse up and down a trail for more than 40 years must curtail his/her activities to help conserve sheep, and simultaneously state that using a helicopter and net-gun to capture and collar the last females remaining in the same general area is legitimate because it constitutes a research activity. The public will not accept such logic. Further, continued releases of captive-bred mountain sheep from a facility with a history of diseases (Ostermann et al. 2001) into areas occupied by the endangered sheep in the peninsular ranges (Ostermann et al. 2001, Turner et al. 2005) challenge the credibility of scientists charged with maintaining separation between domestic sheep and the endangered sheep in the Sierra Nevada. In the absence of logic and credibility, restoration and conservation of mountain sheep, and the ESA in particular, will be subjected to intensified scrutiny and potentially devastating political consequences.

Hunters and those opposed to the take of wild animals for sport have long been at odds with respect to what constitutes conservation and acceptable uses of wildlife resources. Both groups have intense interests in the well-being of wildlife populations, but they must learn to work cooperatively to ensure they have the option of disagreeing in the future. Unless all those concerned with the well-being of wild sheep offer concerted effort to ensure that habitat is protected, that movement corridors remain intact, that habitat is managed to enhance conservation objectives, and that bureaucratic ideologies are modified to facilitate maintenance of viable populations, the future of wildlife conservation will be ever more challenging.

There are many successes with respect to the conservation of wild sheep in California, and they came about as a result of the efforts of many people, in many agencies working cooperatively on behalf of the species. Many individuals, including Don Landells and Jim Bicket, with whom I worked closely on innumerable projects to benefit wild sheep, have been a source of encouragement and entertainment, and were the best of companions. Many evenings spent around campfires in the Mojave Desert while we sipped cheap beer or good tequila, and played banjos and guitars, ended with discussions of the future for mountain sheep in the deserts of California. Some of the ideas in this essay had their origins around those campfires. It was our collective opinion that mountain sheep, at least in California and, perhaps, throughout the west, had the potential to instill great controversy and, because of that alone, could have important implications for the future of wildlife conservation. I trust that others concerned with the conservation of mountain sheep have the foresight to recognize this, and will rise to the many challenges of the future. For this to occur, however, more people must understand and practice a conservation ethic (Tsukamoto 1986). If we are unable to do so, conservation efforts will be less effective, and the future of mountain sheep will be increasingly less certain.

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Decreased Horn Basal Circumference in Bighorn Sheep Rams Following Asymptote of Population Growth Curves

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Abstract: Large horn size in harvested trophy bighorn sheep (*Ovis canadensis*) is associated with high monetary return to states and provinces that sell hunting licences. Revenues are directed towards wild sheep management programs, therefore options to produce large rams are of particular concern to wildlife managers. Translocated populations of Rocky Mountain bighorn sheep in alpine habitat in New Mexico grow rapidly, often doubling every 3 yr and produce rams with significantly larger mean horn basal circumference than rams harvested from the source population. The source population exhibited asymptotic growth curves hypothesized to be associated with a density dependent response to resource limitation as reflected in decreased basal horn circumference. In the Pecos Wilderness population started in 1965, basal horn circumference was significantly larger ($\boldsymbol{P} < 0.02$) prior to the asymptote of population growth for mature ($\geq$ 6 yr $\text{mean}_{\text{base}}$ = 14.9 in vs. 14.4 in; mean_{age} = 7.9 yr vs. 8.6 yr) and immature rams (< 6 yr; $\text{mean}_{\text{base}}$ = 14.4 in vs. 13.5 in; mean_{age} = 4.3 yr vs. 4.3 yr). The Wheeler Peak population started in 1993 with 33 bighorn sheep translocated from the nearby Pecos Wilderness population. Harvest of mature rams born post-translocation in Wheeler Peak began in 2000. Mature rams harvested in the Wheeler Peak population had significantly larger ($\boldsymbol{P} < 0.001$) mean basal circumferences ($\text{mean}_{\text{base}}$ = 15.7 in; mean_{age} = 7.9 yr; n = 16) than those harvested simultaneously from the source population ($\text{mean}_{\text{base}}$ = 14.1 in; mean_{age} = 8.4 yr; n = 28). In addition, horn length (39.2 in vs. 35.7 in) and Boone and Crockett scores (184.4 in vs. 164.8 in) were significantly greater for Wheeler rams than for Pecos. To date, rams born after the asymptote of the population growth curve in Wheeler Peak have not been harvested. Minimizing the reduction of horn basal circumference by keeping bighorn populations below carrying capacity is a management goal in New Mexico. The effects of experimentally-lowered populations on horn size have been limited because population reduction using translocation only has not been effective. Ewe harvests will be required to better understand this relationship.

BIENN. SYMP. NORTH. WILD SHEEP AND GOAT COUNC. 15: 14

Key words: Bighorn sheep, horn size, New Mexico, *Ovis canadensis*, population growth.

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Ramifications of the Hunt: Horn Growth, Selection, and Evolution of Bighorn Sheep in British Columbia

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Abstract: Natural and artificial selection may work in opposing directions on horn size in wild sheep. The horns of bighorn sheep (*Ovis canadensis*) rams are both a heritable, fitness-related trait and a trait selected by trophy hunters. Population management regimes for sheep trophy hunting in British Columbia are based primarily on sex and horn-curl criteria. The potential selective, evolutionary effect of these management strategies has only recently attracted attention. If trophy hunting is an artificial selection pressure expressed by the removal of the largest or fastest-growing males from the population, the fitness of large-horned rams should decrease, and small-horned rams may be favoured. Compulsory inspection data for hunter-harvested bighorn sheep rams have been recorded in British Columbia since 1975. Analysis of total horn length and growth annuli measures provides an excellent opportunity to assess temporal trends in ram horn size, and explore relationships among horn growth and harvest management strategies. Preliminary analyses show a strong correlation between early horn growth and harvest age: rams with fast-growing horns are shot at a younger age than rams with slow-growing horns. This result has implications for individual reproductive success because rams with large horns may have a shorter life expectancy. Measuring a phenotypic response to artificial selection on a heritable trait is of evolutionary and conservation interest. Our findings suggest that trophy sheep management based on minimum horn-curl criteria and unlimited-entry hunts may over time favour rams with slow-growing horns.

BIENN. SYMP. NORTH. WILD SHEEP AND GOAT COUNC. 15: 15

Key words: bighorn sheep, British Columbia, harvest management, horn growth, *Ovis canadensis,* phenotypic response.

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Influence of Trophy Hunting and Habitat Degradation on Horn Growth of Bighorn Sheep

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Abstract: Knowing the length of each horn increment helps us gain insight into the main factors influencing growth and condition of bighorn (*Ovis canadensis*) rams. Trophy hunting management requiring a minimum horn size for animals to be harvested may select against the desired trophy phenotype if it increases the mortality of individuals with large horns. I analyzed a 25-yr data set on horn growth and age of harvested bighorn sheep rams in two populations in the southern interior of British Columbia to investigate temporal trends in horn size. I assessed the effects of population density, weather, and trophy hunting on horn growth in two populations, one (Ashnola) managed on a limited-entry draw and one (south Okanagan) managed as unlimited-entry for B.C. residents. The yearling horn increment in harvested rams decreased by 10% over 25 yr in the south Okanagan but was unchanged in the nearby Ashnola population over the same time period. Habitat deterioration and selective hunting may have driven the decline in yearling increment in the south Okanagan. Intense hunting may have selected for smaller-horned rams in the south Okanagan, although habitat deterioration also may have contributed to a temporal decline in horn growth. Rams shot at a younger age had greater early horn growth than rams shot at an older age. Rams with the fastest growing horns were removed as early as 3 yr, before they had the opportunity to reach high dominance status and achieve many paternities. Rams with fast-growing horns may be selected against under ¾ curl, unlimited-entry regulations. Long-term data on biological indicators such as horn annuli length, along with genetic information are useful tools for wildlife managers to monitor wildlife habitat and population quality, and can aid in the management and conservation of wild sheep and other terrestrial mammals.

BIENN. SYMP. NORTH. WILD SHEEP AND GOAT COUNC. 15: 16

Key words: bighorn sheep, biological indicator, British Columbia, conservation, habitat degradation, horn growth, *Ovis canadensis*, population quality, trophy hunting.

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Complications in Dall Sheep Management in Alaska: A Case of Agency Abdication?

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Abstract: Eighteen years ago, the Alaska Department of Fish and Game (ADF&G) essentially withdrew from Dall sheep (*Ovis dalli dalli*) management. This withdrawal was driven by a regulatory change which defined surplus Dall sheep for harvest as full curl rams. Subsequently, changes in prevailing weather put sheep populations in decline throughout the state. About the same time predator management was suspended. Eventually, the abundance and subsequent annual harvest of mature rams declined from an average of almost 1,200 to the all-time low of 650 rams. In 2004 declining harvests coupled with rumors of significant harvests of sub-legal rams lead to mandatory inspection of most harvested rams. This meant ADF&G and enforcement wardens were to determine whether harvested ram horns met legal harvest criteria. A number of "litmus tests" which were not accountable to the legal or geometric definitions were developed, and confusion reigned. Almost a quarter of the reported ram harvest in 2004 and 2005 was not recorded as inspected. Data indicated a violation rate of about 1%. Nevertheless, the Alaska Board of Game increased the demand on the Department to inspect and plug most harvested ram horns. In this paper, I suggest these actions were inappropriate for Alaska's management needs. I also argue agency abdication of management responsibility, including user education to facilitate respect for regulations, led to this chain of events, and probably was causative. Managers are reminded that there is more to management than setting seemingly conservative seasons and bag limits.

BIENN. SYMP. NORTH. WILD SHEEP AND GOAT COUNC. 15: 17-27

Key words: Dall sheep, full curl regulation, harvest, horn plugging, management.

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Over the last 20 yr, the Alaska Department of Fish and Game (ADF&G) had minimal success in influencing Dall sheep (*Ovis dalli dalli*) management decisions in Alaska. Changes were driven by biologically aware hunting interests outside ADF&G and generally (and unsuccessfully) were opposed by the Department. The first purpose of my paper is to chronicle and comment on the history of this development and show it is possible to change harvest regulations which are inimical to management success. Secondly, the paper may serve as a reminder to managers that successful regulation of wildlife harvests is best based on species biology which is adequately communicated to the public.

History

ADF&G withdrawal from sheep research/management. The most effective way to manage Dall sheep has been made a subject of controversy (Whitten 2001, Heimer et al. 2002). On one hand, the biologically aware public takes the view that sheep autecology is unique, and Alaska's Dall sheep should be managed according to what has been learned through specific research and empirical management trials such as Heimer and Watson (1990) and Heimer (1999). These studies indicate Class IV rams are the only sustainable biological surplus from a Dall sheep population living in an intact ecosystem where open hunting is allowed. Other harvest regimes in open entry hunting areas disrupt Dall sheep social behavior resulting in reduced production/survival/ recruitment and harvest of mature rams (Heimer 1990).

On the other hand, the established ADF&G-approved position is that Alaska's full-curl harvest restriction exists not for biological but for aesthetic reasons. Whitten (2001) wrote "Although many biologists disagreed with the Dry Creek [benefits of older ram presence] hypothesis, those ideas held immense appeal for traditional sport hunters because of their implication that [full curl] trophy hunting was the optimal harvest strategy for sheep. The Alaska Board of Game incrementally enacted more conservative horn curl regulations and by 1993, full-curl hunting for males only was normal for most of Alaska. *The Board still receives proposals from the public for more rigorous enforcement of full-curl-only management whenever sheep populations are faring poorly. (emphasis by the current author)* Disagreement and confusion continues among professional biologists…" [Alces 37: 484]. In summary, Whitten (2001) spoke for the Department when he said "Numerous papers expounded on various aspects of the Dry Creek hypothesis and attempted to explain how abundance of large males moderated Dall's sheep social behavior and ecology, and was the key to population vitality. Findings on which those hypotheses were based were unsubstantiated. Harvest never removed all mature males. Depressed survival of young males in the Dry Creek population never occurred. Reduced productivity could not be linked to male abundance, but was correlated with weather. *Nevertheless, regulations allowing harvest of only full-curl males now apply in nearly all general hunts for Dall's sheep in Alaska. In retrospect, restrictive horn-curl regulations were not necessary for conservation of this mountain ungulate. However, full-curl regulations have served a useful purpose (emphasis added).* In the 1990s, attention and funding for wildlife management in Alaska gravitated more toward subsistence issues and to moose [*Alces alces*], caribou [*Rangifer tarandus*], and their predators. Money for sheep research and monitoring dwindled . . . *the unanticipated benefit of full-curl management has been a hands-off, self-regulating, popular, and inexpensive regime of harvest (emphasis added).* [ALCES 37: page 492, column 2 paragraph 2, lines 1-24 and 36-38]

The italicized portions from Whitten (2001) indicate that changes to the minimal harvest size regulations for Dall sheep in Alaska were made in spite of official ADF&G opposition. Actually, this opposition was strident (Alaska Board of Game 1989a). In retrospect, the sequence of events shows ADF&G withdrew from Dall sheep management with establishment of the full-curl ram harvest regulation in 1989. In an interview published in the Alaska Foundation of

North American Wild Sheep (FNAWS) newsletter, an ADF&G Research Coordinator confirmed the position that sheep were "self-managing" under the full-curl regulation (Gordon 2003).

Population declines-weather. Two yr after ADF&G withdrew from Dall sheep management, Dall sheep populations began a notable downturn across most of Alaska. From fragmentary data gathered by ADF&G Area Biologists, the unexpected statewide decline appeared to be weather-mediated failure of lamb production during the early 1990s as "lee side" mountain weather seemed to change for the worse where sheep were concerned.

Alaska's better sheep habitats lie within mountain ranges dominantly oriented east/west across Alaska, and perpendicular to prevailing northward air movement from the Gulf of Alaska. Heimer et al. (1994) reported average ten-fold greater population densities on optimal "lee side" or snow-sheltered north-facing habitats of Alaska's prime sheep habitats. As information on the statewide lamb production failures of the early 1990s was synthesized, an explanatory hypothesis suggested that alterations in the warm Pacific Current in the Gulf of Alaska either produced more storms or set storms on atypical tracks that missed typical geographic snow barriers and produced unfavorable weather on the prime habitats (Heimer 1995).

The failures probably were not density-dependent in the classic sense, but were functions of transiently increased environmental resistance due to unfavorable weather effects on lamb production. Dall sheep show increased post-mature adult mortality during and lower productivity after winters with deep snow accumulation (Watson and Heimer 1984, Heimer and Watson 1986a). From these findings, we reasoned lamb production failures are most likely due to deep snow precluding access to higher quality food plants late in gestation thus contributing to lowered birth weight. Low birth weight has a strong negative correlation with neonatal survival (Scotten 1997). Hence, unfavorable weather effects should be expected to influence population productivity more than density-mediated nutritional stress Heimer (1983). Even dense populations where quality of forage is most likely to be limiting produce spectacularly high lamb:100 ewe ratios when environmental resistance is transiently lowered (Heimer and Watson 1986a). Populations which might otherwise appear to be at carrying capacity produce lambs at the rate of 70 to 85 lambs:100 ewes instead of the average 30 to 40 lambs:100 ewes when winters are "light" and "green up" is early.

Population declines - predation. Wolves (*Canis lupus*) have been considered a major force in Dall sheep population control since Murie (1944), and are a major component of environmental resistance to Dall sheep population growth (Heimer 1999). Coincident with the changes in weather in the early 1990s, predator management (control) was suspended. Additionally, coyotes (*Canis latrans*) emerged (or perhaps re-emerged) as a major source of Dall sheep mortality, particularly among lambs (Scotten 1997).

Trapper harvest records dating back to the first quarter of the 20th Century indicate coyote presence in Alaska, but do not seem to reflect high abundance (Rearden 1998) or great significance as a Dall sheep predator. In contrast, Scotten (1997) showed coyotes were responsible for a quarter of lamb deaths in the Alaska Range. Subsequently, Pruhs (2004) showed predation on Dall sheep was higher during periods of higher coyote abundance inferred from highs in hare (*Lepus* spp.) populations in the eastern Alaska Range. Hence, it appears increased predation on Dall sheep likely is a function of increased coyote abundance.

The increase in abundance probably resulted from general expansion of coyote populations and ranges in many areas of Alaska. Specifically, conversion of about a quarter of a million acres from boreal forest (poor coyote habitat) to open fields (good coyote habitat) in the flats just north of the central Alaska Range probably accelerated coyote expansion. The original plan driving this conversion was for agricultural production of barley (*Hordeum* spp.) for export. However, the optimistic projections of Alaskan agronomists were not met. Instead of becoming amber waves of grain against the purple mountain's majesty, these generally fallow open fields became prime habitats for grasshoppers (Orthoptera), voles (Microtinae), and coyotes. The presence of wolves did not preclude the dramatic expansion of coyote populations. Dall sheep became a preferred prey item for coyotes colonizing mountain habitats.

Consequently, lower lamb production and increased predation led to declining sheep populations. Initially centered on lambs and younger sheep, and with no ongoing monitoring of Dall sheep internal population dynamics (Heimer 1994), the decline was not apparent until ram classes which "should" have been shot by hunters failed to show up in reported harvests. Annual harvests declined from an average of about 1,200 rams at full curl in the mid to late 1980s, to the low of 650 rams. Present harvest seems to have stabilized at about 2/3 of the former average (~800 rams/yr over the past several years).

Management Effects

Without a systematic inventory program or other field data, ADF&G was in no position to take or defend a management action. Having adopted the position that full-curl regulations rendered Dall sheep "self-managing," alleged declining sheep populations and smaller harvests were not a concern for the Department. However they did raise alarm among sheep hunters. ADF&G was surprised. In the Alaska Range, coyote research showing intense predation on lambs resulted from public complaints about the sheep decline near Fairbanks. No management responses resulted from ADF&G.

With respect to predation, coyote harvest regulations did not keep pace with the emergence of abundant coyote populations becoming a dominant mortality factor for Dall sheep. The bag limit for hunting coyotes (2/yr) was one fifth that for wolves, thus facilitating coyote expansion. Several proposals to increase coyote harvests were offered by the public. In 1999 and 2001, W. Heimer and R. Chaney presented proposals to the Alaska Board of Game which encouraged hunting of coyotes (Gordon 2004). Still, the interest in coyote hunting and trapping was insignificant in the face of the overall influence of burgeoning coyote populations on depressed Dall sheep populations.

Biological, social, and economic effects of management inaction. As the number of rams available for harvest decreased, ram harvests declined and hunter dissatisfaction grew. The scarcity of harvestable rams also exacerbated the competition between professional guides who specialize in guiding non-resident hunters, and resident sheep hunters. Alaska residents may hunt sheep every year by purchasing a resident hunting license. Consequently, while harvest success is important, they can always "try again" next year, perhaps in a different area. However, the professional guide who is limited to a specific area of operation and does not have this option. Guides must succeed for their clients or their reputation, business, and livelihoods likely suffer.

As mature Class IV rams became less abundant and competition between resident hunters and guides intensified, rumors that guides were taking sub-legal rams became so pervasive that ADF&G and enforcement wardens often were informed. Still, no proactive management or enforcement action was taken by appropriate agencies. Consequently, sheep hunters took action in the form of the Alaska FNAWS Board of Directors proposing mandatory inspecting and plugging of all harvested Dall sheep horns. This practice is common to most other jurisdictions with wild sheep jurisdictions, and was seen as likely to prevent harvest of sub-legal rams. Plugging sheep horns has its roots in the illegal sale of bighorn trophies, and is based on the rationale that if every horn is registered by its plug and the associated identifying data, it will be impossible for thieves and poachers to sell.

ADF&G resisted mandatory plugging of Dall ram horns, with the rationale that there was no documented problem with sale of horns from Alaska and that theft and sale of Dall sheep trophies was insignificant on the broad societal scale. Additionally, ADF&G argued the sheer volume of work involved in inspecting, plugging, and record keeping for almost a thousand sets of horns each year was not worth the cost, given that no defined problems existed.

The defense against plugging was successful as long as the ADF&G position was argued effectively before the Alaska Board of Game. However, as the Department defended its position less vigorously, public support increased due to increased sophistication by plugging program advocates. They gathered statistics from an area where harvest of immature rams was allowed by permit and argued the same harvest rate occurred across Alaska. Additionally, they took their data to local Fish and Game Advisory Committees. It should be noted that the extrapolations did not meet the normal rigorous standards the Board of Game expects from ADF&G. Statistical principles were violated, particularly those relating to sample sizes and extrapolation from a unique area to the whole state; but no notice was taken.

Inspection program sponsors were able to use the selected statistics to generate an anti-guiding backlash among some local Fish and Game Advisory Committees. Advisory committees advise the Alaska Board of Game about regulatory proposals which the Board either adopts or rejects. Committees are made up of local residents with interest and knowledge of fish and game resources in their area, and advisory committees often reflect local biases. Hence one strategy for getting *ad hoc* regulations passed is to gather support from local advisory committees to influence the statewide Board of Game.

As a result, the Board of Game passed a modified version of the proposal which required inspection and sealing, but not plugging, wherever ram horn restrictions applied. The system was not uniform because some subsistence sheep harvests essentially are unregulated (Heimer 1986, 1998a, 1998b) and inspections were not required for subsistence-harvested sheep. Enforcement wardens vigorously supported this regulation. They anticipated getting signed documents that would facilitate court prosecutions from any hunters ADF&G referred as potential violators. The new regulation required certification and a record by ADF&G assessing whether each harvested ram met legal criteria. Horns which failed were referred to enforcement wardens for further action.

Inspection program sponsors were disappointed to learn that the basic policy of enforcement wardens is to be "hunter friendly" and the wardens did not adopt a zero tolerance policy: If a ram was at least 7/8 curl but not full curl, a verbal warning would be issued; if not more than 7/8 curl, a written warning was considered appropriate; if not at least 7/8 curl, the hunter was to be issued a citation to appear in court as a violator (G. Folger, AK Bur. Wild. Enforc. Supervisor, Fairbanks, pers. comm.). Similarly, enforcement wardens did not get what they wanted, because acceptable horns were simply sealed with a green "spaghetti fish tag" while horns referred from ADF&G got a red "spaghetti fish tag." There was no hunter-signed document which might be argued as an admission of guilt. No additional data of potential management use were recorded. Horns could be inspected either at ADF&G offices or by enforcement wardens. ADF&G kept records of how many horns staff inspected; wardens did not.

ADF&G was unhappy because it lost to lay hunters before the Board of Game, and the Department had to do what it considered meaningless and unnecessary work. Inspection program sponsors were unhappy at the lack of a zero tolerance enforcement policy. Enforcement wardens were unhappy because there was no hunter signature on what amounted to a confession to be used in prosecution. ADF&G also was somewhat embarrassed because having been conspicuously inactive in sheep management for the previous 15 yr, it lacked personnel familiar with the rationale or definition of full curl ram harvests.

A Summary of Changing Legal Definitions. In 1974 creation of the Tok Management Area, where trophy management was the primary objective, resulted in Alaska's first definition of full curl. It was not established in regulation by the Board of Game, but simply added as a condition of the trophy permit issued by ADF&G. As crafted by the ADF&G sheep biologists, a full curl was defined as "the horn of a mature mountain sheep, the tip of which has grown through 360 degrees of a circle described by the outer surface of the horn, as viewed from the side". Other information accompanying the early Tok Management Area permits stated that "to be legal, rams must have a full-curl or larger horn or have both horns broomed (naturally broken). A full curl ram has horns which have grown through 360 degrees when viewed looking down the axis of the horn spiral". Photographs and drawings were included.

Comparatively high harvest rates from the Tok Management Area, as well as accumulating research findings drove experimental full-curl harvests in other game management units. The legal definition promulgated through the Alaska Board of Game as Hunting Regulations #25 for experimental full-curl harvests of mountain or Dall sheep was the same as used in 1974 (Alaska Board of Game 1984).

In 1988 the full curl definition was modified to read as "full curl horn means the horn of a mature male Dall sheep, the tip of which has grown through 360 degrees of a circle described by the outer surface of the horn, as viewed from the side or with both horns broken". ADF&G included sketches or photographs in the hunting regulations depicting full-curl ram horns. These visual aids were of variable quality and utility for hunters charged with finding legal rams to harvest.

In 1989, the full-curl regulation was expanded across most of Alaska because harvests increased up to 35% with its implementation in experimental areas (Heimer and Watson 1990). This change occurred despite maximum resistance from ADF&G leadership, which rejected data indicating increased maximal rates at full-curl harvest. These data indicated maximal harvests of 3/4 or 7/8 curl rams were inimical to maximum sustainable ram harvests (Heimer et al. 1984, Heimer and Watson 1986b; 1990). In an effort to maintain traditional intuitive maximum harvest philosophy and regulatory prerogative, ADF&G persuaded the Board of Game to implement Alaska Hunting Regulations #30, that read "Full curl horn of a male (ram) Dall sheep means A: That the tip of at least one horn extends up to or above the level of the posterior base of the horn when viewed at a right angle from the side, or B: That both horns are broken, or C: That the sheep is at least eight (8) years of age as determined by growth annuli" (Alaska Board of Game 1989b). This was ADF&G's last successful sheep management initiative before the Alaska Board of Game for 18 yr.

This broad definition technically allowed for harvest of mature rams as well as any ram having a horn tip extending above the level of the posterior base of the horn when viewed from the side. Technically, this meant any ram less than half curl <u>or</u> more than full curl was legal for harvest. After several failed prosecution attempts, the Attorney General's Office wrote ADF&G and the Board of Game stating that the definition was so broad as to be unworkable (J. O'Bryant, pers. comm.) and recommending a change. After another contentious Board meeting, Alaska Hunting Regulations #31 changed the definition to "full curl horn of a male (ram) Dall sheep means A: That the tip of at least one horn has grown through 360 degrees of a circle described by the outer surface of the horn as viewed from the side, or B: That both horns are broken, or C: That the sheep is at least eight (8) years of age as determined by horn growth annuli" (Alaska Board of Game 1990).

In spite of difficulties applying the definition in the field and in court, the definition remains unchanged.

Discussion

Practical Full Curl Definitions--Or Not. Most legal definitions of harvestable rams are based on the notion that ram horns grow in a circular pattern. Generally they do. Consequently, it is common regulatory practice to define ram harvest criteria as portions of the circle of horn development where hunting opportunity is sufficient to generate harvest pressure that could be inimical to management success. Hence we have seen regulations allowing harvest of 1/2 curl, 3/4 curl, 4/5 curl, 7/8 curl, and full curl rams (Demarchi 1978).

Geometrically, ram horn is a solid, most correctly described as a conical helix, while a circle is a construct of plane geometry. This introduces complexity with respect to viewing perspective. "Seeing the circle" of a ram horn requires projecting the solid conical helix onto a plane from a uniquely appropriate point in space. To successfully make the projection from geometrical solid to planar construct requires the observer to view the horn down the center of the horn helix. When viewed from this perspective, the outer surface of the horn typically describes a circle. While hunters and other sheep aficionados have been successfully performing this projection in the field for decades, setting a legally definable standard to horn development for anticipated use at trial in the United States court system proved challenging for the biologists at ADF&G. In response to this challenge, they defined several "litmus tests." These tests proved problematic because they did not account for differences between plane and solid geometry.

Stick Test. The first test was whether the tips of an unbroomed set of ram horns intersect a line drawn (or a stick placed) across the basal surfaces of the horns where they adjoin the skull. This test has its origins in the Merchant jig used in the Yukon Territory (Merchant et al. 1982). The attractiveness of the Merchant jig lies primarily in its "go/no-go" digital nature. Any set of ram horns either passes or fails. There is no subjective judgment involved. Note that even though the Yukon definition uses the term full curl, as defined by the Merchant jig, the defined thinhorn minimum horn size for harvest essentially is equivalent to Alaska's earlier 7/8 curl definition. Consequently, the Alaska definition of full curl requires a ram ~2 yr older than a typical Yukon full curl, and 45° more projected circular growth.

The Merchant jig seems to work well in Yukon where judgment is arbitrarily and objectively made by the apparatus, and any offending hunter is guilty if the horns do not satisfactorily "dance [with] the jig." My experience as a consultant in an appeal of a jig-defined sub-legal Stone's (*Ovis dalli stonei*) ram indicates that in the Yukon system, the jig essentially convicts the hunter, whose only recourse then lies through the appellate court.

In Alaska, the system is notably different. The hunter may be charged if a set of horns does not appear to meet legal criteria, but the burden of proof beyond reasonable doubt lies with the state. This system is not well suited to digital criteria like the Merchant jig. Nevertheless, the appeal of an objective pass or fail test led to several proposals to establish the "Yukon full-curl" as the Alaska standard. However, the *de facto* Alaskan 7/8 curl ram, and compromised maximal harvest at that level (Heimer and Watson 1990) is not compatible with Alaska's statutory language regarding how wildlife shall be managed.

It is unlikely that definers such as the Merchant jig pass/fail test are compatible with the U.S system of jurisprudence. Further, I argue that objective tests are inappropriate because essentially they try to provide a "digital" solution to an "analog" phenomenon. Finally, I suggest misapprehension of these factors as well as the success of the Merchant jig in Yukon led ADF&G managers to establish the stick test. To my knowledge, it has never been introduced or challenged in a court trial in Alaska.

Line of the Circle test. As defined by ADF&G, the line of the circle appears to be a lay term for a tangent to the circle projected from the horn helix. By Euclidian definition, the tangent is perpendicular to a radius of the circle "tangent to" the circumference of that circle. In this test, the inspecting biologist was to view the horn from the side and imagine a line perpendicular to the radius of the horn circle at the anterior base of the horn, and another line perpendicular to a radius at the horn tip. If the tangents (lines of the circle) were congruent, that is, fell on top of each other, the horn was judged to be full curl.

Perhaps coincidentally, this test is virtually identical in approach and findings to simply viewing down the axis of the outer surface of the horn helix, which projects the "circle of horn growth" in the vast majority of rams. A true full-curl horn projects to a planar circle when viewed so the horn tip lines up with the anterior base. If the horn is not full curl, the resulting projected planar figure is not a circle. For reasons not presently understood, the human eye is very good at identifying circles, and few hunters make mistakes if given proper orientation. This orientation essentially has been absent from ADF&G communications for 15 yr. Still, documented hunter error from the sealing project was insignificant. This speaks highly for Dall sheep hunters in Alaska or very poorly for enforcement of the sealing requirement.

Age and Brooming. Rams in Alaska are legal at a minimum age of 8 yr by horn annuli. This allows harvest of rams that are old but may not be full curl in horn development. Eight years is the mean age at full curl in Alaska (Heimer and Smith 1975). Hunters are discouraged from trying to determine age in the field, and this criterion exists primarily as a safety net for hunters who shoot mature rams whose horns might not meet the full curl definition.

Heimer and Smith (1975) determined the chances a ram will broom (break by fighting) both horns before Class IV status (8 yr or full curl) are remote. Hence, Dall rams in Alaska are legal for harvest if both horns are broomed. Age determination is somewhat subjective, and the difference between a badly worn horn tip and a lightly broomed horn is even more subjective. These hunter protection criteria appear well suited to the US/Alaska system of jurisprudence, and represent no concern for well informed, patient hunters.

Appropriate Management Actions?

In the fall of 2006, the Alaska Board of Game required that Dall ram horns from areas where regulations define a minimum legal horn size must be plugged as well as inspected. Measurements common in other jurisdictions requiring plugging, such as photographs and segment lengths and diameters, are not required. This increased burden placed on ADF&G despite its strident objections may further buttress the hypothesis that ADF&G withdrawal from active sheep management created a management vacuum that was filled by non-professionals. I believe something should be done to put the agency charged with managing this important resource back in the position of management leadership for 2 basic reasons.

Legally, ADF&G is mandated (through the Commissioner's office) to manage the resource for the benefit of the economy and general well-being of the people of Alaska. Agency withdrawl from active management should be administratively corrected. Socially, while specific hunting interests stumbled into the dominant manager role, they were ill-equipped to do so. Successful management requires professional-level knowledge and informed public participation from research to regulations.

If the Roosevelt Doctrine is followed, these responsibilities demand active agency participation in promulgation of biologically sound harvest regulations. For maximum effectiveness, a management program also must interpret these regulations to the public so they generally are understood as necessary for conservation. At the deeper level, successful management results from public acceptance of biologically-driven regulations in which the public can make a collective societal investment. When this happens, regulations essentially become self-enforcing. In contrast, regulations imposed for arbitrary reasons or defined as arbitrary do not assure management success. I suggest that the low violation rate was likely a remnant of former sheep harvesting mores rather than the threat of prosecution. These sorts of mores develop when the public embraces the notion that regulations exist because they facilitate sharing of commonly-owned resources as defined by Alaska law. Law-abiding Alaskans forego wanton harvest on the premise that it is in their best interest to do so. They presume that sharing living resources through harvest restraint due to seasons and biologically-based bag limits will produce adequate abundance for harvest and personal use at a later time.

For this to work, the agency must begin with biologically-driven regulations clearly articulated to the consuming public. Successfully alleging regulatory change is biologically driven, and hence in the best interest of the resource and the public, requires agency credibility. Credibility will be best established by agencies which take an active interest and conspicuous efforts in monitoring, researching, and managing the resources entrusted to their care and management. Agency success also requires communicating these activities to the public along with the rationale for restrictions on human activities. After all, law only eliminates the worst in human behavior; it does not assure the best.

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Bighorns and Little Horns Revisited

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Abstract: During the 1960s a series of horn measurements of bighorn rams (*Ovis canadensis*) from the eastern slopes of Alberta was recorded. The horn base circumferences of rams from the chinook belt south of the Bow River were significantly larger than ram horns to the north. A subsequent series of horn base measurements up to forty years later had the same results. However, there were some notable exceptions in central and northern Alberta. Ram horn bases increased significantly following a controlled ewe removal program in central Alberta on Ram Mountain and decreased to former levels after cessation of ewe removals. Ram horns at northern coal mine reclamation sites had larger horn bases than ram horn measurements prior to reclamation.

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Key words: Alberta, bighorn sheep, chinook belts, coal mine reclamation, forage availability, horn measurements, *Ovis canadensis*.

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In light of the discussions in recent years regarding the potential impact of trophy hunting on the size of ram horns (Coltman et al. 2003), I compared the size of horns on rams harvested under trophy seasons 40 years ago with those on rams harvested under trophy seasons today. Since the 1960s approximately 7000 trophy rams have been registered from an Alberta population of about 6000 bighorns. During the investigation of horn registrations, other information came to light and is presented here as well.

In 1969 I presented a paper titled *Bighorns and Littlehorns* at a meeting of the Northwest Section of The Wildlife Society in Victoria, B.C. (later published as Wishart 1969). At that time and again in 1982 (Wishart and Brochu 1982) I reported that horn base circumferences of bighorn sheep (*Ovis canadensis*) rams from the chinook belt of southern Alberta were significantly larger than ram horn bases to the north. The chinook belt refers to an area where warm winter winds have created montane ecoregions which have the warmest winter temperatures of any forested ecoregion in Alberta. Since the 1960s, other river valleys with montane climate and vegetation north of the Bow River were described. These valleys also provide extensive and extended grazing periods for ungulates during the winter months (Strong and Leggat 1992).

In addition to climatic factors, a controlled herd reduction experiment of the bighorn sheep herd on Ram Mountain in central Alberta 52°N, 115°W provided an opportunity to examine gross effects of nutrition on bighorn basal circumference

(Jorgenson et al. 1998). Similarly, coal mine reclamation near Cadomin (53°N, 117°W) and Smoky River (54°N, 119°W) created bighorn habitat featuring pit walls adjoining heavily-fertilized forage areas seeded with grasses and legumes on two northern bighorn ranges which allowed additional evaluation of nutritional effects on bighorn horn growth. Results of these influences on ram horn growths are described herein.

Methods

From 1961 to 1967 ram horn sizes were determined from information recorded in over 500 sheep hunter questionnaires. Results were confirmed from approximately 600 measurements of annular horn segments of rams at taxidermy shops from both north and south of the Bow River in southwest Alberta. During those years the legal minimum for a harvestable ram was an animal whose horns completed a 3/4 curl. The 4/5 curl regulation began in 1968 and registration of ram heads began in 1971 where similar information from the 1960s was obtained, that is, age, location, horn length, and horn basal circumference. All measurements were recorded in inches in the 1960s and all the metric measurements from registrations were converted to inches for this analysis. Horn bases in the 1960s were compared to this century (2001-2005) from a selection of four wildlife management units (WMUs) south of the Bow River and four WMUs north of the Bow. Three northern WMUs were analysed separately due to significant events affecting the horn growth of rams. The non-parametric Mann-Whitney U and Kruskal-Wallis tests were utilized for all comparisons used in this study ($\alpha=0.05$).

Results

With two notable exceptions involving coal reclamation sites (discussed below) there were no significant differences in horn base circumferences from the 1960s and this century ($U=10144.0$, $P=0.6$) Rams south of the Bow River had significantly larger horn bases than rams north of the Bow River (1960s: $U= 2984.5$, $P<0.001$; 2000s: $U= 16307.0$, $P<0.001$) with no apparent change in circumference after 40 years (Table 1).

In the 1960s the difference in base circumference between north and south held true right into the record classes. For example, horn basal circumference from southern Alberta bighorn sheep recorded in *Records of North American Big Game* (Boone and Crockett Club 1964) averaged 15.5 in while basal circumference from northern bighorn sheep averaged 15 in. This difference was highly significant ($P<.001$) (Wishart 1969). Horn basal circumference reached the maximum at 5 yr of age in southern Alberta and at 6 yr in northern Alberta (Wishart 1969).

Table 1. Average ram horn base circumferences (in inches) south and north of the Bow River in southwest Alberta during the 1960s and during this century.

	1960s (n)	2000s (n)
North of Bow River	14.8 ± 0.1 (337)	14.5 ± 0.1 (165)
South of Bow River	15.6 ± 0.1 (165)	15.9 ± 0.2 (129)

Ram Mountain (WMU 429)

The results of ewe removals and the significant effect on increased incremental horn development in bighorn rams on Ram Mountain have been reported (Jorgenson et al. 1998). Registrations of ram horn lengths and basal circumferences from Ram Mountain provide similar results (Table 2).

During the ewe removal the registered horn measurements are from rams that were produced during the period when yearling ewes were breeding and the herd was young and highly productive. The ram horns produced at that time are some of the largest ever recorded for Ram Mountain. Horn basal circumference increased even as age decreased (U=141.5, *P*=0.04) during the period of ewe removal, perhaps associated with reduced competition for food resources (Jorgenson et al. 1998). When the ewe removals ceased, the population more than doubled, the yearling ewes stopped breeding, and horn growth among rams diminished significantly in basal circumference from the period of ewe removal (U=112.5, *P*=0.01).

Cadomin reclamation site (WMU 438)

Ram horn sizes in the Cadomin area were typical of northern rams until the 1980s. As reclamation efforts featuring fertilized grasses and legumes on mined-over lands increased, horn size of rams responded with increased growth from 1991 to 2004 (U=1723.0, *P*=0.02) (Table 3). Along with increased horn growth there was a rapid increase in population growth from 320 bighorns prior to 1980 to over 800 on the mine sites during the 1990s (MacCallum 2000). A new world record bighorn ram was harvested from the Cadomin area on 28 November, 2000 (Boone and Crockett Club 2005). Although over 200 ewes and lambs were removed (translocated) from the Cadomin area during the 1990s to maintain herd productivity (MacCallum 2000), the mine population appeared to stabilize after 2000. Horn basal circumferences have subsequently declined significantly in recent years (U=3556.5, *P*=0.002) (Table 3).

Smoky River reclamation site (WMU 446)

The Smoky River herd in WMU 446 appears to be a founder population since it has the least heterozygosity of all the bighorns in Alberta (Patterson et al. 2007). The herd occurs in the most northern montane zone of the province, yet the rams show exceptional horn growth (Table 4). These rams enjoy effects of both warm chinook winds during the winter and local coal mine reclamation efforts designed to promote ungulate use similar to those at the Cadomin site. The herd is very accessible by road and harvest management features ewe permits. In addition, harvest of bighorn sheep of either

Table 2. Horn measurements (in inches) of rams registered from Ram Mountain in west central Alberta before, during, and after ewe removal (1976 to 1999).

		Average ± Standard error		
	n	Age	Horn base	Horn length
Before ewe removal	15	7.4 ± 0.5	14.7 ± 0.1	32.5 ± 0.6
Ewe removal	30	6.3 ± 0.3	15.0 ± 0.1	31.5 ± 0.5
After ewe removal	18	7.2 ± 0.4	14.4 ± 0.2	31.7 ± 0.5

Table 3. Average horn measurements (in inches) of rams taken near the protected coal lease reclamation sites in the Cadomin area in western Alberta (WMU 438).

Year	n	Age	Base	Length
1976-1981	96	7.6 ± 0.2	14.6 ± 0.1	32.3 ± 0.3
1982-1991	236	7.7 ± 0.1	15.4 ± 0.1	33.6 ± 0.2
1992-2001	261	8.8 ± 0.1	15.4 ± 0.1	36.3 ± 0.3
2002-2004	40	8.8 ± 0.3	15.0 ± 0.1	36.8 ± 0.6

Table 4. Average horn sizes (in inches) of the rams from Smoky River in western Alberta (WMU 446) at a mine reclamation site in a montane ecoregion.

Year	n	Age	Base	Length
1991-1995	24	5.4 ± 0.3	15.7 ± 0.1	32.3 ± 0.6
1996-2000	42	4.9 ± 0.2	15.6 ± 0.1	30.9 ± 0.4
2001-2005	48	5.3 ± 0.2	15.6 ± 0.1	32.6 ± 0.9

sex and any age by First Nations is allowed. Most rams removed are harvested by special permit and are killed as soon as they reach legal age. Some rams produce legal-sized horns as young as 3 yr old. In spite of the very northerly location, local conditions result in these rams having the fastest and largest growing horns in Alberta (Table 4).

Rams harvested at Smoky River feature larger basal circumferences than rams on Ram Mountain despite the fact that they reach legal size at an earlier age than those from Ram Mountain. Age at harvest is the consequence of the 4/5 curl regulation which states “a line drawn from the most anterior point of the horn base must pass in front of the anterior margin of the eye to the tip of the horn when viewed in profile”. In other words, the leading edges of horns with large bases extend well in front of the eye, whereas, smaller horn bases do not.

Conclusion

After forty years of trophy hunting, no detrimental effect on the horn size of bighorn rams could be determined based on horn base circumferences. However, some beneficial effects on horn growth were detected. All such effects occurred in improved forage-related situations where bighorn rams produced horns with large bases. During the 1960s in Alberta, bighorns with the largest horn bases occurred in the chinook belt of southern Alberta where winter ranges often are cleared of snow by warm winter winds. Following an experimental population reduction featuring removal of ewes on Ram Mountain, horn measurements in rams increased significantly as population size was reduced to a level where there was decreased intraspecific competition for food resources. Similarly, increased forage on coal mine reclamation sites in the Cadomin area resulted in significant increases in ram horn basal circumferences. Finally, exceptional horn bases developed in rams exposed to all three forage enhancement situations, that is, coal mining reclamation sites, ewe seasons, and living in the chinook zone of the Smoky River. Generally, bighorn rams in Alberta with access to the most plentiful and palatable forage for a variety of reasons produce the largest horns.

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GIS Mapping of North American Wild Sheep and Mountain Goat Translocations in North America, Exclusive of Desert Bighorn Sheep Ranges

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***Abstract*:** At the 10th Biennial Symposium of the Northern Wild Sheep and Goat Council in 1996 in Silverthorne, Colorado, a workshop was held to exchange, verify, and update transplant records for wild sheep (*Ovis* spp.) and mountain goats (*Oreamnos americanus*) in 18 states, provinces, and territories. Biologists from state/provincial/territorial wildlife management agencies compared transplant records as donors and/or recipients of wild sheep and mountain goats, as far back as records were available. Tabular summaries were included in the 10th NWSGC Proceedings. In winter 2005-2006, transplant actions since 1995 were requested from each of those 18 states, provinces, and territories. Transplant actions were plotted for each state/province using Geographic Information System mapping, to graphically depict inter- and intra-state/province/territory translocation of wild sheep and mountain goats. Individual maps were developed for each state, province, and territory, as were composite maps for wild sheep and mountain goats in the western USA and Canada. These maps represent a "snapshot in time" portrayal of translocation efforts to date, and should provide a foundation for future genetic review and analysis of wild sheep and mountain goat transplant actions in North America, exclusive of desert sheep ranges in the southwestern USA and Mexico.

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Key words: GIS, mountain goat, Northern Wild Sheep and Goat Council, translocations, wild sheep.

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Use of Digital Elevation Data to Predict Bighorn Sheep Habitat at Badlands National Park

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Abstract: Originally, Audubon's (a.k.a., Badlands) bighorn (*Ovis canadensis auduboni* now *O. c. canadensis*) was described as a subspecies of Rocky Mountain bighorn sheep inhabiting the Badlands of western South Dakota, USA. By 1925, the last bighorn sheep from the White River Badlands in southwestern South Dakota was harvested. To restore this native ungulate to its former range, 20 Rocky Mountain bighorn sheep (*O. c. canadensis*) were introduced to Badlands National Park (BADL) from Pikes Peak, Colorado, in 1964. In 1995, bighorn sheep habitat in the greater BADL area was evaluated using Digital Elevation Model (DEM) data using 30- and 90-m^2 resolution, and biomass estimates for the badlands of North Dakota. Suitable habitat was identified in 802 km^2 of the 5,322 km^2 at BADL and it was estimated that BADL could sustain 400 to 600 bighorn sheep. Escape terrain was the dominant variable affecting the extent of bighorn sheep habitat, as other components were not limiting. Due to the ruggedness and steepness of the highly erodable clay badlands, we reevaluated bighorn sheep habitat at BADL using 10-m^2 DEM data. Our model identified 1,938.8 km^2 of suitable habitat in the greater badlands ecosystem, 2.5X more than the previous estimate based on the coarser resolution. These data will be used to identify areas of suitable habitat for other bighorn sheep reintroductions at BADL and to reevaluate carrying capacity estimates in the greater badlands ecosystem.

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Key words: Audubon's bighorn, Badlands National Park, Digital Elevation Model, habitat, *Ovis canadensis auduboni*, Rocky Mountain bighorn sheep.

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Originally, Audubon's (a.k.a. Badlands) bighorn (*Ovis canadensis auduboni* now *O. c. canadensis* [Wehausen and Ramey 2000]) was described as a subspecies of Rocky Mountain bighorn sheep (*O. c. canadensis*) inhabiting the badlands of the Yellowstone and Missouri rivers in eastern Montana, eastern Wyoming, western North and South Dakota, and northwestern Nebraska (Valdez and Krausmann 1999). By 1925, this subspecies was extirpated throughout its range in South Dakota. Management policy states that the National Park Service will maintain as parts of the natural ecosystems of parks all native flora and fauna and will strive to restore extirpated native plant and animal species to parks (if) the population can be self-perpetuating (U. S. Department of the Interior, National Park Service 2000). Therefore, to restore this native ungulate to its former range, 20 Rocky Mountain bighorn sheep were introduced from Pikes Peak, Colorado to a 60.7-ha enclosure in Badlands National Park (BADL) in 1964 (Ramey et al. 2000).

In 1967, a *Pasteurella* outbreak reduced the number of captive sheep to 14 (2 adult rams, 2 adult ewes, 4 yearling ewes, 3 ram lambs, and 3 ewe lambs) (Ramey et al. 2000), and these were released into the wild. In 1981, 8 sheep from the North Unit of BADL colonized the South Unit, initiating a second subpopulation. In 1982, a second *Pasteurella* and/or bluetongue epizootic reduced the North Unit population to 50 to 60 animals. By 1988, the 2 sub-populations reached 140 individuals (Singer and Gudorf 1999) but a third disease epizootic reduced the total BADL population to about 60 animals by 1996. At this time, 12 ewes and 4 rams from the Pinnacles area in the western part of the North Unit were translocated to the Cedar Pass area in the eastern part of the North Unit of the Park.

Based on the estimated effective population size and analysis of molecular genetic data, the bighorn sheep population at BADL had been through a population bottleneck at founding (Ramey et al. 2000). A mixed-sex augmentation of more than 30 bighorns from an outbred native population of Rocky Mountain bighorn sheep was recommended to restore genetic diversity and provide short- and long-term contributions to the BADL population (Ramey et al. 2000). These authors further recommended that the introduced bighorn sheep should augment the current population and add a new subpopulation to the existing 3 in BADL. Supplemental populations of more than 5 sheep were recommended to provide increased group vigilance and a lower per capita risk of predation resulting in higher individual survival rates (Mooring et al. 2004), although a minimum of 20 translocated individuals also have been recommended (Douglas and Leslie 1999). Therefore, in conjunction with the South Dakota Game, Fish and Parks, and the New Mexico Game and Fish, 23 sheep (10 adult ewes, 2 yearling ewes, 5 ewe lambs, and 6 ram lambs) captured from Wheeler Peak, New Mexico were transported and released at BADL in September 2004.

To aid restoration of bighorn sheep throughout their historical range habitat in the greater BADL area was evaluated. Using the parameters and model for evaluating bighorn sheep habitat developed by Smith et al. (1991) and refined by Johnson and Swift (1995), Sweanor et al. (1995) estimated that BADL could maintain 400 to 600 bighorn sheep. Digital elevation models (DEM) with 30- and 90-m^2 resolutions were used to determine escape terrain slope, buffer, and aspect. Forage biomass estimates were unavailable for BADL, so estimates for the badlands of North Dakota were used to estimate forage production in BADL (Sweanor et al. 1995). In addition, water availability was not evaluated. A total of 802 km^2 of the 5,322 km^2 study area was suitable bighorn sheep habitat and 3,012 km^2, 1,410 km^2, and 503 km^2 for summer, winter, and lambing range, respectively, was available (Sweanor et al. 1995). Escape terrain was the dominant variable affecting the amount of suitable habitat because other components such as horizontal visibility, water availability, natural barriers, and human-use areas were not limiting

Due to the ruggedness and steepness of the highly erodable clay badlands (Weedon 1999), using a finer resolution was deemed useful in identifying specific habitat requirements of bighorn sheep. Therefore, our study objective was to map suitable by applying the model developed by Sweanor et al. (1995) using 10-m^2 DEM data.

Study area

The study area encompassed 5,322 km^2 located in Pennington, Shannon, and Jackson counties in southwestern South Dakota (Sweanor et al. 1995). It included Badlands National Park and adjacent lands in the Buffalo Gap National Grasslands and Pine Ridge Indian Reservation, interspersed with private land. Areas located within the White River badlands consist of very fine, unconsolidated clay with thin beds of sandstone or isolated concretions (Weedon 1999). Sharp gradients in altitude occur throughout 700 to 1,000 m (Sweanor et al. 1995). Topography of the badlands is the coincidence of elevation, rainfall, carving action of streams, and substrate, resulting in slumps, natural bridges, arches, sod tables, toadstools, and isolated flat remnants of the higher plains (Weedon 1999). Vegetated slumps along with mixed-grass prairie sod tables occur in close proximity to steep badland terrain and are important feeding areas for bighorn sheep (Gamo et al. 1993). Temperature ranges from -41 C to 47 C, and annual precipitation averages 41 cm (Weedon 1999).

The badlands encompass true short-grass prairie, midgrass prairie, and bunch grass types with plant species including western wheatgrass (*Pascopyrum smithii*), green needlegrass (*Nassella viridula*), blue grama (*Bouteloua gracilis*), and needle and thread grass (*Hesperostipa comata*), fringed sage (*Artemisia frigida*), prairie junegrass (*Koeleria macrantha*), little bluestem (*Schizachyrium scoparium*), green sagewort (*A. ludoviciana*), purple coneflower (*Echinacea angustifolia*), and buffalo grass (*Buchloe dactyloides*) (Weedon 1999). Patches of Rocky Mountain juniper (*Juniperus scopulorum*) and eastern red cedar (*J. virginiana*) occur in upper protected draws and slopes (Weedon 1999). Other species such as plains cottonwood (*Populus deltoides*), peach-leaved willow (*Salix amygdaloides*), box elder (*Acer negundo*), green ash (*Fraxinus pennsylvanica*), and American elm (*Ulmus americana*) occur in the deciduous complex along the White River (Weedon 1999). Although 42% of BADL is covered by prairie grasslands, over 46% is clay formations on which vegetation is sparse or absent (Von Loh et al. 1999).

Methods

The habitat model used by Sweanor et al. (1995) eliminated areas which do not fit the identified criteria for bighorn sheep habitat. The model identified escape terrain (ET), buffer (BT), horizontal visibility (HV), water sources (WS), natural barriers (NB), human-use areas (HU), man-made barriers (MB), and domestic livestock (DL) as important characteristics affecting habitat suitability of bighorn sheep. The criteria for these parameters were:

ET = include land areas with slope >27° but <85°

BT = include land areas within 300 m of ET and land areas ≤ 1000 m wide bounded on at least 2 sides by ET
HV = remove areas with visibility <55%
WS = remove land areas >3.2 km from water sources
NB = remove land areas with rivers > 56.6 m^3/second, visibility <30% that are 100 m wide, and cliffs > 85° slope
HU= remove areas covered by human development
MB = remove areas inaccessible due to man-made barriers including major highways, wildlife-proof fencing, aqueducts, and major canals
DL = remove areas within 16 km of domestic sheep use.

Area of suitable bighorn sheep habitat was calculated using as ET + BT - HV - WS - HU - MB – DL.

In the model used by Sweanor et al. (1995) openness of habitat was adequate throughout the study area; therefore, HV was not a limiting factor. Water sources were insufficiently documented; thus, incorporating the WS parameter inaccurately reduced the estimate of suitable bighorn sheep habitat. No natural landscapes were considered barriers; therefore, NB was excluded from the model. Man-made areas (4.8 km^2) occupied by highways and roads (not considered a barrier), and group-campsites, visitor-information centers, and scenic overlooks were removed from the total estimate of suitable habitat. Areas within 16 km of domestic sheep also were not applicable. Therefore, ET and BT were the only parameters that limited bighorn sheep in the greater badlands ecosystem (Sweanor et al. 1995). Using geographic information system with 10-m^2 DEM data, we reevaluated ET and buffer BT in the greater badlands ecosystem study area.

Results and Discussion

Using 10-m^2 DEM data, we determined that 1,938.8 km^2 (or 37.1 %) was suitable bighorn sheep habitat. Using the finer resolution, we predicted nearly 2.5 times more bighorn sheep habitat than Sweanor et al. (1995). Similarly, in comparing habitat available to desert bighorn sheep (*O. c. mexicana*), average land surface ruggedness derived from 30-m data was greater than that derived from 100-m elevation data because the finer resolution detected smaller changes in elevation data (Devine et al. 2000). Locations of female desert bighorns also had greater average land surface ruggedness in 30-m compared to 100-m elevation data. Johnson and Swift (2000) tested the effect of using finer elevation data at Mesa Verde, Colorado and identified 629 km^2 and 401 km^2 of core bighorn sheep habitat using 1:24,000 and 1:250,000 scale data, respectively (i.e. predicting more habitat with a finer resolution). They concluded that analyses conducted at different scales leads to variable results and can have critical implications to management decisions for bighorn sheep restoration.

Because the bighorn sheep population in BADL never exceeded 140 individuals, biologists have questioned the 400 to 600 animal carrying capacity estimate of Sweanor et al. (1995). Some studies grossly overestimate true carrying capacity of bighorn sheep (DeYoung et al. 2000). Determining true carrying capacity of a population is critical to survival because the closer to carrying capacity, the more severely the population can be affected by climatic vicissitudes (e.g., drought) (Macnab 1985). Although we predicted 2.5 times more available escape terrain with our model than Sweanor et al. (1995), based on vegetation coverage we suggest that forage availability in close proximity to escape terrain is probably a limiting factor for population growth at BADL. As recommended by Ramey et al. (2000), our data will assist BADL biologists in the conservation and management of lands identified as critical habitat in promoting restoration of this prairie bighorn sheep population.

