BC Environment

Status of the Rocky Mountain Bighorn Sheep in British Columbia

by
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Ministry of Environment, Lands and Parks
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PREFACE

The Rocky Mountain Bighorn Sheep (*Ovis canadensis canadensis*) (RMBS) is a sturdy and handsome ungulate of rough terrain, a majestic species adapted to the rigours of living in the Rocky Mountains. As one of the two subspecies of Bighorn Sheep occurring in British Columbia, RMBS lives in grasslands and seral shrub lands along the western flanks of the southern Rocky Mountains, where wind and warmer temperatures result in shallow to zero snow depths. The abundance and distribution of RMBS have always been restricted due to their use of specialised wintering habitats and their dependence on rough, precipitous terrain for predator-avoidance.

Much has been published about Rocky Mountain Bighorn Sheep but no one report has summarised the extensive literature or attempted to develop an overview status report for British Columbia. Currently, this subspecies is on the British Columbia Blue List of terrestrial vertebrates, which are considered "vulnerable." RMBS are likely to become endangered or threatened in British Columbia if factors affecting their vulnerability are not reversed. There is ample reason to write a status report for this subspecies because it is vulnerable, and populations of bighorns are subject to cycles in which disease and habitat play major roles. Dramatic die-offs of bighorns have occurred periodically and have involved stressors, such as poor nutrition, trace mineral deficiency, high animal density, interspecific competition, extreme weather, harassment by humans and dogs, exotic diseases, and parasites. Habitats used by bighorns are adversely affected by timber management practices, fire suppression, mining exploration and developments, hydroelectric developments, large scale commercial recreation developments, motorized and especially helicopter assisted back country recreation, residential developments, and livestock grazing.

This status report on Rocky Mountain Bighorn Sheep is intended to develop a detailed understanding of the biology and threats for this species with the objective of assisting managers, government, and industry in setting goals for management, habitat protection and acquisition, enhancement projects, and future research.

The long term sustainability of RMBS will depend on using a metapopulation approach to develop goals for land acquisition and protection for the maintenance of habitat and movement corridors, and the development of operational prescriptions, such as prescribed burning, access planning, improved livestock grazing, and protection from contact with domestic sheep (*Ovis aries*). The key to maintaining RMBS lies with the ability of the Wildlife Branch to effect the co-operation and support of the other government agencies and land owners, including: Ministry of Forests, BC Assets and Lands, ranchers, loggers, prospectors, miners, and conservationists interested in the protection of RMBS.

Keywords: Rocky Mountain, Bighorn Sheep, *Ovis canadensis canadensis*, status, vulnerable, at risk, metapopulation, herd, conservation, disease, ecology, trophy hunting.

DISCLAIMER

The views expressed herein are those of the author(s) and do not necessarily represent those of the BC Ministry of Environment, Lands and Parks.

In cases where a Wildlife Bulletin also contains a recommended status for the species, this recommendation may be the opinion of the author and may not necessarily reflect that of the Wildlife Branch. Official designation is be made by the Wildlife Branch in consultation with experts, and the data contained in the report will be considered during the evaluation process.

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SUMMARY

1 GENERAL BIOLOGY

Rocky Mountain Bighorn Sheep (RMBS) (*Ovis canadensis canadensis*) are one of two subspecies of Bighorn Sheep in British Columbia, the other being California Bighorn Sheep (*Ovis canadensis californiana*). Basic biology and ecology is similar for both subspecies. RMBS are characterised by high reproductive productivity (r_m=0.265 to 0.308), high adult survival (90% to 95%), but low survival of young to 1 year (~33%). Complex spatial and temporal range use patterns are characteristic of RMBS and, together with their fragility, have implications for genetics, disease transmission, and conservation efforts.

2 CONSERVATION BIOLOGY

The population of RMBS in British Columbia can likely be conceptualised as being part of one large metapopulation with the Bighorn Sheep in Alberta and adjacent parts of Montana. Recent genetic studies have suggested that RMBS in these subpopulations have low genetic variation, which can be attributed to probable founder effect and genetic drift.

Fragmentation of habitat leading to loss of interconnectedness is a major concern for the future survival of RMBS in British Columbia. Maintenance of existing connectivity and re-establishing prehistoric movement corridors are essential objectives. Artificial transplants to maintain genetic diversity must be weighed against maintenance of genetic uniqueness and potential introduction of pathogens.

3 SUB-SPECIES DISTRIBUTION AND ABUNDANCE

Prior to human settlement, RMBS were considered to have a more or less continuous range throughout the Rocky Mountains of Western North America. The history of the abundance of RMBS in North America for over 100 years, however, has been one of major cyclic die-offs and recoveries. Diseases have been the major cause of these epidemics and recent review studies have correlated die-off dates with the introduction of domestic sheep in the USA. The numbers of domestic sheep on rangelands peaked in the USA at 28 million in 1920, and remained high until 1945 and the collapse of the sheep ranching industry. The population of Canadian RMBS was estimated to be >10,000 between 1800 and 1860. By 1915, a dramatic decline brought the population down to 1775–3400. In British Columbia, this die-off was followed by a subsequent recovery and then other die-offs in the 1940s, 1960s, and 1980s. While populations in British Columbia have generally been increasing over the short term, the trend since the 1920s has been downward. Based on current past experiences and current habitat conditions, a major all-age, either sex die-off should be expected in the near future.

4 HABITAT

BC's native RMBS habitat occurs mainly in the Rocky Mountains of the East Kootenay south of Golden. The extent and quality of winter range is the principal limiting factor. Bighorn Sheep are typically confined for six to seven months of the winter to low elevation, low snow cover, southern exposed slopes close to rocky escarpments and talus slopes. These rocky areas provide protection from predators, as well as thermal cover during lambing. Other ecotypes winter either on high elevation windswept alpine and subalpine ridges, or on south-facing grasslands in the montane forest zone. Productive bluebunch wheatgrass (*Agropyron spicatum*) and rough fescue (*Festuca scabrella*) are important as winter range for all ecotypes. All three ecotypes summer in alpine and subalpine habitats.

5 LEGAL PROTECTION AND STATUS

RMBS in British Columbia are defined as "big game" under the *Wildlife Act* and are classified as a Blue-listed or vulnerable species by the Wildlife Branch. RMBS are not protected by legislation other than the general provisions to regulate the use and movement of all wildlife and the prohibition of domestication under the *Wildlife Act*.

6 LIMITING FACTORS AND RISKS

The threats to RMBS include human-caused habitat alienation, including residential, commercial, industrial, recreational, agricultural, and access developments; and habitat management policies. Such policies as domestic livestock grazing and forest fire suppression and resulting forest encroachment have had serious impacts on Bighorn Sheep. Forage competition and poor nutrition have been critical stressors along with trace mineral deficiencies, high animal densities, weather, and harassment by humans and dogs. Other limiting factors for RMBS include competition from native ungulates, noxious weeds, and predation. Direct losses to predation are generally not as important as the fact that predation has forced females and young to

use less risky and usually less productive habitats. The most important impact of grazing has been disease die-offs from contact with domestic sheep and cattle. No studies have reported Bighorn Sheep that remained healthy after contact with domestic sheep, and all wildlife professionals have concluded that Bighorn Sheep and domestic sheep should not occupy the same ranges or be managed in proximity to each other.

7 SPECIAL SIGNIFICANCE OF THE SPECIES

RMBS are a high-profile, valuable big game species which, as a member of the mountain sheep genus, are appreciated by a majority of adult British Columbians for a variety of reasons, including food, cultural, art, photography, and trophy value. A relatively high percentage of BC's adult human population participate in wildlife activities associated with the group of wildlife comprising mountain sheep, goats (*Oreamnos americanus*), and Caribou (*Rangifer tarandus*) despite the limited distribution and accessibility of members of this group." Mountain sheep, including RMBS, are valued by resident hunters at $83.20 per day and are rated the highest of all seven provincial ungulate species surveyed in terms of hunters' willingness to pay.

8 HARVEST MANAGEMENT

RMBS have traditionally been hunted for trophy males under either a 3/4-curl or full-curl ram restriction. Ewe hunting seasons have been designed to help reduce herds that have exceeded the carrying capacity of their winter ranges. Some ram harvests and all-ewe harvests are regulated by LEH and all sheep taken must be submitted to the Wildlife Branch for compulsory inspection. The Provincial Wildlife Harvest Strategy sets out the principles and guidelines for RMBS management in the province and most hunting is for "trophy" males under restrictive horn curl regulations.

9 CONSERVATION MEASURES

A metapopulation approach must be used to develop a strategic plan for managing RMBS in British Columbia. Expansion of protected areas, particularly Wildlife Management Areas (WMAs), and maintenance of connective movement corridors is essential for the long-term viability of RMBS. An aggressive program of prescribed burning and improved livestock grazing practices should be instituted to enhance and maintain RMBS winter range. Access management planning must be initiated for controlling road and helicopter access. Commercial backcountry recreational developments must be sited so as to prevent impacts on RMBS populations. Lastly, but perhaps of greatest importance, there must be no grazing of domestic sheep permitted on Crown lands within 16 km of areas known to be frequented by RMBS and a program of public education should be developed that will educate farmers and ranchers to understand how lethal domestic sheep, even "healthy" domestic sheep, are to RMBS.

10 RESEARCH NEEDS

Research is needed on many aspects of RMBS ecology, including the viability of subpopulations and metapopulation, the implications of metapopulation structure for conservation, dispersal rates among and within subpopulations, disease transmission, and lamb mortality. Research should also be able to address issues raised by land use activities, such as mining, fire suppression and subsequent forest encroachment, recreational and urban and access developments, and land alienation. High priority must be placed on completing the capability/suitability mapping of winter ranges.

11 EVALUATION

Currently RMBS is on the Blue List of terrestrial vertebrates that are classified as "vulnerable." This means they are likely to become threatened or endangered in British Columbia if factors affecting their vulnerability are not reversed. The provincial or national ranking for RMBS is currently S3, which is on the Blue List. This status report has developed a revised ranking that includes viability of subpopulations, and the fragility of the species and its habitat in British Columbia. This revised ranking is S2S3 for the provincial or national rank.

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1 GENERAL BIOLOGY

1.1 Origin and Taxonomy

Rocky Mountain Bighorn Sheep (*Ovis canadensis canadensis*) belong to the Order Artiodactyla (even-toed ungulates), Suborder Ruminantia (ruminating or cud-chewing mammals), Family Bovidae (horned ungulates, including cattle, antelopes, and goats), and tribe Caprini. Caprini is sometimes called the goat-antelope subfamily and includes such species as Ibex (*Capra ibex*), Musk Ox (*Ovibos moschatus*), Mouflon (*Ovis musimon*), and Mountain Goats (*Oreamnos americanus*).

Large wild sheep evolved in Asia during the early Pleistocene. During the late Pleistocene, ancestors of today's North American sheep evolved their distinctive characteristics while isolated in the ice-free Beringian glacial period (Cowan 1940; Korobitsyna et al. 1974). This was a period during which ice covered much of the northern part of North America above a southern margin extending from what is now Washington State to New Jersey. When the continental and cordilleran glaciers blocking this route melted, these ancestors migrated southward into western Canada and the US. The isolation of ancestors of Bighorn Sheep in the western U.S. during the Wisconsin glaciation period resulted in the differentiation of Rocky Mountain and desert bighorns (Korobitsyna et al. 1974).

Formerly, taxonomists relied almost exclusively on morphological skull measurements to separate species and subspecies of large mammals (e.g., Cowan 1940). However, cranial differences are often a reflection of age and environmental conditions affecting growth. Under natural conditions without the benefit of controls, few cranial measurements should be expected to be consistently statistically reliable indices upon which to base species or subspecies differences. Shackelton et al. (1999) states that Rocky Mountain Bighorn Sheep (RMBS) and California Bighorn Sheep (CBS) were taxonomically separated from each other based only on small differences in selected measurements of the skulls of adult males. Nine years of electrophoretic studies of 59 populations involving nearly 1000 individuals showed that CBS do not have glyoxylase, which RMBS frequently have, and their transferrin type frequencies appear different from those of Desert Bighorn Sheep (DBS) (*Ovis canadensis nelsoni)* (Jessup 1990). Ramey (1991, 1993, 1995) has recommended that of the four subspecies, only a single subspecies of Desert Bighorn Sheep (*O. c. nelsoni*) be recognised as a result of morphometric measurements, protein and mtDNA analysis. Similarly, Ramey (1999) has suggested that Rocky Mountain and California subspecies be recognised as one subspecies (*O. c. canadensis*)**.**

Traditionally, the species and subspecies concepts were based on the biological species concept in which a "good species" is a group of interbreeding natural populations isolated from other such groups (Mayr 1991). The species concept is currently under revision; criteria for defining species can now include morphologic, chromosomal, serologic, behavioural, palaeontologic, ecological, biochemical, genetic, or a combination of two or more of these (Huelsenbeck and Rannala 1997). The debate continues as to whether CBS and RMBS are distinctly separate subspecies or only constitute separate ecotypes and the matter is as yet unresolved. For the purposes of this review, it will be assumed that the two are separate subspecies. The reasons for recognising both subspecies are the fact that the subspecies are geographically separated (allopatry), prior convention, and because no taxonomic revision has been made (Shackleton et al. 1999).

1.2 Physical Description

RMBS are the largest of the New World species of the genus *Ovis.* They are a medium sized ungulate, with rams weighing an average of 117 kg to a maximum of ~135 kg and ewes weighing an average of 65 kg to a maximum of ~80 kg (Stelfox 1993). The colour of the pelage on the head, neck, and dorsal body of both CBS and RMBS is dark to medium rich brown. Both CBS and RMBS possess a short black tail and a white muzzle, plus ivory white rump and ventral patches. In high elevation wintering sheep, the pelage often becomes bleached over the winter by exposure to the sun and wind to a light cream or "off-white" colour, while normal wear and breakage of the hair tips results in dulling and greying of the pelage of sheep wintering at lower elevations by spring. As the new coat begins to grow at the onset of early summer, the previous year's coat begins to shed in large patches giving Bighorn Sheep a rough, scruffy appearance.

Mature RMBS possess powerful muscular front and hind quarters; sturdy necks, legs, and backs; and robust, concave hooves with rough, flexible under-pads; all of which are adaptations to a life travelling in steep, rugged, rocky terrain. Both sexes support horns which, because of drought in the case of Desert Bighorn Sheep and winter weather in the case of RMBS, stop and start growing at least once per year resulting in visible external growth rings or annuli. The horns of RMBS rams may reach 125 cm. Rams develop a frontally strengthened skull plate and an expanded sinus structure designed to create space (pneumation) that acts to cushion the impacts of blows. The horns of rams form the concussive weapons used during highly ritualised contests between males for access to females and are displayed in threatening postures to establish rank order among males (Geist 1971).

1.3 Breeding Age and Frequency

In RMBS, ewes reach puberty as early as 1.5 years, but do not usually mate for the first time until at least 2.5 years old (Geist 1971; Wishart 1975). Smith (1954) maintained that males are capable of mating at 2.5 years of age, but stated that the usual age of first mating for males is 3.5 to 4.5 years of age. Hogg (1988) found that rams of 2–4 years in a captive herd participated in the rut using alternate mating tactics. Age of first reproduction ranged from 2 to 6 years in RMBS studied in Alberta, but only 13% of ewes delayed primiparity until 4 years or later (Jorgenson et al. 1993). Under natural conditions, where older rams are present, rams begin active participation in the rut at approximately 6 years. Younger rams are sexually mature, but Geist (1971) believed that they were prevented from breeding by older males.

On average, ewes that lambed at 2 years of age are larger and heavier with longer horns, both as lambs and as yearlings, than those that waited to reproduce (Jorgenson et al. 1993). However, the lambs of 2-year-old ewes are smaller and less viable than lambs of older ewes (Festa-Bianchet et al. 1995). A long term study from Alberta concluded that, contrary to other ungulate species, the age of first reproduction in RMBS is less predictable from body size (Jorgenson et al. 1993). Consequently, the fitness cost of variation in age at primiparity may be independent of body size during the first two years of life. Maternal age and mass did not have a strong effect upon the offspring's age at first reproduction and the data did not falsify the hypothesis that the number of mature rams interacts with ewe density to affect the age at first lambing of bighorn ewes (Jorgenson et al. 1993).

Population density does affect lactation (or lambing), as 2-year-olds were less likely to lactate in high population densities than at low population densities (Jorgenson et al. 1993). Very small yearling females do not mate, as evidenced by a lack of lactation as 2-year olds; there appears to be a minimum mass below which young ewes do not breed (Jorgenson et al. 1993). Thus Jorgenson et al. (1993) have hypothesised that there may be an interaction between body mass and population density since ewes may conserve body resources for their own growth and survival rather than for reproduction at high population densities. While body mass and population density may explain differences in age of primiparity, there could be other factors involved, such as genetic or other environmental variables (Jorgenson et al. 1993).

Pregnancy rates have been shown to be over 90% of adult females impregnated in RMBS and bearing one young per year (Hass 1989; Jorgenson 1992). Twinning has been verified in CBS (Blood 1961; Spalding 1996; Eccles and Shackleton 1979). Twinning has been indicated in RMBS, but has not been verified (Eccles and Shackelton 1979; Hass 1990).

In contrast to Asiatic sheep, RMBS have a long life expectancy and a low reproductive potential (Geist 1971). The condition of the population, however, can determine the length of life and the reproductive potential. For instance, in declining or stable populations, adults will generally live for 10 or more years; Geist (1971) claimed they may even reach maximum ages of 20 years for rams and 20–24 years for ewes, although this has not been recorded in British Columbia. He also claimed that in an expanding population with high reproductive effort, most adults will only reach an average of 6–7 years. However, even in circumstances of rapid population expansion, in at least one East Kootenay herd the range of ages was much greater than than the 6–7 years observed by Geist (Shackleton 1973).

Since the length of life and the reproductive effort varies with the population's condition, the lifetime fitness varies considerably. The over-winter number of lambs observed per 100 ewes has ranged from 15.5 to 87 in studies from Alberta (Geist 1971).

1.4 Timing of Reproductive Events

As with most northern ungulates, the mating period or rut is timed to optimise the availability of abundant nutritious forage at parturition (Hebert 1973; Bunnell 1982; Thompson and Turner 1982). The seasonal movements occur so that not only do bighorn avoid harsh weather, they may take advantage of the "flush" of new vegetation growth (Hebert 1973; Shackleton and Bunnell 1987). Demarchi (1982) found a trend for later lambing in RMBS than in CBS, although there is overlap in timing. Published accounts of the chronological lambing periods of 30 North American mountain sheep populations, compiled by Bunnell (1982) and 22 populations, compiled by Thompson and Turner (1982), revealed a wide range in rutting periods across the range of the genus *Ovis.* Vegetation green-up starts at lower elevations in the spring and gradually progresses upslope, providing high-quality forage over an extended period of time.

Because of the wide latitudinal and elevational range of habitats, the rutting period and therefore the lambing period of RMBS may vary considerably between herds.

Festa-Bianchet (1988b) points out that population density and resource abundance can result in lambs being born outside the optimal period. Among all populations lambing begins later and duration is shorter at more northern latitudes and/or higher elevations. Bunnell (1982) concluded that populations feeding on vegetation of less predictable growth patterns ("desert type") have lengthy lambing seasons, while populations feeding on vegetation exhibiting more predictable growth patterns ("alpine type") have shorter lambing seasons, typically two oestrus cycles in length. Thompson and Turner (1982) concluded, "…bighorn lambing occurs coincident with the period of vegetative development when the environmental regime ameliorates neonate survival." Thus, in BC, herds that winter or lamb at high elevation or the northern portion of their distribution may rut and lamb a full month earlier than herds that winter and lamb at lower elevations and/or in the southern areas of the province. Typically in BC, rutting occurs from early November to early December, with parturition occurring around 175 days after conception beginning in early June, peaking in mid June, and ending the first week of July. (Cowan and Guiget 1965; Shackelton 1999). RMBS that live at high elevation all year round appear to rut 1–2 weeks later than Rocky Mountain Trench herds in the East Kootenay, but this must be studied to determine this definitively.

1.5 Productivity

Productivity varies both within herds between years and between herds. While it is commonly believed that early development is critical for growth and reproductive success, mass at one month was not correlated with adult mass, but mass at four and 12 months both had significant correlations with adult mass (Festa-Bianchet et al. 1996). This indicates that the quality or quantity of maternal attention can affect adult body mass and subsequently reproductive success (Festa-Bianchet et al. 1996).

Although up to 100% of adult ewes may be impregnated each fall in CBS (Harper 1984a, 1984b), there is some debate over the possibility of foetus resorption when the nutritional value of the forage is below maintenance level. However, it is most likely that, unless extremely malnourished, ewes carry the foetus to term where the lamb quickly succumbs to factors relating to its own poor nutrition and compromised immune system. For example, initial lamb production was 79–85 lambs per 100 ewes in central Idaho in 1992; however, a pneumonia epizootic resulted in 7 lambs per 100 ewes by 4–6 weeks old (Akenson and Akenson 1992). It was suggested that the decrease in lamb survival was due to population levels beyond the carrying capacity of the winter range combined with severe drought. This density-dependent mortality serves to reduce the population to levels where intraspecific competition is lowered and forage quality and quantity are restored, resulting in the restored health of the surviving herd members.

During periods of nutritional stress (i.e., scarce forage resources), the age of first reproduction is postponed and mature ewes favour their own survival over producing a lamb (Festa-Bianchet and Jorgenson 1998). The result of these density-dependent factors is reduced productivity which, under natural conditions, should result in relatively stable populations. However, disease introduced from domestic sheep may alter this balance by adding further stress on the animals. This creates the population cycles documented in RMBS over the last 80 years.

1.6 Mortality and Survival

Bighorn Sheep are most vulnerable to death during their first year of life. This mortality is not uniform; it appears to be concentrated into two distinct time periods. The first occurs during the first weeks following parturition. The second occurs during winter. Harper's (1984a, 1984b) data suggest that nearly 100% of oestrous ewes may be impregnated and that fetal resorption will not occur unless ewes are in extremely poor condition. Lambs are particularly vulnerable during the first few days after birth, when predation and/or disease are major factors. However, predation risk is reduced because Bighorn Sheep lambs are born in precipitous terrain relatively safe from predators (Festa-Bianchet 1988b).

Ewes in poor condition during the rut are more likely to give birth late in the season. Since this is more likely to occur in an over-crowded population, this may be a form of density-dependent population control (Festa-Bianchet 1988b). Death from malnutrition occurs in later weeks (Festa-Bianchet 1988a). Bighorn populations are regulated through density-dependent feedback on fecundity and on lamb survival, and that density dependence only kicks in at intermediate population levels (Shackleton et al. 1999).

Previous reports of yearling:ewe ratios (an estimator of lamb mortality) range from 8:100 to 61:100 (Wildlife Branch Records). At best, annual lamb mortality is nearly 40% and at worst >90%. Causes of mortality are varied and most are linked to habitat condition (i.e., poor habitat condition leads to poor body condition and health). Fall precipitation of the preceding year has been shown to have a significant positive effect on lamb survival in Desert bighorns (Douglas and Leslie 1986). Strong spring winds have a negative effect. Similar effects may occur on low elevation winter ranges in the East Kootenay Trench where, in some years, fall weather is conducive to a short period of regrowth of forage grasses, particularly *Poa* spp.

Body mass is often identified as a key variable affecting survival. Large size in larger animals is usually associated with increased survival on a seasonal basis (Festa-Bianchet et al. 1997). In general, this has been shown to be true for Bighorn Sheep. However, the effects of body mass varied considerably with age, sex, and population size (Festa-Bianchet et al. 1997).

