BC Environment

Status of the California Bighorn Sheep in British Columbia

by
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Ministry of Environment, Lands and Parks
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PREFACE

British Columbia's megafaunal resources include California Bighorn Sheep (*Ovis canadensis californiana*) in its long and varied list. Perhaps a more appropriate common name would be "grasslands bighorn." A slightly smaller subspecies than the Rocky Mountain bighorn, the California Bighorn Sheep is more commonly found in areas with large expanses of open southerly and westerly-facing grassland slopes, parkland forest, canyons, and deep valley walls, east of the Cascade Mountains and west of the Selkirk and Rocky Mountains, from the Chilcotin River in the southern interior of the province to the Sierra Nevadas of California. The abundance and distribution of California Bighorn Sheep (CBS) 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 on CBS, but no one report has summarised the extensive literature or attempted to develop an overview status report for this species in British Columbia. Currently, CBS is on the British Columbia Blue List of terrestrial vertebrates that are considered vulnerable and "at risk." Although CBS are not presently considered endangered or threatened in British Columbia, if factors affecting their vulnerability are not reversed they are likely to become so. Just before the turn of the twentieth century, populations of CBS in the USA were reduced markedly, probably due to the introduction of disease from domestic sheep. The recovery of CBS in the USA and BC has largely been due to restoration programs and the introduction of sheep mainly from the Junction herd in British Columbia. While CBS populations have increased, high lamb mortality is present in some BC herds and habitats have been reduced over the years. Ranges used by bighorns maybe adversely affected by timber management practices, fire suppression, mining development, hydroelectric development, residential development, and livestock grazing.

This status report on California 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 CBS 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 CBS lies with the ability of the Wildlife Branch to achieve the cooperation and support of the other government agencies and land owners, including the Ministry of Forests, BC Crown Lands and Assets, ranchers, loggers, prospectors, miners, and conservationists interested in the protection of CBS.

Keywords: California, Bighorn Sheep, *Ovis canadensis californiana*, 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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FNAWS

Wild Sheep Society of B.C.

SUMMARY

1 GENERAL BIOLOGY

California Bighorn Sheep (CBS) belong to the species *Ovis canadensis*, which includes Rocky Mountain Bighorn Sheep and Desert Bighorn Sheep. Although it has been hypothesised that the subspecies evolved due to diverse environmental conditions, recent DNA evidence suggests that there may be no difference between the subspecies.

The pregnancy rate of CBS can be as high as 100%, but the age of greatest vulnerability is during the first few weeks following birth and during the first winter. High summer mortality in CBS has been recorded in the Fraser River Basin Ecosection within the past 5 to 7 years. While Bighorn Sheep have an estimated r_m value of 0.308, the average rate of increase for CBS populations is generally less than 0.10. As a general rule, an over-winter lamb:ewe ratio of approximately 30:100 is the required minimum to maintain a CBS population. Immature males concentrate their energy on growth, making them more vulnerable to parasites and pathogens.

Complex spatial and temporal range use patterns are characteristic of Bighorn Sheep and, together with their fragility, have implications for genetics, disease transmission, and conservation efforts. While Bighorn Sheep have philopatric tendencies, they also can have many seasonal home ranges, and the rams' migration patterns are often patched together from following routes of several different older rams.

2 CONSERVATION BIOLOGY

At present, CBS in British Columbia can be conceptualised as four separate metapopulations that probably developed from one or at most two large metapopulations that existed prior to European contact.

Fragmentation of habitat leading to loss of interconnectiveness is a major concern for the future survival of CBS 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

Except for small remnant herds in California, CBS were extirpated from the USA by the late 1800s and early 1900s, likely as a result of the introduction of disease from domestic livestock, particularly domestic sheep, and competition for forage. In British Columbia, declines occurred but were not as severe, leaving several populations reduced but still viable. A relaxation of import quotas caused a sudden collapse of the domestic sheep ranching industry and freed the public lands in the USA and British Columbia of intensive livestock grazing. This reduced competition allowed some range recovery and a lessening of the threat of disease transmission. An aggressive recovery program was initiated throughout the former range in six USA states and British Columbia, utilising sheep largely from the Junction and Fraser River herds. By 1996, CBS had increased from a few hundred in the USA in 1935 to >6000, while in British Columbia the number increased from <1000 in 1935 to about 4600 in 1990.

4 HABITAT

CBS occupy steep canyons and mountainous terrain in the Southern Interior and Central Interior Ecoprovinces. The principal factors limiting distribution and abundance include the extent of the area suitable for wintering Bighorn Sheep , the quality and quantity of forage species (principally bluebunch wheatgrass and fescues), areas giving security from predators, and areas with low snow cover. Although some herds of CBS, like RMBS, winter on alpine and subalpine ridges, most winter ranges occur on steep, low-elevation, south-facing slopes in the Fraser, Thompson, Okanagan, Similkameen, and Kettle watersheds.

5 LEGAL PROTECTION AND STATUS

CBS 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. CBS 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 principal threats to CBS are habitat management policies and human-caused habitat alienation, including residential, commercial, industrial, recreational, agricultural, and access developments. 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 CBS include competition from native ungulates, noxious weeds, and predation. Direct losses to predation are not generally 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.

7 SPECIAL SIGNIFICANCE OF THE SPECIES

CBS are a high profile, valuable big game species which, as a member of the mountain sheep genus, are appreciated by a majority of British Columbians for a variety of reasons, including food, cultural, art, photography, and trophy values. A relatively high percentage of BC's adult human population participate in wildlife activities associated with the group "mountain sheep, goats, and caribou" despite the limited distribution and accessibility. Mountain sheep, including CBS, are valued by resident hunters at $83.20 per day and, in a survey on willingness to pay, were rated the highest of all seven provincial ungulate species.

8 HARVEST MANAGEMENT

The Provincial Wildlife Harvest Strategy sets out the principles and guidelines for CBS management in the province. CBS 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 Limited Entry Hunt and all sheep taken must be submitted to the Wildlife Branch for compulsory inspection.

9 CONSERVATION MEASURES

A metapopulation approach must be used to develop a strategic plan for managing CBS in British Columbia. Expansion of protected areas, particularly Wildlife Management Areas, and maintenance of connective movement corridors is essential for the long-term viability of CBS. An aggressive program of prescribed burning and improved livestock grazing practices should be instituted to enhance and maintain CBS 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 detrimental impacts on CBS populations. Lastly, but perhaps of greatest importance, grazing of domestic sheep must not be permitted within 16 km of areas known to be frequented by CBS and a program of public education should be developed that will educate farmers and ranchers about the lethal effects domestic sheep, even "healthy" domestic sheep, have on CBS.

10 RESEARCH NEEDS

Research is needed on many aspects of CBS 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, CBS is on the Blue List of terrestrial vertebrates, which means they are considered "vulnerable." This classification indicates that 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 CBS is currently S3, which is on the Blue List. This status report has developed a revised ranking that includes viability of sub-populations 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

California Bighorn Sheep (*Ovis canadensis californiana*) 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 Goat (*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 US. The isolation of ancestors of Bighorn Sheep in the western US 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 California Bighorn Sheep (CBS) and Rocky Mountain Bighorn Sheep (RMBS) 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) (*O. c. 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 California and Rocky Mountain 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 and 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; 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

CBS are the second largest of the New World species of the genus *Ovis.* Slightly smaller than mature RMBS, they are a medium-sized ungulate with rams weighing an average of 82 kg to a maximum of ~93 kg, and ewes weighing an average of 48 kg to a maximum of ~66 kg (VanSpall 1997). 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 CBS, like RMBS, possess powerful, muscular front and hind quarters, sturdy necks, legs and backs, and robust, concave hooves with rough, flexible underpads, all of which are adaptations to a life travelling in steep, rugged, rocky terrain. Both sexes support horns that, because of drought in the case of Desert Bighorn Sheep DBS (*Ovis canadensis nelsoni)* and winter weather in the case of CBS, stop and start growing at least once per year, resulting in visible external growth rings, or annuli. The horns of CBS rams may reach

110 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

The literature does not contain specific references to reproductive age in CBS. However, in RMBS, ewes reach puberty as early as 1.5 years but do not usually mate for the first time until 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 (Jorgenson et al. 1993). Maternal age and mass did not have a strong effect upon the offspring's age at first reproduction and the data did not disprove 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); 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 environmental variables (Jorgenson et al. 1993).

Pregnancy rates have been shown to reach 100% of adult CBS females to be impregnated (Harper 1984a; Harper and Cohen 1985) and bearing one young per year. Twinning has been verified in CBS (Blood 1961; Spalding 1966; Eccles and Shackleton 1979). Eccles and Shackleton (1979) hypothesised that CBS in Vaseux Lake had a higher incidence of twins but that mortality is higher due to smaller birth sizes.

In contrast to Asiatic sheep, CBS 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 die in 10 or more years and may even reach maximum ages of 20 years for rams and 20–24 years for ewes (Geist 1971). In an expanding population with high reproductive effort, most adults will only reach an average of 6–7 years (Geist 1971). Since the length of life and the reproductive effort varies with the population's condition, the lifetime fitness varies considerably.

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). CBS lamb from late April to mid-June, with a peak in late May (can vary by two weeks depending on the phenology of the vegetation (Blood 1963; Demarchi 1982). The peak of rut in the Ashnola herd is mid to late November (Blood 1963). The Junction, Vaseux Lake, and Ashnola herds rut earlier and lamb earlier than RMBS in British Columbia. The seasonal movements occur so that not only do Bighorn Sheep take advantage of the "flush" of new vegetation growth in the spring, but they may also avoid harsh weather (Hebert 1973; Shackleton and Bunnell 1987). Vegetation green-up starts at lower elevations in the spring and gradually progresses upslope, providing high-quality forage over an extended period of time. Demarchi (1982) found a trend for earlier lambing in CBS than in RMBS, although there is overlap in timing. He also determined that CBS transplanted from the Junction herd to several locations in the USA adjusted the timing of the rut ostensibly to time parturition with the local timing of spring green-up.

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.* 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 oestrous 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 in the northern portion of their distribution may rut and lamb a full month earlier than herds that winter and lamb at lower elevations or in the southern areas of the province. Demarchi (1982) compiled data on the lambing periods of 12 herds of CBS in British Columbia, Washington, North Dakota, Oregon, Idaho, and Nevada that originated from transplants of bighorns from the Junction herd. The data revealed that the peak of the lambing period shifted away from mid-May in the southern populations to as early as mid-April and as late as mid-June. Demarchi (1982) concluded that the source herd possessed enough genetic variability to allow for a rapid change in the breeding season to adapt to a number of highly variable climatic regimes into which the sheep were transplanted.