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Breeding Migration, Gene Flow, and Management for Connectivity in Bighorn Sheep

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Abstract: Many bighorn sheep (*Ovis canadensis*) populations are isolated by development and habitat loss. Previous study by our group indicated marked, adverse effects of inbreeding in an insular population of bighorns deprived of migration for only 10 to 12 generations. Using life history and movement data over 17 yrs in a native complex of populations, we show that males (commonly) and females (less frequently) make temporary migrations to other populations solely to breed and these breeding migrations are likely the primary source of gene flow in the species. Ram migrations on a spatial scale encompass many populations. Eight rams fitted with GPS collars and originating in a single source population, ranged over a collective area of 1000 km^2 and together visited a total of 7 distinct matrilines during the 4 to 6 wk breeding season. Individual rams in this group visited 1 to 5 different matrilines and traveled a total of 50 to 150 km out from and back to their natal herd. We present evidence that decisions to migrate are understandable in terms of male mating strategy and suggest that managers can encourage (or discourage) connectivity by using harvest regulations to manipulate regional patterns of population sex ratio and male age structure.

BIENN. SYMP. NORTH. WILD SHEEP AND GOAT COUNC. 15: 40

Key words: Bighorn sheep, dispersal, gene flow, genetics, *Ovis canadensis*, population structure.

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Genetic Rescue of an Insular Population of Bighorn Sheep

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Abstract: Many bighorn sheep (*Ovis canadensis*) populations are isolated by development and habitat loss. Isolation at small size is thought to reduce individual and population fitness via inbreeding depression. However, little is known about the timescale over which adverse genetic effects may develop in natural populations or the number and types of traits likely to be affected. Benefits of restoring gene flow to isolates therefore also are largely unknown. In contrast, potential costs of migration (e.g., disease spread) are readily apparent. Management for ecological connectivity is controversial and sometimes avoided. Using pedigree and life history data collected over 25 yr, we evaluated genetic decline and rescue in a population of bighorn sheep founded by 12 individuals in 1922 and isolated at an average size of 42 animals for 10 to 12 generations. Immigration was restored experimentally beginning in 1985. We detected marked improvements in reproduction, survival, and 5 fitness-related traits among descendents of the recent migrants. Trait values increased from 23 to 257% in maximally outbred individuals relative to coexisting, minimally-outbred individuals. This is the first demonstration of increased male and female fitness attributable to outbreeding in a fully competitive natural setting. Our findings suggest that genetic principles deserve broader recognition as practical management tools with near-term consequences for large-mammal conservation.

BIENN. SYMP. NORTH. WILD SHEEP AND GOAT COUNC. 15: 41

Key words: Genetics, heritability, inbreeding, outbreeding, *Ovis canadensis,* Rocky Mountain bighorn sheep.

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Age-related Horn Growth, Mating Tactics, and Vulnerability to Harvest: Why Horn Curl Limits may Select for Small Horns in Bighorn Sheep

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Abstract: Male bighorn sheep (*Ovis canadensis*) complete about 80% of horn growth by age 5, yet horn size appears to play little or no role in their mating success until they are 6-8 yr old. Only the most dominant rams, typically 8 yr and older, can tend estrous ewes. Subordinate rams use alternative mating tactics whose success appears independent of their horn size. Rams with fast-growing horns may become 'legal' to harvest a few years before those large horns lead to higher mating success. If hunting pressure is high, rams with rapidly growing horns will have lower lifetime mating success than rams with slow-growing horns that do not become legal until an older age. Because ram horn size is inheritable, harvest of rams with rapidly growing horns may favor genetically small-horned rams. We documented this phenomenon at Ram Mountain, where rams with horns of 4/5 curl or greater were 'legal' and hunting by Alberta residents was unrestricted, leading to an average harvest rate of about 30% of 'legal' rams. Because traits that affect horn size in rams are genetically correlated with fitness-related traits in ewes, selective hunting may have affected the demographic performance of the population. The selective effects of trophy hunting should increase with hunting pressure and decrease with immigration of rams from protected areas.

BIENN. SYMP. NORTH. WILD SHEEP AND GOAT COUNC. 15: 42-49

Key words: genetics, heritability, mating success, *Ovis canadensis canadensis,* paternity, Rocky Mountain bighorn sheep, trophy hunting

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In most of their range outside protected areas, bighorn sheep (*Ovis canadensis*) are managed based on a horn curl limit, so that only rams whose horns exceed a minimum size can be legally harvested. Although in many States horn curl limits are associated with a limited number of permits, until recently in much of Alberta or British Columbia any resident could purchase a trophy sheep license and hunt in all or most of his or her province. Harvest was only limited by the availability of ‘legal’ rams or by the difficulty of access (Festa-Bianchet 1989).

Sport hunting plays an important role in the conservation of mountain sheep in North America (Geist 1994) and, increasingly, large mammals elsewhere (Leader-Williams et al. 2001). Very large sums are expended by tourist hunters who seek large-horned rams, providing recreational opportunities and the possibility, sometimes realized, of using funds generated through hunting for conservation and management (Erickson 1988, Harris and Pletscher 2002). Because of hunting regulations and hunter preference, however, the survival of large-horned rams may be lower than that of small-horned ones, particularly if harvest rates are high. There are many examples of harvest-induced changes in the morphology and life history of exploited species (Hartl et al. 1991, Rijnsdorp 1993, Jachmann et al. 1995, Ericsson et al. 2001, Harris et al. 2002, Festa-Bianchet 2003, Swenson 2003, Olsen et al. 2004, Walsh et al. 2006) and it is important for managers to know whether selective harvest of large-horned rams could lead to artificial selection favouring genetically small-horned rams.

Coltman et al. (2003) reported that in one population of bighorn sheep, 30 yr of unlimited-entry harvest of rams with horns describing at least 4/5 of a curl led to a decrease in breeding values (the genetic component of a trait, estimated from a pedigree analysis and trait measurements of related individuals) for both horn length and body mass. That paper stimulated much interest on the potential evolutionary consequences of sport harvest. Increasingly, evidence is accumulating that sport hunting has selective effects on morphology and life history (Martinez et al. 2005, Zedrosser 2006, Garel et al. 2007). A few people, however, appeared not to understand the paper, feared its consequences for a cherished status quo, and questioned its motivations (Heimer and Lee 2004). Because of the importance of the potential evolutionary consequences of trophy hunting on mountain sheep, and because of misinterpretations of Coltman et al. (2003) disseminated in various outlets, we provide a brief summary of published evidence that selective hunting of bighorn rams may have a selective effect. We also explore some of the management actions that may exacerbate or attenuate artificial selection through trophy hunting.

Horn size is inheritable

Horn or antler size of many ungulates is affected by non-genetic characteristics, including age, population density, habitat and soil quality, and weather conditions (Bunnell 1978, Hoefs 1984, Wehausen 1989, Jorgenson et al. 1993, Fandos 1995, Hoefs and Nowlan 1997, Jorgenson et al. 1998, Toïgo et al. 1999, Festa-Bianchet et al. 2000; 2004, Mysterud et al. 2005). Horn and antler size, however, are also dependent on genotype (Stewart and Butts 1982, Fitzsimmon et al. 1995, Lukefahr and Jacobson 1998, Wehausen and Ramey 2000, Kruuk et al. 2002, Coltman et al. 2003). In bighorn sheep at Ram Mountain, Alberta, both horn size and body mass have a strong inheritable component (Réale et al. 1999, Coltman et al. 2003; 2005). Once environmental variables and age are controlled, the sons of large-horned rams tend to have larger horns than the sons of small-horned rams (Coltman et al. 2005).

Horn growth is rapid early in life

Much of the growth in horn length in bighorn rams takes place during the first five years of life (Jorgenson et al. 1998). Under a 4/5-curl regulation some rams can reach 'legal' horn size at 4 or 5 yr, and exceptionally at 3 yr (Festa-Bianchet 1986;1989, Jorgenson et al. 1993).

Horn size affects mating success only for dominant rams

Based on behavioural observations and visual estimations of horn size, Geist (1971) concluded that large-horned rams had higher mating success than small-horned ones. Subsequently, several distinct mating tactics used by bighorn males, which to some extent depend on horn size were identified (Hogg 1984;1988). Although a relationship existed between horn size and mating success was long assumed, only molecular techniques can quantify the reproductive success of bighorn rams. Male reproductive success has been measured in 3 populations of bighorn sheep: Sheep River and Ram Mountain in Alberta, and the introduced National Bison Range population in Montana (Hogg and Forbes 1997, Hogg 2000, Coltman et al. 2002; 2003; 2005, Hogg et al. 2006). Those results confirm that the largest-horned (or heaviest, or most dominant) rams, that can defend estrous ewes, have a much higher reproductive success than other rams. Analyses of paternity success also reveal that other rams father lambs by using alternative mating tactics, as suggested by Hogg (1984). Importantly, however, the mating success of rams using alternative tactics is not dependent on horn size, possibly because direct competition plays a limited role in their copulatory success. Only for males that have achieved high dominance status, typically those in the top 2-4 places in the social hierarchy, do individual characteristics such as dominance, body mass, and horn size play an important role in mating success (Hogg and Forbes 1997, Coltman et al. 2002). Because rams grow in both horn size and mass with age, depending on population age structure the top spots in the hierarchy are typically occupied by rams aged 7 yr and older (Hogg and Forbes 1997, Coltman et al. 2002). For the (mostly younger) rams lower in the hierarchy, horn size affects social status but has a limited if any effect on their mating success.

Rams with fast-growing horns reach 'legal' status years before they reach the top of the dominance hierarchy.

Rams in Alberta rams with rapidly growing horns can be 'legal' at 4 yr but do not reach the top of the dominance hierarchy for another 2-4 yr (Pelletier and Festa-Bianchet 2006). Those rams can be harvested at 4 or 5 yr (Festa-Bianchet et al. 2004), while rams whose horns become 'legal' at a later age (or never) have a higher life expectancy and presumably a higher probability of reaching the top dominance ranks. It should be pointed out that records of harvested rams rarely include 'illegal' rams, and therefore provide a biased impression of age-specific horn size, as the fastest-growing rams are shot at younger ages. With the 30% harvest rate of legal rams typical of Ram Mountain added to natural age-specific mortality, a ram legal at age 4 yr has about a 15% chance of surviving to rut at age 7 yr, while a ram not legal until 8 yr (that only faces natural mortality) has about a 64% chance of surviving over the same period (Jorgenson et al. 1997, Loison et al. 1999). Recent research on both bighorn sheep and Alpine ibex (*Capra ibex*) casts doubt over the hypothesis that horn growth is negatively correlated with longevity in either species (Geist 1966; 1971). Instead, the relationship appears to be positive, as one may expect if large-horned males were high-quality individuals (von Hardenberg et al. 2004, Pelletier et al. 2006). Consequently, if rams with fast-growing horns were not harvested at 4 to 6 yr of age, their survival to the age where large horns make a strong positive contribution to reproductive success may well be higher than the average for all rams (Coltman et al. 2003). Interestingly, Geist (1966) compared horn length of rams that died at 7 to 11 yr and 12 yr and older, yet his data frequently are cited to support the selective killing of 4- and 5-yr-old rams with rapid horn growth. None of Geist's work supports the contention of higher mortality at 4 to 6 yr for rams with large horns.

Selective hunting selects

Coltman et al. (2003) showed that over 30 yr of unlimited-entry harvest of 4/5-curl rams, the average breeding value for horn and body size (two traits that are genetically correlated (Coltman et al. 2005)) declined. Rams on the mountain now have horns both phenotypically and genotypically smaller than those of rams on the mountain 5 sheep generations ago. That conclusion was based on the analysis of pedigrees established over 30 yr and included over 700 marked sheep and hundreds of horn measurements. Mother-lamb links established by behavioural observations were supplemented by 241 paternity links established through 20 microsatellite loci, in addition to several paternal half-sibships where individuals were inferred to share a father although that father was not sampled. In that study, some rams with genetically and phenotypically small horns achieved high social status and high reproductive success because their horns never became 'legal' and they survived past 10 yr. Fast-growing rams became 'legal' several years before their large horns could confer to them a high reproductive success. Most of those fast-growing rams were shot at a young age, leading to negative correlations between horn length breeding value and both longevity and known lifetime reproductive success. In unhunted populations, those correlations would presumably be positive.

Management strategies

Sport hunting is a valuable conservation tool (Geist 1994, Leader-Williams et al. 2001, Harris and Pletscher 2002, Festa-Bianchet 2003) and it is a manager's responsibility to ensure that harvest strategies are sustainable, both on a demographic and evolutionary basis. We must consider what can lead to artificial selection and what management strategies can avoid or at least limit artificial selection, bearing in mind that, inevitably, any hunting strategy will lead to some effect, either ecological or evolutionary, on the hunted population.

Clearly, the major factors that affect the intensity of artificial selection through hunting include the definition of 'legal ram', the possibility of immigration from unhunted (and therefore unselected) populations, and the intensity of harvest on 'legal' rams. Ram Mountain is an isolated population that is unlikely to obtain any 'genetic rescue' (Hogg et al. 2006) from sheep originating in protected areas, but most other sheep populations in Alberta could receive immigrant rams from the national parks during the rut (Hogg 2000). Protected areas may therefore play a key role on a management strategy at the landscape level. The 4/5-curl definition used at Ram Mountain until 1996 led to fast-growing rams being selectively removed before they could benefit from their large horns by achieving high social status. The move to a 'full-curl' regulation in 1997 may have come too late for this population, but it has now been implemented in some parts of Alberta and is used in most of British Columbia. Because some large rams never fit the definition of full curl, and others may reach it after obtaining a mating benefit from large horns, a definition of 'legal' ram as 'full' rather than '4/5' curl may lessen the selective effect of hunting. Whether that is the case or not remains to be seen. Finally, the unlimited-entry management used in most of Alberta makes a complete kill of all rams in the year they become legal a possibility, particularly in areas with easy motorized access. At both Ram Mountain (with relatively difficult access) and Sheep River (where the easily accessible part of the range used by rams is protected from hunting), harvest rate of 'legal' rams was about 30% (Festa-Bianchet 1986), but it may be much higher in other areas. Unfortunately, information on the harvest rate of 'legal' rams is seldom available for other areas. A greater effort to estimate harvest rates of 'harvestable' (*i.e.* legal) rams is required.

A management scheme involving a limited number of permits, distributed through a draw, would decrease the intensity of artificial selection by allowing some large-horned rams to survive to rut as mature rams. The difficulties involved in estimating hunter success under a draw system, and in estimating the available number of mature rams, however, cannot be underestimated. A conservative management strategy is called for. It will likely involve a lower rate of harvest than what was applied in Alberta under the unlimited-entry 4/5-curl rule, and lead to a much larger proportion of rams dying of natural death rather than from sport harvest.

We found a decrease in the genetic component of horn length, but the definition of what can and cannot be shot relies on both horn length and shape. Depending on horn shape, different rams may attain 'legal' status with horns of different length. Further investigation of the possible selective effects of hunting should concentrate more directly on some measurement of horn shape that makes rams either 'legal' or more attractive as trophies (Garel et al. 2007).

Management of bighorn sheep has never been easy. The identification of possible selective effects of trophy hunting presents managers and hunters interested in the conservation of mountain sheep with an additional challenge. We fully expect them to rise to that challenge.

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Population Structure of Rocky Mountain Bighorn Sheep from Microsatellites and Mitochondrial DNA Genotyping

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Abstract: We collected bighorn sheep (*Ovis canadensis*) fecal samples non-invasively from Glacier National Park and hunter-kill tissue samples from across southern Alberta. We genotyped samples at 22 to 24 hypervariable microsatellite DNA loci and sequenced 800 base pairs of mitochondrial (mt) DNA. Microsatellite genotyping error rates, among the lowest recorded for non-invasive studies (0.13% – 1.6% per locus), varied significantly between sampling locations and times ($P < 0.001$). This illustrates the importance of quantifying genotyping error rates for each study population separately (and for each sampling period), before initiating a non-invasive study. Preliminary analyses suggest substantial substructure and limited gene flow on a relatively fine geographic scale. For example, 2 sampling locations in Glacier Park were separated by ~30 miles but differed substantially for microsatellite markers ($F_{ST} > 0.10$) and for maternally-inherited mtDNA markers ($F_{ST} > 0.50$). Although preliminary, this suggests male-biased gene flow exists and approximately 1 to 10 reproductively-successful genetic migrants per generation. It also suggests these markers and data sets would be useful to detect poaching and track the source population of illegal trophies and body parts.

BIENN. SYMP. NORTH. WILD SHEEP AND GOAT COUNC. 15: 50

Key words: Bighorn sheep, genetics, microsatellite, mitochondrial DNA, *Ovis canadensis,* population structure.

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Forensic DNA-Typing of Bighorn Sheep in the Province of Alberta

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Abstract: Rocky Mountain bighorn sheep (*Ovis canadensis*) are highly prized big game animals in North America and Alberta has produced many top scoring sheep. The high value hunters and naturalists place on this relatively scarce resource makes effective protection and management of bighorn sheep a necessity. In addition, the species occupies only a small fraction of its former range. Protection of bighorn sheep through enforcement of wildlife statutes presents many challenges. Poaching of wild sheep usually takes place in remote locations with few if any witnesses and wildlife officers typically have large territories to patrol, making direct detection of a poaching incident very unlikely. However, forensic DNA-typing enables officers to link wildlife offenders to illegal kill sites even when only trace amounts of biological material are present. We validated DNA-typing tests and databases for forensic use in protecting bighorn sheep. Fourteen short tandem repeat loci and 1 sex-typing locus were amplified in 3 multiplexed reactions via the polymerase chain reaction (PCR). Resulting DNA fragments were resolved using capillary electrophoresis. Populations of sheep from southern (south of Bow River) to central (Smoky River) Alberta appropriate for use as forensic databases for bighorn sheep in Alberta. Generally, populations south of the Athabasca River had higher levels of heterozygosity than north of the river. Flanking sequence tag (FST) values, a measure of population differentiation, increased with increasing geographic distance. These data, and knowing that the northern populations are near the range limits for the species, support the hypothesis that northern populations represent "founder populations". Furthermore, evidence suggests that the Athabasca River acts as a barrier to gene flow in this species. Our data have been used in conviction of offenders who illegally took bighorn sheep in Alberta and also may be useful for sheep management.

BIENN. SYMP. NORTH. WILD SHEEP AND GOAT COUNC. 15: 51

Key words: Alberta, bighorn sheep, DNA-typing, forensic, *Ovis canadensis*, PCR, poaching.

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Phylogeographic Investigation of Bighorn Sheep in California

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***Abstract*:** Many bighorn sheep subspecies (*Ovis canadensis* spp.) differences proposed in 1940 have not stood up to recent morphometric and genetic analyses when coupled with a sound definition of subspecies. However, the suggestion that bighorn sheep in the Sierra Nevada of California were different from adjacent desert sheep has found support. Differences were found in the mtDNA control region using RLFP data and significant skull shape differences from cranial morphometric data. We assessed DNA sequence data for 515 base pairs of the mtDNA control region for about 550 different sheep from 35 populations in California. These included large samples from the Sierra Nevada and six populations to the immediate east. Samples from the Rocky Mountains, British Columbia, Stone's, Dall's, and snow sheep were included for perspective. Bighorn sheep in the Sierra Nevada have only one haplotype, and it is as different from desert bighorn as are Rocky Mountain bighorn. However, in the Sierra Nevada clade there are two additional haplotypes; one in the Inyo Mountains immediately east of the southern Sierra Nevada, and one across a series of connected ranges to the southeast of the Inyo Mountains. Both haplotypes occur at high frequency, but are mixed with haplotypes of desert bighorn. For comparison, we currently are sequencing about 1100 base pairs of a more conserved mtDNA gene (ND5) for a select subsample of sheep.

BIENN. SYMP. NORTH. WILD SHEEP AND GOAT COUNC. 15: 52

Key words: desert bighorn sheep, genetics, mitochondrial DNA, phylogeny, phylogeography, taxonomy.

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Highways Block Gene Flow and Cause Rapid Decline in Genetic Diversity of Desert Bighorn Sheep

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Abstract: Rapid expansion of road networks reduced connectivity among populations of flora and fauna. The resulting isolation is assumed to increase population extinction rates, in part due to loss of genetic diversity. However, there are few cases where loss of genetic diversity has been linked directly to roads or other barriers. We analyzed the effects of such barriers on connectivity and genetic diversity of 27 populations of *Ovis canadensis nelsoni* (desert bighorn sheep). We used partial Mantel tests, multiple linear regression, and coalescent simulations to infer changes in gene flow and diversity of nuclear and mitochondrial DNA markers. Our findings link a rapid reduction in genetic diversity (up to 15%) to as few as 40 yr of anthropogenic isolation. The presence of interstate highways, canals, and developed areas apparently eliminate gene flow and presumably prevent recolonization of empty habitats. Our results suggest that anthropogenic barriers constitute a severe threat to the persistence of naturally fragmented populations.

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Key words: Desert bighorn sheep, genetics, microsatellite, mitochondria DNA, *Ovis canadensis nelsoni*, population structure.

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Seasonal Variation in Ruminating Behaviour of Bighorn Sheep

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***Abstract*:** Rumination is a key step in the digestive process of bighorn sheep (*Ovis canadensis*). This physiological process occupies a large part of the day, and as such has major impact on behavioural outcomes. Since individuals spend large amounts of their time in groups they must synchronize their activities. However, throughout the year different sex and age groups face varying energy demands. We tested the hypothesis that yearly changes in energy demands and environmental conditions on different sex and age groups result in a change in ruminating behaviour. We have collected rumination data for a group of marked bighorn sheep throughout the year at monthly intervals. Preliminary data analysis suggests different classes vary ruminating behaviour according to temporal changes in the yearly cycle.

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Key words: bighorn sheep, energy demands, environmental conditions, *Ovis canadensis,* rumination.

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Social Structure of Male Bighorn Sheep and the Consequences of Associations

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Abstract: Male bighorn sheep (*Ovis canadensis*) live in dynamic, usually single sex, social groups throughout the majority of the year. In these groups they interact continuously with each other in a variety of interactions clearly observable as clashes, kicks, and play, or so subtle that observations are not possible. When interactions are difficult to observe directly, time spent in proximity to one another while laying or grazing may provide an alternative for describing relationships. We analyzed the social structure of our study population to include group composition between and within groups, interactions between individuals, and relatedness of individuals. We described patterns of spatial associations between pairs of individuals and attempted to determine the consequences of these spatial patterns (benefits to the participants). With this approach we also may see if social factors along with individual characteristics such as body size, horn size, and age give a better predictor of ram hierarchy and therefore, how social structure and associations contribute to individual reproductive success.

BIENN. SYMP. NORTH. WILD SHEEP AND GOAT COUNC. 15: 55

Key words: bighorn sheep, individual characteristics, *Ovis canadensis*, reproductive success, social structure, spatial associations.

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Effects of Birth Date, Sex, Maternal Characteristics, and Environmental Conditions on Mass and Survival of Bighorn Lambs

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Abstract: For ungulates living in strongly seasonal environments, variation in parturition date should have strong fitness consequences. We investigated birth date interactions with sex, maternal characteristics, and environmental variables to affect the growth and survival of bighorn sheep (*Ovis canadensis*) lambs and yearlings. Over 13 yr, the estimated birth date of 206 lambs ranged from May 21 to July 18. Late-born lambs of both sexes were lighter at weaning than early-born lambs. Weaning success of the mother the previous year and November to December precipitation affected the date of birth. Birth date had no effect on lamb summer growth rate. To assess the parameters affecting lamb mass at weaning, we tested a model including lamb characteristics, maternal previous reproductive status, maternal mass and age, and environmental conditions. Fecal crude protein values during summer correlated positively with lamb mass in September. Birth date affected lamb survival if considered alone, but not when weaning mass was included in the model. Birth date had a negative effect on yearling mass in early June. However, when accounting for the mass of lambs in September, birth date was not significant on mass of yearlings and 2-yr-olds in June and September for either sex. Lamb mass in September correlated with June and September mass as yearlings, but had no correlation with mass at 2 yr. Our results suggest that birth date affects several traits of individuals, such as mass in June and September. This, in turn, affects survival and ultimately may affect individual fitness. During the short growing season, bighorn lambs must accumulate sufficient body resources to survive winter, and females may be selected to synchronize birth with forage productivity. Our data also suggest complex relationships among different factors, and maternal quality plays an important role in affecting lamb life history.

BIENN. SYMP. NORTH. WILD SHEEP AND GOAT COUNC. 15: 56

Key words: bighorn sheep, birth date, forage productivity, *Ovis canadensis,* survival, synchronize births.

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Cause-Specific Average Annual Mortality in Low-Elevation Rocky Mountain Bighorn Sheep

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Abstract: In August 1998, 16 adult and 7 lamb Rocky Mountain bighorn sheep (*Ovis canadensis*) were transplanted to the Manzanos Mountains, New Mexico to augment a low-elevation herd with <20 bighorns. One additional ram was translocated in December 1998. All translocated adults were radiocollared. This herd is located southeast of Albuquerque in a canyon vegetated with juniper (*Juniperus* spp.) and pinyon pine (*Pinus edulis*). Bighorns sheep were released in Monte Largo Canyon (n=14), and approximately 26 km south near the confluence of Sand and Abo Canyons (n=10). A single track railroad runs through Abo Canyon. In January 1999, 9 bighorns occupying the mountain before the 1998 release were captured and radiocollared in Sand Canyon. From 1998 to 2003, sheep were monitored from the ground and during fixed-wing flights. When mortality signals were received, carcasses were collected and assessed for cause of death. We used the nested survival model in program MARK to analyze annual herd mortality rates and cause-specific mortality rates from mountain lion (*Puma concolor*) predation and train strikes. Overall average annual mortality for the herd was 0.29 (SE = 0.01). Mortality resulting from mountain lion predation (0.11, SE = 0.01) was greater than train strikes (0.07, SE = 0.01). Average annual mortality was greater for translocated (0.36, SE = 0.02) than extant sheep (0.20, SE = 0.01), and greater for males (0.36, SE = 0.02) than females (0.27, SE = 0.01). The cause-specific average annual mortality from mountain lion predation was greater for translocated (0.16, SE 0.01) than extant bighorns (0.04, SE = 0.01), and greater for rams (0.23, SE = 0.02) than ewes (0.07, SE = 0.01). Cause-specific mortality rates from train strikes were greater for extant (0.17, SE = 0.01) than for translocated bighorns in Sand Canyon (0.09, SE = 0.01). The population in autumn 2003 was approximately 20 bighorn sheep. Unless management programs are developed to reduce mountain lion predation and train strike mortality, the Manzanos bighorn population may go extinct.

BIENN. SYMP. NORTH. WILD SHEEP AND GOAT COUNC. 15: 57

Key Words: Bighorn sheep, Manzanos Mountains, mortality, mountain lion, New Mexico, predation, *Ovis canadensis,* train strike.

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A Monitoring Protocol to Assess Pneumonia-caused Mortality as Limiting a Bighorn Sheep Population

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Abstract: The role of pneumonia in bighorn sheep (*Ovis canadensis*) population dynamics is obvious when all-age dieoffs occur in large populations. However, in other situations, few if any dead animals may be recovered and the cause of population decline or stagnation may be less obvious. These include declines in small populations with few or no radio-collared animals and cases where a population is limited by low recruitment. This information is useful to focus restoration activities; however, managers often have limited time and resources to devote to monitoring cause-specific mortality. Based on information collected in Hells Canyon from 1997 to 2005 and a review of the literature, temporal patterns often are observed when pneumonia-caused mortality occurs in bighorn sheep adults and lambs. These patterns can be detected by periodic monitoring of radio-collared and unmarked animals during critical seasons. The protocol is a relatively simple and useful first step for assessing probable limiting factors in bighorn sheep populations.

BIENN. SYMP. NORTH. WILD SHEEP AND GOAT COUNC. 15: 58

Key words: bighorn sheep, limiting factors, monitoring, mortality, *Ovis canadensis,* pneumonia, population.

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Response of Bighorn Sheep to Restoration of Winter Range

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Abstract: Winter range for bighorn sheep (*Ovis canadensis*) in southeastern British Columbia declined in both quality and availability due to forest ingrowth over the last several decades. In 2002 and 2003 we applied mechanical treatments to a 200 ha portion of traditional bighorn winter range near Radium Hot Springs, B.C. in an attempt to improve habitat suitability. Treatments included timber removal with retention of clumps of veteran trees, brushing, piling and burning, and noxious weed control. We monitored bighorn sheep response to these treatments by deploying GPS radio collars on 10 sheep each year from 2002 to 2004 and collecting daily location points for each animal. Considered over entire calendar years, study animals increased their use of the treated area from 1.0% of daily locations in 2002 to 8.9% in 2004 ($P < 0.001$). Post-treatment use of the treated area was greatest in March and April when sheep use of the treated area increased from 0% in 2002 to 20.4% in 2004 ($P < 0.001$). Our research demonstrates that mechanical treatments designed to mimic natural open forest ecosystems can result in a rapid increase in use by bighorn sheep, particularly when the treated areas are adjacent to occupied habitat.

BIENN. SYMP. NORTH. WILD SHEEP AND GOAT COUNC. 15:59-68

Key words: bighorn sheep, British Columbia, habitat, mechanical treatment, *Ovis canadensis,* prescribed fire, radio-telemetry, restoration, winter range.

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In winter, most populations of bighorn sheep (*Ovis canadensis*) in southeastern British Columbia depend on low-elevation open forest and grassland habitats historically maintained by frequent, low-intensity ground fires (Demarchi et al. 2000) or by mixed fire regimes of frequent low-intensity fires with occasional stand-replacing fires (Gayton 2001). These habitats have declined due to forest encroachment resulting from fire suppression over much of the last century (Davidson 1994). Gayton (1997) estimated that forest encroachment results in an annual loss of 1% of southeastern British Columbia open forest and grassland habitat. Additionally, critical winter range is lost to, or impacted by, competing land uses, including urban and rural settlement, agriculture, resource extraction, and off-road motorized recreation (Demarchi et al. 2000, Tremblay 2001, Tremblay and Dibb 2004). At Radium Hot Springs, B.C. the bighorn sheep population currently consists of about 200 animals, although periodically through the 20th century the herd declined to as few as 20 individuals through disease-induced die-offs (Stelfox 1978). More recently, deteriorating range conditions on traditional bighorn sheep winter habitats were implicated in the partial abandonment of these ranges by sheep in favour of artificial grasslands such as golf courses, residential lawns, and highway rights-of-way within and adjacent to the town (Tremblay and Dibb 2004). This situation is believed to increase habituation of bighorns, expose them to harassment by dogs, and increase mortality of bighorns along highways. Consequently, Tremblay (2001) recommended restoration of portions of historic bighorn winter range in the Radium Hot Springs area.

The potential success of a habitat restoration program will depend, in part, on the ability of the target species to find and then utilize restored habitats. Geist (1971, 1974) reported that bighorn sheep are poorly adapted to dispersing into available habitat, but instead transmit knowledge of seasonal ranges from generation to generation. This lack of exploratory behaviour of bighorn sheep, resulting in part from a reliance on steep, rocky terrain and high visibility, limited the success of translocation programs in the western United States (Goodson et al. 1996, Singer et al. 2000). However, sheep have successfully occupied newly available habitats created through habitat manipulation where the treated areas were adjacent to occupied habitat. In Utah, Smith et al. (1999) reported that within two years sheep made significantly increased use of areas treated with logging. Similarly, Arnett et al. (1998) documented sheep using burned areas in Wyoming within two years where the burned areas had little or no spatial separation from existing sheep winter range. In the Radium Hot Springs area we predicted that bighorn sheep could reoccupy restored habitats adjacent to their currently occupied winter range, provided that treatment prescriptions result in substantial improvements in visibility and forage quality.

Study area

The study area comprised the winter ranges of bighorn sheep in and adjacent to the village of Radium Hot Springs, British Columbia (50°37’20”N, 116°04’18”W). The restoration sites were situated on benchlands at the foot of Redstreak Mountain in the western ranges of the Rocky Mountains (Figure 1). Elevation was approximately 1000 m, although in the area it ranged from 850 m at the Columbia River to nearly 2,800 m on the highest summits of adjacent mountain ranges. Slope on the restoration sites ranged from flat to approximately 48°, with small areas of steeper rocky cliffs, particularly in the eastern portion along the lower slopes of Redstreak Mountain. Aspects were predominantly west or southwest, although there were some areas of flat terrain with subdued eastern aspects.

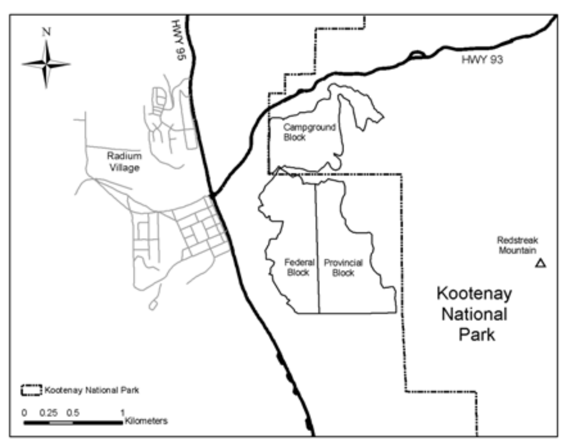

Figure 1. Layout of habitat restoration blocks for bighorn sheep in relation to Radium Hot Springs and Kootenay National Park, 2002 to 2004.

Climate at valley bottom sites was characterized by low precipitation and warm temperatures compared to higher elevation sites in the adjacent mountains (Achuff et al. 1984). Mean annual temperatures were near 5.0^{o} C at Radium Hot Springs and mean annual precipitation was 366 mm at the nearby Kootenay Park west gate (Janz and Storr 1977).

The study area was dominated by stands of Douglas-fir (*Pseudotsuga menziesii*), interspersed with white spruce (*Picea glauca*), trembling aspen (*Populus tremuloides*), and patches of grassland (Achuff et al. 1984). Desirable forage plants for bighorn sheep, including rough fescue (*Festuca campestris*) and bluebunch wheatgrass (*Pseudoroegneria spicata*), occurred in the study area but have been negatively affected by conifer encroachment (Page 2005).

Human facilities featured prominently within the study area. The Village of Radium Hot Springs, a resort community with approximately 750 permanent residents, had about 1000 hotel rooms and two golf courses. A wide variety of activities, including motorized and non-motorized recreation, forestry, mining, and agriculture took place throughout the study area, which was bisected by provincial Highways 93 and 93/95.

Methods

We carried out ecological restoration work on the Redstreak benches in the winters of 2002 and 2003. This consisted of thinning trees to an average of 8 m spacing with retention of individual and small clumps of veteran trees. We also completed brushing, piling and burning, non-native plant control measures, and a limited amount of planting of native grasses. Treatment occurred in three blocks: provincial crown land ("provincial block") treated in 2002, as well as federal crown land belonging to Kootenay National Park ("federal block") and in and around Redstreak campground ("campground block") in Kootenay National Park, both treated in 2003. The campground block treatments had additional objectives of ensuring facility protection and safeguarding against future wildfire or prescribed fire, but were expected to provide ecological benefits similar to the other treatment blocks. In total, 173 ha of land were treated, comprising 9.0% of sheep winter range as defined by the 95% fixed kernel density function for all sheep winter (October through April) telemetry points.

We captured bighorn sheep by free-range darting while the sheep occupied their winter ranges, between January and March inclusive. We used a combination of xylazine-ketamine, or occasionally xylazine-telazol or ketamine-medetomidine (Dibb 2007). We selected adult animals only, and aimed for a ratio of 6 females to 4 males. We selected one-half to three-quarter curl rams, but avoided selecting full-curl rams since those animals could experience increased mortality risk during the fall hunting season. All study animals were fitted with GPS radio collars (Avanced Telemetry Systems Inc., Isanti, MN) programmed to log two or more GPS locations per day for up to 12 months, covering at least the period from just prior to study animals leaving their winter range in spring to just after the animals return to their winter range in the fall. Collars were removed in November or December and were unavailable for approximately 8 weeks during annual refurbishment. Refurbished collars then were deployed on a new sample of sheep for the subsequent year.

We assessed bighorn response by using a GIS to determine the number of telemetry points inside and outside the

Table 1. Bighorn sheep daily telemetry locations inside restoration areas, 2002 and 2004.

	Locations in Restoration Area					
	2002		2004			
	N	% Inside	N	% Inside	χ2	P
Females and males; all months	1830	1.0	1721	8.9	121.0	<0.001
Females and males; Mar-Apr	466	1.1	329	20.4	87.1	<0.001
Females; Mar-Apr	329	0.0	183	10.9	37.4	<0.001
Males; Mar-Apr	137	3.6	146	32.2	38.4	<0.001
Females; May	113	0.9	137	19.0	21.0	<0.001
Males; May	78	1.3	117	12.8	8.3	0.004

restoration area in each period during each year from 2002 to 2004. We considered the 2002 data, collected before completion of the restoration work, to be pre-treatment data. The telemetry data used for the comparison was limited to a maximum of one point per day from daylight hours to reduce the potential for temporal autocorrelation of successive data points, and was restricted to 3D GPS points with position dilution of precision (PDOP) values of less than 6.0, guided by British Columbia Resource Inventory Committee standards (Geographic Data BC 2001). We made various comparisons based on particular months and sex classes. Pre-treatment and post-treatment telemetry results among years were compared using chi-square tests and Fisher's Exact Test (O'Rourke et al. 2005). We compared the average annual days of use of the restoration area per animal among the three years of the study using two-sample t-tests (Schlotzhauer and Littell 1997). We examined several terrain variables in order to make habitat comparisons between restoration sites and other winter range areas: slope and aspect were calculated from a 30-m resolution digital elevation model, and elevation was derived directly from GPS telemetry data or from the digital elevation model. We characterized space use of sheep in selected periods of each year using 90% fixed kernel density functions provided in the Animal Movements extensions for ArcView 3.3 (Hooge and Eichenlaub 1997).

Results

Bighorn sheep made increasing use of the restoration areas over the period from 2002 to 2004 (χ^2 = 121.0, $P \leq 0.001$). Pooled location data for both sexes over the entire year yielded an increase in the use of treatment habitat from 1.0% (percentage of total daily points in restoration area) in 2002 to 3.2% in 2003 to 8.9% in 2004 (Table 1).

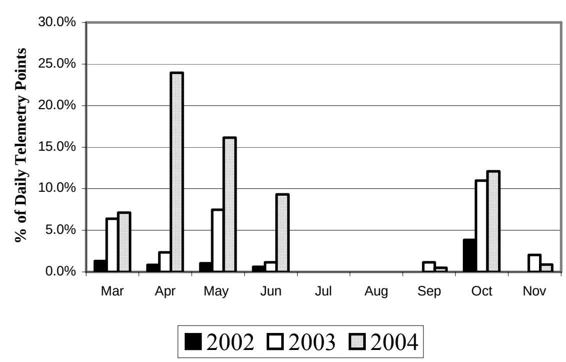

Figure 2. Bighorn sheep use of restoration areas by month. Restoration treatments were completed by March 2003.

Most use of the restoration area occurred in March through June, prior to the sheep migrating to their lambing or summer ranges, and in October, when the sheep were moving between summer and winter ranges (Figure 2). We collected few sheep GPS points in December through February during annual collar refurbishment, but ground surveys of the restoration area confirmed that little use occurred during this period. In March and April 2002 1.1% of location points for both sexes were within the restoration area (Table 1). By 2004 this increased to 20.4% (χ^2 = 87.1, $P \leq 0.001$). The 90% fixed kernel density function for location points in March and April in each year illustrates that sheep extended their occupied habitat east to include the campground and federal blocks by 2004 (Figure 3). Use of the restoration area by rams in this same period increased from 0% in 2002 to 32.2% in 2004 (χ^2 = 38.4, $P \leq 0.001$). For female sheep the effect appeared to be strongest in May, with use increasing from 0.9% in 2002 to 19.0% in 2004 (χ^2 = 21.0, $P \leq 0.001$).

The increased use of the restoration area was distributed among all study animals in the post-treatment years of our study. In 2002, prior to treatment, 6 of 10 animals were recorded on at least 1 day within the boundaries of the restoration sites (range = 1–5, SD = 2.0) for an average of 1.8 days per animal. In 2003, all 10 study animals were recorded using the restoration area (range = 1-25, SD = 7.4) for an average of 73 days per animal. . In 2004, all nine study animals

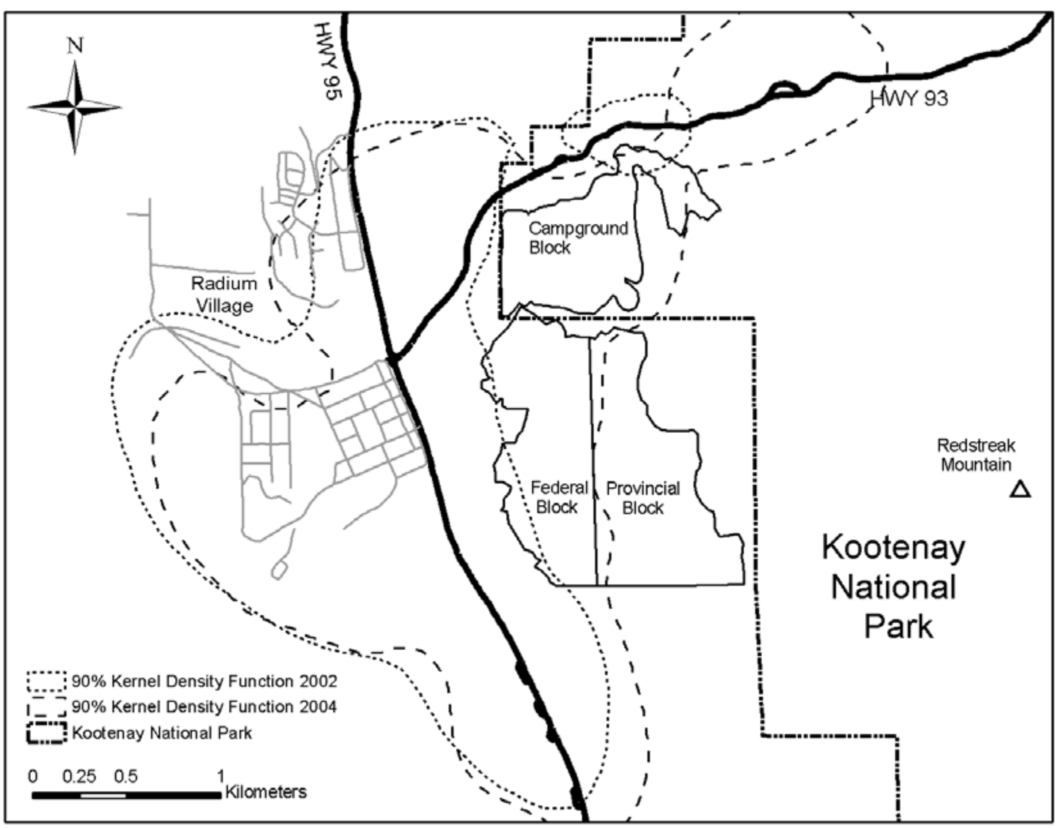

Figure 3. Pre-treatment (2002) and post-treatment (2004) 90% fixed kernel density functions for daily telemetry points of all collared bighorn sheep in March and April.

used the restoration area (range = 1-43, SD = 15.6) for an average of 17.0 days per animal. The difference in average annual days of use per animal from 2002 to 2004 was 15.2 ($T_{17} = 3.06$, $P = 0.007$; Figure 4).

Sheep made far greater post-treatment use of the federal and campground blocks treated in 2003 than they did of the provincial block treated in 2002. Of 244 daily telemetry points within the combined restoration areas recorded in all three years of our study, only one point (in 2003) was within the provincial block even though this block comprised 40.1% of the treated area. Slopes in the provincial block ranged from 0° to 23.2° and averaged 9.2° (SD = 4.96), and were similar to those in the combined federal and campground blocks (range of 0° to 25.7°, average of 9.36°, SD = 5.11). These slopes also were similar to the average slope of 11.6° (SD = 8.9, *n* = 2060) selected by sheep over the entire study area in winter, but are much gentler than the average slope of 25.3° (SD = 12.2, *n* = 3776) selected in summer. There was little difference in the elevations of restoration sites, with the federal and campground blocks averaging 1057.0 m (SD = 48.7) and the provincial block averaging 1010.3 m (SD = 19.3).

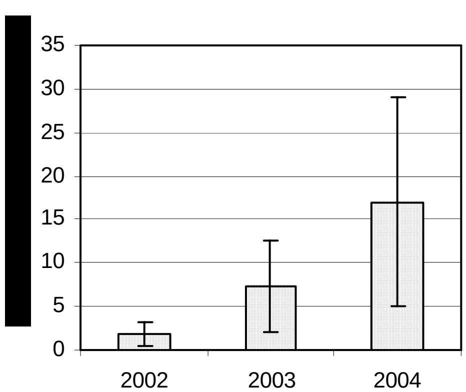

Figure 4. Average annual number of daily telemetry points in restoration area per animal, 2002 to 2004. Error bars represent 95% confidence intervals.

These elevations all were slightly higher than average elevations selected by sheep in winter (914.0 m, SD = 98.3, *n* = 2060). We also detected little difference in the slope aspects characterizing the restoration sites, with subdued east and west aspects being prevalent on most sites. Post-treatment overstory and understory vegetation characteristics were broadly similar on the federal and provincial blocks (Page 2005), although some areas within the campground block retained greater cover in order to provide visual screening and privacy for campers.

Discussion

Most post-treatment use of the restoration area by bighorn sheep occurred in October, and March through June, periods when prior to treatment the sheep were still on winter range elsewhere in the Radium area. We speculate that this reduced the amount of bighorn grazing pressure on limited natural winter range, although the sheep also used artificial grasslands that do not seem to be in short supply, such as lawns and golf course fairways. In all three years of our study, the sheep selected rutting ranges (November through December) and post-rut winter ranges (January through February) almost exclusively in Radium village, on the golf course, and along highway 93/95 road allowances, with some use of natural habitats on the edge of these developed areas. This continued use of artificial habitats during November through February could have been a response to the availability of high quality forage prior to normal green-up, due to the shallower snow packs on the lower elevation artificial habitats, or simply a result of strong traditional affinity to these sites. The restoration areas seem to be used as fall and spring "transitional" ranges between summer and winter ranges. The restored sites provide sheep the opportunity to forage on mainly native plants in areas with relatively little human activity, thereby reducing the potential for habituation. Use of these sites also may reduce interactions with domestic dogs and reduce the risk of collisions with motor vehicles. Continued monitoring of the sheep population will be needed to assess how sheep respond to expected recovery of forage plants in the restoration sites, and whether after a period of adaptation sheep will begin to adjust their rut and post-rut ranges in response to the availability of these restored habitats.

Sheep did not make significantly more post-treatment use of the 2002 restoration site (provincial block) compared to pre-treatment use in spite of this site having terrain and vegetation characteristics similar to the 2003 treatment sites. The 2003 sites were immediately adjacent to occupied sheep winter range, whereas the 2002 site was 500 to 1500 m distant. In addition, anecdotal observations of sheep from the five years prior to our study indicate that at least some sheep made occasional prior use of the 2003 sites, but not the 2002 site (Parks Canada, unpublished data). We believe this is consistent with the hypothesis that bighorn sheep are reluctant to colonize available habitats that are not immediately contiguous with currently occupied habitats (Geist 1971, Smith et al. 1999, Arnett et al. 1998). Since the 2003 federal block was located adjacent to the provincial block and is now used by sheep, it remains possible that sheep will eventually colonize the 2002 block. Continued monitoring of the population will be useful in determining the extent to which this occurs.

Researchers developing bighorn sheep habitat models typically define escape terrain as slopes exceeding approximately 27^{o} and suitable habitat in a narrow buffer of escape terrain, usually 100 to 300 m wide (Singer et al. 2000, Zeigenfuss et al. 2000, Tremblay 2001, McKinney et al. 2003). Similarly, observational or telemetry evidence indicates bighorn sheep prefer slopes exceeding 31^{o} (Fairbanks et al. 1987) or even exceeding 45^{o} (Risenhoover and Bailey 1985, Rubin et al. 2002). Female desert bighorns (*Ovis canadensis mexicana*) using urban environments selected areas with gentler slopes than did a neighboring population that did not use urban areas, although even the urban sheep selected slopes greater than 55^{o} relative to availability (Rubin et al. 2002). These authors determined that adult survival rates were similar in the two areas, but lamb survival was low in the urban population, suggesting increased predation due to use of riskier terrain. Our results indicate that bighorn sheep at Radium generally did not winter on or close to escape terrain, either within the restoration areas or elsewhere on their winter range. We speculate that optimal foraging behavior and predator avoidance may have led to selection in winter of human-dominated habitats with relatively flat terrain. Predation rates were low during our study, but the use of urban habitats exposes sheep to increased risk of mortality from motor vehicle collisions. Mortality of 5 collared sheep included 3 due to highway collisions, 1 due to disease, and 1 suspected due to a fall; no predation was recorded.

Management implications

Mechanical treatments designed to mimic natural open forest ecosystems can result in a rapid increase of use by bighorn sheep, particularly when the treated areas are adjacent to occupied habitat. We recommend application of similar treatments at Radium and elsewhere in southeastern British Columbia to maintain bighorn winter and transitional range. Similar treatments also might be applicable to movement corridors. The scale of the forest ingrowth problem is such that prescribed fire, as well as mechanical treatment, will be necessary to treat large areas and to treat steep slopes or other areas where mechanical techniques may be impractical. We recognize that in many cases treatment costs will not be offset by revenue generated from sales of harvested wood, and that treatment areas may have to be priorized. Consequently, it will be important to continue monitoring the response of bighorn sheep to different treatments in order that limited resources available to carry out treatments can be targeted to have the most benefit. In particular we recommend monitoring bighorn sheep response to prescribed or natural wildfire, and monitoring over long enough periods to assess whether and how sheep adapt over time to the availability of new habitat. We also recognize that the loss of habitat to forest ingrowth is detrimental to other species and ecological processes beyond bighorn sheep. Restoration of these other ecological values is part of the greater research and management program of the region, but is beyond the scope of this paper.

Urban development is proceeding rapidly in southeastern British Columbia but little information is available on the effects such development may have on bighorn sheep. Our results suggest the potential value of manipulating habitat for bighorn sheep in an experimental context with the aim of enabling sheep to occupy natural sheep habitat where they are less at risk of mortality from predation, motor vehicle collisions, or disease from domestic livestock. At Radium Hot Springs this could be achieved by restoration of habitats within or near escape terrain and adjacent to currently occupied sheep ranges. These results could be used in managing sheep populations on the urban fringe of other areas.

Acknowledgments

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Summary of Health and Trace Mineral Testing of Bighorn Sheep at the Luscar and Gregg River Mine Sites of West-Central Alberta

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Abstract: An important part of reducing disease related risks associated with translocation of wildlife is to understand the disease history of the source population. Bighorn sheep (*Ovis canadensis*) from the Luscar and Gregg River mines located in west-central Alberta have been translocated to several locations in the western U.S. and Alberta since 1984. I obtained test results for 282 bighorn sheep captured on the mine sites for health and trace element testing prior to translocation or for release on site. Contagious ecthyma is endemic in bighorns at both mine sites, but general body condition is good and no severe cases have been recorded. Bluetongue virus, parainfluenza-3 virus, infectious bovine rhinotracheitis, bovine viral diarrhea, and vesicular stomatitis were not detected during this study. Low antibody prevalence against bovine respiratory syncytial virus (0.026) was detected in 1990, but not in 1995. Low antibody prevalence for ovine progressive pneumonia was detected in 1999/2000, but not in 1990 or 1995. Anaplasmosis, Johne's disease, Leptospirosis, and *Brucella ovis* were not present. A number of strains of *Mannheimia (=Pasteurella) haemolytica* and *Pasteurella trehalosi* were isolated from the upper respiratory tract of bighorn sheep at the Luscar Mine. At least 28 biovariants were identified, 13 of which were unique. *Pasteurella multocida* was not cultured from this population. Test results for exposure to *Toxoplasma gondii* were negative for 16 bighorn sheep captured in 1990. *Psoroptes* spp. mites were not detected on any sheep and ticks (*Dermacentor andersoni*) were uncommon. This summary presents a general health profile of a high quality bighorn sheep population that has had little, if any, contact with domestic livestock.

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Key words: Alberta, bighorn sheep, Gregg River Mine, health testing, Luscar Mine, *Ovis canadensis*, trace elements, translocation

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The decline and extirpation of bighorn sheep *(Ovis canadensis)* populations throughout much of the western United States in the 1800s (Buechner 1960) resulted in extensive efforts by wildlife managers to rehabilitate and restore locally extirpated or diminished populations (Krausman 2000). Recovery plans for bighorn sheep populations in the U.S. and Canada often use translocation as a tool to fill unoccupied habitats and to augment existing herds. However, disease-related mortality was likely a large part of the problem, and disease, primarily pneumonia, continues to play a major role in depressing the growth of bighorn sheep populations and contributing to local extirpations (Singer et al. 2000, Cassirer and Sinclair 2007). Understanding the disease history of the source population can reduce disease-related risks associated with translocating bighorn sheep by minimizing the possibility of exposing animals to novel pathogens. Testing source populations for presence of, or exposure to, pathogens before translocation to a new area was recommended by Jessup et al. (1995), IUCN (1998), Dubay et al. (2002), and Foster (2005). Protocols for disease testing of herds of origin and release, and for moving bighorn sheep from Canada to the U.S., were developed by the Western Wildlife Health Committee (2001*a*; *b*).

Bighorn sheep voluntarily colonized reclaimed lands associated with two open pit coal mines located in west-central Alberta, Canada in an area known as the Coalbranch. The two mines: Elk Valley Coal Corporation, Cardinal River Operations, Luscar Mine (Luscar Mine) and Coal Valley Resources Inc., Gregg River Mine (Gregg River Mine) are situated at the base of the Front Ranges of the Rocky Mountains and support a high quality population of bighorn sheep. These sheep are characterized by large body size (MacCallum 1991), high lamb:ewe ratios, high density and numbers, and strong population growth (Fig. 1). In 2006 the autumn lamb:ewe ratio was 69 lamb:100 ewe. The maximum count in late autumn 2006 was 1,065 sheep, and the annual rate of gain on the two mines between 1986 and 2006 was 7.3% during which time ewes were removed at an average annual rate of 7.4% (Bighorn Wildlife Technologies 2007*a; b*). No pneumonia outbreak has been recorded in the mountain ranges containing the mines since bighorn sheep were first studied in the area (Stelfox 1964*a; b,* 1966, Lynch 1971; 1972, Smith and Lynch 1974, Kosinski 1976, Smith et al. 1977, MacCallum 1991; 1997, MacCallum and Kielpinski 1991), nor during annual surveys conducted on the two mines since 1985 (Bighorn Wildlife Technologies 2007*a; b*).

Introduction of diseases from domestic sheep has been implicated as a cause of pneumonia in bighorn sheep but it is unlikely that bighorn sheep on the Luscar and Gregg River mines have come into contact with domestic sheep, goats, or pigs. The nearby mining hamlet of Cadomin supported a dairy from 1912 to 1952; likewise, there was a dairy in the former mining towns of Luscar and Mountain Park (Hughes 1995, CIM 1998, Chiesa and Smilanich 1999). The dairy at Luscar was located near the present day plant for the Luscar Mine. Feed and stock were brought in by train as an all weather road joining the Coalbranch communities to the outside world was not completed until 1951. Horses and mules were used in the underground coal mines in the Coalbranch, but there were no domestic sheep or goats. Pigs may have been kept for a short time prior to slaughter (Ross 1976). The hamlet of Cadomin is the nearest habitation and is subject to Yellowhead County Bylaw No. 03.06 (3)a. The bylaw states: "*No fur-bearing animals, fowl or livestock other than domestic animals* [male or female dog or cat] *shall be permitted within a hamlet*".