The strongest effect of body mass was on the survival of lambs at high population densities because small lambs experienced higher mortality than large lambs (Festa-Bianchet et al. 1997). At high population densities, there are greater numbers of small lambs and these animals are at greater risk of winter mortality (Festa-Bianchet et al. 1997). Yearling males are more susceptible than yearling females to parasite infection and pathogens (Festa-Bianchet 1989a, 1991a). Mortality was density-dependent for yearling females but not for yearling males (Jorgenson et al. 1997). Festa-Bianchet et al. (1997) suggest that there is stronger selection for individual quality (the largest, healthiest and fittest) among male lambs than female lambs at high population densities. Male survival to yearling age was biased towards higher-quality individuals. There is also evidence of increased maternal care for males at high population densities (Bérubé et al. 1996). There was no difference in lamb mortality between high and low elevations due to forage quality during a pneumonia die-off in central Idaho in 1992 (Akenson and Akenson 1992).

Generally, for both sexes, there is sufficient selection during the first two years of life so that, by the age of 2, only high quality individuals have survived (Festa-Bianchet et al. 1997; Jorgenson et al. 1997). By using marked animals, Festa-Bianchet (1989) found that annual mortality averaged 33% for yearlings (much higher than results from skull collections, which are biased towards older, larger skulls) and 18% for 2-year-olds. In the absence of major predation or disease, adult ewes exhibit high survival rates up to 95% until approximately 7 years of age (Jorgenson et al. 1997). Where there is a moderate level of predation, adult ewe survival is reduced and may be less than 62.5% (Wehausen 1996). Under conditions of heavy predation by Cougars (*Felis concolor*) in isolated herds, adult ewe mortality may reach 100% (Wehausen 1996). The survival of older ewes had the least association with large body mass of all groups considered, andthere was no significance for prime-age ewes and adult rams (Festa-Bianchet et al. 1997). Ewes of 3–6 years of age seem to gain sufficient mass to carry them through the winter period of low quality forage and thus do not seem to compromise their short-term survival through heavy reproduction (Festa-Bianchet et al. 1997). Older ewes, however may be affected by reproduction due to lower mass gains (Festa-Bianchet et al. 1997). Ewes of all ages experience a cost to reproduction as they experience a decrease in resistance to parasites and pathogens as a consequence of reproduction (Festa-Bianchet 1989a). Male offspring cause more reduction in immunity for ewes than female offspring because of greater energy demands. The most accurate predictor of individual survival appears to be mass in mid-September. Winter mass loss and summer mass gain were either unrelated to survival or less powerful predictors (Festa-Bianchet et al. 1997).

Immature male ungulates must concentrate their metabolic resources on growth in order to become large enough for future competition for females. This means that they are more vulnerable to parasites and pathogens, store less fat, and put less energy into their immune system (Festa-Bianchet 1989). Festa-Bianchet (1989) concludes that this riskier strategy of immature males is probably common to most sheep populations and is not unique to populations that had older males removed through hunting. Survival of adult rams generally is lower than ewes (Jorgenson et al. 1997). Geist (1971) found 11% mortality for rams (3.9% for rams 2–7 years old and 23% for rams 8–17 years old). In Alberta, natural mortality of males >3 years old averaged 10% yearly (Festa-Bianchet 1989). Males >7 years old had a greater decline in survival than females of the same age (Jorgenson et al. 1997). Jorgenson et al. (1997) found that males of 2 and 3 years old had higher survival rates than males 4–6 years old. Where hunters remove most of the males older than 5 years of age, the natural mortality of males increases at 3–5 years possibly due to stress of rutting at an early age (Geist 1971). During an epizootic, the mortality rates of all age-classes are substantially elevated and productivity is markedly reduced, resulting in a rapid decline in population size over a two- or three-year period (Gates 1965; Bandy 1966; Demarchi 1972; Davidson 1994).

1.7 Population Structure

Because of the importance of monitoring population structure for management purposes, sex and age class data is normally collected for all bighorn herds inventoried.

The literature and wildlife agency files are replete with data from herd classification counts (HCC) on sex ratios and age class structures of nearly every managed sheep population in North America.

Population dynamics can be expressed solely as births, deaths, immigration and emigration. Whether stable, increasing, or declining depends on the net effect of those factors. Lamb:ewe ratios are commonly used as indicators of Bighorn Sheep population vigour. High proportions of lambs are assumed to imply healthy, expanding herds of high quality, while the reverse is implied for herds with low ratios (Geist 1971). McCullough (1994) cautioned wildlife managers that HCC by themselves do not estimate population size changes. McCullough (1994) states, "Sex and age ratios usually are expressed on the basis of 1 or 100 females, illustrating that HCC is an approach analogous to life table analysis and has the same deficiencies for interpretation of population dynamics. An independent estimate of population size is required to safely interpret HCC results." Contingent upon an independent population estimate, McCullough (1994) recommends that HCC be used together with management experiments to maximise usefulness of the method.

The difficulty in distinguishing yearling ewes from lambs and yearling rams from ewes (Geist 1971) further limits the usefulness of such data when obtained by aerial census. Festa-Bianchet (1992) states, "…it appears that there is no substitute for complete counts to assess changes in bighorn population size. Age ratios cannot reliably forecast such changes." Age ratios cannot reliably forecast such changes unless used in combination with other population parameters. In addition, the age ratios must be tested objectively by such methods as ground surveys and mark-resighting tests. Also, nursery groups are not randomly distributed, so the entire population must be surveyed in order to maintain the predictive power of HCC. Jorgensen (1992) correlated actual ewe:lamb ratios with known changes in population size but he, too, cautioned against using lamb:ewe ratios collected during HCC as a single index to determine population vigour.

The foregoing limitations notwithstanding, some generalisations may be made regarding Bighorn Sheep population sex and age structure. A search of the literature and a review of the BC Wildlife Branch files in Cranbrook produced lamb:ewe ratios that varied from 70 to 95:100 immediately post-partum to 40 to 70 during late summer and fall to 10 to 74 post-winter, with 30 to 50 being most commonly reported (Wildlife Branch records; Geist 1971; Bodie and Hickey 1980; Irby et al.1988; Skonsberg 1988). TAESC (1982) recorded a 10-year lamb:ewe ratio average of 55:100 in the Elk River Valley.

Under most natural conditions, males experience higher mortality rates than females. In unhunted populations, however, bighorn rams may equal or outnumber ewes (Buechner 1960; Geist 1971). For example, in Banff National Park, ratios were maintained at 90 to 94 males per 100 females (Geist 1971; Skonsberg 1988), while in moderately hunted herds in Montana and south-eastern BC, 25 to 85 rams per 100 ewes were reported (Bodie and Hickey 1980; Wildlife Branch records). An equal sex ratio was observed by Cowan (1944), who classified a total of 1470 RMBS in the unhunted populations of Banff, Jasper, and Yoho national parks. During periods of high hunting mortality in south-eastern BC in the early 1960s, ratios of 11 to 33 rams per 100 ewes were common (Davidson 1994; Wildlife Branch records).

Adult Bighorn Sheep generally experience an annual mortality rate of about 10% from natural causes. For a RMBS population to remain stable, it must maintain an over-winter lamb:ewe ratio of approximately 30:100. Any fewer and the population will decline; any more and the population will increase. Providing that mortality (or removal) of the ewe component remains below 10%, in general, the rate of increase or decline will depend on how far the lamb:ewe ratio deviates from 30:100.

1.8 Population Dynamics

Shackelton et al. (1999) summarised the reproductive potential of mountain sheep as follows:

> *The intrinsic rate of natural increase (r_m) represents the exponential rate of population growth when no resource is limiting; i.e., when the population is increasing at its genetic potential (Caughley 1977). Following the assumption of 1 lamb/year, birth of first lamb when females are 3 years old, a unitary sex ratio, a stable age distribution, and no mortality, Buechner (1960) calculated an r_m for bighorns of 0.258, but there is empirical evidence for r_ms considerably higher than this. Between 1922 and 1929, the National Bison Range herd in Montana increased at a rate of 0.288 (Hass 1989), and the Fort Peck herd had an r_m = 0.265 over 11 years and 0.305 over 4 years (Buechner 1960). The most conservative of Buechner's assumptions is first breeding at 3 years of age, but incorporating the assumption that 2-year-old females can produce lambs, the r_m value becomes about 0.308 (doubling time = 2.25 years).*

1.9 Characteristics of Movements and Seasonal Home Ranges

1.9.1 Movement characteristics

Complex spatial and temporal range use patterns are characteristic of subpopulations of Bighorn Sheep. These natural patterns of migration and socialisation have serious implications for some aspects of genetics, disease transmission, and conservation efforts. In addition to frequent movements by individual rams and infrequent movements by small bands of ewes, Bighorn Sheep have three kinds of major movements: 1) local shifts within home ranges; 2) seasonal migrations between home ranges; and 3) rare mass emigrations (Geist 1971). Local shifts are usually due to environmental factors, such as a crust forming on snow or abnormally low snowfall in the winter (allowing a more disperse distribution), or sprouting vegetation in the spring (drawing the sheep to higher elevations) (Hebert 1973). Seasonal migrations are not simply a response to weather, forage, or pests, but are more complex, internally motivated movements that are synchronised by external environmental factors, most likely light regime (Geist 1971) and forage development and maturation (Hebert 1973). Mass emigration is a deviation in movement patterns usually due to deterioration of habitat (Geist 1971).

None of these movements is rigid, nor is the movement the same for all individuals within a group; the tempo of the movement also varies. The movement of rams to wintering areas is a slow drift, with smaller groups appearing gradually (Geist 1971; TAESC 1982); the same is true for the departure of wintering grounds, while the trip to rutting grounds is rapid and determined (Geist 1971). The migrations of rams are probably synchronised by the rut, whereas migration for ewes is probably synchronised by lambing (Geist 1971). For both sexes, these migrations are initiated by endocrine/hormonal changes stimulated by the length of day. Other events are less accurately timed.

1.9.2 Sexual segregation of home ranges

Bighorn are gregarious but live in sexually segregated groups (Geist 1971). Group living improves feeding efficiency and predator detection and avoidance. During the lambing season, ewes seek solitude in rocky bluffs near their winter range to protect lambs from inclement weather (Geist 1971) and to avoid predation on lambs (Shackleton and Bunnell 1987; Festa-Bianchet 1988b). Ewes and lambs are highly vulnerable for several days following birth. Shackelton et al. (1999) states, "…the only consistently effective anti-predator strategy at this stage seems to be the female's selection of an isolated and precipitous area to give birth." Indeed it is such rugged "escape terrain" that often defines or limits the suitability of otherwise productive range to sustain Bighorn Sheep. After the ewe-lamb bond is formed and lambs are fully mobile, they join other maternal groups and move up-slope to summer range. Rams over 1.5 years normally form all-male groups and only occasionally frequent ewe-juvenile groups during the summer. Sexual segregation outside the rut has been hypothesised to reduce intraspecific competition and disturbance of ewes and lambs by males (Geist and Petocz 1977; Shank 1982).

In the fall, both sexes migrate towards the female/juvenile wintering areas. Rutting may occur on winter range (e.g., Wigwam herd), or it may occur part way between summer and winter range (e.g., Phillips Creek herd). Social interactions between males (i.e., displays of antagonistic dominance behaviour) to establish and reinforce dominance hierarchies occur well before the rut. The importance of this behaviour is realised through the establishment of a dominance hierarchy that presumably results in the successful courtship and insemination of oestrous females by the most dominant males (i.e., the largest, healthiest, and fittest), although immature males are known to copulate with ewes (Blood 1963; Giest 1971). After the rut, males over 1.5 years separate from the female-juvenile groups and move to separate, usually smaller winter ranges, while female/juvenile groups either remain on or move to the main winter ranges until spring.

1.9.3 Home range

Male bighorns use as few as two and as many as six separate home ranges during a year. For large bands of rams, the types of home ranges can include pre-rut, rutting, mid-winter, later-winter/spring, salt lick, and summer (Geist 1971). Some winter and summer at high elevation, but on separate mountains, such as all the Elk Valley herds. The herds in the Trench, however, winter at low elevation and summer at high elevation. Ewes can use as many as four ranges, including winter, spring, lambing, and summer ranges (Geist 1971; Fiesta-Bianchet 1986). Generally, ewes use two or three seasonal ranges (Geist 1971; Shackleton 1973; Wishart 1978; Festa-Bianchet 1986). When two ranges are used, they are a summer and winter range. In late September or early October, large bands of rams move to a fall concentration area where they generally stay from two to five weeks. From this pre-rut range in the first week of October or the first week in November, they disperse to rutting grounds until the end of December (Geist 1971; Schuerholtz 1982). At this time some rams will return to pre-rut home range, while others move to mid-winter home ranges where they spend 271–303 days (Geist 1971). Some young rams and the ewes will remain at the rutting grounds. By mid-March, rams return to the fall concentration area for a massive spring concentration. In summer, the rams move to salt licks for a few weeks and then to summer range.

Ewes arrive later on the wintering areas and depart earlier, spending 240 to 268 days on wintering areas (Geist 1971). Ewes and rams may occupy the same or adjacent winter ranges, but the rams often make use of more marginal habitats on cliffs and rugged terrain (TAESC 1982). The fall concentration area will usually be where the ewes remain in the winter (Geist 1971). In late March or April, separate winter/spring range may be used once the snow hardens or is reduced enough to allow movement. Females move to lambing areas in late May, June, or the beginning of July. Pregnant ewes were found to move from higher quality forage to an area of lower quality to provide better protection from predation (Festa-Bianchet 1988b). Festa-Bianchet (1988b) concludes that lambing range selection may be based on a combination of nutritional and anti-predator constraints. In Ewin Creek of the East Kootenay, parturition occurred from mid-May to mid-June and ewes summered in the lower elevation forests without forming distinct nursing bands (TAESC 1982). Lambing may take place on the winter range or in a separate lambing range. In late June or early July, barren females, juveniles, and rams move to summer ranges.

1.9.4 Size of home range and distance between seasonal ranges

Seasonal home ranges vary considerably not only in size, but also in the distance to other seasonal home ranges. Mid-winter home ranges can be as small as 0.8 km^2 or as large as 5.9 km^2 in spring and fall (Geist 1971). The winter range for the Ewin band of approximately 150 sheep was 1.4 to 2 km^2 (TAESC 1982). This means that 0.47 to 0.50 ha would be required to support one ewe, based on grazing capacity (average forage requirement of 30 kg per sheep and a grazing time of five months). Generally, home ranges are part of a mountain or a whole mountain. Of the four ungulates studied on Premier Ridge in the East Kootenay of BC, Bighorn Sheep were the most localised and specific in their response to environmental factors, such as slope and rockiness (escape terrain), and they tended to use small, rather specific areas (Hudson et al. 1975). The distance separating one seasonal range to another can be one steep gorge or it can be a trek of 24–40 km from summer to winter ranges (Smith 1954; Geist 1971; Wishart 1978). Hengel et al. (1992) reported that some ewes in Wyoming moved >51 km from wintering to lambing areas. Ewes in central Idaho migrated 1–40 km from winter ranges to lambing ranges (Akenson and Akenson 1992). Kopec (1982) found home ranges averaged 541 ha for ewes and 798 ha for rams in Montana. Ewes' home ranges were the smallest during lambing, 47 ha, and largest during the fall, 273 ha. The rams' smallest range was in winter range, averaging 21 ha, and largest during the spring range, averaging 305 ha. The size of lambing areas (an area where ewes were consistently observed with lambs) ranged from 3 ha to 150 ha in Idaho (Akenson and Akenson 1992). In Montana, Semmens (1996) estimated home range size for lamb-ewe groups were from 6.4 to 32.9 sq. km using radiotelemetry data from three subpopulations.

1.9.5 Home range fidelity

Generally, female Bighorn Sheep show philopatric (fidelity to home range) tendencies and this has been noted specifically in Rocky Mountain Bighorn Sheep (Geist 1971; Fiesta-Bianchet 1986; Stevens and Goodson 1993). Geist (1971) found that ewes returned to the same range 90% of the time, while rams returned 75% of the time. Both sexes have a strong home range fidelity to a particular mountain, but generally ewes' return rate to a specific range is higher than males. Bighorn Sheep appear to repeatedly use traditional areas, but once factors such as range structure and forage quality are considered, their ability to adapt is more fully appreciated (Hudson et al. 1975). Obvious deviations, however, are generally those sheep whose movements are more unpredictable, such as rams under four years of age, or older sheep that may skip migrations, such as an older barren ewe (Geist 1971). Intermountain movements by ewes may sometimes be remnants of historic migration patterns on a larger scale that are in danger of being lost (Bleich et al. 1990). Unusual long distance movement was found in Central Idaho in ewes whose lambs had died (Akenson and Akenson 1992). One radio-tagged ram moved 105 km from Radium to Golden in 1972, and between 1966 and 1969, three tagged bighorns from Waterton moved 75 km to Crowsnest Pass (Stelfox 1992). It has been suggested that observations of females far removed from permanent populations is evidence of exploratory and migratory behaviour by females and that with additional radiotelemetry research, more support for these behaviours, and possibly colonisation, may be collected (Bleich et al. 1996).

1.9.6 Origin of routes

Migration patterns are not simply maternal home ranges that are learned by both sexes of lambs from mothers. Both rams and ewes may have several different home range groups, but these movements are generally orderly and predictable (Geist 1971). Young rams develop migration routes from following older rams and this may involve patching together migration routes from following several older rams. This often inefficient movement usually involves routes that pass by several bands of females but probably reduces inbreeding, removes the rams from critical ewe winter range, and reduces competition (Geist 1971). Pre-rut dispersal and long movements during rutting season may have been selected for since males might breed more females, and the reproductive success has been shown to be higher (less barrenness, less loss of lambs at birth, and higher birth weight) (Geist 1971). This is probably due to “hybrid” vigour from greater genetic distance of parents.

2 CONSERVATION BIOLOGY

Conservation biology is a discipline that seeks to prevent the loss of the variety and variability of organisms and their ecological complexes based on the assumption that natural systems have functional, historical, and evolutionary limits that anthropogenic changes often cross (Primack 1993). Theoretical models and testable hypotheses from the perspective of this discipline are useful for managing over broad ecosystems using landscape ecology and metapopulation management. Three categories of events (which are frequently stochastic) threaten small populations with extinction: environmental, demographic, and genetic. Bleich et al. (1996) has detailed four possible causes of metapopulation extinction in Bighorn Sheep: distribution, adaptation, demographic, and genetic. Environmental and demographic (including distribution and adaptation) causes are often of greater importance for the long term persistence of a species. Genetic issues continue to be studied and discussed, not only because they can be the source of viability problems, but also because genetic *techniques* can give insight into such factors as evolution, dispersal rates, and habitat fragmentation.

2.1 Metapopulation

The naturally fragmented distribution of Bighorn Sheep appears to fit a metapopulation model. This model has largely replaced island biogeography as the theoretical framework for fragmentation issues (Wiens 1996). Metapopulation is a series of populations or local subpopulations with dynamic patterns of local extinctions and recolonizations (Fiedler and Jain 1992). The metapopulation model has important implications for maintaining evolutionary processes since a subdivided population may preserve variation (minimising genetic drift) better than a single larger population of equal size (Simberloff 1988). Schwartz et al. (1986) was the first to apply the metapopulation model to DBS in the eastern Mojave Desert. Since then there have been several additional publications about populations in the southern Mojave Desert and Central and South-eastern California (Bleich et al. 1990; Bleich et al. 1996), as well as for RMBS in the USA and Canada (Luikart and Allendorf 1996). Armentrout and Boyd (1994) provided information on the extensive fragmentation of all subspecies of Bighorn Sheep, including RMBS. They suggest that metapopulation management is necessary to avoid fragmentation and loss of additional populations and habitats. Due to this and other work (e.g., Ramey 1993), the U.S. Bureau of Land Management and other agencies have begun to manage over broad ecosystems, resulting in a focus on landscape ecology and metapopulation management (Armentrout and Boyd 1994). Sufficient data may be required in the future on vital rates, spatial and temporal correlation between the vital rates of subpopulations, and dispersal distances to confirm the specific applicability of the metapopulation model to RMBS (Hanski and Gilpin 1991; Doak and Mills 1994). Hanski and Gilpin (1991), however, have added that the delimitation of local populations is often subjective but that metapopulation thinking naturally applies to populations that are divided into discrete habitat patches. Thus, despite the absence of proof that there are population parameter differences between subpopulations, Bighorn Sheep do have discrete habitat patches and range groups that are important for management and conservation, particularly for assessing their at risk status.

Using mitochondrial (mt) DNA analysis, Bleich et al. (1996) demonstrated that ranges in southern California <15 km apart are part of the same metapopulation. Although sheep can traverse intermountain distances >20 km (Schwartz et al. 1986), the philopatry of females is evident in the differences in mtDNA among herds (Bleich et al. 1996). Bailey (1992) has proposed an arbitrary size or potential size for a metapopulation to be at least 1000 for practical and theoretical reasons particularly for coordinating management. To facilitate management, Bailey (1992) has identified three types of metapopulation structures: 1) megapopulation of ≥1000 individuals without barriers to dispersal; 2) core-satellite metapopulation of ≥1000 with ≥1 core herd of ≥150 sheep and several smaller satellite herds that depend on core herds; and 3) patchy metapopulations of ≥1000 distributed in interdependent herds of ≤100 sheep. Understanding the structure can be crucial for managing sheep, particularly for issues such as disease transmission. RMBS probably fit as a core-satellite metapopulation in British Columbia, Alberta, and part of Montana, with the core situated in Alberta.

Bleich et al. (1996) maintain that habitat fragmentation is the most significant threat to Bighorn Sheep. Unoccupied habitat patches, suboptimal habitats, and peripheral populations are important for evolutionary processes and to maintain interconnectedness and therefore must not be eliminated. Unsuitable habitat can be extremely important as stepping stones for Bighorn Sheep for historic, existing, or potential migratory or exploratory corridors. Intermountain movement is necessary for gene flow, but has the negative potential as a route for disease transmission.

Luikart and Allendorf (1996) used the term "region" in a discussion about genetic variability in Rocky Mountain Bighorn Sheep populations as groups of contiguous herds separated by substantial geographic distance or potential barriers to gene flow. While they did not use metapopulation terminology, a region can probably be considered a metapopulation. Canada was identified as one region that included the Rocky Mountain Bighorn Sheep of BC and Alberta. Other regions identified in this particular study were: Sun River Montana, Idaho-western Montana, southern Montana, Wyoming, and Colorado. Contiguous herds or subpopulations were defined as being separated by <15 km and having limited interchange of individuals using radiotelemetry and marking studies (Luikart and Allendorf 1996).

All the Rocky Mountain Bighorn Sheep in BC were considered one contiguous herd, while three contiguous herds were identified in Alberta in this particular study. Luikart and Allendorf (1996) may have under-estimated the interconnectedness of herds between BC, Alberta, and Montana, since their subpopulations are <15 km apart and therefore can be considered as one metapopulation. The Ten Lakes herd in Montana has contact with the Wigwam herd in BC, and the Waterton National Park bighorn herd is shared between BC, Alberta, and Montana.

BC has managed the East Kootenay Bighorn Sheep in isolation from sheep in Alberta and Montana. The infection of sheep in Alberta in 1983 was eventually traced back to the East Kootenay die-off. This highlights the necessity of using a seamless approach for activities and projects, such as herd management, transplants, and management of domestic sheep. Luikart and Allendorf (1996) show differentiation for variation in mtDNA, demonstrating there is little dispersal happening between herds in Canada and Sun River in Montana. This habitat fragmentation may be problematic since these herds were formerly connected.

2.1.1 Subpopulation, herd and band

A subpopulation can be defined as two or more wintering herds that share a common summer range. A metapopulation is made up of two or more subpopulations (Table 1). "Herd" commonly refers to one group of ewes and their progeny using a particular area and is normally named by their winter range (Festa-Bianchet 1986). Herd is a logical unit since Bighorn Sheep generally breed and winter in a discrete, identifiable group. As the unit for research and management, the herd and its definition have implications for conservation and management. Festa-Bianchet (1986) has shown that a herd using a winter range may actually be made up of distinct subgroups that use different portions of the

Table 1. Population divisions of Bighorn Sheep based on a metapopulation conceptual model.