1.5 Productivity

Productivity varies both within herds between years and between herds. Specific research has not been done on the effects of body mass on reproduction in CBS. However, in RMBS, while it is commonly believed that early development is critical for growth and reproductive success, mass at 1 month was not correlated with adult mass but mass at 4 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 CBS ewes may be impregnated each fall (Harper 1984*a*), there is some debate over the possibility of foetus resorption when the nutritional value of the forage is below maintenance level. For RMBS, the overwinter number of lambs observed per 100 ewes has ranged from 15.5 to 87 in studies from Alberta (Geist 1971). However, it is most likely that, unless extremely malnourished, ewes carry the foetus to term, when the lamb subsequently quickly succumbs to factors relating to its own poor nutrition and compromised immune system. For example, initial RMBS lamb production was 79–85 lambs per 100 ewes in central Idaho in 1992; however, a pneumonia epizootic resulted in 7 per 100 ewes by 4–6 weeks old (Akenson and Akenson 1992). This high summer lamb mortality has been observed recently in CBS in the Fraser River Basin Ecosection within the past 5–7 years (Harper 1995; F. Harper, pers. comm.; H. Schwantje, pers. comm.). Classified counts have recorded August lamb:ewe ratios as low as 7:100 and March ratios as low as 3.5:100. It has been hypothesised but not tested that the decrease in lamb survival was due to heavy lungworm infection of the lambs, exacerbated by Bighorn Sheep population levels exceeding the carrying capacity of the winter range. Jorgenson et al. (1998) hypothesised that this potentially density-dependent mortality may serve to reduce the population to levels where intraspecific competition is lowered, resulting in the restored health of the surviving herd members.

Wehausen et al. (1987a) found recruitment rates in CBS in southern California were positively correlated with winter precipitation rates (affecting nutrition) and negatively correlated with rising population density. 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 livestock may alter this balance by adding further stress on the animals. This may be a major factor in the population cycles documented in CBS.

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. Lambs are particularly vulnerable during the first few days after birth, when predation and disease are major factors. Harper (1984b) determined that 60% and 72% of total annual lamb mortality, of tagged and untagged ewes respectively, occurred in the first three weeks post-partum. The Bighorn Sheep in Harper's study area did not use security cover. However, predation risk is reduced where Bighorn Sheep lambs are born in precipitous terrain that is relatively inaccessible to predators such as Cougars (Festa-Bianchet 1988*b*).

Drawing from RMBS research, 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 in CBS (an estimator of lamb mortality) range from 8:100 to 61:100 (Wildlife 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 and spring winds have a negative effect on lamb survival in Desert bighorns (Douglas and Leslie 1986). Similar effects may occur on low elevation CBS winter ranges, such as Kamloops Lake and South Thompson where in most years fall rains and mild temperatures result in regrowth of grasses, particularly *Poa* spp. D. Shackleton (pers. comm.) observed that Vaseux sheep sometimes enter winter in visibly poorer condition after dry falls.

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).

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 a population is 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 and may mask changes in absolute numbers. 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 HCCs as a single index to determine population vigour.

The foregoing limitations not withstanding, 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 (various dates) in Kamloops, Williams Lake, and Penticton produced lamb:ewe ratios that varied depending on season: 70 to 95:100 immediately postpartum, 40 to 70:100 during late summer and fall, 10 to 74:100 post winter, with 30 to 50:100 being most commonly reported post-winter (Wildlife Branch records various dates; Buechner 1960; Demarchi 1982).

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 the Ashnola watershed in the 1960s following a long period of closed hunting seasons and several years of light ram harvests, ratios of >110 rams to 100 ewes were maintained (Blood 1961, Demarchi 1965a). In moderately to heavily hunted herds, 25 to 88 rams per 100 ewes were reported (Wildlife Branch records; Demarchi 1965a).

Adult Bighorn Sheep generally experience an annual mortality rate of about 10% from natural causes, such as old age and predation. As a general rule, for a CBS population to remain stable under most conditions, 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%, it can be generally stated that 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 yrs).*

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 crust forming on snow allowing dispersion during winter, 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), as is the departure from wintering grounds, while the trip to rutting grounds is rapid and determined (Geist 1971). The migration of rams is 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 Home range

Male bighorns use as few as two and as many as six separate home ranges during a year. CBS exhibit similar movement patterns as RMBS. For major ram bands, their ranges can include pre-rut, rutting, mid-winter, later-winter/spring, salt lick, and summer ranges (Geist 1971; Demarchi and Mitchell 1973). Ewes can use as many as four ranges including winter, spring, lambing, and summer ranges (Geist 1971; Fiesta-Bianchet 1986). Generally, ewes use two to three seasonal ranges (Geist 1971; Demarchi and Mitchell 1973; 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). 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. 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.

1.9.3 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 upslope 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 areas may occur part way between summer and winter range (e.g., some bands of the Churn Creek herd), or rutting may occur on the winter range (e.g., other bands of the Churn Creek herd and the Ashnola Mountain 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, which 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 sheep are known to copulate with ewes (Blood 1963; Geist 1971). After the rut, males over 1.5 years separate from the female-juvenile groups, moving to separate winter ranges, while female/juvenile groups either remain on or move to winter ranges until spring.

1.9.4 Size of home range and distance between seasonal ranges

Home ranges can vary. The winter range for the Ewin band (RMBS) of approximately 150 sheep was 1.4 to 2 km^2 (TAESC 1982). 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). Mid-winter home ranges can be as small as 0.8 km^2 and spring and fall ranges can be as large as 5.9 km^2 (Geist 1971). 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.

Seasonal home ranges vary considerably not only in size, but also in the distance to other seasonal home ranges. The distance separating one seasonal range from 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).

1.9.5 Home range fidelity

Generally female Bighorn Sheep show philopatric tendencies (Geist 1971; Festa-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 are generally those sheep whose movements are more unpredictable, such as rams under 4 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 evidence for these behaviours, and possibly evidence of 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 movements between them are generally orderly and predictable (Geist 1971). Young rams develop migration routes from following older rams; 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 may locate and breed more females, and reproductive success may 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, historic, 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.

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 recolonisations (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 (*Ovis nelsoni*) in the eastern Mojave Desert. Since then there have been several additional papers published on studies in the southern Mojave Desert and Central and South-eastern California (Bleich et al. 1990, 1996), as well as for RMBS in USA and Canada (Luikart and Allendorf 1996). Armentrout and Boyd (1994) provided information on the extensive fragmentation of all subspecies of Bighorn Sheep including CBS. 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 USA 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 sub-populations, and dispersal distances to confirm the specific applicability of the metapopulation model to CBS (Hanski and Gilpin 1991; Doak and Mills 1994). Hanski and Gilpin (1991), however, have added that the delimitation of local populations is 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.

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 individuals for practical and theoretical reasons, particularly for co-ordinating 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. 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 interconnectiveness and therefore must not be eliminated. Unsuitable habitats 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.

2.1.1 British Columbia metapopulation

Before Europeans colonised British Columbia, the population of CBS was probably one or at the most two large metapopulations; one occupying the Fraser and Thompson watersheds in the central and northern portion of the Southern Interior Ecoprovince and the other in the Okanagan Similkameen watersheds in the southern portion of the Southern Interior Ecoprovince (Sugden 1961; Demarchi et al. 1990). The Fraser-Thompson metapopulation may have been core-satellite metapopulations with the Fraser subpopulation as the core in the western metapopulation.

Today, in addition to natural barriers, conifer invasion and habitat alienation and loss of former grasslands to development, British Columbia's CBS may be configured as four separate metapopulations, assuming 15 km is the critical distance between metapopulations (Bleich et al. 1996). Separated by 20 to 60 km, these four metapopulations are: 1) Fraser River, 2) Thompson River, 3) Okanagan-Similkameen, and 4) Kettle-Granby River. Currently, CBS probably exist as a core-satellite in the Fraser metapopulation and as patchy metapopulations in Thompson, Okanagan-Similkameen, and Kettle-Granby.

The Okanagan-Similkameen metapopulation is connected to the U.S. herds in Washington at Hull Mountain and Sinlahekin (T. Chapman, pers. comm.; R. Lincoln, pers. comm.). This is the same situation for the Grand Forks-Vulcan herds with a corridor along the Kettle River Valley in Washington. While these are operating functionally as separate metapopulations due to fragmentation, there are not substantial geographic or cultural barriers to gene flow other than distance. This is critical since an aggressive translocation program combined with programs that enhance habitat and protect corridors could connect these metapopulations. Whether or not there are still suitable habitats and corridors available (which could restore the integrity of the original single metapopulation) requires intensive study that is beyond the scope of this report.

2.1.2 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

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	Okanagan-Similkameen
Subpopulation (contiguous herds)	Two or more wintering herds which share a common summer range	After Luikart and Allendorf 1996	Ashnola
Herd	A self-sustaining group of ewes and their progeny using a particular area and named by their discrete winter range	Festa-Bianchet 1986	Crater Mountain
Band A	cohesive, home-range group that is a subgroup of a herd	Geist 1971	Hargreaves

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

Most females and young California Bighorn Sheep live in groups of around 25 members (Shackleton 1999). Blood (1963) found the average size of all groups of CBS observed to be 9.3 animals, and varied from 1 to 75. The average size of groups of ewes was 10.7, rams 6.1, mixed (ewes/juveniles/rams) 12.6, although sizes of groups varied by season (Blood 1963). 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; VanSpall and Dielman 1997). 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 of survival. 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 a segment could be heading for extinction (e.g., Short Creek herd, which disappeared during the late 1990s (R. Lincoln, pers. comm.)

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). 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.

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 $\geq$50 to manage for genetic variability (Franklin 1980), which would keep the inbreeding rate <1% or they will lose variability over generational time. This means a population size of N$\geq$150 would be required to avoid short-term loss of genetic variability (Fitzsimmons and Buskirk 1992).

Bleich et al. (1996) stated that demographic processes are more important than genetics for Bighorn Sheep. 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. Only careful population monitoring over an unacceptably long period of time will determine who is correct (Armentrout and Boyd 1994).

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 ones. 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 systematically to avoid extreme inbreeding (Schwartz et al. 1986). Past concerns about inbreeding may have been based on closed population models, which have 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, however, have been hypothesised due to, for example, the correlation of poor horn growth to age 3.5 years with a bottlenecked population of <60 of Bighorn Sheep compared to herds with N≥150. 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).

Since small founder populations of CBS have been used to start herds in Oregon, Idaho, and North Dakota, questions have been raised about CBS genetic variation, founder effect, and inbreeding. Szczys et al. (1998) sampled sheep from seven herds in three regions studied in British Columbia, and determined that there are low levels of genetic variation compared to other mammals studied. There was a small difference between observed and expected average heterozygosity, which they conclude indicates low levels of inbreeding. The authors are not aware whether all seven of these herds were either directly or indirectly sourced from a single, largely isolated population, i.e., the Junction herd. Therefore the low levels of genetic variation are explained by the commonality of the source herd (R. Denome, pers. comm.).

There are a number of mechanisms for Bighorn Sheep that may prevent or reduce inbreeding. The vagility of females and the migration capabilities of both males and females have probably been underestimated. Philopatry in Bighorn Sheep is not complete since young rams 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 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; 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).

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. This must be balanced by ensuring a certain level of inter-connectiveness whether naturally occurring or by planned periodic translocations (which must consider genetic uniqueness and potential introductions of pathogens).

While there may not be immediate genetic concerns overall for CBS in British Columbia and in the USA, these populations have undergone some dramatic fluctuations in numbers and may require a careful management approach. British Columbia and Washington 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. 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 and can be used to develop testable hypotheses, management programs, and evaluations of the status of CBS in British Columbia.