The Luscar and Gregg River mines are separated from arable land to the east by a minimum of 80 km of boreal forest that is unsuitable for bighorn sheep. Jasper National Park and the Rocky Mountains lie west of the mines. The dominant land use north and south of the mines is timber harvesting, resource extraction, recreation, and wilderness-based tourism. Horses and some llamas are used for bighorn sheep hunting in the area. Because of the size and health of the bighorn sheep population

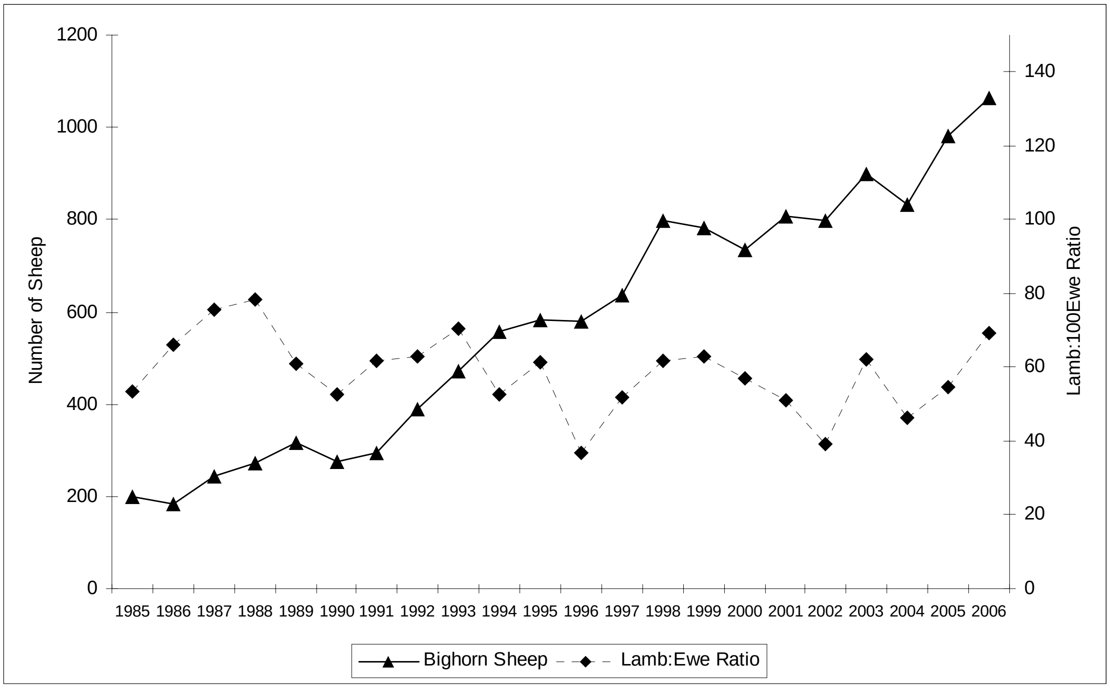

Figure 1. Maximum count of multiple fall surveys, and lamb:100 ewe ratio of bighorn sheep on Luscar and Gregg River mines, Alberta, 1985 to 2006.

on the mines, and ease of capture, these animals are used frequently for translocations to the U.S. and Alberta. The health and trace element profile presented in this paper indicates a high quality bighorn sheep population with no history of pneumonia outbreaks, and little, if any, exposure to domestic livestock.

Study area

The Luscar and Gregg River mines are located on the east side of the Canadian Rockies about 50 km south of Hinton, Alberta. The two mines lie adjacent to each other and are separated by the Gregg River. The mines occur in subalpine habitat immediately below alpine habitat and are characterized by a Cordilleran Climatic Regime and Rocky Mountain vegetation comprised of lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmanni*), and subalpine fir (*Abies lasiocarpa*) forests, primary succession shrub communities (*Salix* spp.-*Betula glandulosa*), and scattered grasslands (Strong 1992). Summers are cool (July daily mean temperature <13° C) and showery, with a short 165 to 170 d growing season (Chetner et al. 2003). The frost-free period is 85 to 95 consecutive days. Most precipitation falls in summer (>325 mm between May 1 to August 31). Winters are snowy (250 to 275 mm precipitation between September 1 and April 30) and cold (January daily mean temperature -12 to -10°C) and charact-erized by frequent chinooks (warm dry winds that descend on the eastern side of the Rocky Mountains) that periodically reduce snow cover.

Much of the mined areas are reclaimed specifically as bighorn sheep habitat by provision of high quality herbaceous food in close proximity to escape terrain. Other features important to bighorn sheep, such as readily available mineral licks exposed by the mining process, also are present (MacCallum and Geist 1992). Reclamation is on-going on both mines. Bighorn sheep that occupy the mines are part of a large metapopulation inhabiting the Front Ranges of the Rocky Mountains. Conventional radio-telemetry with 19 bighorn sheep from the mines indicated that these sheep are part of 2 local populations that interact with 5 nearby populations (MacCallum 1997). The 7 local populations straddle approximately 210 km of the Jasper National Park eastern boundary. Bighorn sheep from the Front Ranges responded to the mine reclamation by occupying the new habitats, expanding their range, and exhibiting a rapid population growth. Similar responses by bighorn sheep were documented for logging and burning in Utah (Smith et al. 1999). The entire metapopulation has not been surveyed in one year; however, a composite of surveys during different years indicates a minimum winter count of 1,542 bighorn sheep in the metapopulation. Components are: 211 sheep in the Fiddle-Whitehorse-Drummond-Rocky River units (excluding provincial lands) of Jasper National Park (Bradford 1987); approximately 30 sheep in Wildlife Management Unit (WMU) 436, 150 sheep in WMU 437, and 327 sheep in WMU 438, all on provincial lands excluding the 2 mines (Hobson and Ficht 2002); and 824 sheep on the mines in winter 2006 (Bighorn 2007*a; b*). Note the number of sheep in WMU 438 increased from 235 in 1963 (Stelfox 1964a). This metapopulation is now one of the largest in North America (Toweill and Geist 1999).

Methods

I obtained disease and trace element test results from states and agencies that translocated bighorn sheep from the Luscar Mine to various locations in the U.S. and Alberta between 1990 and 2001. Results also were assembled from various captures conducted for research projects on the Luscar and Gregg River mines since 1985. Various laboratories were used (Appendix A). Field testing protocols varied from year to year depending on the jurisdiction involved. Analysis and interpretation of laboratory tests in veterinarian reports and published literature were quoted in the absence of laboratory reports and referred to especially for interpretation of sero-positive or false-positive results.

Viruses. Clinical signs as well as biopsies of the mucosal epithelium from the vulvar region were used to confirm contagious ecthyma (CE, orf). Agar gel immuno-diffusion (AGID) and complement fixation (CF) (Veterinary Diagnostic Laboratory, Oregon State University 1995) were used to detect exposure to bluetongue virus (BTV). Parainfluenza-3 virus (PI-3) was tested for using virus neutralization (VN) (Nevada Department of Agriculture, Animal Disease Laboratories 1990) and haemagglutination inhibition (HI) (Veterinary Diagnostic Laboratory, Oregon State University 1995). Testing was conducted on blood serum to determine exposure to bovine respiratory syncytial virus (BRSV), infectious bovine rhinotracheitis (IBR), bovine viral diarrhea (BVD), and vesicular stomatitis (VS) using virus neutralization. Agar gel immunodiffusion was used to test for ovine progressive peumonia (OPP)

Bacteria. Agglutination (AGG) (Nevada Department of Agriculture, Animal Disease Laboratories 1990) and CF were used to test for *Anaplasma marginale*

(Anaplasmosis). *Mycoplasma avium paratuberculosis* (Johne's disease) was tested for using CF (Veterinary Diagnostic Laboratory, Oregon State University 1995) and enzyme linked immunosorbent assay (ELISA) (Allied Monitor 1995). Serum was used to test for *Leptospira pomona*, *L. grippotyphosa*, *L. hardio*, *L. icterohaemorrhagiae,* and *L. canicola* using microscopic agglutination titer (MAT). *Brucella ovis* (brucellosis) was tested for using blood agar plate (BAPA) (Nevada Department of Agriculture, Animal Disease Laboratories 1990), Brucellosis card test (Animal Disease Research and Diagnostic Laboratory, South Dakota State University 1999) and the ELISA test. Pharyngeal swabs were taken and bacterial cultures were used to test for *Mannheimia (= Pasteurella) haemolytica*, *Pasteurella trehalosi* (serotype 3 and biotype 2) and *Pasteurella multocida*. *Hemophilus somnus (=Histophilus somni)* was tested for using AGG. Microtiter agglutination (MTA) was used to diagnose *Campylobacter* spp. Bacterial cultures also were used to assess infections of the horn cores.

Parasites. AGG was used to determine exposure to *Toxoplasma gondii*. Gastrointestinal parasites were detected by faecal flotation and lungworms (*Protostrongylus* spp.) were detected using the Baermann technique. ELISA was used to determine if sheep had been exposed to *Psoroptes ovis* (scabies).

Trace Minerals. I also include data on trace mineral levels in whole blood, serum, hair from routine samples, and liver tissue analyzed at necropsy of dead sheep. Trace mineral concentrations for total copper, zinc, sodium, potassium, phosphorus, calcium, magnesium, and iron in serum and plasma were obtained by mixing with a protein-precipitating agent prior to analysis by inductively coupled plasma elemental analysis spectrometers (ICP-AES) (Anderson et al. 2001). Total selenium in animal tissues including blood and serum was obtained by digesting samples in concentrated nitric acid. Selenium concentration is then determined by inductively coupled plasma mass spectrometry (ICP-MS) (Ricks et al. 2005).

Results

Since 1985, 327 bighorn sheep have been captured on the mine sites. I was able to obtain results for 282 of these sheep (Table 1). Results of virus and bacteria tests as well as tests for gastrointestinal parasites and lungworms for the Luscar Mine sheep are presented in Tables 2 and 3, respectively.

On the Luscar and Gregg River mines, CE is most often observed in lambs in spring as scabs on their mouth, which eventually heal after 2 to 3 wk. During the 1999 capture, 51 sheep were sampled and two (1 female yearling and 1 female 4.5 yr) were identified with symptoms of contagious ecthyma and released on site (Cassirer 1999).

During the February 1999 and 2000 captures of bighorn sheep at the Luscar Mine, ulcerative lesions were identified on the edges of the vulva in a number of adult ewes (MacLeod, unpublished). In January and March 2001, 2 biopsy samples from ewes with similar lesions were sent to the Veterinary Pathology Laboratory of Alberta Agriculture in Edmonton and the Canadian Cooperative Wildlife Health Centre in Saskatoon. Both labs reported that the lesions were suggestive of contagious ecthyma. However, results were not conclusive and the origin remains unknown (Bollinger 2001, MacLeod 2001).

A number of strains of *Pasteurella haemolytica* and *Pasteurella trehalosi* (serotype 3 and biotype 2) were isolated from the upper respiratory tract of bighorn sheep at the Luscar Mine. At least 28 biovariants were identified (Cassirer 2005). *Pasteurella multocida* was not

Table 1. Bighorn sheep captured for translocation and/or testing at Luscar Mine, Alberta, 1985 to 2007.

Year	Capture Date	Destination	Available Test Results	Total Translocated
1985	May	game farms, AB	0	18
1986	March 13, 14	game farms, AB	0	6
1986	Apr 9, May 6	Edmonton Valley Zoo, AB	0	2
1986	May 6, 20	AB Fish and Wildlife	0	3
1989	Feb 27	Nevada	0	20
1990	Jan 22	Nevada	25	25
1992	Feb 20	Nevada	31	31
1995	Feb 7	Oregon	49	49
1998	Feb 11	Plateau Mtn., AB	18	31
1999	Feb 9, 10	Hells Canyon, U.S.	20	20
1999	Feb 9, 10	South Dakota	20	20
1999	Feb 9, 10	Luscar Mine, AB	11	0
2000	Feb 8	Hells Canyon, U.S.	37	37
2000	Feb 8	Luscar Mine, AB	1	0
2000	Feb 9	Mount Baldy, AB	0	7
2001	Jan 31	Utah	32	32
2001	Jan 31	Luscar Mine, AB	9	0
2001	March 26	Luscar Mine, AB	10	0
2003	Apr 29	Gregg River Mine, AB	1	0
2004	Nov 24	Ram Mountain, AB	0	6
2005	Mar 16	Ram Mountain,, AB	0	6
2007	Mar 23	Ram Mountain, AB	12	12
2007	Mar 23	Calgary Zoo, AB	2	2
Total			282	327

Table 2. Virus and bacteria testing of bighorn sheep from the Luscar Mine, Alberta, 1990 to 2001. N = negative; P = positive.

	Date	Purpose/Destination	n	Laboratory	Outcome
VIRUSES: Contagious ecthyma (CE)	occasional	Annual surveys	few		Individuals - See text
	1999-2001	Translocation	few		Released on site - See text
Bluetongue (BTV) and epizootic	1990	Nevada	16	WADDL	N [a]
haemorrhagic disease (EHDV)	1992	Nevada	6	WADDL	N [b]
	1995	Oregon	49	OSU VDL	N
	1999-2000	Idaho/South Dakota	89	BAHL	N [c]
Parainfluenza-3 (PI-3)	1990	Nevada	16	WADDL	N [a]
	1995	Oregon	49	OSU VDL	N
	1999-2000	Idaho/South Dakota	89	BAHL	N [c]
Bovine respiratory syncytial virus	1990	Nevada	16	WADDL	4 of 16 positive [a]
(BRSV)	1995	Oregon	49	OSU VDL	N
	1999-2000	Idaho/South Dakota	89	BAHL	N [c]
Infectious bovine rhinotracheitis (IBR)	1990	Nevada	16	WADDL	N [a]
	1995	Oregon	49	OSU VDL	N
	1999-2000	Idaho/South Dakota	89	BAHL	N [c]
Bovine viral diarrhea (BVD)	1990	Nevada	16	WADDL	N [a]
	1995	Oregon	49	OSU VDL	N
	1999-2000	Idaho/South Dakota	89	BAHL	N [c]
Vesicular stomatitis (VS)	1990	Nevada	16	WADDL	N [a]
BACTERIA: Anaplasmosis (ANA)	1990	Nevada	16	WADDL	N [a]
	1995	Oregon	49	OSU VDL	N
	1999-2000	Idaho/South Dakota	89	BAHL	N [c]
Johne's Disease (= Paratuberculosis)	1995	Oregon	39	OSU VDL	N

Leptospirosis	1990	Nevada	16	WADDL	N[a]
	1995	Oregon	49	OSU VDL	N
Brucellosis (*Brucella ovis*)	1990	Nevada	16	NADL	N[a]
	1992	Nevada	6	NADL	N[b]
	1995	Oregon	49	OSU VDL	N
	1999-2000	Idaho/South Dakota	89	BAHL	1 sero false-positive, 1 false-suspect (ELISA). Both N on ELISA retest and card test (Cassier 1999). [c]
	2001	Utah	32	BAHL	N
Pasteurella spp. and *Mannheimia* spp.	1998	Plateau Mtn.	18	VPL	*P. haemolytica* 1 of 18 *P. haemolytica* (not type T) 3 of 18
	1999-2000	Idaho/South Dakota	88	DPUG	*P. trehalosi*, *Mannheimia* spp.
	2001	Research	10	AAFRDL	*P. haemolytica* 6 of 10 *Pasteurella* spp. 6 of 10 *P. trehalosi* 3 of 10
Ovine progressive pneumonia (OPP)	1990	Nevada	16	WADDL	N[a]
	1995	Oregon	49	OSU VDL	N
	1999-2000	Idaho/South Dakota	89	BAHL	0.01 (prevalence) [c]
Hemophilus sp.	1990	Nevada	16	WADDL	present in 13 of 16
Hemophilus somnus	1995	Oregon	49	OSU VDL	present in 46 of 49
Campylobacter sp. (Vibrio)	1990	Nevada	16	WADDL	16 of 16
PROTOZOA: Toxoplasmosis	1990	Nevada	16	WADDL	N

[a] Tronstad (1990), [b] Tronstad (1992), [c] Cassirer (2005)

Table 3. Prevalence (% infected) and intensity (mean number larvae, eggs, or oocysts per g faeces) of gastrointestinal parasites and lungworms in bighorn sheep from Luscar Mine, Alberta.

Parasite	Date	Purpose	N	Laboratory	Prevalence (Intensity)
Coccidia (*Eimeria* spp.)	1990	Nevada	16	Tronstad 1990	Present
	1999-2000	Idaho/SD	71	WADDL	97 (410)
	March 26, 2001	Research	10	CCWHC 2001	100 (358)
	March 23, 2007	Research	14	FVMUC	100 (937)
Strongyles	1999-2000	Idaho/SD	71	Cassirer 2005	0
Trichostrongyles	March 26, 2001	Research	10	CCWHC 2001	90 (1.5)
Species 1	March 23, 2007	Research	6	FVMUC	100 (77)
Species 2	March 23, 2007	Research	14	FVMUC	93 (15)
Nematodirus spp.	1990	Nevada	16	Tronstad 1990	Present
	1999-2000	Idaho/SD	71	Cassirer 2005	59 (7)
	March 26, 2001	Research	10	CCWHC 2001	60 (6.7)
	March 23, 2007	Research	14	FVMUC	79 (30)
Moniezia sp.	1990	Nevada	16	Tronstad 1990	Present
	1999	Idaho/SD	37	WADDL 1999	3 (28)
	March 23, 2007	Research	14	FVMUC	43 (86)
Marshallagia sp.	March 26, 2001	Research	10	CCWHC 2001	100 (17)
	March 23, 2007	Research	14	FVMUC	100 (71)
Trichuris spp.	1999-2000	Idaho/SD	71	Cassirer 2005	45 (5)
	March 26, 2001	Research	10	CCWHC 2001	50 (12)
	March 23, 2007	Research	14	FVMUC	93 (108)
Tapeworm	Oct 10, 1992	hunter kill	1	Pybus 1997	Present
	March 26, 2001	Research	10	CCWHC 2001	20 (124)
Protostrongylus spp.	Oct 85-Sep 86	Research	329	MacCallum 1991	96 (792)
	March 1987	Research	28	Unpublished	100 (828)
	April 1987	Research	27	Unpublished	100 (1419)
	May 1987	Research	29	Unpublished	100 (217)
	April 1989	Research	25	Unpublished	100 (128)
	October 1989	Research	31	Unpublished	100 (621)
	January 1990	Nevada	16	Tronstad 1990	Present
	April 1990	Research	27	Unpublished	96 (185)
	October 1990	Research	34	Unpublished	97 (130)
	Apr 91-Mar92	Research	311	Unpublished	95 (394)
	Feb 1999, 2000	Idaho/SD	83	Cassirer 2005	83 (47)
	March 26, 2001	Research	10	CCWHC 2001	100 (135)
	March 23, 2007	Research	14	FVMUC	100 (138)

Scabies *(Psoroptes* sp.)	1995	Oregon	49	UCD	1sero false-positive
	1999-2000	Idaho/SD	89	WADDL	Negative

cultured from this population (Table 2).

Since 1998, several skulls of mature bighorn sheep rams from the vicinity of the Luscar and Gregg River mines have been returned or reported to the Alberta Fish and Wildlife Diagnostic Lab in Edmonton indicating horn core deterioration that was identified when the sheaths were removed during the taxidermy process. These skulls have weakened and degenerated bone cores (bone material covered by the keratin horn sheath). The bone changes appear to be associated with a long-term bacterial infection in some skulls. Bacteria from two fresh heads with affected horn cores was identified as nonspecific secondary bacterial invaders (*Staphylococcus* spp. and *Corynebacterium* spp.). Neither skull had any evidence of a primary bacterial pathogen associated with potential bone core erosion (Pybus 2006).

Gastrointestinal parasite eggs, oocysts, or larvae detected in faeces of sheep from the Luscar Mine included *Eimeria* spp. [protozoan]; trichostrongyles, thread-necked strongyles (*Nematodirus* spp.), abomasal worm (*Marshallagia* sp.), and whipworm (*Trichuris* spp.) [nematodes]; and a tapeworm *(Moniezia* sp.) [cestode].

Cassirer (2005) detected no strongyles (other than *Nematodirus* spp.) in 83 samples in 1999 and 2000; however, trichostrongyles were detected in 10 sheep (90% prevalence) sampled March 26, 2001 (Table 3). Kutz (2007) reported the presence of *Marshallagia* sp., *Nemotodirus* sp., *Eimera* (at least 2 species), *Trichuris* sp., and 2 species of *Trichostrongylus* in samples from 14 lambs captured March 23, 2007 on the Luscar and Gregg River mines. Trichostrongyles are very common in bighorn sheep (Uhazy and Holmes 1971, Samuel et al. 1977).

All or most sheep shed larvae of the lungworms *Protostrongylus stilesi* and/or *Protostrongylus rushi* (Table 3). Mean number of larvae was high (>1400 LPG faeces) during the rut in late autumn and during late winter in 1985/86. A two-sample t-test of log normalized data was used to compare LPG values between 1985/86 and 1991/92. There was no difference ($F = 1.05$, df = 315, $P = 0.3352$).

Psoroptes sp. (scabies) infection was not detected (Table 3). Blood serum from 49 sheep captured on the Luscar Mine in 1995 was negative for exposure to *Psoroptes ovis* with one exception. This sheep may have been a false-positive (Boyce 1995).

The Rocky Mountain wood tick (*Dermacentor andersoni*) is present but few have been observed on the bighorn sheep during winter capture events.

Trace minerals in liver and serum of bighorn sheep from the Luscar and Gregg River mines are summarized in Tables 4 and 5. Mean selenium (ppm ww) in whole blood (Table 5) included 2 data points identified as outliers (1.4 and 1.81 ppm ww). These samples were from female sheep 6 mo old. After removal of the outliers, a two-sample t-test indicated no differences in selenium values ($P = 0.15$) between lambs (n=22) and all other ages (n=107).

Table 4. Mineral concentrations (ppm ww) in liver of 3 bighorn sheep from Luscar and Gregg River mines, Alberta. Information from 2000 provided by F. Cassirer, Idaho Fish and Game.

	Female 2.8 yr Feb 2000	Female 4^{+} yr Feb 2000	Female 1 yr Apr 2003	Approximate adequate ranges [a]	Adequate mature sheep mineral levels
Laboratory	UIASL	UIASL	BCAHC	UIASL	BCAHC
Molybdenum	1.20	1.60	NS[b]	0.40-0.80[c]	NS
Zinc	62	47	44	25-50	30-75
Cadmium	0.24	0.32	< 0.2	< 0.20	< 0.50
Lead	BDL[b]	BDL	< 2	< 2.00	< 5.0
Manganese	2.10	2.60	2.3	2.00-5.00	2.0-4.5
Iron	221	138	220	40-100	30-250
Copper	5	6	35.9	25-100	25-100
Selenium	0.622	0.583	0.56	0.250-0.800	0.25-1.50
Calcium	NS	NS	71	NS	38-80
Magnesium	NS	NS	168	NS	118-220

[a] The indicated ranges are only guidelines and the analytical results need to be interpreted in conjunction with management and dietary factors, as well as clinical and/or postmortem observations
[b] NS = Not Sampled; BDL = Below Detection Limit
[c] Based on domestic sheep

Table 5. Mineral concentrations (ppm ww) in serum of bighorn sheep from Luscar Mine, Alberta, 1999 to 2001. Approximate adequate ranges are from UIASL.

	N[a]	Mean	SD	Min	Max	Range	Approximate adequate ranges[b]
Copper	126	0.53	0.23	0.07	2.20	2.13	1.17 - 2.56
Zinc	129	0.86	0.44	0.34	2.20	1.86	0.90 - 1.84
Calcium	129	96	10	63	114	51	80 – 100
Magnesium	129	24	2	16	32	16	20 – 33
Phosphorus	129	48	13	25	91	66	35 - 82
Iron	129	1.63	0.45	0.96	3	2.04	1.60 - 2.20
Selenium	50	0.182		0.04	1.40	1.36	0.040 - 0.130
Selenium [c]	131	0.613		0.3	1.81	1.51	0.040 - 0.130

[a] Does not include blanks, below detectable levels , or quantity not sampled.
[b] The indicated ranges are only guidelines and the analytical results need to be interpreted in conjunction with management and dietary factors, as well as clinical and/or postmortem observations
[c] Whole blood

Whole blood selenium levels differ among years (MacCallum 2006). Mean values (ppm ww) were 0.648 in 1999 (n=52 sheep); 0.750 in 2000 (n=38); and 0.443 in 2001 (n=41). After removal of the two outliers (as above), one-way analysis of variance indicated differences between years ($P = 0.0002$).

Mean selenium concentration in 36 hair samples from 1999 (0.791 ppm ww, range 0.400 - 1.100) was within normal values (MacCallum 2006). For comparison, normal levels of selenium in wool of domestic sheep are 0.20 - 4.00 ppm dw (UIASL).

Discussion and summary

Dubay et al. (2002) compiled a comprehensive literature review and risk assessment of specific disease concerns for translocation of bighorn sheep. I summarized the status of specific diseases on the Luscar and Gregg River mines and threat to bighorn sheep (Appendix B) using the risk assessment from Dubay et al. (2002) and other literature as noted.

Viruses. Contagious ecthyma is enzootic in bighorn sheep of the Luscar and Gregg River mines, particularly lambs in spring. General body condition of sheep in this study was good (MacCallum 1991) and no severe outbreaks have been recorded, even though they have occurred in nearby Jasper National Park (Samuel et al. 1975), to the south at Ram Mountain (Jorgenson 1990), and elsewhere (Merwin and Brundige 2000). Ewes and lambs with symptoms of CE are released on site.

Foreyt et al. (1996) published health parameter data for bighorn sheep considered healthy on Hall Mountain, Washington. No viruses were isolated, although low antibody prevalence against PI-3 (12%), BVD (2%), and RSV (<1%) indicated exposure to these respiratory viruses. In 7 bighorn sheep populations in Montana, Aune (1998) detected serologic evidence for respiratory virus antibodies in all herds regardless of whether they had experienced an epizootic pneumonia outbreak. The most common respiratory viruses were PI-3 and BRSV. Sero-prevalence did not compare uniformly with virus isolation results in the Montana study (Aune et al. 1998). Cassirer (2005) reported antibodies to PI-3 in each [Hell's Canyon] population every year sampled except the Lostine population in 2002; prevalence ranged from 9 to100%. Titers to other viral pathogens occurred with low prevalence in resident sheep in the Canyon, including BTV (5 individuals in 5 populations), BRSV (2 individuals in 1 population), BVD (7 individuals in 3 populations), EHD (5 individuals in 4 populations), and OPP (3 individuals in 2 populations). No titers were detected to IBR (Cassirer 2005).

Bacteria. Prevalence of *Anaplasma* sp. was high in the bighorn sheep from Hall Mountain, Washington although its significance was unknown (Foreyt et al. 1996). Six percent of 82 of these sheep tested positive for *Brucella ovis* (titer >1:10), although it was not isolated from tissue, an indication that the reactions may have been false-positive. Antibodies to *Anaplasma* sp. were detected in 45 of 229 sheep in 5 of 6 [Hell's Canyon] populations (Cassirer 2005). No titers were detected to *Brucella ovis* in the Hell's Canyon bighorn sheep (Cassirer 2005).

The primary cause of bacterial infections of the bone core of older rams on the Luscar and Gregg River mines is unknown. Apparent infection of a 13-yr old captive ram (spring 2006) at the Thorne/Williams Wildlife Research Center in Sybille, Wyoming was reported (Schultz 2007): "*On the back side of his horn there was a crack less than 2 inches, about 4-5 inches on the base on the back side. It had some yellow/clear discharge and staining along the crack's edge*." Potential factors include age, aggressive behaviour, trauma, and weakness of horn keratin. Older sheep often show signs of wear and tear - gray hairs about the face and muzzle, scarring of the face and body, longer or broomed horns, and worn or malaligned teeth. Bighorn sheep on the Alberta coal mines are considered a high quality population characterized by high lamb:ewe ratios, large body size, high density and numbers, and a strong population growth. Bighorn sheep from high quality populations tend to show more juvenile behaviour, i.e., fighting (Geist 1971). High degree of fighting between male sheep from the Luscar and Gregg River mines could contribute to increased amount of trauma to their horns including broken or cracked horns which may allow opportunistic bacteria to enter under the horn sheath.

Parasites. Seasonal variation occurred in the intensity of lungworm larvae in faeces from bighorn sheep on the Luscar Mine (MacCallum 1991). Larval output rose each month during the fall, peaked in December, then declined during the winter. Larval output during summer months was very low compared to winter months. The high prevalence of *Protostongylus* spp. in bighorn sheep from the Luscar Mine is consistent for the season sampled and appears to have no detrimental effect on individual sheep. Similar high prevalence in bighorns was documented at Hall Mountain, Washington (Foreyt et al. 1996) and in various Montana sheep herds (Aune et al. 1998), but LPG values overall were higher from the Luscar and Gregg River mines. Cassirer (2005) reported higher larval prevalence (G = 56.57, 5 df, P < 0.0001) and intensity ($F_{5, 346}$ = 25.07, P < 0.0001) in sheep transplanted to Hell's Canyon from Cadomin [Luscar Mine] and the Missouri Breaks than in resident sheep or in adults that died from pneumonia. LPG in faecal samples from bighorn sheep on the Luscar Mine and from on the nearby Redcap Range for March 1986 showed a significant difference (t = 3.02 df=29, P < 0.05) (MacCallum 1991). LPG values from sheep from Redcap were higher (n=21, $\bar{x}$ = 1499.1, SD=1155.6, range 54-3744) than those from the Luscar Mine (n=26, $\bar{x}$ = 673, SD=540, range 36-2380). Despite these high counts, there has been no outward manifestation of pneumonia to indicate multiple stressors are reducing resistance of the Luscar Mine herd to disease.

Similar to my findings, Foreyt et al. (1996) reported that ticks (*Dermacentor albipictus*) on sheep from Hall Mountain were uncommon.

Trace Minerals. Differences in concentrations of trace minerals considered adequate for bighorn sheep exist between testing laboratories (Table 4). Trace minerals were within adequate range (minimum UIASL, maximum BCAHC) for zinc, cadmium, manganese, iron, selenium, calcium, and magnesium. Lead was below the detection limit in the liver of two adult ewes (UIASL). Lead in the 1-yr-old female was at the level considered adequate by UIASL and well below the level considered adequate by BCAHC. Copper levels were below levels considered adequate for the two adult ewes and within normal range for the 1-yr-old female. Molybdenum was higher than levels considered adequate in the liver of the two adult ewes. Opportunistic collection of livers from dead sheep on the mines would augment the current small sample.

Mean concentrations of trace elements in serum samples from 129 bighorn sheep from the mines were within adequate range (UIASL) for calcium, magnesium, phosphorus, and iron. Mean zinc concentration was below concentrations considered adequate, as was copper.

Mean selenium concentration was slightly higher than normal in serum and above normal (UIASL) in whole blood of sheep from the mines but mean concentration in serum was within adequate range used for bighorn sheep in B.C. (0.130-0.203 ppm ww, Lemke and Schwanthe 2005). Selenium concentrations in liver and hair samples were within values considered normal for bighorn sheep. There are no clinical signs of selenium toxicity in sheep from the Luscar Mine (MacLeod 2001). Selenium serum values at the Alberta reclaimed coal mines were higher than those from bighorns from various locations in B.C. (Lemke and Schwantje 2005) but lower than those from domestic sheep at low selenium exposure sites in an Idaho reclaimed phosphate mine (Fessler 2003). This suggests that bighorn sheep at the Luscar and Gregg River mines are not accumulating selenium in toxic amounts (MacCallum 2006). Selenium in these bighorn sheep may simply represent one end of the range of tolerance in wild sheep.

This paper summarizes test results for various pathogens and trace elements in bighorn sheep from the Luscar and Gregg River mines and provides a general health profile for a high quality bighorn population that has had little or no contact with domestic sheep, goats, or cattle. This documentation and the continued good health of the bighorn sheep from the Luscar and Gregg River mines support using these animals as a healthy source for translocation to other areas.

Acknowledgments

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Appendix A. Laboratories used to test for disease and trace minerals in bighorn sheep of the Luscar and Gregg River mines, Alberta.

Laboratory	Abbreviation	Tests Conducted
Alberta Fish and Wildlife Diagnostic Lab, Edmonton, AB	AFWDL	bacteriology
Alberta Agriculture Food and Rural Development Lab, Edmonton, AB	AAFRDL	bacteriology
British Columbia Animal Health Centre, Abbotsford, BC	BCAHC	toxicology
Bureau of Animal Health Labs, Boise, ID	BAHL	serology
Canadian Cooperative Health Center, Saskatoon, SK	CCHC	histology
Faculty of Veterinary Medicine, University of Calgary, AB	FVMUC	parasitology
Nevada State Department of Agriculture, Division of Animal Industry, Animal Disease Laboratories, Elko, NV	NADL	serology, bacteriology
Oregon State University Veterinary Diagnostic Laboratory, OR	OSU VDL	serology
Department of Pathology, University of Guelph, ON	DPUG	bacteriology
University of Idaho Analytical Sciences Laboratory, Moscow, ID	UIASL	toxicology
University of Idaho, Caine Veterinary Teaching Center, Caldwell, ID	CVTC	bacteriology
University of California, Davis, CA	UCD	serology (scabies)
Veterinary Pathology Lab, Edmonton, AB	VPL	histology, bacteriology
Washington Animal Disease Diagnostic Laboratory, Pullman, WA	WADDL	serology, parasitology

Appendix B. Status of specific diseases on the Luscar and Gregg River mines and potential threat to bighorn sheep.

Disease	N	Luscar & Gregg R. mines	Threat to bighorns [summarized from Dubay et al. (2002) or as noted].
Viruses			
Contagious ecthyma (CE)	Fe	Present	Widespread and posing little risk.
Bluetongue (BTV) and epizootic haemorrhagic disease (EHD)	16	Not present	Widespread, poses health risk to areas where these diseases are absent or to naive animals translocated to enzootic area.
Parainfluenza-3 (PI-3)	15	Not present	Widespread and believed to pose little risk to bighorn sheep. Alone, PI-3 may not be important but may be fatal in combination with other pathogens and/or stressors.
Bovine respiratory syncitial virus (BRSV)	15	Low prevalence (0.026)	Widespread and believed to pose low risk to bighorn sheep, but information lacking. Alone, RSV may not be important but may be fatal in combination with other pathogens and stressors.
Infectious bovine rhinotracheitis (IBR)	15	Not present	Widespread and appears to pose little health risk to bighorn sheep.

Bovine viral diarrhea (BVD)	15	Not present	Widespread exposure, uncertain significance, requires more research.
Ovine progressive pneumonia (OPP)	15	Not present in 1990, 1995. Low prevalence in 1999-2000 (0.01).	Slowly progressive viral disease of adult [domestic] sheep caused by an ovine lentivirus (USDA 2003).
Vesicular stomatitis (VS)	16	Not present	Sporadic, reemerging viral disease of cattle, horses, and swine. Also affects [domestic] sheep and goats. Many wild species, including deer, bobcats, goats, raccoons, and monkeys susceptible (USDA 1996).
Bacteria			
Anaplasmosis (ANA)	15	Not present	Widespread but appears to pose little direct health risk for bighorn sheep.
Johne's disease (Paratuberculosis)	39	Not present	Isolated problems in bighorn sheep. Managers and veterinarians should monitor for clinical signs if the disease documented previously in a herd. Do not use such herds for translocations.
Leptospirosis	65	Not present	Widespread in many wildlife species, uncertain in bighorn sheep, but seems to pose minor health risk.
Brucella ovis	19	Not present	Uncertain for bighorn sheep. Additional research needed with bighorn sheep sympatric with infected elk and bison in enzootic areas. Testing bighorn sheep from enzootic areas should be considered.
Pasteurellosis	11	*Pasteurella trehalosi* 6 biovariants; 2 unique *Mannheimia* spp. 22 biovariants; 11 unique *P. multocida* not present	Many *Pasteurella* spp. and biotypes widespread and present in most bighorn sheep and domestic livestock herds. Many *Pasteurella* spp. of domestic sheep origin considered fatal to bighorn sheep. Those of bighorn sheep origin may present health risk to naive animals, but difficult to predictably identify. Capacity to predict effects of *Pasteurella* spp. on source or recipient bighorn sheep populations not yet available. Therefore, pre-movement culturing of bighorns in source and recipient herds can be considered; however, disease history is more important. Prevention of contact between all domestic and wild sheep is paramount.
Hemophilus sp.	65	Present High prevalence (0.91)	*Haemophilus somnus* (reclassified as *Histophilus somni*). Associated with respiratory disease in American bison, domestic sheep, and cattle. Also harboured in reproductive tracts and associated with reproductive failure in domestic sheep and cattle (Ward et al. 2006).
Campylobacter spp.	16	Present 100% prevalence (1.0)	Commonly found in intestinal tracts of dogs, cats, poultry, cattle, swine, monkeys, wild birds, and some humans (USDA 1991).
Parasites			
Toxoplasmosis	16	Not present	*Toxoplasma gondii* is one of the most common parasitic protozoan infections of humans and other warm-blooded animals. Worldwide from Alaska to Australia (USDA 2007).
Scabies (Psoroptic mites)	13	Not present	Localized with potential for substantial morbidity and mortality, especially in naive animals.

Comparison of Ultra Sound and Serology for Determining Pregnancy in California Bighorn Sheep

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Abstract: Between January 2001 and December 2004 we captured 229 adult California bighorn sheep (*Ovis canadensis californiana*) ewes from seven Oregon herd ranges and two Nevada herd ranges and compared two techniques for determining pregnancy. Blood serum was used to run Pregnancy Specific Protein B (PSPB) analysis. Ultra sound analysis was completed at capture using trans-dermal or rectal transducers. Differences in determining pregnancy between the two techniques occurred in 16% of the samples. In ewes captured more than 45 d after the peak of rut, most differences occurred when ultra sound analysis failed to identify a fetus but PSPB analysis indicated the ewe was pregnant. In ewes captured less than 45 d after the peak of rut, most differences occurred when ultra sound analysis identified a fetus being present but PSPB analysis indicated the ewe was not pregnant.

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Key words: California bighorn sheep, pregnancy, PSPB analysis, ultrasound.

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Bighorn Sheep Leukocyte Receptor for Leukotoxin Secreted by *Mannheimia (Pasteurella) haemolytica*

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Abstract: *Mannheimia (Pasteurella) haemolytica* is an important etiological agent of pneumonia, a highly fatal disease of bighorn sheep (*Ovis canadensis*). *M. haemolytica* produces an exotoxin which is cytolytic to all subsets of bighorn sheep leukocytes. This leukotoxin is regarded as the most important virulence factor of this organism. Hence identification and characterization of the receptor for leukotoxin on bighorn sheep leukocytes is an important prerequisite for understanding the pathogenesis of this disease. Antibodies specific for CD18, the β subunit of β_2-integrins, inhibit leukotoxin-induced cytolysis of bighorn sheep leukocytes suggesting that CD18 may serve as a receptor for leukotoxin on bighorn sheep leukocytes. Confirmation of bighorn sheep CD18 as a receptor for leukotoxin requires demonstration that the recombinant expression of bighorn sheep CD18 in leukotoxin-non-susceptible cells renders them susceptible to leukotoxin. Therefore, we cloned and sequenced the cDNA encoding CD18 of bighorn sheep, and transfected a leukotoxin-non-susceptible murine cell-line. Cell surface expression of bighorn sheep CD18 on the transfectants was tested by flow cytometry with anti-CD18 antibodies. Transfectants stably expressing bighorn sheep CD18 on their surface were subjected to a cytotoxicity assay with leukotoxin. In this assay, the transfectants were effectively lysed by leukotoxin in a concentration-dependent manner, whereas the parent cells were not. These results indicate that leukotoxin utilizes CD18 as a receptor on bighorn sheep leukocytes. Identification of CD18 as a receptor for leukotoxin on bighorn sheep leukocytes should enhance our understanding of the pathogenesis of pneumonia, which in turn should help in the development of control measures against this fatal disease of bighorn sheep.

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Key words: Bighorn sheep, leucocytes, leukotoxin receptor, *Ovis canadensis*, pneumonia.

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Potential Health Risks to Dall's Sheep associated with Domestic Sheep and Goats in the Northwest Territories, Canada

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Abstract/Summary: In Canada's Northwest Territories (NWT), healthy populations of Dall's sheep (*Ovis dalli*), caribou (*Rangifer tarandus*), moose (*Alces alces*), and mountain goats (*Oreamnos americanus*) are important for subsistence and resident hunters in the Mackenzie and Richardson Mountains, and are the basis for a world-class non-resident outfitted hunting industry in the Mackenzies. There is also growing interest in developing the agricultural industries in the Northwest Territories (NWT), including domestic livestock production. However, expansion of the livestock industry could result in pathogen exchange among domestic and wild species, and subsequent negative consequences on the NWT economy. For example, introduction of a domestic sheep strain of the bacterium *Mannheimia haemolytica* has the potential to cause outbreaks of pneumonia in Dall's sheep populations. Introduction of domestic goats and llamas as pack animals for back-country recreation could result in pathogen transfer and negative effects on wildlife populations. We believe that agriculture, tourism, and hunting may coexist only if participants in these activities are aware of potential negative interactions and act to eliminate or minimize them.

To develop a sustainable agricultural industry in the NWT while conserving wildlife species and ecosystem health, it is critical that we understand risk of disease introduction with domestic livestock or exotic species, risk of disease transmission between wild and domestic/exotic animals, and how risks can be mitigated with minimal impact on either sector. The objectives of the current Risk Assessment were to identify the pathogens known to infect domestic sheep, domestic goats, llamas, Dall's sheep and mountain goats, and to examine the disease risks associated with the possible introduction of domestic sheep, goats, and llamas to the Mackenzie and Richardson Mountains.

We identified numerous pathogens in domestic sheep and goats that have had serious negative impacts on the health of bighorn sheep (*Ovis canadensis*). Thinhorn sheep (Dall's and Stone's sheep; *O. dalli* subspp.) may have similar disease susceptibilities, leading to detrimental impacts on wild sheep and goats in the NWT. Nine infectious agents were considered high risk: *Mycobacterium avium paratuberculosis, Mycoplasma conjunctivae* and *M. ovipneumoniae, Pasteurella* spp.*, Mannheimia haemolytica,* contagious ecthyma,

Parainfluenza-3, *Muellerius capillaris,* and *Oestrus ovis*. Ninteen infectious agents were unknown risk for Dall's sheep, 10 were low risk, 128 had no apparent risk at this time, and 3 were important but not reported in Dall's sheep or mountain goats in NWT. Of the risk agents identified, 11 were potential public health concerns. Some disease agents in Dall's sheep and mountain goats may infect domestic sheep, goats, or llamas; however, current management and treatment practices of domestic livestock preclude major concern for present or future agriculture in the NWT.

The Risk Assessment indicates contact between domestic sheep or goats and wild sheep or goats would likely result in significant disease in the wild species, with substantial long-term negative effects on population dynamics and sustainability. **We strongly advise that domestic goats <u>not</u> be used as pack animals, and that domestic sheep and goats not be pastured in the vicinity of Dall's sheep or mountain goat ranges within the NWT**. This recommendation is consistent with the practical experience and recommendations of bighorn sheep managers and biologists throughout Canada and the United States. Experience gained from events in the U.S. and southern Canada clearly highlights substantial economic and social costs in mitigating the effects of diseases of domestic sheep and goats in wild sheep populations. Contact between llamas and wild sheep or goats **may** result in disease in wild species, but data are insufficient to clearly assess the role of camelids as a source of disease.

Risks change as a result of changing management practices in wild and/or domestic livestock, ecosystem balance (climate change, habitat fragmentation), and the discovery or emergence of novel diseases. Our document[2] provides a basis for pro-active guidelines and management policies to prevent negative impacts associated with the possible introduction of domestic sheep, goats, and llamas to the NWT. It also highlights the critical importance for managers and agencies with mandates for animal health to develop science-based assessments for other potential introductions or translocations of wild and domestic species in the NWT and elsewhere. Integration of these recommendations into policy will provide a positive framework for continued development of a healthy domestic livestock industry while promoting healthy wildlife populations in the NWT and sustainability of all forms of wildlife harvest and tourism.

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Key words: Dall's sheep, domestic goat, health risks, literature review, Northwest Territories, *Ovis dalli*.

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[2] http://wildlife1.usask.ca/Publications/NWT_Dall_Mtn_goats_Domestic_sheep_goats_RiskAssessment.pdf

Transmission of Goat Lungworms (*Muellerius capillaris*) from Domestic Goats to Bighorn Sheep

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Abstract: Four domestic goats (*Capra hircus*) passing first-stage larvae of the lungworm *Muellerius capillaris* were co-pastured with 7 Rocky Mountain bighorn sheep (*Ovis canadensis*) not passing larvae. Goats and bighorn sheep were co-pastured on a 0.8-ha pasture for 11 months from May 2003 to April 2004. During the experiment, 2 bighorn sheep died from pneumonia caused by *Mannheimia haemolytica* Biotype A, serotype 2. The remaining 5 bighorns and the 4 domestic goats remained healthy during the experiment. *Muellerius* larvae were detected from all domestic goats on a monthly basis throughout the experiment, and from all 5 surviving bighorn sheep 5 mo after the co-pasturing began. Larvae were detected in low numbers from all bighorns every month thereafter for the 5 mo the goats were in the enclosure and for more than 1 yr after the goats were removed. Six bighorn sheep in 2 similar enclosures without goats did not pass *Muellerius* larvae during the experimental period. *Muellerius capillaris* from domestic goats is capable of infecting bighorn sheep when animals are co-pastured on common range.

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Key words: Bighorn sheep, domestic goat, lungworms, *Muellerius capillaris*, *Ovis canadensis*, parasite transfer.

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Bighorn Sheep Hoof Deformities: A Preliminary Report

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Abstract: In March 2001, 22 bighorn sheep (*Ovis canadensis*) were reintroduced into the Wildcat Hills in the southern Panhandle of Nebraska after nearly a 100-yr absence. During the fall of 2001, one female lamb developed an unusual hoof deformity. Both her front hooves grew to 15-18 cm in length, creating difficulties in mobility. Since that time, one to two female lambs each year developed this deformity. Potential causes of these deformities may be associated with selenium, molybdenum, copper, zinc, anaemia, epizootic hemorrhagic disease (EHD), bluetongue (BT) virus, or genetic bottlenecking. Recognizing the need to understand the cause of the hoof deformities, a study was initiated to address this issue.

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Key words: Bighorn sheep, hoof deformities, Nebraska, *Ovis canadensis*.

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In March 2001, 22 bighorn sheep (*Ovis canadensis*) were reintroduced from Colorado Springs, CO into the Wildcat Hills (41.45.930’ N, 103.45.927’ W) (Figure 1) in the southern Panhandle of Nebraska after nearly a 100-yr absence.

During the fall of 2001, the hooves of both front feet on one female lamb grew to 15-18 cm in length, Since that time, one to two female lambs each year developed similar deformities (Figures 2 and 3).

The goal of our study is to determine the cause or causes which result in the hoof deformities or possibly eliminate some causes to aid in future management plans. The specific objectives are to: (1) establish baseline seasonal foraging habits of bighorn sheep in the Wildcat Hills, (2) establish differences in diet selection and the trace mineral levels in vegetation chosen by ewes and lambs, (3) develop a spatial analysis of plant communities that carry excessive loads of trace minerals, (4) develop baseline data of trace mineral levels in bighorn sheep, (5) develop baseline data of population exposure and possible effects from epizootic hemorrhagic disease (EHD) and bluetongue (BT) virus, and, if time and money are available, (6) test for possible genetic traits or links among affected adults and lambs.

The research was conducted primarily on the Cedar Canyon Wildlife Management Area (WMA), 41 45.930’ N, 103 45.927’ W, and also on two other sites on private ranchland (the Hampton 41 42.374’ N, 103 50.190’ W and Montz properties 41 46.716’ N, 103 55.207’ W) within the Wildcat Hills of southern Nebraska (Figure 1). These areas were chosen based on past bighorn occupancy

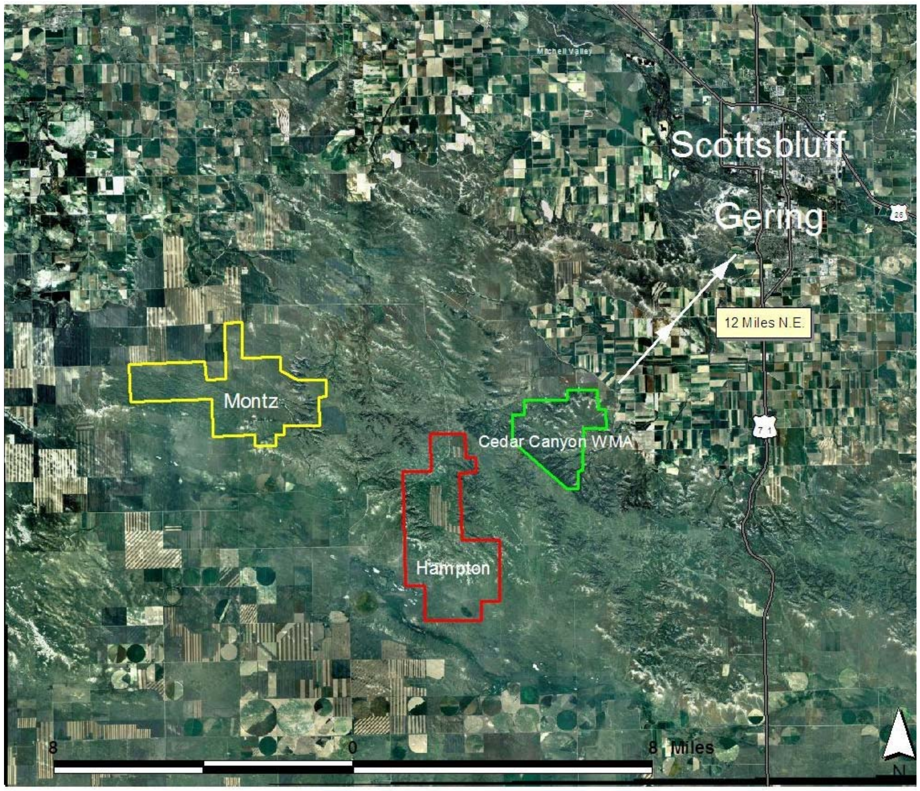

Figure 1. Bighorn sheep hoof deformity study locations in the Wildcat Hills, Nebraska

data and habitat assessment of the Wildcat Hills (Forbes 1999). Trapping and wildlife immobilization are the preferred methods utilized to obtain blood, tissue, and hoof samples from as many different bighorns as possible (Kock et al. 1987). Blood and tissue samples collected from captured bighorns are being tested for EHD and BT viruses (Washington Department of Fish and Wildlife 1999, Howerth and Stallknecht 2000, Michigan Department of Natural Resources 2003), and assessed for levels of selenium, copper, zinc, molybdenum, and possible anaemia (Thorne et al. 1982, Meyer and Harvey 1998, Jurgens and Bregendahl 2002) to establish baseline data from affected and unaffected sheep. For comparison and control, blood and tissue samples will be collected from the Pine Ridge herd and from newly-introduced sheep from Montana in 2005 and/or 2007. These herds are located approximately 160 km north of the Cedar Canyon herd, but occur on range with similar geology and vegetation. Although consistent monitoring of this herd continues, no evidence of the hoof deformity has shown up thus far. They also will provide valuable data in documenting trace mineral levels for bighorns and allow comparison with the Wildcat Hills herd.

Diet is being determined through microhistological analysis (Todd 1975, Fairbanks et al. 1987) of fecal pellets. This type of analysis is a quantified account of the diet through inspection of plant material in fecal samples. Fresh fecal samples from a minimum of 10 sheep (5 ewes and 5 lambs) were collected every month from November 2004 to November 2005. Samples were collected randomly from the ground within 4 hr of observed defecation. To determine plant species consumed and percentage consumed by selected ewes and lambs, bite counts (Canon et al. 1987, Ruckstuhl et al. 2003) were conducted for 2 wk each month

Figure 2. Hoof deformity on lamb in 2003. Photo by Bob Grier.

Figure 3. Hoof deformity on 3 yr old ewe (developed as a lamb). Photo by Nebraska Game and Parks Commission.

focusing on 4-6 different sheep. Actual bite counts were confirmed by collecting samples from grazed plants (Canon et al. 1987, Ruckstuhl et al. 2003). Plant samples collected are being tested for selenium, molybdenum, copper, and zinc content following established forage analysis techniques (Bauer 1997, Davis et al. 2002).

Past bighorn observational data were analyzed to identify range occupancy and distribution. From these data, four transects were established. The vegetative transects will provide evidence of seasonal forage production and plant species composition for the area. Soil samples will be gathered from the study area to determine trace mineral levels (Bauer 1997, Davis et al. 2002) and identify any correlation between trace minerals in plants and soils.

As of this writing, data analysis and results are pending. However, early indicators suggest that selenium, molybdenum, zinc, EHD, and BT may not be associated with the hoof deformity.

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Selenium Supplementation, Parasite Treatment, and Management of Bighorn Sheep at Lostine River, Oregon

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Abstract: Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) were restored to Hells Canyon when 20 sheep were released in Oregon in the Lostine River drainage in 1971. The Lostine bighorn sheep population was studied and managed intensively since then. Since 1977, salt supplemented with selenium and other trace minerals was available to bighorn sheep on the Lostine winter range. Blood selenium levels in the Lostine bighorn population are the highest of all populations tested in Hells Canyon. In 2002, removal of selenium-supplemented salt from the Lostine winter range resulted in a drop in whole blood selenium levels. Wintertime mineral supplementation continued in 2003, resulting in a return to previous whole blood selenium levels. Notwithstanding high selenium levels, the Lostine bighorn population experienced an all-age pneumonia epizootic in 1986/1987, followed by periods of poor lamb survival. Beginning in 1982 the bighorn sheep at Lostine River were treated periodically with fenbendazole for lungworm (*Protostrongylus* spp.). From 2003 to 2005 sheep were treated with ivermectin for lungworm and scabies mites (*Psoroptes* spp.). These parasites were not detected in December 2005 or January/February 2006 and appear to be absent or, if present, occurring at very low levels.

BIENN. SYMP. NORTH. WILD SHEEP AND GOAT COUNC. 15:98-106

Key words: Hells Canyon, Lostine River, lungworm, Oregon, *Ovis canadensis canadensis, Protostrongylus* spp., *Psoroptes* spp., Rocky Mountain bighorn sheep, scabies, selenium.

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Rocky Mountain bighorn sheep were re-established in Oregon in 1971 with the release of 20 animals from Jasper National Park, Alberta, Canada into the Lostine River drainage. The Lostine population, grew and numbered 95 bighorn sheep by 1978. The sheep winter on high elevation grasslands near the original release site and migrate southeast to summer on alpine ranges in the Wallowa Mountains.

The Lostine bighorn sheep population is one of the Hells Canyon study herds and was intensively studied, managed, and monitored throughout the year from aircraft and the ground since 1999. Animals are habituated to human presence by years of winter feeding for the purpose of trapping and transplanting, disease testing, disease and parasite treatment, and individual marking. A corral trap is used to capture animals for blood sampling, ear tagging, and radio-collaring. Forty-three bighorns of an estimated population of 90 currently are individually marked. Annual repetitive ground surveys are used to determine lamb survival, ram to ewe ratios, and total numbers. Research activities have identified home range use and causes of mortality (Cassirer 2005a).

The winter population objective of approximately 80 animals is maintained by means of transplants and hunting. The Lostine sheep population is used as a source to re-stock vacant ranges. A limited-entry season for rams began in 1978 and a season for 2 any-ram tags was authorized in 2006. Other management activities included purchase of the 400 ha Lostine Wildlife Area by the Oregon Department of Fish and Wildlife, prescribed spring burns to control conifer and shrub encroachment on winter range, noxious weed control, and water development. In addition, domestic sheep allotments on summer ranges were eliminated; one by negotiations and the other by purchase. No domestic sheep allotments were active in the Wallowa Mountains since 1999.

Herein we describe the selenium status of the Lostine bighorn sheep population of the Hells Canyon area of Oregon, and examine the effects of selenium supplementation on whole blood levels in bighorn sheep. Treatments for lungworm (*Protostrongylus* spp.) and scabies mites *(*Psoroptes* spp.) detected in bighorn sheep at Lostine River also are described.