Population divisions	Definition	Citation	Example
Metapopulation	Two or more subpopulations that have no barriers to dispersal and/or are <15 km apart	Bleich et al. 1996	BC, Alberta, and northern Montana
Subpopulation (a.k.a. contiguous herds)	Two or more wintering herds that share a common summer range	After Luikart and Allendorf 1996	Columbia Lake
Herd	A self-sustaining group of ewes and their progenyusing a particular area and named by theirdiscrete winter range	Festa-Bianchet 1986; R. Forbes, pers. comm.	Canal Flats
Band	A cohesive, home-range group that is a subgroup of a herd	Geist 1971	MaryAnn Creek

range. Ewes form stable bands or "home range groups," a definition of subgroups found among herds of domestic sheep (Geist 1971).

The size of RMBS subgroups can vary from two to more than 40 sheep, with the largest reported in BC being 110 (Shackleton 1999). These subgroups or bands may sometimes intermix with other bands on a seasonal range, but maintain a distinct migration pattern and separate population dynamics, physical characters, relation between range quality, and population characteristics (Festa-Bianchet 1986). Bleich et al. (1996) suggest that matrilines may be the real operational metapopulation unit since females (possibly lone females) may be the founders of subpopulations, while the males are responsible for nuclear gene flow. Unless subgroups are identified, management programs could fail to recognise subgroups that are undergoing problems. Stevens and Goodson (1993) warn about the need to pay attention to substructures within a bighorn population since the overall population could be increasing, while at the same time a segment could be heading for extinction.

2.2 Demographics

A minimum viable population (MVP) for Mountain Sheep has been estimated to be greater than >100 or 125 (Berger 1990). MVP, while often controversial, is a concept of the minimum number of organisms that constitutes a viable population for a particular species over a long period of time, such as 100 years. Viability is a state in which the species maintains its vigour and potential for evolutionary adaptation (Soule 1987). Berger (1990) found that of the 122 populations of the three sub-species (Rocky Mountain, California, and Desert) studied, 100% of populations of Bighorn Sheep with <50 individuals went extinct within 50 years. The rapid loss of populations was found not likely to be caused by food shortage, severe weather, predation, or interspecific competition and therefore 50 is not a minimum population that is viable over the long term. Populations with >100 individuals persisted for up to 70 years. Berger (1990) concludes that genetic and etiological factors influence bighorn reproduction and survival and, thus, their persistence. Wehausen (1995) has raised doubts about the likelihood of extinction for the populations that Berger (1990) identified. MVP models have mainly focused on genetic issues, but it is widely recognised that demographic and environmental factors are usually of greater significance in the occurrence of extinction. Bleich et al. (1996) stated that demographic processes are more important than genetics for Bighorn Sheep. Only careful population monitoring over an unacceptably long period of time will determine who is correct (Armentrout and Boyd 1994). Effective population size (the size of an idealised population that can counteract the effects of genetic problems) for Bighorn Sheep has been estimated to be Ne ≥50 to manage for genetic variability (Franklin 1980), which would keep the inbreeding rate <1% or they will lose variability over generational time. This means a population size of N≥150 would be required to avoid short-term loss of genetic variability (Fitzsimmons and Buskirk 1992).

While striving to manage for larger populations is not ill-advised, the importance of small populations should not be undervalued. These small populations can be critical for connecting larger habitats as stepping stones (Bleich et al. 1996) or for augmenting population size as one subpopulation of a larger metapopulation. Factors such as MVP are critical for establishing translocation protocols, maintaining corridors, and minimising fragmentation. FitzSimmons and Buskirk (1992) caution that the "objective of genetic management of Bighorn Sheep populations should be to minimise the loss of naturally-occurring genetic variability, rather than to maximise genetic variability through out-crossing to distant herds. Thus Franklin (1980) suggests that Ne>500 (which means a population >1530) would be necessary over the long term to reduce genetic loss, but this assumes little or no exchange of individuals among herds. Most herds are not this big, but by maintaining exchange between subpopulations and herds by reducing fragmentation and restoring habitat corridors, it is possible to maintain or increase the size of Ne. FitzSimmons and Buskirk (1992) suggest that managers use a range of one to five immigrants per generation to retain 90% of the long term genetic variability in planning supplemental transplants. Before such a program is instituted, however, studies should establish existing natural immigration rates and the implications of such a program.

2.3 Genetics

Genetic concerns in the extinction of species centre around two main factors: inbreeding depression (lowered fecundity and viability) and genetic drift (the loss of rate of variance in alleles).

2.3.1 Inbreeding

Concern about inbreeding in Bighorn Sheep has been based primarily on four main factors: 1) the popular but unsubstantiated assumption that Bighorn Sheep declined to approximately 2% of the historic population level in North America; 2) the distribution of Bighorn

Sheep on isolated mountain habitats; 3) the polygynous mating system of Bighorn Sheep; and 4) the development of human cultural features that prevent dispersal of sheep (Schwartz et al. 1986). An additional concern could be the slow recovery and recruitment rates in populations that have suffered a die-off (Demarchi 1972).

Inbreeding has not been well documented in natural populations, even in very small populations. The slight evidence for inbreeding depression in Great Tits (*Parus* sp.) is the only published account for a wild population, while several articles have been published detailing biological and genetic mechanisms that work to systematically avoid extreme inbreeding (Schwartz et al. 1986). Past concerns about inbreeding may have been based on closed populations models that had a greater chance of inbreeding. Generally, unrestricted interbreeding in large populations has been considered as the solution to genetic problems (Simberloff 1988). It is also possible that low levels of gene flow may be necessary to prevent loss of genetic diversity in small populations (Schwartz et al. 1986). Inbreeding may be a minor problem in Bighorn Sheep due to interpopulation movements that are difficult to detect (e.g., long range movements of individual males). Some inbreeding effects have been hypothesised, however, due to the correlation of poor horn growth to age 3.5 years with bottlenecks of population size <60 of Bighorn Sheep compared to herds with N≥150, for example. Stewart and Butts (1982) suggest that minimum historic population size is the primary factor in determining horn growth rates for Bighorn Sheep. In other ungulates, allozyme variability has been positively correlated with reproductivity, fetal growth rate, longevity, and antler size (FitzSimmons and Buskirk 1992).

There are a number of mechanisms that may prevent or reduce inbreeding for Bighorn Sheep. The vagility (freedom to move) of female Bighorn Sheep and the migration capabilities of both males and females have probably been underestimated. Philopatry in Bighorn Sheep is not complete since a young ram will patch together several migration patterns from several different older rams, and females have also been shown to have more variation in their migration patterns. There is potential for much undetected intermountain movement. The ability of mountain sheep to cross artificial obstacles, such as highways, has been underestimated (Schwartz et al. 1986).

2.3.2 Random genetic drift

Random genetic drift is defined as the changes in allele (forms of a gene) frequency in a population from one generation to another due to chance fluctuations. Genetic drift is a concern for smaller populations, such as Bighorn Sheep, because of the potential for loss of alleles. The particular combination of alleles of four genes on a chromosome is called the haplotype, and the haplotype frequency can be compared among groups of Bighorn Sheep to detect possible genetic drift and loss of alleles. Bighorn Sheep would be expected to have substantial genetic drift due to overlapping generations, few breeding females in most populations (f=<100), dramatic population size changes over time, and the sometimes high variation in reproductive success of females (Luikart and Allendorf 1996).

Of the 50 Bighorn Sheep tested from native herds in BC and Alberta, 48 individuals had the same mitochondrial mtDNA AAA haplotype (Luikart and Allendorf 1996). This was a low allozymic variation compared with sheep from Montana, Wyoming, and Colorado (Luikart and Allendorf 1996). Low allozymic variation indicates that there has probably been genetic drift in the populations of Bighorn Sheep in Canada. Luikart and Allendorf (1996) attribute the lower level of genetic variation to probable founder effect and genetic drift during recolonisation following the Wisconsin Ice Age 10,000–20,000 years ago.

The Sun River herd in Montana and the Tarryall herd of Colorado had the highest genetic variation of all the herds tested (Luikart and Allendorf 1996). These are some of the largest herds in the US that have been used as source populations for transplants. The metapopulation structure of these herds has probably assisted in maintaining different mtDNA haplotypes (Luikart and Allendorf 1996). Sun River is a metapopulation of contiguous herds that at one time was a contiguous population with herds in Alberta and BC (Luikart and Allendorf 1996). Thus, the differential in genetic variation between the RMBS in BC and the Sun River herd confirms that the exchange of individuals has dropped or ceased. The historic connection between these herds may need investigation and then, depending on the conclusion of such a study, perhaps corridor restoration would be appropriate, if feasible.

Generally, haplotype frequency was heterogeneous among herds within 5–15 km of each other, indicating that these herds maintain separate cohesive groups with little or no exchange of individuals (Luikart and Allendorf 1996). There is great difference in the variation of mtDNA as exemplified by the heterogeneity in frequency of haplotypes among herds and the distinct and differentiated haplotypes among regions. Overall, Luikart and Allendorf (1996) conclude that Rocky Mountain Bighorn Sheep have a sequence divergence in the number of haplotypes that is within the range of five other artiodactylids in North America, and that the mtDNA variation in RMBS is higher than in DBS. The strong genetic drift indicated by population differentiation in RMBS may be due to low levels of gene flow of mtDNA among contemporary herds. The low gene flow may be the result of habitat fragmentation and population bottlenecks, such as epizootic die-offs over the last 200 years (Luikart and Allendorf 1996). The differentiation could also be due to the philopatry and forest encroachment in habitat over the past 10,000 years (Luikart and Allendorf 1996). Phylogeographic analysis has not indicated long term population isolation or difference. Yet Luikart and Allendorf (1996) warn that lack of phylogeographic structures does not negate the importance of managing highly differentiated populations as separate units to maintain variation and distinctiveness. However, this must be balanced by ensuring a certain level of interconnectiveness, whether naturally or possibly by planned periodic translocations (which must consider genetic uniqueness and potential introduction of pathogens).

While there may not be genetic concerns overall for RMBS in North America, the populations in Canada, and particularly in BC and the most northern herd in Alberta, may require a slightly different management approach. The BC herd and the northern Alberta herd had 0.00 haplotype diversity compared to 0.65 of herds immediately south in Montana (Luikart and Allendorf 1996). BC and Alberta should ensure that gene flow is not impeded among shared herds through fragmentation of habitats or the loss of connective corridors. For herds that have experienced die-offs, rapid population growth will increase the chance that different alleles at a locus will be increased. Since only six sheep from Premier Ridge and Columbia Lake were tested in BC, the variability of sheep from other locations in BC may be higher and, therefore, natural historic or potential movement should not be restricted.

If genetic drift is suspected to be problematic in the future, then the introduction of some genetic material with more variability could be explored, perhaps from herds with more variation. While gene flow from herds with more variability can reduce random genetic drift problems, it can also facilitate disease transmission and actually reduce variability over the long term. Thus, it is important that the metapopulation structure be maintained by using transplanting judiciously and not creating a new problem through too much interbreeding.

The metapopulation structure is a useful model for conceptualising environmental, demographic, and genetic issues for Bighorn Sheep. It can be used to develop testable hypotheses and subsequent management programs and also to evaluate the status of RMBS in British Columbia.

3 SUB-SPECIES DISTRIBUTION AND ABUNDANCE

3.1 North America

3.1.1 Historic distribution

For this status report, distribution describes a species' geographic and ecological range – the species' actual occupation of an area, based on the accumulation of information over long periods. It does not represent one point in time, such as a sighting or an occurrence (Gaston 1996). Useful historical information on the distribution of RMBS at the time of European and Asian settlement in western North America is severely lacking. Estimates of distribution exist at the very specific level of specimen occurrences useful for taxonomic studies (e.g., Cowan 1940; Hall and Kelson 1959), or the very general level useful only to provide a gross overview (e.g., Hornaday 1914; Seton 1927; Buechner 1960; Johnson 1983). The distribution of RMBS prior to European and Asian settlement was postulated by most historians to have been a more or less continuous range throughout the Rocky Mountains of western North America from northwestern Alberta to northern New Mexico and Arizona (Buechner 1960). Buechner (1960) lends credibility to Seton's (1927) claims of a super-abundant bighorn fauna with extensive, almost continuous distribution. Recently mountain sheep biologists have undertaken comparisons of past distribution based on the generalised maps of Hornaday (1914) and Seton (1927) with current distribution based on accurate information (Demarchi and Demarchi 1999). Seton's (1927) map presents an exaggerated picture of a species formerly vast in extent and currently suppressed to only 2% of its former abundance (Luikart and Allendorf 1996). While no specific information is available about the details of the historic range of RMBS, as a habitat specialist with a narrow niche, they were unlikely to have had a continuous distribution or to have been as abundant as these authors claimed and others continue to suggest (Hebert and Evans 1991). The ecological niche used by RMBS was probably always more specific and restricted than maps of their original North American distribution imply (Demarchi 1977; Johnson 1983).

The extent of the historic distribution was probably only slightly greater than the present range, particularly in British Columbia and Alberta. Severe winters have always restricted the availability of winter range and the quality and quantity of forage in those winter ranges, making these limiting factors. In addition, the availability of cliffs limited their distribution as high visibility areas and escape terrain are a necessary component of strategy for avoiding predation. Rocky Mountain Bighorn Sheep were bounded by other subspecies with which they occasionally bred, leading to intergrades between subspecies (Cowan 1940; Buechner 1960). To the west were the California (*Ovis canadensis californiana*) bighorns in British Columbia, Washington, Oregon, California, and the western part of Nevada. To the south and southwest were the Desert bighorns (DBS) (*O. canadensis nelsoni*) in Nevada, California, New Mexico, Arizona, Texas, and Mexico. To the east were the Audubon bighorns (*O. canadensis auduboni*) of the Badlands in western Montana, the Dakotas, and Nebraska, but these were never numerous. The last record of the occurrence of this subspecies was in 1916 (Buechner 1960). They have since been replaced in North Dakota with CBS from the Junction in 1956 and 1989, and from Big Bar in 1996 (Hatter and Blower 1996), and in Montana and South Dakota with RMBS.

3.1.2 Current distribution

The historic scattered distribution of RMBS has been reduced significantly to become smaller patches of suitable habitat due to displacement by domestic sheep, settlements, access corridors, intensive agriculture, and industrialisation.

Currently, Rocky Mountain Bighorn Sheep occur in scattered locations along the Rocky Mountains from west of Grand Cache, Alberta to northern New Mexico (Figure 1). RMBS are more abundant and continuously distributed in the rainshadow of the Eastern Slopes of the Continental Divide throughout their range. The most northerly portion of the range of Rocky Mountain Bighorn Sheep is in the Narraway and Kakwa watersheds of British Columbia and Alberta, tributaries of the Smoky River, 75 km west of Grand Cache on the Continental Divide. The southerly limit of the Continental Range is northern New Mexico and Arizona. While the last sighting of a native Rocky Mountain Bighorn Sheep in New Mexico was in 1906, there were reintroductions from Banff National Park beginning unsuccessfully in 1932, and then continuing with further successful reintroductions in the 1940s, 1960s, and 1970s from Banff, Wyoming, and Montana, which resulted by 1970 in a population of 300 RMBS (Synder 1974). RMBS from British Columbia and Alberta were also transplanted to aid recovery efforts in California, Oregon, New Mexico, Utah, Washington, and Wyoming (Hatter and Blower 1996; Smith et al. 1996).

A reliable habitat capability analysis would be useful to determine the limits of historic distribution and abundance. Attempts to classify Bighorn Sheep habitat capability on an ecoregion scale or smaller in the U.S. have not been successful (Boyd and Armentrout 1996). Demarchi (1994) developed and mapped the Central North American Cordillera and adjacent plains to the ecodivision and the ecoprovince levels. A comparison of current Bighorn Sheep distribution based on Trefethen (1977) produced a reasonable correlation with these ecodivisions based on a visual assessment (Figure 1). Currently, the four Bighorn Sheep subspecies occur in eight ecodivisions and in 18 ecoprovinces in North America (Table 2). The ecodivisions and ecoprovinces in Canada that support RMBS occur primarily along the east slopes of the Rocky Mountains to Grand Cache, Alberta and along the west slopes of the Rocky Mountains to Golden, BC (latitude 51°). Stelfox (1992) describes these eastern slopes as "pervious shale, sandstone, and limestone mountains with steep eastern escarpments and gentle westerly slopes which have developed into productive grasslands." The critical reason why these areas are chosen by sheep for winter is that the snow is shallow as a result of prevailing westerly winds and solar radiation. South of latitude 51° in the East Kootenay Trench, RMBS are found west of the Continental Divide; the western slopes of the Rockies in this area are situated in a rainshadow and have a milder climate and consist of a less resistant geological substrate than those to the north of latitude 51°.

3.1.3 Abundance

Seton (1927) estimated that prior to 1800 there were 1.5 to 2.0 million Bighorn Sheep, including all subspecies, across North America from Canada to Mexico (Buechner 1960). However, because all species and subspecies of mountain sheep in North America share common habitat requirements and exist at similar densities, comparing historic and present North American distribution and abundance of Dall's sheep and Stone's sheep brings the accuracy of this estimate into question. Demarchi (1977) maintained that Seton's estimate was about ten times too high and that approximately 150,000 to 200,000 was a more realistic estimate of historic Bighorn Sheep abundance. Population size is determined by ecological niches and by density-dependence, birth, death, and dispersal characteristics of the species. Bighorn Sheep are too narrowly defined to have been able to utilise all of the habitat within the range drawn by early conservationists, such as Hornaday (1914) and Seton (1927).

Regardless of their original numbers, bighorn populations declined significantly during the last half of the 1800s due to excessive hunting, scabies disease,

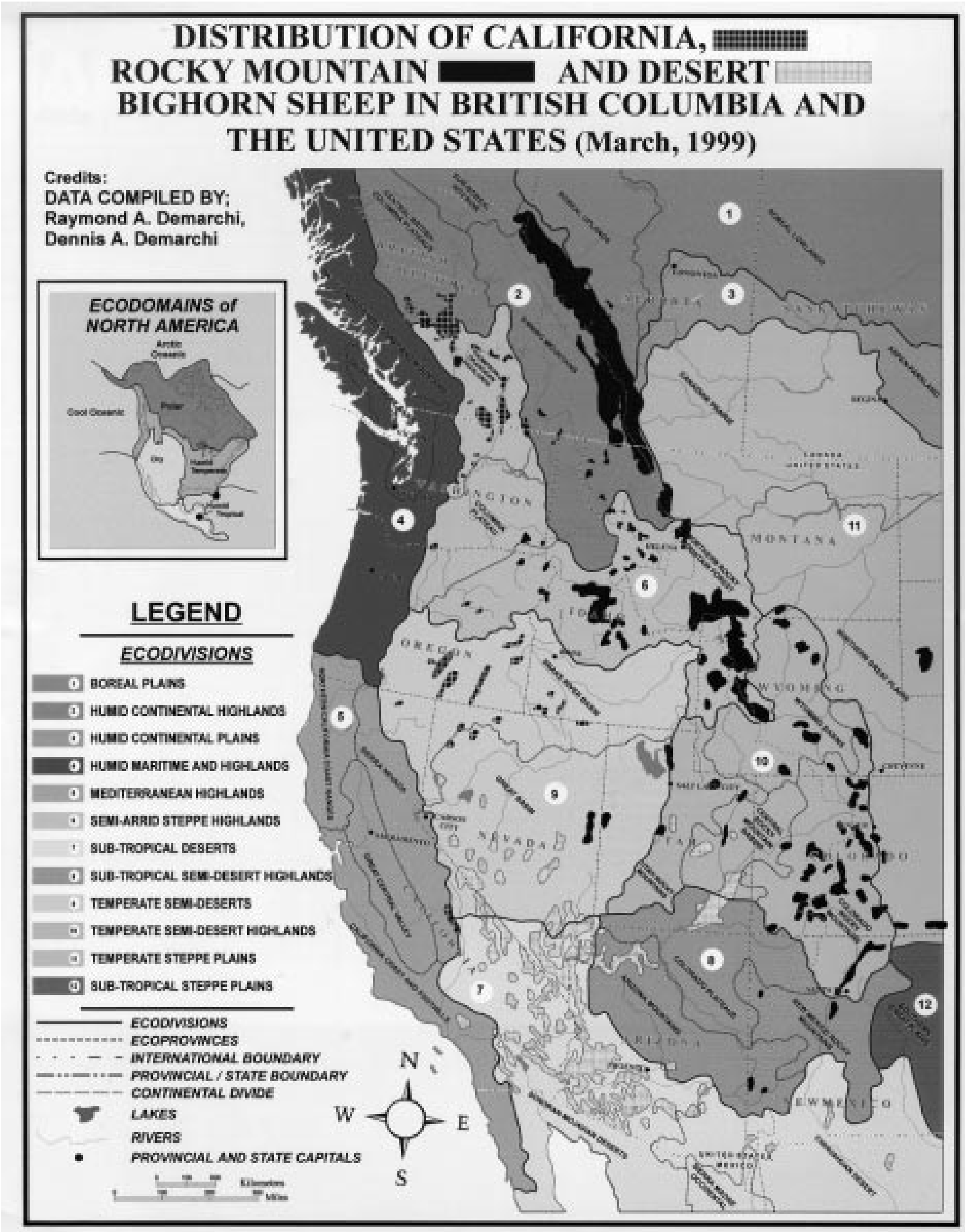

Figure 1. Distribution of three subspecies of Bighorn Sheep in North America within ecodivisions and ecoprovinces of North America (from Demarchi 1994).

Table 2. North American distribution of the three major subspecies of *Ovis canadensis* in relation to ecodivisions and ecoprovinces (from Demarchi 1994).

Ecodivision	Ecoprovince	Bighorn Sheep Subspecies
Humid Continental Highlands	Sub-boreal Interior	*canadensis*
	Shining Mountains	*canadensis*
	Central British Columbia Plateaus	*californiana*
Semi-arid Steppe Highlands	Northern Rocky Mountain Forest	*canadensis* + *californiana*
	Columbia Plateau	*californiana*
	Thompson-Okanagan Highlands	*canadensis* + *californiana*
Sub-tropical Deserts	Sonoran-Mojavian Deserts	*nelsoni*
Sub-tropical Semi-desert Highlands	Colorado Plateaus	*nelsoni*
	Arizona Mountains	*canadensis* + *nelsoni*
	New Mexico Rocky Mountains	*canadensis*
Temperate Semi-deserts	Great Basin	*canadensis* + *nelsoni*
	Snake River Basins	*californiana*
Temperate Semi-desert Highlands	Wyoming Basins	*canadensis*
	Colorado Rocky Mountains	*canadensis*
	Utah Rocky Mountains	*canadensis*
	Central Rocky Mountain Basins	*canadensis*
Temperate Steppe Plains	Northern Great Plains	*canadensis* + *(auduboni)*
Mediterranean Highlands	Sierra Nevada	*californiana*

livestock competition, and restriction of winter range (Hornaday 1914; Cowan 1940; Buechner 1960; Sugden 1961; Stelfox 1971; Goodson 1982). Populations of both RMBS and CBS in many mountain ranges in the United States were eliminated, the latter subspecies finally disappearing from all but a remnant area in Southern California. A major reduction of RMBS occurred in Yellowstone National Park between 1870–1877 (Buechner 1960), and in Idaho between 1870–1880 and 1890–1910 (Smith 1954). In Wyoming, Bighorn Sheep generally maintained high population levels until 1880, when domestic sheep were herded onto bighorn range (Buechner 1960; Goodson 1982). Devastating psoroptic scabies epidemics, presumably contracted from domestic sheep, were reported beginning in 1859 in Colorado and spreading to other western states concomitant with the expansion of domestic sheep ranching (Boyce et al. 1990). Efforts began in the late 1800s to reverse this trend and included hunting closures, intensified predator control [Lynx (*Lynx canadensis*), Bobcat (*Lynx rufus*), bear (*Ursus* spp.), Golden Eagle (*Aquila chrysoetos*), Coyote (*Canis latrans*), Gray Wolf (*Canis lupus*), and Cougar], and the establishment of some refuges and parks. In spite of these efforts, there were major die-offs attributed to scabies, which reduced populations considerably throughout the range in the 1920s, 1930s, and through the 1950s (Buechner 1960; Stelfox 1976; Boyce et al. 1990). In Montana, the Sun River herd was decimated during the winters of 1925, 1927, and 1932 (Couey and Schallenberger 1971). By the 1930s, Bighorn Sheep were unhealthy and unproductive, and in 1941 they reached such a low ebb in density and distribution that they were considered endangered (Couey and Schallenberger 1971).