3 SUB-SPECIES DISTRIBUTION AND ABUNDANCE

3.1 North America

3.1.1 Historic distribution

Useful historical information on the very early European and Asian contact distribution of CBS 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; Cowan 1940; Buechner 1960). For this status report, distribution of a species describes its geographic and ecological range, the actual occupation of an area as a result of accumulated information over long periods, and does not represent one point in time, such as a sighting or an occurrence (Gaston 1996). Prior to human settlement, the distribution of California Bighorn Sheep was from the Sierra Nevadas of California, north through the Cascades of eastern Oregon, Washington, and southern British Columbia, and on the eastern slope of the Coast Mountains between 50° and 52° north latitude (Cowan 1940). The geographic range of CBS was bounded by the range of other subspecies with which they occasionally bred, leading to intergrades (Cowan 1940). To the east were the Rocky Mountain Bighorn Sheep. Further east were the Audubon Bighorn (*O. canadensis auduboni*) of the Badlands, which eventually became extinct. To the south and southwest were the DBS.

No specific information is available about the details of the historic range of California Bighorn Sheep but, as a habitat specialist with a narrow niche, they were unlikely to have had a continuous distribution, as some authors continue to state. The ecological niche used by CBS was probably always more specific and restricted than maps of the original North American distribution imply (e.g., Buechner 1960). A habitat capability analysis would be useful to determine the limits of historic distribution and abundance. In the USA, attempts to classify sheep habitat capability, on an ecoregion scale or smaller, have not been successful (Boyd and Armentrout 1996). Buechner (1960) lends credibility to the hypothesis of an very abundant bighorn fauna with extensive distribution. This presents a distorted picture of the species by exaggerating both its former numbers and extent and therefore the degree of its decline. Recently, sheep biologists have undertaken comparisons of past distribution based on this generalised and inaccurate data with current distribution based on more accurate information (Demarchi and Demarchi 1999). This comparison has determined that the extent of the historic distribution was probably only slightly larger than the present post-reintroduction range. Severe winters have always restricted the availability of winter range and the quality and quantity of forage in those winter ranges, making these factors limiting. In addition, the availability of cliffs probably limited their distribution because high visibility areas and escape terrain were always a necessary component of Bighorn Sheep habitat for predator avoidance. As restricted and scattered as they were, the historic distribution of all subspecies of bighorns, however, has been reduced even further into smaller patches of suitable habitat due to a variety of factors, including, settlements, access corridors, industrialisation, range depletion, forest succession, and disease contracted from domestic sheep.

3.1.2 Current distribution

Native herds in all of the states in the USA (except California) were extirpated by the late 1800s and early 1900s. By 1954, California Bighorn Sheep were confined mainly to British Columbia, with a small number living in California (Buechner 1960). Since 1954, California Bighorn Sheep have been re-introduced from British Columbia to California, Idaho, Nevada, North Dakota, Oregon, Utah, and Washington, resulting in their re-establishment in much of their historic range (Figure 1). Transplant projects have continued into 1999 and now CBS are widely distributed in areas of their historic range. Most of the transplants that have resulted in successful re-establishment of CBS populations originated from the Junction and Big Bar herds, with a few from Vaseux, Keremeos, Kamloops Lake/Harper Ranch (Hatter and Blower1996) (Table 3). The other two North American bighorn subspecies define the broad geographic limits of CBS distribution. Currently, the three subspecies of Bighorn Sheep occur in eight ecodivisions and in 18 ecoprovinces in North America (Table 2).

Rocky Mountain Bighorn Sheep from Banff were twice transplanted into the former range of CBS to Spences Bridge in 1927 and 1970, and once adjacent to native CBS range at Squilax in 1927. In 1933, RMBS were moved from Squilax to Adams Lake, which lies outside of the historic range of both subspecies (Hatter and Blower 1996) (Table 4). This

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

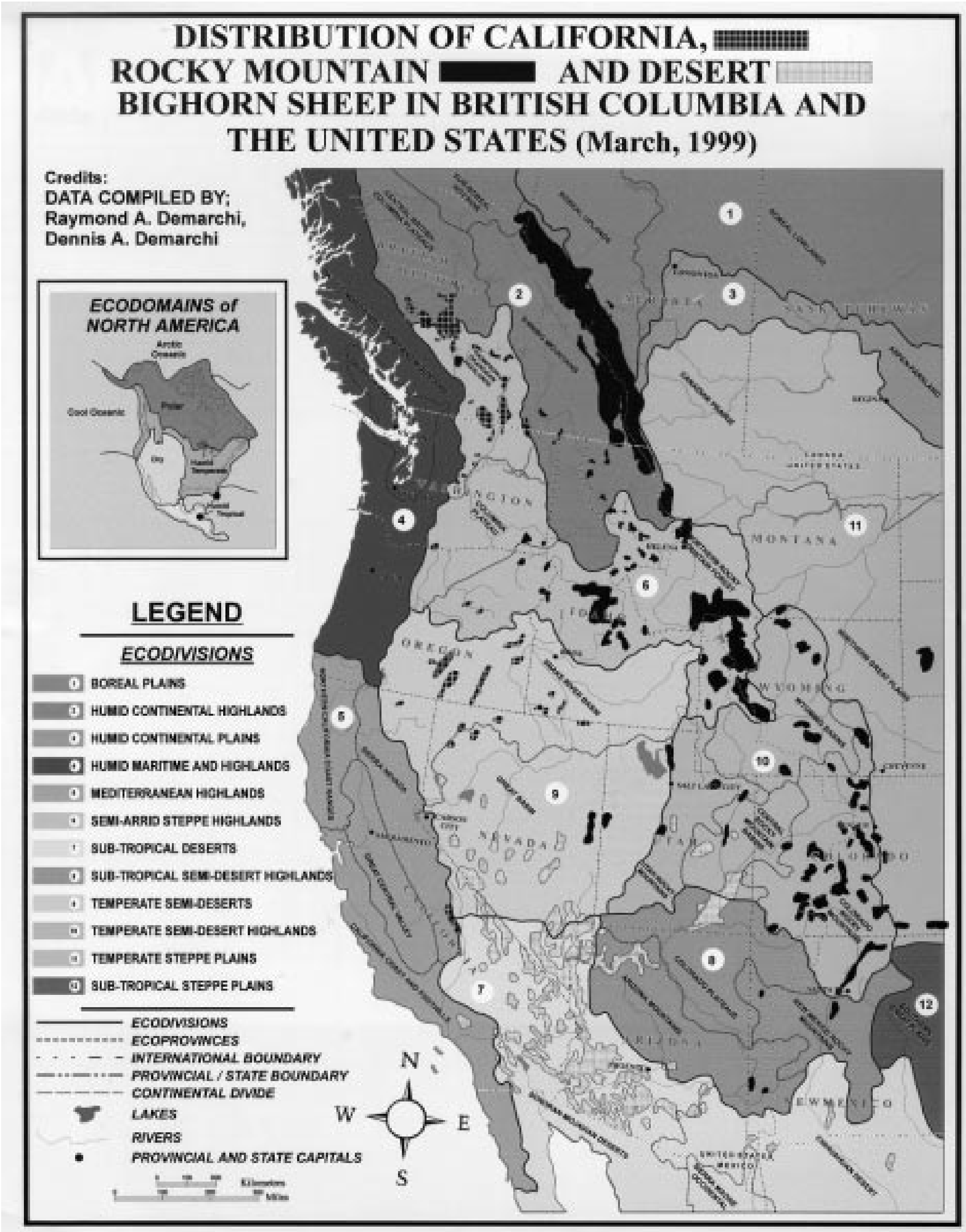

Figure 1. Distribution of three subspecies of Bighorn Sheep in North America within ecodivisions and ecoprovinces of North America (from Demarchi 1994).

latter herd struggled for survival until 1965 (Cowan and Guiguet 1965), died out, and was replaced with CBS from the Junction herd in 1986 (D. Blower, I. Hatter, D. Low, pers. comm.).

3.1.3 Abundance

Seton (1927) estimated that prior to 1800 there were 1.5 to 2.0 million Bighorn Sheep across North America from Canada to Mexico, including all species (Buechner 1960). This figure continues to be used as the basis for Bighorn Sheep abundance under pristine conditions (Hebert and Evans 1991; Luikart and Allendorf 1996). Comparing and contrasting past and present North American distribution and abundance of thinhorn sheep with the current distribution and abundance of Bighorn Sheep brings this high estimate into question. Demarchi (1977) maintained that Seton's estimate was about 10 times too high and that approximately 150,000 to 200,000 individuals was more accurate. Since population size is determined by ecological niches and by density-dependent, birth, death, and dispersal characteristics of the species, Seton's estimates are considered unrealistic.

Table 3. History of California Bighorn Sheep transplants from British Columbia to the USA (Hatter and Blower 1996).

Year	Source	Destination	Number
1954	Junction	Oregon	20
1956	Junction	N. Dakota	18
1957	Junction	Washington	18
1963	Junction	Idaho	19
1965	Junction	Idaho	9
1966	Junction	Idaho	10
1967	Junction	Idaho	12
1971	Junction	California	10
1978	Vaseux	Nevada	12
1983	Junction	Nevada	19
1984	Junction	Nevada	12
1985	Junction	Nevada	20
1988	Deer Park (Junction)	Idaho	14
1988	Junction	Nevada	18
1989	Junction	N. Dakota	10
1989	Junction	Nevada	33
1989	Keremeos (Ashnola)	Nevada	20
1990	Churn Creek	Nevada	13
1990	Junction	Nevada	15
1995	Big Bar	Nevada	42
1996	Kamloops	Washington	32
1996	Big Bar	N. Dakota	20
1996	Big Bar	Nevada	20
1996	Kamloops	Utah	23
1999	Kamloops	Nevada	23
TOTAL			**462**

Table 4. History of bighorn mountain sheep transplants within historic California bighorn range in British Columbia. All California Bighorn Sheep unless otherwise specified (Hatter and Blower 1996).