Study area

The Lostine bighorn population is located in the Wallowa Mountains in the northeast corner of Oregon (45º 23' 53.51'' N, 117º 23' 20.66'' W). The Wallowa Mountains encompass an area of approximately 575 km² and are part of the Hells Canyon area of Oregon, Idaho, and Washington. The bighorn sheep winter range on the Lostine is on a high elevation southwest-facing grassland slope with rugged limestone outcroppings. Most of the area was burned in a wildfire in August 1966. North slope vegetation presently is composed of grasses and shrubs with considerable conifer regeneration. Controlled burns conducted on the lower slopes in 1992 and 2004 reduced tree and shrub encroachment. Elevations range from 1,341 m to nearly 2,286 m on the lower Sheep Ridge. Periodic warm fronts and strong winds generally keep the grassy south slopes snow-free.

Summer range for the Lostine bighorn sheep herd is characterized by U-shaped glaciated valleys, alpine basins, rugged precipitous terrain, and sharp ridge tops (Matthews and Coggins 1994). Elevation ranges from 1,400 to 3,000 m. Dense timber stands occur below 2,287 m. Douglas-fir *(Pseudotsuga menziesii),* white fir *(Abies concolor),* and western larch (*Larix occidentalis)* are the most abundant tree species. Scattered timber stands occur above 2,287 m with subalpine fir (*Abies lasiocarpa)*, and white-bark pine (*Pinus albicaulis)* predominating. Forbs and grasses are the most abundant plant forms on high elevation ridge tops. Avalanche chutes provide additional open feeding areas.

Specific Management

1. Wintertime selenium supplements

The Wallowa Mountains located in the Hells Canyon area of northeast Oregon have low selenium levels in soil and forage (M. Lathrop, local veterinarian, personal communication). Local stockmen supplement the diet of domestic cattle and sheep with selenium to prevent white muscle disease caused by low selenium levels. Since 1977, salt supplemented with selenium and other trace minerals were made available to bighorn sheep on the Lostine winter range (Coggins 1977). Commercial 50 lb blocks contain 0.009% selenium by weight as well as other trace minerals. Bighorn sheep readily use salt blocks placed on the Lostine winter range.

From 1999 to 2006, whole blood samples were collected by Hells Canyon Initiative biologists and veterinarians from bighorn sheep in the Lostine population and from 5 other bighorn sheep populations in the Hells Canyon area of Oregon, Washington, and Idaho. Whole blood samples also were collected from the Lostine population in 1982. The Analytical Sciences Laboratory, University of Idaho, Moscow, Idaho analyzed samples for selenium and other trace minerals such as zinc, iron, and copper.

2. Lungworm treatment with fenbendazole and ivermectin

To identify the intensity of *Protostrongylus* spp. lungworm larvae and other parasites in bighorn sheep on the Lostine winter range, fecal samples were collected regularly since 1975. Dr. Bill Foreyt, Washington State University (WSU), conducted the analyses using Baermann technique. The bighorn sheep at Lostine River were treated with fenbendazole in alfalfa pellets for lungworm control periodically since 1985 (Foreyt et al. 1990b). More recently ivermectin in alfalfa pellets was used for lungworm control and from 2003 to 2005 for scabies control (Coggins and Matthews 2003).

3. Treatment for Scabies

Hair loss in bighorn ears is considered visual evidence of scabies was first observed in December 2002 and *Psoroptes* spp. mites were identified in ear swabs from sheep in the Lostine population in January 2003 (Dr. Bill Foreyt, WSU, personal communication). Treatment started in February 2003 using alfalfa pellets (WSU deer ration #9017) with 13.5 mg ivermectin powder per pound of pellets. Drug dosages were increased to 18 mg ivermectin per pound of pellets in 2004. Dr. Bill Foreyt prescribed the dosage rate for treatment pellets. Treatment pellets were prepared by the WSU feed department. The procedure consisted of providing pellets for a period of 8 to 9 d, with a break of 1 to 4 wk between treatments to allow mite eggs time to hatch and thus make the treatment more effective.

Number and composition of bighorn sheep at the feed site was recorded. An estimate of the amount of pellets consumed and drug ingested by the sheep present was made at each feeding. Visual hair loss in the ears of individual sheep was noted and scored from 0 to 2, depending on severity. Ear swabs collected from all captured bighorn sheep were sent to WSU for analysis. Treatments were completed in 2003, 2004, and 2005, but not in 2006.

Results and Discussion

Low selenium levels in forage were suspected as a contributing factor for bighorn sheep declines in Wyoming (Dean et al. 2002). Hnilicka et al. (2002) hypothesized that wetter conditions resulted in less selenium uptake by bighorn sheep from forage growing on granitic summer range soils, thus lowering lamb health and survival in the Whiskey Mountains, Wyoming. In Hells Canyon, differences in selenium values among populations were not significantly related to adult survival, lamb survival, recruitment, population growth, or occurrence of epizootics (Cassirer 2005a).

In 1982 and 1999 to 2006, 116 whole blood samples collected from all age and sex classes in the Lostine bighorn sheep population were analyzed for selenium levels (Table 1).

Table 1. Winter selenium levels (ppm wet weight) in whole blood of 116 bighorn sheep from the Lostine population in Oregon.

Year	*n*	Mean	SD	Minimum	Maximum	Difference
1982	12	0.224	0.047	0.15	0.29	0.14
1999-2000	15	0.392	0.092	0.21	0.54	0.33
2000-2001	10	0.384	0.184	0.127	0.573	0.446
2001-2002	19	0.313	0.134	0.1	0.49	0.39
2002-2003	10	0.365	0.125	0.12	0.54	0.42
2003-2004	15	0.467	0.078	0.36	0.62	0.26
2004-2005	15	0.434	0.124	0.27	0.78	0.51
2005-2006	20	0.524	0.156	0.29	0.82	0.53

Regardless of high selenium levels, the Lostine bighorn sheep population experienced an all-age pneumonia epizootic in 1986/1987 after known contact with domestic sheep (Coggins 1988). The herd experienced 66% mortality. Poor lamb survival, likely from pneumonia, was documented for 2 yr following the outbreak with 11 lambs per 100 ewes in 1987 and 10 lambs per 100 ewes in 1988 (Coggins and Matthews 1992). Lamb survival was below 25 lambs per 100 ewes in 1996/1997 and 1997/1998 and decreased to 9 lambs per 100 ewes in 2003/2004 (Figure 1). Clinical signs of pneumonia were observed in lambs in the summers of 1996, 1997, and 2003, but no dead sheep were recovered and the cause was not determined. We believe pneumonia is the primary cause of summer lamb mortality.

This study was conducted due to speculation that selenium levels may be naturally higher on the Lostine range and not the result of supplementation. In December 2001, salt with no selenium or trace minerals was provided to assess whether whole blood selenium levels would decline in the Lostine population. Mean blood selenium levels from 9 bighorn sheep captured at that time was 0.41 ppm. In February 2002, selenium blood levels in 10 sheep declined to 0.22 ppm (Figure 2). In March 2002, selenium-supplemented salt was provided once again to the bighorn sheep on the Lostine winter range. Selenium levels in 10 sheep in January 2003 increased to 0.37 ppm. Thus selenium blood levels for the Lostine population returned to levels similar to those prior to removal of the selenium-supplemented salt (0.37-0.58 ppm). Selenium supplementation has continued through 2006.

Blood samples for selenium analyses were collected from 6 Hells Canyon bighorn sheep populations from 1997 to 2005, including the Lostine population (Table 2) (Cassirer 2005b). Selenium levels in all populations were much lower than in the Lostine herd. Supplemental salt is accessible to some of these herds, but not with any regularity. Either these herds do not use artificial licks or only small portions of the sheep use them. Winter population densities in the Lostine area are higher than other herds and most animals use licks regularly (Figure 3).

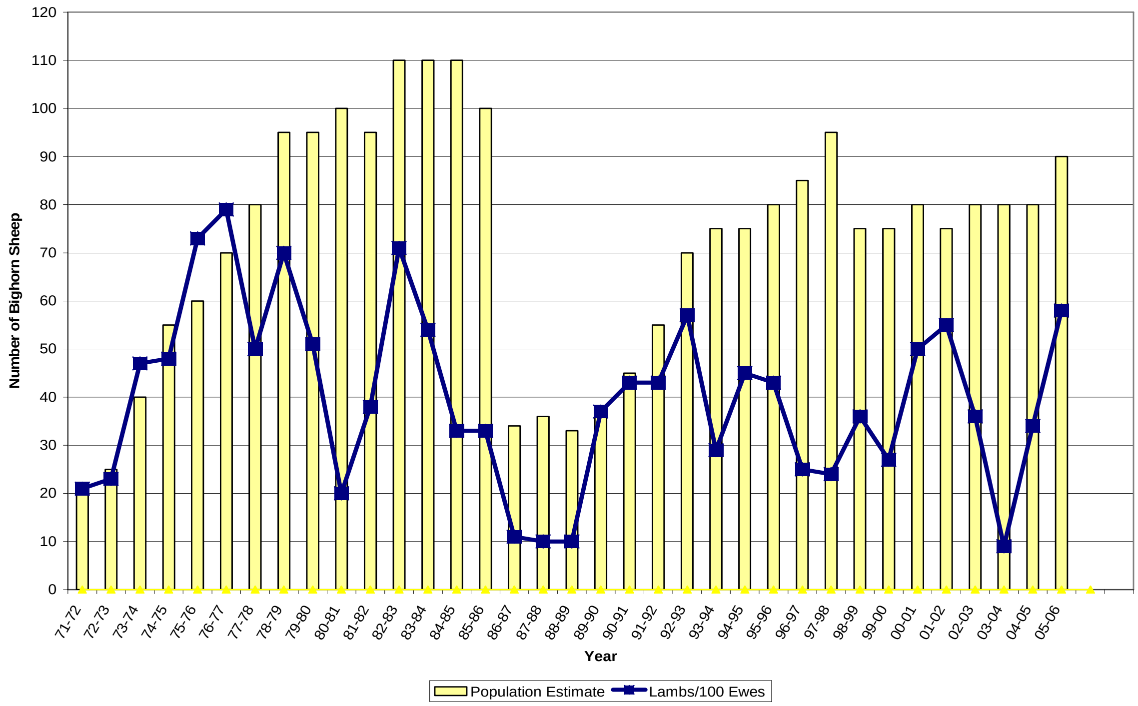

Figure 1. Annual population estimate and productivity of the Lostine bighorn sheep herd in Oregon, 1971 to 2006.

The Lostine population has a long history of wintertime feeding with salt supplemented with selenium and trace minerals. It also has the highest selenium levels of any of the Hells Canyon populations tested (Table 2). Notwithstanding high selenium levels, disease outbreaks and poor lamb survival occurred in the Lostine bighorn sheep population. However, lamb survival in the Lostine population has been better than other Hells Canyon populations that reported minimal lamb survival over a several year period. Similar to the Lostine population, these other Hells Canyon populations also have been in close proximity to domestic sheep or goat herds. Mean selenium values for the Asotin bighorn herd was 0.09 ppm. These were the lowest in Hells Canyon herds, yet pneumonia has not been detected in Asotin sheep and lamb survival has been good (Cassirer 2005a).

The lungworm-pneumonia complex was identified historically as the causative factor for a number of pneumonia epizootics (Buechner 1960, Forrester 1971, Worley, et al. 1988). Foreyt and Johnson

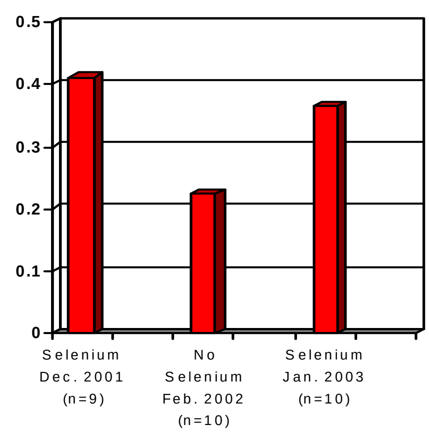

Figure 2. Whole blood selenium (ppm ww) of bighorn sheep in the Lostine population with and without selenium-supplemented salt.

Table 2. Winter selenium levels (ppm wet weight) in whole blood of 214 bighorn sheep from 6 herds in the Oregon, Washington, and Idaho portions of Hells Canyon, 1997 to 2005.

Winter Range	***n***	**Mean**	**SD**	**Minimum**	**Maximum**	**Difference**
Asotin, WA	13	0.09	0.06	0.03	0.22	0.19
Imnaha, OR	27	0.11	0.07	0.02	0.26	0.24
Wenaha, OR	25	0.11	0.08	0.02	0.33	0.31
Black Butte, WA	16	0.19	0.09	0.06	0.38	0.32
Redbird, ID	17	0.21	0.07	0.11	0.33	0.22
Lostine, OR	**116**	**0.39**[a]	**0.15**	**0.10**	**0.82**	**0.72**

[a] Includes 1982 data

(1980) recommended using anthelmintic drugs to reduce lungworm infection and improve herd health. Following this recommendation, the Lostine population was treated in January 1982 in an attempt to reduce the number of larvae and improve lamb survival. Lamb survival improved from a low of 20 lambs per 100 ewes in 1981 to 71 lambs per 100 ewes in 1983. However, lamb survival declined to 33 per 100 ewes in 1984 and 1985, and then an all-age epizootic occurred in 1986/1987. Lungworm treatment did not prevent the disease outbreak nor improve lamb survival from 1987 to 1989 (Figure 1). Lungworm levels continued to decline with repeated treatments (Table 3).

Scabies was introduced to Hells Canyon in December 1984 when 28 bighorns were transplanted from the Salmon River, Idaho to the Wenaha River drainage near the Oregon–Washington border. Scabies mites were confirmed in a transplanted ewe with infested ears. Scabies spread to other Hells Canyon bighorn herds over time and likely caused heavy mortality sheep in the Cottonwood Creek area, Washington (Foreyt et al. 1990a).

Several rams with clinical symptoms of scabies were observed in the Lostine bighorn sheep population in December 2002. Following treatment with ivermectin in alfalfa pellets during February 2003, January-February 2004, and February 2005. No clinical evidence of scabies was observed in 2006 and all 20 ear-swabs collected in 2006 were negative for mites.

Figure 3. Bighorns at the salt lick, Lostine River, Oregon.

Table 3. Lungworm larvae in fecal samples from the Lostine bighorn sheep population in Oregon, 1981 to 2006. Lungworm treatment years in bold print.

Year	***n***	**Number of samples with lungworm larvae**	**% Infected**
1981	10	10	100
1982	32	20	63
1983	12	7	58
1984	60	38	63
1985	20	15	75
1987	18	4	**22**
1988	21	1	**5**
1989	3	0	**0**
1990	7	0	**0**
1991	6	0	**0**
1992	8	1	**13**
1994	12	0	**0**
1995	19	0	**0**
1997	Composite	0	**0**
1999	21	0	**0**
2000	54	2	**4**
2001	27	0	**0**
2002	10	1	**10**
2003	18	1	**6**
2004	43	0	**0**
2005	24	1	**4**
2006	39	0	**0**

No treatment was given in 2006. Annual monitoring of the Lostine bighorn population will continue and if scabies is detected, the population will be treated again.

Conclusions

1. Supplementing bighorns with selenium salt resulted in increased selenium blood levels in the Lostine bighorn sheep population.
2. All-age pneumonia outbreaks occurred in the Lostine bighorn sheep population regardless of higher selenium levels in whole blood. Lamb survival in the Lostine population was higher than other Hells Canyon populations exposed similarly to domestic livestock, suggesting that disease recovery time may have been shortened because of higher selenium levels.
3. When selenium-supplemented salt was re-introduced, selenium whole blood levels for the Lostine population returned to levels similar to those prior to removal.
4. Fenbendazole and ivermectin administered to the Lostine bighorn sheep population in alfalfa pellets reduced lungworm levels dramatically.
5. Improved lamb survival occurred for two years following treatment for lungworm, but lower numbers of larvae did not prevent an all-age epizootic or subsequent periodic poor lamb survival.
6. Ivermectin in alfalfa pellets appeared to greatly reduce or eliminate *Psoroptes* spp. in the Lostine bighorn sheep population.
7. No mites were detected in the Lostine sheep in 2006 and there was no visual evidence of hair loss attributed to scabies.

Disease outbreaks occurred in the Lostine bighorn sheep population despite lungworm larvae reduction and selenium supplementation. Lamb survival in the Lostine population was higher than other Hells Canyon populations similarly exposed to domestic livestock. Scabies control may be accomplished by feeding ivermectin in alfalfa pellets. We believe separation of bighorns and domestic sheep and goats is still the best disease prevention.

Acknowledgements

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Effects of Mineral Supplements on California Bighorn Sheep in Northern Nevada

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Abstract: Routine capture of California bighorn sheep (*Ovis canadensis californiana*) in northwestern Nevada in 2000 resulted in a high rate of mortality. Capture and handling protocols, along with biological samples, were evaluated to discern the causative agent or process responsible for the excessive mortality. The only consistent result was low blood selenium levels, a key element in maintenance of the immune system and lactation in female sheep. From 2000 to 2004 mineral supplements were added to areas frequented by bighorns in hopes of elevating metabolic mineral levels. In 2000, pretreatment samples indicated 6 of 31 samples at or above normal liver selenium levels; however, considerable variability among animals in all areas indicated site differences with regards to geology, moisture patterns, selenium availability in soil and plants, and plant composition. No significant change was seen in mean selenium level for the control samples over the course of the study; whereas, treated units showed a significant increase from 2000 to 2004 ($t = 2.73$, $P = 0.006$). Stable or elevating lamb ratios allowed for herd growth in control units during the study. Lamb ratios in treated units were variable, with only one unit showing a significant increase. Herd performance, as measured by finite rates of increase, were strongly positive for most herds in treated or control units. Application and monitoring of mineral blocks in any given mountain range cost approximately $4,500/yr based on distributing 40 blocks at key sites. Treated units had a significant increase in mean liver selenium values, but there was no strong evidence to indicate the increase was due solely to the use of mineral supplements. Herd performance was not increased during the study, but only one herd within a treated unit showed any signs of declining numbers. If the management goal is to prevent major declines rather than produce population increases, mineral supplements may be rationalized.

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Key words: bighorn sheep, health, mineral supplements, Nevada, pneumonia, population growth, selenium

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Throughout the western United States, bighorn sheep (*Ovis canadensis*) restoration efforts intensified over the last 2 decades. Costs and benefits of "putting sheep on the mountain" have been great. Each new bighorn population adds to the value of these herds as well as the growing concern for their sustainability. Epizootics in wild bighorn sheep populations occur at a tremendous cost to sportsmen and achieving the goals of restoring bighorns to historic habitats. A growing appreciation by biologists and pathologists, is that secondary stressors, both environmental and intrinsic, may be predisposing or contributing to epizootics. Ill-thrift bighorns that lack a strong and previously-challenged immune system may be at greater risk when harsh environmental conditions or intrinsic stressors occur. One of the key elements to maintaining a healthy and effective immune system to viruses and bacteria is selenium (National Research Council 1985, Berger 1993, Underwood and Suttle 2000, Hnilicka et. al. 2002). Few, if any, studies focused on measuring selenium levels in bighorn with or without mineral supplements to determine baseline selenium levels and to monitor populations relative to the importance of selenium in maintaining a healthy herd and positive population responses (survival and recruitment). Donald et al. (1993) provided selenium supplements to domestic ewes and found increased survival of newborn domestic lambs.

The impetus to evaluate the influence of selenium on maintaining healthy bighorn herds came about during a routine aerial net gun capture of California bighorn sheep (*Ovis canadensis californiana*) between January 31 and February 2, 2000, in Humboldt County, Nevada (41.65 N, 118.73 W). Five bighorn herds were captured from the Santa Rosa Range (Unit 051, North), Montana Mountains (Unit 031), Pine Forest Range (Unit 032), Bartlett Peak (Black Rock Range, Unit 034), and the Jackson Mountains (Unit 035) (Fig. 1). A high rate of mortality occurred in which 21% of 33 sheep died in the transport trailers prior to release. The capture project was stopped and potential reasons for the high mortality rate assessed, including review of the field methods, analysis of samples collected, and necropsy of 3 of the dead sheep (Sohn 2000).

Capture and handling processes were evaluated to determine if excessive stress may have led to the bighorn mortalities. Helicopter pursuit times for most of the animals were < 5 min (acceptable in comparison to previous operations in Nevada). Day time temperatures were ~13° C (elevated above typical temperatures of 4 - 10 ° C). Rectal temperatures were elevated (most were >41 ° C) compared to past net gun captures in Nevada in which only 10 – 30% are >41° C (Nevada Division of Wildlife, unpublished data). Standard preventive treatments of antibiotic (Penicillin, 5 cc), vitamin E/selenium supplement (Bo-Se, 3 cc), anthelmintic (Ivermectin, 3 cc), and clostridial vaccine (8-way, 2 cc) were given subcutaneously to each bighorn. Standard biological samples included pharyngeal and nasal swaps, fecal pellets, and blood from the jugular vein. Handling times on the ground prior to loading into trailers for a few animals was >5 min (normal is 3 – 4 min) but there was no apparent pattern between bighorns that died and time spent on the ground.

Blood samples were assessed for several disease agents including: *Brucella ovis, Leptospira interrogans,* infectious bovine rhinotracheitis virus, bovine viral diarrhea virus, bovine respiratory syncytial virus, parainfluenza-3 virus (PI-3), ovine progressive pneumonia virus, bluetongue virus, and epizootic hemorrhagic disease virus (EHD) (California Animal Health and Food Safety Lab). Only positive results are reported. Seven of 16 sheep from the Santa Rosa Range, 3 of 5 from Bartlett Peak, and 1 from Pine Forest had antibodies against PI-3. One bighorn from the Montana Range had antibodies against EHD. One sheep from each of the Montana and Bartlett Peak ranges, 3 from Pine Forest, and 2 from Jackson Mountains had antibodies against *L. interrogans.* However, the low levels

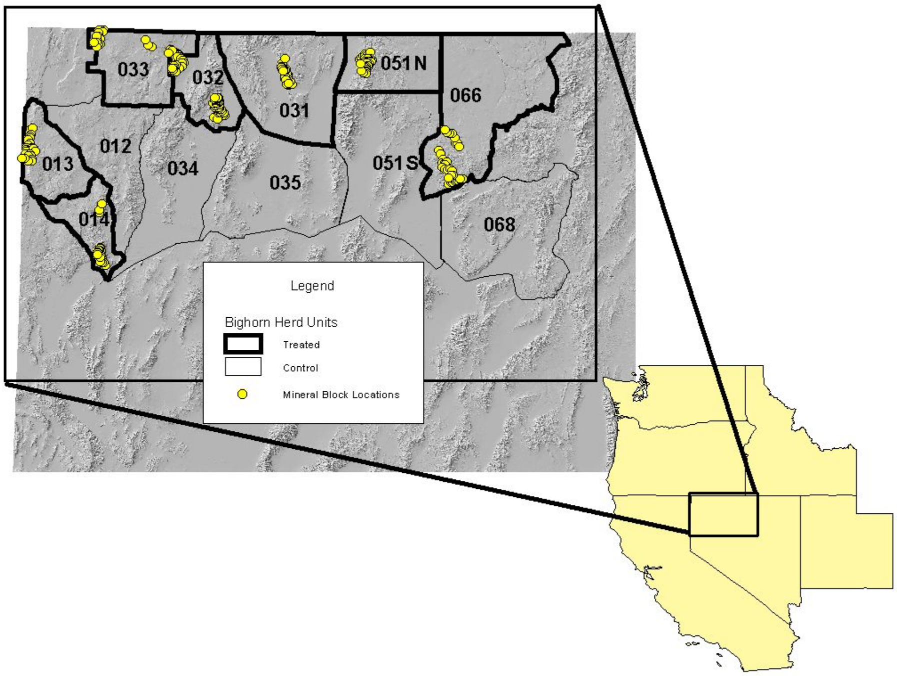

Figure 1. Geographic distribution of treated (blocks) and control (no blocks) management units in northern Nevada.

suggest no ongoing problem at the time of capture.

On February 15, 2000, Nevada Division of Wildlife (NDOW) biologists, pathologists, and wildlife veterinarians met to discuss future steps needed to isolate the cause of mortalities. From this meeting, a second capture was suggested to collect more biological samples, and assess general body condition and response to helicopter pursuit. In late February 2000, 21 bighorns were captured including 1 ewe that died during handling as a result of complications associated with verminous pneumonia.

Necrospy of three bighorns that died during the initial capture provided no consistent clues or pattern of mortality, in particular, no *Pasteurella* spp. or biotype of concern were isolated (Table 1). Ten nasal cultures from the second capture were negative for virus or *Chlamydia* spp. isolations. Moderate numbers of *Protostrongylus* spp. (nematode lungworms) were found in 25% of the bighorns. In 52% of the sheep low blood selenium levels occurred relative to the normal range in domestic sheep of 0.08 to 0.5 ppm. (California Animal Health and Food Safety Lab, unpublished data). This normal range of blood selenium is consistent with other research in domestic sheep (Hnilicka et al. 2002) and bighorns (Puls 1994). Selenium is a key element in maintenance of the immune system (National Research Council 1985, Berger 1993, Underwood and Suttle 2000, Hnilicka et. al. 2002) and lactation in females (Smith 1994). There was no apparent causal relationship between environmental conditions and the mortalities.

Discussions and evaluations of pertinent facts and realistic solutions continued among pathologists and veterinarians.

Table 1. *Pasteurella* spp. in pharyngeal and nasal swabs from California bighorn sheep in northern Nevada, January and February 2000.

Species	Biovariant	Beta hemolytic	# of sheep	Mountain Range
Pasteurella trehalosi	2	no	7	Santa Rosa
	2^{B}	no	7	Santa Rosa
	4	no	3	Santa Rosa
	2	no	5	Montana
	4	no	1	Montana
	2	no	3	Pine Forest
	2	no	4	Bartlett Peak
	2^{G}	yes	1	Bartlett Peak
	2	no	5	Jackson
	2^{B}	no	3	Jackson
P. haemolytica	1^{α}	yes	1	Santa Rosa
	$9^{\alpha\beta R}$	yes	1	Santa Rosa
	3	no	1	Montana
	5	no	1	Montana
	10^{α}, $10^{\alpha B}$	no	6	Montana
	1	yes	1	Pine Forest
	1^{B}	no	3	Pine Forest
	3	no	1	Pine Forest
	5	no	4	Pine Forest
	8	no	1	Pine Forest
	$9^{\alpha\beta R}$	yes	3	Pine Forest
	1^{B}	no	2	Bartlett Peak
	3^{B}	no	1	Bartlett Peak
	$9^{\alpha\beta R}$	yes	2	Bartlett Peak
	$10^{\alpha\beta E}$	no	2	Bartlett Peak
	16^{E}	yes	1	Bartlett Peak
	3	no	1	Jackson
	5	no	1	Jackson
	10	no	3	Jackson
	16^{E}	no	1	Jackson
P. multocida	*multocida b*	no	2	Bartlett Peak

Selenium levels were the only parameter with significant departure from normal levels. Therefore, we developed a study to add mineral supplements to areas frequented by bighorns in hopes of elevating metabolic mineral levels as measured from the liver of harvested animals.

Methods

The study design used California bighorn sheep herd management units as the sampling unit (Fig. 1). Biological samples (as below) from rams harvested in fall hunting seasons were used to evaluate changes in selenium levels, parasite loads, and past bouts of pneumonia within sampling units. Some management units initially identified as part of the study were eliminated due to lack of samples. The largest bighorn population, located in Unit 051, was separated into two subunits to equalize sample sizes among units. Six treated units and four control units were used in the final analyses (Table 2).

Beginning with the 2000 bighorn hunting season, all hunters were given sampling packets to collect liver, lung, and fecal samples as pre-treatment samples prior to mineral supplementation. Post-treatment samples were collected from rams harvested during the late summer of 2001, 2002, and 2004. Liver tissue was assessed for selenium levels (ppm) (standard trace element screen by California Animal Health and Food Safety Lab), fecal pellets were examined for parasite larvae (larva per gram) (modified Baermann technique by Department of Veterinary Microbiology and Pathology, Washington State University, as per Samuel and Gray 1982), and lung tissue assessed by histopathology (California Animal Health and Food Safety Lab). Trace element screening for minerals other than selenium was discontinued after 2000 due to funding concerns and fairly standard values observed. Parasitologic examination focused primarily on detecting *Protostrongylus* spp. larvae in fecal pellets, although they provide, at best, only a relative index of *Protostrongylus* organisms actually in the lungs (Festa-Bianchet 1989, Festa-Bianchet 1991). Histopathology of lung tissue was done to detect scarring indicative of previous pneumonia, evidence of verminous pneumonia, and to substantiate fecal larval identity.

During June 2001, mineral blocks were dropped from a hovering Bell Jet Ranger helicopter in remote sites within treated units. To reduce use by horses and cattle, blocks were not placed near water. Blocks consisted of 70% sodium chloride, 4% calcium, 2.5% magnesium, 0.36% sulfur, 0.24% potassium, 0.15% phosphorus, 2500 mg/lb zinc, 370 mg/lb iodine, 248 mg/lb iron, 48 mg/lb selenium, 5.8 mg/lb manganese, and cane molasses to bind the minerals and prevent leaching before animal use (Garino Livestock Supply, Chico, California). A block was placed outside the NDOW field office in Winnemucca near the study area in June 2001 to allow field

Table 2. Study design of mineral application to bighorn management units in northern Nevada, 2001 to 2004.

Treated Units		Control Units	
Unit	**Mountain Range**	**Unit**	**Mountain Range**
013	Hays Canyon Range	012	Calico Mountains
031	Montana Mountains	034	Black Rock Range
032	Pine Forest Range	035	Jackson Mountains
033	Sheldon National Wildlife Refuge	051 South	Santa Rosa Range
051 North	Santa Rosa Range		
066	Snowstorm Mountains		

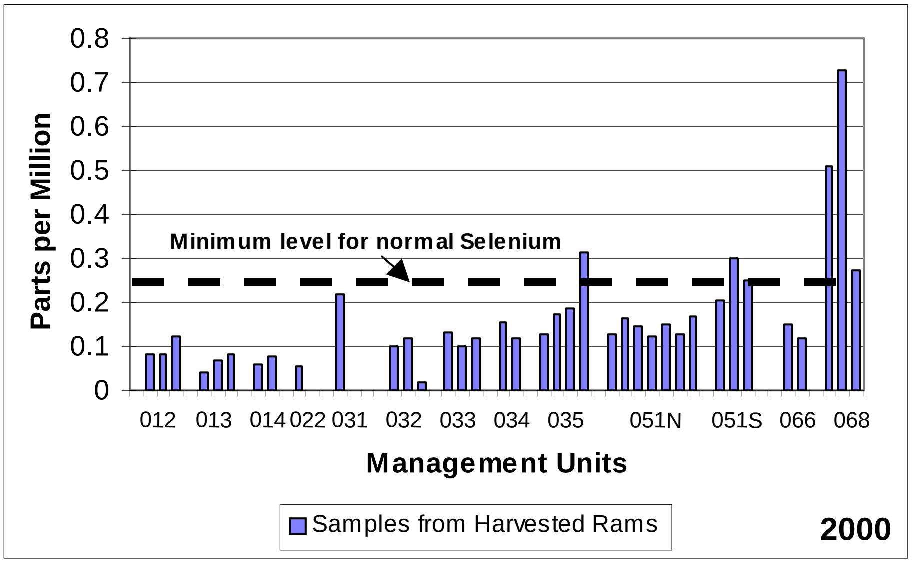

Figure 2. Pretreatment liver selenium levels from harvested California bighorn sheep in northern Nevada, August and September 2000.

personnel to account for weathering in estimating the actual animal use of blocks in treated units.

Analysis of variance (ANOVA) with significance level of $P \leq 0.05$ was used to examine the variability of liver selenium levels in treated and control units from 2000 through 2004. Students *t*-test was used to compare treated and control sample means within and among years.

Results

Annual data: Thirty-seven usable samples were collected from hunter-harvested rams during the pretreatment period in 2000 (31 samples from treated or control units). All but 6 liver samples had below normal selenium levels (normal 0.25 – 1.5 ppm based on domestic sheep; California Animal Health and Food Safety Lab, December 2000, unpublished data) (Fig. 2). Abnormal results on other trace minerals included: copper – 2 samples below normal, 13 elevated, and 1 toxic level (264 ppm) (normal 25 – 100 ppm); zinc – 7 samples below 25 ppm (normal 30 – 75 ppm); lead – 2 samples at 4 and 7 ppm (normal <1.0 ppm) (California Animal Health and Food Safety Lab, unpublished data). Six of 30 fecal samples had moderate to high lungworm larvae counts (10 – 123 larve per gram) (William Foreyt, pers. comm.). Histopathologic examination of lung tissues revealed mild verminous pneumonia in 7 samples. Lung samples from the 3 rams harvested in the southern portion of Unit 051 had mild verminous pneumonia.

Thirty-one usable liver samples were collected from hunter-harvested rams in 2001. All but 5 liver samples had below normal selenium levels (Fig. 3). Only 2 of 29 fecal samples had moderate or high lungworm larvae counts. Mild verminous pneumonia was detected in only 1 lung sample. Coincidentally, 31 usable liver samples were collected from hunter-harvested rams in 2002. All but 6 liver samples had below normal selenium levels (Fig. 4). Only 1 of 30 fecal samples had moderate or high lungworm larvae counts. A small number of *Protostrongylus* spp. larvae were found in one lung sample.

Table 3. Field assessment of mineral blocks checked in summer 2002 for use by bighorns.

Mountain Range	Unit	Total Blocks	# Checked	% Checked	% used	% moderate to high use
Hays Canyon Range	013	25	0	0	na[a]	na
Granite Range	014	20	0	0	na	na
Montana Mountains	031	30	26	87	46	19
McGee Mountain	032	30	0	0	na	na
Pine Forest Range	032	40	26	65	54	4
Sheldon NWR	033	18	0	0	na	na
Santa Rosa North	051	40	31	78	84	52
Snowstorms	066	33	8	24	88	50
TOTAL		236	91	39		

[a]na -not applicable

Table 4. Selenium (parts per million) in livers from hunter-harvested California bighorn rams in northern Nevada, 2000 to 2004.

	Treated Units			Control Units		
Year	Mean	SE	N	Mean	SE	N
2000	0.119	0.011	19	0.177	0.023	12
2001	0.144	0.015	17	0.170	0.021	10
2002	0.182	0.015	21	0.178	0.023	10
2004	0.203	0.029	18	0.168	0.049	6

Twenty-four usable liver samples were collected from hunter-harvested rams in 2004. No lungs or fecal samples were collected. Nine liver samples had normal selenium levels (Fig. 5).

Mineral block use by bighorn sheep was checked during summer 2002 in 4 mountain ranges with treated units (Table 3). A relatively high proportion of blocks were checked but estimated use was variable, particularly the number of blocks assigned to the moderate to high use category.

Treatment and year comparisons: Considerable variability in liver selenium levels was observed in samples collected in 2000, the pretreatment year, in both treated and control units ($F_{1,36}$ = 0.08, P = 0.779). Mean liver selenium levels between treated and control units in 2000 (Table 4) were significantly different (t_1 = 2.31, P = 0.017), indicating considerable site differences among and within mountain ranges. Although the pretreatment control mean was higher than the treated mean, both were below the minimum selenium standard of 0.25 ppm.

Two-way ANOVA evaluating treatment and yearly variation in mean liver selenium levels across all years of the study revealed a significant difference between treatments ($F_{1,160}$ = 17.39, P < 0.001). There was no significant change in mean selenium level in control samples over the course of the study;

however, selenium levels increased steadily in treated units (Fig. 6). Due to small sample size (n = 2 within a single unit and year) and large variability among samples within control units, statistically significant changes in mean selenium values from 2000 to 2004 in any given unit were not detected. However, increases from 2000 to 2004, some almost 2-fold, were noted in the following treated units: 031 (n = 1 for 2000; 5 for 2004), 032 (n = 3, 3), and 051 North (n = 7, 3) and in the control unit 034 (n = 2, 2) (Fig. 7).

The number of lung samples with evidence of potential verminous pneumonia declined from 2000 to 2002. Similarly, the number of moderate to high counts of *Protostrongylus* spp. larvae in fecal pellets declined from 6 of 30 samples in 2000 to 1 of 30 in 2002.

Productivity (number of lambs: 100 ewes) was assessed each year from 2000 to 2004. Control units showed either stable or elevating ratios that allowed for herd growth (Fig. 8). The ratios in treated units were variable (Fig. 9), with only Unit 032 having a significant increase in lamb ratios, but not until 2004. Most herds had positive to strong finite rates of increase in treated and control units (Table 5). Two exceptions were the treated Unit Group 066, 068 that declined 19% and the control Unit 051 South that experienced a major dieoff from late 2003 to early 2004 due to unknown causes.

Table 5. Population growth rates for bighorn sheep populations from 2000 to 2005. Animals removed or added as part of transplant program accommodated in 2005 estimates.

Treated Units			**Control Units**		
Unit	% change	annual rate	Unit	% change	annual rate
013	67	1.11	012	50	1.08
031	56	1.10	034	17	1.03
032	11	1.02	035	33	1.06
033	31	1.06	051 South	-57	0.85
051 North	10	1.02			
066, 068	-19	0.96			

Discussion

Many factors contribute to the overall health of bighorn herds. Unfortunately, often these factors are not within the control of wildlife managers, or are cost prohibitive. The impetus for this study was to see if mineral supplements, a reasonable and affordable management action, could elevate bighorn liver selenium levels, and if this would result in increased herd health and/or performance. Statistically, treated units had a significant increase in mean liver selenium values, while control units showed no change, but there was no strong evidence to indicate this increase was solely due to the use of mineral supplements.

Comparing mineral block use and changes in liver selenium during the study showed mixed results. There were only 3 units that had at least 50% of the blocks checked. The north end of Unit 051 in the Santa Rosa Range showed both moderate to high mineral block use and a dramatic increase in mean selenium levels of harvested rams during the study. The Montana Range Unit 031 had only 19% of the blocks checked with moderate to high use and only a minimal increase in liver selenium was observed. Unit 032, the Pine Forest Range had only 4% of the total blocks checked with moderate to high use yet the liver selenium levels doubled during the study. In Unit 032 the block use and selenium level relationship is confounded by the fact that McGee Mountain blocks were not checked and the harvest ram samples each year from Unit 032 included 1 or 2 rams from McGee Mountain area. Since rams are nomadic and have large home ranges, a ram harvested in one area could easily have spent considerable time elsewhere during other parts of the year. In addition, liver selenium levels in rams may not accurately reflect values in ewes and lambs in the same herd.

In determining whether mineral deficiencies prevent herd growth, there must be a measurable impact to survival fitness or performance. In most cases where lack of selenium is a major concern in management of bighorn or domestic sheep herds throughout western North America, lamb recruitment was the primary parameter affected (Donald et al. 1994, Hnilicka et al. 2002). In our study, control units had either stable or elevating lamb ratios that allowed for herd growth. Two mountain ranges had consistently low selenium levels over the course of the study (Units 012 and 013); yet reasonably good lamb production. Other mountain ranges or units had too much variability to determine whether selenium levels effect lamb production.

Costs and feasibility of conducting large-scale "on-the-ground" management can be prohibitive or impractical. We used mineral supplements because of the relatively low costs involved. Approximately $4,500/year was needed for application and monitoring of mineral blocks in any given mountain range, based on distributing 40 blocks at key sites. This includes cost of dispersing blocks, field checks on 25 to 50% of the blocks depending on topography and access to the sites, and collection of liver selenium levels from sheep, primarily rams. Monitoring must be an integral component to measure the success or failure of any health supplement program and to allow fine-tuning to improve potential success.

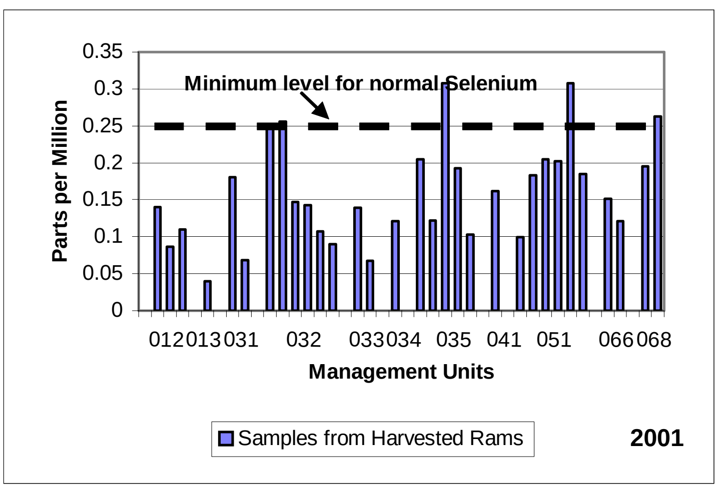

Figure 3. Liver selenium levels from harvested California bighorn sheep in northern Nevada, August and September 2001. Since mineral blocks were present only since June 2001, treated and control units were not differentiated.

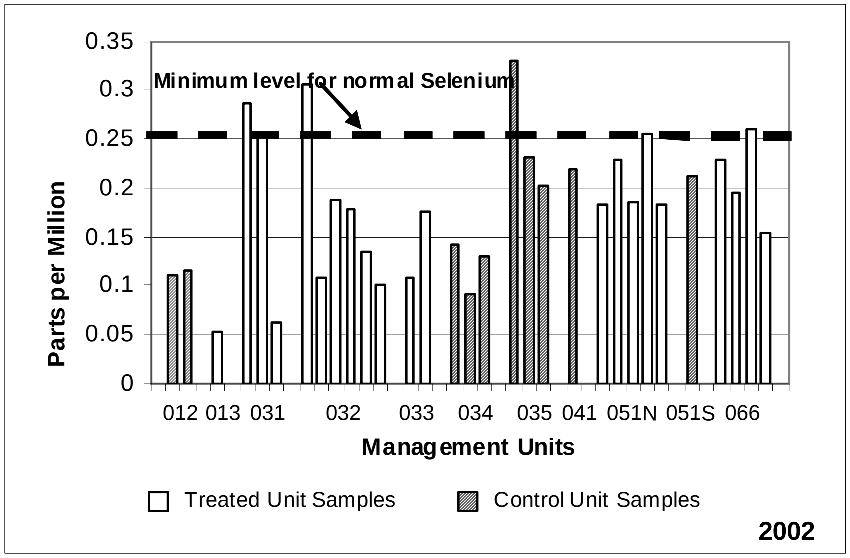

Figure 4. Liver selenium levels from harvested California bighorn sheep in northern Nevada, August and September 2002.

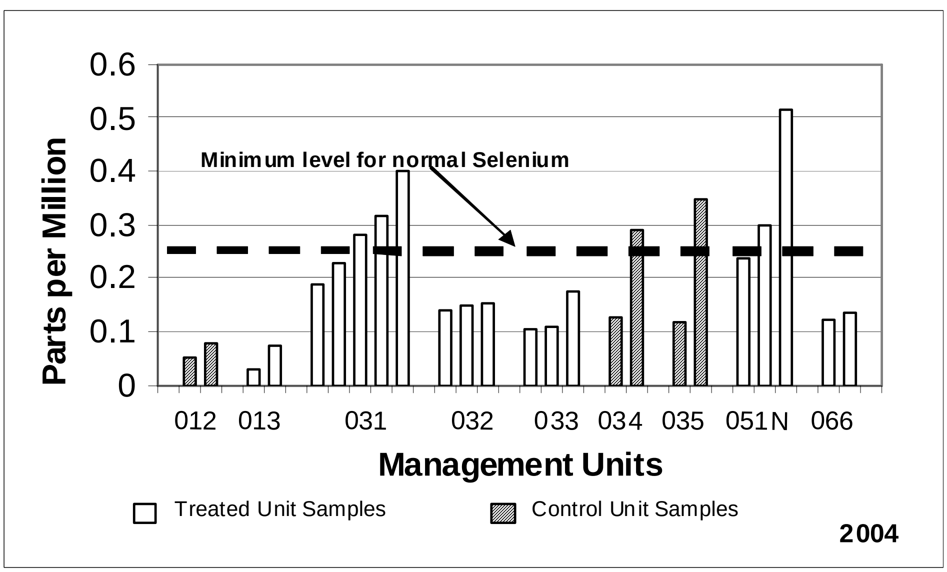

Figure 5. Liver selenium levels from harvested California bighorn sheep in northern Nevada, August and September 2004.

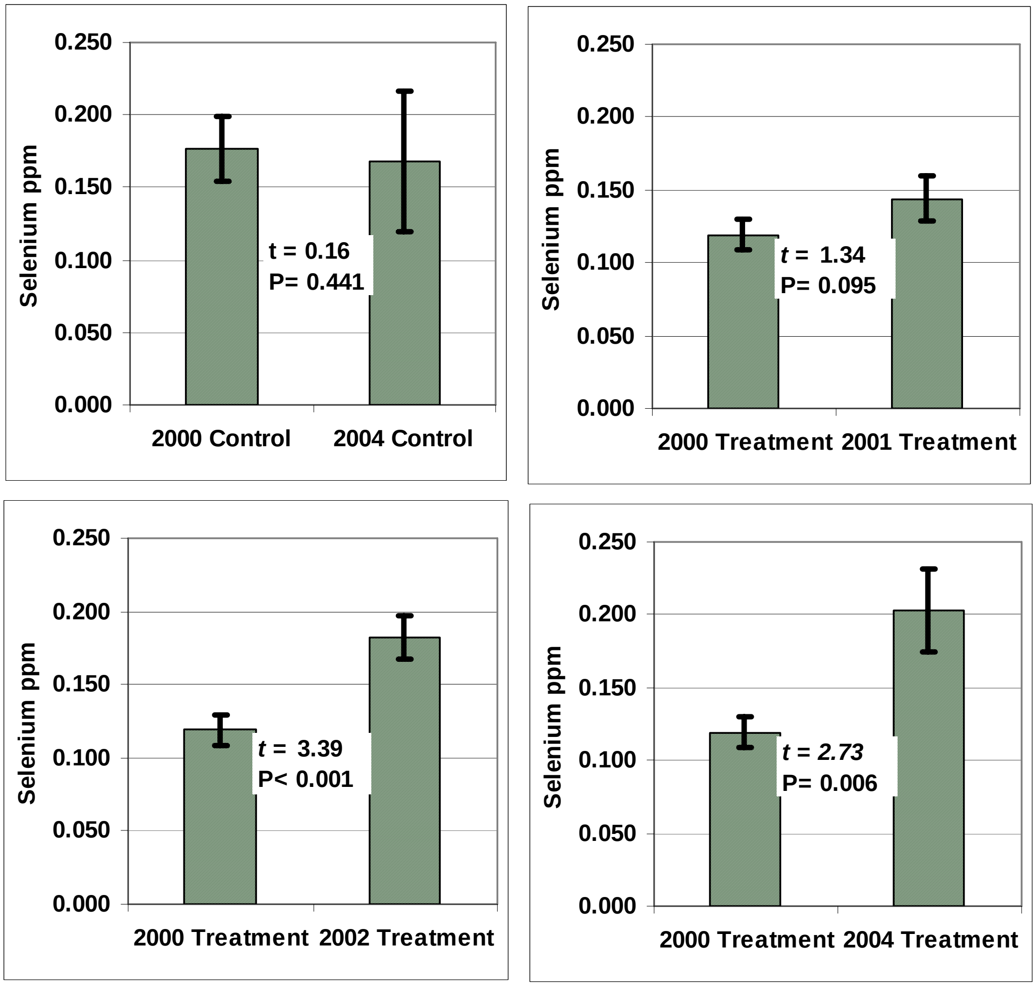

Figure 6. Comparison of yearly differences in mean liver selenium levels in California bighorns in northern Nevada.

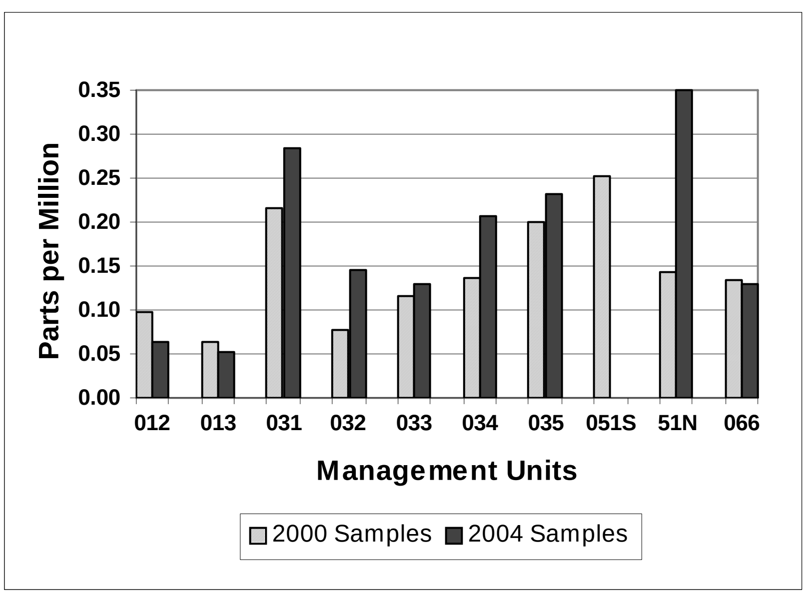

Figure 7. Comparison of mean liver selenium levels in California bighorns before (2000) and after (2004) mineral treatment in northern Nevada.

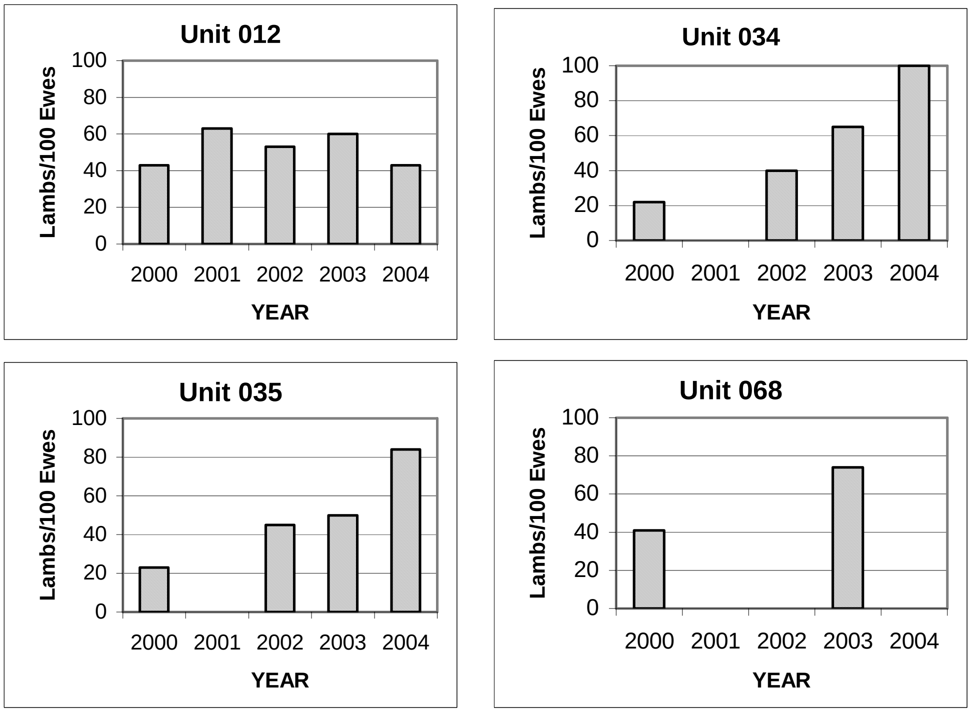

Figure 8. Lamb to ewe ratios (collected from August – November) in control units where no mineral blocks were applied.

Placement of blocks at watering and feeding sites or geographic features frequented by bighorns may enhance overall use of the blocks. But this may be off-set by blocks being used by feral horses and livestock.

If health assessments indicate bighorn immune systems are compromised by past exposure to viruses, or soil/vegetation analysis indicates significant differences in selenium availability compared to most other areas, then a mineral supplement effort may be warranted. However, use of mineral blocks simply because it is doable and relatively inexpensive compared to other more permanent or landscape-wide management actions, is not prudent.

Though the relationship of mineral use and selenium levels in the Santa Rosa Range is intriguing, no herd performance markedly increased during the study. If the management goal is to prevent major declines rather than to produce population increases, then mineral supplementation may be rational. Investigation of bighorn population declines is leading to wider acceptance that multiple stressors involving environmental, climatic, and biological variables contribute to the decline. There are many variables and conditions that contribute to major population declines. Selenium is certainly not a “silver bullet” or even “insurance” to guard against epizootics or other health-related risks to a herd. This study also contributed to establishing standard selenium levels in wild bighorn herds in the Great Basin from which to base informed decisions on the need or opportunity to enhance it.

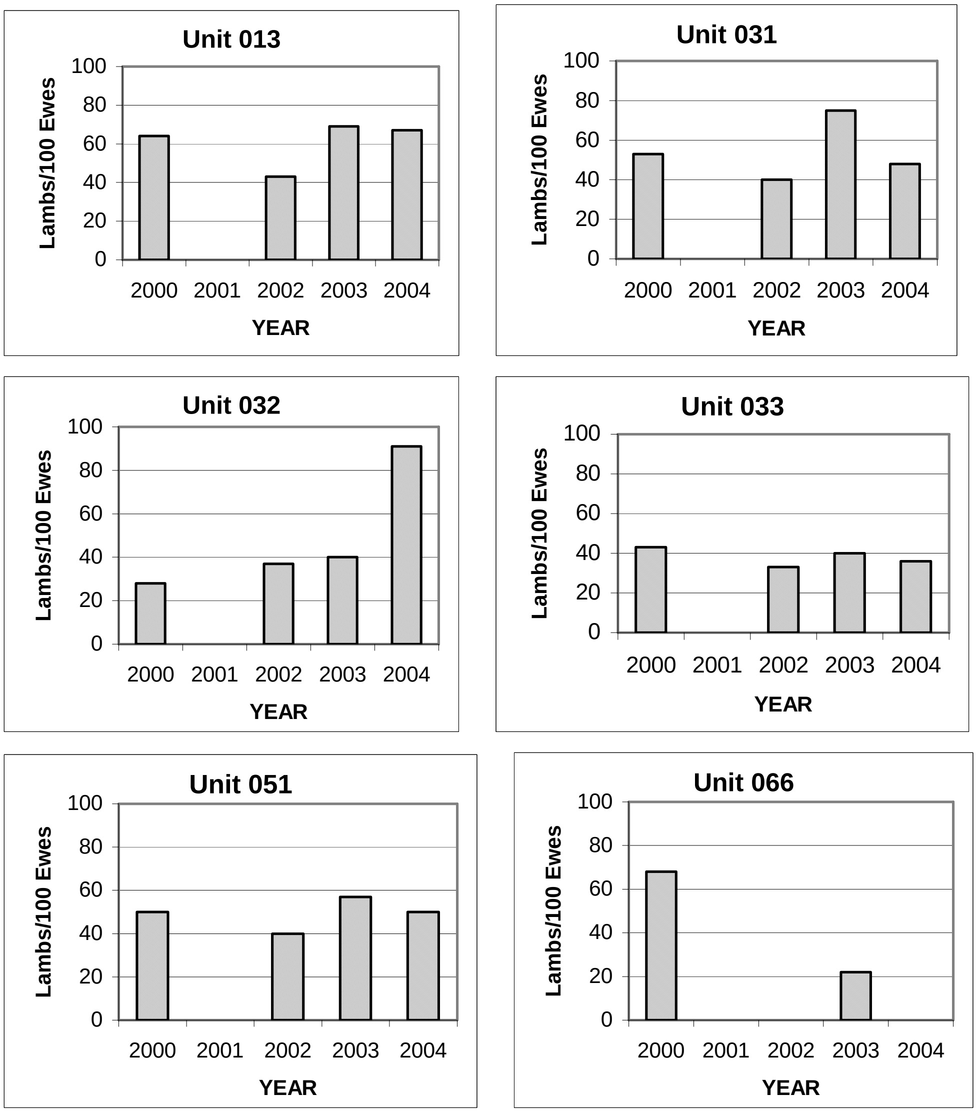

Figure 9. Lamb/ewe ratios in units treated with mineral supplements beginning June 2001.