The number of domestic sheep on rangelands in 11 western states increased to approximately 28 million in 1920 and remained high until 1945 (Goodson 1982). In nearly all instances, major RMBS die-offs coincided with dates of introductions of domestic sheep (Goodson 1982; Boyce et al. 1990).

Reintroductions of Bighorn Sheep into empty habitats and habitat restoration in the 1950s, began to slow the decline in some areas, but many populations continued to decline and many attempts at reintroductions ended in failure (Trefethen 1977; V.L. Coggins, pers. comm.). The largest native herd in Montana, in the Sun River drainage, numbered 6000 in 1971 (Couey and Schallenberger 1971). During the period 1945 to 1978, significant declines in grazing of domestic sheep on western rangelands in the USA and Canada occurred largely due to economic factors, including rising transportation and herding costs, and increased foreign mutton imports (Goodson 1982). The removal of domestic sheep freed many vacant bighorn habitats of the serious threats of fragmentation, range deterioration, and exotic diseases and parasites. A program of transplants and range enhancements was initiated (Wishart 1975; Trefethen 1977; Goodson 1982; Hatter and Blower 1996).

By 1960, there were 15,000 to 18,200 bighorns of all sub-species in the United States (Buechner 1960).

Table 3. Estimates of Rocky Mountain Bighorn Sheep in North America 1975 to 1996 (Gilchrist 1998).

Jurisdiction	1975	1983	1993	1996
Alberta Provincial Lands	4520	4500	5000	6000
Alberta National Parks	4000	4500	4750	5000
British Columbia	1250	2100	3100	3000
Arizona	0	100	500	600
California	0	0	0	0
Colorado	5000	5200	6000	6532
Idaho	4500	4500	4500	4500
Montana	2250	3000	5000	4500
New Mexico	300	350	630	570
North Dakota	0	0	0	0
Nevada	6			329
Oregon	55	250	515	500
South Dakota	150			150
Texas	0	0	0	0
Utah	0			500
Washington	20	100	335	200
Wyoming	4500	6065	6965	6860
TOTAL	**26,281**	**30,665**	**37,295**	**39,241**

Buechner (1960) suggested that the population could and should be increased two to three times the 1960 level. The US RMBS population in 1960 was 8300–9900, which increased to 12,000–14,000 in 1976 (Trefethen 1975; Demarchi 1977) (Table 3). Shackleton et al. (1999) estimated that the population of all subspecies of bighorns in North America in 1994 was <62,000. Armentrout and Boyd (1994) estimate that there has been a 35% reduction in historic amount of habitat in the US. Livestock grazing, timber management practices, and habitat fragmentation continue to reduce habitat. Armentrout and Boyd (1994) maintain that 15 of the 55 bioregions occupied by RMBS have less than 50 individuals and there is potential for an additional 19% loss of habitat. Livestock grazing and disease are the top two population limiting factors (Armentrout and Boyd 1994).

3.2 Canada: Alberta and British Columbia

3.2.1 Historic and current distribution

British Columbia's major native Rocky Mountain Bighorn Sheep population is distributed in herds in the Rocky Mountains of the East Kootenay region of southeastern BC between the Kicking Horse River in the north and the US border in the south, including one small herd that ranges into Montana east of Eureka during the summer months. British Columbia's Rocky Mountain Bighorn Sheep population is connected at both extremes and along its range with sheep herds in Alberta (Figure 2). Thus Rocky Mountain Bighorn Sheep exist as one large more or less continuous population in the Canadian Rocky Mountains, south of 54° 40′. While the higher elevation alpine and subalpine habitats along the summit of the Continental Divide serve as summer range, identifiable separate herds winter in either province, with several small herds wintering on or immediately adjacent to the summit of the continental divide (Kakwa, Simpson River, Ewin Ridge, Sheep Mountain, Deadman Pass, and Crowsnest Pass herds). In Alberta, the range is nearly continuous along the Rocky Mountains East Slope during the growing season and occurs in specific, defined locations of suitable habitat during the winter months.

Although there have been isolated sightings north of Ice Mountain (54° 40′), the most northerly part of their range begins on the BC-Alberta border in an area between the Narraway River and Jarvis Creek, from where it extends south to about the headwaters of the Morkill River. The distance between Jarvis Creek at 54° 25′ and the next herd wintering in BC at Golden at 51° 18′ is 380 km. Sheep from Alberta herds only occur occasionally and sporadically during the summer along the continental divide in the remote headwaters of the Jarvis, McGregor, Morkill, and Wood rivers (i.e., Hamber Provincial Park). The most continuous distribution of RMBS habitat in BC begins north of the Kicking Horse River at Golden and extends southward between the East Kootenay Trench and the continental divide to the International Border (49°). The greatest changes between the historic and current distribution of RMBS in BC have been the introduction of RMBS in 1927 into the Spence's

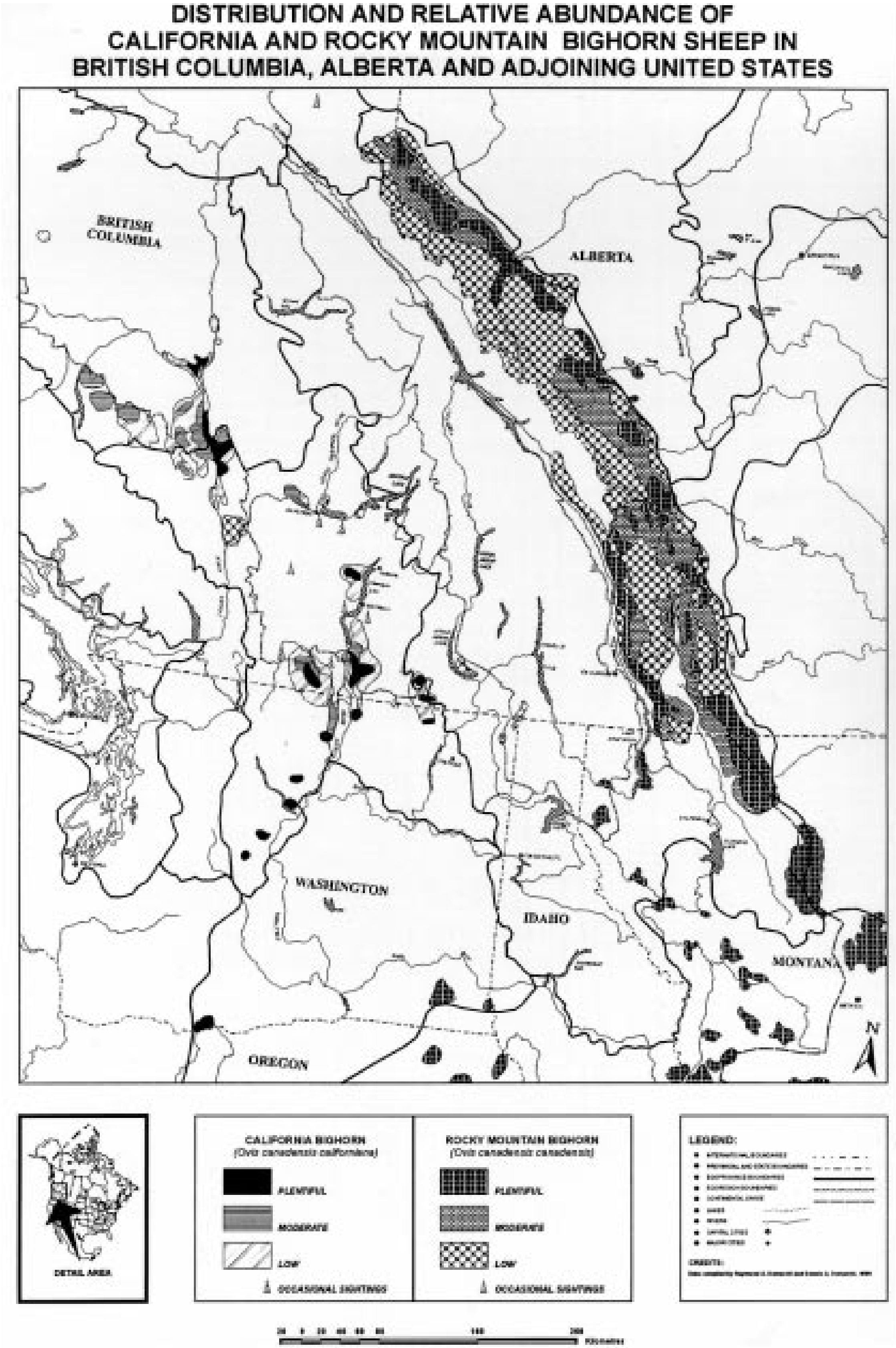

Figure 2. Current distribution of California Bighorn Sheep and Rocky Mountain Bighorn Sheep by ecoregions and ecosections in British Columbia and adjacent jurisdictions (after Blower 1988; Demarchi 1994; L. Bailey, pers. comm.; J. Jorgenson, pers. comm.; R. Lincoln, pers. comm.).

Bridge and Squilax areas which lie within and adjacent respectively, to historic CBS ranges.

Two other areas now support struggling herds in the Castlegar and Salmo areas in the West Kootenay, which were never known to support either subspecies (Bailley-Grohman 1900; Cowan and Guiguet 1965; G. Woods, pers. comm.). The Deer Park area near Castlegar received 20 RMBS in 1985 and 18 in 1957 from the East Kootenay (Hatter and Blower 1996) (Table 4). The South Salmo herd is the result of an unassisted northern expansion of RMBS from a herd in the Hall Mountain area of northeast Washington that originated with transplants from Waterton Lake National Park and Thompson Falls, Montana in 1972 and 1982, respectively (Johnson 1983). Both the South Salmo and the Hall Mountain herds are maintained by supplemental winter feeding.

3.2.2 Historic abundance

In Canada, populations of RMBS were believed to be >10,000 between 1800 and 1860, and were located concentrated in the Rocky Mountains of southeastern British Columbia and adjacent Alberta (Stelfox 1971, 1992). Unlike the USA, where Bighorn Sheep were nearly decimated during this period (Buechner 1960), this high level of abundance persisted despite interspecific competition from other ungulates, introduced horses, cattle and domestic sheep, predation, hunting by First Nations people, adverse weather, fires, and disease (Stelfox 1992). Declines in local populations began to be noticed as early as 1850, and by 1905, enough depletion was evident both in BC and Alberta that an inventory was commissioned (Millar 1916). This inventory, completed in 1915, confirmed that a dramatic decline had brought the population down to 1775–3400 individuals. Year-round, non-selective hunting by First Nations people, explorers, miners, and railway workers had a drastic impact, driven by the use of firearms, an increase in demand for meat, particularly the preferred meat of Bighorn Sheep, and the high value of trophy ram heads (Millar 1916). Severe winters in 1886–87, 1887–88, and 1906–07, were additional factors along with interspecific forage competition, particularly from burgeoning numbers of cattle and wild horses, and railway and mining construction (Stelfox 1971, 1992). Liberal game laws and a general disregard for them were blamed for the decline and thus began 52 years of continuous protection from hunting in some areas (Stelfox 1992).

From 1915–1936, the Canadian population increased from 2500 to 8500 due to protection from hunting, decreased interspecific competition from livestock and other ungulates, reduced predation due to low Cougar and wolf populations, and favourable range conditions due to extensive fire in late 1800s and early 1900s. This period of higher population numbers was followed by a period from 1937 to 1950 of rapid declines of 75%–85% in many national parks and die-offs on provincial lands (Stelfox 1976, 1992). The effect of livestock was not limited to forage competition but also involved the introduction of exotic diseases. The three major die-offs in BC since 1939 followed contact between Bighorn Sheep and

Table 4. History of Rocky Mountain Bighorn Sheep transplants within southeastern British Columbia (from Hatter and Blower 1996).

Year	Source	Destination	Number
1982	Wigwam	Bull River	16
1984	Columbia Lake	Elko	28
1984	Columbia Lake	McGuire Creek	7
1985	Columbia Lake	Tulip Creek	20
1985	Columbia Lake	McGuire Creek	10
1986	Columbia Lake	Elko	11
1986	Stoddart Creek	Wigwam	47
1986	Columbia Lake	Wildhorse	5
1987	Columbia Lake	Wildhorse	12
1987	Columbia Lake	Lakit Lake	11
1987	Columbia Lake	Mause Creek	17
1989	Radium	Wigwam	20
1989	Stoddart Creek	McGuire Creek	19
1992	Radium (Stoddart Creek)	Ram Creek	22
1993	Ewin Ridge	Bingay	7
1993	Radium	Ram Creek	27
1994	Radium	Ewin Ridge	10
TOTAL			**289**

domestic sheep on their ranges (Goodson 1982; Davidson 1994). Fire suppression and consequent forest encroachment on ranges, increased vehicular access into mountain areas, and highway and railway mortality all had an increased impact on populations. Recovery of bighorns occurred during the 1960s in Alberta due to reduced stocking rates of livestock and lower numbers of wild ungulates, mild winters, and low predation as a result of extensive government supported predator control.

3.2.3 Current abundance

Ten years prior to the 1964 die-off at Bull River, Smith (1955) predicted the East Kootenay die-off would occur and be caused by domestic sheep infecting the wild sheep. Disease was recognized as a major factor in the USA CBS die-offs. While fluctuations may occur normally in wild populations, the amplitude of those fluctuations, once diseases contracted from domestic sheep were a factor, were dramatic enough to seriously threaten populations. Along the eastern slope of the Rocky Mountains in Alberta, there were approximately 10,000 bighorns by 1970 (Stelfox 1971). In 1975, Trefethen estimated the population of Rocky Mountain Bighorn Sheep in Canada was between 8400 and 9900. In 1987, the estimate for RMBS in British Columbia was 2500 and increasing (Murray 1987). While Canada's population has fluctuated widely (Demarchi and Demarchi 1967; Stelfox 1971), the total population of Rocky Mountain Sheep in Canada was estimated to be 11,500 to 11,700 in 1997: 10,300 in Alberta and 1500 to 1700 in British Columbia (Shackleton 1997) (Table 5).

In 1965–67, in the East Kootenay, where the sheep were concentrated, an unusually deep and crusted snow combined with pneumonia-lungworm disease and deteriorated winter ranges resulted in a major die-off, reducing the population from more than 2000 to less than 1000, a 70% reduction in the main herds affected (Demarchi 1977; Goodson 1982; Stelfox 1992). Davidson (1992) describes die-offs in 1964–67 and 1981–83 in the East Kootenay, as being preceded by mixing of domestic sheep with wild Bighorn Sheep for at least 1 month. By 1976, there had been a recovery and the numbers had increased to about 1300, 60% of the pre-die-off population (Demarchi 1977; Demarchi et al. 1977; Wishart 1974). Of these, 75 to 100 were in Kootenay National Park and the rest were on provincial lands. The total of other small populations in British Columbia resulting from transplants into former CBS habitats, plus the small native Kakwa herd numbered between 250 to 350. Natural recovery from the 1960s die-off brought the population back to 2100 by 1980 but once again an epizootic pneumonia disease reduced the population to 1550 by 1983, a decrease of 26% (Stelfox 1992; Davidson 1994). Heavy snowfalls and wet, early summers provided conditions suitable for the lungworm's intermediate snail hosts which preceded die-offs in 1964 and 1981 (Schwantje 1988b). The synergism of infectious agents and environmental factors in the respiratory disease complex of RMBS has occurred in 12 herds along the western, low elevation ranges while the 8 herds at higher elevations in the Elk River Valley were not affected (Schwantje 1988b). By 1998, the BC Wildlife Branch estimated that there were 3100 RMBS in British Columbia.

3.2.4 Population trends

Demarchi (1970) maintained that, "Since their earliest recorded sightings in the early 1800s by David Thompson, Bighorn Sheep populations situated in the Rocky Mountain Trench have followed a series of wide fluctuations in their numbers." Stelfox (1976) concludes that Bighorn Sheep in the Rocky Mountains have a cyclic die-off every 25 years as a result of exceeding the range carrying capacity. The die-offs sometimes last for three years, killing nearly all individuals in some herds (Demarchi and Demarchi 1994). Malnutrition, resulting from exceeding the carrying capacity, in concert with unusually severe winters, makes animals susceptible to pneumonia-lungworm disease. Predation, interspecific competition, and man-made influences are additional factors. The eruptive fluctuation patterns (an increase in numbers over two decades followed by a marked decline) (Caughley 1970) lead Stelfox (1976) to conclude that Bighorn Sheep have no intrinsic self-regulating mechanisms. Mechanisms that regulate distribution and abundance are density-dependent processes (biogeography, evolution) at the macro-scale, and stochastic events (local populations and interacting species) at the local population level, but habitat and resource availability are also important. Shackleton (1997) maintains that populations of Rocky Mountain Bighorn Sheep are increasing or stable in Canada at the present time, while he recognises several southern populations are recovering from recent, disease-related die-offs.

Fluctuations in bighorn numbers may be a natural part of their population cycles (M. Festa-Bianchet, pers. comm.), but it is unlikely that the amplitude of those fluctuations were as high before domestic sheep introduced pneumonia to the wild herds and habitats were reduced in size. Die-offs of 75%–85%

Table 5. Population estimates of Rocky Mountain Bighorn Sheep in British Columbia 1960 to 1996 (Wildlife Records 1998).

Region/MU	Location	Sub pop	1960	1970	Year 1985/86	1990/91	1995/96
4-01	Flathead	Flathead			40	40	40
4-02	Phillips Creek	Galton			35	70	100
4-02	Maquire/Red Canyon				30	50	50
4-02	Wigwam.China Wall	Wigwam			100	200	300
4-21	Wildhorse River	Wildhorse-Lussier			14	70	50
4-21	Estella (tracy Creek)				55	80	80
4-21	Premier Ridge				120	160	120
4-21	Marmalade				55	70	70
4-21	Lussier/Blackfoot (Van Nostrand)				60	90	60
4-22	Elko (Lizard Ridge)	Bull-Lizard			30	100	85
4-22	Bull River				40	110	130
4-22	Upper Bull (Boivin)	Elk Valley-West			15	20	20
4-23	Brule Creek				30	30	30
4-23	Crossing Creek				50	50	50
4-23	Quarrie creek				70	30	50
4-23	Bingay Creek				15	30	30
4-24	Rock Canyon				15	15	15
4-23	Upper Elk (Tobermorey)	Elk Valley-East			30	30	30
4-23	Eagle/Brownie				25	25	50
4-23	Todhunter				25	25	35
4-23	Imperial Ridge 20				20	20	20
4-23	Ewin Creek				225	225	225
4-23	Sheep Mountain				70	70	70
4-23	Deadman Pass				20	20	40
4-23	Corbin				25	25	25
4-24	Whiteswan	White River			20	20	20
4-24	Mt. Glenn				20	20	20
4-24	Nine Mile (Gibralter Rock)				20	20	20
4-25	Columbia Lake	Columbia Valley-East			250	225	120
4-25	Windermere				25	35	35
4-25/34	Radium/Stoddart Creek				160	200	240
4-25	Assiniboine	Upper Kootenay			120	120	60
4-25	Kootenay/Cross River				15	15	15
4-36	Kicking Horse Pass	Kicking Horse			0	15	35
7-18/19	Kakwa Kakwa				95	95	100
4-08	South Salmo (Lost Mt)	introduced			5	30	25
4-15	Deer Park (Pine Ridge)	introduced			0	70	40
3-17	Spences Bridge	introduced			100	350	400
326	Chase	introduced			40	6	20
TOTAL					**1944**	**2540**	**2485**

cannot be sustained over the long term. The most recent population recovery in the East Kootenay can probably be attributed to habitat enhancement and better management of winter ranges by instituting rest- and deferred-rotation grazing systems, imposing motor vehicle access restrictions on winter ranges, and attempted disease control (Davidson 1991). However, as the population increases, so does the probability of an epizootic die-off. A die-off may be imminent within the next five years based on the past frequency of die-offs every 20 years. If the next die-off does not reduce the population below the 1983 levels of 1550 and if recovery occurs, particularly to 1997 levels, then it could be that these cycles will continue indefinitely and may not be a problem. However, if the trend continues to move downward, then there may be concern about the ability of these sheep to recover from a subsequent population crash. The estimated trend, based on estimated population rates from 1920 to 1983, appeared downward in the East Kootenay (Davidson 1994).

This trend, however, is based upon higher population figures from 1900 to 1920, when census figures were less reliable than figures from 1930 to the present. Thus, the trend is upward during the short term of 20 years, but over the long-term it is unknown.

4 HABITAT

4.1 Habitat Distribution

Demarchi's (1994) Ecoregions of North America defines the limits of Bighorn Sheep habitat distribution by subspecies or ecotype, for the most part, as shown by Figure 1. There is a close correlation between the distribution of the three subspecies of Bighorn Sheep and the boundary lines for ecodivisions and ecoprovinces (Demarchi and Demarchi 1999). Therefore, the respective subspecies appear to fit within definable ecological units (or conditions). An attempt to apply the ecoregions proposed by Bailey et al. (1994) resulted in a low correlation with sheep distribution in North America (Boyd and Armentrout 1996).

Figure 2 is a further subdivision of ecological units to the ecoregion and ecosection levels and demonstrates a high correlation between these habitat units and the distribution of RMBS and CBS shared between British Columbia, Alberta, Montana, and Washington. This results in a logical explanation for the ecological separation of the two subspecies of Bighorn Sheep.

4.1.1 North America

Populations of RMBS have been managed in isolation by province and state. However, many populations are connected and the distribution of habitat points this out clearly. Habitat is not restricted by borders and neither are sheep; British Columbia shares its RMBS population with Alberta and Montana. At present, North America has been mapped to the ecoprovince level and British Columbia to the ecosection and habitat unit or biogeoclimatic subzone level. Table 6 indicates the ecodivisions and ecoprovinces that contain RMBS habitat and reflects the differences in resolution between North America and British Columbia.

4.1.2 Canada

The BC portion of the Rocky Mountain Bighorn Sheep population is integrated with the Alberta portion. Populations that winter in one province are likely to migrate into summer range that straddles both provinces. Table 7 exhibits the ecoprovinces and ecoregions inhabited by RMBS in British Columbia and Alberta.

4.1.3 British Columbia

The great topographic relief where bighorn habitat occurs creates a variety of habitat types; in fact, several biogeoclimatic zones occur in proximity wherever there is bighorn habitat (Shackleton and Bunnell 1987; Demarchi et al. 1990). This variation results in the utilisation of diverse habitat types within home ranges. Rocky Mountain bighorn prefer habitats with steep grasslands and broken krummholz terrain (Demarchi 1986), including open grasslands, alpine, subalpine, shrub-steppe, rock outcrops, cliffs, meadows, moist draws, riprian areas, talus slopes, plateaus, deciduous forest, clearcut or burned forest, and conifer forest. Use of habitat varies daily and seasonally with changes in requirements for food, rest, safety, thermal cover,

Table 6. Ecodivisions and ecoprovinces where Rocky Mountain Bighorn Sheep habitats are found in North America (from Demarchi 1994).