Year	Source	Region	Destination	Region	Number
1927	Banff NP (RMBS)	AB	Spences Bridge	3	49
1927	Banff NP (RMBS)	AB	Squilax (Chase)	3	50
1933	Squilax (RMBS)	3	Adams Lake	3	20
1955	Junction	3	Buff Lake	5	9
1955	Junction	5	Vaseau	8	4
1955	Junction	5	Whitewater	5 ?	2
1956	Junction	5	U.B.C.	2	4
1956	Junction	5	Dog Creek	5	8
1956	Junction	5	Gang Ranch (Churn Creek)	5	6
1957	Junction	5	U.B.C.	2	4
1957	Junction	5	Vaseux	8	10
1966	Junction	5	Kamloops	3	11
1970	AB	AB	Spences Bridge	3	12
1978	South Thompson (RMBS?)	3	Harper Ranch	3	1
1984	Vaseau	8	Pass Creek	8	20
1985	Junction	5	Harper Ranch	3	6
1985	Junction	5	Dog Creek	5	12
1985	Vaseux	8	Grand Forks (Kettle Creek)	8	12
1985	Junction	5	Adams Lake	3	1
1986	Junction	5	Adams Lake	3	13
1986	Junction	5	Dog Creek	5	13
1986	Vaseux	8	Grand Forks	8	13
1987	Junction	5	Word Creek	5	7
1998	Junction	5	Kamloops	3	12
1998	Junction	5	Word Creek	5	12
1988	Spences Bridge (RMBS)	3	Squilax	3	4
1990	Junction	5	Chilco Lake	5	13
1994	Big Bar	3	Seton lake	3	23
1994	Junction & Churn Creek	5	Taseko Mt	5	32
1998	Kamloops	3	Penticton Creek	8	12
TOTAL					**395**

Hebert and Evans (1991) estimated that the original population of California Bighorn Sheep throughout five western states and British Columbia was about 100,000. Although there is a record of one sighting of 500 CBS along the International Boundary between Washington and British Columbia in 1889 (Buechner 1960), there are no data in the historic record to support such an estimate; most of what little record does exist is anecdotal. In other locations in Washington, CBS were not plentiful, but east of the Cascades in Oregon, CBS were common along the terraced canyon walls of the Deschutes River, around the canyons and buttes of the lava beds, and probably in nearly every mountain range in the eastern part of the state (Buechner 1960). Written records confirm that sheep were abundant in the lava beds and in the mountains of north-eastern California and the Sierra Nevadas (Buechner 1960). Buechner (1960) also states that sheep occupied every suitable mountain range in Nevada.

Bighorn populations declined significantly during the last half of the 1800s due to excessive hunting, scabies (*Psoroptes* spp.), livestock competition, and restriction of winter range (Buechner 1960; Sugden 1961; Goodson 1982). Populations in many mountain ranges in the United States were extirpated. Scabies epidemics, presumably contracted from domestic sheep, were reported throughout the western USA beginning in 1888. By 1900, the population of CBS had declined to 1500–2000, and these were largely restricted to British Columbia and California (Buechner 1960; Trefethen 1975; Hebert and Evans 1991) (Table 5). Efforts began in the late 1800s to reverse this trend and included hunting closures, intensified predator control for Lynx (*Lynx canadensis*), Bobcat (*Lynx rufus*), bear (*Ursus* spp.), Golden Eagle (*Aquila chrysaetos*), Coyote (*Canis latrans*), Gray Wolf (*Canis lupus*), and Cougar (*Felis concolor*). Some refuges and parks were also established. 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).

By the 1930s, the Bighorn Sheep populations in the USA were considered unhealthy and unproductive and, in 1941, the species was considered endangered due to low density and poor distribution (Couey and Schallenberger 1971). The extirpation of CBS occurred in South Dakota in the late 1800s, in 1915 in Oregon, 1935 in Washington, 1940 in Idaho, and 1946 in Nevada (Trefethen 1975; Hebert and Evans 1991). Reintroductions of sheep into empty habitats and habitat restoration in the 1950s began to slow the decline in some areas, but many populations continued to decline. A significant decline in grazing of domestic sheep on western rangelands in the USA and Canada between 1945 and 1978 resulted from adverse economic factors, including rising transportation and herding costs and increased foreign mutton imports (Goodson 1982). The collapse of the domestic sheep industry created new opportunities for Bighorn Sheep recovery, and a vigorous program of transplants and range enhancements was initiated (Wishart 1975; Goodson 1982; V.L. Coggins, pers. comm.).

Since Washington, Oregon, and Nevada had no native herds left by 1953, re-introductions to establish captive nursery herds and new populations were made from the Junction herd near Williams Lake, BC (Buechner 1960; Spalding and Mitchell 1970; Hatter and Blower 1996). A transplant was also made to North Dakota from Oregon in 1968 (Spalding and Mitchell 1970). In 1960, California had the only native CBS herds left in the USA, numbering 390 (Spalding and Mitchell 1970) and by 1971, CBS were considered rare in California (Trefethen 1975; Hebert and Evans 1991).

By 1960, there were <20,000 bighorns of all subspecies in the United States (Buechner 1960) and by 1974, this number had increased to <42,000 (Wishart 1978). The United States' CBS population in 1960 was 390, which increased to 1120 by 1970, and to about

Table 5. Estimates of North American California Bighorn Sheep 1900 to 1996 (from Buechner 1960; Trefethen 1975; Hebert and Evans 1991; Gilchrist 1998).

Jurisdiction	1900	1950	1970	1975	1983	1993	1996
British Columbia	1350	1500	1650	1850	2250	3000	4500
USA Total	400	390	1120	1273	2060	4310	6107
California		390		195	350	350	200
Idaho				50	100	500	1100
North Dakota				250	250	300	325
Nevada				30	60	500	1085
Oregon				348	900	2000	2737
Washington				400	400	660	660
TOTAL	**1750**	**1890**	**2770**	**3123**	**4310**	**7310**	**10,607**

1300 in 1974 (Trefethen 1975; Spalding and Mitchell 1970). The USA population of California Bighorn Sheep increased over 20 years to 4995 in 1994 (Armentrout and Boyd 1994). If the US and BC populations in 1990 were combined, there was a total of over 9000 CBS and the trend was increasing (Hebert and Evans 1991). Armentrout and Boyd (1994) estimated that there had been a 43% reduction in historic amount of habitat in the USA, and that 20% of former habitat was unoccupied but suitable for re-introductions. Livestock grazing, timber management practices, and habitat fragmentation continue to reduce habitat. Shackleton (*in* Demarchi and Demarchi 1994) estimated that the population of all subspecies of bighorns in North America in 1994 was <62,000. This is triple the 1960 population estimate, but a recovery to only one-third of the median estimate of 150,000–200,000 in 1800 as suggested by Demarchi (1977).

3.2 British Columbia

3.2.1 Historic and current distribution

CBS in British Columbia have undergone a considerable reduction in distribution and abundance since primitive times (Buechner 1960; Sugden 1961). Originally CBS were in the arid grasslands of the valleys of the Fraser, Thompson, Nicola, Lower Bonaparte, Okanagan, and Similkameen rivers, and along the higher valleys west of the Fraser River, Bridge River, Seton Lake, Anderson Lake, Taseko Lake, Chilko Lake, Tatlayoko Lake, and Mosley Creek (Sugden 1961). Sheep probably disappeared in the Thompson, Nicola, and lower Bonaparte before European and Asian contact (Sugden 1961). Reductions in populations have since occurred in the Okanagan and Similkameen areas. CBS were successfully re-introduced to the Thompson River in the 1960s, and to the Kettle-Granby in the 1980s. Today, British Columbia's native CBS population is distributed in herds in the Okanagan-Similkameen, Thompson, Fraser, and Kettle-Granby drainages (Figure 2). These populations are not continuously connected; they are fragmented into herds that have limited interchange. Armentrout and Boyd (1994) describe CBS in the USA as in a "semi-feast or famine" population situation, with most populations over 100, but highly fragmented from each other and threatened by livestock grazing and disease as main limiting factors. Other populations could easily become endangered, as is the case with four populations in California.

3.2.2 Abundance

In British Columbia, populations of CBS were believed to have disappeared in the Thompson River drainage by the late 1800s. CBS in the Okanagan and Similkameen began to decline in the late 1800s and hunting seasons were discontinued in 1909 (Sugden 1961; Chapman 1998). By the 1950s it was thought that the population had recovered, although Sugden (1961) felt there was no difference in the size of the provincial population between 1900 and 1960 (Table 6).

In the Okanagan-Similkameen, CBS competed with domestic sheep, cattle (*Bos taurus*), and horses (*Equus caballos*) for land and forage (Blood 1961; Demarchi 1965a; Demarchi 1965b). Spalding and Bone (1969) tactfully listed five activities that could "disrupt" CBS, including cattle-raising, orchards, lumbering, land development, and recreational use. Sugden (1961) recorded that the herds west of the Fraser River in 1960 were half the population of the early 1900s. This decline was commonly blamed on predation by Cougars, Golden Eagles, and Coyotes, excessive hunting in rutting season, and illegal hunting. Ignoring the role of habitat, these theories reflected the popular wisdom of the time for the causes for the declines of most big game species during the early years in the development of wildlife management in Western Canada and the USA (Baillie-Grohman 1900; Hornaday 1906; Millar 1916).

Sugden (1961) disputed these theories, asserting that declines of sheep probably began with agriculture, particularly sheep and cattle grazing, orchards, and settlement. Cattle drives began in the late half of the 1800s, followed by domestic sheep ranching. The BC decline of sheep in the late 1800s was not as severe as in the USA, where many herds were decimated. The initial decline in British Columbia may have been due to intensive market and sport hunting (Baillie-Grohman 1900). In the Ashnola, declines occurred later than in the Okanagan, and the Ashnola continued to attract hunters until 1895 (Sugden 1961). It was common for hunters to kill 10 or 12 ewes and rams in a single herd. Grazing by cattle, horses and domestic sheep began in the Similkameen valley in the late 1800s and expanded into the Ashnola Valley (Sugden 1961; Demarchi 1965b; Pitt and Alleye-Chan 1985). Overuse of the forage resource by domestic livestock was common and excessive use by cattle continued into the mid-1960s (Blood 1961; Sugden 1961; Demarchi 1965a).

In 1960, the population of CBS in BC was 1235 (Sugden 1961). Habitat acquisition and range management helped to counteract the effects of