Acknowledgments

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A Pneumonia Epizootic in Bighorn Sheep in the South Okanagan Region of British Columbia

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Abstract: Pneumonia is considered the most important disease of bighorn sheep *(Ovis canadensis),* with *Pasteurella multocida, P. trehalosi* (*P. hemolytica* type T), and *Mannheimia hemolytica* being the most commonly reported organisms. Contact between domestic and wild sheep has resulted in pathogen transfer producing significant mortality of bighorn sheep. In 1999, contact with domestic sheep in the South Okanagan region of British Columbia preceded the first recorded all-age dieoff in bighorn sheep in the region. Almost every risk factor identified in the literature as a stressor to bighorn sheep was present at the time of the outbreak, including *Pasteurella multocida* and *Mycoplasma* spp. Public concern, local interest, and agency management responses were rapid and extensive. A workshop to develop a Recovery Plan for the metapopulation was attended by local, national, and international representatives. Although cause and effect was not confirmed, a high priority recommendation from the workshop was to reduce the potential for future wild and domestic sheep contact. A project was initiated to collaborate with and inform local producers of wild sheep health and the potential risks of contact with domestic sheep. Guidelines were developed for the management of domestic sheep near critical bighorn sheep habitat with goals to prevent or reduce contact. Follow-up investigation suggests many herds are recovering.

BIENN. SYMP. NORTH. WILD SHEEP AND GOAT COUNC. 15: 121

Key words**:** Bighorn sheep, British Columbia, domestic sheep, management, *Ovis canadensis*, pneumonia.

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Bighorn and Domestic Sheep Interface Program in Southeastern British Columbia

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Abstract: Some bighorn sheep die-offs are linked with diseases contracted from domestic sheep. This study explores means of mitigating this issue while engaging domestic sheep producers in the solutions. We assessed bighorn habitat quality and quantity, carrying capacity, health and morphology, location and movement, population dynamics, and exposure risks to domestic sheep and goats. Field study reports were obtained from many sources including our previous work, a Parks Canada telemetry program, and input from producers. Here we review the interface potential as well as mitigation options of buy-out, alternative livestock and relief pastures, domestic sheep exclusion covenants, profit á prendre, legal restrictions, fences, and guardian dogs. For each method we considered practicality, cost, and property tax ramifications for the producer. Successful implementation of any measure requires careful review on a case-by-case basis but overall, buy-out coupled with profit á prendre provides the best "blanket" solution.

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Key Words: Bighorn sheep, British Columbia, disease transmission, domestic sheep, East Kootenay

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Earlier phases of the Bighorn and Domestic Sheep Interface Program (BDSIP) in southeastern British Columbia focused on collecting data from stakeholders, including domestic sheep producers, scientists, resource people, and governmental departments (Adams and Zehnder 2002). This allowed us to see the scope of the problem in East Kootenay and to open lines of communication among various interested or affected groups. More recently, gap analysis identified successful strategies undertaken in other jurisdictions. Although education and communications continue through a regional committee and regular landowner contact, from 2001 to 2006 we focused on alternatives to separate domestic and bighorn sheep and implement the best options. Our goal is to find solutions which enhance the sustainability of regional agriculture while resolving the disease risks. Herein we report on the East Kootenay component of the BDSIP, implemented in conjunction with Helen Schwantje from the British Columbia Ministry of the Environment and Daryl Stepaniuk of South Okanagan California Bighorn Sheep Recovery Project.

Methods

We constructed maps to show the proximity of high risk domestic producers to bighorn sheep winter range along the

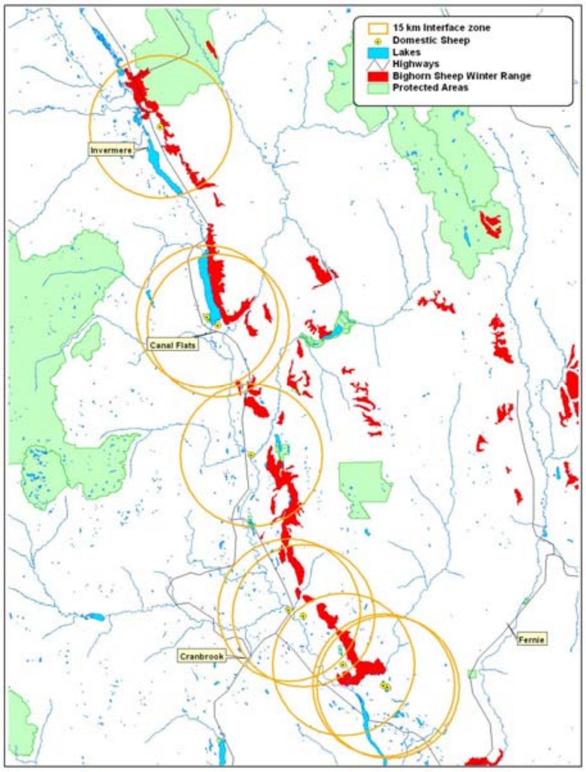

Figure 1. Location of domestic sheep in proximity to bighorn sheep winter range in southeastern British Columbia.

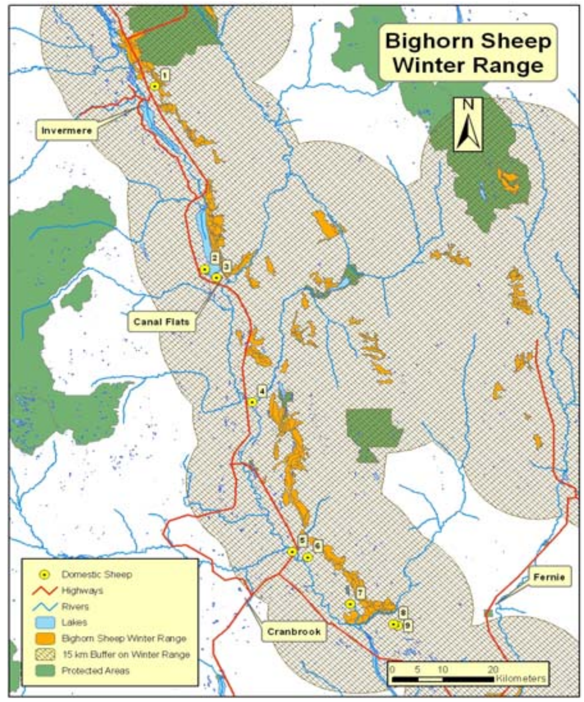

Figure 2. Bighorn winter range relative to high risk domestic sheep producers in southeastern British Columbia. Numbers indicate specific producers.

Rocky Mountain trench in southeastern British Columbia. We based the maps on universal transverse mercator (UTM) locations of high risk producers and data on bighorn winter range, as determined from a telemetry study of bighorn sheep headed by Alan Dibb with Parks Canada. We applied a GIS layer showing an interface buffer radius of 15 km, generally accepted as the minimum distance to mitigate the risk of bighorn contact with domestic sheep (Bureau of Land Management 1992).

We investigated a number of direct mitigating options to determine what combination would create the most desirable result. These included buy-out, alternative livestock and relief pastures, domestic sheep exclusion covenant, profit á prendre, legal restrictions, fences, and guardian dogs. The cost and property tax implications associated with each approach were considered. We also interviewed sheep producers to determine which solutions they perceived to be workable.

Results and Discussion

Interface overlap

We mapped the potential risk of overlap of domestic sheep producers and bighorn sheep from two perspectives: the location of high risk sheep producers relative to bighorn sheep winter range (Figure 1) and the location of bighorn sheep winter range relative to high risk sheep producers (Figure 2). We also established the proximity of domestic producers to the specific locations of GPS-collared bighorns from the Radium band of sheep (A. Dibb, unpublished data). We displayed the data points on a Landsat map in relation to the problem areas and buffer zones (Figure 3). Many domestic producers were located in areas with little or no separation from bighorn populations. Separation distances ranged from 242 m to 3362 m (2174 m on average). The data reinforced a previous concern (Adams and Zehnder 2002) that the danger of a massive die-off of bighorn sheep in the East Kootenay is very high. Regular updating of this map is a useful tool to monitor the ongoing risk.

Mitigation Options

Buy-out. This involves negotiated purchase of domestic flocks, coupled with a restriction against sheep being reintroduced to the parcels of land under question. This option would be dependent on funding and the willingness of the producers, not all of whom find this acceptable.

Alternative livestock and relief pastures. All producers zoned as agriculture by the Regional District are concerned with loosing their preferential tax status. The introduction of alternative livestock allows the landowner to retain the preferential tax status of legitimate farmers who surpass a gross agricultural income requirement. Assignment of land currently used in domestic sheep production as "relief pastures" for the cattle industry could produce a similar result. Cattle ranchers can apply to have the preferred tax status remain on these properties if used as part of the cattle operation. The forest service also expressed interest in this approach as an alternative to ranges scheduled for restoration burns.

Domestic sheep exclusion covenant. This is a legally binding agreement attached to the title of a lot. In our case, it restricts the owner from raising sheep on property under covenant. Landowner agreement can be purchased at a typical cost per farm of approximately $21,000 to negotiate and monitor the covenant in perpetuity (Table 1). Estimated cost of applying this option to the highest risk producers in the East Kootenay is ~$250,000. Although this option could provide an acceptable solution, the Agricultural Land Commission (ALC) found this approach to be an unacceptable restriction on land zoned for agriculture and exercised its power of veto. A similar situation occurred in the Southern Okanagan California Bighorn Sheep Recovery Project (Dave Stepaniuk, personal communication), although efforts continue to have the ALC decision overturned. The Commission may reconsider amendments to the wording in the covenant. Further evaluation of the merit of this approach is contingent upon the ALC.

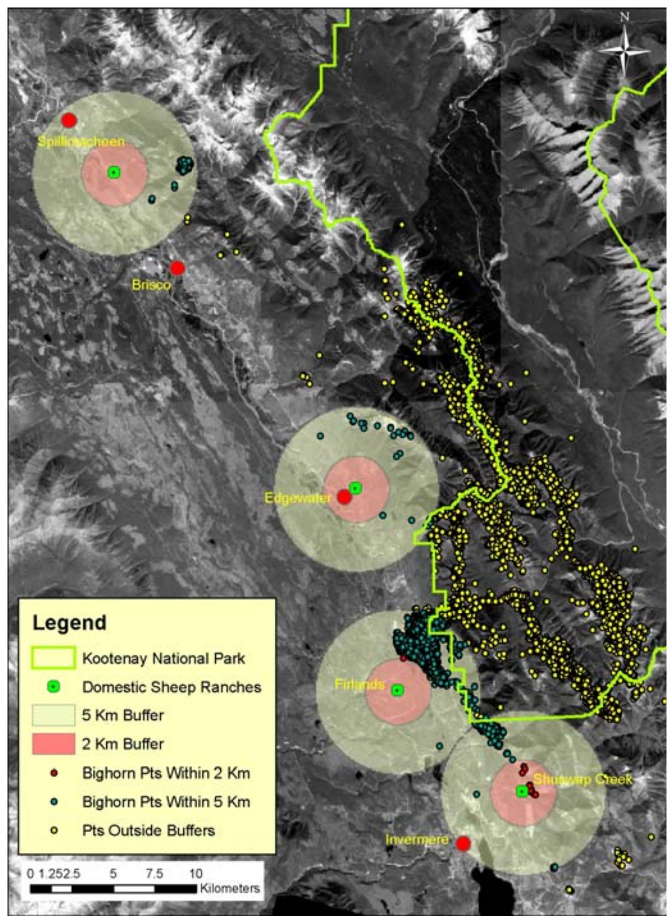

Figure 3. Location of collared bighorns from the Radium band relative to domestic producers in southeastern B.C.

Table 1. Cost estimates of a domestic sheep exclusion covenant (costs per typical farm).

	Description	Time/ Distance (hr or km)	Rate ($/hr or km)	Cost
Stage 1: Negotiation of Conservation Covenant				
Land Trust Time	Site visits to property & discussions with landowner	24	50	1,200
	Draft and review covenant	16	50	800
	Follow-up	8	50	400
	Baseline	8	50	400
Legal Time	Lawyer for land trust	8	150	1,200
Travel	Mileage (average distance 200km x 3 visits)	200	0.42	252
Fees	Registration fees			200
	Total Negotiation Costs			**4,452**
Stage 2: Purchase of Conservation Covenant				
	Value (1% assessed property value on the land only). Typically 50 acres x $3500/acre x 3%			**5,250**
Stage 3: Monitoring and Defense of Covenant				
	Endowment fund of $10,000 to cover perpetual costs over the life of each covenant			10,000
Land Trust Time	1 visit per year	8	50	400
Travel	Mileage to property (average distance 200km)	200	0.42	84
Legal Defense	One time cost to defense fund			1,000
	Total Monitoring Costs			**11,000**
Total Cost/Typical Farm (Stage 1+2+3)				**~20,600**

Profit á Prendre. A profit á prendre is a remnant of old English common law, although it retains modern precedence. It allows one landowner to purchase certain rights to another landowner's property, such as the right to fish, to graze, to cut trees. Conservation organizations use it to help secure the wishes of the property owner. In our case, the right to farm sheep on a lot could be sold to a conservation organization, which would not exercise this right and effectively accomplish the same result as a covenant. This approach removes domestic sheep from the lot, and is registered against title and legally binding. Also, it does not require approval of the ALC. Rough cost to establish this option with high risk producers (Table 2) is estimated as slightly less than that to pursue the covenant option (Table 1). However, costs are difficult to determine, in particular the value of grazing pastures and net income over 25 yr.

Legal Restriction. Directors of the Regional District of the East Kootenay (RDEK) area requested a legal solution to the problem. This approach must be work-

Table 2. Profit á prendre costs per typical farm.

	Description	Time/ Distance (hr or km)	Rate ($/hr or km)	Cost
Stage 1: Negotiation of Profit á Prendre				
Land Trust Time	Site visits to property & discussions with landowner	24	50	1,200
	Draft and review	16	50	800
	Follow-up	8	50	400
	Baseline	8	50	400
Legal Time	Lawyer for land trust	8	150	1,200
Travel	Mileage (average distance 200km x 3 visits)	200	0.42	252
Fees	Registration fees			200
	Total Negotiation Costs			**4,452**
Stage 2: Purchase of Profit á Prendre				
Option A	Value of grazing pasture over 25 yrs			
Option B	Net income from sheep over 25 yrs			
	Estimated Purchase Costs			**~4,500**
Stage 3: Monitoring and Defense of Profit á Prendre				
	Endowment fund of $5,000 to cover perpetual costs over the life of each agreement			5,000
Land Trust Time	1 visit per year	4	50	200
Travel	Mileage to property (average distance 200km)	200	0.42	84
Legal Defense	One time cost to defense fund			1,000
	Total Monitoring Costs			**6,284**
Total Cost/Typical Farm (Stage 1+2+3)				**~20,236**

able and not unnecessarily restrictive to agricultural activities. This situation presently is not a high priority with RDEK but actions on this approach will continue to be monitored by the program.

Fences --A double exclusion fence is an acceptable mitigation strategy. Two fences, with a 1 m “sneeze zone” between, are required to accommodate the viability of disease pathogens in airborne mucous. We considered various fence designs, including a triangular suspended fence demonstrated in the Okanagan (Figure 4). A perpendicular perimeter fence protects private property from intrusion, and a second structure attached to the base and suspended at an angle along the inside keeps domestic herds at least 1 m from the perimeter.

An exterior perimeter 2.6m high fence consisting of high-tensile game wire and a 1 m minimum separation from an interior domestic sheep fence is preferred. Approximately 15 km of fence is required to encompass areas of highest concern in the East Kootenay, This is based on an estimate of the the property owners most likely to choose this option. Estimated cost of 15 km of ‘elk fence’ plus 15 km of page wire fence was $310,000 [in 2005]. Some producers want to retain their flocks and this type of fencing presents a reasonable option to them. However, the need for ongoing maintenance and continual risk of breeches in the fence make a buy-out with profit á prendre more attractive than fencing.

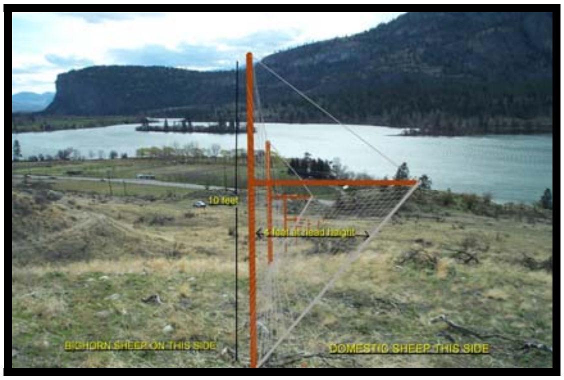

Figure 4. A triangular fence design demonstrated in the Okanagan.

Figure 5. Guardian dog with domestic sheep.

Dogs. Use of guardian dogs by domestic sheep producers is increasing (Figure 5). Various breeds, including maremma, komandore, and great pyrenees, are successful as deterrents to predators. Because of their instinct to protect the flock to which they are bonded, a well-trained dog will not allow any unfamiliar animal near the flock. These dogs could enforce the separation between a domestic flock and bighorn sheep, but only in combination with other mitigating strategies (like fencing), maintenance of necessary training, and dogs from proven working parentage. Suitable dogs cost $400 to $800 to purchase.

High risk procedures

One high risk producer in the Radium area moved sheep into a hay field to graze in order to take advantage of residual grass from the summer season. This was not normal practice. Usually sheep were grazed in rotation on paddocks with domestic sheep fencing which, coupled with location, provided a reasonable level of security. Use of the hay field drastically increased the possibility of contact with bighorns because of its location and lack of a sheep-proof fence. As a temporary solution, the sheep were penned in a more secure location and fed hay. The producer remained interested in other options but was reluctant to remove the sheep for fear of losing the advantageous tax status. Negotiation efforts turned to finding a long term solution. Any mitigation program must include a component of case-by-case flexibility.

Education and Communications

We communicated openly with stakeholders throughout the program. All domestic sheep owners in the study area were concerned over the potential for disease transmission between domestic and bighorn sheep. They were interested in finding a mutually beneficial solution to this issue. Producers who depend on income from sheep to retain a preferred tax status need a solution that mitigates any increase in land taxes.

From 2001 to 2006, high and medium risk producers were contacted to establish the status of their flocks. Most retained their sheep, although some discontinued their breeding programs. We visited high risk producers and recorded the specific locations of their flocks. The resultant potential interface map (Figure 1) was included in various presentations to raise awareness of the issue among domestic and bighorn sheep managers. Media interviews and educational sessions with land conservation organizations highlighted the issues and focused on broad involvement in potential solutions. The Wild Sheep

Stewardship Committee (WSSC), representatives from BC Ministry of Environment, BC Ministry of Agriculture, East Kootenay Wildlife Association, Southern Guides & Outfitters Association and sheep producers, was formed with the goal to maintain consultative lines of communication in order to brainstorm on a means of multiple-land-use with acceptable levels of risk for the indigenous wildlife. This resulted in a protocol to deal with wild sheep in direct contact with domestics. Local conservation officers were advised of the bighorn and domestic sheep issue, and asked for input on the protocol. A reporting procedure is now in place and presentations at various wildlife conferences communicate the process to other jurisdictions. Educating groups and individuals is ongoing and integral to the success of the project.

Management implications

- GIS maps and bighorn sheep telemetry data should be updated regularly as they are valuable tools to monitor fluctuating borders of the high-risk interface areas between domestic and bighorn sheep.
- The most preferred mitigation option is a combination of buy-out and profit á prendre.
- Appropriate fences provide an immediate solution for those producers who wish to keep their flocks. But fences require maintenance and regular monitoring to ensure perimeters remain intact. A double fence combination of high-tensile “elk fence” perimeter with an inner domestic sheep page-wire fence is preferred.
- Legal zoning needs further investigation. Legislated restrictions must be sensitive to the needs of agriculture as well as the protection of bighorns.
- The Wild Sheep Stewardship Committee is a great forum for continued brain-storming, problem-solving, and stakeholder liaison. It also provides for ongoing education and outreach with stakeholders and the public.

Acknowledgements

Thanks are extended to Alan Dibb and Dave Gilbride for their input and for sharing the data from their research. The GIS maps were prepared in consultation with Pere Wallenius.

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Faecal Survey for Parasites of Stone's sheep in the Muskwa-Kechika Region, British Columbia, Canada

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Abstract: In spring and late summer from 2000 to 2002, 408 faecal samples were collected from Stone's sheep (*Ovis dalli stonei*) from several herds in the Muskwa-Kechika Management Area, British Columbia (BC). We found eggs of the gastrointestinal parasites *Marshallagia* sp., *Nematodirus* spp., *Trichuris* sp., trichostrongyles (multiple parasites of this family produce identical eggs), *Skrjabinema* sp., *Moniezia* sp., and coccidea *Eimeria* spp.. As well, we found two types of protostrongylid larvae; dorsal-spined larvae identified as the muscleworm *Parelaphostrongylus odocoilei* (using DNA analysis), and straight-tailed larvae identified as lungworms *Protostrongylus* spp.. Stone's sheep populations in B.C. did not have unusual levels of parasitism when compared to other wild sheep populations, although there were differences in parasite fauna and seasonal patterns in parasite shedding. Recommendations for the future include definitive identification of adult parasites, targeted monitoring of herds with higher intensities of parasite shedding (especially the more pathogenic parasites) and/or evidence of a population decline, and expanded population health monitoring. Monitoring might include examination of healthy and dead sheep for verminous and bacterial pneumonia which cause sporadic mortality in Dall's sheep (*Ovis dalli dalli*) and large-scale, all-age die-offs in bighorn sheep (*Ovis canadensis*). Stone's sheep are likely susceptible to pneumonia, as well as parasites and pathogens of domestic animals, based on evidence of transmission between bighorn sheep and domestic livestock elsewhere.

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Key words: British Columbia, faecal survey, gastrointestinal parasites, *Ovis dalli stonei*.

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Fecal Glucocorticoid Concentrations of Free-Ranging Stone's Sheep

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Abstract: Wild sheep do not readily expand their ranges or colonize new areas, making them especially susceptible to local anthropogenic and environmental disturbance. High levels of glucocorticoids can compromise the immune system and potentially increase susceptibility to diseases such as pneumonic pasteurellosis, the most serious infectious disease of wild bighorn sheep. Fecal glucocorticoids currently serve as the best measure for monitoring the physiological response of stressors with non-invasive samples. Our goal was to define baseline levels and seasonal variation in concentrations of glucocorticoids for Stone's sheep (*Ovis dalli stonei*). We compared fecal samples from sheep in two areas that differed in anthropogenic access and development, predicting that glucocorticoid concentrations would be higher with greater human disturbance. A secondary objective was to examine the relationship between cortisol and corticosterone, two glucocorticoids that commonly are used to describe stress in vertebrates. Concentrations of cortisol and corticosterone in feces from Stone's sheep were higher in summer than late winter, but did not differ between the two areas. We recommend measuring corticosterone concentrations for describing fecal glucocorticoid levels in Stone's sheep because of easy recovery and lower within-season variation than cortisol.

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Key words: corticosterone, cortisol, glucocorticoids, *Ovis dalli stonei*, Stone's sheep, stress

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Wild sheep are particularly susceptible to disturbance and exhibit physiological and behavioural responses to humans and aircraft in close proximity (MacArthur et al. 1982, Stockwell et al. 1991, Bleich et al. 1994, Papouchis et al. 2001, Frid 2003). These disturbances have been recognized as imposing energetic costs on sheep and may alter habitat use, increase susceptibility to predation, or increase nutritional stress (Stockwell et al. 1991, Bleich et al. 1994). Chronic environmental stress is believed to contribute to initiation of pneumonia epizootics in bighorn sheep (*Ovis canadensis*) (Kraabel and Miller 1997). Although epizootics have not been observed in wild thinhorn sheep (*Ovis dalli*) and disease has not been identified as a factor limiting thinhorn populations (Nichols and Bunnell 1999), Dall's sheep (*O. d. dalli*) developed pneumonia from *Pasteurella haemolytica* under experimental conditions (Foreyt et al. 1996). Also, lungworms (*Protostrongylus* spp.) which can damage lung tissues and potentially set up secondary invasion by bacteria (Bunch et al. 1999) have been identified in Stone's sheep (*O. d. stonei*) (Luckhurst 1973, Seip 1983, Jenkins et al. 2005). The susceptibility to disease, philopatric nature, and inability to readily disperse or expand ranges (Geist 1971, Worley et al. 2004) make Stone’s sheep particularly sensitive to disturbance. With increasing resource development of sheep habitat and access to sheep ranges, stressors imposed on Stone’s sheep are likely to escalate with potentially serious consequences (Paquet and Demarchi 1999).

Stress elicits physiological and behavioural responses that can be invoked by physical or psychological stressors (Reeder and Kramer 2005). Response to stressors culminates in the release of adrenaline and glucocorticoids from the sympathetic nervous system (SNS) and hypothalamic-pituitary-adrenal axis (HPA). Both systems play a role in the fitness of an individual by enabling the animal to deal with short-term (SNS) and long-term (HPA) challenges (Reeder and Kramer 2005). Prolonged production of glucocorticoids, however, can be detrimental to the health of an animal (Breazile 1987, Reeder and Kramer 2005). Chronic stress can impede reproduction, alter feeding behaviour and efficiency, cause hypertension and ulceration, and suppress the immune system (Breazile 1987).

Monitoring environmental and anthropogenic stress in animals is difficult because of the stress placed on the animal by the act of sampling (Moberg 1987). Traditionally, measures of stress have been obtained from glucocorticoids (i.e., corticosterone and cortisol) in blood serum or plasma (Harlow et al. 1987, Moberg 1987), but values often were inflated because of the rapid response to stress during handling (Moberg 1987). Plasma glucocorticoids can increase within 2-3 min of an animal being induced with a stressor (Sapolsky et al. 2000). In contrast, fecal excretion of glucocorticoids is determined largely by the time needed for glucocorticoids to travel through the digestive system (Millspaugh and Washburn 2004). Sheep and other large ruminants have relatively long digestive systems with slow passage rates (Millspaugh and Washburn 2004). Millspaugh et al. (2002) documented a temporal delay in glucocorticoid response in fecal samples of at least 10-12 hrs, following adrenocorticotropic hormone (ACTH) challenges on white-tailed deer (*Odocoileus virginianus*). Within 30 hrs of the induced stressor, fecal glucocorticoid measures returned to pretreatment levels. Bighorn sheep responded similarly under comparable ACTH treatments (Miller et al. 1991). The temporal lag between glucorticoid secretion in blood and excretion in feces limits the ability of fecal glucocorticoids to reflect circadian periodicity (observed in desert bighorn sheep (*O. c. nelsonii*), Turner 1984). This indicates that fecal measures better reflect average concentrations of circulating glucocorticoids and, therefore, are ideal for measuring long-term stress in wild animals (Millspaugh and Washburn 2004). In addition, collection of samples can be accomplished without disturbing or handling study subjects (Wasser et al. 2000, Millspaugh et al. 2002, Reeder and Kramer 2005).

Fecal glucorticoid assays have been used with numerous vertebrate taxa, as reviewed in Millspaugh and Washburn (2004). Miller et al. (1991) validated the assays in bighorn sheep and monitored responses of chronic stress in fecal and urine samples using cortisol concentrations. Even though sampling is non-invasive, sampling protocols and biological factors can influence measures of fecal glucocorticoids (Millspaugh and Washburn 2004).

Sampling issues include sample selection, age, condition, storage and transportation, weight, and assay type. Known biological issues influencing fecal glucocorticoid concentrations of free-living mammals are sex, age, diet, body condition, and reproductive status of sampled individuals (Millspaugh and Washburn 2004). Seasonal trends in glucocorticoid concentrations also are common in most mammals (Romero 2002). None of these biological factors has been quantified for wild sheep.

Our goal was to define baseline levels and seasonal variation in concentrations of fecal glucocorticoids in Stone's sheep. In comparing samples from two areas that differed in anthropogenic access and development, we predicted that glucocorticoid concentrations would be higher near greater human disturbance. A secondary objective was to examine the relationship between cortisol and corticosterone, the two glucocorticoids most often measured to describe stress in vertebrates (Moberg 1987).

Study Area

The study area was in the Besa and Prophet River watersheds of the Muskwa-Kechika Management Area (MKMA) in northern British Columbia (Fig. 1), between 57° 20' and 57° 40'N and 123° 10' and 123° 45'W (additional description in Walker [2005]). The 6.4 million-ha MKMA is distinguished by protected areas (i.e., provincial parks) and special management zones that accommodate industrial development as long as wildlife and other socio-environmental values are recognized. Although the Besa and Prophet River watersheds are largely unprotected, Stone's sheep are found throughout this mountainous region. Recreational activity is confined primarily to the southern portion of the study area where there is a permanent outfitter camp and a government designated all-terrain vehicle (ATV) trail. The trail is used from spring through fall and extends the length of the Neves valley in close proximity to several easily accessible mountains inhabited by Stone's sheep. The majority of ATV activity occurs during the summer and fall, with some snowmobile activity during winter. Although there is currently no significant industrial development, increased oil and gas exploration is probable in the southern portion of the study area. Several seismic lines are established in the Neves valley. The northern portion of the study area, encompassing Duffield Creek, is extremely remote and lacks any permanent anthropogenic development. The Neves and Duffield drainages are separated by the Besa River and data from GPS-collared Stone's sheep indicated no animal movements between these areas (Walker 2005).

Methods

Fecal samples were collected during early winter (December and January), late winter (March and April), and summer (July) of 2002 and 2003. Samples in early winter were taken from captured adult Stone's sheep ewes throughout the study area. Ewes were captured by helicopter and radio-collared, in accordance with the guidelines of the Canadian Council on Animal Care (2003), as part of a research project evaluating resource selection strategies of Stone's sheep (Walker 2005). Stone's sheep segregate sexually (Geist 1971, Luckhurst 1973, Seip 1983) with rams occupying distinct ranges or portions of a range away from ewes most of the year except during the breeding season (Geist 1971).

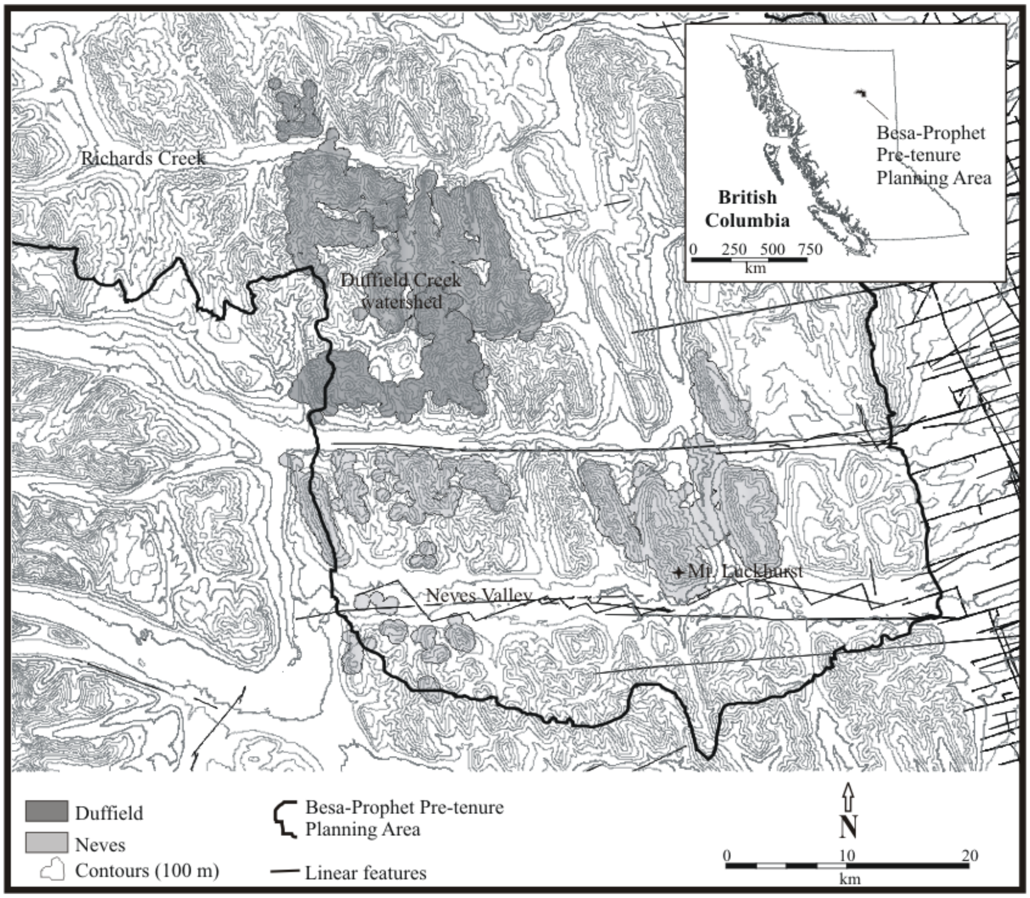

Figure 1. Study area within the Besa-Prophet Pre-tenure Planning Area in the Muskwa-Kechika Management Area of northern British Columbia.

Samples from late winter and summer were collected opportunistically from ranges frequented by maternal females. To minimize sampling the same individuals, we selected at least three different sites occupied by sheep within the Neves and Duffield ranges each year. We tried to alleviate confounding issues associated with age of the sample and sex of the animals by selecting only fresh samples from sites recently or still occupied by female sheep. During early winter samples were fresh because sheep often defecated in response to capture. During late winter we only collected pellets that were on top of the last snowfall and which were not frost-burnt or discolored by weathering. Summer samples were fresh if still moist. We did not collect samples from lambs (easily distinguished by small pellet size) and only went to ranges unoccupied by rams. With the exception of the fecal samples obtained directly from captured sheep (which would not have had time to indicate immediate stress), we minimized the influence of aerial disturbance by collecting samples more than 2 days after aircraft activity near collection sites. Aircraft activity was considered influential if an aircraft flew at or below the uppermost elevational ranges in the study area. Because of the remoteness of the study area and our central location within it, we were aware of all low-level aircraft activity around sheep ranges during periods of sampling.

All 85 fecal specimens were frozen within 2 hrs of collection until subsequent analyses for glucocorticoid content by

Prairie Diagnostic Services, Saskatoon, Saskatchewan. Fecal samples (10-12 pellets) were lyophilized in 20-ml vials and then ground. Approximately 0.25 g of each dry fecal sample were combined with 5 ml of 90% AnalaR grade methanol and inverted frequently for 24 hr. Following refrigeration overnight, samples were centrifuged for 20 min at 1500 g. One-ml aliquots of each methanol supernatant were then dried under air. Each aliquot was reconstituted with 100:1 absolute ethanol and 1 ml of steroid diluent from the corticosterone ^{125}I RIA assay kit (ImmuChem^{TM} Double Antibody, MP Biomedicals, Costa Mesa, California), capped, spun, and left overnight.

Corticosterone content of 50-µl aliquots was determined using the ICN corticosterone RIA antibody (MP Biomedicals, Costa Mesa, California), which is effective in detecting endogenous adrenal activity in a wide array of species (Wasser et al. 2000). Samples (50 µl) also were quantified for cortisol using the DPC Cortisol Coat-A-Count radioimmunoassay (Diagnostic Products Corporation, Los Angeles, California). Results were calculated to give ng/g feces. Sample concentrations were multiplied by 2 for the 50-µl sample size, multiplied by 5 for the 1 ml of methanol originally dried, and divided by the weight of the original fecal sample to give final units of ng glucocorticoid/g feces.

We compared glucocorticoid values between Neves and Duffield populations using a two-way ANOVA of fixed effects with population nested within three seasons. Values were log-transformed after examining assumptions of normality and homogeneity of variance (Levene's test). Tukey's honestly significant difference (HSD) test was used as a post-hoc comparison of main effects within significant models (Zar 1999). The relationship between corticosterone and cortisol was described using Pearson's correlation coefficient (Zar 1999). Statistical significance was assumed at $\alpha \leq 0.05$ and all statistical procedures were conducted using Statistica 6.0 (Statsoft Inc., Tulsa, Oklahoma).

Results

Seasonal differences were observed for both corticosterone ($F_{2,79} = 24.28$, $P < 0.001$) and cortisol ($F_{2,79} = 3.62$, $P = 0.031$) (Fig. 2). Corticosterone levels across all sheep increased from early winter (33.5 ± 1.94 ng/g feces, mean ± SE) through late winter (41.0 ± 1.85 ng/g feces) to summer (56.0 ± 2.94 ng/g feces) and all seasonal comparisons were significant after post-hoc analysis. Average cortisol levels were similar from early winter to late winter and between early winter and summer, but levels in late winter were significantly lower than in summer. Average fecal glucocorticoids of Stone's sheep in the Neves and Duffield Creek drainages followed similar seasonal change and were not significantly different for either corticosterone ($F_{3,79} = 0.96$, $P = 0.418$) or cortisol ($F_{3,79} = 0.11$, $P = 0.954$). Cortisol levels were much more variable than corticosterone. Across seasons, cortisol ranged from 3.6 to 111.8 ng/g of feces in summer and early winter, respectively, with variation averaging 63% of the mean. The variability in cortisol was higher than the range (21.5 to 94.2 ng/g) and coefficient of variation (36%) for corticosterone. In spite of differences in variation and temporal patterns, corticosterone and cortisol measures were positively correlated ($r = 0.68$, $n = 85$, $P < 0.001$) (Fig. 3).

Discussion

Glucocorticoid concentrations are recognized as a physiological index for monitoring stress responses in mountain sheep (Harlow et al. 1987). Corticosterone and cortisol were detected readily in the feces of Stone's sheep. Typically one

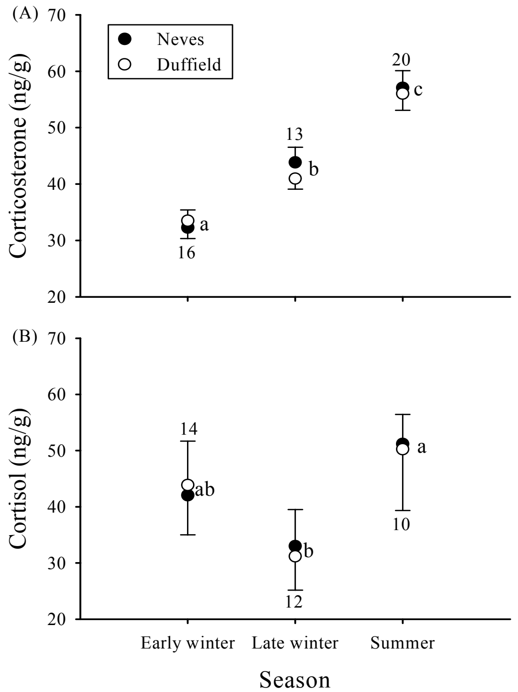

Figure 2. Corticosterone (A) and cortisol (B) concentrations (mean ± SE) in fecal samples from Stone's sheep in 2002 and 2003. Sample size adjacent to error bars in Neves Valley (A) and Duffield (B). Mean values sharing the same letters were not significantly different.

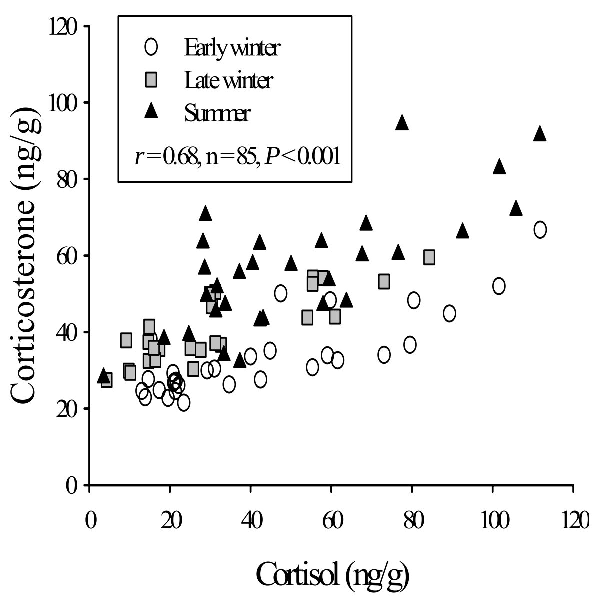

Figure 3. Seasonal relationship between corticosterone and cortisol concentrations in fecal samples from Stone's sheep in northern British Columbia during 2002 and 2003.

hormone tends to be more prevalent than the other in a given species, but both may persist in measurable quantities (Millspaugh and Washburn 2004). Their relationship to each other has been poorly described and trends between cortisol and corticosterone differ between captive and free-ranging desert bighorns (Turner 1984). Cortisol is generally the most prevalent glucocorticoid of large mammals (Millspaugh and Washburn 2004). In Stone's sheep, however, corticosterone provided a less variable measure of glucocorticoid concentrations than cortisol in every season. This may be due largely to the ability of the assay to cross-react or recover corticosterone more consistently than cortisol, as noted by Wasser et al. (2000). The variation exhibited in fecal corticosterone was still considerably greater than the 10% coefficient of variation described for fecal assays used on bighorn sheep under experimental conditions (Miller et al. 1991).

Contrary to our predictions, the glucocorticoid concentrations in the Neves and Duffield populations of sheep were similar even though anthropogenic access to the Neves Valley is greater. The glucocorticoid concentrations probably represent relatively undisturbed levels of stress or habituation by individuals in the Neves Valley or indicate that the disturbance did not elicit a response by sheep.

Fecal glucocorticoid concentrations in Stone's sheep fluctuated seasonally with higher levels in summer than late winter. Elk (*Cervus elaphus*) from Custer State Park in South Dakota also experienced highest fecal glucocorticoid concentrations during summer when air temperatures and anthropogenic disturbance were highest (Millspaugh et al. 2001). These factors, as well as seasonal metabolic rhythms and vulnerability of offspring to predation, may contribute to the elevated glucocorticoid concentrations in Stone's sheep during summer. Female sheep with lambs generally forage less efficiently, spending less time foraging and more time vigilant than nonmaternal ewes (Risenhoover and Bailey 1985, Frid 1997). Compared to the 1.5 million annual visitors to Custer State Park (Millspaugh et al. 2001), the anthropogenic influence on sheep in our study area was minimal. In northern B.C., temperatures are highest during the summer months but snow is common during any month of the year (Meidinger and Pojar 1991). Thus thermal stress by high temperatures is unlikely.

Seasonal variability in glucocorticoids has been described primarily during the breeding season and to a lesser extent during parturition in mammals (Romero 2002, Millspaugh and Washburn 2004). These periods generally are associated with increases in adrenal activity of most vertebrates. But no seasons are associated consistently with elevated glucocorticoid concentrations across mammalian taxa (Romero 2002). In golden-mantled ground squirrels (*Spermophilus saturatus*), seasonal patterns in corticosterone and cortisol can be associated with changes in body mass and fat deposition (Boswell et al. 1994). Corticosterone levels in female ground squirrels were highest in June during lactation, coinciding with increased lean body mass. Cortisol appeared to mediate corticosterone levels because an increase in fat deposition occurred simultaneously with increased cortisol and decreased corticosterone concentrations. The change in mass gain from muscle to fat occurred well after peak lactation (Boswell et al. 1994). Although the feedback mechanisms among cortisol, corticosterone, and mass dynamics are not confirmed, the inferences may provide insight into why late winter levels of Stone's sheep did not follow similar seasonal patterns. Corticosterone levels in Stone's sheep may remain high in late winter in order to increase lean muscle mass to compensate for the loss of protein reserves during winter and gestation. Although we were unable to collect samples from female Stone's sheep during late summer and fall, we would expect a marked reduction in corticosterone concentrations as females weaned their lambs into the fall if patterns were similar to those in ground squirrels. Cortisol concentrations also should increase with the deposition of fat prior to the fall breeding season. More research is needed to clarify the biologically inherent variation and relationships between these two glucocorticoids.

Romero (2002) described three hypotheses for explaining seasonal patterns in glucocorticoid concentrations. The energy-mobilization hypothesis predicts that glucocorticoid concentrations will be elevated during energetically expensive seasons such as breeding, or mid- to late gestation (Robbins 1993). The behaviour hypothesis infers that glucocorticoids exert control over behaviour and that the stressor is irrelevant. The preparative hypothesis posits that glucocorticoids prepare the individual for seasonal life history changes and that changes in seasonal concentrations are evolutionary reflections preparing an individual for upcoming challenges. These hypotheses are not mutually exclusive and all likely contribute to the seasonal glucocorticoid rhythm of a species (Romero 2002). Selecting the hypothesis that best explains the seasonal trends in Stone's sheep is difficult considering fecal samples were not collected throughout the year. Increased movement rates by Stone's sheep during summer (Walker 2005) and the high energy costs of lactation (Gittleman and Thompson 1988) lend support to the energy-mobilization hypothesis. Stone's sheep ewes in the Besa-Prophet also experienced the greatest mortality during lambing and early summer (Walker 2005). If female Stone's sheep perceive themselves or their young to be at increased risk of mortality, then the preparative hypothesis also may apply. Determining the range of acceptable concentrations and duration of chronic stress an individual can withstand without experiencing the deleterious effects (Millspaugh and Washburn 2004) is fundamental to understanding the effects of disturbance on fecal glucocorticoids. Glucocorticoids are important to an animal's well-being (Romero 2002, Reeder and Kramer 2005) and elevated levels do not automatically equate to reduced fitness. Without understanding normal variation and effects, inferences regarding the consequences of elevated glucocorticoids are inappropriate (Millspaugh and Washburn 2004). Continued research on baseline glucocorticoid measures throughout the life history of a species is required to enhance our understanding of the physiological status of disturbance-sensitive species in the wild. Our study documents the first baseline information on glucocorticoid levels and the range of naturally occurring variation during three seasons for Stone's sheep in an area where future disturbance associated with resource extraction and increased access is likely to occur.

Management Implications

Wild sheep do not readily expand their ranges or colonize new areas (Geist 1971, Worley et al. 2004), which makes them especially susceptible to local anthropogenic and environmental stressors. Increases of glucocorticoids under captive conditions can increase the susceptibility of bighorn sheep to pneumonic pasteurellosis (Kraabel and Miller 1997), the most serious infectious disease of wild bighorn sheep (Bunch et al. 1999). By describing baseline levels of glucocorticoids in Stone's sheep, we provide a reference to gauge the physiological cost of potential disturbance from environmental or anthropogenic sources. Anthropogenic disturbances can elevate glucocorticoid concentrations in other large mammals (Wasser et al. 2000, Millspaugh et al. 2001, Creel et al. 2002). We recommend measuring corticosterone concentrations rather than cortisol for describing fecal glucocorticoid levels in Stone's sheep because of lower within-season variation and easy recovery. Fecal glucocorticoids currently serve as the best measure for monitoring the physiological response of stressors with a non-invasive and easily attainable source of data (Wasser et al. 2000, Millspaugh and Washburn 2004). For fecal glucocorticoids to be most useful, however, more research is needed to identify the levels of glucocorticoids that are deleterious to individuals and that indicate a potential impact on population health.

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Habitat Selection by Mountain Goats in South Coastal British Columbia

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Abstract: We analyzed data from 18 Global Positioning System collars from 2001 to 2003 in southwestern coastal British Columbia to improve understanding of mountain goat (*Oreamnos americanus*) habitat use and its relation to forestry operations. We described seasonal home ranges, movements, and winter habitat selection patterns to predict winter habitat use in similar geographic areas. Seasonal periods were determined for individual goats by observing shifts in elevation use. We used a Geographic Information System (GIS), digital forest cover mapping, and a 25-m raster digital elevation model (DEM) to determine habitat selection at 2 different scales. At a broad scale of selection, we pooled locations from 18 goats and conducted chi-square analyses. At a fine scale of selection, we used logistic regression to determine resource selection functions (RSF) for 15 individual goats. We used an information theoretic approach (Akaike's Information Criterion) to select the most likely models from an *a priori* set of candidate models to determine biological factors driving coastal winter habitat selection. We averaged selection coefficients from individual RSFs in a second-stage analysis to develop predictive maps of relative likelihood of use across the study area. Use of younger forests was greater than expected, particularly among male goats, and was largely associated with previously-burned stands 20 to 40 yr old. However, use of mature and old forests was relatively high for both sexes and was higher for males (42%) than for females (29%). Presence data was best fit by global models. Selection coefficients of RSFs were relatively consistent but variable for forest volume. At the fine scale, males were consistently associated with higher forest volume and older forest age. Females were more often associated with older forest age yet with lower forest volume.

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Key words: British Columbia, coastal forest, habitat selection, mountain goat, *Oreamnos americanus*, resource selection function, winter range

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British Columbia has the greatest area of natural mountain goat habitat in North America and supports over half of the world's population of mountain goats (Krausman 1997). The species is classified provincially as yellow-listed (of management importance) because of its regional importance and special management interest. Mountain goats exhibit behaviours associated with 2 ecotypes in British Columbia, one associated with drier snow conditions in the interior and another associated with wetter coastal climates. The coastal ecotype winters at relatively lower elevations and has been associated with old forests and steep slopes (Hebert and Turnbull 1977, Schoen et al. 1980, Fox 1983, Smith 1994). One of the main management concerns for coastal populations is associated with forest harvest trends. As practices such as heli-logging allow harvest of marginal habitats at higher elevations, this may conflict with goat habitat.

Our objectives were to learn more about movement patterns and seasonal habitat use by goats in southern coastal British Columbia. Further, we wanted to determine the characteristics of winter habitats selected by goats, predict goat habitat use on the landscape, and relay information to coastal forest managers. Our goals included determining seasonal home ranges of collared goats, movement patterns, and use of habitat categories and attributes, particularly within forested habitats. We also created a multivariate model to allow wildlife managers to predict seasonal use of winter goat habitat and identify driving factors in goat habitat selection. Given that the province is finalizing legislated ungulate winter range for mountain goats, this information is beneficial in designing such areas.

Study area

The study area, centered near Bute and Toba Inlets of the Sunshine Coast Forest District (SCFD) of British Columbia, was situated approximately 200 km northwest of Vancouver on the southern mainland coast (Figure 1), west of Vancouver Island. These fiord inlets consist of steep sidewalls and extend up to 25 km inland to glaciated areas. Typical drainages range from approximately 4 to 10 km wide, peak to peak, and elevations ranged from sea level to approximately 2700 m. Logged areas occurred in lower valley positions of most drainages. The study area was situated in the southern portion of the North Pacific Range ecosection, where the following biogeoclimatic zones occurred: the Coastal Western Hemlock Zone, Mountain Hemlock Zone and Alpine Tundra (Green and Klinka 1994). Forests occurred in montane and submontane ecosystems. Forest types consisted mainly of Douglas-fir (*Pseudotsuga menziesii*) and western red cedar (*Thuja plicata*) in the drier subzone variants, western hemlock (*Tsuga heterophylla*) and amabilis fir (*Abies amabilis*) in the cooler, wetter variants, and mountain hemlock (*Tsuga mertensiana*) and amabilis fir in the Mountain Hemlock Zone.

Methods

Global Positioning System (GPS) collaring: We attempted to randomly select animals from within independent social groups. However, safe capture sites limited the selection procedure; steeper coastal headwalls, particularly associated with the northern shores of the Toba Inlet, were excluded from potential capture sites. Using aerial net gunning from helicopter, crews captured 24 mountain goats from November 2 to 6, 2001 and on September 11, 2002 in 12 different drainages.

We used two types of GPS collars: model G2000 (Advanced Telemetry Systems, Inc., Isanti, Minnesota, USA) on 11 female and 4 male goats, and model 2200R (Lotek Wireless Inc., Newmarket, Ontario, Canada) on 6 female and 3 male goats. The former collar fix schedules were designed to permit 2 yr of observations at a

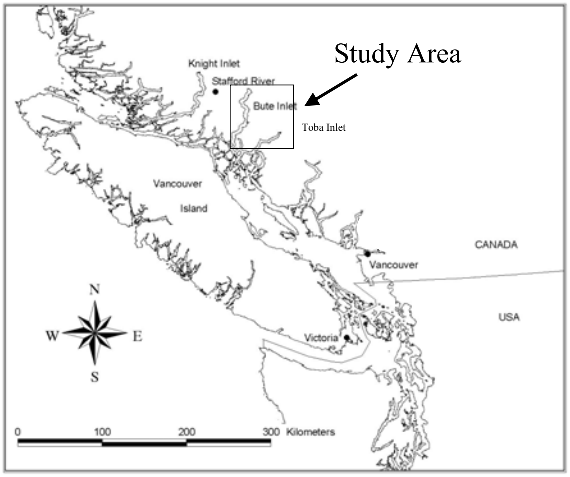

Figure 1. **Approximate location of study area near Bute and Toba inlets, B.C.**

fix-attempt rate of 3 locations per day, while the latter were designed to allow 1 yr of observation at 8 fix-attempts per day. GPS data from another 4 mountain goats in adjacent Stafford Valley (Taylor 2002) were used for range size determination and to assess potential risk of harvest related to slope. To ensure accuracy of locations, we discarded all GPS locations with positional dilution of precision (PDOP) greater than 10. GPS fix-rate bias can lead to inaccurate or incorrect habitat selection interpretations (Moen et al. 1996, 1997; Rempel et al. 1995; Dussault et al. 1999, 2001; Taylor 2002; Frair et al. 2004) but may not pose large problems for studies in environments with less-variable fix likelihood (D'Eon et al. 2002). We used three-dimensional and two-dimensional fix locations to maintain large sample sizes and minimize GPS fix-rate bias (Taylor 2002) based on testing GPS collar performance, modeling fix-rate with GIS over the landscape, and applying correction weights to each goat location, as described in Taylor et al. (2004).

We assigned locations for each goat into 1 of 2 seasons (winter or non-winter), dependent upon whether the animal was in a high- or low-elevation portion of its home range. From our Digital Elevation Model (DEM), we recorded the elevation associated with each goat location and calculated the weekly mean elevation per animal per year. Weekly means were averaged, and 3-wk running means calculated. Individual winter periods were determined from the largest weekly shifts in the range of weekly-elevation shifts.

We used ArcGIS 8.3, ArcView 3.2 (Environmental Systems Research Institute, Inc.) and custom-developed scripts for GIS analysis. MELP KID (ArcView 3.2 extension, BC Ministry of Environment, Lands and Parks) was used to convert geographic co-ordinates (datum 186 World Geodetic System 1984) and UTM (North American Datum 1983 (NAD 83), zone 10) projections to BC Albers Standard Projection (datum NAD 83, BC Ministry of Sustainable Resource Management). Range data for goats were analyzed with the ArcView extension Animal Movement (Hooge et al. 2002). We used base topographic layer data from 1:20 000 BC terrain resources information management files (TRIM). We created a triangular irregular network DEM using ArcGIS 8.3 and mass points as an input, followed by raster conversion. To analyze topographic attributes, we used 6 terrain variables derived from DEM: elevation, slope, slope position, distance to escape terrain, terrain ruggedness, and insolation (solar loading). From 1:20,000 forest cover inventory data (Ministry of Forests 1995), we used 5 forest cover variables including biogeoclimatic variant, habitat class (Table 1), leading species, net primary forest stand volume, and forest crown closure. We produced a 25-m grid cell raster for each variable and spatially linked values with GIS to all winter goat locations.

Table 1. Definitions of codes used in chi-square tables.

Forested habitat variable	Description
Other	No typing available, non-sufficiently restocked forest
NPF	Non-productive forest
Early	Forest (<40 yr)
Young	Forest (40-80 yr)
Mature, open	Forest (81-250 yr, <50% crown closure)
Mature, dense	Forest (81-250 yr, >50% crown closure)
Old, open	Forest (>250 yr, <50% crown closure)
Old, dense	Forest (>250 yr, >50% crown closure)

We estimated escape terrain on the landscape by deriving polygons based on DEM slopes greater than 50° (119%), consistent with a coastal habitat model from Alaska (Smith 1994). The ArcView script nearfeat.avx was used to determine distance (m) from goat locations and available locations to nearest edge of an escape-terrain polygon. We used the script shortwavc.aml to calculate insolation, or amount of potential (clear-sky) direct solar radiation for a given raster cell over a given time period (Kumar et al. 1997), and accounting for hill shading at hourly intervals. We calculated mean daily insolation (kj/m^2/day) for 3 time periods (November-December, January-March, and April-May) and then selected the period which best fit mountain goat presence data, using a data-dredging technique (highest R^2 value).