Ecodivision	Ecoprovince
Humid Continental Highlands	Sub-boreal Interior Eastern Continental Ranges
Semi-arid Steppe Highlands	Northern Rocky Mountain Forest Thompson-Okanagan Highlands
Sub-tropical Semi-desert Highlands	Arizona Mountains New Mexico Rocky Mountains
Temperate Semi-deserts	Great Basin
Temperate Semi-desert Highlands	Wyoming Basins Colorado Rocky Mountains Utah Rocky Mountains Central Rocky Mountain Basins
Temperate Steppe Plains	Northern Great Plains

Table 7. Ecoprovinces and ecoregions where Rocky Mountain Bighorn Sheep habitats are found in Canada (from Demarchi 1995 and Ecological Stratification Working Group 1995).

Ecoprovince	Ecoregion
Southern Interior Mountains (Shining Mountains)	Northern Continental Divide Southern Rocky Mountain Trench Western Continental Ranges Eastern Continental Ranges Northern Columbia Mountains Selkirk-Bitteroot Foothills
Sub-boreal Interior	Central Canadian Rocky Mountains
Southern Interior (Thompson-Okanagan Highlands)	Interior Transition Ranges Thompson-Okanagan Plateau

Table 8. Distribution of Rocky Mountain Bighorn Sheep habitat in British Columbia in relation to the ecoregions and ecosections (described by Demarchi 1995) and biogeoclimatic zones (Ministry of Forests 1992).

Ecoregion	Ecosection and Biogeoclimatic Zone	Comment:
Northern Continental Divide	Crown-of-the-Continent (AT, ESSF, MS) Border Ranges (AT, ESSF, MS, ICH)	Summer range along Continental Divide for herds wintering in Alberta and Montana. Supports some of the largest high and low elevation wintering herds in the province. Extensive interchange with Alberta and Montana sheep herds.
Southern Rocky Mountain Trench	East Kootenay Trench (IDF, ICH)	Fall-winter-spring range. Contains most of BC's RMBS winter range.
Western Continental Ranges	Southern Park Ranges (IDF AT, ESSF, MS, ICH) Central Park Ranges (AT, ESSF, ICH) Northern Park Ranges (AT, ESSF, SBS)	High and low elevation wintering herds. Extensive summer range and interchange with Alberta herds. Peripheral summer range along continental divide for herds wintering in Alberta. Peripheral summer range for Kakwa herd.
Eastern Continental Ranges	Front Ranges (AT, ESSF)	BC portion supports Kakwa herd–a high elevation wintering herd on Continental Divide. Most northerly RMBH in North America. Alberta portion supports almost all sheep in Alberta.
Northern Columbia Mountains	Southern Columbia Mountains (ICH, ESSF, AT)	Colonised from 1972 transplant to Hall Mountain, Wash. Dependent on supplemental feeding.
Selkirk-Bitteroot Foothills	Selkirk Foothills(ICH, ESSF, AT)	Straggling transplant from 1985 and 1987 transplants.
Central Canadian Rocky Mountains	Hart Foothills (AT, ESSF) Hart Ranges (AT, ESSF)	Occasional summer sighting. Peripheral summer range for Kakwa herd.
Interior Transition Ranges	Pavilion Ranges (PP, IDF, MS, ESSF)	Currently viable *canadensis* herd from 1927 transplant from Banff into vacant (?) native *californiana* range. Needs DNA testing to see if cross-breeding with *californiana* is occurring.
Thompson-Okanagan Plateau	Thompson Basin (BG, PP, IDF) Northern Thompson Upland (IDF, MS, ESSF, ICH)	Spences Bridge population expansion Not considered native sheep range. Straggling *canadensis* (Chase) and *californiana* (Adams Lake) transplants.

Table 9. Biogeoclimatic zones (Ministry of Forests 1992) and broad habitat classes (Resources Inventory Committee 2000) inhabited by Rocky Mountain Bighorn Sheep in BC.

Biogeoclimatic Zone	Broad Habitat Class
Bunchgrass (BG)	Alpine Grassland (AG)
Ponderosa Pine (PP)	Alpine Meadow (AM)
Interior Douglas-fir (IDF)	Alpine Unvegetated (AU)
Interior Cedar-Hemlock (ICH)	Antelope-Brush Shrub/Grassland (AB)
Montane Spruce (MS)	Big Sagebrush Shrub/Grassland (SS)
Sub-boreal Spruce (SBS)	Bunchgrass Grassland (BS)
Engelmann Spruce-Subalpine Fir (ESSF)	Douglas-fir Lodgepole Pine (DL)
Alpine Tundra (AT)	Douglas-fir-Ponderosa Pine (DP)
	Engelmann Spruce-Subalpine Fir Dry Forested (EF)
	Engelmann Spruce-Subalpine Fir Dry Parkland (FP)
	Engelmann Spruce-Subalpine Fir Wet Parkland (WP)
	Interior Douglas-fir (DF)
	Lodgepole Pine (LP)
	Montane Shrub/Grassland (MS)
	Orchard/Vineyard (OV)
	Ponderosa Pine (PP)
	Rock (RO)
	Spruce-Douglas-fir (SD)
	Subalpine Grassland (SG)
	Subalpine Meadow (SM)
	Talus (TA)
	Trembling Aspen Copse (AC)

rutting, and lambing (Risenhoover and Bailey 1985). Table 8 lists the ecoregion, ecosection, and biogeoclimatic zones inhabited by RMBS in British Columbia. Similarly, Table 9 lists the biogeoclimatic zones and broad habitat classes used by Rocky Mountain Bighorn Sheep. These habitats are widespread throughout the bighorn's range.

4.2 Habitat Trend

Davidson (1991) indicated that 25% of the traditional winter and spring habitat of bighorn range bordering the Rocky Mountain Trench has been alienated and/or developed in the last 50 years. Such conflicting land uses have been and will be inevitable because low elevation bighorn habitat is often some of the most desirable for human development.

Davidson (1991) described forest encroachment in the East Kootenay Trench. He indicated that since fires of the 1930s, forest encroachment was occurring at 0.5% to 2% per year on low-elevation winter ranges. Critical winter range habitat has been significantly reduced throughout the Rocky Mountain Bighorn Sheep's range (up to 50%) over the last 70 years. Davidson (1991) also indicated that, due to their higher moisture regimes, encroachment has been even greater on spring and fall transition ranges. The loss of transition ranges forces bighorn to arrive on winter ranges earlier and leave later (increased sedentariness). Over-used winter ranges cause nutritional stress and may initiate lungworm-pneumonia die-offs.

Cover class analysis shows that between 1950 and 1990, habitat cover class 0 (0% to 5% forest canopy coverage of ground) at Columbia Lake East decreased from 21.3% to 12.0%. On habitats around Sheep Mountain and the Libby Reservoir, cover class 0 decreased from 8.3% to 2.3%; between Lost Dog Creek and the base of the Rocky Mountains, the decrease was from 22.1% to 2.1% (Demarchi and Demarchi 1994). Based on the above trends, the rate of winter habitat change is considered "rapid."

4.3 Habitat Status

Winter range is the most critical habitat for Bighorn Sheep (i.e., population limiting) and at present the majority of winter range is in government ownership (Crown Land). However, the current level of habitat protection is inadequate. There are only a few relatively small herds whose total year round range is protected from conflicting uses. Key lands are privately owned and these are subject to developments that are often harmful to RMBS. Demarchi and Demarchi (1994) indicate that key habitat parcels must be secured to ensure the long-term viability of bighorn winter range in the East Kootenay. There are habitat protection options that could be used, including habitat acquisition, creating Wildlife Management Areas, and conservation covenants (Loukidelis and Hillyer 1992; Findlay and Hillyer 1994).

Currently, the national and provincial park systems protect the following herds and habitat: 1) Kootenay National Park contains half the summer, half the winter, and all of the transitional ranges of the Radium-Stoddart Creek herd; 2) Yoho National Park encompasses all of the summer range but none of the winter range for the Golden herd; 3) Mount Assiniboine Provincial Park contains the entire range of the Assiniboine herd; 4) Height-of-the-Rockies Provincial Park contains the entire range of the Quarrie and Bingay Creek herds; 5) Akamina-Kishinena Provincial Park holds the summer range for the Waterton herd; and 6) Kakwa Provincial Park protects the Kakwa herd summer range in the Omineca-Peace Region. In addition to these parks, the East Columbia Lake Wildlife Management Area and the Wildlife Branch property on Mount Broadwood protect important RMBS winter ranges.

4.4 Habitat Characteristics

Rocky Mountain Bighorn Sheep winter on low-elevation, southerly exposed slopes close to rocky escarpments or talus slopes, and summer in high elevation rocky alpine and krummholz areas (Shackleton 1973; Demarchi 1986). However, two other ecotypes in the East Kootenay that winter on high-elevation, windswept, alpine and subalpine ridges (Shackleton 1973; TAESC 1982; Demarchi 1986), or winter in exposed south-facing grassland slopes at mid-elevation in the montane forest of the Fording Valley (Demarchi 1968a; TAESC 1982). As with the lower elevation wintering herds, these two ecotypes summer in the alpine and in subalpine forests. Although the three ecotypes are spatially separated, their habitat and forage requirements are similar (e.g., mineral licks, migration corridors, and proximity to escape terrain for security from predators, especially during lambing). Table 10 provides a summary of coarse habitat requirements used for Bighorn Sheep habitat mapping within the known range (Sweanor et al. 1996).

Undisturbed climax grasslands, such as bunchgrass ranges (especially Bluebunch wheatgrass [*Agropyron spicatum*] and rough fescue [*Festuca scabrella*] habitats), are particularly important as winter range for all ecotypes. Also, forest stages 4 to 9 (pole/sapling to old forest) are used for security and thermal cover. Use of grasslands and seral shrublands in the East Kootenay Trench and Border Ranges ecosections by bighorn occurs mainly during winter. Here, bunchgrasses, such as wheatgrasses (*Agropyron* spp.), fescues (*Festuca* spp.), bluegrasses (*Poa* spp.), needle grasses (*Stipa* spp.), and various forbs and shrubs (Davidson 1994) are eaten. Summer range is often alpine areas with kobresia (*Kobresia* spp.), sedges (*Carex* spp.), grasses, and a diversity of forbs used as forage.

TAESC (1982) compared seasonal forage habits of alpine and lower montane forest wintering herds in the Elk Valley. The diet pattern reflected the phenological plant development from spring to mid-summer. Sheep forced by deep snow to stay on high-elevation winter ranges until early summer (i.e., Ewin Ridge and Sheep Mountain herds) consumed proportionately more

Table 10. Coarse feature requirements used for habitat mapping of Rocky Mountain Bighorn Sheep (after Sweaner et al. 1996).

Habitat Requirement	Definition
Escape terrain	Areas with slope >27° and < 85°
Escape terrain buffer	Areas within 300 m of escape terrain and areas ≤1000 m wide that are bound on ≥ 2 sides by escape terrain
Vegetation density	Areas must have visibility >55%, as defined by the mean percent of squares visible on a 1m^2 target, divided into 36 equal squares, 14 m from an observer viewing N, E, W, S from a height of 90cm along a 10 pt, 280 m transect.
Water sources	Areas must be within 3.2km of water sources
Natural barriers	Areas that Bighorn Sheep cannot access are excluded (e.g., rivers > 200 cubic feet per second, areas with visibility <30% that are 100 m wide, cliffs with >85° slope)
Human use areas	Areas covered by human development are excluded
Man-made barriers	Areas that cannot be accessed due to man-made barriers are excluded (e.g., major highways, wildlife-proof fencing, aqueducts, major canals)
Domestic livestock	Areas within 16km of domestic sheep are excluded

graminoids (59%) than sheep from grasslands in the mid-elevation Montane Spruce Biogeoclimatic Zone (i.e., Todhunter and Imperial Mountains) (28%). The diet of the latter at the same time was dominated by forbs (57%) and shrubs (14%). In comparison, during spring and summer, the alpine-wintering sheep used fewer shrubs (3%) but also heavily utilised forbs (36%). Conifers constituted a low percentage of the diet for both ecotypes, although more conifers were used in spring and summer by the alpine-wintering ecotyope. Principal grasses included *Festuca scabrella, Poa* spp., *Elymus* spp., and *Phleum alpinum*, while *Penstemon* spp., *Epilobium angustifolium, Antennaria lanata*, and *Anaphalis margaritacea* were the preferred forbs, and *Sambucus* spp. and *Salix* spp. were the most commonly used shrubs. During the summer-fall period, the diets of both ecotypes were dominated by graminoids (*Festuca* spp. including *F. scabrella, Poa* spp., *Carex* spp., *Elymus* spp., and *Agropyron spicatum*). Forbs were predominantly *Penstemon* spp., *Antennaria lanata,* and *Lupinus* spp. The winter diet was also dominated by grasses, particularly *Festuca scabrella* (53% to 61%), *Poa* spp. (12% to 22%), *Agropyron spicatum* (up to 7%), and *Carex* spp. (2% to 11%). Shrubs and forbs, including *Antennaria lanata* (up to 9%) and *Penstemon* spp. (up to 2%), formed a relatively minor component of the winter diet.

Talus slopes and cliffs are commonly sparsely vegetated but provide habitat for resting, lambing, rutting, and security. These areas are generally vegetated with shrubs that can be important to foraging. Important shrubs and trees include: gooseberry (*Ribes* spp.), rose (*Rosa* spp.), willow (*Salix* spp.), saskatoon (*Amelanchier alnifolia*), kinnikinnik (*Arctostaphylos uva-ursi*), lodgepole pine (*Pinus contorta*), juniper (*Juniperus* spp.), and grouseberry (*Vaccinium* spp.) (Blood 1967).

The use of deciduous and coniferous forests by bighorn tends to be limited (McCann 1956). Bighorn avoid forested areas because reduced visibility impairs predator detection (Geist 1971; Risenhoover and Bailey 1985). However, open mature conifer forests can provide bighorn with important habitats for forage and thermal cover, particularly during periods of weather extremes. (Demarchi and Mitchell 1973; R. Lincoln, pers. comm.).

Very little research has been conducted to determine the specific trace mineral needs of bighorn. However, it appears that mineral licks are an important source of essential minerals for most mountain ungulates (Cowan and Brink 1949; Hebert 1967). This may be especially true for Rocky Mountain bighorns because soil-mineral content is low throughout their distribution (Van Dyke 1978), which likely results in forage with low mineral content (Smith 1954). It is also suspected that trace mineral deficiency is one factor that contributes to epizootic die-offs in bighorn (Packard 1946; Schwantje 1988a). Certain trace minerals, such as selenium and copper, have been suggested as being limiting in some habitats (Schwantje 1988a). Mineral content among licks varies considerably (Dormaar and Walker 1996), suggesting that various types of licks may serve different needs and that sheep utilise more than one lick site. Habitat conservation plans that fail to take this into account may cut off access to certain key mineral licks at the expense of sheep health. Unfortunately, the distribution and locations of mineral licks used by sheep are not well known. Demarchi and Demarchi (1994) mapped known mineral licks in the Kootenay region using information from local residents and guide-outfitters. However, it is unlikely that this resulted in a comprehensive catalogue of all mineral licks in the region.

Water requirements for bighorn are not clearly established. However, it has been postulated that water is not a limiting factor (McCann 1956) and it appears that bighorn can go long periods without free-standing water.

5 LEGAL PROTECTION AND STATUS

5.1 North America

The species has not been given any special status nationally in Canada or in the U.S., but is rated individually by each provincial and state jurisdiction. Both Alberta and BC classify RMBS as “big game” under their respective Wildlife legislation, while in the adjacent states of Montana, Idaho, and Washington, they are classified under their Game legislation as “Game Species.” Additionally, they are rated as S3 in Washington and Idaho, but are not rated in Montana. The U.S. Bureau of Land Management classifies RMBS as a “Sensitive Species.”

5.2 British Columbia

British Columbia was granted jurisdiction over all wildlife in the province, including Rocky Mountain Bighorn Sheep, under the *British North America Act.* Although classified by the Wildlife Branch of the Ministry of Environment Lands and Parks as a Blue-listed or vulnerable species, Rocky Mountain Bighorn Sheep are not protected by legislation other than by the general provisions for all vertebrate wildlife under the provincial *Wildlife Act*. The *Wildlife*

Act empowers the Director of Wildlife to regulate the use and movement of all wildlife in the province. Domestication of nearly all species of native wildlife, including Bighorn Sheep, is prohibited under the provisions of the *Wildlife Act.*

Specific areas of habitat are designated national or provincial parks or protected areas and as such are under the jurisdiction of the *National Parks Act* and the British Columbia *Park Act,* respectively. Proposed guidelines under the *Forest Practices Code of British Columbia Act* for Bighorn Sheep under the Identified Wildlife Management Strategy, while approved in February 1999, have not yet resulted in any additional habitat protection.

Next to the threat of disease from contact with domestic sheep, the introduction of disease through the transplanting of Bighorn Sheep – even though confined to the same subspecies – poses serious health risks to the province's Bighorn Sheep. Other species besides Bighorn Sheep are also at risk through *ad hoc* movements of wildlife, from marmots to bison and from bighorns to grizzlies. The existing transplant review process should be revised to include species specialists from other agencies, jusidictions or outside government.

6 LIMITING FACTORS AND RISKS

6.1 Habitat Alienation

Bighorns face many threats to their long-term survival, the greatest of which is probably human-caused habitat loss and alienation. Humans eliminate or reduce bighorn habitats in many ways. The impacts of human activities on native wildlife species are usually negative. Although hunting decimated many wildlife populations following Euro-Asian settlement of North America, today's declines are more often the result of habitat loss and alienation through the activities of people. Generally, impacts threatening bighorn habitat in the Rocky Mountain Bighorn Sheep's range are and have been:

- residential developments: townsites and rural homesteads;
- access developments: highways, logging roads, right-of-ways, etc;
- industrial developments: forestry, mining, and dams;
- agricultural developments: croplands and livestock grazing on private and Crown lands; and
- recreational developments and activities: golf courses, ski hills, all terrain vehicle (ATV) and helicopter use, etc.

A major boom in land alienation and settlement occurred in BC during the late 1890s and early 1900s. It is no accident that die-offs began in the East Kootenay on winter ranges bordering lands used for agriculture, livestock grazing, and residential, recreational, and industrial developments. Townsites for Radium Hotsprings, Fairmont Hotsprings, and Elko were built on traditional sheep range. The golf course at Radium is traditional sheep range and today sheep can be seen in these townsites and on the golf course. Approximately 25% of the winter range for bighorns in the upper Columbia area has been alienated since the 1940s (Davidson 1992). Acreages and subdivisions between Fairmont Hotsprings and Brisco have the potential to disrupt north-south migration of Bighorn Sheep along the western edge of the Rocky Mountains (Davidson 1992).

From 1971 to 1981, 38,500 ha of rural land was converted to urban use; by 1981, 276,000 ha were under urban or rural settlement in the province (Demarchi and Demarchi 1977). Bighorn Sheep have been known to abandon areas due to human activities, such as the abandonment of a ski hill area in 1986–1987 on Mt. Allan during the Winter Olympics in Alberta (Jorgenson 1988). Increased stress also negatively affected the population size, survival rates, and lungworm levels in this herd (Jorgenson 1988). Starting in 1956 (and continuing to the present), private land acquisition programs began to protect critical habitats for Bighorn Sheep, particularly on the winter ranges in the East Kootenay Trench. These include the Starr Ranch at Sheep Mountain, the Neilson property at Bull River, and private property at the east side of Columbia Lake. The size of parcels varies from a few hectares of strategically situated land to over 12,500 hectares of prime winter range on Mount Broadwood on the Wigwam River.

Agricultural developments along the Galton Range and Bull River were established on traditional Bighorn Sheep range. Beef cattle ranching situated mainly on private, arable, valley bottom lands have been allowed grazing permits and long-term leases on Crown land. These areas are the major grasslands and seral shrublands of the East Kootenay Rocky Mountain Trench. In 1987, it was estimated that Crown range supported 200,000 cow/calf pairs and yearlings during the grazing period (Demarchi and Demarchi 1987).

Mining operations became common in the later half of the 1800s as transportation links became constructed. Smaller operations had limited short-term effects, but the first coal mine near Corbin in the Fernie Creek Basin during the Second World War presaged the massive open-pit mines in the Fernie basin. A mine near Sparwood was the first of these operations; it boomed between 1955 and 1979. Open-pit mining and overburden dumping not only altered, but completely destroyed Bighorn Sheep habitat in some areas (Demarchi and Demarchi 1987). Other gypsum and open pit coal mines are currently located on bighorn range as well.

More careful mine planning and reclamation began in the 1970s. This may have replaced some of the more destructive technologies, but some reclamation methods proved to be less effective than originally hoped. Exploration has been destructive, such as the 250 km of trails bulldozed in an area of 20,000 ha of subalpine and alpine Bighorn Sheep habitat in the Fernie Basin from 1969–1971 (Demarchi and Demarchi 1987). Helicopter activity associated with seismic work can not only dislocate sheep, recent literature review suggests it creates unacceptably high levels of physiological stress and resultant negative overall effects on sheep populations (Paquet and Demarchi 1999). In Montana, helicopter-supported exploration and seismic activity caused Bighorn Sheep to be displaced from more productive forage, leaving them vulnerable to major die-offs (Hook 1986). Major seismic work occurred throughout the Southern Rockies on both sides of the Continental Divide in British Columbia and Alberta in the 1950s. Extensive, unplanned, and extremely damaging exploration for coal occurred in the Fernie Coal Basin of the Elk Valley in the late 1960s and early 1970s (Demarchi 1968a; Demarchi 1977). Natural gas seismic activity occurred in the Flathead in the 1980s.

A study from Alberta documented the concentration of Bighorn Sheep near gas well sites, where salty deposits attracted the sheep (Morgantini and Bruns 1988). This concentration is problematic for a number of reasons, including crowding and range depletion, altered distribution, encouraging tame behaviour in the sheep, toxic chemicals, industrial accidents, and vulnerability to hunting (Morgantini and Bruns 1988; Morgantini and Worbets 1988). Road, well site, and coal mine construction can displace Bighorn Sheep. This may be temporary since Bighorn Sheep may re-establish themselves, particularly if mitigation reclaims critical habitat elements, such as escape terrain (MacCallum 1988). Other measure can be taken, such as avoiding drilling during critical periods, controlling access, or proper disposing of drilling wastes (Mead and Morgantini 1988).

Transportation and utility corridors for highways, resource extraction roads, railroads, power transmission lines, and pipelines have had an affect on Bighorn Sheep habitat in the province. The railway, Highway 3 (Crowsnest), and Highway 93 from Radium through Kootenay National Park, have disrupted migration routes along these corridors and caused many Bighorn Sheep mortalities. These transportation and utility corridors occupy habitat, thereby removing it from use; they dissect migration routes and directly kill Bighorn Sheep. Although they seldom occur precisely on bighorn habitat, hydroelectric developments, such as the Aberfeldie Dam on the Bull River and the Elko Dam on the Elk River, interfere with seasonal movements along established, secure corridors, increasing the sheep's exposure to predation.

6.2 Disease, Epizootics, and Parasites

> *It is not possible to state with certainty which diseases Bighorn Sheep had in the past. As technology improves, we have become more knowledgeable about the diseases that sheep contract. These are not necessarily "new" diseases as some suppose; we are discovering diseases that may have been present in the past*. (H. Schwantje, pers. comm.).