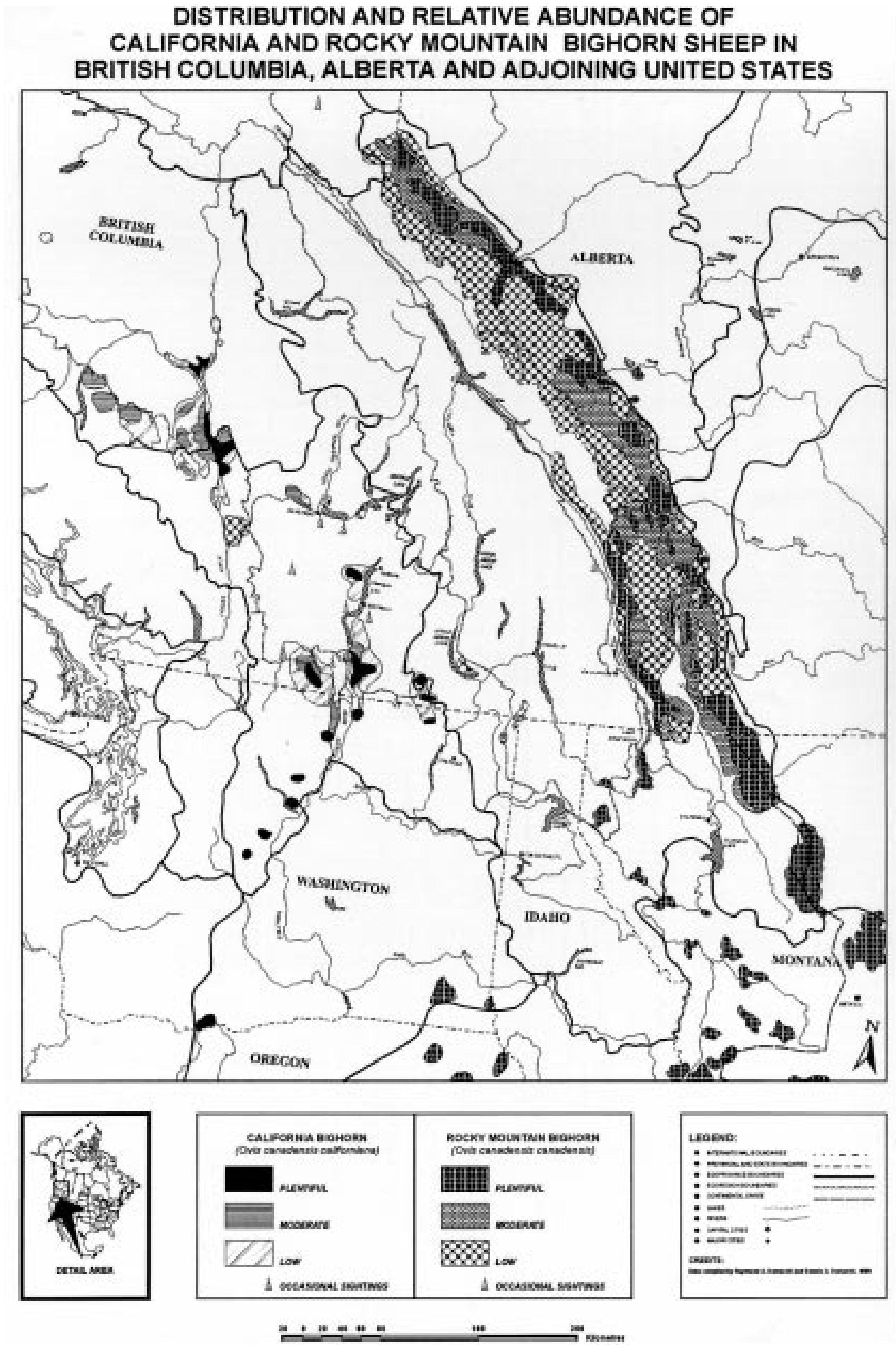

Figure 2. Current distribution of California Bighorn Sheep and Rocky Mountain Bighorn Sheep by ecoregions and ecosections in British Columbia and adjacent jurisdictions (after Blower 1988; Demarchi 1994; L. Bailey, pers. comm.; J. Jorgenson, pers. comm.; R. Lincoln, pers. comm.).

Table 6. Population estimates of California Bighorn Sheep in British Columbia from 1970 to 1998 (Wildlife Branch 1998).

Metapop	Subpop	Herd Winter Range Location	Region-Unit	1960	1970	1985	1990	1998
Fraser	Ilgachuz	1. Ilgachuz (Anahim)	5–12		8	15		5
	Junction	2. Junction (Riske Creek)	5–14	200	360	550	500	300
	Nemaiah-	3. Nemaiah/Tsuniah	5–4	60		70	150	60
	Yohetta	4. Yohetta/Tatlow (W. Taseko)	5–4		40		50	30
	Fraser West	5.Taseko Lake (E. Taseko)	5–4	75	125	250	150	40
		6. Mt. Sheba/Tyaughton/Relay Mtn	3–32 & 5–3		40		60	80
		7. Churn Crk/Camelsfoot Range	5–3			250	350	200
		8. Lower Churn Crk/Fraser R.	3–32 & 5–3	200	130	350	500	225
		9. Fraser River West	3–32 & 5–3				175	250
		10. Mission Ridge	3–33?		0		22	60
		11. Duffy Lake	3–16	25				0
		12. Shulaps	3–32	25	65	65	150	100
		13. Bendor Range	3–33?	30				0
		14. Texas Creek	3–16		13			0
	Fraser East	15. Alkali/Dog Creek	5–2	25	35	45	75	175
		16. Kelly Crk/Dog Crk	3–31	50	100	300	600	450
		17. Lillooet-Kelly Cr. (Pavilion)	3–17					200
Thompson	Thompson	18. Kamloops Lake (Tranquille)	3–29		18	150	225	225
		19. South Thompson	3–27			25	75	225
	Adams Lake	20. Adams Lake (Squam Bay)	3–37					15
Okanagan-	Okanagan	21. Shorts Creek	8–11	45	75	50	60	5
Similkameen		22. S. Okanagan (Penticton/Vaseux Lk)	8–1 & 8–9	200	325	750	700	470
	Ashnola	23. Ashnola-Similkameen	8–3 & 8–7	250	400	350	650	350
Kettle-Granby	Kettle-Granby	24. Kettle-Granby River	8–15			20	175	125
			TOTAL	**1185**	**1734**	**3240**	**4667**	**3590**

activities that negatively affected CBS (Spalding and Bone 1969). Although Sugden (1961) concludes that population fluctuations were the rule and that hunting and predation merely replaced disease or starvation, it is likely that the presence and role of diseases from domestic sheep were poorly understood. Ten years prior to the 1964 die-off at Bull River, however, Smith (1955) predicted the East Kootenay die-off would occur and be caused by domestic sheep infecting the wild sheep. Disease was recognised 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. Ritcey and Low (1986) stated that there were no records of a die-off of Bighorn Sheep of either subspecies ever having occurred in the Thompson Region.

In 1970, British Columbia had 2/3 of the total North American population of CBS: 1764–1879 sheep in 17 herds; that is, 15 native herds and the Dog Creek and Kamloops Lake herds, which had been introduced from the Junction herd (Spalding and Mitchell 1970; Wildlife Branch 1998). Demarchi (1977) estimated the population of CBS in British Columbia was 1900 in 1975, or 65% of the North American population. In 1985, the estimate for CBS in British Columbia was 3000–3240 and stable (Murray 1987). By 1990, the BC Wildlife Branch estimated the CBS population in British Columbia to be 4645. It is presently estimated to be 3030–3625 (1998) (Wildlife Branch 1998; Toweill and Geist 1999).

3.2.3 Population trends

There was a trend for increase in populations of CBS from the early 1960s through the 1980s (Ritcey and Low 1986) and into the early 1990s (see Table 1). The provincial population of CBS increased from 1764 in 1970 to 3240 in 1985 and then to 4645 in 1990 and subsequently declined to 3630 in 1998. All-age-die-offs have not had a significant effect on CBS in British Columbia recently, but poor lamb survival continues to be a concern for future population trends.

Table 7. Ecodivisions and ecoprovinces where California Bighorn Sheep habitats are found in North America (after Demarchi 1994).

Ecodivision	Ecoprovince
Humid Continental Highlands	Central British Columbia Plateaus (Central Interior)*
Semi-Arid Steppe Highlands	Northern Rocky Mountain Forest Columbia Plateau Thompson-Okanagan Highlands (Southern Interior)*
Temperate Semi-Deserts	Snake River Basins
Mediterranean Highlands	Sierra Nevada

*Names used in British Columbia only.

4 HABITAT

4.1 Habitat Distribution

Demarchi's (1994) Ecoregions of North America defines the limits of Bighorn Sheep distribution by subspecies or ecotype, for the most part (Figure 1). There is a close correlation between the distribution of the three North American 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).

The subdivision of Demarchi's (1994) ecological units to the ecoregion and ecosection levels and the overlaying of Bighorn Sheep distribution demonstrates a high correlation between these units and the distribution of RMBS and CBS shared between British Columbia, Alberta, Montana, and Washington (Figure 2). This results in a logical explanation for the ecological separation of these two subspecies of Bighorn Sheep.

4.1.1 North America

Populations of CBS have been managed in isolation by each province and state. The most southerly of British Columbia's ecosections that support CBS are shared with Washington state. However, many populations are connected and the distribution of CBS habitat by ecodivision and ecoprovince points this out clearly. Habitat is not restricted by borders and neither are sheep (Table 7). At present, North America has been mapped to the ecoprovince level and British Columbia to the ecosection and habitat unit or biogeoclimatic subzone level. The following tables reflect these differences in resolution.

4.1.2 British Columbia

Bighorn habitat is characterised by great topographic relief, which results in a variety of biogeoclimatic zones within a comparatively small geographical area (Shackleton and Bunnell 1987; Demarchi et al. 1990). This variation results in the utilisation of a variety of habitat types within home ranges. 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, riparian 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, rutting, and lambing (Risenhoover and Bailey 1985). Table 8 lists the ecoregion, ecosection, and biogeoclimatic zones inhabited by CBS in British Columbia. Similarly, Table 9 lists the biogeoclimatic zones and broad habitat classes used by Bighorn Sheep. These habitats are widespread throughout the bighorn's range.

4.2 Habitat Trend

More and more of the traditional winter and spring habitat of bighorn range is being alienated and/or developed. 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.

Conifer encroachment onto native grasslands and loss of seral-shrub-grassland range has been accelerated by aggressive fire suppression practices of the provincial Ministry of Forests over the past 40 or more years. Davidson (1991) described forest encroachment in the East Kootenay which is believed to exemplify the situation on Interior grasslands. He indicated that since fires of the 1930s, forest encroachment was occurring at 0.5% to 2% per year on low-elevation winter ranges. Davidson (1991) also indicated that,

Table 8. Distribution of *Ovis c. californiana* 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
Thompson-Okanagan Plateau	Northern Okanagan Highland (IDF, ICH, MS, ESSF, AT)
	Northern Okanagan Basin (BG, PP, IDF)
	Southern Thompson Upland (IDF, ICH, MS)
	Northern Thompson Upland (IDF, ICH, MS, ESSF)
	Thompson Basin (BG, PP, IDF)
Okanagan Highland	Southern Okanagan Basin (BG, PP)
	Southern Okanagan Highland (PP, IDF, MS)
Northern Cascade Ranges	Okanagan Range (BG, PP, IDF, MS, ESSF, AT)
Interior Transition Ranges	Southern Chilcotin Ranges (PP, IDF, MS, ESSF, AT)
	Pavilion Ranges (BG, PP, IDF, MS, ESSF, AT)
Chilcotin Ranges	Central Chilcotin Ranges (IDF, MS, ESSF, AT)
Fraser Plateau	Chilcotin Plateau (IDF, SBPS, MS, ESSF)
	Fraser River Basin (BG, PP)
	Cariboo Basin (IDF)
	Western Chilcotin Upland (MS, ESSF, AT) (Extirpated?)

Table 9. Biogeoclimatic zones (Ministry of Forests 1992) and broad habitat classes (Resources Inventory Committee 2000) inhabited by 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)
Montane Spruce (MS)	Antelope-Brush Shrub/Grassland (AB)
Sub-Boreal Pine Spruce (SBPS)	Big Sagebrush Shrub/Grassland (SS)
Interior Cedar Hemlock (ICH)	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)

due to their higher moisture regimes, encroachment has been even greater on spring and fall transitional ranges. The loss of transitional ranges forces bighorn to arrive on winter ranges earlier and leave later (increased sedentariness). Over-used winter ranges cause nutritional stress and may increase lungworm (*Protostrongylus* spp.) infections, which in turn exacerbate lungworm-pneumonia die-offs.