Because we were most interested in mountain goat habitat selection in relation to forestry, we focused analyses on habitat use during winter. We conducted 2 main analyses at different scales. In the first analyses, we determined habitat selection at Johnson's (1979) second order of selection by analyzing goat selection of winter ranges from the study area. We obtained a census of available units by systematically sampling from a 50-m grid of the study area defined by determining the minimum convex polygon from all goat locations. We conducted modified chi-square tests (Neu et al. 1974) for all variables. We pooled animals by sex, and used Bonferroni confidence intervals (Byers and Steinhorst 1984) to determine habitat categories significantly selected. We briefly report on the most important findings from this analysis; additional details are provided in Taylor et al. (2004).

In the second analyses, we assessed finer habitat selection at Johnson's (1979) third order of selection by using stand selection within individual goat home ranges. We calculated multivariate logistic regression resource selection functions (RSF) for individual goats (Manly et al. 2002) to predict relative likelihood of goat use. We obtained a census of availability by systematically sampling from 25-m raster cells within each goat's 95% adaptive kernel range. Goat locations were weighted for low values of GPS fix likelihood. A GPS location was classified as 1 for dependent variable presence and 0 for available location.

We created an *a priori* set of candidate models (Taylor et al. 2004) associated with different biological requirements of goats, including security from predators, thermoregulation, and snow avoidance, and from previous models from the literature (Smith 1994, Gross et al. 2002). To maintain a high number of locations per variable, we kept the number of model parameters to a minimum. Before creating candidate models, we tested for multi-collinearity of input variables and did not use more than 1 variable in 1 model when Pearson's correlation values were greater than 0.7 (Tabachnick and Fidell 1996). Forest variables including age, crown closure and volume, and topographic variables including slope position and elevation were collinear.

We then used Akaike's Information Criterion (AICc; Burnham and Anderson 1998) based on maximized log-likelihood values to select the model most likely to best fit the presence data. Analyses were conducted for 8 females and 7 males. We ordered models in relation to fit and calculated weights of evidence suggesting which model was the best inference. We also used AIC weights to compare model weights relative to one another. From individual RSF models (first-stage analysis), we made inferences to the population of goats (second stage analysis), by averaging *B* coefficients across individuals (Manly et al. 2002). This enabled us to calculate an average RSF model per cohort (males and females). To assess accuracy of RSFs, we estimated standard error of coefficients across all models using n-1 degrees of freedom and standard deviation of n individual estimates (Manly et al. 2002).

To approximate potential harvest risk, we determined the amounts of old and mature forests present within the winter ranges of 22 goats. We then used GIS to link the slope classes associated with these forests. Although many factors (including market economics, terrain stability, soil moisture, and site regenerative ability) determine the potential harvest of forests, slope class is one of the major factors associated with forest operability in coastal environments.

Results

General goat movement patterns

Eighteen complete datasets gathered from 24 collared goats included 4496 annual female observations and 5199 annual male observations, and 2430 male winter observations and 2605 female winter observations. Seven goats died of natural causes and 2 of capture myopathy. Of the natural mortalities, 2 females died as a result of avalanches and wolverine tracks and scat were observed at 2 other mortality sites.

Individual fix success differed widely during the winter. Overall winter fix success for 6 goats with Lotek collars ranged from 13.2% to 60.5% and averaged 37.8%, and for 12 goats with ATS collars ranged from 10.8% to 42.4% and averaged 25.4%.

We observed a distinct shift in elevation use by goats (Figure 2). Although they generally remained at high or low elevations during a given seasonal period, goats shifted between low and high elevation within a relatively short period from the second week of May to the first week of June (weeks 18 and 23; Figure 3). Goats descended to lower elevation habitats during a slightly longer period from the first week of November to the second week of December (weeks 44 and 51; Figure 3).

Movements along valleys during winter ranged from 0.9 to 5.5 km for females (average 2.3 km) and 1.4 to 4.3 km for males (average 2.8 km). Complete annual movements for 7 females ranged from 2 to 6 km, and for 6 males from 3 to 10 km. Except for elevation shifts and movements associated with rutting, where male goats moved up to 6 km from

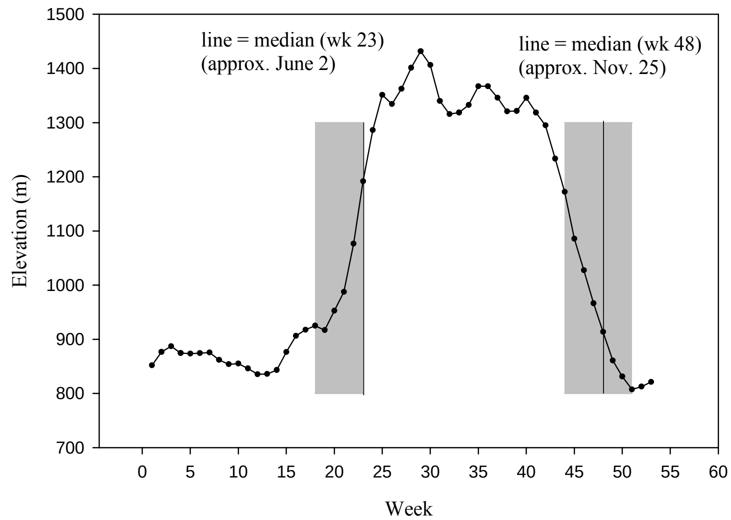

Figure 2. Three-wk running mean of elevation used by goats in coastal British Columbia. (Shift period in grey)

November to December, goat habitat use remained in close proximity (~2 km) to winter habitats. Females with kids did not move from typically-used winter areas. Few goats crossed into other drainages. Consistent seasonal trends in shifts of aspect were not observed, and most seasonal ranges were located on southerly aspects.

Neither winter nor annual range size differed by sex (t = -1.367, p = 0.183; t = -1.926, p = 0.069). Mean winter range size was 140 ha for females and 271 ha for males. Seventy-five percent of winter ranges were less than ~184 ha for females and 270 ha for males (Figure 4). Mean annual range size was 295 ha for females and 544 ha for males. Seventy-five percent of annual ranges were less than ~440 ha for females and 800 ha for males (Figure 4). Some of the mean differences were likely attributable to greater male movements during the rutting period.

GPS datasets with complete winter data for two years were available for 6 individuals (4 females and 2 males). Overlap of winter ranges both years was high; 3 of 4 females (Figure 5) and 2 of 2 males (Figure 6) exhibited nearly identical use from one winter to the next. In some cases forest polygons in which goats showed high site fidelity were only several hundred meters wide.

Tests of the 2 types of collars showed that Lotek and ATS GPS collars differed markedly in fix-rate bias (different likelihood of receiving a location from a given fix attempt), depending on the GPS-fix environment (forest and terrain characteristics). To ensure that our selection analyses were properly interpreted, we independently corrected fix-rate bias for each collar type (Taylor et al. 2004).

Broad scale winter habitat selection - chi-square analyses

Positive habitat selections occurred when use exceeded availability. We present selection analyses only for those variables later included in final multivariate models; further analyses are presented in Taylor et al. (2004).

Forty-two percent of male goat use occurred in mature or old forest, compared

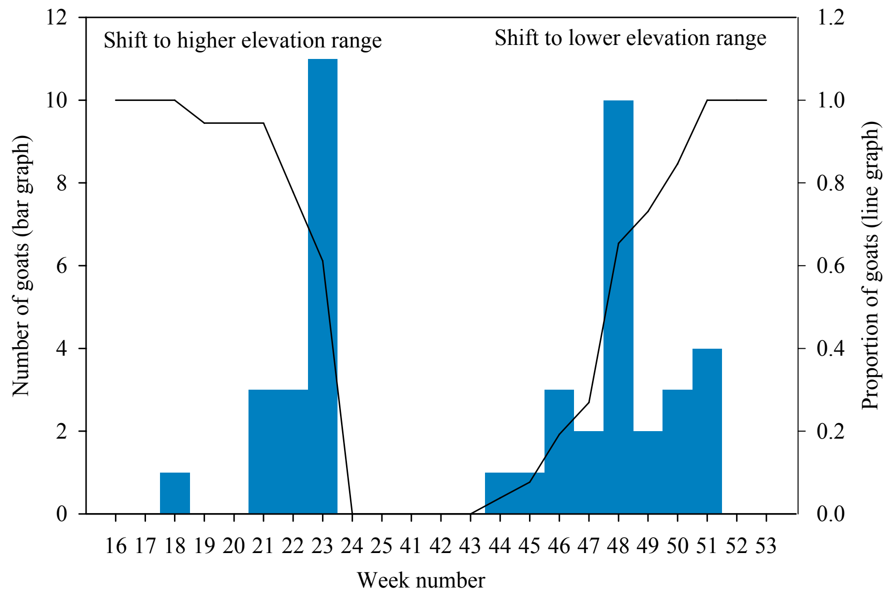

Figure 3. Elevation shifts by mountain goats in coastal British Columbia.
By wk 48, 70% of goats shifted to lower elevation and 10 goats shifted that wk.

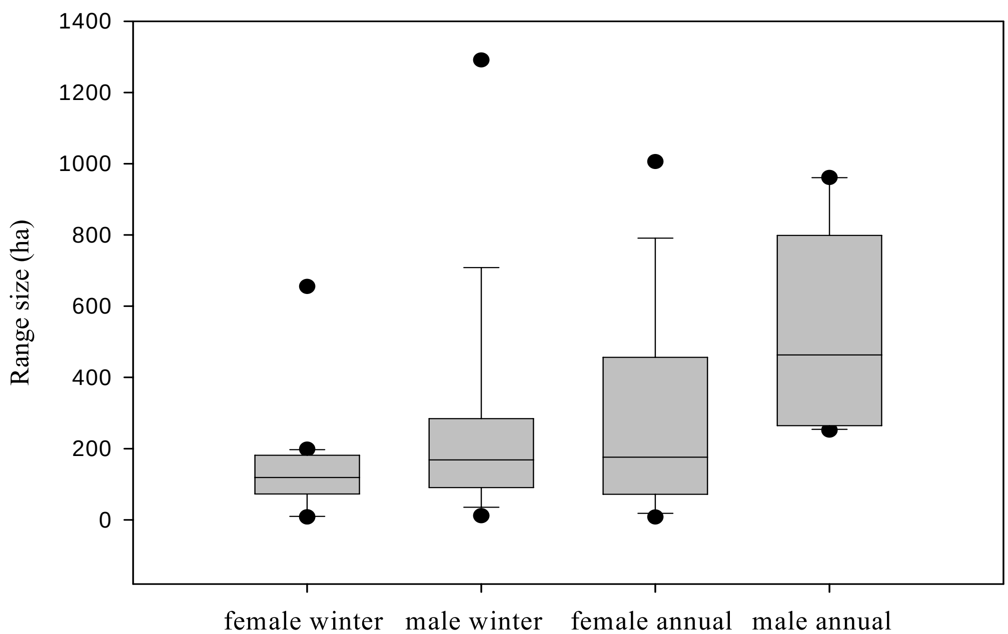

Figure 4. Seasonal and annual mountain goat home ranges in coastal B.C., November 2, 2001 to August 25, 2003. Each box outlines the 25th , 50th , and 75th percentile (lower, upper, and median lines, respectively) Whiskers indicate 10th and 90th percentiles. Black points represent outliers.

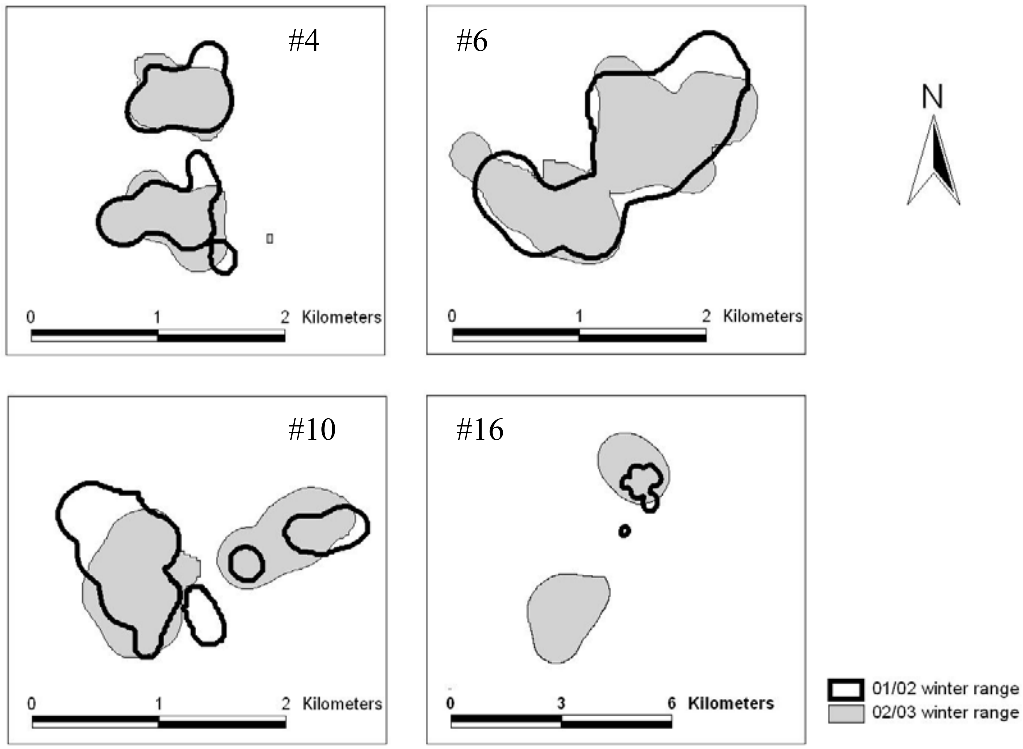

Figure 5. Winter home ranges of 4 female mountain goats in coastal B.C., 2001/2002 and 2002/2003.

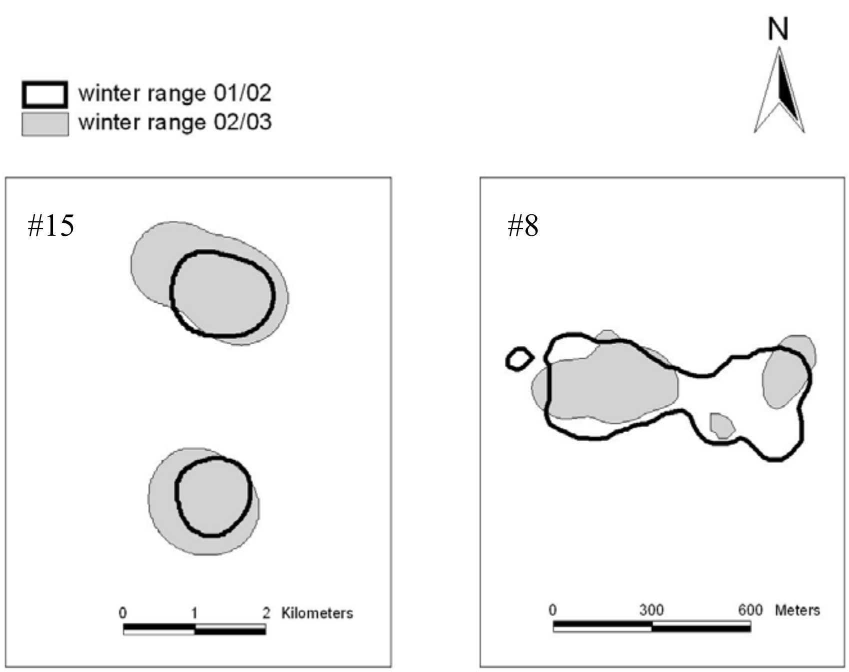

Figure 6. Winter home ranges of 2 male mountain goats in coastal British Columbia. Movements likely associated with rut were removed.

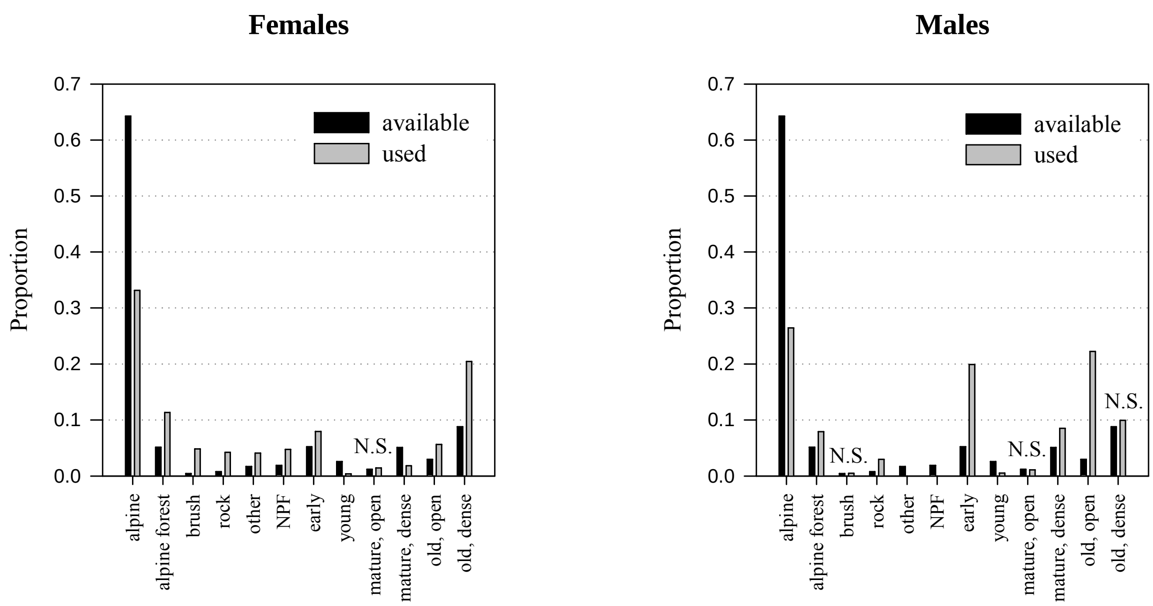

Figure 7. Selection of habitat classes by female and male mountain goats

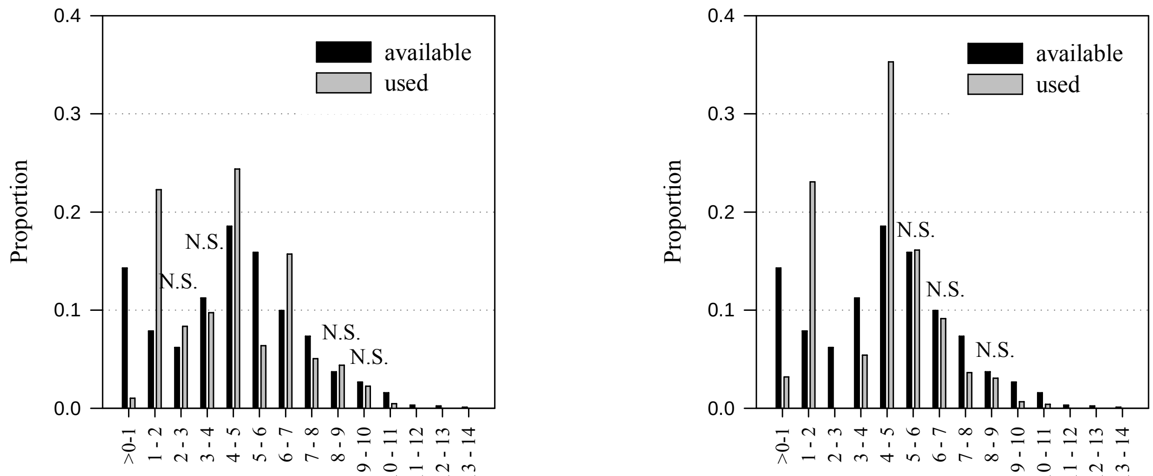

Figure 8. Volume classes selected by female and male mountain goats (in 100's m3/ha)

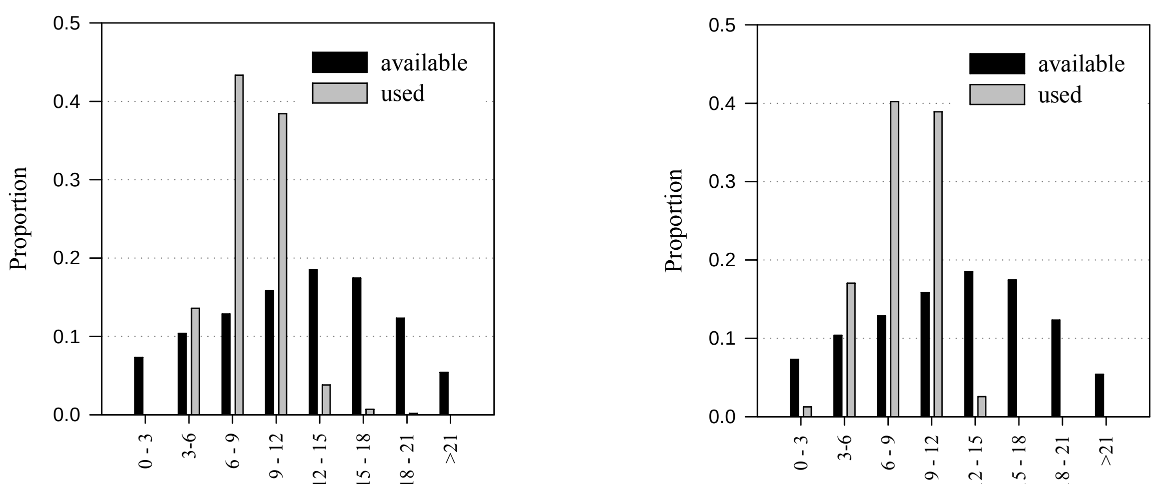

Figure 9. Elevation classes selected by female and male mountain goats (in 100 m's)

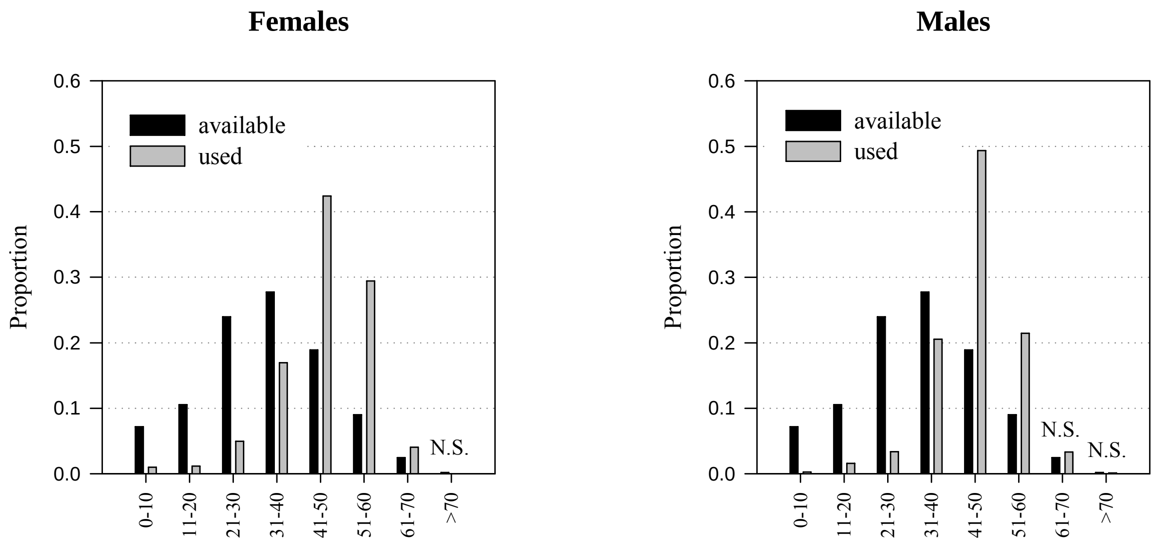

Figure 10. Slope classes selected by female and male mountain goats (in degrees)

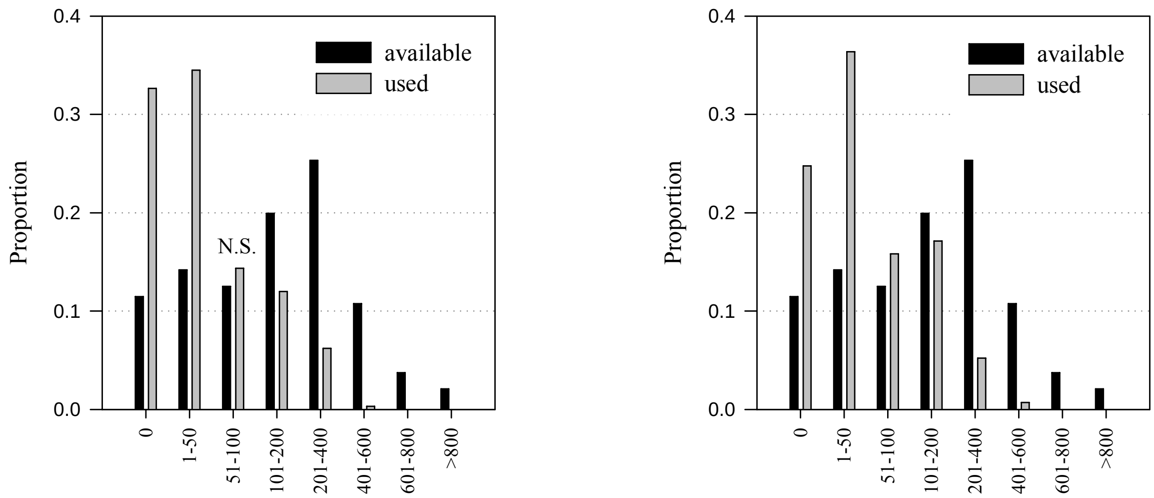

Figure 11. Selection for distance to escape terrain by female and male mountain goats (in m)

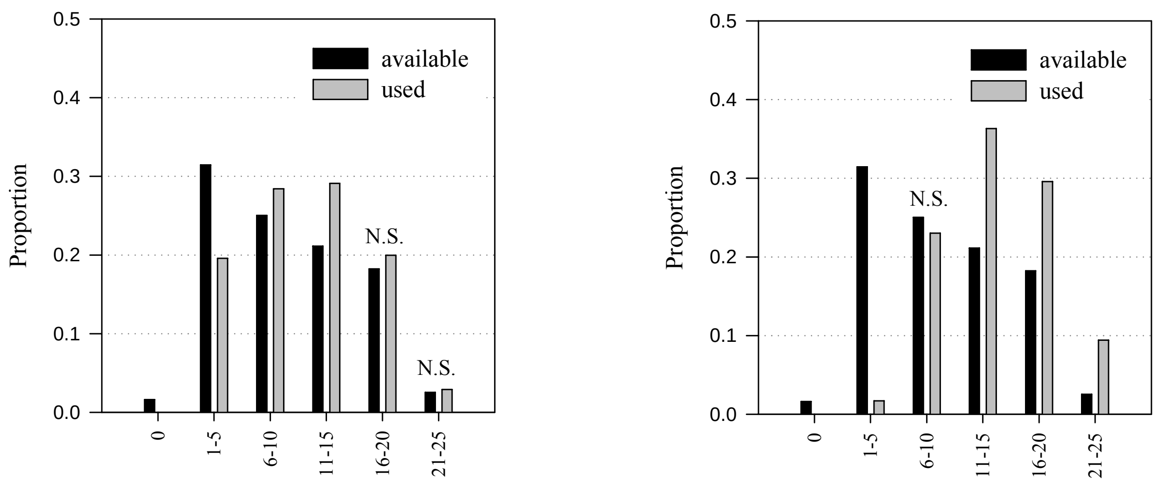

Figure 12. Selection for insolation by female and male mountain goats (in kj/m2/day)

to 29% of female goat use. When located in mature or old forests (>80 yr), females most frequently used old, dense forests (>250 yr) while males most frequently used old, open forests (Figure 7). Unexpectedly, 8% of female locations and 20% of male locations were observed in early forest (<40 yr). Mountain goats also made frequent use of alpine habitat (largely avalanche tracks). Although the rate of use was 33% for females and 26% for males, alpine habitat was used less than its large availability.

At the broad scale of analysis, we did not observe a strong linear trend between forest-stand volume and mountain goat use (Figure 8). The largest use occurred in average and below-average volumes, and goats did not use the lowest volume class.

Both sexes selected elevations between 300 m and 1200 m (Figure 9). Males and females positively selected slopes between 41° and 60° (Figure 10). Females also selected slopes from 61° to 70°. A clear relationship emerged between distance to escape terrain and habitat use by goats (Figure 11). Both sexes made positive selections for habitats within escape terrain polygons and within 50-m distance from these polygons. Males selected habitats within 100 m of escape terrain polygons; females showed neutral selection for these habitats. Goats were negatively associated with habitats greater than 100 m from escape terrain. The solar loading winter period between January and March best fit presence data of both sexes. Both females and males selected habitats associated with relatively high solar loading (Figure 12).

We analyzed location data to determine the disturbance factors associated with early forest (20-40 yr). Goats occurred in this forest category in 25 polygons originating from only 2 female and 2 male goats. The disturbance associated with 16 of these polygons (64%) was attributable to disturbance burns, 1 to a site preparation burn, 4 due to logging, and 4 unknown. The winter home ranges of 7 of the 18 goats included areas that had been logged, especially near the border of a home range. However, goats also occurred in logged areas of 2 home ranges where no wildfires occurred.

Fine scale habitat selection – logistic regression resource selection functions

Global models that included all variables were the favoured models for all 15 goats analyzed at the fine scale (Taylor et al. 2004). Selection for the global model was definitive for 12 of 15 goats (i.e., no competing models within evidence ratios; Burnham and Anderson 1998). For the remaining 3 goats, small weight of evidence ratios (1.2, 1.3, 17.4) indicated that snow interception was a plausible alternate model. Global models that included forest volume were more likely models for 10 of 15 goats, and 5 of 15 models favoured stand age instead of volume. Of the 10 volume models, 2 were nearly equivalent in stand age, where volume was 1.1x and 1.5x more likely to be the best model. Crown closure was much less likely to be the best model to predict presence.

Distance to escape terrain was an important factor in all models.

The most consistent trend in variable selection for global models was distance to escape terrain. In model #3B (Table 2, *and see* Taylor et al. 2004), the largest coefficients (positive) and log odds ratios were associated with insolation. Log odds ratios describe the change in likelihood of habitat use by mountain goats given a unit change of a particular variable (i.e., in model #3B, male goats are almost 3 times more likely to use a given habitat unit during winter when there is a 5 unit increase in insolation ($k^2/m^2/day$)). Relatively consistent trends also were observed with associations for lower elevations in goat annual ranges.

Coefficients for slope were relatively variable among individuals, but were more often observed as positive. Associations between goat presence and forest volume were less consistent. Males had positive associations with forest volume in 6 of 7 cases, while females had negative associations in 5 of 8 cases. However, negative associations tended to be in areas of burned habitats. Both sexes showed relatively consistent positive associations with forest age.

Data on forest volume were not available for all polygons throughout the study area. For this reason, and because evidence for model selection was equivocal between 3A and 3B, we used the global model that included forest age as a predictive tool. Although 5 of 8 female goats had positive associations with forest age, the high coefficients of the 3 females showing negative associations resulted in a negative average for the age variable. To account for the selection of forest age shown by the majority of females, and to map the likely forest use by goats, we removed these 3 females from the average RSF calculation.

On average, ~30 ha of old and mature forest were found within each goat winter home range. Based on slope class alone, 22% of old and mature forests had a high potential risk of harvest, whereas ~31% was greater than 100% slope and therefore considered at no harvest risk (Table 3). The remaining terrain was difficult to assign harvest risk without further information.

Discussion

This project is the first study of coastal mountain goats to analyze habitat selection for individual goats in a multivariate nature. Our datasets provided a high level of detail of goat movement patterns. Although many of our conclusions support previous concepts of goat habitat use, some unexpected results emerged. The development of a predictive tool for goat habitat will enhance the ability of managers to identify goat habitat throughout the landscape and to model habitat supplies under various disturbance scenarios. The refinement of our understanding of goat-habitat attributes should provide management direction and aid identification of winter range for mountain goats on the south coast of B.C..

Table 2. Resource selection function data from averaged winter resource selection function models for 12 mountain goats in coastal B.C. (Model #3B). For example, for every 25m distance from escape terrain, a landscape unit is 0.8 times as likely to be used by a mountain goat during winter.

		7 males			5 females		
Variable	Unit of change	Coefficient Average	Log odds ratio	Standard Error x	Coefficient Average	Log odds ratio	Standard Error x
Distance	25	-0.008	0.8	0.075	-0.008	0.8	0.200
Elevation	200	-0.003	0.5	0.600	-0.002	0.7	0.600
Slope	15	0.000	1.0	0.120	-0.002	1.0	0.090
Insolation	5	0.211	2.9	0.760	0.146	2.1	0.730
Age*	25	0.004	1.1	0.100	0.002	1.1	0.175
Constant		-2.651			-1.634		

*3 female mountain goats with negative forest age coefficients not included.

Table 3. Risk of harvest of old and mature forests in mountain goat winter home ranges in coastal B.C..

Slope category (%)	Old + mature forest (%)	Harvest risk	Rationale in relation to slope class
<60	21.6	high	No terrain assessments required
60-80	21.7	moderate	Terrain field assessment required if terrain mapping not available
80-100	26.2	low	Terrain field assessment required if terrain mapping not available
>100	30.5	nil	Excessively steep slopes

The variability of forest cover types used by mountain goats during winter was unexpected. Some goats selected habitats previously considered marginal for snow interception (e.g., low crown closure) even when snow was relatively deep. During winter, second-growth forests associated with burns were used more frequently than expected, and in a few cases, clearcut habitats were used. Surprisingly, some goats did not use old or mature forest cover during the entire winter period. This area, as well as the majority of second growth habitats used by goats, consisted of forests 20-40 yr after burns. Although goats forage in clearcut habitats during summer (Gilbert and Raedeke 1992), our study is the first to document such use during winter. Similar findings were seen in ongoing research in Washington (C. Rice, Washington Department of Fish and Wildlife, personal communciation). This use likely coincides with low snow levels.

Burns provide short-term benefit to ungulates in the form of increased living vegetative biomass (Ruckstuhl et al. 2000) and nitrogen uptake by vegetation (Shaw and Carter 1990, McWhirter et al. 1992), and also may increase the proportion of palatable diet items over a longer period by preventing succession (Carlson et al. 1993). There are likely 2 reasons goats used burns in our study area: forage-related benefits and snow-free areas during winter.

Similar to previous studies (Fox and Smith 1988, Fox et al. 1989, Smith 1994), a moderate proportion of goat habitat was in mature and old forest, and the least movements often were in older forest stands. Use by male and female goats was positively associated with forest age, although females less than males. Although Smith (1994) described preference for greater forest volume by mountain goats, we found that use of volume classes varied. Goats made highest use of moderate to low volume classes; however, females and males had variable patterns associated with forest volume. Coefficients for selection of volume were positive for most males but slightly more than half of the females were negatively associated with higher volumes. Apparently forest volume is not the primary habitat selection feature.

Exclusive use of younger habitat types by some goats indicated they likely selected high forage availability during winter rather than direct forest stand attributes. One area in our study consisted of steep, snow-shedding, southerly-aspect slopes that provided access to winter forage outside of mature or old forest. This area had relatively snow-free conditions and high concentrations of goats. However, such snow-free areas might have little use during winters with heavier snowfall. Winter periods with heavy snowfall are a critical period for goat winter survival and may be associated with population declines (Joslin 1986).

Goats made little use of unburned logged habitats. Where these habitats occurred, they were frequently on the periphery of goat winter ranges. Such activity did not preclude use by goats, while areas associated with burns appeared to attract goats.

Abiotic variables such as elevation and aspect appeared to be consistent predictors of goat use. For example, goats were positively associated with habitats within 100 m of escape terrain, and use was mostly within 400 m. All individuals were negatively associated with distances away from escape terrain within their home ranges. Goats consistently use areas within 300 to 500 m of escape terrain during winter (Fox 1983, Fox et al. 1989, Poole and Mowat 1997).

When comparing AIC weights of candidate models, snow avoidance was a plausible model for few goats. In terms of biological requirements, no single function was enough to satisfy goat requirements in coastal habitats. Multiple requirements were necessary to provide adequate habitat. Security from predators, thermoregulation, and snow avoidance were all necessary components to fit goat use to winter habitat.

Fidelity for annual winter sites is relatively high (Smith and Raedeke 1982). However, site fidelity to the degree to which we observed was unexpected. Goats consistently used similar areas from one winter to the next. The average area of mature and old forest stands in the average goat winter home range was 30 ha. Our observations are consistent with other coastal studies that reported limited movements relative to other areas in the range of mountain goats (Smith and Raedeke 1982, Taylor and Brunt 2007). Relative to the coast, interior goat populations (Joslin 1986, Lemke 1999) have larger movements and more movements between drainages. This observation, coupled with the relatively short distances goats moved between elevation ranges, may aid managers in predicting winter use from summer home ranges.

Maintaining available snow interception canopy at various elevations adjacent to goat winter ranges may be important during winters with heavy snowfall. Because goats tended to make larger lateral movements (2-3 km) than vertical ones in winter, lateral connectivity also may be important. However, younger stands were used by goats in winter and were not especially restrictive to goat movements (Gordon and Reynolds 2000, this study). Because goats expend greater energy in deep snow packs (Daily and Hobbs 1989), use likely depends on stand age and snowpack condition.

Many factors are involved in determining risk to goat populations due to conflicts with forest harvest. For example, in our area, the harvest operability is lower in montane variants than lower elevation submontane variants (BC Ministry of Sustainable Resource Management 2002). Given goat affinity for escape terrain and high use of montane variants (Taylor and Brunt 2007, Taylor et al. 2004) the potential for harvest of forests preferred by goats may be relatively low. However, our analysis shows at least a low to moderate overlap between harvestable timber and goat winter range. Additional constraints such as the inability to regenerate forests on shallow soil veneers will lower the risk of some goat habitat being logged.

Management implications

Winters with heavier snowfall than our study period are an important consideration for goat habitat management in coastal areas. Considering that site fidelity was high and areas of mature and old forest used per goat were not large, it is important to maintain a relatively high proportion of forest in goat winter ranges in older structural stages. Canopy providing snow interception should be maintained near goat winter ranges at various elevations including the lower submontane variant. Sufficient goat habitat appears harvestable to merit some caution. In areas with low operability, goat habitat may be maintained naturally. However, in areas with higher operability, special attention should be made to ensure preferred winter habitat is maintained.

Goats use a wide variety of habitats during winter and some older forest will be maintained due to relatively high inoperability. Logging in the periphery of goat winter home ranges does not preclude range use and goats appear to make significant use of early forest habitats in burned areas. Logging small portions of goat winter home ranges through group selection or variable-density tree removal may provide more abundant summer forage and winter forage in lower snowfall years, particularly for good snow-shedding areas.

Given the limited monitoring of coastal population trends and understanding of the affects of canopy removal on goat populations, decisions to alter snow interception canopy should be considered in a cautionary and adaptive management context. The strategy should consider selecting some consistent altered and unaltered areas monitored before and after alteration. Ungulate winter ranges designed to protect goat habitat should consist of some areas in which limited harvest may occur, provided sufficient winter snow interception is maintained, and others in which no harvest should occur.

Future site-specific (on-the-ground) analyses would identify the linkage of site selection to resource requirements rather than just habitat features. We recommend further assessment of operability in mature and old forests used by goats in this study. Further research regarding benefits of burned habitats to goats in coastal areas also is warranted.

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Can Horn Length of Mountain Goats Be Used as a Measure of Habitat Quality?

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Abstract: We compared the horn growth of mountain goats (*Oreamnos americanus*) from two areas with different histories and levels of habitat quality. In 1952 and 1953, 18 goats were introduced to Kodiak Island, Alaska. The population now numbers around 1,900 goats and continues to increase. Animals for this transplant were taken from the Kenai Peninsula, Alaska, where goats have been widespread for centuries and are sympatric with Dall sheep (*Ovis dalli*). The Kenai population of roughly 3,000 animals decreased by about 30% over the past 15 yr. We predicted that horn growth on Kodiak, where the habitat is of higher quality, would exceed the growth on Kenai. We measured the length of the first 3 growth increments from horns in both populations from 1998 to 2005. The first horn increment, representing the first 1.5 yr of growth, was highly correlated with and inversely related to the 2 subsequent yearly growth increments. Kodiak goats had longer horn growth than Kenai animals but the difference was greater for females than males. Initial horn growth of mountain goats may be a useful index of habitat quality.

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Key words: Alaska, habitat quality, horn growth, mountain goat, *Oreamnos americanus.*

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Horn and antler growth has been correlated with nutrition for cervids (Moen and Pastor 1998, Schmidt et al. 2001, Bartoskewitz et al. 2003, Weladji et al. 2005) and bovids (subfamily Caprinae: Wishart and Brochu 1982, Bayer and Simmons 1984, Hoefs and Nowlan 1997, Hook 1998, Giacometti et al. 2002). Past work in the genus *Ovis* has shown a variety of methods for describing how habitat may influence horn growth. Variation in horn growth was correlated to primary productivity of forage for Dall sheep (Bunnell 1978). Bighorn sheep (*Ovis canadensis*) had greater annual horn growth when introduced onto new habitat compared to horn growth in parent populations (Picton 1994, Hook 1998), and horn growth may decrease when population densities increase (Jorgenson et al. 1998). Bighorn sheep may defer horn growth and put energy into maintenance when food is limited (Festa-Bianchet et al. 2004).

Relatively few studies related habitat to variation in horn growth in mountain goats. Foster (1978) found differences between male and female goats in the first 1.5 yr of horn growth but did not make regional comparisons. Côté et al. (1998) found lactation negatively affected horn growth but total rainfall had no effect. The nutritional state during the initial years of growth can alter the size and proportions of mountain goat skulls (Cowan and McCrory 1970), and horn length may be correlated to body weight (Bunnell 1980, Houston and Stevens 1988).

Mountain goat populations often exhibit high growth rates when introduced to new habitat (Adams and Bailey 1982, Swenson 1985, Williams 1999). Mountain goats on Kodiak Island increased rapidly after 7 males and 11 females were introduced in 1952 and 1953. They currently number around 1,900 animals and inhabit most of the available habitat on the island. The goat population on the Kenai Peninsula ranges throughout the Kenai Mountains. The current population of approximately 3,000 animals decreased 30% over the past 15 yr (McDonough 2004). This decline may be due to a decrease in habitat quality but could also be due to an array of contributing factors. Kenai goats potentially compete with approximately 1,500 sympatric Dall sheep (Dailey et al. 1984, Laundré 1994). Both species have been present on the Kenai for centuries; native people hunted them long before Alaska was settled by Russians in the late 1700s (Sherwood 1974) and large numbers were documented during early explorations over a century ago (Bennett 1918). Although there are similarities in goat habitat and climate of these 2 regions, both the quality of the summer habitat and the availability of winter range due to typical snow accumulation are lower in the Kenai Mountains compared to Kodiak (Hjeljord 1973). Our objectives were to quantify the early sex and age-specific growth of goat horns and compare this growth between the 2 populations. We made the assumption that horn growth primarily is a function of resource availability (Bunnell 1978; 1980). We hypothesized early horn growth in Kodiak goats would be longer than in Kenai animals.

Study areas

Kodiak Island (13,000 km^2) and the Kenai Peninsula (24,000 km^2) are in southcentral Alaska (Figure 1). Each has a maritime climate. Precipitation is greater along the coast and varies inland with elevation and distance from the coast. The average precipitation on both areas ranges from about 1,270 to 1,780 mm/year (www.ambcs.org, www.wrcc.dri.edu). The Kenai has slightly warmer summer temperatures and colder winter temperatures. Warmer winter temperatures on Kodiak, often above freezing, result in reduced snow depths, at least at lower elevations, and a longer growing season than on the Kenai Peninsula (Hjeljord 1973).

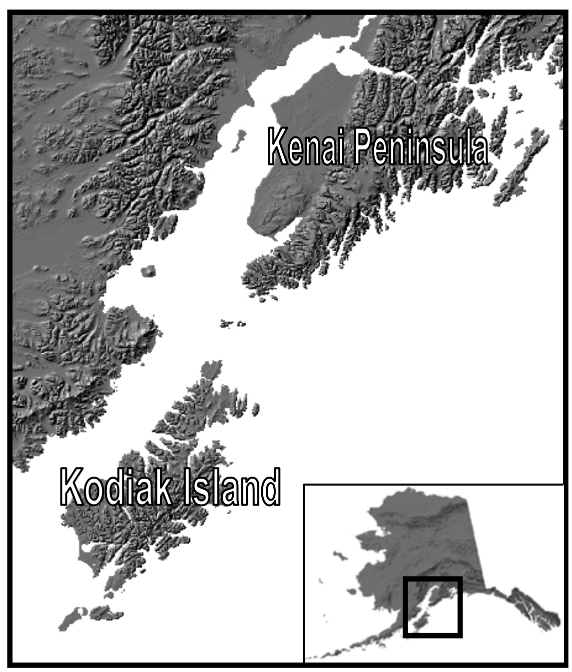

Figure 1. Kodiak Island and the Kenai Peninsula in southcentral Alaska, USA.

The Kenai Mountains range in elevation from 1,300 to 2,000 m above sea level. Peaks on Kodiak range from 700 to 1,300 m above sea level. The vegetation on Kodiak and Kenai is similar and was described extensively in Hjeljord (1973). The most apparent difference between the 2 areas is the limited occurrence of coniferous forest on Kodiak. Alpine tundra (Viereck and Little 1972) covers most higher elevations at both sites. Preferred forage species for goats were more abundant on Kodiak than on the Kenai Peninsula (Hjeljord 1973).

Methods

Counting horn annuli is an accurate method for aging Dall sheep (Geist 1966) and mountain goats (Brandborg 1955, Stevens and Houston 1989). Due to decreasing horn growth with age, total horn length increases only slightly after the age of 3.5 yr for mountain goats (Côté et al. 1998). Therefore, we measured the length of the outside curve of the horn for the first 3 growth increments of goats from Kodiak Island and the Kenai Peninsula from 1998 to 2005. Measurements were taken only on the longer of the 2 horns from goats legally killed by hunters. We did not include broken or broomed horns. Each of the 3 increments corresponds to 1 yr of horn growth except for the first measurement from the tip of the horn to the first discernable annulus that develops during the goat's second winter (Brandborg 1955). We analyzed horn growth using 2-way ANOVA models that included the effects of sex, region (Kodiak and Kenai), and their interaction on horn length. We used Pearson's product-moment analysis to measure correlations among the first 3 growth increments.

We also describe historical data of population size and hunter harvest for these 2 populations. Goat surveys were conducted with fixed-winged aircraft using techniques described in Nichols (1980). Goat surveys were conducted each year on 20 to 40% of the Kenai Peninsula and 40 to 80% of Kodiak. Survey data from Kenai Fjords National Park (2,460 km^2) within the Kenai Peninsula were sporadic and not included in this study. Due to the inability to estimate goats not seen during flights, our survey techniques produce minimum counts and not population estimates. Harvest and survey data for goats are maintained by the Alaska Department of Fish & Game (www.wildlife.alaska.gov).

Results

We measured 988 horn increments on 402 individual mountain goats. Our results were comparable to previous studies that identified sex differences in early horn growth in mountain goats (Brandborg 1955, Cowan and McCrory 1970). A notable similarity was that the first growth increment in males was greater than in females, and females exhibited greater growth in the second and third increments than did males (Hoefs et al. 1977, Foster 1978, Côté et al. 1998) (Figure 2). Kodiak females had longer horn length after 2.5 yr than Kenai females, and males from both populations (Figure 2).

We did not compare each growth increment separately because the growth of the increments was highly correlated. Most notably, there was an inverse relationship between the length of the first measured horn increment (0-1.5 yr) and the subsequent 2 yr (Figure 3). Correlation trends seen in Figure 3 were the same when the data were analyzed separately by region (Kenai and Kodiak) and by sex. The effects of sex, region, and their interaction on only the first horn growth increment were all significant (Table 1). The first increment on Kodiak females (165.2 mm, 95% CI: 161.6-

Table 1. ANOVA of horn length of mountain goats from the Kenai Peninsula and Kodiak Island, Alaska, USA, 1998 to 2005. Effects of the variables on growth of the first horn increment (0-1.5 yr) and summation of the first 3 increments (0-3.5 yr).

	First increment only[1]			First 3 increments[2]		
Variable	df	*F*	*P*	df	*F*	*P*
Sex	2	21892.3	< 0.001	2	33237.8	<0.001
Region	1	40.1	< 0.001	1	9.9	0.002
Sex X region	1	9.5	0.002	1	7.9	0.005

[1] 108 male and 52 female goats from Kenai; 165 male and 77 female goats from Kodiak.

[2] 64 male and 38 female goats from Kenai; 99 male and 53 female goats from Kodiak.

168.8) was 17.8 mm greater than Kenai females (147.4 mm, 95% CI: 143.0-151.8). The first increment on Kodiak males (176.0 mm, 95% CI: 173.5-178.4) was 7.0 mm greater than Kenai males (169.0 mm, 95% CI: 166.0-172.1).

We also conducted an analysis on the combined length of the first 3 increments. This analysis was limited to goats older than 3.5 yr ($n = 254$). As in the previous analysis of only the first increment, the effects of sex, region, and their interaction on the combined length of all 3 increments were all significant (Table 1). Total length of the first 3 increments on the horns of Kodiak females (222.6 mm, 95% CI: 218.9-226.2) was 11.8 mm greater than females on the Kenai (210.8 mm, 95% CI: 206.5-215.1). The difference for males was much less, showing only a 1.8 mm length difference in Kodiak (216.5 mm, 95% CI: 213.8-219.1) over Kenai goats (214.7 mm, 95% CI: 211.4-218.0).

The Kodiak goat population steadily increased after the introduction in the early 1950s while the Kenai population declined since the early 1990s (Figure 4A). The first hunting season for goats on Kodiak was authorized in 1968 through a limited permit hunt (Van Daele and Crye 2004). Kenai goats have been hunted for centuries but harvest data was recorded only since the late 1960s (Figure 4B). Hunts in both areas have been recently managed through different types and numbers of permits based on minimum population sizes (Del Frate and Spraker 1994). The decrease in the Kenai harvest in the late 1970s was due to introduction of a permit hunt system, which initially was restrictive. The harvest of goats on Kodiak recently surpassed the Kenai Peninsula despite the Kenai's larger land mass and higher goat population size (Figure 4B). The harvest rate based on the minimum number of animals counted in 2005 was roughly 9% for Kodiak and about 4% for the Kenai.

Discussion

Anual horn growth is driven by a complex interaction of age, energetic demands, genetic variation, and habitat quality (Festa-Bianchet et al. 2004). We assessed habitat quality indirectly by using horn growth as an index. We assumed Kodiak was a higher quality habitat for goats than the Kenai due to favorable climatic differences, relatively unexploited range (Hjeljord 1973), no competition from Dall sheep (Dailey et al. 1984, Laundré 1994), and the continued growth of the Kodiak population compared to the decline of the Kenai population (Figure 4A). This hypothesis was supported by longer horn growth measured in Kodiak goats.

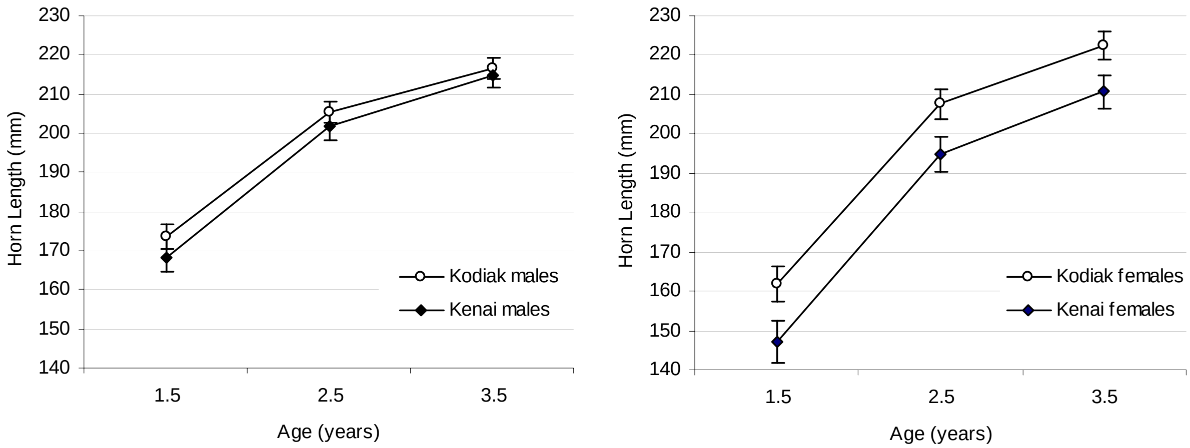

Figure 2. Horn length for the first 3 growth increments of mountain goats from Kodiak Island and the Kenai Peninsula, Alaska, USA, 1998 to 2005. Only goats having all 3 increments (>3.5 yr old) were included. 95% confidence intervals shown.

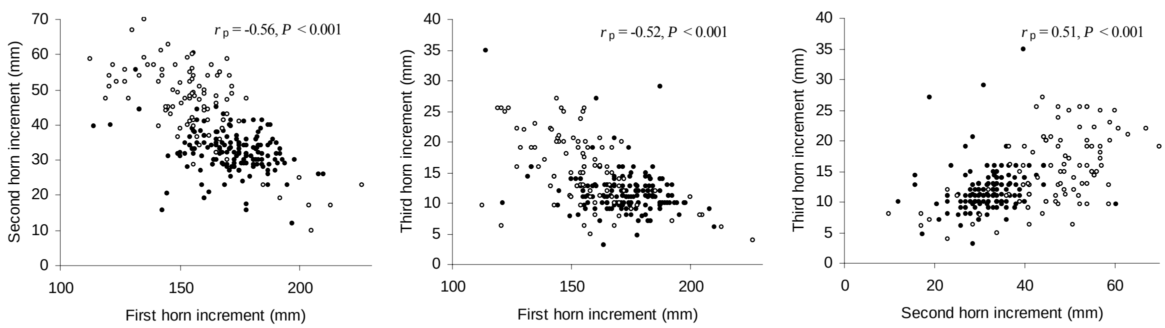

Figure 3. Correlations of the first 3 horn-growth increments from mountain goats on Kodiak Island and the Kenai Peninsula, Alaska, USA, 1998 to 2005. Open circles - females, solid circles - males. Pearson correlation coefficients (r_p) and significance levels shown.

We found growth of the first horn increment was inversely correlated with growth in the subsequent 2 yr. This pattern was seen in Dall sheep (Bunnell 1978, Bayer and Simmons 1984), mountain goats (Côté et al. 1998), Bulgarian chamois (*Rupricapra rupricapra*: Massei et al. 1994), and Cantabrian chamois (*R. pyrenaica*: Pérex-Barberia et al. 1996). Most horn growth studies in the genus *Ovis* focus on males due to their much greater horn growth than females (Bunnell 1978, Bayer and Simmons 1984, Picton 1994). Bunnell (1978) found horn growth in male Dall sheep to be more strongly affected by environmental differences than in females. Mountain goats do not share the degree of horn dimorphism found in Dall sheep so it is appropriate to consider both sexes when evaluating variation in horn growth across populations. We found a significant interaction between region (Kenai and Kodiak) and sex where strong differences were largely between females of these 2 populations.

The first horn increment in the population of Kodiak females was about

Figure 4. Mountain goat survey (A) and harvest (B) data from Kodiak Island and the Kenai Peninsula, Alaska, USA, 1968 to 2005.