There are no data on what Rocky Mountain bighorn habitat and population dynamics were before European-Asian settlement, and no certain way of determining which disease agents may have been acting in any particular area or at any particular time. As a consequence, it is difficult to say whether RMBS populations experienced the boom and bust cycles exhibited today. It is unlikely however, that Bighorn Sheep evolved with, and withstood, epizootics that decimated up to 95% of local populations. A population under that amount of selective pressure would likely have gone extinct long ago. Indirect evidence to support this hypothesis comes from other sheep populations in North America. Stone's Sheep and Dall's Sheep do not exhibit the exaggerated population cycles of today's Rocky Mountain Bighorn Sheep. The reason for this might be the fact that the former two subspecies have never had contact with domestic sheep and, therefore, have not been introduced to pneumonia-causing bacteria (*Pasturella* spp.). Unfortunately, the same cannot be said about Rocky Mountain Bighorn Sheep.

Schwantje (1988a) and Bartlett (1987) reviewed literature on bighorn die-offs. The term die-off is relative and generally refers to a rapid increase in animal mortality caused by a pathogen (i.e., an epizootic disease) leading to a relatively quick decrease in a population. Many agents acting singly or with others have been implicated (Bartlett 1987; Schwantje 1988a). Die-offs are divided into two clinical types: all-age die-offs and summer lamb mortality (Spraker 1979).

6.2.1 *Pasteurella*

Bacteria, such as certain *Pasteurella* spp. commonly present in domestic sheep, can induce fatal pneumonia in otherwise healthy bighorns within days to weeks of nose-to-nose contact or inoculation with bacterial culture (Foreyt and Jessup 1982; Onderka 1986; Onderka and Wishart 1988). Similar results were observed when bighorns were inoculated with a *P. haemolytica* biotype from a cattle vaccine (Onderka et al. 1988). Conversely, pneumonia outbreaks in the absence of domestic sheep are associated with additional environmental stressors, such as heavy burdens of lungworms, which normally parasitise bighorn as their definitive host. Because lungworms and bighorns have probably coevolved, lungworms at low to moderate levels in healthy bighorns do not appear to present a problem; in fact, most bighorns carry these nematodes (Blood 1963; Uhazy et al. 1973). Excessive parasitism by lungworms has been shown to cause high mortality in lambs. Lungworms appear to become a problem when other external factors are present. Lungworm loads may increase due to unusually elevated soil moisture levels. Irrigated agriculture fields that attract Bighorn Sheep may exacerbate the problem since the high animal density, increased grazing pressure, and increased number of lungworm-carrying snails ingested may lead to higher infection rates (F. Harper, pers. comm.; P. Dielman, pers. comm.; H. Schwantje, pers. comm.).

In several situations where die-offs have occurred in the U.S., wild sheep were seen in the presence of domestic sheep within a few months, weeks, or even days of exhibiting severe respiratory distress. Examples include the 1941, 1964, and 1981 die-offs of Bighorn Sheep in the East Kootenay at Radium, Bull River, and McGuire Creek, respectively (A. Cooper, pers. comm.; Demarchi and Demarchi 1967; Davidson 1994). While they could not prove it conclusively, Cassirer et. al. (1996) strongly suspected that the source of a *P. haemolytica*-associated die-off that resulted in a loss of 327 sheep, including 50% to 75% of the sheep in four Oregon and Washington herds, was caused by one feral goat (*Capra hircus*).

Ungulates other than domestic sheep may also be potential carriers of diseases infectious to Bighorn Sheep. In an experiment to determine the possible transmission routes of *P. haemolytica*, Foreyt (1994) exposed healthy RMBS to llamas (*Llama glama*), domestic goats, Mountain Goats (*Oreamnos americana*), cattle *(Bos taurus),* domestic sheep, and Mouflon sheep (*Ovis musimon*). All were carriers of strains of *P. haemolytica.* The experimental bighorns remained clinically healthy during and after contact with the llamas, cattle, Mountain Goats, and domestic goats, but all of the bighorn died from acute bronchopneumonia after contact with the domestic sheep and the Mouflon sheep.

A literature review (Martin et al. 1996) found that in fenced and free-ranging herds, most contact between domestic sheep and Bighorn Sheep resulted in pneumonia and death of all or most bighorns, while the domestic sheep remained healthy. *Pasteurella haemolytica* (usually biotype A, serotype 2) is the major pathogen responsible for death and no studies reported Bighorn Sheep that remained healthy after contact with domestic sheep (Martin et al. 1996). Since no method currently exists to prevent Bighorn Sheep from contracting pneumonia after contact with virulent strains of *Pasteurella*, "all wildlife professionals have concluded that Bighorn Sheep and domestic sheep should not occupy the same ranges or be managed in close proximity" (Martin et al. 1996). All North American wild sheep species examined have demonstrated varying exposure to viruses such as bluetongue (BT), epizootic hemorrhagic disease (EHD), parainfluenza-3 (PI-3), respiratory syncyticial virus, and bovine virus diarrhoea (BVD). In several cases, viruses, other bacteria, and organisms such as mycoplasma and chlamydia, have been isolated from bighorn mortalities in die-offs (H. Schwantje, pers. comm.). Serological results for three East Kootenay herds studied, however, found little exposure to these viruses (Schwantje 1986). In 1987, the introduced herd of RMBS near Chase suffered a die-off, being reduced from about 50 individuals to less than 5 (Shackelton 1999). The die-off was described by Agriculture Canada as an outbreak of "haemorrhagic disease" and attributed to EHD. This is similar to blue tongue virus and causes identical pathological lesions.

Following an all-age die-off, lambs produced by surviving ewes experience high post-natal mortality during summer months for up to three years (Spraker et al. 1984; Coggins and Matthews 1992). Spraker et al. (1984) suggested that the chronic stress experienced by ewes may inhibit the development of the fetal thymus and reduce colostral antibodies. As a result, lambs experience impaired immunity. After all-age die-offs with lungworm involvement, ewes carry elevated levels of lungworms. Lungworm larvae can be transmitted directly from the ewe to the foetus (Forrester and Senger 1964), causing mortality or inducing fatal pneumonia (H. Schwantje, pers. comm.).

V.L. Coggins (pers. comm.) reported that sheep transplanted from Jasper to Oregon suffered higher losses to scabies than did resident Bighorn Sheep. Thus sheep in British Columbia with limited exposure to infectious organisms may be particularly vulnerable to organisms of domestic livestock, particularly domestic sheep.

6.2.2 Complex of factors

Animals experiencing environmental pressures (stressors) requiring physiological compensation are said to be "stressed" (Selye 1956). The mechanisms causing stress are complex, but can be outlined simply. Exposure to stressors stimulates endocrine responses that allow the animal to cope. However, if the stressors are chronic, they can be detrimental to animal health. Under chronic stress, an animal's immune system is compromised. Immuno-compromised bighorns are more vulnerable to infectious diseases and parasitism, including lungworm proliferation and subsequent pneumonia-causing respiratory infections (H. Schwantje, pers. comm.).

Many potential stressors of bighorn have been identified. Stressors implicated in bighorn die-offs have included: poor nutrition, trace mineral deficiencies, high animal density, interspecific competition, weather, harassment by humans and dogs, and high parasite levels (Schwantje 1988b; Davidson 1994). Well-intentioned efforts on the part of individuals or non-government organisations to "correct" problems through the establishment of supplemental winter feeding stations or artificial mineral licks can exacerbate the transmission of disease through severe over-crowding and contamination of feeding sites and mineral licks. The complexity of processes involved with population declines in RMBS has been illustrated by Risenhoover et al. (1988) in a conceptual model (Figure 3). Diseases from livestock are one of the initiating factors (above the dashed line) and the resulting population decline may result in several self-perpetuating cycles (below the dashed line). While disease may be considered only one factor, it can be extremely important when it is immediately fatal.

Schwantje (1988b) found differences between low and high elevation wintering bighorn herds in the East Kootenay that predisposed bighorns at low elevation to all-age die-offs in 1981, high animal density, poor nutrition, parasites, and trace mineral deficiencies. Columbia Lake herds at low elevation had high lungworm levels, reduced nutritional indices, and lower selenium levels at high densities. Higher elevation herds at Ewin Creek at lower density had access to better nutrition and lower levels of lungworm infection. Outbreaks of pneumonia had a long term effect on viability of young lambs for three years post die-off in the Wigwam River (Schwantje 1988b).

Lack of experimental controls and treatments leaves researchers unsure of the role played by single stressors and even less about their interactions. However, a recurring depressed lamb recruitment rate in California Bighorn Sheep suggests that disease may be more than a secondary factor precipitated by nutrition (Wehausen et al. 1987a). Wehausen et al. (1987) suspect that cattle, rather than Bighorn Sheep, are the long-term reservoirs of infection of BT and EHD, which can shift from chronic to acute form when cattle are stressed. In addition, Parainfluenza-3 (PI-3) may be involved as a virus that can persist in non-invasive states in Bighorn Sheep (Wehausen et al. 1987a). Thus cattle may be a recurring source of infection much as cattle-infected wildlife with rinderpest of the Serengeti Plains in Africa (Wehausen et al. 1987a). Temporal patterns in Bighorn Sheep populations seem to be a long-term pattern induced by time lags (such as the lag in population decline due to adult longevity and age structure), combined with multiple stable stages resulting from the nonlinearities associated with the dependence of the disease pathogenicity on the nutritional state of the host (Wehausen et al. 1987a).

6.2.3 Parasites

Other than lungworm (particularly *Protostrongylus stilesi* and *P. rushii)*, both external and internal parasites of bighorns are considered by most Bighorn Sheep biologists to be of minor consequence to the health of RMBS in British Columbia (Blood 1963). Psoroptic scabies mites (*Psoroptes* spp), believed to be introduced by domestic sheep, were blamed for the decimation of both CBS and RMBS in the U.S. in the mid to late 1800s and early 1900s (Buechner 1960; Goodson 1982). A recent die-off of bighorn from scabies was reported in Oregon and Washington (Foreyt et al. 1990). However, neither species of scabies mites (*Psoroptes equi-ovis* or *Sarcoptes ovis*) have been identified in BC.

A comprehensive list of gastro-intestinal parasites was compiled for RMBS by Worley and Seesee (1992) from 11 western Montana RMBS herds involving 68 sheep over an 18-year period. Many of these herds occur within the same ecoprovince as the East Kootenay population. Sixteen helminth and coccidian species were found, of which 64% also parasitised domestic sheep. The abomasal nematode*Marshallagia marshalli* was the most prevalent species overall, followed by *Nematodirus* spp. Both genera are known to destroy intestinal epithelial tissue and interfere with digestion and absorption of nutrients. Worley and

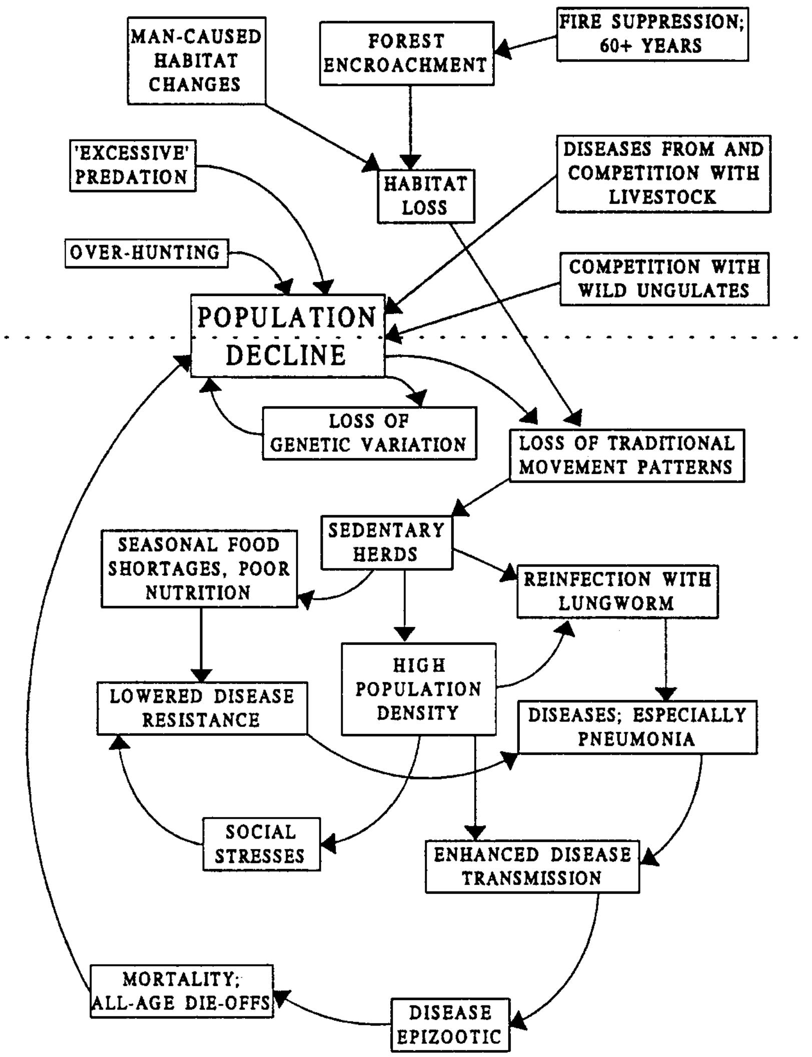

Figure 3. A conceptual model demonstrating initiating factors (above the dashed line) and self-perpetuating cycles (below the dashed line) that have been involved in the population decline of Bighorn Sheep (adapted from Risenhoover et al. 1988).

Seesee (1992) suggest that these parasites and others may constitute a recognisable but previously overlooked stress factor in Bighorn Sheep.

6.3 Forage Competition

Competition occurs when resources cannot meet the combined demands of users or when an organism interferes with another such that resource acquisition by the latter is hindered. Competition is a general term that can be qualified as competition between species (interspecific competition) and competition within species (intraspecific competition). The degree of resource competition (e.g., space and forage competition), whether it is among or between species, varies depending on the resource and the competitors.

6.3.1 Domestic livestock

Protection of critical Bighorn Sheep winter ranges from alienation and all ranges from domestic sheep and goats is a critical need. A definite cause-and-effect relationship exists between diseases introduced by domestic sheep and mountain sheep. This relationship has been suspected since at least 1954 (Smith 1954) and proven since 1982 (Foreyt and Jessup 1982). The recommendation of the Northern Wild Sheep and Goat Council is to provide a buffer of at least 4 km between domestic and wild mountain sheep, while others recommend 16 km (Sweanor et al. 1996). The provincial government has vegetation management guidelines for Crown land, but has not taken any action, to date, to protect wild sheep from domestic sheep on private land.

As grazers, the feeding ecology of Bighorn Sheep and cattle shows much overlap. To minimise interspecific competition, wild species tend to select different habitats (Hudson et al. 1975; Nelson and Burnell 1975). The opportunity for habitat partitioning is implicit. When available forage is restricted (as in winter or in areas of limited primary production), the coexistence of Elk and bighorn may represent the best of a bad situation for both species, which would likely avoid each other if given the opportunity.

Big game and livestock need not occupy the same habitat simultaneously to be in competition (Smith and Julander 1953). An example of this type of unilateral competition occurs in the spring, summer, or fall when cattle use sheep winter range; this may reduce the forage availability to sheep during this critical season. In the spring, sheep follow the band of green-up vegetation, feeding on the new growth of grasses and forbs. This is a critical period for the plants because if they are repeatedly grazed at this time, production later in the year may be reduced (Mueggler 1967). Therefore, these plants may not support a second grazing by cattle if they are to support sheep the following winter and spring.

The history of domestic livestock in the East Kootenay dates back to the early 1700s when Kutenai Indians introduced horses (*Equus caballus*) (Haines 1938, cited in Demarchi 1986). Cattle were introduced in the mid-1800s (Demarchi 1986) and grazing occurred on Crown lands without control. Overgrazing by livestock in the 1920s and 1930s was problematic for Bighorn Sheep and included grazing by thousands of wild horses until the 1940s. The *Grazing Act* of 1919 required a permit to graze Crown land, but trespass grazing still accounted for up to 30% of legitimate grazing until 1960 (Demarchi et al. 1969, cited in Demarchi 1986). This resulted in overgrazing and ecosystem degradation of native grasslands and seral shrubland communities, affecting Bighorn Sheep ranges.

Wildlife and livestock conflicts came to a head in the 1970s, resulting in two significant changes. First, the provincial government began repatriating land for wildlife use; second, the government initiated a program of "deferred rotation grazing" and "co-ordinated resource management plans" (CRMPs) to manage forage for livestock and wildlife. For the first time, wildlife was recognised as a legitimate user of Crown land and forage resources. These CRMPs improved ranges of Bighorn Sheep in Wildhorse River, Bull River, Lewis Creek, and Premier Ridge. Interagency support and funding for this highly successful formal operational level planning process was gradually reduced over the past decade and CRMP has apparently recently ceased as a planning process in the Kootenay Region or elsewhere in the province. In 1987, the Ministry of Forests estimated that provincial Crown range supported 200,000 cow/calf pairs and yearlings during the summer grazing period (Demarchi and Demarchi 1987). Thus, there continues to be a need to review the condition of ranges and make appropriate changes in grazing allotments and timing with the involvement of the Wildlife Branch. However, without a formal process such as CRMP within which such interagency planning can occur, this is unlikely to happen.

Livestock ranching and agriculture are believed to play important roles in the die-off cycle of bighorns (i.e., through disease transmission and resource competition). Eight range units in the East Kootenay support cattle on bighorn winter range. Ten small farms raise domestic sheep on private land near or adjacent to bighorn habitat. Excessive competition for forage with livestock can be detrimental to bighorns because quality winter range is limited.

Behavioural studies indicate that the presence of cattle alter habitat use patterns of sheep (Bissonette and Steinkamp 1996). Core areas used by bighorns decreased along with the distance to escape terrain. The presence of cattle on Bighorn Sheep range reduces the area available for bighorns to forage on not only through diet overlap but through physical displacement, as well. Cunningham and Bailey (1992) documented the decline and habitat abandonment by Bighorn Sheep on Battlement Mesa, Colorado during 1906–1990 due to probable vegetation changes, intensive livestock grazing through the 1950s, poaching, and an increasing Elk population.

6.3.2 Native ungulates

Mountain Goats, Elk, and Mule Deer (*Odocoileus hemionus*) ranges substantially overlap mountain sheep range in BC and competition for forage is assumed but has rarely been quantified. Winter range availability is often cited as one of the major factors limiting ungulate populations. Although the summer habitat requirements of Mountain Goats closely resembles those of Bighorn Sheep, only the mountain sheep ecotype that winters at high elevations can be considered to be in competition with Mountain Goats to the extent that it could affect the population sizes of both species. The majority of Bighorn Sheep winter at low elevations along with most other ungulates, and competition for forage on winter ranges from Elk and Mule Deer may be substantial. Elk numbers in the East Kootenay increased from about 7000 in 1974 to about 28,000 in 1980, affecting high capability Bighorn Sheep ranges due to competition between species (Davidson 1992). In some areas, the opposite may be true. For example, it was found that on Premier Ridge Bighorn Sheep and Mule Deer begin to overlap in distribution during spring green-up as they became less localised, but during winter they tend to use distinct ranges (Hudson et al. 1975). Past competition may have forced the two species into sufficiently different spatial niches such that the level of competition is reduced.

When resources are scarce (i.e., through intra- and interspecific competition), bighorn ewes reduce maternal care to favour their own mass gain over the development of their lambs (Festa-Bianchet and Jorgenson 1998). This may result in decreased over-winter lamb survival during periods of high density and would act as a population limiting, density-dependent mortality factor. Also, fluctuating resource availability may result in the postponement of first reproduction by ewes (Festa-Bianchet et al. 1995), thereby lowering the rate of population growth.

6.4 Fire Suppression and Forest Encroachment

Bighorn Sheep are dependent on early successional forest stages. Existing policies regarding forest fire prevention, detection, and suppression has changed the dynamics of ecosystems that evolved with fire to the detriment of many fire-dependent species, including Bighorn Sheep. Forest preservation for biodiversity and protection for economic reasons run counter to optimum bighorn habitat management. Wakelyn (1987) determined that forest succession significantly decreased bighorn range in Colorado, and Demarchi and Demarchi (1994) suggested that forest encroachment severely reduced bighorn ranges throughout the East Kootenay.

Forest succession may also interfere with seasonal movement patterns. As the density of trees increases, the visibility decreases. As a result of decreased visibility, Bighorn Sheep may abandon traditional movement corridors in response to the increased predation risk associated with decreased predator detection. In the past, the Rocky Mountain Trench experienced large, frequent fires that maintained much habitat in early successional stages (Demarchi 1986). Fire suppression policies of the MOF have allowed the growth and expansion of the Trench's forests (Demarchi and Demarchi 1994). Trees monopolise sunlight, water, and nutrients. As the grass and forb components of a site decrease, so do the values of such sites to grazing ungulates.

Burned sites experience higher rates of grazing and increased forb production compared to non-burned sites (Easterly and Jenkins 1991). However, the benefits of spring burning to enhance winter forage for Bighorn Sheep are reduced on ranges that experience summer-long grazing by sympatric populations of Elk and deer (Easterly and Jenkins 1991).

6.5 Access Disturbance

Bighorn Sheep are by necessity a highly vigilant species. They are constantly aware of their surroundings and are alert for potential hazards. The harassment of wildlife by the presence of humans, whether in the form of wildlife viewing stands, aerial censuses, snowmobiles, helicopters, vehicles, or domestic dogs, can cause undue stress on an animal (MacArthur et al. 1982; Krausman and Hervert 1983; Stemp 1983). While the effects of occasional disturbance are likely minimal, the effects of repeated harassment may have detrimental effects, including foraging efficiency reduction (Stockwell et al. 1991; Bleich et al. 1994), which possibly leads to poor health, reduced growth and reduced reproductive fitness (Geist 1979). Chronic disturbance on immuno-compromised individuals or populations may be a factor involved in past epizootic die-offs.

A part, or all, of a local population may become habituated to chronic disturbance. These sheep lose their wariness and successive generations may change their natural habits and sometimes become dependent on artificial sources of forage, such as golf greens, alfalfa fields, and lawns. They are then susceptible to increased highway mortality, harassment by people and dogs, and a dependency on artificial food sources that may be only temporarily available.

Many parts of the East and West Kootenays have been transformed from the largely roadless wilderness in the 1950s to heavily roaded land in all the managed areas, and in those with forest or coal leases. Because of the ruggedness of most sheep habitat, road density possibly remains below a critical threshold, but access developments have bisected migration corridors and winter ranges, such as those at Bull River and Elko. Access restrictions were first initiated in the Kootenays in 1978. Management for access in the Kootenays has centred around snowmobiles and ATV access on key winter ranges and the restriction of motor vehicles for the purposes of hunting. Establishing road closures for specific purposes while leaving the road open for other uses has only been a partial, tenuous solution. The provincial program of co-ordinated access management planning (CAMP) was developed by the Wildlife Branch in the Kootenays in co-operation with Ministry of Forests. Although adopted as a provincial policy, it has not been implemented to the point that benefits have accrued to Bighorn Sheep.

6.6 Predation

Predation is a possible limiting factor for bighorn populations (Hass 1989 *in* Shackleton et al. 1999). Eight carnivore and raptor species likely prey on bighorn: Grizzly Bear (*Ursus arctos*), Black Bear (*Ursus americanus*), Cougar, Bobcat, Lynx, Gray Wolf, Coyote, and Golden Eagle (Kennedy 1948; Buechner 1960; Sugden 1961; Cowan and Guiguet 1965). It is difficult to determine the precise effect predation has on bighorn populations because predation undoubtedly varies over space and time.

Wolves, Coyotes, Cougars, and Grizzly Bears are suspected to take a considerable portion of the annual bighorn production. Bighorn Sheep predation by Cougars was 0–13% of the sheep population in a study in southwestern Alberta (Ross et al. 1997). Ross et al. (1997) found that Cougar predation on Bighorn Sheep is largely an individual, learned behaviour. Most do not kill sheep, but some did prey heavily upon them (one female killed 9% of the population and 26% of the lambs over a single winter).