Based on the observations of MELP biologists, the rate of winter habitat change is considered "rapid." CBS managers have expressed concerns for the loss of habitat through forest fire suppression and forest succession (T. Ethier, F. Harper, and J. Youds, pers. comms.). It is critical to the health of Bighorn Sheep populations that their traditional habitats be repatriated.

4.3 Habitat Status

Winter range is the most critical habitat for Bighorn Sheep (i.e., population limiting); currently, most of it is under government ownership (Crown land). However, the current level of habitat protection is inadequate. Key habitat parcels must be secured to ensure the long-term viability of bighorn winter range. In addition, several habitat protection options are available, ranging from habitat acquisition to creating Wildlife Management Areas and conservation covenants (see Loukidelis and Hillyer 1992; Findlay and Hillyer 1994). The recent purchase of the Empire Valley Ranch, with the support of Forest Renewal BC and the Canadian Parks and Wilderness Society, has protected key habitat from further alienation. At present, WMA status for the Ashnola Watershed is proposed and, if adopted, will provide protection for this important international herd (Bryan and Peatt 1994). Two other WMAs currently provide protection to the Junction and Kamloops Lake CBS herds, the Dewdrop and Junction WMAs. The protected area system affecting CBS consists of many small parks. A few parks protect, to varying degrees, the range of some herds, including: 1) the Junction herd year-round range in Junction Sheep Range Provincial Park (formerly Junction Wildlife Management Area); 2) the Churn Creek herd winter range in Churn Creek Park; 3) the Elbow/Relay herd year-round range in Big Creek/South Chilcotin Park; 4) Kamloops Lake peripheral winter range in Lac du Bois Grassland;, 5) Limestone summer and winter range in Marble Range and Edge Hills parks; and 6) the Ashnola herd summer lamb/ewe habitat in Cathedral Provincial Park.

Some key bighorn winter and summer ranges are partially or wholly encompassed by Indian Reserves. These include, Ashnola (summer range), Vaseux, North Thompson, Dog Creek, and Nemaia Range. Habitat condition varies, but because many areas are subject to year-round grazing by cattle or horses, it is generally classed as only “fair to poor.” In addition, housing, commercial recreational and industrial developments, such as the 2000 lot subdivision and cable tram to the top of the Mt. St. Paul in the North Thompson, immediately north of Kamloops (currently being constructed) will reduce the capability of the area to support Bighorn Sheep.

4.4 Habitat Characteristics

CBS in British Columbia exhibit three seasonal habitat use strategies. First, the majority of populations winter on low-elevation, southerly exposed slopes close to rocky escarpments or talus slopes, and summer in high elevation alpine and subalpine areas (Blood 1961; Sugden 1961). Second, there is an ecotype that winters and summers on high-elevation, windswept, alpine ridges and mountains (e.g., the Taseko, Elbow/Dash/Relay, Shulaps, and Yohetta/Tatlow herds) (P. Dielman, pers. comm.; F. Harper, pers. comm.). Third is the ecotype that winters and summers at low elevations along the Fraser River canyon in the Fraser River Ecosection (e.g., Junction and Fraser River East and West populations) (Demarchi and Mitchell 1973; F. Harper, pers. comm.). Although the three ecotypes are spatially separated at different times of year, 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). These basic habitat requirements are also similar to those required by RMBS. Table 10 provides a summary of coarse habitat requirements used for Bighorn Sheep habitat mapping within the known range (Sweanor et al. 1996).

In a study near Penticton, BC, CBS utilised 14 grass species, 47 forbs, and 18 woody species (Wikeem and Pitt 1992). Undisturbed climax grasslands, such as bunchgrass ranges [especially bluebunch wheatgrass

Table 10. Coarse feature requirements used for habitat mapping of Bighorn Sheep (after Sweanor 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 90 cm along a 10 pt, 280 m transect.
Water Sources	Areas must be within 3.2 km 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 16 km of domestic sheep are excluded

(*Elymus spicatum*) habitats], are particularly important (Blood 1967; Demarchi 1968). Also, forest seral stages 4 to 9 (pole/sapling to old forest) are used for security and thermal cover. Use of grasslands and seral shrublands by bighorn occurs mainly during winter. Here, bunchgrasses such as bluebunch wheatgrass (*Elymus spicatum*), junegrasses (*Koeleria* spp.), fescues (*Festuca* spp.), bluegrasses (*Poa* spp.), needle grasses (*Stipa* spp.), and various forbs and shrubs are eaten (Blood 1967; Demarchi 1968; Wikeem 1984; Wikeem and Pitt 1992). Summer range is often alpine areas with kobresia (*Kobresia* spp.), sedges (*Carex* spp.), grasses, and a diversity of forbs used as forage. Talus slopes and cliffs are 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 include: gooseberry (*Ribes* spp.), cinquefoil (*Potentilla* spp.), sagebrush (*Artemesia* spp.), rose (*Rosa* spp.), maple (*Acer* spp.), saskatoon (*Amelanchier alnifolia*), kinnikinnik (*Arctostaphylos uva-ursi*), juniper (*Juniperus* spp.), and blueberry (*Vaccinium* spp.).

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 forests can provide bighorn with important habitats for forage and thermal cover (Demarchi and Mitchell 1973). During a recent low temperature/deep snow event, CBS retreated to old-growth Douglas fir forests, presumably to escape deep snow and to seek forage from Douglas-fir (*Pseudotosuga menziesii*) needles, twigs, and litter-fall (R. Lincoln, pers. comm.). Talus slopes and rock outcrops within coniferous forests are also used as hiding cover by rams during the hunting season, and possibly for thermal cover during hot summers.

Very little research has been conducted to determine the specific trace mineral needs of bighorns. 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 Bighorn Sheep because soil mineral content is low throughout their distribution (Van Dyke 1978). Further, this often results in forage with low mineral content (Smith 1954). Trace mineral deficiency is also one possible factor contributing to epizootic die-offs in bighorn (Schwantje 1988a; Packard 1946). Mineral content among licks varies considerably (Dormaar and Walker 1996), suggesting that: 1) various types of licks may serve different needs; and 2) 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.

Water requirements for bighorn are not clearly established and there is some debate as to the importance of water. McCann (1956) postulated that water is not a limiting factor and concluded that bighorn can go long periods without free-standing water. Payer and Coblenz (1997) determined that water availability affected the distribution of rams during summer on Pober Jim Ridge in Oregon. The senior author, while studying CBS in the Ashnola, observed during June 1963 that for approximately ten days prior to leaving the lambing range, ewes made daily trips of about 1 km to water, leaving up to seven lambs in a group attended by a single ewe.

5 LEGAL PROTECTION AND STATUS

5.1 North America

The species *Ovis canadensis* 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. In the states adjacent to British Columbia, Idaho, and Washington, CBS are classified under the respective game acts as “Game Species.” Additionally, they are rated as S3 in Washington and Idaho but are not classified in Montana. The U.S. Bureau of Land Management classifies Bighorn Sheep as a “Sensitive Species.”

5.2 British Columbia

British Columbia was granted jurisdiction over all wildlife, including California Bighorn Sheep, under the *British North America Act.* British Columbia classifies CBS as “big game” under the provincial *Wildlife Act.* Although classified by the Wildlife Branch of the Ministry of Environment, Lands and Parks as a Blue-listed or vulnerable species, CBS 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 as provincial parks or protected areas and are under the jurisdiction of the British Columbia *Park Act*. 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, jurisdictions or outside government.

6 LIMITING FACTORS AND RISKS

6.1 Habitat Alienation

Bighorn face many threats to their long-term survival, the greatest of which is probably human-caused habitat 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 alienation or human developments. Generally, threats to bighorn habitat in the California Bighorn Sheep's range have been and continue to be any or all of the following:

- 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 land;
- recreational developments and activities: golf courses, ski hills, all terrain vehicle (ATV) use, helicopter-supported recreation, etc.

A major boom in land alienation and settlement occurred in British Columbia during the late 1890s and early 1900s. Since CBS originally occupied low-elevation grasslands in an area with an attractive climate, they were pushed out by human development in the Okanagan-Similkameen during these early times, while west of the Fraser their distribution had not changed (Sugden 1961). West of the Fraser, settlements were not developed until later. From 1971 to 1981, 38,500 ha of rural land in British Columbia was converted to urban use; by 1981, 276,000 ha were under urban or rural settlement in the province (Demarchi and Demarchi 1967). Land acquisition programs have attempted to counteract some of the effects of land alienation. In the 1970s, land was acquired in the Ashnola River, Vaseux Lake, and Chilcotin River areas to remove cattle from critical Bighorn Sheep ranges and to stop subdivision developments (Demarchi in Trefethen 1975).

Mining operations in British Columbia became common in the latter half of the 1800s as transportation links became constructed. In the 1930s, miners re-invaded goldfields along the Middle Fraser River basin and caused concern because of killing sheep for meat (Demarchi in Trefethen 1975). Sugden (1961) mentions mining operations as a potential problem for Bighorn Sheep that could disturb their distribution and decrease their numbers. 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). Such practices as open-pit mining and overburden dumping can destroy and alter Bighorn Sheep habitat (Demarchi and Demarchi 1967). CBS may have abandoned what was believed to be a former summer range on Black Dome Mountain, where a mining operation currently exists.

While reclamation and more careful planning, beginning in the 1970s, may have replaced more destructive technologies, some reclamation methods have proved to be less helpful than originally hoped. Mining exploration has also been destructive, such as the 250 km of trails bulldozed in an area of 20000 ha of subalpine and alpine Bighorn Sheep habitat in the Fernie Basin from 1969–1971 (Demarchi and Demarchi 1967). Dislocation of sheep can be caused by helicopter activity associated with seismic work, which, in Montana, caused Bighorn Sheep to be displaced from more productive forage, leaving them vulnerable to major die-offs (Hook 1986).

Transportation and utility corridors for highways, resource extraction roads, railroads, power transmission lines and pipelines have all had negative effects on Bighorn Sheep habitat in the province. These transportation and utility corridors occupy habitat thereby removing it from use, they subject bighorns to toxic substances used to keep plant growth down, dissect migration routes, and directly kill Bighorn Sheep. For CBS, examples of these types of impacts can be found on Highway 3 in the Kettle Valley and Highway 97 at Vaseux Lake.

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 pre-European contact habitat and population dynamics and no certain way of determining which disease agent may have been acting in any particular area at any particular time. As a consequence, it is difficult to say whether CBS populations of the past experienced similar patterns and amplitudes of population fluctuations exhibited today. Bartlett (1987) and Schwantje (1988a) 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). Although CBS all but disappeared in the USA in the late 1800s and early 1900s, there are no records of an all-age die-off of California Bighorn Sheep ever having occurred in BC. However, losses have occurred in the past and markedly increased summer lamb mortality has been common. Recently, in the Junction, Churn, and West Fraser herds, biologists observed lambs unable to keep up with herds, weak, with episodes of violently coughing. Subsequent post-mortems have revealed bacterial pneumonia with the presence of lungworm in lambs under six months. Harper (pers. com.) first noted decreasing lamb survival in the east Fraser herds in 1992, and confirmed lungworm-caused mortality in 1995. Shortly after, similar high lamb mortality was observed in the Churn and West Fraser herds (J. Youds, pers. comm.). Recent aerial surveys indicate that lamb survival in these herds may now be increasing.