10% longer (17.8 mm) than for Kenai females. When all 3 increments were combined, the horn length of Kodiak females was about 5% longer (11.8 mm) than Kenai females. Differences between males in the two populations showed longer growth on Kodiak but the discrepancy was minor compared to females. Kodiak females had longer horns after 2.5 yr than male goats from either population. Our data suggests the higher quality habitat on Kodiak primarily affects female horn growth and is somewhat negligible in males.

Animals in the subfamily Caprinae can both break the tips of their horns and also wear them down over time (Brandborg 1955, Schaller 1977). However, horn tip wear in mountain goats may be limited (Côté et al. 1998). We believe horn wear did not bias our results because we did not include animals with broomed or broken horns. Moreover, assuming tip wear is constant over time, we found no differences in the ages of goats sampled between the two populations. The ages of measured females for Kenai (mean = 5.6 yr) and Kodiak (mean = 5.9 yr) were not statistically different (t = 0.6, df = 125, P = 0.26) nor were there differences between males on Kenai (mean = 4.4 yr) and Kodiak (mean = 4.4 yr) (t = 0.2, df = 229, P = 0.43). There may be a bias in using goats killed by hunters if they are not representative of the population. Hunters ostensibly choose to take the largest goat they can. If this bias exists, it would have occurred in both populations. However, considering the large variation in horn size and ages of animals measured in our study, which included many yearlings not used in our analyses, we do not believe this biased the results of our study.

Genetic variation was the primary explanation for differences in horn growth between 2 populations of Dall sheep in the Yukon Territory, Canada (Hoefs and Nowland 1997). Furthermore, small horn size in some bighorn sheep populations may be due to genetic bottlenecks (Stewart and Butts 1982) or low heterozygosity (Fitzsimmons et al. 1995). Mountain goats used to populate Kodiak Island were taken from the Kenai Peninsula, but we do not know the possible effects of introducing so few individuals.

It is noteworthy that female mountain goats on Kodiak in an apparently high-quality habitat dedicate a portion of their annual energy budget to horn growth above those in a lower quality habitat, even as they approach reproductive age. Female mountain goats reproduce once a threshold body weight is achieved, irrespective of age (Houston et al. 1989), and there is a modest but positive correlation between horn length and body weight (Houston and Stevens 1988). We do not know if the greater horn growth in Kodiak goats occurred independent of or along with a greater body size. However, it is possible that energy devoted to horn growth for female goats on Kodiak may represent surplus energy only available in high-quality habitats. Data on age of first breeding for female goats in both our populations along with data on body size would be needed to properly address these questions.

Management implications

Horn length is used widely as an index of habitat quality (Bunnell 1978, Wishart and Brochu 1982, Côté et al. 1998). For mountain goats, the first 1.5 yr of horn growth is cited as a measure of "population quality" (Foster 1978). The higher quality habitat on Kodiak, as measured by horn length, was detected in the first 1.5 yr of horn growth and when the first 3.5 yr were combined. However, differences in horn length between our populations were greater when only the first 1.5 yr of growth were analyzed due to the inverse relationship between this initial growth and the 2 subsequent yr. Horn growth is more deterministic in mountain goats than in wild sheep species. It is not clear if there is a benefit for an individual to grow long horns. Indeed, horn growth may not be important in sexual selection (Côté et al. 1998). It may be adaptive in high quality habitats to put some surplus energy into early horn growth and then defer energy into body size and reproduction. Horn growth between the first two winters of life is typically the longest growth increment in mountain goats. If fast initial horn growth in high quality habitats allows an individual to redirect energy to growth in body size or early reproduction, the first 1.5 yr of horn growth may indeed be a good measure of habitat quality.

Mountain goats typically do not grow horns longer than 26 to 28 cm, although there can be large variation within a population, especially when the population has a large and heterogeneous range. Considering the horn growth differences of 2 cm or less in our study, detectable differences in horn growth for mountain goats might be limited to studies with large sample sizes. Our study contributes to other work that identified differences in the dynamics of introduced and native mountain goat populations (Adams and Bailey 1982, Swenson 1985, Williams 1999).

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Historical Literature Pertaining to the Occurrence of Mountain Goats in Oregon

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Abstract: Wildlife managers of the 20th century generally accepted south central Washington as the southernmost range of indigenous mountain goats *(Oreamnos americanus)* in the Coastal and Cascade mountains of North America. We reviewed historical publications to provide 21st century managers a more complete review of native mountain goat distribution. Criteria used to dismiss non-credible material is discussed. A significant number of historical documents published during the 1800s place mountain goats south into Oregon and California. Based on our interpretation of the literature, we conclude that goats were native in historical times at least as far south as the central Cascades and the northeast mountains of Oregon.

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Key words: Cascade Mountains, distribution, literature review, mountain goat, *Oreamnos americanus*, Oregon.

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Proximate Costs of Reproduction in Female Mountain Goats

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Abstract: Lactation entails high energetic costs that increase total energetic requirements. To compensate, lactating females are expected to increase nutrient intake. Our aim was to determine whether specific foraging strategies were used by lactating females to increase their overall energy intake and compensate for the high costs of lactation. The project took place at Caw Ridge, in the foothills of the Rocky Mountains of west-central Alberta. Data were recorded on the foraging behaviour of individually marked female mountain goats (*Oreamnos americanus*) using focal animal and scan samplings. Vegetation samples were collected at foraging sites of lactating and non-lactating females to determine vegetation biomass and quality. Lactating females increased foraging time and intensity (i.e., biting rate), as well as rumination time and intensity (i.e., chewing rate) compared to non-lactating females. This suggests they ingested more vegetation and were more efficient at assimilating nutrients than non-lactating females. However, they did not seem to use better foraging sites, since vegetation quality and abundance at foraging sites were similar for all females. In June, lactating females spent more time near safe habitats (i.e., escape terrains) compared to non-lactating females, whereas no difference was found during the rest of the summer. This suggests that lactating females used safer foraging sites only when kids were most vulnerable to predation. Lactating females completed the molt of their winter coat on average 8 d later than non-lactating females, suggesting that they had fewer nutrients to allocate to growth of a new coat than females not bearing the cost of lactation. Therefore, lactating females seem to modify their behavior to compensate for the high energetic costs of lactation, but they cannot fully compensate for these costs.

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Key words: Alberta, energetic costs, foraging strategies, lactation, mountain goat, *Oreamnos americanus*.

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Rutting Behaviours of Male Mountain Goats in Relation to Age

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Abstract: Age generally correlates with body mass, size, and secondary sexual characters, and is a major determinant of mating success in most wild ungulates. However, in mountain goats (*Oreamnos americanus*) little information is available on how age may influence reproductive effort of males and access to females. We conducted behavioural observations to investigate the effects of age on male activity budgets using marked individuals from the population of Caw Ridge, Alberta. Data were collected during summer (May to September 1995 to 2005) and the rut (November 2004 to 2005), and compared according to male age. All age classes allocated most of their time to foraging and resting activities during summer. During the rut adult males (≥3 yr) increased time spent in sexual behaviours, particularly mate guarding, at the expense of foraging and resting. Unlike other ungulate species, yearling goats did not participate in the rut and had a similar time-budget as in summer. Two-year olds performed sexual behaviours but did not gain access to oestrus females. All matings occurred during the second half of November and involved males aged ≥4 yr. A highly linear dominance hierarchy among males may partly explain the higher mating success of prime-aged males (≥6 yr). Alternative mating tactics such as coursing (as previously described in bighorn sheep, *Ovis canadensis*), also were observed in mountain goats and differed according to age. Genetic analyses confirmed that age at first reproduction in male mountain goats from Caw Ridge is not reached before the age of 3 yr.

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Key words: Alberta, behaviour, mating success, mountain goat, *Oreamnos americanus*.

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Monitoring Mountain Goat Use of Mineral Licks in Response to Alternative Forest Harvesting Scenarios in Northern British Columbia

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Abstract: Mountain goats (*Oreamnos americanus*) show strong fidelity to mineral licks. Traditional use by successive generations of goats result in well-used trail systems through forested habitat between alpine summer ranges and valley bottom mineral licks. Adaptive management is used to develop recommendations for effective operational guidelines for logging activities adjacent to valley-bottom mineral licks used by mountain goats. The Ospika Goat Adaptive Management Trial will assess the effects of 2 logging treatments on the use of mineral licks by mountain goats in the Ospika River drainage in northcentral British Columbia. "Buffered" treatment, completed in winter 2002/2003, involved retention of 150 m of forest adjacent to a mineral lick and along both sides of the access trail while the remaining area was clearcut. "Clearcut" treatment was completed at the same site 3 yr later, and involved complete removal of the buffer strip adjacent to the lick and trail. Remote radio-telemetry data-loggers are used to determine timing, frequency, and duration of lick visits by radio-collared goats. Remote cameras are used to determine total numbers, group sizes, age/sex composition, and timing of visits of all goats using the licks. Monitoring occurs at control and treatment sites, as well as 1 yr before (2002) and 3 yr after (2003-2005) the "buffered" treatment. Monitoring will occur at control and treatment sites for 2 yr after the recently completed "clearcut" treatment (2006 and 2007).

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Key Words: British Columbia, forest harvest treatment, mineral lick, mountain goat, *Oreamnos americanus..*

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Does Survey Effort Influence Sightability of Mountain Goats (*Oreamnos americanus*) during Aerial Surveys?[1]

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Abstract: Practical techniques to estimate sightability of mountain goats (*Oreamnos americanus*) during aerial surveys have not been developed or are poorly tested. I evaluated sightability of 28 radio-collared goats in 2 study areas in southeastern British Columbia to assess whether sightability increased with increased helicopter survey effort, and to explore what factors might affect sightability. Three surveys at different survey effort were conducted in each study area, during which attempts were made to locate collared goats 64 times. I detected no relationship between survey effort ranging from 1.3 to 6.1 min/km^2 and sightability from 38 to 83%. Sightability averaged 63%. Only animal activity and larger group size influenced goat sightability. Sightability tended to decrease with increasing vegetation cover. Survey efforts >2.0 min/km^2 do not appear to result in higher sightability. For surveys of large areas not well known to surveyors, a 60–65% sightability correction may be realistic, with a target of approximately 1.5 min/km^2 effort.

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Key words: British Columbia, mountain goat, *Oreamnos americanus*, sightability, survey effort.

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Development of Results-based Tourism Guidelines in British Columbia: Implications for Mountain Goat Management

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Abstract: Helicopter-supported recreation is expanding throughout British Columbia, Canada. In response to concerns regarding the potential effects of such activity on mountain goats (*Oreamnos amercianus*) and other wildlife, the BC Ministry of Environment convened the Tourism Wildlife Project Team in February 2004. Comprised of representatives from the tourism sector and government, the team was directed to develop user friendly, results–based guidelines for tourism on public land in British Columbia. A risk-based approach was adopted because comprehensive scientific/ technical data are not available for many issues and are unlikely to become available in time to guide management strategies. The guidelines are organised according to activity category, ecosystem type, season, and outline results, desired behaviours, indicators, and limits. With respect to mountain goats, the guidelines recommend aircraft stay at distances sufficient to prevent changes to the behaviour of animals. They also recommend the use of topographic features and flight practices to ameliorate disturbance. This collaborative approach has a number of benefits, including better stakeholder buy-in compared to a regulatory approach, a focus on outcomes rather than inputs, increased support for adaptive management, and consideration of both scientific information and operational experience. However, this approach also accepts a higher management risk compared to more prescriptive approaches and its success depends on extensive monitoring.

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Key words: adaptive management, British Columbia, collaborative approach, guidelines, helicopter, mountain goat, outcomes, recreation, Tourism Wildlife Project Team.

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In 2004, the Northern Wild Sheep and Goat Council released a position statement expressing concerns related to the effects of helicopter activities on mountain goats and their habitats (Hurley 2004). In British Columbia, the provincial government's first attempt to develop guidelines to manage helicopter activity in relation to mountain goats met with resistance due to differences in opinion about implementation and success in achieving desired results. In response, the province developed result-based guidelines. Herein we describe the collaborative development of guidelines, and the strengths and limitations of this approach.

Background

In 2001, the British Columbia Ministry of Environment published the Interim Guidelines for Mitigating the Impacts of Commercial Backcountry Recreation on Wildlife in British Columbia (BC Ministry of Water, Land and Air Protection 2001). The guidelines provided a detailed review of current knowledge (including scientific and management literature, and professional opinion) regarding the effects of backcountry recreation activities on wildlife species. The document also outlined strategies to mitigate potential negative effects of tourism activities on wildlife and their ecosystems (Wilson and Hamilton 2005).

Stakeholder and public consultation on the Interim Guidelines began shortly after their release and resulted in diverse feedback. Though there was universal support for the wildlife conservation goal of the guidelines, there was substantial disagreement on the approach that should be used for achieving the goal. Environmental and recreation groups suggested the guidelines should be made into enforceable regulations, whereas the tourism sector promoted a non-regulatory "best environmental practices" approach that pertained to more than just wildlife and applied to all backcountry users, not just commercial backcountry recreation tenure holders (Brown 2001).

To address the opposing viewpoints, the BC Ministry of Environment convened the Tourism Wildlife Project Team ("the team") in February 2004 - a collaborative tourism sector and government project team including representatives from the agency responsible for land tenure issuance in British Columbia (Ministry of Tourism, Sport and the Arts), the association representing helicopter/ snowcat skiing operators (Helicat Canada), the Wilderness Tourism Association, and the Council of Tourism Associations. The team was charged with the development of user-friendly guidelines for use by government decision-makers and tenured tourism operators. The mission, as set out in the Terms of Reference, was "to facilitate the collaborative development of a management framework for the stewardship of wildlife and ecosystems by the tourism sector operating on Crown Land in British Columbia" with a focus on tourism sector activities occurring on public land and the management of these activities as they relate to wildlife and ecosystem values.

Guideline framework

A strategy document placed the guidelines in the context of other policy tools available to manage tourism activities and their effect on wildlife and ecosystems. Management intent of the strategy was "to ensure that recreation activities in the backcountry do not compromise the current distribution of wildlife, the sustainability of their populations, or the integrity of their habitats" (Wilson and Hamilton 2005).

The strategy recognized three broad policy tools that can be applied to different management situations, depending on the ecological risk associated with a particular backcountry recreation activity:

Prohibition – activity not allowed in specific areas or during specific periods of the year. Examples include specific protected areas, parks, or special habitats where certain uses are prohibited by statute or other policies.

Limits on inputs – activity allowed but quotas applied to the number of users or their activities. Examples include setting limits on the number of users or the timing of use in a particular area to reduce ecological risk.

Limits on outcomes – activity allowed within the context of guidelines. The guidelines developed by the team apply this broad category of policy tools by setting desired outcomes for specific values.

Application of the guidelines to a particular activity depends on the answers to the following nested questions: 1) should the activity be allowed in the context of associated ecological risks? If so, then 2) how should impacts be limited? The guidelines are organised according to activity category, ecosystem type, and season and are applied in the development of management plans by tourism operators. The guidelines specify Desired Results with respect to wildlife and their habitats and Desired Behaviours that outline the practices of users most likely to achieve desired conditions. Indicators are established that measure whether a desired condition is being achieved and limits are presented that set the upper and lower bounds around indicators.

The guidelines are web-based, enabling users to search by activity or ecosystem type (http://www.env.gov.bc.ca/ /wld/BMP/bmpintro.html; BC Ministry of Environment 2006)

Relevance to mountain goat management

In all cases, one of the Desired Behaviours is to stay at distances sufficient to prevent changes in the behaviour of animals. Results specified in the guidelines focus on minimizing physiological stress and avoiding displacement from preferred habitats. Indicators and limits are specified. Activity categories of primary concern to mountain goat management are aerial-supported recreation (e.g., helicopter and fixed-wing) (Table 1) and ground-based motorised recreation in the winter (Table 2) and snow-free periods (Table 3). The guidelines also specify special management of critical habitats such as mountain goat winter ranges (Table 4).

Aerial-related recreation. The guidelines specify a default 1.5 km horizontal (Côté 1996, Goldstein et al. 2005) and 500 m vertical separation from goats and goat habitat, although a single default distance may not meet the desired outcomes in all cases because multiple variables influence the behaviour of animals (Wilson and Shackleton 2001). Further, the guidelines specify no intentional “flight-seeing” or purposeful harassment of wildlife is to occur (Table 1).

Site-specific mitigation strategies consider such variables as local topography, adjusting flight paths, and drop off/ pick up points. Operators may reduce the potential effects of their activities on mountain goats by distributing aerial activities across the operating area so that identified habitat areas receive less use (particularly for landings and take-offs) relative to areas where the probability of interaction with mountain goats is lower. The use of regular, predictable flight paths is encouraged and using flight paths on the opposite side of the valley from known habitats is promoted as a means of reducing disturbance potential. The guidelines specify that operators should fly at distances from goat habitats sufficient to prevent changes to behaviour of animals (i.e. if they might be in the area but not visible). Normally, this is a minimum 1500 m horizontal separation, unless the flight path is separated from the habitat by geographic barriers. Where aircraft are within this default separation distance, they are to maintain maximum vertical separation from the areas (normally more than 500 m).

Additional mitigation strategies include flying aircraft in a way that reduces noise and ensures that animals are not surprised by sudden encounters (limiting rapid ascents/ descents which increase helicopter rotor noise). Operators and management agencies are encouraged to have monitoring and feedback systems in place to show due diligence with respect to meeting the intent of this category. Operators are advised to employ established practices of BC's helicopter and snowcat skiing association (HeliCat Canada) such as using flight routes that do not directly overlap areas where animals are encountered regularly, and adjusting flight paths when animals are encountered inadvertently (BCHSSOA 2003).

Ground-based motorised recreation (winter and snow-free periods). Motorised recreation (such as the use of off road vehicles) is the primary concern for direct disturbance of mountain goats in winter (Table 2) and snow-free periods (Table 3). As for aerial-supported recreation, one of the desired behaviours for tourism operators is to stay at distances sufficient to prevent changes in the behaviour of animals. For motorised recreation, the guidelines specify a >500 m line-of-sight default setback from large mammals for motorized ground-based activities in open areas. Intentional wildlife viewing using motorised vehicles is prohibited.

Applying the guidelines to mountain goat habitats. Defining occupied mountain goat habitat is challenging because not all habitats are occupied at all times. In addition, goats are cryptic and often not easily seen during aerial surveys, and repeated surveys can result in disturbance. The guidelines distinguish between habitats consistently occupied and those identified by suitability modelling approaches. They specify 3 habitat categories. Occupied habitats are areas where animals are seen in the current season and/or animals consistently occupy year after year. The range is mapped as "occupied" or "high relative probability for encountering animals during winter". These areas are to be avoided by helicopter operators. High probability/ potential habitats are areas where previous goat use is documented; operators are directed to minimize use (i.e. develop site specific mitigation strategies) within these areas and avoid animals when inadvertently encountered. Mapped but unverified (low suitability) habitats have no use restrictions; however, flights in these areas are to include cursory presence/ absence inventories. If animals are encountered, the classification of such areas immediately changes to Occupied.

In all cases, regular information exchange is encouraged so that the most current information guides development of site specific mitigation strategies.

Alternative strategies. Tourism operators may either adhere to all desired behaviours listed in the guidelines for the particular activity or activities that they are authorized to undertake or are applying for; or, they may propose alternative strategies to achieve the specified results. Alternative strategies must be included in the management plan submitted by the proponent where deviation is proposed from either the desired behaviours or the default distances specified in the guidelines. There must be a corresponding alternative strategy for all listed results if the operator decides not to adopt the desired behaviours or default distances specified in the guidelines for a particular activity or special management issue. Alternative strategies must include a suite of behaviours designed to achieve the listed result, monitoring and an adaptive plan to ensure results are being met, and sign-off by a qualified professional (i.e. a competent member of a certifying body with standards of practice and member accountability, for example, British Columbia College of Applied Biology).

Since the guidelines are intended to be result-based, they are subject to ongoing monitoring by provincial government agencies in cooperation with tourism industry associations to assess compliance of operators and effectiveness in achieving specified results. These guidelines also are intended to be periodically reviewed as new information comes available. Monitoring results, new science, and operational experience will be considered during future revisions, as per the principles of adaptive management (Salafsky et al. 2001).

Limitations of approach

The management intent is considerably broader than the original Interim Guidelines. However, the team identified some key challenges. The strategy originally was intended to apply to all backcountry recreation users. Commercial tourism operators tenured under the British Columbia *Land Act* embraced the approach, but opportunities to apply the guidelines to public recreational users or non-tenured recreation operators are limited. There is a need to test and refine indicators through monitoring programs. Such monitoring can be both time-consuming and expensive. It remains unclear if the proposed indicators are sensitive enough to provide meaningful results in the relatively short time needed to manage tourism operations.

Management recommendations

Based on the experience of BC's Tourism Wildlife Project Team in developing a results-based approach to tourism and wildlife, we offer the following recommendations relevant to mountain goats:

- Knowledge gaps need to be addressed through targeted research. Effectiveness of the 1500 m default distances and alternate strategies developed and implemented by operators require further assessment;
- Monitoring approaches to test the effectiveness of proposed indicators and limits need further work;
- Collaborative monitoring of tenure issuance and compliance with the guidelines should occur; and,
- Training tenured operators should be combined with public outreach to clubs and associations wherever possible to communicate intent of the guidelines and secure their broad application.

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Table 1. Guidelines related to direct disturbance of wildlife developed for commercial recreation tenure holders using aircraft in British Columbia.

Results	Desired behaviours	Indicators	Limits
• Minimize physiological and behavioural changes in animals associated with aircraft activity. • Minimize changes in habitat use resulting from aircraft activity.	• Record wildlife encounters, actions taken, and responses of animals. • Obey all area closures. • Do not harass wildlife. • Focus activities in areas and times of the year when wildlife are least likely to be disturbed (seasonal closures might be necessary). • Take immediate action to increase separation distances when animals react to aircraft. • Use consistent flight paths, preferably in the center of valleys, or the valley side opposite key wildlife habitat. If key wildlife habitats are in the center, fly on one side of the valley rather then the center. • Stay at distances sufficient to prevent changes to the behaviour of animals (more than 500 m line-of-sight is the default).	• Proportion of encounters resulting in an alarm response. • Population abundance and distribution trends of wildlife species.	• No increase in rate of alarm responses over time caused by aircraft. • No harassment caused by aircraft. • No abandonment of habitats caused by aircraft.

Table 2. Guidelines related to direct disturbance of wildlife developed for commercial recreation tenure holders using ground-based motorized vehicles during winter in British Columbia.

Results	Desired Behaviours	Indicators	Limits
• Minimize physiological and behavioural disruption. • Minimize changes in habitat use.	• Record wildlife encounters, actions taken, and responses of animals. • Remain on established trails or in areas of high visibility where no wildlife are present. • Obey all signs and area closures. • Do not harass wildlife. • Do not feed wildlife. • Do not handle wildlife. • Do not allow dogs to be at large and harass wildlife. • Pack out all garbage. • Turn off engine, remain on machine, and yield to wildlife on trails and roads. • Focus activities in areas where wildlife are least likely to be disturbed (seasonal closures might be necessary). • Stay at distances sufficient to prevent changes to the behaviour of animals (at least 500 m in open areas is the default for large mammals).	• Proportion of encounters resulting in an alarm response. • Population abundance and distribution trends of wildlife species.	• No increase in rate of alarm responses over time caused by motorized activities. • No harassment caused by motorized activities. • No abandonment of habitats caused by motorized activities.

Table 3. Guidelines related to direct disturbance of wildlife developed for commercial recreation tenure holders using ground-based motorized vehicles during the snow-free season in British Columbia.

Results	Desired Behaviours	Indicators	Limits
• Minimize physiological and behavioural disruption. • Minimize changes in habitat use.	• Record wildlife encounters, actions taken and responses of animals. • Remain on established trails. • Obey all signs and area closures. • Do not harass wildlife. • Do not feed wildlife. • Do not handle wildlife. • Do not allow dogs to be at large and harass wildlife. • Pack out all garbage. • Yield to wildlife on trails and roads. • Turn off engine, remain on machine and yield to wildlife on trails and roads. • Focus activities in areas and times of year when wildlife are least likely to be disturbed (seasonal closures might be necessary). • Stay at distances sufficient to prevent changes to the behaviour of animals (at least 500 m in open areas is the default for large mammals).	• Proportion of encounters resulting in an alarm response (movement by animals, usually to safer locations). • Population abundance and distribution trends of wildlife species.	• No increase in rate of alarm responses over time caused by motorized vehicles. • No harassment caused by motorized vehicles. • No abandonment of habitats caused by motorized vehicles.

Table 4. Guidelines developed for commercial recreation tenure holders operating in and near mountain goat winter range habitat in British Columbia.

Results	Desired Behaviours	Indicators	Limits
• Minimize physiological or behavioural disruption of Mountain Goats. • Continued occupation of Mountain Goat winter ranges.	• Do not land in identified Mountain Goat winter ranges . • No intentional "flight-seeing" of Mountain Goats/sheep. • Stay at distances sufficient to prevent changes to the behaviour of animals (more than 1500 m line-of-sight is the default). • Avoid occupied habitats where Mountain Goats/sheep have been seen in the current season and/or animals consistently occupy the area and the area is mapped as occupied. • Minimize use in areas of high probability or potential, where there is documented past use by Mountain Goats or sheep. • No behavioural restrictions apply in areas not considered Mountain Goat/sheep habitat, or where potential habitat is mapped with no verification of Mountain Goat/sheep use.	• Continued occupancy of Mountain Goat winter ranges.	• No harassment caused by aircraft. • No abandonment of Mountain Goat winter ranges caused by aircraft.

Density-dependence in Vital Rates and Population Growth in Mountain Goats: Population Regulation or Limitation?

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Abstract: Density-dependence plays a central role in wildlife management. Most harvesting scenarios assume that if density is lowered by harvest, recruitment will be stimulated by reduced intraspecific competition for resources. We used 15 yr of longitudinal data on the growth, survival, and reproduction of marked mountain goats (*Oreamnos americanus*) at Caw Ridge, Alberta to assess the effects of population density on vital rates and population growth rate. We found very little evidence of density-dependence in population dynamics. Despite an 88% increase in total population and a 69% increase in the number of adult females, there was no decline in kid production and survival to 1 yr, no increase in age of primiparity, and only minor negative effects on the mass of juveniles. However, population growth and kid survival to one year correlated with the average mass of yearling males in mid-July, suggesting that yearly changes in resource availability affected the population dynamics of mountain goats. Average mass of yearling females was not correlated with population growth rate or kid survival. In years when fecal crude protein in early June was high, kids were heavier by mid-summer. We suggest that the mountain goat population on Caw Ridge was mostly food-limited and that its growth essentially was independent of population density. Predation played a limited role on population dynamics. Predation on small, isolated populations of mountain ungulates could vary with the behaviour of individual predators in a density-independent manner, and therefore may be highly unpredictable. Although it is likely that over the very long term some goat populations may reach carrying capacity and display density-dependence, our long-term research on Caw Ridge provides little support for a consumptive management strategy based on the assumption of density-dependence or compensatory mortality in native populations.

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***Key words*:** Alberta, mortality, mountain goat, *Oreamnos americanus*, population density, population dynamics.

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Population Dynamics and Harvest Potential of Mountain Goat Herds in Alberta

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Abstract: Understanding population dynamics is a central issue for managing large mammals. Modelling allows population ecologists to increase knowledge about complex systems and better predict population responses to diverse perturbations. Mountain goats (*Oreamnos americanus*) appear sensitive to harvest, but the relative influences of survival and reproductive rates on their population dynamics are not well understood. Using longitudinal data on age- and sex-specific survival and reproduction from a marked mountain goat population in Alberta, we built a stage-class matrix model and used it to predict short-term numerical changes for 11 other goat populations in Alberta for which only data from aerial surveys were available. Overall, the model provided an acceptable fit to changes in population size for 8 of 12 populations. Temporal trends in population size were underestimated in 2 populations and overestimated in another 2, suggesting that these populations had different vital rates than those of the intensively studied population. Sensitivity analyses revealed that survival of mature females (5 yr and older) had the greatest elasticity for population growth. Modelled management scenarios indicated that non-selective yearly harvest rates above 1% of goats aged 2 yr and older were not sustainable over the short-term for most populations. The simulations also revealed that small (*n* = 25) and medium-size (*n* = 50) populations, which correspond to the majority of goat populations in Alberta, had high extinction risk (18 to 82% over 40 yr) even in the absence of harvest. Our results confirm that mountain goat populations are very sensitive to harvest, indicate that female harvest should be prevented, and suggest that even though there is a high demand for goat hunting in Alberta, most populations in this province, and probably small populations elsewhere, cannot withstand any exploitation.

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Key words: Alberta, management, mountain goat, *Oreamnos americanus*, population dynamics.

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Seasonal and Sex-specific Variation in Terrain Use and Movement Patterns of Mountain Goats in Southeastern Alaska

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Abstract: Fundamental differences in fitness requirements between male and female individuals result in sex-linked ecological variation within many species of large mammals. Determining the extent to which sex-specific requirements alter behavioral strategies and subsequent spatial use patterns has important implications for conservation and management of species such as mountain goats (*Oreamnos americanus*). In this study, location data were collected from 22 GPS radio-collared mountain goats (11 males, 11 females) during September 2005 to February 2006. These data were integrated with terrain data layers in a GIS framework to address questions about sex-specific variation in movement patterns and terrain use across a 600 km^2 study area located in southeast Alaska. Male mountain goats exhibited greater rates of movement than females during the rut but not during fall or winter. As a result, male home ranges were significantly larger than females during this period. Both males and females moved to lower elevations with the onset of winter but did not differ with respect to altitudinal distribution. Following the rut, the period when sexual aggregation occurs, females used areas in which slope was steeper, distance to escape terrain was less, and terrain ruggedness was greater than areas used by males. Overall, these preliminary findings detail differences in terrain and spatial use patterns between male and female mountain goats and suggest that vulnerability to anthropogenic disturbance factors may be sex-specific.

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Key words: Alaska, mountain goat, movement patterns, radio-collar, terrain use

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Elucidating patterns of resource use and movement play an important role in our understanding of the ecology and conservation of many species. While many factors may influence variation in these fundamental ecological characteristics, the sex of individuals in a population represents one variable of principal interest (Clutton-Brock et al. 1982, Main et al. 1996). This is particularly evident among polygynous ruminants that display pronounced sex-specific contrasts in morphology, social behavior, and life history strategies (Clutton-Brock et al. 1982). These patterns arise because natural selection acts on males and females in disparate ways as a result of fundamental differences in their reproductive characteristics (Darwin 1871).

Mountain goats (*Oreamnos americanus*) provide an interesting example for evaluating sex-mediated differences in patterns of resource use and movement as a result of sexual body size dimorphism, social organization, and narrow constraints on habitat use requirements (Côté and Festa-Bianchet 2003). Adult male mountain goats are 40 to 60% larger than females (Houston et al. 1989). As a result, males are expected to experience greater nutritional requirements but may also be less prone to predation. In addition, energetic resources required for successful reproduction are partitioned differently between males and females. In particular, polygynous males do not participate in rearing of young and maximize reproductive success by utilizing behavioral strategies that optimize their ability to mate with many high quality females during a limited 4 to 6 wk rutting season (Brandborg 1955, Geist 1964). Females, on the other hand, maximize their reproductive success by selectively breeding with a single high quality male (Brandborg 1955) and, perhaps more importantly, optimizing foraging and habitat use decisions that enable acquisition of adequate nutritional resources required for survival and successful rearing of young (Cote and Festa-Bianchet 2001); a period that may span at least 10 months (Chadwick 1977).

Largely unique among North American ungulates, mountain goats exhibit distinct morphological adaptations that enable them to live in steep, rugged mountain environments characterized by extreme climate conditions. It is widely recognized that the preferential for use of such habitat types is primarily linked to avoidance of predation (Schaller 1977, Smith 1983, Fox and Streveler 1986). At smaller spatial scales, these environments are composed of a mosaic of forage-rich alpine meadows and barren cliffs that provide escape terrain. Because of this juxtaposition of habitat types, mountain goats likely face trade-offs between utilizing forage-rich but relatively dangerous alpine meadows and forage-poor but safe cliff habitats. Such sex-specific trade-offs in habitat use have been documented in other mountain ungulate species (Bleich et al. 1997) and provide a framework for interpreting resource use patterns in mountain goats.

In this paper two principal research questions were addressed: (1) do adult male and female mountain goat home range and movement patterns differ during and outside of the rut?, and (2) do adult male and female mountain goats differ in their use of "safe" terrain features during periods outside of the breeding season?

Study area

We studied mountain goats in a 600 km^2 study area in a mainland coastal mountain range east of Lynn Canal, a post-glacial fjord located near Haines in southeastern Alaska (Figure 1). The study area is oriented along a north-south axis and bordered in the south by Berners Bay (58.76N, 135.00W) and by Dayebas Creek (59.29N, 135. 35W) in the north. Elevations range from 1920 m to sea level. This area is an active glacial terrain underlain by late cretaceous-paleocene

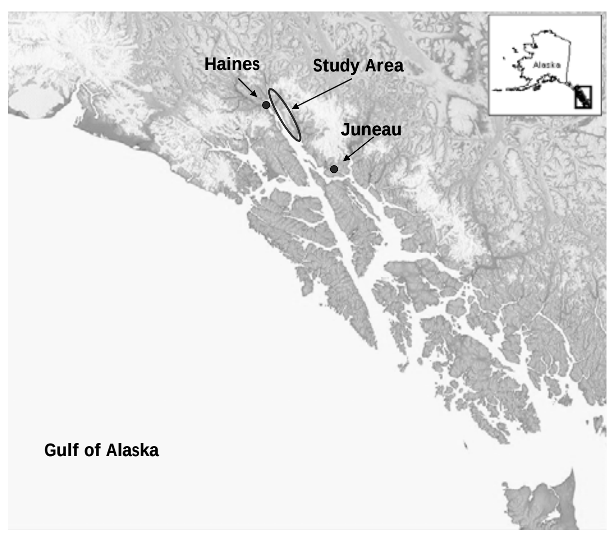

Figure 1. Mountain goat study area along the east side of Lynn Canal, Alaska.

granodiorite and tonalite geologic formations (Gehrels 2000). Specifically, it is a geologically young, dynamic, and unstable landscape that harbors a matrix of perennial snowfields and small glaciers at high elevations (i.e. above 1200 m) and rugged, broken terrain that descends to a rocky, tidewater coastline. The northern part of the study area is bisected by the Katzehin river, a moderate volume (~1500 c/fs; USGS, unpublished data) glacial river system that is fed by a tributary of the Juneau Icefield.

The maritime climate in this area is characterized by cool, wet summers and relatively, warm snowy winters. Annual precipitation at sea-level averages 143 cm and winter temperatures rarely are less than -15C and average -1C (Haines, AK; National Weather Service, Juneau, AK, unpublished data). Elevations at 800 m typically receive ca. 650 cm of snowfall, annually (Eaglecrest Ski Area, Juneau, AK, unpublished data). Predominant vegetative communities occurring at low-moderate elevations (<500m) include Sitka spruce (*Picea sitchensis*)-western hemlock (*Tsuga heterophylla*) coniferous forest, mixed-conifer muskeg, and deciduous riparian forests. Mountain hemlock (*Tsuga mertensiana*) dominated 'krummholtz" forest comprises a subalpine, timberline band occupying elevations between 500-750 m. Alpine plant communities are composed of a mosaic of relatively dry ericaceous heathlands, moist meadows dominated by grasses and forbs, and wet fens. Avalanche chutes are common in the study area, bisect all plant community types, and often terminate at sea-level.

Methods

During September and October 2005, we captured 22 adult mountain goats (11 male, 11 female) using standard helicopter darting techniques (Taylor 2000). Mountain goats were immobilized by injecting 3.0/2.7mg of carfentanil citrate (males/females, respectively) via projectile syringe fired from a Palmer dart gun (Cap-Chur, Douglasville, GA). During handling, all animals were carefully examined and monitored following standard veterinary procedures (Taylor 2000) and routine biological samples and morphological measures collected. Following handling procedures, the effects of the immobilizing agent was reversed with 100mg of naltrexone hydrochloride per 1mg of carfentanil citrate (Taylor 2000). All capture procedures were approved by the State of Alaska Animal Care and Use Committee.

Telonics TGW-3590 GPS radio-collars (Telonics Inc., Mesa, AZ) were deployed on all animals captured. Radio-collars were programmed to collect GPS location data at 6-hr intervals. During each location attempt ancillary data about collar activity (i.e. percent of 1-second switch transitions calculated over a 15-min period following each GPS fix attempt) was simultaneously collected. Complete data-sets for each individual were remotely downloaded (via fixed-wing aircraft) at 8-wk intervals. Location data were post-processed and filtered for "impossible" points and 2D locations with PDOP (i.e. position dilution of precision) values greater than 10, following D'Eon et al. (2002) and D'Eon and Delparte (2005).

Seasons were defined by using remotely collected activity sensor data as a proxy for defining behaviorally mediated changes in seasonal activity patterns. Specifically, GPS collars were deployed with mercury tip switches programmed to record the proportion of 1-sec switch transitions that occurred over a 15-min period coordinated with GPS location attempts (ie. 6-hr intervals). Previous research on comparable species documented reliable linkages between actual animal behavior and remotely collected activity switch data (Coulombe et al. 2006). As a result, I assumed that the proportion of switch transitions correlated positively with animal activity. Thus, distinct changes in activity patterns were used to define biologically relevant seasons for mountain goats.

Location data were integrated into a GIS (ArcView 3.2, ArcGIS 9, ESRI, Redlands, CA) in order to derive spatial attribute information for each data point. Digital elevation models (30-m resolution; NASA 2004) were used to estimate elevation (m), slope (degrees), distance (m) to slopes greater than 40 degrees (hereafter "distance to cliffs") and standard deviation of elevation within a 60 m radius of point locations (hereafter "topographic roughness"). Distance moved between successive locations was calculated at different time steps (1-d and 5-d intervals). Fixed-kernel home ranges (95% isopleths) were calculated using the least-squares cross validation (LCSV) technique to parameterize the smoothing function (Seaman and Powell 1999, Seaman et al. 1999). Both movement distance and home range area were calculated using surface area rather than planimetric area functions (following Jenness 2004). This approach enabled more precise estimates of space use parameters; planimetric area calculations tended to underestimate actual space use by 20.3%, on average (K. White, unpublished).

To compare seasonal and inter-sexual differences in male and female home range sizes, I used analysis of variance (ANOVA) and Tukey HSD pair-wise comparisons (Zar 1999). To evaluate seasonal and sex-specific differences in movement distances (1-d and 5-d intervals), elevation, slope, distance to cliffs and topographic roughness, daily mean values, and 95% confidence intervals were estimated for each sex category. Confidence intervals for population means were estimated using the variance among the individual animal mean values, which were based on all observations for each goat within the relevant season (Steel and Torrie 1980). Confidence intervals that did not overlap were considered to be evidence of sex differences. This analysis emphasized estimation of variable means (i.e. elevation, distance, etc.), rather than explicitly testing hypotheses; this approach was used because it provided a more descriptive assessment of variability in male-female differences at short time intervals.

Results

During September 27 to October 15, 2005, 22 adult mountain goats (11 male, 11 female) were captured and deployed with GPS radio-collars. Between September 27, 2005 and February 10, 2006 a total of 8576 GPS locations (mean ± SE = 389 ± 4 locations/animal) were acquired and used in subsequent analyses.

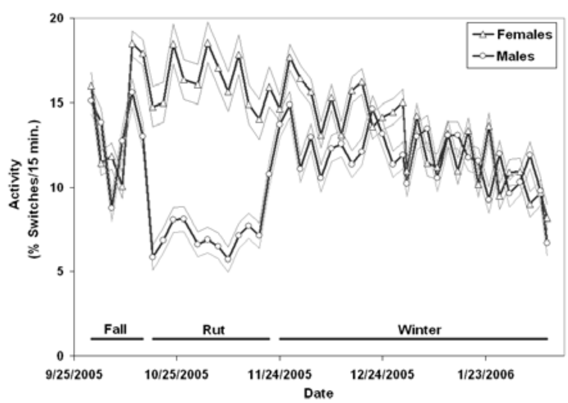

Figure 2. Activity patterns for male and female mountain goats between September 27, 2005 and February10, 2006. Activity data derived from tip-switch sensors located on Telonics TGW-350 GPS radio-collars. Daily mean ± 95% confidence intervals.

As defined by the proportion of switch transitions, male and female mountain goat activity patterns were similar except between October 18 and November 23, 2005, when male activity patterns were significantly less than females (Figure 2). Based on Geist (1964), I assumed this period of reduced male activity coincided with the rut. The period between September 27 and October 18 was defined as fall while the period between November 23, 2005 and February 10, 2006 was defined as winter (Figure 2).

Movement rates for males and females were similar during fall and winter; however, rates significantly deviated during the rut. Specifically, movement rates were significantly greater for males than females, particularly when analyzed over 5-d time intervals (Figure 3, 4). During the shorter 1-d time step, movement rate overlap between males and females was evident for brief periods but overall was greater for males despite greater variability in estimates at this time scale (Figure 5). Significant differences were detected in seasonal home range estimates for males and females ($r^2 = 0.32$, $F_{5,52} = 12.71$, $P < 0.001$; Figure 6, 7). Specifically, males used larger home ranges than females during the rut; however, home range estimates did not differ by sex during other seasons. Altitudinal distribution did not differ between males and females (Figure 8). An overall decline in mean elevation of all goats occurred with the onset on winter conditions at high elevations, though variability was evident in this relationship and coincided with the occurrence of an abnormally warm, late-season storm system November 17 to 25, 2005.

Overall, I estimated mean differences in slope, distance to cliffs, and terrain ruggedness were significantly different between males and females during the post-rut, winter period (Figure 9 to 11). Specifically, my findings indicate that females used steeper slopes that were more rugged and closer to cliffs than males. No differences were detected in terrain use comparisons between males and females during the breeding aggregation period, or rut.

Discussion

Adult male and female mountain goats face differential selection pressure as a consequence of variation in morphology and associated life history strategies. By comparing behavioral differences between males and females during the breeding season, it is possible to characterize mechanisms each sex employs to maximize chances for increasing individual fitness.

Similar to previous research in southeast Alaska (Schoen and Kirchhoff 1982, Smith and Raedeke 1982), male and female mountain goats in this study exhibited substantial differences in movement rates and home range sizes. Males moved widely across the landscape during the breeding season, presumably in search of receptive females, while females used relatively small areas and moved less. These differences in space use and movement patterns suggest males exhibit behavioral strategies during the rut that enable increased chances to successfully breed with as many females as possible. Females, on the other hand, exhibit space use strategies that encompass relatively small areas that, possibly, maximize chances of discovery by high quality males during the breeding season.

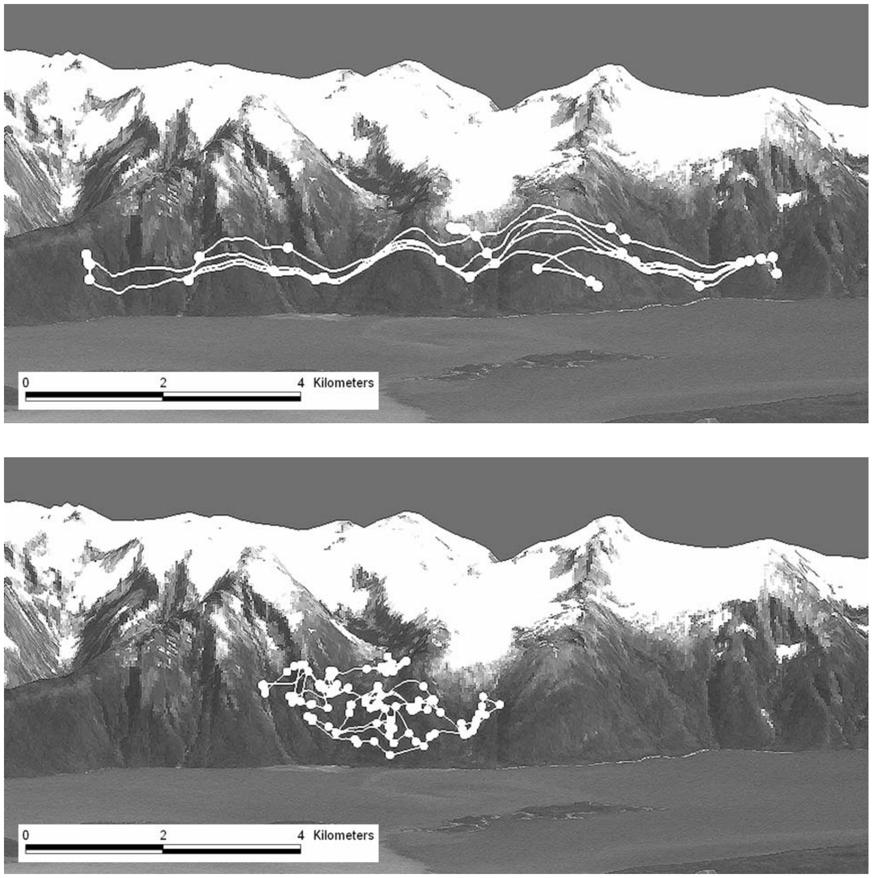

Figure 3. Representative 1-day interval movement patterns for radio-collared male (Goat #16; upper) and female (Goat #10; lower) mountain goats during the rut (October 18 to November 23, 2005).

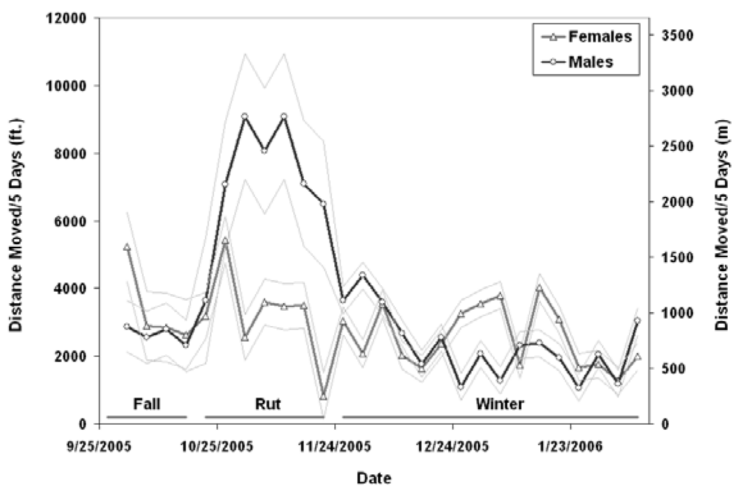

Figure 4. Distance moved by male and female mountain goats between September 27, 2005 and February 10, 2006: 5-d mean ± 95% confidence intervals.

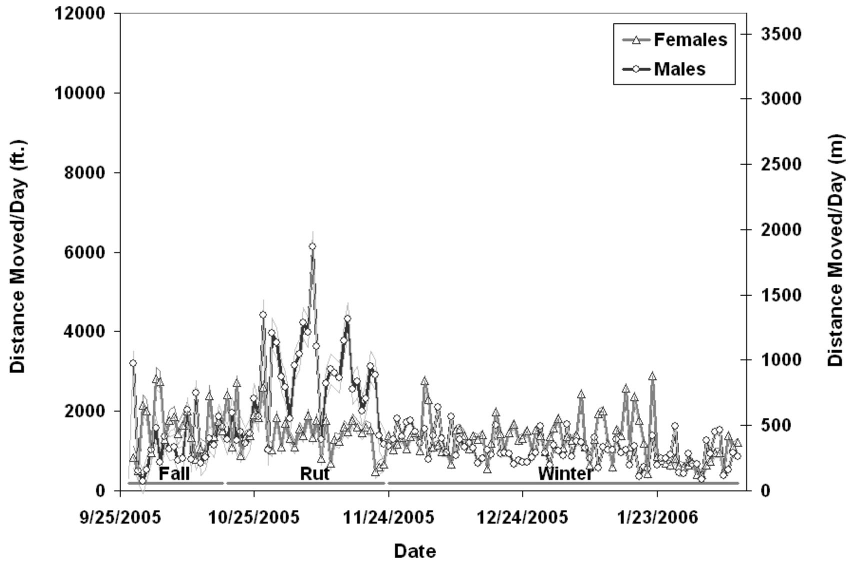

Figure 5. Distance moved by male and female mountain goats between September 27, 2005 and February 10, 2006: daily mean ± 95% confidence intervals.

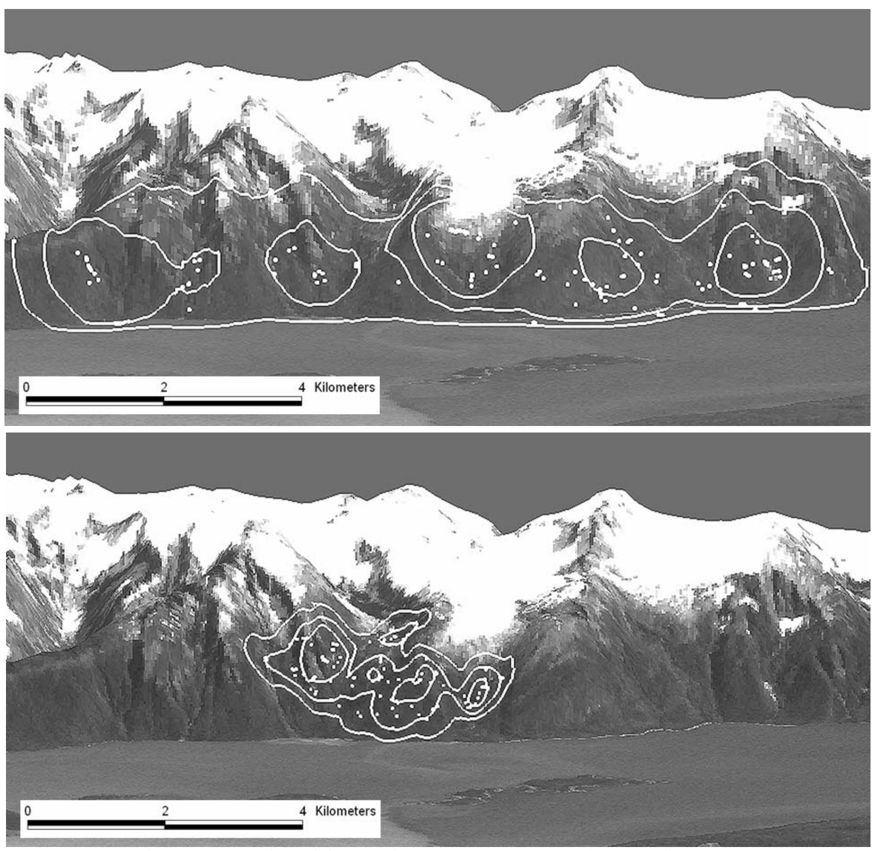

Figure 6. Home range size (95% fixed kernel) for representative male (Goat #16; upper) and female (Goat #10; lower) mountain goats during the rut (October 18 to November 23, 2005).

Since body size of males is substantially larger than females, females may be potentially more vulnerable to attacks by large mammalian predators (Curio 1976). Additionally, females also are more likely to be associated with related young or sub-adults, than males; a factor that further predisposes them to increased predation-risk. Findings from this study, consistent with previous mountain goat research in southeast Alaska (Schoen and Kirchhoff 1982), suggest females use safe terrain features to a greater extent than males. This pattern was specifically evident during the post-rut period when females used steeper more rugged terrain in areas closer to cliffs than did males. While largely consistent with expectations associated with predation-mediated habitat-use trade-offs, the affinity for use of steep, rugged terrain by females also may be due to lower snow depths in these habitat types during winter (Fox 1983).

In coastal mountain regions mountain goats typically migrate from high elevation summer ranges to lower elevation, forested winter ranges (Hebert and Turnbull 1977, Fox et al. 1989). However, whether males and females maintain similar altitudinal distributions during winter in southeast Alaska is less clear (Schoen and Kirchhoff 1982, Smith 1986). In this study I documented sex-independent altitudinal migrations by mountain goats that coincided with the onset of the first winter storms. Overall, 80% of all winter locations were at elevations less than 600 m above sea-level. These findings represent an interesting contrast to those of Hundertmark et al. (1983) which documented mountain goats inhabiting an upper tributary of the Chilkat river valley, approximately 55 km north, wintered primarily in windswept, high elevation habitats. Consequently, it appears that over-wintering strategies of mountain goats can vary over relatively small spatial scales and are not likely related to different sex ratios in each population.

The extent to which the sexes segregate or employ different strategies for utilizing resources in their environment and avoiding mortality have important implications for conservation and management of species. For instance, differences in sex-specific movement patterns during the rut likely result in increased vulnerability of males to hunting pressure as a consequence of increased movement and visibility. Disparities in visibility of males relative to females also may alter their observability during routine population monitoring surveys. Extensive landscape-level movements of males during the rut appear to be an important element of rutting behavior. If habitat connectivity is altered by industrial activity and inhibits movement of male goats, reproductive success and population productivity may be diminished due to lower copulation rates and/or increased incidence of second estrous mating events. Thus, acquisition of information about sex-specific variability in habitat use and movement patterns may help resolve key challenges associated with management and conservation of mountain goats.

Differences in sex-specific patterns of terrain use and movement were not always evident. Such findings are nonetheless significant for conservation of mountain goats. In particular, the observation that both sexes utilized low-elevation areas extensively during the critical winter period is important in devising conservation strategies that limit the effects of human disturbance on mountain goats. In southeast Alaska, industrial activity (i.e. mining, road construction,

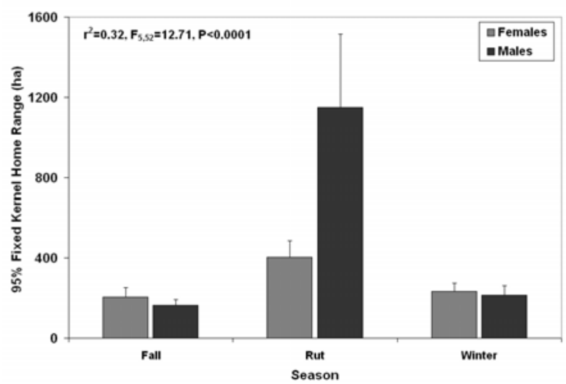

Figure 7. Seasonal home range sizes (95% fixed kernel) for male and female mountain goats. Mean ± SE.

timber harvest) is primarily confined to low elevation habitats, and identifying the extent to which such activity is sympatric with mountain goat winter range can help guide policy decisions that strive to ensure adequate protection of mountain goat populations in this region.

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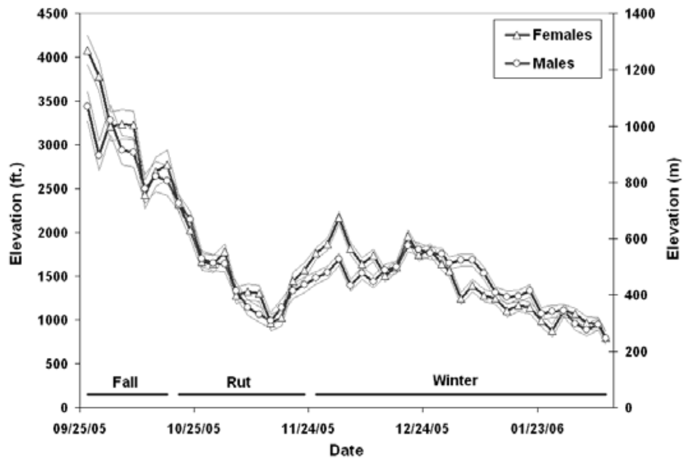

Figure 8. Mean daily elevation for male and female mountain goats between September 27, 2005 and February 10, 2006. Mean ± 95% confidence intervals.