Bighorn Sheep have two basic adaptations to predation and these have affected their habitat preference: 1) great agility on rocks; and 2) keen vision to detect predators at sufficient distances to make escape probable (Bleich et al. 1990). A study of wolf prey selection in Banff National Park, where several species of ungulates were available as prey, found that Bighorn Sheep were avoided (Huggard 1993). It was concluded that this avoidance was due to low habitat overlap between these two species.

Perhaps of greater significance than direct losses to predators are the short- and long-term effects and consequences of predation. Festa-Bianchet (1991b) suggests that the social systems of Bighorn Sheep have been shaped by anti-predator and foraging strategies that rely on learned traditions. Range abandonment, partitioning of sexes, and forcing ewe/lamb groups into sub-optimal habitats have all been demonstrated in recent radiotelemetry-assisted studies (Huggard 1993; Wehausen 1996; Bleich et al. 1997). Bliech et al. (1997) found evidence to support the hypothesis that because of their smaller body size, their potentially greater vulnerabilty to predation, and the need to minimise the risk to their offspring, female ungulates and their young use habitats with fewer predators and greater opportunities to evade predators than do mature males; but that males are able to, and do, exploit nutritionally superior areas. They concluded that sexual segregation likely results from differing reproductive strategies of males and females among sexually dimorphic ungulates. Males may enhance their fitness by exploiting habitats with superior forage and thereby enhance body condition and horn growth while simultaneously incurring greater risks than do females. In contrast, females appear to enhance their fitness by minimising predation risks to their offspring at the expense of nutritional quality. They suggest further that how food and risk of predation are arrayed in the environment may affect whether males or females inhabit better quality ranges, as well as which sex moves to produce spatial separation. This hypothesis explains the findings of Harrison and Hebert (1988) on why Cougar predation was almost exclusively focused on rams in the Junction and Churn Creek herds.

6.7 Noxious Weed Invasions

Noxious weed invasions are of great concern. In addition to the threats of forest encroachment, noxious weeds are invading many winter ranges. The MOF has an active program of weed control. Herbicides are presently used extensively, but the use of bio-control agents (namely insects that eat the weeds) will, hopefully, provide lasting protection in the future. Herbicide spraying of knapweed (*Centaurea* spp.) has been ongoing at Juniper Heights, Stoddart Creek, Mt. Swansea Road, Canal Flats, Premier Ridge, and all range units within the Cranbrook Forest District since the late 1970s. In 1994, the MOF undertook a "weed control" project on Juniper Heights with a focus on controlling leafy spurge (*Euphorbia esula*).

6.8 Winter Severity

Although Bighorn Sheep are tolerant of low temperatures, severe winter weather in the form of high snowpack levels may force Bighorn Sheep into dense forest canopy areas that provide snow interception. This, in turn, could increase vulnerability to predation because of reduced predator sightability. High snow depths would also result in decreased forage acquisition, which could lead to reduced health. A relatively long-term study of the Ram Mountain and Sheep River populations in Alberta concluded that winter weather did not affect survival (Jorgenson et al. 1997). However, reduced survival rates associated with the lungworm-pneumonia complex may be the result of several stress factors acting together (Risenhoover et al. 1988), including winter severity.

7 SPECIAL SIGNIFICANCE OF THE SPECIES

7.1 Use and Value

7.1.1 First Nations

Although salmon (*Oncorhynchus* spp.) and Mule Deer were preferred sources of food, First Nations in British Columbia placed a high value on Bighorn Sheep and used the meat, hides, bones, and horns. Bighorn Sheep were likely hunted as long as 7000 years ago, shortly after the withdrawal of Pleistocene glaciers. Bighorns were a principal source of food and sinew for First Nations people. Drill handles, combs, and knives were made from bones. Large ceremonial spoons and handles for utensils were made from the horns (Banfield 1974). The horns of adults males were also fashioned into ladles and bowls after heating in hot water and allowing them to dry to a durability greater than clay or wood (Davidson 1992). In some cases, either the artifact or the raw horn was traded as far as the coast (Shackleton *in* Toweill and Giest 1999).

First Nation's people of the Rocky Mountains depended upon big game, including Bighorn Sheep, for their survival. Perhaps the best and most recent example were the Stoney Indians, who numbered 400 to 600 and, as recently as 1915, ranged freely and hunted the Rockies from Crowsnest Pass to the Brazeau River. Millar (1916) estimated that the Stoneys annually harvested between 2000 and 3500 big game animals, consisting of one third Bighorn Sheep and the rest deer and Moose. Prior to 1914, their activities were not subject to the provincial *Game Act* and were considered to be the major conservation threat to big game populations, including Bighorn Sheep (Millar 1916).

7.1.2 Early history

The meat of the bighorn was prized both by Indians and early settlers and is considered by some to be the most palatable of all American big game species (Banfield 1974). However, the tallowy taste and texture of Bighorn Sheep lowered their value to some who utilised them only when other sources of protein were not available. While exploring the upper Columbia and Kootenay Rivers in the East Kootenay in 1807–08, David Thompson reported hunting bighorns for sustenance in the Rockies near present-day Windermere (Hopwood 1971). He recorded in his journals, "At the latter end of autumn and through the winter there are plenty of red deer [Elk] and the antelope [Mule Deer], with a few mountain sheep." Although Thompson recorded procuring the skins of at least one hundred Mountain Goats, "the thighs of 130 red deer," and numerous deer, the only other mention of the presence of sheep was that on one hunting expedition they only managed to wound one. The diet of gold miners at Fort Steele on the Wildhorse River between 1860–1890 included RMBS (Davidson 1992).

Sport hunting was facilitated by the extension of the Crowsnest Railroad line to Fernie, Fort Steele, Invermere, and Golden between 1898 and 1900 (Baillie-Grohman 1900). Following a report of a trapper near Fort Steele shooting the largest bighorn ever recorded during the winter of 1892–1893, more interest in hunting in the East Kootenay was stimulated (Baillie-Grohman 1900). Guide-outfitting of sportsmen from the USA, Great Britain, and Germany began in the East Kootenay with the first steamboat travel on the Columbia River, increased after completion of the Canadian Pacific Railroad line in 1889(?), and continues today (Baillie-Grohman 1900; Davidson 1992; Wildlife Branch Records). Unlike the early days of 60- to 90-day hunts that covered several hundred miles, guided non-resident hunting trips today are usually 10 days in duration and are confined to specific guide-outfitter territories (Wildlife Branch Records; Davidson 1992).

7.2 Public Interest

Although North American's oldest and largest big game trophy record keeping organisation, the Boone and Crockett Club, does not differentiate between RMBS and CBS, many sheep hunters recognise both subspecies as distinct for trophy record keeping purposes (Boone and Crockett Club 1988). The Trophy Wildlife Records Club of BC maintains separate records for both species and all four subspecies of mountain sheep in the province (Big Game Records of British Columbia 1988). Hebert and Evans (1991) provided the Boone and Crockett Club with an analysis of the cranial and genetic variations of the two species of bighorns as the basis for the recognition of CBS as a separate subspecies from RMBS, as they do for DBS in the U.S.

The fact that society places a high value on all races of mountain sheep, including RMBS, is exemplified by use of the species' image in a great variety of forms. Sheep and their natural habitats are extensively used as *objects d' art* and the male sheep, with its large curved horns, has wide appeal and is extensively utilised in product marketing (e.g., some trucks and wine).

There is considerable interest in RMBS among hunting and wildlife conservation organisations, such as rod and gun clubs and fish and game associations, which have been in existence for nearly 100 years in BC. Numerous non-government organisations have developed to conserve big game species in general and mountain sheep specifically. National and international organisations, such as the Boone and Crockett Club, Safari Club International, Shirkar-Safari-Club, the Wildlife Management Institute, and the Foundation for North America Big Game, are concerned with the conservation of all hunted wildlife, including wild sheep, while the Foundation for North American Wild Sheep (FNAWS) and the Wild Sheep Society of BC focus almost entirely on mountain sheep and their habitats. These organisations contribute substantial funds and volunteer labour for research and management programs (Stelfox 1992). Other provincial conservation organisations with a varying degree of interest in conservation of Bighorn Sheep include the BC Wildlife Federation, the Guide-Outfitters Association of BC, the Federation of BC Naturalists, the BC Environmental Network, and the Canadian Parks and Wilderness Society.

In addition to the outdoor experience, each year hunters kill and take home rams mainly for the horns or head as a trophy to mount on the wall. The meat is also used, although it is usually of secondary value since many sheep hunters look askance at those who would pursue sheep merely for the meat rather than for the trophy. In terms of value per day hunted, mountain sheep are valued by resident hunters at $83.20 per day and are rated the highest of all seven provincial ungulate species surveyed, and second only to Grizzly Bears in hunters' willingness-to-pay (Reid 1997a, 1997b). The Wildlife Branch determined that 511 resident and 31 non-resident RMBS hunters in the Kootenay Region hunted 4761 days and spent $1.16 million, with a total net economic value in 1991–92 of $386,000 (Reid 1992; Thornton 1998).

Sheep capes are valued by trophy hunters whose original capes are lost or destroyed, while horns have both aesthetic value and value for crafts. Undersized and other illegal sheep horns and capes are annually auctioned in British Columbia for these purposes. In Alberta and several U.S. states special hunting opportunities (i.e., "Governor's Permit") are both auctioned to the highest bidder and raffled as part of a government program to raise funds for bighorn research and management. In some instances, the amount raised for a single hunt has been as high as $500,000 USD. The highest price for the opportunity to hunt a bighorn in Canada was set in Alberta in 1998 with a successful bid of $400,000 CDN. A similar "Director's Permit" was instituted in BC in 2000. The first auction netted about $215,000 CDN for wildlife management, with 75 percent of these funds directed to sheep conservation projects. The BC Habitat Conservation Trust Fund annually supports fish and wildlife conservation projects throughout the province. Funded almost exclusively from surcharges on resident and non-resident fishing, hunting, and trapping licenses, the Trust Fund has supported some major CBS and RMBS research and enhancement projects since its inception in 1981.

Non-hunting recreationists also benefit from these research and management programs because their chances to view bighorn in their natural environment are increased by sheep conservation projects that help ensure the maintenance of healthy, well-distributed populations. Wildlife viewing sites for native RMBS herds include: Elko, Bull River, Premier Lake, Columbia Lake, Radium Hot Springs, and Kootenay

National Park. Viewing sites for introduced RMBS on non-native ranges include: Salmo-Creston Highway, Syringa Creek Provincial Park, Chase, and Spences Bridge.

In a survey of the general public's attitudes toward wildlife, 89% of British Columbia residents polled expressed an interest in mountain sheep (Self 1982). Reid (1998) found that of the 29% of BC residents who were categorised as "direct wildlife users," 23% participated in outdoor activities associated with the group "goats, sheep, and Caribou." In the Kootenay Region, which supports nearly all of the province's RMBS and where 32.5% of the public were categorised as direct wildlife users, 51% participated in outdoor activities associated with the group "goats, sheep, and Caribou. Reid (1998) estimated that direct wildlife participation accounted for $391.7 million in expenditures annually, with $21.8 million of this total expended in the Kootenay Region. The net economic value from direct wildlife participation was estimated at $792 million, with $77 million of this attributed to wildlife participation in the Kootenay Region. The amounts attributable to RMBS were not calculated but, based on the interest expressed in both the surveys of Self (1982) and Reid (1998), are concluded to be significant.

8 HARVEST MANAGEMENT

8.1 Management History

Since the inception of laws regulating the harvest of wildlife in North America, beginning around the late 1800s and early 1900s, hunting of mountain sheep was restricted to the harvest of males only. Because of the impressiveness of the horns and the difficulties of hunting in sheep habitat, sheep hunting was considered a challenge and recreational hunting quickly evolved into hunting for large "trophy" males.

At the turn of the 19th century, the hunting of both sexes of mountain sheep, but particularly mature rams, was a popular sport. As a result of extensive and uncontrolled hunting, the first closed seasons in BC were instituted by Order of the Executive Council in 1906. Subsequent open seasons involved males only.

Robinson (*in* Murray 1987) provides a comprehensive review of the 200-year history of wildlife conservation law in the province, from its early fur trading and exploration phase in the late 18th century. The following is a brief summary of hunting regulations for mountain sheep:

- 1859 First wildlife laws passed but did not include mountain sheep.
- 1890 $50 licence fee and a bag limit of eight sheep for non-residents.
- 1905 Bag limits of three rams for non-residents and five for residents.
- 1906 Regulated mountain sheep open and closed seasons.
- 1909 Specific area hunting closures established.
- 1913 First resident hunting licence requirement.
- 1955 3/4-curl regulation.
- 1964 Sheep tag-licence introduced.
- 1972 (RMBS) Mature ram 7/8-curl.
- 1974 Select limited entry hunts (LEH).
- 1976 Compulsory inspection requirement.
- 1976 (RMBS) Mature ram full curl

8.2 Response to Hunting

The systematic removal of older aged "trophy" rams has been hypothesised to have anegative affects on the social and biological performance of a population in a number of negative ways, including reduced productivity (Geist 1971, 1975; Morgan 1974). Others, including Bubenik (1971 cited *in* Stringham and Bubenik 1974), have generalized between ungulate species to suggest that significant reductions in the older aged male component allows active participation in the rut by immature males. Rutting by young, growing males is hypothesised to cause stress, which exacerbates mortality; less time is spent feeding and resting, and more time is spent sparring, running, and rutting with the result that energy is diverted from somatic growth and fat deposition prior to the onset of winter and directed instead towards sexual development and rutting activities. Festa-Bianchet (1989) argued that whether or not young rams participate in breeding, they nonetheless become involved in rutting activities and expend considerable energy. He hypothesised that the differential higher mortality rate of young males may be independent of hunting removals of older rams and is likely common to most sheep populations due to the greater forage requirements of immature males and their greater vulnerability to disease.

No direct studies of the effects of heavy ram removals from free-ranging Bighorn Sheep populations were found in the literature search. However, all subspecies of North American mountain sheep exhibit similar biological traits and social behaviours. Heimer and Watson (1982, 1990) identified a number of potential undesirable population and behavioural consequences of removal of most mature rams in a given population. They provided data that supported the hypothesis that excessive removals of mature rams adversely affected the survival of younger rams. Singer and Nichols (1992) reported on the results of a study of heavily hunted and unhunted Dall's sheep populations in Alaska over a 15-year period. No evidence was obtained that removal of all or nearly all rams equal to or greater than 3/4-curl (i.e., approximately 5 years and older) for the first 11 years and 7/8-curl (i.e., approximately 6 years and older) for the last four years influenced productivity, recruitment, or survival. Subtle changes, however, including aggressive courtship behaviour and increased use of ewe-lamb winter ranges by young rams, were observed in the heavily hunted population, suggesting that further research was required.

Two methods are available to reduce sheep populations and to maintain sheep numbers within the limits of the carrying capacity of their winter range: limited entry ewe-lamb hunting, and trapping removals for transplanting purposes. Jorgenson et al. (1993) demonstrated that an isolated Bighorn Sheep population in the absence of predation or major disease remained stable despite removals of 12–24% of the total ewe population. In the population with hunting removals, the prevalence of lactation in 2-year-olds was higher and the survival of orphan and non-orphan lambs was similar. The number of rams produced was unchanged, but horn growth was greater at 4 and 5 years of age in the removal population. Jorgenson et al. (1993) cautioned against ewe removals in populations with a history of pneumonia because, in these herds, population growth following die-offs appears slow and density-independent, and hunting mortality would likely be additive. M. Festa-Bianchet (pers. comm.) also warned that ewe removals for hunting or transplanting purposes must be based on accurate, up-to-date inventory information because of the additive effects of mortality caused by predation.

8.3 RMBS Management Guidelines

The principles and conditions for managing RMBS are set out in the Provincial Wildlife Harvest Strategy (Halladay and Demarchi 1996). The following guidelines are set out under the Bighorn Mountain Sheep Harvest Management Standards.

8.3.1 Provincial management principles and goals

In general, Bighorn Sheep will be managed to optimise population sustainability within ecosystems while allowing for options and opportunities associated with viewing and hunting. Hunting of RMBS has been restricted for the past 20 years primarily to the harvest of "full curl" rams. One management goal will be to maintain or, where necessary, restore appropriate sex and age rations. Because Bighorn Sheep are a Blue-listed species in British Columbia, they will be managed more cautiously than Yellow-listed ungulates.

8.3.2 Hunting policies

Where Bighorn Sheep hunting seasons are prescribed, the level of harvest will be adjusted to meet hunter demand within the constraints of conservation and allowance for non-hunting uses. Wherever possible, sheep hunting regulations will be kept simple, uniform within ecosystem units, and consistent over time. Ewe and lamb hunting may be provided where sheep numbers have increased above caring capacity. Where a sheep population is below potential carrying capacity due to recent occupation of new habitat or suppression by a mortality factor such as predation, ewe and lamb hunting will not normally be allowed. Regulation will require that hunters remove the edible portions of the carcass to a place of consumption and submit specified parts for compulsory inspection.

8.3.3 Regulating harvest

Where hunting seasons are prescribed, Bighorn Sheep will normally be harvested under a general open season "full curl" regulation. Limited entry hunting (LEH) permits may be implemented to regulate the resident harvest. Quotas and administrative guidelines will be employed to regulate the guided non-resident harvest. The general open season for rams will normally start on 10 September for southern ecosystems/or and on 15 August for northern ecosystems. Hunting seasons will normally be closed by 31 October. Special "ewe or lamb only" hunts may extend until 30 November. Both sexes may require harvesting to meet population objectives. LEH ram seasons are normally for any yearling or older ram to allow the distribution of the harvest over all age classes and to reduce enforcement problems.

8.3.4 Harvest monitoring

Compulsory inspection of all harvested mountain sheep will continue. The Annual Hunter Sample and Guide-Outfitter returns will also continue so that data from successful and unsuccessful sheep hunters can be consolidated. Annual Management Unit estimates of the number of hunters, number of days spent hunting, and number of sheep harvested will continue to be used to monitor trends in hunter demand and the harvest.

8.3.5 Population monitoring

Wherever possible, absolute abundance and sex/age composition will be monitored within established provincial Bighorn Sheep survey units (discrete mountain blocks) every three to five years. Selection of survey units will be based upon their representativeness within provincial ecoregions and logistic considerations. Where feasible, and where required to verify sightability, a sample of mountain sheep will be marked and mark-recapture methods used to estimate total numbers. Additional site-specific surveys will be conducted where required. Population modelling will be used to monitor population trends at the ecosystem level and may utilise indices of habitat condition as reflected by growth performance from horn increments and recruitment (e.g., lamb-ewe counts).

8.4 Provincial Hunting Regulations

Hunting regulations under the auspices of the *Wildlife Act* set out the periods and conditions under which RMBS may be hunted and exported from the province. The main provisions are as follows:

- While special limited entry hunting seasons are applied in the Salmo-Creston area and in Mount Assiniboine Provincial Park, all other bighorn hunting seasons in the province are under a general open season. A “full curl bighorn ram” regulation is in effect for all RMBS ram hunting seasons under general open season or limited entry hunts in the province.
- RMBS are not listed in the Convention on International Trade (CITES), but are exporters are required to have a permit issued if exporting this species more than 30 days from the date of the kill. If exported less than 30 days from the date of the kill, either the species licence or the Compulsory Inspection Data Sheet may serve as an export permit.
- Bighorn Sheep are included in the list of Compulsory Inspected Species and must be submitted to an official of BC Environment for the purpose of taking measurements within 15 days of the kill.
- British Columbia is part of a North American system of recording wild sheep identification and hence all sheep horns that are taken in the province must be inspected by an officer of BC Environment and a numbered metal plug inserted in one of the horns.
- Surplus bighorns are also used for reintroductions. Populations in Canada are particularly important for this purpose since there have been extensive reintroduction programs in the U.S. (Hatter and Blower 1996).

9 CONSERVATION MEASURES

9.1 Strategic Plan

A metapopulation approach must be used to develop a strategic plan with goals and objectives for managing wide-ranging Bighorn Sheep over a larger scale. Armentrout and Boyd (1994) suggest erasing jurisdictional boundaries and creating an interagency group to oversee this strategic planning. Such interagency groups would have the following responsibilities: 1) determine the historic and current geographical distribution of Bighorn Sheep; 2) determine where fragmentation has occurred and the boundaries for the metapopulation; 3) establish the functionality and viability of metapopulation and local subpopulations, demographic studies, and habitat trends; and 4) identify potential habitats for recovery and develop projects for maintaining the metapopulation over the long term. From this information a set of goals can be developed, along with management objectives based on sound techniques. To date, the Wildlife Branch has not instituted a metapopulation planning process, although Luikart and Allendorf (1996) have identified some genetic issues that could serve as a starting point for metapopulation planning.

Bailey and Woolever (1992) caution that goals for management of Bighorn Sheep may not be consistent with the goals for management of wilderness areas (or other land designations), and that management plans must recognise and provide for natural processes in Bighorn Sheep population ecology. These natural processes include: 1) fluctuation in herd size and sex-age composition; 2) emigration and immigration; 3) natural selection; 4) variation in range use; 5) metapopulation dynamics; and 6) zero contact with domestic sheep. Providing for these processes will involve larger areas and often requires coordination between management agencies and between jurisdictions.

9.2 Management and Conservation Measures

Management measures for RMBS must include a variety of land use processes and management techniques in order to adequately address many population and habitat issues (Mitchell and Prediger 1975; Demarchi and Demarchi 1994). Managers should identify steps that should be taken to protect the species. These should include:

- land use designations, habitat acquisition, strategic (higher level) land use planning processes (protected areas, wildlife management areas, buffer zones, wildlife corridors, Land and Resource Use Planning, property covenants);
- operational land use planning, forest, grazing, agricultural and mining prescriptions, stewardship programs, public education programs;
- disease mitigation and abatement;
- translocations;
- access management plans and control;
- habitat enhancement; and
- population and harvest management.

9.2.1 Land use planning and habitat acquisition

Bighorn Sheep habitat can be protected through a variety of land use designations and planning processes, including habitat acquisition. The current system of provincial and national parks and wilderness conservancies does not adequately address the protection of bighorn winter range. Therefore, the long-term protection of important bighorn ranges through a program of title and rights acquisitions for private and Crown lands must be ensured. Also, the government should identify important bighorn range on Crown-owned land parcels that can be secured before they are sold or alienated through forest practices, mining, agriculture, or commercial recreation developments. The government should also secure property rights and enter into legal agreements with landowners of critical sheep habitat (see Loukidelis and Hillyer 1992; Findlay and Hillyer 1994). Not only must actual seasonal ranges be protected, but protection of movement corridors may be critical as a conservation tool that can improve the viability of populations (Beier and Noss 1998). Local land use planning processes, such as Land and Resource Management Planning which allows community sectoral representation, can establish land use zones that allow for recognition and protection of Bighorn Sheep ranges and corridors. Stewardship programs, such as landowner programs and property covenants, and operational planning, such as forest harvest planning, grazing prescriptions, and agricultural and urban planning, must include requirements of Bighorn Sheep where appropriate. Public education programs can be useful for informing private landowners how they can protect Bighorn Sheep range.

To protect bighorn habitat further, it is important to ensure that key Crown land parcels (i.e., those that are located on Bighorn Sheep winter range) are not alienated through developments and/or resource extraction. In addition, co-operative arrangements for the protection and management of important RMBS habitats within Provincial Forests should be increased significantly. Commercial backcountry recreation developments must not proceed without due consideration for the protection of important RMBS habitats.