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 bighorn have probably co-evolved, lungworms at low to moderate levels in *healthy* bighorn do not appear to present a problem; in fact, most bighorn 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.).

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. 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.

Although never demonstrated in BC for CBS, 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. CBS are susceptible to fatal results from exposure to domestic sheep, as has been shown with transplanted herds in Lava Bed National Monument in California in 1981 and 1988 (Wehausen et al. 1987b; Hebert and Evans 1991). Similarly, CBS in pens adjacent to domestic sheep died from *Pasteurella* (Hebert and Evans 1991). Other examples include the 1941, 1964, and 1981 die-offs of RMBS in the East Kootenay at Radium, Bull River, and

McGuire Creek, respectively (A. Cooper, pers. comm.; Demarchi and Demarchi 1967; Davidson 1991). Although all of these results were obtained with Rocky Mountain Bighorn Sheep, there is no reason to believe that California bighorn are not vulnerable to such diseases given the close genetic relationship between the two sub-species.

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 domestic sheep remained healthy. *Pasteurella haemolytica* (usually biotype A, serotype 2) is the major pathogen responsible for death; 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 experienced varying exposure to viruses, such as bluetongue (BT), epizootic haemorrhagic 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 Sheep involved in die-offs (H. Schwantje, pers. comm.). However, serological results for three East Kootenay herds studied 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 bluetongue virus and causes identical pathological lesions.

V.L. Coggins (pers. comm.) reported that sheep transplanted from Jasper to Oregon suffered higher losses to scabies than 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 bighorn 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 1991). Well-intentioned efforts on the part of individuals or non-government organisations to "correct" their 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.

Lack of experimental controls and treatments leaves researchers unsure of the role played by single stressors and even less sure about their interactions. However, a recurring depressed lamb recruitment rate suggests that disease may be more than a secondary factor precipitated by nutrition (Wehausen et al. 1987a). Wehausen et al. (1987a) 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).

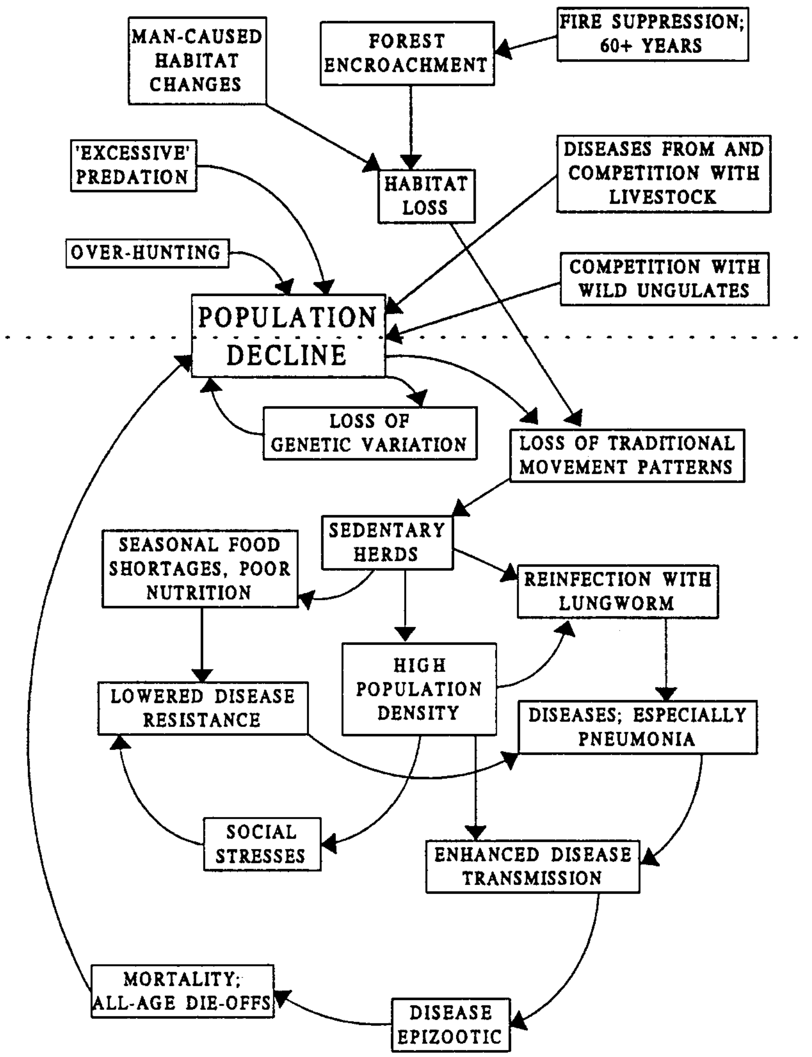

Figure 3. A conceptual model demonstrating initiating factors (above the dashed line) and self-perpetuating cycles (below the dashed line), which have been involved in the population decline of Bighorn Sheep (adapted from Risenhoover et al. 1988).

6.2.3 Parasites

Other than lungworm (particularly *Protostrongylus stilesi* and *P. rushii),* both external and internal parasites of bighorn are considered by most Bighorn Sheep biologists to be of minor consequence to the health of CBS 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 US 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, no cases of *Psoroptes* have been identified in British Columbia.

Blood (1963) identified the following parasites in post-mortem examinations of two clinically healthy CBS ewes from the Ashnola herd:

1. Coccidia (*Eimeria* spp)
2. Thin-necked bladder worm (*Cysticercus tenuicollis* Rudolphi)
3. Protostrongylid lungworms (*Protostrongylus* spp.)
4. Sheep pinworm (*Skrajabinema ovis* Skrjabin)
5. Abomasal worms (*Ostertagia ostergi* Styles; *O. occidentalis* Ransom; *O. circumcincta* Stadelmann)
6. Medium stomach worm (*Marshallagia marshalli* Ransom)
7. Thin-necked strongyle (*Nematodirus* sp.)
8. Ruminant whipworm (*Trichuris discolor*)
9. Winter tick (*Dermacentor albipictus* Packard)
10. Spinose ear tick (*Otobius megnini* Duges)
11. Wood tick (*Dermacentor andersoni*) (Sugden 1961. Churn Creek)

A more comprehensive list of gastro-intestinal parasites was compiled by Worley and Seesee (1992) from 11 western Montana RMBS herds. While these parasites and more are frequently found on CBS in British Columbia, they are unlikely to significantly affect CBS health on their own.

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 (i.e., interspecific competition) and competition within species (i.e., 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 to mountain sheep; this 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. The provincial government has vegetation guidelines for Crown land but, to date, has not taken any action to protect wild sheep from domestic sheep on private lands.

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 deer 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, which 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 BC dates back to the early 1700s, when Kutenai Indians introduced horses (*Equus caballus*) (Haines 1938; Lamb 1960). Cattle (*Bos taurus*) drives in the latter half of the 1800s brought domestic animals through the Okanagan on their way to the goldfields. In the Similkameen, grazing by cattle and domestic sheep began in the late 1800s and spread to the Ashnola Valley. Cattle ranching began in the 1880s and was the major industry in the dry grassland interior of British Columbia in 1960 (Sugden 1961). Domestic sheep raising began later in the 1920s. As early as 1925, the Bighorn Sheep decline in the Okanagan was blamed principally on human settlement and orchards (Williams in Sugden 1961). West of the Fraser, grazing of domestic animals was suspected to be reducing the productivity of the ranges. Approximately 4000 domestic sheep were grazed on portions of Bighorn Sheep summer range west of the Fraser from 1937 to 1958 (Sugden 1961). Beef cattle ranching situated mainly on private, arable, valley bottom lands has been allowed highly subsidised grazing allocations and long-term leases on Crown land throughout historic Bighorn Sheep ranges in BC. This has resulted in overgrazing and ecosystem degradation of native grasslands and seral shrubland communities. In 1987, the Ministry of Forests and Lands estimated that Crown range supported 200,000 cow/calf pairs and yearlings during the summer grazing period (Demarchi and Demarchi 1987). The development of a domestic sheep industry resulted in damage to fragile low elevation and alpine grasslands in the interior in such places as the Yalakom and Ashnola valleys (Demarchi and Demarchi 1987). There was a collapse in the domestic sheep industry in North America around the 1940s due to the dropping of import quotas for foreign mutton and wool (Goodson 1982).

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). Wildlife and livestock conflicts came to a head in the 1970s on provincial rangelands managed by the Ministry of Forests and resulted in two significant changes. Between 1972 and 1975, the BC government intensified efforts to repatriate land for wildlife use with the help of non-government organisations by acquiring several key parcels of CBS winter range in the Ashnola, Vaseux Lake, Churn Creek, and Junction ranges. Secondly, beginning in July 1975 and extending to the early to mid-1980s in Williams Lake and the mid 1990s in other regions, the provincial government introduced a program of "deferred rotation grazing" and "coordinated resource management planning" (CRMP) to manage forage for *both* livestock and wildlife and to integrate the needs of all natural resource users at the operational level. For the first time, wildlife was recognised as a legitimate user of Crown land and forage resources. This period of formal interministry co-operation at the operational level between was short-lived however, as special federal government funding was terminated and no source of alternative funding was provided by the provincial government. The Williams Lake Region was the first to abandon the process when the federal funds ran out. In the remaining regions, the CRMP program continued only until recently, albeit at a much reduced level of management and co-ordination.

Livestock ranching and agriculture are believed to play important roles in the health of bighorn (i.e., through disease transmission and resource competition). Excessive competition for forage with livestock can be detrimental to bighorn, as quality winter range is limited. In addition, behavioural studies indicate that the presence of cattle alter habitat use patterns of sheep (Bissonette and Steinkamp 1996). Core areas used by bighorns decrease along with the distance to escape terrain. The presence of cattle on Bighorn Sheep range reduces the area available for bighorns to forage, not only through diet overlap, but through physical displacement as well.

6.3.2 Native ungulates

Mountain Goat, Elk, and Mule Deer ranges substantially overlap Mountain Sheep range in BC and competition for forage is assumed but has rarely been quantified. For the most part, Elk are uncommon on CBS winter range. Winter range availability is often cited as one of the major factors limiting ungulate populations. Although the summer habitat requirements of Mountain Goats closely resemble those of Bighorn Sheep, only the high elevation 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. However, the majority of CBS winter at low elevations where Mule Deer, primarily a consumer of browse, are the main potential native competitor for forage.

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 rate. Also, uncertainties about 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 social and economic reasons can run counter to optimum bighorn habitat management. Wakelyn (1987) determined that forest succession significantly decreased bighorn range in Colorado, and Demarchi and Demarchi

(1994) suggest that forest encroachment has severely reduced Rocky Mountain 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, Bighorn Sheep may abandon traditional movement corridors in response to the increased predation risk associated with decreased predator detection. This is a problem with many herds, including the Shorts Creek/West Side herds in British Columbia for which the summer range is becoming increasingly isolated from the winter range (R. Lincoln, pers. comm.). The same situation is suspected with the Marble Range sheep herd, which is a migratory component of the West Fraser population.