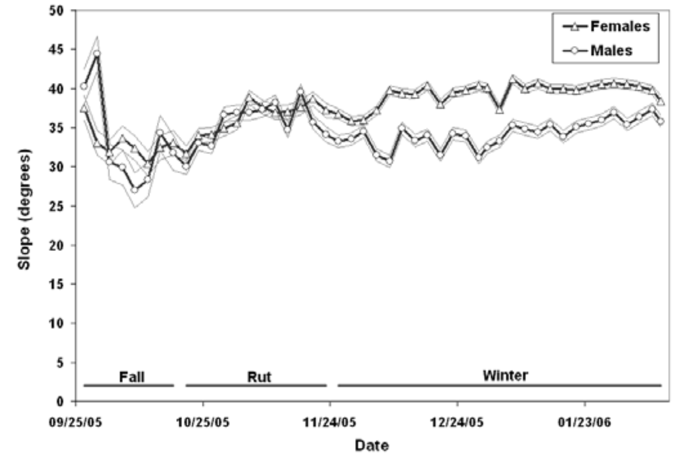

Figure 9. Mean daily slope used by male and female mountain goats between September 27, 2005 and February 10 2006. Mean ± 95% confidence intervals.

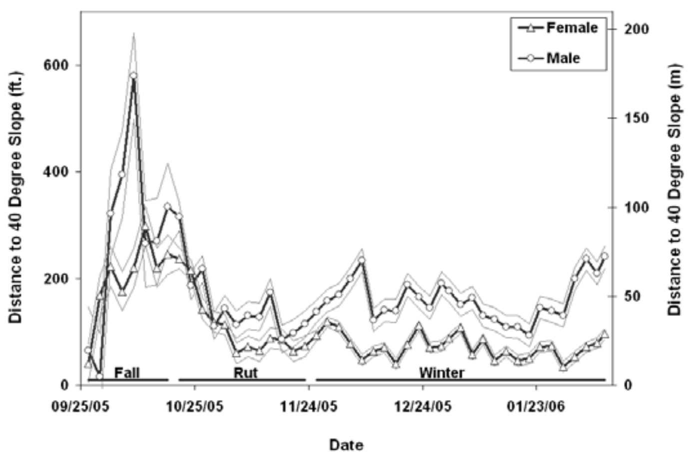

Figure 10. Mean daily distance to cliffs for male and female mountain goats between September 27, 2005 and February 10, 2006. Mean ± 95% confidence intervals.

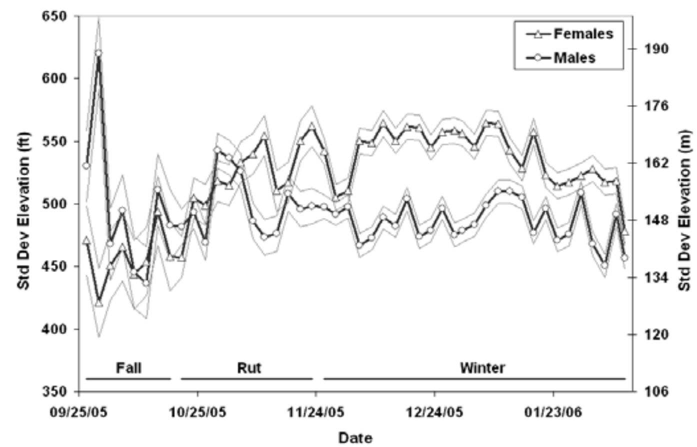

Figure 11. Mean daily terrain ruggedness used by male and female mountain goats between September 27, 2005 and February 10, 2006. Mean ± 95% confidence intervals.

Assessing the Feasibility of Effectiveness Monitoring for Mountain Goat Winter Ranges in Forested Areas of British Columbia

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Abstract: Mountain goats (*Oreamnos americanus*) are a relatively common resident of British Columbia's most rugged habitats. Winter is a critical period due to nutritional deprivation and high energy expenditure related to thermoregulation and mobility in snow. As a result, B.C. is legally establishing winter ranges to provide critical life requisites for wintering mountain goats. I developed monitoring protocols and ecological baselines associated with selected indicators for assessing effectiveness of winter ranges, and tested the feasibility of their implementation in 2 areas: 35 km southeast of Houston, B.C. and a coastal site approximately 20 km southwest of Squamish, B.C. The following indicators were monitored: proportion of suitable/capable habitat managed as mountain goat winter range, forest cover characteristics, movement among winter ranges, forage availability, snow depth and consolidation, and sustained winter use. In general, field methods were practical, although the ability to navigate steep or broken terrain limits field sampling in many areas. In addition, assessing forage availability was deemed impractical because of the broad diets of mountain goats. Extensive monitoring increases overall robustness of mountain goat management by examining the full range of suitable ecological conditions and appropriate practices. As a result, management can move beyond attempting to achieve a single optimum condition and can focus on managing to a range of acceptable outcomes.

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Key words: British Columbia, effectiveness monitoring, mountain goats, *Oreamnos americanus*, winter range,

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British Columbia has a significant responsibility for managing mountain goats (*Oreamnos americanus*) because >50% of the world's population resides in the province (Shackleton 1999). The winter season is a critical period for mountain goats due to nutritional deprivation and high energy expenditure related to thermoregulation and mobility in snow (Wilson 2005a). As a result, provincial legislation allows for legal designation of mountain goat winter ranges. Wilson (2005a) identified a suite of indicators in relation to key questions to monitor effectiveness of mountain goat habitat management. The next steps in developing an effectiveness monitoring programme was to develop protocols based on the suite of indicators, to establish ecological baselines, and to test the methods in pilot project areas. I developed office and field monitoring procedures and herein present results of pilot implementation of the field procedures in two study areas.

Assessment criteria and proposed monitoring protocols

This project included developing monitoring protocols for effectiveness indicators related to mountain goat winter range (Wilson 2005a). Protocols included: assessment criteria, methods regarding collection and analysis, and ecological baselines against which to monitor trends. Wilson (2005a) provided broad "desired conditions" for each potential indicator, some of which provide obvious ecological baselines while others needed to have baselines established. Baselines generally are unavailable in the literature and were inferred from measures of current conditions. Current conditions were determined from field investigations on the pilot study areas, where extensive and intensive indicator data were collected. In some cases, ecological baselines are impractical to establish and monitoring must be based simply on year-to-year comparisons.

Proportion of Suitable or Capable Habitat Managed as Mountain Goat Winter Range

The proportion of suitable or capable habitat under management is a measure of the effectiveness of the overall management strategy because such areas generally are not at risk from human activities. Use of suitable or capable habitat as the basis for the calculation depends on the population goal (i.e., maintenance or recovery of the local mountain goat population). Determining the proportion of suitable or capable habitat protected and/or managed as mountain goat winter range is an office procedure dependent on availability of maps of winter range boundaries and other constrained areas such as parks and protected areas, as well as maps of all suitable or capable mountain goat winter range. This is expected to be a one-time calculation when winter ranges are established.

Maps of suitable or capable mountain goat winter range can be derived using a variety of methods (Wilson 2005b). A systematic aerial inventory (Rochetta 2002) provides the opportunity to characterize both fine-scale habitat characteristics as well as the presence of mountain goats. Habitat models also have been used to identify "potential" winter range areas based on topographic and forest cover characteristics (Gross et al. 2002, Heinemeyer et al. 2003). However, these models typically over-estimate the availability of suitable winter ranges and reconnaissance to confirm habitat characteristics and occupancy by goats is still necessary. Also, the detailed terrain characteristics of microsites used by wintering goats cannot be resolved by available mapping (Jex 2004). A blend of methods using maps, aerial photo interpretation, and survey flights also is an option (Pollard 2002, Dunsworth 2004).

There is no ecological baseline associated with the proportion of suitable or capable habitat managed as mountain goat winter range; rather, this statistic provides a management baseline that reflects the landscape-level potential for managing and protecting mountain goat winter range. The goal of capturing all winter ranges can be justified by the relative paucity of suitable or capable winter habitat for mountain goats.

Forest Cover Characteristics

Forest cover is an important characteristic of some mountain goat winter ranges, particularly in coastal regions where deep, unconsolidated snow forces mountain goats to elevations below treeline where dense canopies intercept snowfall and reduce snow depths on the ground (Wilson 2005b). Ensuring that forest canopy conditions are sufficient to moderate snow depths on winter ranges, and ensuring that canopy conditions persist over the long-term, are the reasons for monitoring forest cover characteristics. Monitoring is focused on forested buffers surrounding suitable escape terrain because there are outstanding questions related to the required extent of forested buffers in terms of snow interception cover and buffers from disturbance. Although trees associated with escape terrain are important features on some ranges (e.g., in coastal areas), they usually are not threatened by harvest plans and generally it is too dangerous to assess such areas on the ground.

The main function of forest cover on mountain goat winter ranges is to reduce snow depth on the ground, thus percent canopy cover of different strata is the most important variable. Abundance of arboreal lichens also is important because lichen litterfall can provide an important food source when other forage is unavailable due to deep snow conditions, particularly in coastal areas (Fox and Smith 1988).

Forest characteristics of a winter range at the time of legal establishment form the ecological baseline against which future monitoring results should be assessed, unless recovery of forest characteristics is an objective for the winter range.

Movement Among Winter Ranges

Winter ranges usually are established only where suitable habitat exists. Therefore, they tend to be small and distributed within a matrix of less suitable habitat. Although some mountain goats remain within areas smaller than most established winter ranges for large parts of the season, more typically animals move between patches of suitable habitat (Taylor et al. 2004). As a result, it is important that forest harvesting activities in areas between ranges do not interfere with movements of mountain goats. However, there has been little research on the effects of harvesting on movement of mountain goats between winter ranges. Given the absence of data, it also is important to document movements of goats between patches of suitable winter habitat, wherever possible.

Ecological baselines related to movement among winter ranges are difficult to establish. Failure to detect movements among winter ranges does not necessarily indicate that the ranges are ineffective. Nor does it necessarily mean that the intervening forest matrix is unsuitable for goats. Mountain goat movements are highly variable and there is no reason to assume that every goat would necessarily use 2 or more ranges. If detecting the movements of only a few goats is expected, the resulting data would be a poor indicator of movement patterns of the local population.

Forage Availability

Mountain goats are generalist herbivores with varied diets (Laundré 1994). Characteristics of the forest understorey determine the availability of forage for wintering mountain goats. Goats in coastal ranges subsist on forbs, ferns, conifers, lichens, and mosses (Hjeljord 1973). As snow depths increase, the proportion of forbs and ferns in the diet declines (Fox and Smith 1988). At snow depths of >50 cm, forbs and ferns become unavailable and goats forage on conifer leaves and lichens from standing trees and litterfall, and on mosses from substrates not covered by snow (Fox and Smith 1988). Older forests generally are associated with more abundant arboreal lichens and litterfall (Rochetta 2002). In interior regions where snow depths on high-elevation, windswept winter ranges are shallow, winter diets of mountain goats are dominated by grasses and shrubs (Laundré 1994).

In general, ranges with adequate forage are expected to have tall and vigorous shrub growth above the snow line and abundant literfall for periods of deep snow fall. Given the varied diets of mountain goats and the relative paucity of evidence of feeding expected in the field, ecological baselines related to forage availability generally are impractical.

Snow Depth and Consolidation

Mountain goat winter ranges are characterized by features that moderate snow depths. This allows goats adequate mobility while minimizing their energy expenditure. Interior mountain goat populations tend to winter at high elevations on windswept south and southwest-facing slopes, but heavy snowloads in coastal mountains force goats to move to low elevation areas in search of food sources not buried by deep snow (Fox and Smith 1988, Fox et al. 1989, Shackleton 1999). Mountain goats in the Cascades have habitat use characteristics intermediate between coastal and interior ecotypes (Gilbert and Raedeke 1992).

Objectives for winter ranges managed for mountain goats usually emphasize retention of forest canopy to intercept snow; therefore, monitoring should be focused on whether forest characteristics on the range are sufficient to moderate snow depth to an extent that mobility of mountain goats within the winter range is higher than areas outside the winter range.

Snow depths vary considerably within and between years. As a result, a key measure of the moderating effects of winter range characteristics is the difference between snow depths in open reference areas and under canopy within the boundaries of the winter range. Snow depth is not the only factor affecting mobility of mountain goats; snow consolidation also can vary considerably with snowfall patterns, freeze-thaw dynamics, and other variables.

Deep snows impose higher energetic costs through reduced mobility and reduced forage availability. Mobility of similarly-sized ungulates (e.g., mule deer; *Odocoileus hemionus hemionus*) becomes restricted as snow depths exceed 25 cm and significantly so if depths exceed 50 cm (Ungulate Winter Range Technical Advisory Team 2005 and references therein).

I propose an ecological baseline of ensuring that conditions on winter ranges result in snow depths generally <40 cm and sinking depths of <25 cm. Establishing ecological baselines for snow depths related to forage availability is more difficult because of adaptability of mountain goat diets and lack of information on energetic or fitness consequences of switching food sources as snow depths increase.

Evidence of Sustained Winter Use

Consistent winter use over many years is the most important indicator of effectiveness of winter areas established for mountain goats. Where local goat populations are monitored by telemetry, use of winter ranges can be determined through analysis of point location data. These analyses will under-estimate actual use because usually only a small and unrepresentative sample of the population is radio-collared. Telemetry data can confirm occupancy but can not establish whether winter ranges have been abandoned. Monitoring based on radio-collared animals is not a practical long-term strategy because most telemetry studies last only a few years.

Use also can be determined from annual aerial reconnaissance flights; however, animals and tracks are difficult to locate under canopy. Ground reconnaissance can determine use under forest canopy reliably because tracks, pellets, and browse can be measured directly. But only a subset of winter ranges are practical and safe to survey on the ground.

The ecological baseline for sustained winter use should simply be continued relative use over time, based on track count density or, where permanent pellet removal sites can be established, pellet density (no statistically significant change over >2 yr).

Methods for pilot program

Office Procedures

Proportion of Suitable or Capable Habitat Managed as Mountain Goat Winter Range- This involves a simple GIS area comparison between the final mountain goat habitat map and the final policy map illustrating legal winter ranges. Maps illustrating suitable or capable mountain goat habitat are not available for all areas; therefore, this criterion can not be applied everywhere.

Forest Cover Characteristics - Evidence of blowdown or forest health can be assessed either qualitatively or quantitatively by comparing digital orthophotos taken at different times.

Movement Among Winter Ranges - Movements between winter range areas can be documented through analysis of telemetry location databases. These databases are unlikely to provide information on travel routes but can confirm goats travel between winter ranges.

Sustained Winter Use - Point location data can be plotted in relation to winter range boundaries in a GIS framework.

Field Procedures

Field procedures include data collected from aerial reconnaissance and ground surveys. The following data can be collected during aerial survey flights:

Forest Cover Characteristics - Blowdown and forest health can be assessed qualitatively.

Movement Among Winter Ranges - Tracks of mountain goats usually are separated from those of other ungulates by the terrain in which they are found. Tracks usually are observed in areas above treeline and provide limited information on use of the forest matrix between winter ranges areas. Although tracks can be inventoried during fieldwork (see procedures below), it is impractical to confirm travel between winter ranges because of the area involved.

Sustained Winter Use - Winter aerial inventory surveys (RIC 2002) are used most commonly to establish occupancy of mountain goat winter ranges, but goats frequently are missed. Ground surveys are more reliable but are impractical to conduct on every winter range.

Ground collection of field data related to forage availability, snow depth and consolidation, and evidence of use can be collected in aggregate. Candidate winter ranges for sampling should be determined from all available information, including recent aerial photos/digital orthophotos. Mountain goats live in steep and often treacherous terrain and many areas can not be accessed safely, particularly in winter. Safety is the primary concern in all field sampling. It might not be obvious from photos whether winter ranges can be navigated safely and local knowledge should be canvassed before selecting a winter range for sampling. As mentioned previously, field monitoring is focused on forested buffers that surround suitable escape terrain. These forested areas generally are safer for surveyors but safety can not be assumed.

The number of winter ranges sampled depends on available resources and costs associated with field work (e.g., helicopter transit costs). Winter ranges with recent clearcuts along at least one edge are useful for sampling because they provide an opportunity to assess any blowdown effects and also provide good reference points for assessing snow depths.

Ideal locations for transect sampling are in clearcuts near the winter range boundary on shallow slopes and on an aspect similar to most of the winter range. Points should have navigable transects at ~45° up or downslope, if practicable. More than one point of origin can be identified if resources allow more extensive sampling. Points of origin should be flagged so they can be located in future years.

Field sampling involves the following tasks:

1. Navigate to point of origin and select area for plot approximately 20 m from winter range boundary with no forest overstorey, if possible. Record plot data (Table 1).

2. Mountain goat tracks encountered along transects can be followed to look for evidence of browse, beds, hair, etc. Effort spent backtracking depends on the abundance of tracks and time available.

3. If areas of intense use (see below) by goats are encountered (e.g., large pellet concentrations and hair, often on rocky outcrops with little or snow cover), note GPS location and take photographs. Mark the area with paint blazes and a tree marker, and make detailed notes of the location. Areas of intense use can be further monitored by clearing pellets from small plots (e.g., 1 m^2) at the beginning of winter and returning in spring to assess use. Pellets can be dried and weighed, counted or simply photographed to assess relative use.

4. Return to the plot location and take a bearing that traverses the winter range at ~45°angle (upslope or downslope). Establish next plot 20 m inside winter range boundary and repeat steps 1-3.

5. Continue establishing plots at either 20 or 50 m intervals, depending on size of the winter range and feasibility of navigating the transect. The objective should be at least 5 plots along the transect within the winter range boundary. The number of transects and, hence, the sampling intensity will differ among winter ranges.

Data Analysis

Most monitoring data require only summary statistics and qualitative comparisons. The exceptions are snow and sinking depths, crown closure, and pellet removal data. The relationship between snow and sinking depths and canopy characteristics can be explored using regression analyses by forest type. Relative use of intensive use sites, as measured at pellet removal plots, can be compared among years using frequency analyses if pellets are counted (e.g., chi-squared or g-tests, or log-linear analyses where additional variables are considered), or comparisons among means (t-tests, ANOVA) where pellets are weighed and data are available for several sites and/or years.

A variety of techniques for analysis of telemetry data can illustrate movement among winter ranges. For this project I illustrated the spatial relationship among telemetry locations by generating a “spanning tree” by mountain goat and year. Spanning trees do not connect consecutive locations but rather create a network of

Table 1. Monitoring information collected at plot transects in mountain goat winter ranges.

Indicator	Variable	Methods
Plot context	Site characteristics	Estimate slope with clinometer, aspect with compass, elevation from altimeter or GPS; UTMs from GPS, take photograph.
Snow depth and consolidation	Depth	Measure to nearest 5 cm with graduated pole at 10 locations within 20 x 20 m plot; note depth of crust layers
	Consolidation	Sink graduated ski pole into snow using strength of one arm, record sinking depth to nearest 5 cm at 10 locations within 20 x 20 m plot
Forest cover characteristics	Canopy	Percent cover for tree layer; dominant species in A1, A2, and A3 layers within 20 x 20 m plot
Forage availability	Shrub, herb, and moss abundance	Percent cover for shrub, herb, and moss layers above snow line within 20 x 20 m plot
	Lichen/litterfall	Estimate lichen abundance, estimate lichen-bearing branch litterfall within 20 x 20 m plot
Use by mountain goats	Visible sign	Record all tracks (and sinking depth), pellets, and hair in 20 x 20 m plot and number of tracks along transects

points based on minimum Euclidean distances without loops. The resulting network is relatively simple to interpret for the purposes of assessing movements among winter ranges.

Pilot program study sites

Two pilot study areas were established, one for interior ecotype mountain goats and one for coastal ecotype goats (Hebert and Turnbull 1977). Foxy Canyon is an "interior" site located 35 km southeast of Houston, BC (Figure 1). A continuous section of canyon extends for approximately 13 km at depths of 50-150 m along Foxy Creek. The canyon consists of discontinuous bedrock cliffs and steep forested slopes. Surrounding forest is comprised primarily of lodgepole pine (*Pinus contorta*) and hybrid white spruce (*Picea glauca x engelmannii*). The climate is northern continental, with long, relatively cold and dry winters and short, warm summers.

The canyon supports a minimum population of 37 goats (as of September 2000), with use concentrated near the canyon rim (Turney et al. 2001, Mahon and Turney 2002). Twenty-seven mountain goats were radio-collared (8 GPS and 19 VHF) in Foxy Canyon and nearby areas in January and March 2003 (Turney and Roberts 2004, Turney 2005). Some collars were still active in winter 2005-6 (L. Turney, pers. comm.).

Howe Sound winter ranges are located on the south coast of British Columbia, approximately 20 km southwest of Squamish, B.C. (Figure 1). Winter ranges are located on warm aspects that extend from lower elevations in Douglas-fir (*Pseudotsuga menziesii*) and western hemlock forest (*Tsuga heterophylla*), up through higher-elevation western and mountain hemlock (*Tsuga mertensiana*) forests and into the alpine. The climate on the south coast is maritime, with very wet but mild winters producing shallow or absent snow packs at low elevations and very deep snow packs at higher elevations.

Pilot program results

Field procedures were applied in 2 locations within Foxy Canyon on 23

February 2006. Data were collected at 10 field plots along 2 transects on either side of the canyon. Within the Howe Sound area, data were collected from 5 plots along one transect in McNab Creek. Sampling transects did not follow a 45° angle upslope during any of the surveys because Foxy Canyon slopes were gentle and variable, and Howe Sound slopes were very steep (often >80%) and progress was governed by navigable terrain.

Proportion of Suitable/Capable Habitat Managed as Mountain Goat Winter Range

This indicator was not completed because data were not available; however, there also were practical limitations to completing the analysis that might be relevant to other areas. In Foxy Canyon, linework was still being negotiated on the basis of a preliminary habitat model (Turney 2004, R. Heinrichs, pers. comm.). The habitat model also required revision (L. Turney, pers. comm.). Legally-established mountain goat winter ranges in Howe Sound were not yet approved, so the final policy layer was not available. The map of winter ranges had undergone many revisions, based on improving biological knowledge and on negotiations with forest licensees.

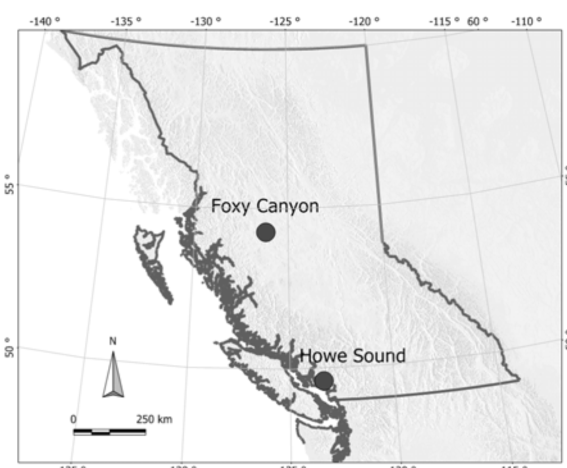

Figure 1. Study areas where protocols assessing effectiveness of mountain goat winter range areas were tested.

Forest Cover Characteristics

Forest cover characteristics were monitored to ensure forests contribute to winter range persistence and reduce snow depths on the ground. Procedures related to range persistence are either office-based or require extensive aerial inventory, both of which were beyond the scope of the pilot project. The snow monitoring component is addressed (with ecological baselines) below.

Movement Among Winter Ranges

Telemetry data from January to April 2003 (n = 8 goats and 2651 locations) and November 2003 to March 2004 (n = 5 goats and 1056 locations) indicated that mountain goat movements in Foxy Canyon were restricted largely to a single winter range area, although there was evidence of movements between ranges in consecutive winters (Figure 2). A complete aerial reconnaissance was not completed.

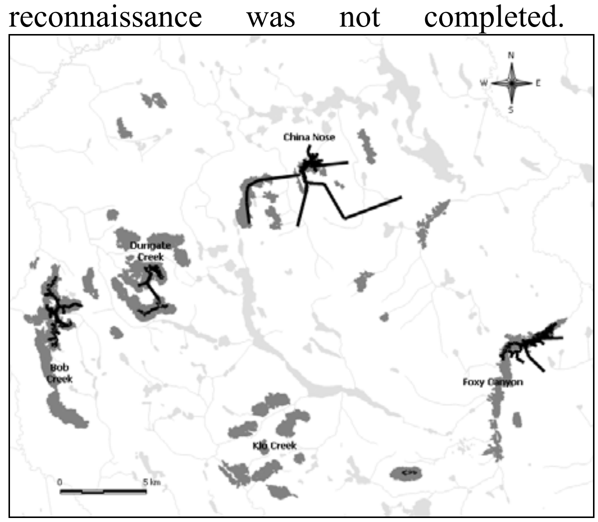

Figure 2. Spanning tree diagrams from data of radio-collared mountain goats (L. Turney, *unpubl. data*) January to April 2003 (n = 8 goats, 2651 locations) and November 2003 to March 2004 (n = 5 goats, 1056 locations). Spanning trees restricted to single winter season. Winter range areas are in dark grey.

Although tracks were visible during flights over and near Foxy Canyon, no tracks were detected between winter areas because the terrain was low elevation forest. No telemetry data were available for the Howe Sound area. Tracks within the winter range were visible from the air, but flight times were inadequate to inventory the surrounding area for evidence of tracks between ranges.

Forage Availability

Following mountain goat tracks resulted in evidence of feeding on subalpine fir (*Abies lasiocarpa*) blowdown in a partially harvested site in Foxy Canyon. Otherwise, shrub cover was variable but evidence of feeding was not detected, nor was feeding on the sparse lichen litterfall evident. I found evidence of browse throughout the area surveyed in Howe Sound; however, species-specific use could not be identified because the area was used extensively by wintering black-tailed deer (*Odocoileus hemionus columbianus*).

Snow Depth and Consolidation

Snow at Foxy Creek habitat plots (n = 7) was 23 to 62 cm deep and depths correlated with crown closure (Figure 3). Sinking depths (n = 7) were 13 to 23 cm and did not change significantly with crown closure (Figure 3). Sinking depths of tracks observed in plots (n = 4) were 10 to 25 cm. Snow depths in plots where mountain goat tracks were observed at Foxy Creek (n = 3) were <40 cm, while plots where tracks were not observed (n=4) had snow depths exceeding 40 cm. The role of snow depth in restricting forage opportunities is unclear, primarily because feeding was relatively rare. Feeding

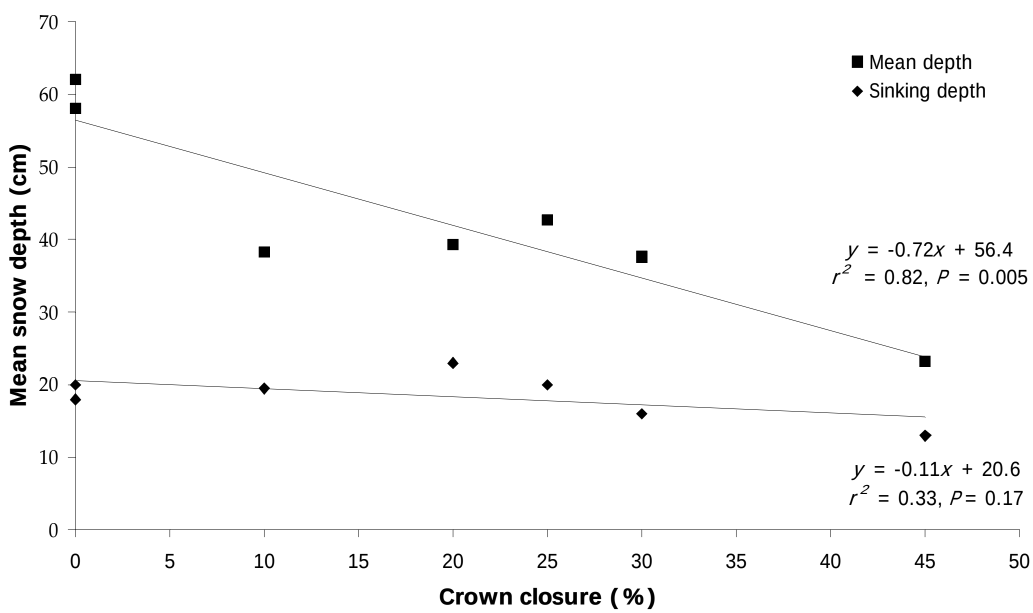

Figure 3. Effect of canopy closure on mean snow depth and sinking depth in assessment plots at the Foxy Creek study area.

evidence varied between cratering for ground forage and browsing blowdown.

Low elevation portions surveyed in Howe Sound had very limited snow cover, due in part to timing of the survey (23 March). Under canopy, snow cover was completely absent below 450 m and but was continuous above 750 m. Without canopy closure there were intermittent snow patches 11 to 20 cm deep at 432 m elevation and >1 m deep at 774 m. Although there were no tracks in deep snow at 774 m, there were tracks sinking 10 cm under canopy in snow depths of 30 to 60 cm with a crust layer at 30 cm.

Sustained Winter Use

Mountain goat use was clearly evident in the Foxy Canyon area. Recent tracks were common and pellets, urination, and feeding sites were seen. In addition, sites of intense use near the canyon rim could be used to establish pellet removal plots to monitor use between years. Nearly all use was under forest canopy. Use in partially-logged forest stands was rare and restricted to a few tracks and evidence of feeding. Identifying mountain goat use in Howe Sound was more difficult because of use by black-tailed deer, particularly at lower elevations. Pellets of deer and goats could be distinguished with some certainty and presence of hair in some instances confirmed the identification. Use by mountain goats was not detected below 600 m. Tracks also were common but could not be identified to species because the snow was melting.

Pilot program discussion

Although the pilot project focused on the field component of the monitoring protocols, office protocols are equally important and may constitute the majority of monitoring activities in some areas. Field monitoring is expensive and technically difficult or impossible in some areas. However, there is no substitute for ground-based work when assessing habitat characteristics and use by mountain goats under the forest canopy. The mix of office and field monitoring will differ among areas and perhaps years as resources are available.

Similarly, determining proportion of suitable/capable habitat managed as mountain goat winter range may or may not be possible for a given area. In areas where winter ranges were mapped for many years, the original biological or policy rationale may not be obvious. In areas where winter ranges were mapped recently, or are in the process of being mapped, there usually is an independent biology-based map generated by a habitat model and then verified through field investigation. In these situations, the proportion of suitable or capable winter range habitat under management can be calculated.

Monitoring forest cover changes is a relatively simple procedure. Forest cover on goat winter ranges is most threatened by blowdown along edges with recent cutblocks. Catastrophic events such as insect-kill or fire also are risks that vary. Forest cover *per se* is not a critical variable for mountain goats but serves a number of critical purposes. Dense canopy closure can moderate energetic costs by reducing snow depths on the ground. Older forests can be an important source of lichens, which goats eat when more palatable foods are unavailable. Forested buffers around escape terrain can provide protection against disturbance, to which mountain goats appear to be particularly sensitive (Wilson and Shackleton 2001). In Foxy Canyon (away from the Canyon rim) and Howe Sound, forest cover was critical for moderating snow depths and allowing mountain goats to move throughout the winter range.

Monitoring movement among winter ranges is a significant challenge in determining the effectiveness of habitat managed for wintering mountain goats. Sparse, short-term telemetry data are insufficient to monitor movements over the long-term as the forest matrix changes. Aerial survey flights provide anecdotal information because tracks are visible only in unforested areas. Even where winter ranges are separated by expanses of unforested habitat, movements are difficult to detect because mountain goats can remain on specific ranges for long periods and move to different areas infrequently (Taylor et al. 2004).

In addition, ecological baselines are difficult to establish because movement patterns of mountain goats are highly variable and there is no *a priori* basis for assuming movement between winter ranges is a key life requisite, particularly when the scale of winter range areas varies across the province. It may be better to infer movements between winter ranges from other indicators. For instance, evidence of sustained use indicates goats reach the winter range area and the intervening forest matrix is not a barrier to movement. In areas of declining use by mountain goats, hypotheses can be tested with monitoring data. For example, the decline could be a function of changing ecological conditions in the winter range, the surrounding forest matrix, other anthropogenic features (e.g., new roads or other development), or declines in local mountain goat populations.

The varied diets of goats reduces the utility of monitoring forage availability. In addition, evidence of feeding was rare in the study areas. It was most common in Howe Sound, but could not be attributed definitively to mountain goats. Although expected, energetic or fitness consequences of switching from higher quality items to lower quality food items (forbs and conifers, respectively), have not been quantified. Beyond qualitative assessments of availability, more formal monitoring of forage probably is impractical.

Snow depth and consolidation are key variables on winter ranges. They influence energy balance by restricting mobility and access to some forage (although the consequences are difficult to quantify). Maintaining high canopy closure in order to reduce snow depths on the ground in areas surrounding escape terrain is the principle effect on timber supply to the forest industry. Thus, characterizing and monitoring this relationship is an important focus of effectiveness monitoring. These data also are relatively easy to collect and analyze. Monitoring snow depths in a variety of forest types and structural conditions will provide valuable information. Ecological baselines of snow depth and consolidation are relatively easy to establish based on the relationship between observed tracks and snow depths, and direct measurement of track depths. I recommend snow depths <40 cm and sinking depths <25 cm as preliminary baselines that can be confirmed through additional field sampling.

Use by mountain goats during consecutive winters over the long term is the most important indicator of effectiveness of winter ranges. In areas of low or non-existent canopy closure this can be established relatively easily and quickly using reconnaissance-level aerial surveys to look for tracks and animals. Use of heavily timbered areas cannot be determined from the air; however, use in these areas is most important to establish because retaining forested buffers creates the most significant timber supply impact. Use was relatively easy to confirm on the ground under the forest canopy, although not all areas and conditions are favourable. Nor will it be practical to investigate all winter ranges through field sampling because of safety concerns. The systematic bias created by sampling relatively accessible and safe home ranges should be considered in the interpretation of any results. In addition, areas where winter ranges of mountain goats overlap with those of other species can create challenges for definitively identifying species-specific use.

Adaptive management

Effectiveness monitoring is a key task in adaptive management and results form the basis for adjustments to habitat management for mountain goats. Adaptive management relies on variation in management "treatments" to test different policies and practices (Walters 1986, Sit and Taylor 1998). As a result, the process is most effective where monitoring is extensive and encompasses as broad a range of ecological conditions and management practices as possible. Extensive monitoring also tends to increase overall management robustness because it promotes an understanding of the full range of suitable ecological conditions and appropriate practices. As a result, management can move beyond achieving a single optimum condition and can focus on managing the system within a range of acceptable outcomes using a more extensive policy and practices "toolbox" (Johnson 1999).

Many factors and interactions among factors determine the effectiveness of winter range areas managed for mountain goats. In addition, external factors can influence indicators used to measure effectiveness. For example, sustained use by goats is a function of habitat characteristics and trends in local mountain goat populations, which are each affected by climatic events, disease, and hunting regulations. As a result, the effectiveness of winter ranges must be inferred from the weight of evidence provided by a number of indicators. In this complex system, evidence could be conflicting or contradictory and managers must carefully weigh the different lines of evidence and document the logic of expert-based conclusions.

Although extensive monitoring increases understanding of the ecological system and response to management practices, it generally is impractical to establish controlled and replicated "management experiments" to definitively test the efficacy of all policy and management options. Again, the evidence must be weighed and conclusion documented. Although not the ideal adaptive management scenario, it provides a better basis for decision-making and a framework for continual improvement.

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Wintering Strategies by Mountain Goats in Interior Mountains: Preliminary Results

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Abstract: Winter is an important season for mountain goats (*Oreamnos americanus*), characterized by generally restricted movements and high juvenile mortality. Winter habitat selection and wintering strategies were examined in 2 adjacent areas of southeastern British Columbia: the southern Purcell Mountains (deeper, moist snow with few wind-swept slopes) and the southern Rocky Mountains (shallower, dry snow with more exposed wind-swept ridges). Fifteen GPS collars were placed on goats in each area from January 2004 to August 2005, covering 2 winters which differed in snow depth severity between near normal (winter 2003/2004) and 25 to 40% below normal (2004/2005). We examined mountain goat habitat selection using multivariate logistic regression at the scales of winter range within home range (broad scale), and at the stand level within winter range (fine scale), with a focus on the winter of normal snow depths. Male home ranges (83.5 km^2; 95% fixed kernel) were 2.5 times larger than those of females (32.6 km^2). Winter range size did not differ between areas (average 1.8 km^2 and 2.6 km^2 for males and females, respectively) and varied from 2.2 to 8.0% of home range. Topographic variables dominated model selection. At the broad scale, goats in both areas selected winter ranges closer to escape terrain in more rugged terrain, on warmer aspects (solar radiation modelling), and containing less mature dense forest than within the home range. At the fine scale, goats in both areas selected rugged habitat at upper mid-elevations and on warmer aspects. Alpine areas were avoided in the Purcells and selected in the Rockies. The ruggedness index was an extremely strong variable in the models. No selection for mature forests was observed in either area, and there was little availability or use of early seral stands. During the low snow winter of 2005, goats used 2.2 to 3.4 times larger ranges and hourly movement rates were 25 to 50% greater than in winter 2004. While females in the Purcells used lower elevation during winter 2005, no other differences in elevation use between winters were detected. Goats wintering in areas of higher snowfall made less use of open, high-elevation alpine habitats compared with animals wintering in areas of lower snowfall. However, our hypothesis that goats in areas of deeper snow make greater use of old and mature stands was not supported.

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Key Words: British Columbia, habitat, mountain goat, multivariate logistic regression, *Oreamnos americanus,* Purcell Mountains, Rocky Mountains.

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Factors Limiting Bighorn Sheep in the Yarrow-Castle Region of Southwestern Alberta

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Abstract: During the early 1980s, pneumonia was responsible for a drastic decline in bighorn sheep (*Ovis canadensis*) in Alberta's Yarrow-Castle area. Over 2 yr, the population decreased from ~400 sheep to fewer than 150. By 1995, the population recovered to ~200 individuals. Aerial surveys indicated that a general decline in bighorn ewes through the mid-1990s recently stabilized. Reasons for failure to reach the population size observed in the early 1980s currently is unknown; however, it may be linked to various factors, including spatial changes in range use, predation, reduced food quantity and/or quality, reduction in habitat quantity and/or quality, or poaching. Alternatively, the population may be at carrying capacity under current habitat conditions or inbreeding may reduce vigor of the population. We measured vital demographic rates that may help identify crucial limiting factors. Activities completed include capture and collaring of 46 ewes, monitoring reproductive success and survival, preliminary identification of seasonal ranges, and calculation of annual reproductive and survival rates. Prime-aged ewe survival during 2003 was low compared to bighorn ewe survival rates in Alberta, while the value for 2004 was on par with other Alberta populations. The population is experiencing growth but the reproductive rate may be rather sensitive. During the lambing period in 2003, 28 of 33 collared ewes bore lambs of which 11 survived to yearlings. In 2004, 14 of 25 lambs survived to 1 yr. Data gathered during our 3-yr study will be used to develop a predictive, age-structured population model. Information collected from GPS collars will be linked to resource selection patterns, and ultimately provide key areas for habitat enhancement initiatives. Our data will establish the foundation for future recommendations to help determine the most effective approach for management of this population.

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Key words: Alberta, bighorn sheep, limiting factors, *Ovis canadensis,* population growth.

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Selenium Levels in Bighorns in British Columbia

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Abstract: We compiled existing trace mineral levels in a database containing toxicology laboratory results for 1,132 bighorn sheep (*Ovis canadensis*) tissue and serum samples, covering the period 1978 through 2004. Descriptive statistics for 19 data subsets for each subspecies and metapopulation are included in this database. Our summary of trace mineral data for bighorn sheep in B.C. will be available for use by researchers and managers in B.C. and other jurisdictions across wild sheep ranges. This reference can be used to steer future investigations of bighorn sheep nutrition and health in general, but particularly with respect to implementation of the Fraser River California Bighorn Sheep Management Plan and the South Okanagan Bighorn Sheep Recovery Plan.

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Key words: Bighorn sheep, British Columbia, database, *Ovis canadensis*, trace minerals.

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Is Rapid Horn Growth Associated with Increased or Decreased Longevity?

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Abstract: Rapid horn growth has been associated with decreased longevity in an unhunted population of bighorn sheep (*Ovis canadensis);* however, this may have been due to a cohort effect. Recent research assumes that rapid growth results in increased longevity. We tested whether rapid growth is associated with increased or decreased longevity for rams dying of natural causes in populations with little or no hunting by using horn measurements from natural mortalities of 91 male thinhorn sheep (*O. dalli*) from Yukon Territory, Canada. Horns were gathered over 36 yr from 11 populations. Rapid growth was associated with reduced longevity for sheep aged 5 yr and older. A Monte Carlo simulation clearly showed (P = 0.016) that environmental fluctuations and population differences in growth rate could not account for the negative association between growth rate and longevity. The negative association between growth rate and longevity in unhunted populations was similar to that in hunted populations in the Yukon. Concern has been raised that hunting policies based on horn curl can have a detrimental effect on rams, because rams with faster growth can be shot at a younger age than rams with slower growth. However, our results suggest that hunting regulations based on horn curl may reflect the natural mortality situation in which sheep with rapid horn growth die at an earlier age. Our study further highlights the need for the existence and study of protected populations to properly assess the impacts of selective harvesting.

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Key words: horn growth, longevity, *Ovis dalli*, thinhorn sheep, Yukon Territory.

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Staining *Protostrongylus* spp. First-Stage Larvae with Carmine-Propionic Acid

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Abstract: Pneumonia mortality caused by bacteria *Pasteurella/Mannheimia* spp. is the major problem in Rocky Mountain bighorn sheep (*Ovis canadensis*) in Colorado. Lungworms (*Protostrongylus* spp.) contribute to stress and exacerbate the problem. It is difficult to differentiate the metastrongyle nematodes on morphology of first-stage larvae. *Protostrongylus stilesi* can transmit across the placenta and is associated with high lamb mortality. *Protostrongylus rushi* is not associated with significant mortality. A low-tech method for differenting *Protostrongylus* spp. would help with health-related management of wild sheep. Carmine-propionic acid staining method has been used with other parasitic strongylate nematodes. Lungworm larvae were collected from feces of bighorn sheep from the Sangre de Cristo Mountains of southern Colorado using the Baermann technique. Staining times of 1 to 5 hr with carmine-propionic acid enhanced internal anatomy of larvae and has potential for differentiating first-stage larvae of the primary lungworm species in bighorn sheep. This research supported by a Colorado Division of Wildlife Grant (# IA-OSA-1346-06).

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Key words: Bighorn sheep, lungworm, *Ovis canadensis, Protostrongylus* spp., staining technique

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Feared Negative Effects of Publishing Data: A Rejoinder to Heimer et al.

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Abstract**:** The Proceedings of the 14th Symposium of the Northern Wild Sheep and Goat Council contained a 'compilation' by Wayne Heimer of critiques of a paper published by Coltman et al. (2003) in *Nature.* That 'compilation', published without giving us a chance to respond, refers to a 'sheep management community' including only those who do not agree with Coltman et al. (2003). It attempts to convey the impression that the paper was not based on empirical data and incorrectly claims that environmental effects on horn and body size were ignored. It uses the Boone and Crockett record book to argue that bighorn (*Ovis canadensis*) rams are increasing in size, ignoring the fact that only large rams make it to the record book and that the number of bighorn sheep has increased substantially over the last few decades. The paper by Geist in the 'compilation' does not critique Coltman et al. (2003). The compilation confuses management regimes at Ram Mountain and elsewhere and provides a data-free defense of the status quo in sheep management. We are confident most sheep managers are interested in our data and will consider their implications
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Key words: Genetics, heritability, horn size, mating system, *Ovis canadensis,* paternity, Rocky Mountain bighorn sheep, trophy hunting,

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Most bighorn sheep (*Ovis canadensis*) hunting in Alberta involves an unlimited-entry 'trophy' hunt. Any resident can buy a sheep licence and the harvest is limited by the availability and accessibility of rams with horns describing 4/5 curl, reached by some rams at 4 yr of age and by many at 5 to 6 yr (Festa-Bianchet 1986, Jorgenson et al. 1993). Although it had long been assumed that larger-horned rams had higher fitness (Geist 1971), only recently data became available on mating success of bighorn rams (there are no published data on male mating success of any other mountain ungulate). Ram reproductive success was quantified in two populations in Alberta and one in Montana (Hogg and Forbes 1997, Coltman et al. 2002). While results confirm that large-horned males have high reproductive success, they reveal a strong interaction with age, so that only males at the top of the social hierarchy (typically aged 7 yr and older) benefit substantially from large horns. Other males rely on alternative mating strategies whose success is low and appears independent of horn size. That result confirms observations that rams employing alternative tactics rely mostly on speed, agility, and willingness to take risks, rather than combat with other rams (Hogg 1984;1988, Hogg and Forbes 1997). A ram with fast-growing horns will achieve high reproductive success if it survives to 6 to 7 yr (Coltman et al. 2002), but under unlimited-entry 4/5-curl regulations it may be harvested at 4 to 5 yr.

From those observations, and noting that ram horn length has a strong inheritable component (Coltman et al. 2005), one could predict that rams with slow-growing horns may be advantaged if their large-horned competitors were eliminated by sport hunting. That prediction led to a test based on information from pedigrees and calculation of breeding values for individual rams in the isolated population of Ram Mountain, Alberta (Jorgenson et al. 1998). Those empirical data confirmed artificial selection favouring small-horned rams (Coltman et al. 2003). More recent analyses suggest that systematic removal of high-quality individuals may lower the frequency of other fitness-enhancing traits, and possibly contribute to population stagnation (Coltman et al. 2005).

Until recently, the potential genetic effects of selective harvests figured more prominently in fisheries than in wildlife literature (Harris et al. 2002, Festa-Bianchet 2003). In the near future there should be more data available to assess what (if any) are the evolutionary impacts of sport harvest on wildlife.

Critiques of Coltman et al. (2003) were published in the 2004 Proceedings of the Northern Wild Sheep and Goat Council (Heimer 2004) as a 'compilation' that included personal attacks on the authors of the 2003 paper, who were not given the opportunity to defend themselves.

The apparent goal of the 'compilation' is set in the 'Compiling author's note and comment', suggesting that the data in Coltman et al. (2003) should be ignored and attention should instead be focused on the 'radical' anti-hunting spin given to it by the 'tabloid press'. The compilation appears to focus on two major critiques: It implies that Coltman et al. (2003) was based on computer simulations, not real data, and suggests that environmental effects were ignored in the analysis. Both claims are false.

Coltman et al. (2003) analyzed over 1000 horn and body measurements of 200 rams aged 2 to 4 yr and a population pedigree encompassing over 700 individuals, reaching back to 1971. Maternal linkages obtained through behavioural observations were supplemented using 20 microsatellite loci to identify 241 paternities and 31 clusters of paternal half-sibs, individuals sharing the same (but unknown) father. Data were analyzed using accepted statistical methods widely applied by quantitative geneticists in the domestic animal literature. Substantial effort was made to separate genetic and environmental causes of variation in horn and body size, again using accepted statistical methods. Coltman et al. (2003) specifically accounted for environmental effects by including the average mass of yearling ewes (that has a stronger correlation with lamb survival and ram horn growth than population density, presumably because it accounts directly for changes in resource availability).

'Breeding value' is the value of a phenotypic trait predicted to be expressed by the descendant of a particular individual. Breeding values are based on the performance of an individual's known relatives in pedigree. Animal scientists routinely use these techniques to select breeders for traits of commercial interest based on pedigree and performance data.

The first paper in the compilation series, by Michael and Margaret Frisina, reports that half of the bighorn rams in the Boone and Crockett Record Book scoring more than 200 points were shot between 1987 and 1997, that over half the top 100 rams were killed in the last 20 yr and that a new 'world record ram' was shot in Alberta in 2000. None of this is surprising. Many populations of bighorn sheep restored over the last few decades are expanding into unused habitat, where rapid horn growth is expected. There are a lot more bighorns today than 30 or 40 yr ago. In populations managed through a draw, the chances of a ram surviving to grow large horns presumably are higher than under unlimited-entry regulations. In addition to not accounting for the increase in sheep numbers, the use of a Record Book as a source of data assumes that reporting frequency does not change through time, and that 'record rams' are a random sample. At Ram Mountain, as ram horns became smaller through a combination of genetic and environmental effects, many rams never reached the 4/5-curl threshold (Jorgenson et al. 1998). These rams would not appear in records of shot animals, because it would be illegal to kill them. Data from harvested rams have many uses, but also several limitations (Martinez et al. 2005).

The 'Alberta record ram' was taken during a special hunt from a population that spends most of the regular hunting season in areas where hunting is not allowed. It illustrates the kind of rams that could be in Alberta if those with fast-growing horns were not selectively removed when aged 6 yr and younger.

The Frisinas state that Coltman et al. (2003) was not based on empirical data and that it did not account for environmental effects, two claims refuted above. They also claim our analyses did not account for the genetic contribution of mothers, yet Coltman et al. (2003) states that 709 maternities were used in pedigrees. The Frisinas provide a spirited defense of hunting, but we have no idea of what led them to suggest that our paper criticized successful sheep conservation programs.

Eric Rominger's paper, labeled a 'call to academic accountability', does not allow for the possibility that both genetic and environmental factors may affect horn growth. Festa-Bianchet et al. (2004) ascribed over two-thirds of the variance in body mass and annulus circumference to changes in resource availability and age. We stand by that result. Age and resource availability are important in determining horn size, but that does not imply that genotype has no role to play. As density on Ram Mountain declined, horn size of rams declined (Fig. 1, see also Fig. 2 in Coltman et al. 2003). Horn growth rates remained low despite the very low density of recent years. That is why instead of population density we accounted for yearly changes in resource availability by the average mass of yearling ewes in June.

Rominger's paper suggests that traits must be all-genetic or all-environmental. Our analysis partitioned environmental from genetic variance because both are important. We have now released sheep from an unselected population onto Ram Mountain and will monitor the growth of descendants with varying admixtures of 'local' and 'immigrant' genes. The importance of genetic rescue of stagnating, isolated populations was illustrated by an

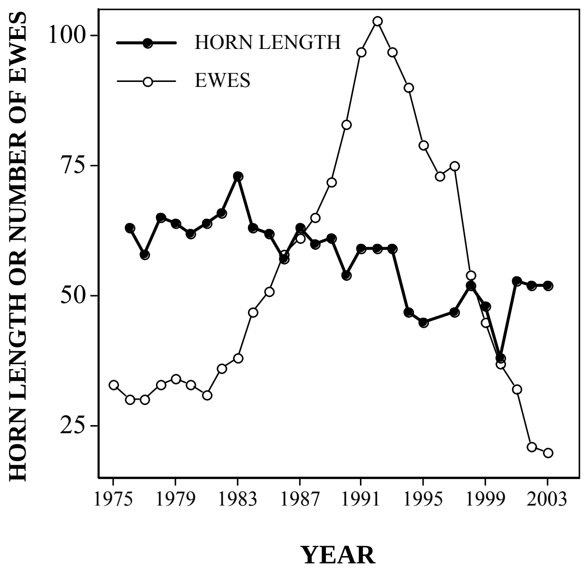

Figure 1. Average horn length of 4-yr-old bighorn sheep rams and number of ewes at Ram Mountain, Alberta, 1975 to 2003. Ram horn length continued to decrease after the number of ewes declined in 1995-2003.

elegant experiment in Montana (Hogg et al. 2006).

We find no need to issue an Errata/Corrigendum. Eric Rominger owes us an apology.

The paper by Val Geist is not a critique of our 2003 paper. Geist doubts that the decline in horn size is permanent but otherwise agrees with our conclusions. We don't know if the decline is permanent, but recent experimental work in fish suggests that overcoming the effects of artificial selection may be difficult (Walsh et al. 2006). Ram Mountain is an isolated population and some alleles present at the beginning of our study have now been lost (D. Coltman, unpublished data). There can be no evolution without genetic variability. After pointing out environmental effects on horn and antler growth (with which we are in agreement), Geist lists earlier examples of artificial selection on antler shape. In writing, Val Geist confirmed that he does not disagree with our 2003 paper. Why then is his paper in this 'compilation'?

The paper by Heimer and Lee includes offensive language and personal accusations. It claims that Coltman et al. (2003) compromised wild sheep conservation because it may be used as fuel for anti-hunting campaigns in the U.S. The result of this could be the loss of conservation funding coming from hunters and hunting organizations. Instead, we suggest that hunters and managers are interested in ensuring that trophy hunting regimes are sustainable. In many hunted deer, moose, reindeer, chamois, wild boar, pronghorn, black bear or sheep (adult males only in most cases) populations, most of which are managed sustainably, most adults die by getting shot (Festa-Bianchet 2003). Avoiding harvest could be a very strong selective pressure.

The same paragraph states that what we reported is not new because 'Reproductive success was quantitatively linked with dominance three decades ago'. The supporting citation is Geist (1971), which does not have data on paternity. Again, the interactions between dominance, horn growth, age, and mating strategy revealed by recent research (Hogg 1984;1988, Hogg and Forbes 1997, Coltman et al. 2002, Pelletier 2005, Pelletier and Festa-Bianchet 2006, Pelletier et al. 2006) are ignored. The relationship between either dominance or horn size and mating success is not linear.

Without citing a source, the next statement claims that only 3 to 10% of available rams are harvested in Alaska. Clearly, the lower the harvest rate, the lower the potential for artificial selective effects. What is meant by 'available rams' is important here. Most rams are not 'available' because they are not legal. The key question is what proportion of legal rams are taken. In the Yukon, with curl regulations similar to those in Alaska, approximately 37% of registered rams are shot the year they become legal, and about 72% within one year of reaching legal size (J. Carey, Yukon Environment, pers. comm.). That does not mean that the yearly harvest rate is 37% because it does not account for natural mortality, but it implies that the 3 to 10% figure may be an underestimate. Genetic consequences were observed at Ram Mountain with a harvest rate of ~35% of legal rams (Festa-Bianchet 1986) or about 5 to 8% of all rams.

The next section laments that papers by Heimer in the Northern Wild Sheep and Goat Council Proceedings are not given sufficient prominence. We strongly encourage those interested in sheep management to read all papers by Heimer as well as Whitten (2001).

Heimer and Lee argue that because 50% of lambs are not sired by dominant rams, selection against large horns cannot occur. Here they miss two points. First, the 50% of paternities by dominants typically belong to 2 to 3 rams each year, while the 50% by subordinates are shared by 10 or more individuals. That mating distribution implies a high potential for rapid selection for the genetic characteristics of the few highly successful rams. Second, as recognized by their own quote: "alternative mating tactics [are] less dependent on body and weapon size", horn size plays a limited role in the reproductive success of subordinate rams. Therefore, shooting a 6-yr-old with large horns ends its life before those horns helped achieve high mating success.

The final sentence is insulting and attempts to belittle people who have devoted a lifetime of effort to understanding the ecology and conservation of mountain ungulates.

Where do we go from here?

Ram Mountain is an isolated population that during our study fluctuated between 26 and 152 adults. It likely experienced genetic drift in addition to artificial selection, and is highly unlikely to receive immigrants from unhunted populations. Future research should focus on other possible genetic effects of trophy hunting, and on what management strategies can avoid artificial selection. Managers should be particularly concerned about the potential effects of selective hunting in small populations, including those recently established. Trophy hunting of mountain ungulates is a potential conservation tool for many species, particularly in Asia, that are threatened by habitat destruction, exotic disease, and poaching (Harris and Pletscher 2002). It is important not to perpetuate management strategies that select for small horns.

Full-curl regulations may decrease the selective effect of hunting by allowing some large-horned rams to survive to an age where large horns confer a high mating success. There may be differences in the determinants of mating success in bighorn and thinhorn (*Ovis dalli*) rams, and we do not know what level of selective harvest is tolerable before genetic consequences are generated. We suspect that a limit on the number of large-horned rams harvested (either through a draw or simply because of the inaccessibility of terrain) would decrease the selective effect of trophy hunting. Hence the urgent need to quantify harvest pressure in terms of the proportion of legal rams taken. We observed a selective effect with a 35% harvest of legal rams, therefore we recommend a lower harvest rate, but currently cannot suggest a more precise harvest goal. Finally, the potential role of protected areas as sources of unselected rams is worthy of investigation, for two reasons. It may dampen the selective effects of hunting, and it may lead to one-way gene flow out of protected areas, possibly decreasing effective population size inside those areas (Hogg 2000). There is much more to mountain ungulate conservation than trophy hunting. We are confident that managers will consider the potential implications of our work.

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