The designation of key wildlife habitat as a Wildlife Management Area (WMA) is a promising way to secure habitat in order to ensure its long-term viability. WMAs may be established where conservation measures are considered essential to the continued wellbeing of resident or migratory wildlife that are of regional, national, or global significant. Lands of strategic importance to bighorn herds and WMA relevance are:

- Mt. Broadwood – Wigwam Flats
- Columbia Lake East
- Premier Ridge – Estella
- Bull River – Pickering Hills
- Stoddart Creek
- Sheep Mountain (Elko, BC)
- Grace Creek – Ewin Creek
- Crossing Creek
- West face of the Galton Range
- Mutton Creek – Nine Mile Creek – Mt. Glen

WHAs should be established on some critical ranges (e.g., lambing areas and mineral licks). Some transitional ranges as well as certain alpine forage and/or escape habitat should receive WHA designation. The specifics of WHA locations, size, exposur,e and degree of protection will vary with each herd and will be determined by regional BC Wildlife Branch staff (Wildlife Branch 1997b).

9.2.2 Operational planning

Operational planning processes involve the management of resources and can only occur after the strategic planning process allocates resources or designates land use areas or land use zones. Some of the strategic land use planning processes will involve operational planning or making decisions about the level of resource use that will be allowed within land use zones. Other processes are strictly operational, such as 5-Year Development Plans for forest harvesting. The Identified Wildlife Management Strategy of the Forest Practices Code has been an attempt to provide some standards for forest harvest. The following prescriptions have been laid out under this strategy for Bighorn Sheep (Wildlife Branch 1997a):

Management objectives

- Minimise access to control and prevent human disturbance and to avoid invasions of non-indigenous plants onto grassland communities.
- Avoid disturbance to lambing/natal areas. Natal times are generally between April and 15 July. However, times may vary for each species and by location. The Ministry of Environment, Lands and Parks (Wildlife Branch) should be consulted for species- and location-specific times.

Management practices

Access

- Do not construct roads unless there is no other practicable option and the variance is approved by district manager and designated environment official.
- Avoid disturbance to lambing/natal areas from April through 15 July unless approved by district manager and designated environmental official.

Range

- Maintain grassland seral stage distribution as specified by regional wildlife and range staff.
- Range developments (e.g., cattle drift fences, water troughs, and mineral or salt blocks) should be implemented only after consultation with regional BC Environment and range staff.

Silviculture

- Avoid use of helicopters for timber removal during critical times. Consult BC Environment so a designated Environment official can specify appropriate time frames.
- Prohibit the use of domestic sheep to minimise epizootics, predators, and competition for forage.

Planning Objective

- Maintain sensitive ranges other than winter range.

Currently, under the Forest Practices Code, there are some established landscape unit planning considerations, but these are not mandatory. These considerations are that migratory Bighorn Sheep must be managed on an ecosystem basis, incorporating low-elevation winter ranges, transitional ranges and high-elevation summer ranges. Connectivity between seasonal ranges should be maintained. Additional recognition and protection of certain lower grasslands and alpine habitat within higher level plans will ensure the retention of year-round bighorn ranges.

9.2.3 Disease mitigation and die-off abatement

The prevention of transmission of disease from domestic sheep to Bighorn Sheep is paramount to sustaining healthy bighorn populations. According to the habitat definition developed by Sweanor et al. (1996), suitable wild sheep habitat does not occur within 16 km of domestic sheep. It is recommended that potential domestic sheep farms be located at least 16 km from Bighorn Sheep range, or have a significant natural barrier. For those sheep farms that already exist within the range of Bighorn Sheep, the extent of contact should be documented. Any contact should be immediately prevented through exclosure fencing. The presence of cattle can also significantly alter the behaviour and habitat use of Bighorn Sheep (Bissonette and Steinkamp 1996). Therefore, where grazing allocations apply to bighorn winter range, it is recommended that grazing rotations be adjusted to minimise the contact between cattle and Bighorn Sheep.

A health protocol developed for domestic sheep used for vegetation management in British Columbia and Alberta was developed on the basis of ensuring healthy domestic sheep access to forest lands for silvicultural weed control. Under this protocol, domestic sheep are examined and treated for foot rot and inspected and monitored specifically for pseudotuberculosis, contagious ecthyma (CE), and internal and external parasites. Guidelines have been developed and include a review process whereby BC Wildlife biologists and Habitat Protection biologists are to document the presence of wild sheep and goat herds near the proposed vegetation management site. If these are present, the project is refused.

Given the rapid mortality of bighorns infected with domestic strains of *P. haemolytica*, drug treatment of sick bighorns is not an option. Drug treatment (i.e., ivermectin, fenbendazole, or cambendazole) of bighorns experiencing high lungworm loads has not been successful in Colorado (H. Schwantje, pers. comm.). However, in some wild Bighorn Sheep, decreased lungworm larvae output and increased lamb recruitment have been attributed to drug application (Schmidt et al. 1979; Foreyt et al. 1990; Davidson 1994). The use of drugs on wild Bighorn Sheep is often carried out without addressing the reason(s) why lungworms have become a problem in the first place.

If "stress" increases lungworm loads, allowing establishment of pneumonia-causing organisms, drug treatment addresses the wrong part of the problem. Prolonged maintenance of "medicated" herds indicates managerial failure. Fougere-Tower and Onderka (1988) found that faecal samples taken 40 days after treatment with ivermectin showed increases in lungworm larvae output. Samuel (1988) concluded that ivermectin behaved similar to cambendazole; although lungworm larvae production is suppressed for up to four weeks after treatment, adult lungworms are not eliminated. Davidson (1991) also found that although fenbendazole effectively reduced lungworm larvae output, "the effects were short-lived". The short duration of drug effectiveness suggests that treatments must be on-going, are cost-prohibitive, are unlikely to be delivered at an effective dose for each animal, and add an undesirable degree of "artificiality" to bighorn herds (Demarchi 1970). Unless the initial stressors are alleviated, naturally healthy bighorns cannot be expected. It is very likely that RMBS populations will experience future die-offs. When die-offs occur, management actions to lessen their impact should be taken. If a bighorn die-off does occur, then the actions described in the following recommendations should be undertaken:

1. A pathologist should attempt to diagnose the cause(s). The efficacy of subsequent treatments will depend on the diagnosis.
2. Potential stressors should be eliminated or reduced on critical winter habitats when they are identified.
3. Translocations to or from herds experiencing die-offs should cease until the problem is corrected, unless they can be treated and healthy individuals given a veterinarian's clean bill of health.
4. The risk that the die-off will spread to other herds must be assessed. If the risk is significant, the MELP should consider culling and safely disposing of extremely ill animals.
5. If the die-off is associated with harsh weather conditions and lungworm is involved, the Wildlife Branch should consider administering anthelminthics, antibiotics, and trace mineral supplements while bighorn are on the winter range. This approach will only be practical if there is a high probability that habitat conditions will be more favourable the following winter. The first objective of this program would be to reduce disease levels in animals that may contact individuals from other herds during the spring and summer. The second would be to improve recruitment by reducing summer lamb mortality. Such a program may be required for two or three years after the die-off.
6. After the die-off, a period of two or three years should elapse before bighorns are translocated to the site. This period will allow some assessment of factors contributing to the die-off and help ensure translocated animals are not infected by surviving residents.

Domestic sheep must *never* use bighorn range or contact bighorns (Coggins and Matthews 1992). This precaution is paramount to the health of bighorns. In addition, by maintaining the habitat in good condition and regulating animal numbers according to habitat capability, die-offs may be avoided.

9.2.4 Translocations

British Columbia has a long history of wildlife translocation (Janz 1988; Hatter and Blower 1996). The earliest records for sheep transplantation date back to 1933, when 20 Rocky Mountain Bighorn Sheep were translocated from Squilax, BC to Adams Lake, BC.

The problems associated with translocations are now serious concerns for managers. Founder effect and genetic drift can occur within small reintroduced herds of Bighorn Sheep (Skiba and Schmidt 1982; Fitzsimmons et al. 1997). Therefore, management practices should minimise the loss of genetic variation from re-introduced populations of Bighorn Sheep. Ways to avoid this problem are to: 1) transplant >75 sheep; and/or 2) periodically augment small re-introduced herds by the addition of more animals from the source herds. For the latter solution, it is not recommended that animals from other sub-populations be used. This will minimise disease transmission across large geographic areas and will also likely facilitate social integration (Roy and Irby 1994). Mixing of populations can mix organisms that may be well-tolerated by unstressed sheep but are not well-tolerated by translocated sheep.

Data on the effects of removals on source herds are lacking (Stevens and Goodson 1993). Assessment of these effects is necessary, especially when the removals are large relative to the size of the source population and when maintenance of a viable source population is the management goal. The recovery time, or the time required to replace the removed animals, should be incorporated into the assessment of the population for future removals. Stevens and Goodson (1993) recommend that removals be based on the productivity of source herds rather than on their *assumed* compensatory responses to removals.

The United States has relied heavily on transplants to re-establish herds of both RMBS and CBS because most of its RMBS herds and nearly all of its CBS herds were extirpated by the early 1900s. Although the results of the recovery program have been significant and the program could not have been successful without transplants, in many instances, insufficient care has been taken in matching the receiving site with the donor herds. British Columbia has not been immune to problems and the Wildlife Branch has used these criteria for transplants (Hatter and Blower 1996):

- The proposed transplant site must provide sufficient and suitable habitat to support a viable population of mountain sheep, as determined by comprehensive study.
- Prior study must establish that the introduction will not adversely effect the numbers, health, or utilisation of currently present wildlife species at either the transplant source or the transplant site.
- The race of mountain sheep to be transplanted must be from a herd of "pure" strain and it must be transplanted in range of its own subspecies that is similar to the most accessible subspecies.
- Prior study must establish that the introduction will not create intensive land use conflicts with other resource agencies or resource users.

The Montana Department of Fish, Wildlife and Parks follows a rigorous transplant protocol. Their protocol has some similarities to the BC practice, but with some modifications several of these items could be used to improve British Columbia's protocol:

- If translocation is proposed to historic site or one with a depressed population, evaluate the habitat to determine the reason(s) for the lack of bighorns and determine if the area can support more. The reasons for the initial extirpation or reduction must be determined to have been corrected. If predators are suppressing bighorns on otherwise healthy range, transplants will likely only supplement predator diets.
- Determine the health status of the herd to be transplanted and the herd, if applicable, to be augmented (e.g., faecal lungworm larvae trends, serological profile) to ensure that sick bighorns are not translocated to healthy populations and vice versa.
- Keep genetic strains intact as much as possible by emphasising transplants within continuous ranges.
- Evaluate the potential for future consumptive and non-consumptive uses, including access. Recently transplanted bighorns and/or augmented herds must not be hunted until they have stabilised and can withstand harvest (i.e., close monitoring is needed to demonstrate that there is sufficient recruitment and good health).
- Determine priority areas for translocations (i.e., sites with depressed populations, historic sites) by the fall before translocation is to take place.
- Transplant young (e.g., <3 years) animals to minimise losses from the knowledge-base of the donor herd and to minimise losses caused by older animals that often attempt to return to their initial range.
- Release animals on good quality winter range near (i.e., within 300 m) escape terrain.

A preliminary investigation prepared for the BC Wildlife Branch (Spalding 1996) reported on approximately four potential sites for CBS transplants after collecting this information about sites: 1) available range; 2) historic evidence of sheep presence; 3) conflicts with other resource users; and 4) attitude of local First Nations peoples. This investigation gave recommendations for the number of Bighorn Sheep for the potential transplants and possibilities for range improvements. Before implementing these recommendations, there is a need to develop a broader strategic plan that should include the completion of biophysical inventory and a metapopulation analysis. In addition, the above protocol would be useful.

Considering the long term consequences of transplants, the existing Wildlife Branch Transplant Committee might consider whether it would be beneficial to include some outside wildlife scientists on the committee, including representation from academia and consultation with representatives of the wildlife agencies of adjacent jurisdictions. Input from conservation biologists with an interest in metapopulation and genetics would be beneficial. Translocations will continue to play an important role in bighorn management. The key to their success is careful planning and monitoring. If the above criteria are not met, translocations could be futile or even disastrous.

9.2.5 Access management

Access management has long been a priority with the BC Wildlife Branch. Access has many detrimental effects on wildlife, including physical disturbance, soil erosion, and increased legal and illegal hunting mortality. Demarchi and Demarchi (1994) made several recommendations regarding access management in the East Kootenay. First, bighorn should be counted only once per year (on their winter ranges) by helicopter or fixed-wing aircraft to reduce harassment. Second, a policy concerning the off-road use of all-terrain vehicles (ATV) for hunting purposes should be developed. Third, habitat degradation due to ATV traffic should be mitigated through such a policy and through an active program of education, and enforcement. Communication to the public is needed regarding the importance of access management.

Commercial back-country recreation in the form of heli-skiing, heli-hiking, and snowmobiling must be eliminated where threats cannot be mitigated or planned, controlled, and monitored through regulation. This will allow strict access control of timing and location that can be delineated to reduce wildlife harassment.

Many hunters feel that bighorn hunting should provide a challenge that is not highly dependent on motorised vehicle use. Limiting vehicle access will impose limitations on some hunters, but if wilderness hunting experiences continue to be sought by most bighorn hunters, then access opportunities must be restricted. If it is not already too late, the use of ATVs, in particular, should be restricted before there is a long history of use. This will reduce the opposition to future access plans.

9.2.6 Adaptive management: habitat enhancement and stewardship programs

In the past, overharvesting, exotic diseases, and reduction of winter range by development, livestock grazing, and forest encroachment, caused population declines of Rocky Mountain Bighorn Sheep in North America. Improvement of sheep habitat is a major goal for the BC Wildlife Branch (Mitchell and Prediger 1975). To maintain or increase population levels, the Wildlife Branch has had an active program of habitat enhancement. The standard types of habitat enhancement include: 1) prescribed fire; 2) selective logging; 3) tree slashing; 4) tree spacing; 5) forage plant seeding; 6) range fertilisation; and 7) noxious weed control. The responses of the habitat to these treatments are largely unknown. Past habitat enhancement projects were rarely evaluated post-treatment due to lack of funding or staffing. An enhancement project was initiated in 1982 to rebuild East Kootenay bighorn populations after the 1981 die-off. One objective was to maintain and create open grasslands and seral shrublands. Also, trace mineral supplementation of licks took place at Phillips Creek, Mt. Broadwood, Wigwam Flats, Bull River, Premier Ridge, and White Swan Lake (Davidson 1994). Anecdotal information suggests that bighorn population growth and increased lamb survival may have been stimulated by habitat enhancements, and on some ranges, by mineral supplementation.

Proper scientific evaluation of this and many other enhancement projects has not been conducted. Any increase in forage quality should be beneficial because offspring growth rates, conception rates, age at first reproduction, and male mating activities are influenced by forage conditions (reviewed in Shackleton and Bunnell 1987). The lack of funding to properly assess the efficacy of past enhancements, however, impairs wildlife managers' ability to learn from their actions. Enhancement projects must be conducted as scientific experiments and monitored over time to develop an effective adaptive management program of habitat enhancement. The use of replicated experimental units and controls to document forage condition, abundance, and animal usage, before and after treatments, must be standard practice. No low-elevation bighorn winter ranges in the East Kootenay are true grassland vegetation climaxes. However, soil moisture conditions and recurring fires have yielded grassland climaxes in some areas. The maintenance of climax grasslands in the Ponderosa Pine and Interior Douglas-fir biogeoclimatic zones requires repeated disturbance by low intensity fires (Peek et al. 1985; Curran 1992). This disturbance, in terms of bighorn habitat enhancement, is usually mimicked through forest harvesting and thinning, and prescribed burning (e.g., Gruell et al. 1986).

Any efforts to manage the habitat of RMBS should strive to provide a mixture of forage species (Wikeem and Pitt 1992). As foraging generalists, RMBS depend on good quality habitat. This habitat is characterised by a complement of plant species that provides a diversity of forage alternatives rather than a few key management species (Wikeem and Pitt 1992). Prevention of the decline of preferred forage species due to noxious weed invasion should tackled by continued participation in government-supported noxious weed control programs.

10 RESEARCH NEEDS

10.1 Disease

- Extensive research is needed on RMBS die-offs. Critical time periods before die-offs must be identified by monitoring both the population and habitat condition through time. With advance warning, managerial actions such as population reduction through trapping or hunting or range improvements, can be taken to mitigate the impact of such events.
- Research is needed on disease transmission, how diseases are being transmitted, methods and procedures for reducing or eliminating contact with domestic sheep and goats, and competition and disease transmission between native ungulates.

10.2 Fragmentation and dispersal rates

- Movement and seasonal home range research would help to determine dispersal rates within and between metapopulations and subpopulations and determines fragmentation zones and viability of populations.
- Research is needed on land use planning on sustainability of RMBS metapopulation.

10.3 Population Dynamics

- Population inventory techniques and advanced population modelling would be useful for understanding population dynamics, sustained hunter harvests, age class structures and sex ratio shifts, etc.
- The key predators of bighorns must be identified on a herd by herd basis, and their impacts estimated. Pertinent information will include the impacts on a temporal and spatial scale and the impacts on sex- and age-classes. Where a single predator (e.g., a Cougar) targets a vulnerable population, it may be necessary to remove that predator to conserve the herd.
- Genetic research to determine uniqueness of genetic material in metapopoulations, levels of inbreeding depression and genetic drift should be carried out.

10.4 Biophysical Inventory

- The habitat capability/suitability mapping on all critical bighorn winter ranges should be completed at a scale of 1:20,000 and by area at 1:5000. Completion of these maps will facilitate management decisions regarding enhancement activities addressing specific concerns.

10.5 Habitat Use and Enhancement

- The key components of habitat use patterns need to be assessed by radio-tracking non-transplanted animals. These data can be used to determine the effects of habitat alteration and enhancement on habitat use and animal movement.
- Mineral use and needs should be traced. Distribution and location of mineral licks utilised by RMBS needs to be monitored.
- Enhancement, monitoring, and research on habitat is necessary.

10.6 Limiting Factors

- Evaluation and assessment of conifer forest encroachment on Bighorn Sheep winter ranges and potential movement corridors is needed. Research is lacking in the field of conifer forest control including prescribed fire and logging.
- Research on the effects of mine reclamation will provide valuable information.
- Access disturbance, particularly helicopter assisted skiing and hiking, needs to be assessed.
- Impacts of open pit mining and effectiveness of mine reclamation needs to be assessed.
- Research on biological control agents for noxious weeds, particularly knapweed (*Centaurea* spp.) should be done.

11 EVALUATION

Currently RMBS is on the Blue List of terrestrial vertebrates. Blue-listed species are considered to be vulnerable but are not yet endangered or threatened under criteria for both provincial and national endangered status (Harper 1994; Munro 1994). Blue-listed species are considered likely to become threatened or endangered in British Columbia if factors affecting their vulnerability are not reversed. Blue-listed species may not be in decline, but their habitat or other requirements are such, that they are vulnerable to further disturbance. The endangerment or rarity ranking system used in British Columbia by the Conservation Data Centre was developed by The Nature Conservancy and is the same as that used for most of North America and in many Latin America countries. This system is based on the number of occurrences of the species but also on factors such as abundance, viability, population trend, range, threats and fragility (Wildlife Branch and Habitat Protection Branch 1995). “Occurrence” is defined ecologically as a location representing a habitat which sustains or otherwise contributes to the survival of a population (Harcombe 1994). Master (undated) has developed a sequential process for ranking which is used in combination with a proposed ranking system for Canada (Harper et al. 1996).

Occurrence

An occurrence is more useful for a species which has few sightings, as an occurrence represents only one point in time (Gaston 1996). For species that has more accumulated information, occurrence is not an appropriate criteria since the *actual occupation* (based on accurate, up-to-date inventory) of an area as a result of accumulated information for long periods (the geographic or ecological range) is best used. The Conservation Data Centre (CDC) (1998) has used herd as an occurrence in their preliminary ranking of RMBS. Currently there are 34 herds of RMBS in British Columbia ranging in size from 5 to 240 individuals on native ranges.

For a status evaluation it would be more useful to use *subpopulation* of a metapopulation since this is the group which will have a longer persistence time and should be used as the basic unit for a status evaluation. A subpopulation for RMBS can be defined as 2 or more wintering herds which share a common summer range. For the purpose of this report 14 subpopulations of RMBS can be identified in British Columbia. For this number of subpopulations (occurrences) there is a rank of "2", "imperilled because of rarity or because of some factors making it vulnerable to extirpation or extinction". After establishing this rank based on occurrence, each of six other factors are considered and used to adjust the rank as more or less vulnerable (Master, n.d.).

Viability

The quality, condition, viability and defensibility of these occurrences is next considered under Master's protocol. Normally the viability of the occurrences is considered. Since a Minimum Viable Population (MVP) figure has been determined for Bighorn Sheep at the subpopulation level, this would be the most appropriate level to use for considering the viability of RMBS. Berger (1990) has determined that the MVP for Bighorn Sheep is probably 125. Out of the 14 subpopulations of RMBS, 0 are extirpated, six are <125 individuals, and eight are $\geq$125.

Population Trend

The population trend for RMBS has been generally upward until 1996, but there has been a subsequent decrease. Some herds are increasing, but others have declined in recent years. Lamb mortality caused by disease and a number of contributing factors, including the respiratory complex, continues to be problematic for some herds. There have been very regular cyclic die-offs of RMBS that dramatically affect population numbers and trends. This may continue.

Population Size

The population size of RMBS (in British Columbia) at the present time is approximately 3000. This is the largest size that inventory figures have recorded, although there may have been a larger population pre-historically when grasslands were probably more wide-spread.

Distribution Trend

The distribution trend of RMBS has not changed significantly from the early part of this century. While the capability (or potential) of the habitat has been diminished by permanent factors such as land alienation, highways, subdivisions, and open-pit mines by <10%, the suitable (or actual) habitat at present is <50% of the capable habitat within the historic distribution because of forest access roads, forest succession, competition with livestock, and human disturbance. The habitat is restricted but can be enhanced and protected.

Threats

The threats to RMBS are numerous and include disease, forest succession, access developments, land alienation, housing developments, and grazing competition. Hunting is not a threat, according to the latest research and based on the conservative hunting regime. While some herds are included within protected areas or have benefited from enhancement projects or transplant programs, there continue to be uncertainties over threats for most herds.

Fragility

RMBS are very fragile and sensitive to human disturbance because human recreation, livestock grazing, and resource extraction affects their behaviour and use of native ranges. Particularly because of diseases from domestic livestock, overgrazing of critical ranges by cattle, and lungworm infections that may be exacerbated by the presence of alfalfa fields and golf courses, RMBS are particularly sensitive to human activities.

The provincial or national ranking for RMBS is currently S3, which is on the Blue list. This status report has developed a revised ranking that includes viability of subpopulations and the fragility of the species and its habitat in British Columbia and North America. This revised ranking is S2S3 for the provincial or national rank (Table 11). The global rank indicator, the rank based on rangewide status, is currently G4G5, which is both 4, not rare and apparently secure but with cause for long-term concern (usually more than 100 occurrences) and 5, demonstrably widespread, abundant, and secure. The Trinomial rank indicator;

Table 11. Number code ranking for criteria used to rank Rocky Mountain Bighorn Sheep as a Blue-listed species in British Columbia.

Criteria	Number Code Rank		
	Provincial/ National	Global	Trinomial
Current Rank	S3	G4G5	T4
Revised Rating:			
Number of subpopulations	B	C	C
Viability of subpopulations	D	D	D
Population trend	C	D	D
Population size	C	C	C
Distribution	D	D	D
Threats to population	B	B	B
Threats to habitat	B	B	B
Fragility of species	A	A	A
Fragility of habitat	B	B	B
Rank	**S2S3**	**G3**	**T3**

denoting rangewide status of infraspecific taxa, is currently T4, not rare and apparently secure, but with cause for long-term concern (usually more than 100 occurrences). The global and trinomial ranks have been revised to G3T3 based on the information collected about North America and RMBS.

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