In the past, the Central Interior experienced large, frequent fires that maintained much habitat in early successional stages. Fire suppression policies of the MOF have allowed the growth and expansion of forests on CBS range. 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 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 add undue stress to 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.

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 domestic dogs, and a dependency on artificial food sources that may be only temporarily available.

Management for access in CBS habitat has centred around snowmobile and all-terrain vehicle (ATV) uses of winter ranges. Employing the access provisions of the *Wildlife Act* to regulate road use for specific purposes provides only a partial, temporary solution to overuse and harassment of CBS. Critical winter range areas, such as Churn Creek and the Junction range, require co-ordinated access management plans, which include road reclamation. However new forest developments, such as are occurring in the Churn Creek watershed, threaten the integrity of movement corridors (P. Dielman, pers. comm.). The Backcountry Recreation Policy of British Columbia Crown Assets and Lands seeks to increase commercialised recreation of backcountry Crown lands. Development of backcountry lodges and helicopter-assisted skiing and hiking threaten the integrity of CBS summer and winter ranges and movement corridors.

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 rufus*), 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 continuously varies over space and time.

Wehausen (1996) determined that Cougar predation effectively halted a previously successful restoration program for Bighorn Sheep in the Sierra Nevadas and reversed the overall population trend. In his study, annual adult ewe survival was reduced to 62.5% and Cougar predation accounted for 100% of all adult ewe mortalities. Hebert and Harrison (1988), studying CBS in the livestock-free Junction herd, concluded that Coyote predation and not range condition, nutrition, stress, parasites, disease, or climate resulted in a significant loss of lambs as reflected in a decline in the seasonal lamb:ewe ratios from the late 1970s until their study. They reported that ten years of extensive "Coyote control" by ranchers and directed trappers resulted in a significant increase in lamb:ewe ratios and an increase in the overall population. In a separate publication, Harrison and Hebert (1988) determined that Cougar predation and not habitat condition or illegal hunting reduced the number and proportion of mature rams in the Junction herd. Evidence was obtained that supported the hypothesis that scavenging of Cougar kills by Coyotes increased the frequency of predation by Cougar.

Bighorn Sheep have two basic adaptations to predation and these have affected their habitat preference: great agility on rocks and 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). Bleich et al. (1997) found evidence to support the hypothesis that because of their smaller body size, their potentially greater vulnerability 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 risks to their offspring albeit 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) as to 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 currently used extensively, but it is hoped that the use of bio-control agents (namely insects that eat the weeds) will provide lasting protection in the future.

An active noxious weed control program, especially for goatsbeard (*Tragopogon* spp.), is needed for the Empire Ranch Wildlife Management Area. Currently there is cooperation among the MOF, Cattleman's Association, Ministry of Transportation and Highways, and the MELP with a noxious weed control problem in the Okanagan. Here, diffuse knapweed (*Centaurea diffusa*) and spotted knapweed (*C. macula*) are the main problems.

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 (Risenhoover et al. 1988), including winter severity.

6.9 Subspecies Intergrades

The overlap and subsequent mixing of subspecies leads to the loss of their individual uniqueness. Cowan (1940) presented a map showing areas of potential intergrades between all subspecies of bighorns in the USA. In British Columbia, such intergradation was not a natural threat because of the extensive geographic barriers between *O. c. canadensis* and *O. c. californiana*. The establishment of *O. c. canadensis* transplanted to Chase and Spences Bridge from Banff National Park in 1927 poses a threat to the subspecies integrity of the South Thompson and Fraser River metapopulations. It is possible that some mixing with introduced RMBS has already occurred within CBS herds east of the Fraser River and north of the Thompson River.

7 SPECIAL SIGNIFICANCE OF THE SPECIES

7.1 Use and Value

7.1.1 First Nations

Bighorn Sheep were likely hunted as long as 7000 years ago, shortly after the withdrawal of the last of the Pleistocene glaciers Although salmon (*Oncorhynchus* spp.) and mule deer (*Odocoileus hemionus*) were preferred sources of food, First Nations people in British Columbia placed a high value on Bighorn Sheep, particularly as an emergency source of food. They are comparatively easy to stalk and kill and occurred with predictability on traditional winter ranges. First Nations used the meat, hides, bones, and horns from Bighorn Sheep. Drill handles, combs, and knives were made from bones, and 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 1991). In some cases, either the artifact or the raw horn was traded as far as the coast (Shackleton *in* Toweill and Geist 1999).

7.1.2 Early history

The meat of the bighorn was prized by both First Nations and early settlers, and was considered by some to be the most palatable of all North American big game species (Banfield 1974). However, the tallowy taste and texture of Bighorn Sheep lowered their value to some who utilized them only when other sources of protein were not available. While exploring the Fraser River for the Northwest Fur Company, Simon Fraser utilised CBS for food and entered the first written record of a CBS found at the confluence of the Fraser and Chilcotin rivers in 1808 (Lamb 1960)

Both CBS and RMBS were prized as big game trophies, particularly by visiting hunters from Europe and the USA, as access to and within British Columbia developed. Non-resident CBS trophy hunting was popular in the Ashnola and other CBS ranges in the southern Interior during the middle to late 1800s (Baillie-Grohman 1900; Nicholson 1905).

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 CBS and RMBS, 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, as they do for DBS.

In general, society places a high value on all races of Mountain Sheep, including CBS, as exemplified by the use of the species' image in a great variety of forms. A Mountain Sheep ram appears on the British Columbia Coat of Arms. 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 CBS among hunting and wildlife conservation organisations, such as rod and gun clubs and fish and game associations, some of which have been in existence for 100 years in British Columbia. Numerous non-government organisations with large memberships 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 and the Wild Sheep Society of British Columbia 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 and 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, most hunters kill bighorn rams mainly for the cape, skull, and horns as a trophy to mount on the wall. The meat is also used, although it is usually of secondary value because 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 were valued by resident hunters at $83.20 per day and were rated second only to grizzly bear in hunters' willingness-to-pay (Reid 1997b). The Wildlife Branch's

Hunter Sample annually surveys a representative sample of hunters. In 1995, for example, 1025 British Columbia residents spent 7025 days hunting CBS and took 129 CBS, while 45 guided non-resident hunters hunted for 295 days and took 38 CBS in the three regions where they occur (Reid 1997b; 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 but for trophy purposes are most valuable to the hunter who legally took them. Undersized and other illegal sheep horns and capes are annually auctioned in British Columbia mainly for arts and crafts purposes. In Alberta and several U.S. states, special hunting opportunities (e.g., "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 with most of the proceeds going directly into conservation projects that benefit wild sheep populations. 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 as their chances to view bighorn in their natural environment are increased because of sheep conservation projects, which help ensure the maintenance of healthy, well-distributed populations. The provincial government initiated, and for a period of years funded, a wildlife viewing program that included opportunities to view Bighorn Sheep in their natural environment. These areas included Vaseux Lake, Ashnola (including Crater, Flatiron, and Snowy mountains), South Thompson/Harper Ranch, Dewdrop Wildlife Management Area (north side of Kamloops Lake), Fraser River canyon from Lillooet to Dog Creek, Junction Range (Riske Creek), Churn Creek/ Gang Ranch, and Empire Valley Ranch (Post et al. 1997).

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) estimated that nearly 200,000 adult BC residents enjoyed 18 million days of participation in direct wildlife activities in 1996. Reid (1998) found that of the 29% of BC residents who were categorised as "direct wildlife users," 23% participated, or 6.7% of the total BC adult population engaged in outdoor activities associated with the group of wildlife comprised of goats, sheep, and caribou. Direct wildlife participation accounted for $391.7 million in expenditures annually. The net economic value from direct wildlife participation was estimated at $792 million. While the amount attributable to CBS was not determined, the interest expressed in both the surveys of Self (1982) and Reid (1998) reveal that it is very significant.

8 HARVEST MANAGEMENT

8.1 Management History

Traditionally, 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 hunting of both CBS and RMBS was extensive and largely unregulated. As a result of pressure on the provincial government by the newly forming resident hunter-conservation groups as well as some influential non-resident hunters and the first closed seasons were instituted by Order of the Executive Council in 1906. (Baillie-Grohman 1900; Hornaday 1906). Subsequent open hunting seasons involved males only.

Robinson (1987 in A. 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 the evolution of hunting regulations for Mountain Sheep:

- 1859 First wildlife laws passed but did not include Mountain Sheep.
- 1890 $50 license fee and a bag limit of eight sheep for non-residents initiated.
- 1905 Bag limits were changed to 3 sheep rams for non-residents and 5 for residents.
- 1906 Regulated Mountain Sheep open and closed seasons were instituted.
- 1909 Specific area hunting closures were established.

- 1913 First resident hunting license requirement began.
- 1955 A 3/4-curl regulation was established for CBS and RMBS.
- 1964 Sheep tag-license was introduced.
- 1974 Select limited entry hunts (LEH) were initiated.
- 1976 Compulsory inspection requirement was started.
- 1976 RMBS mature ram full-curl regulation was initiated.
- 1989 CBS mature ram full-curl regulation initiated.

8.2 Response to Hunting

The systematic removal of older aged "trophy" rams has been hypothesised to have a negative affect on the social and biological performance in a number of ways, including reduced productivity (Geist 1971, 1975; Morgan 1974). Bubenik (in Stringham and Bubenik 1974) generalised 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; energy is diverted from somatic growth and fat deposition prior to the onset of winter and directed towards sexual development and rutting activities.

Festa-Bianchet (1989b) 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. No direct studies of the effects of major 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) and Heimer and Watson (1990) identified a number of potential undesirable population and behavioural consequences from the removal of most mature rams from a population of Dall's sheep in Alaska. 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 over a 15-year period in Alaska. No evidence was obtained that removal of all or nearly all rams equal to or greater than 3/4 curl (i.e., approximately five years and older) for the first 11 years and 7/8 curl (i.e., approximately six 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 removal by trapping 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 annual removals of 12–24% of the total ewe population. In the population with hunting removals, the prevalence of lactation in two-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 four and five 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 CBS Management Guidelines

The principles and conditions for managing CBS 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 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. Because Bighorn Sheep are a Blue-listed species in British Columbia, they will be managed more cautiously than Yellow-listed ungulates. Hunting has been restricted primarily to the harvest of "three-quarter curl" or "full curl" rams. One management goal will be to maintain or, where necessary, restore appropriate sex and age ratios.

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. Ewe and lamb hunting may be provided where sheep numbers have increased above carrying 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.

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/or administrative guidelines will be employed to regulate the guided non-resident harvest. 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 CBS may be hunted and exported from the province. The main provisions are as follows:

- CBS are not listed in the Convention on International Trade (CITES) but are required to have a permit issued for export if exported 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 license 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 re-introductions. Populations in Canada are particularly important for this purpose since there have been extensive reintroduction programs in the USA (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 these 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; 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 Harper (1992) has developed a paper that grouped the 24 herds of CBS in the province into eight subpopulations.

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 co-ordination between management agencies and between jurisdictions.

9.2 Management and Conservation Measures

Management measures for California Bighorn Sheep 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 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 acquisition 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, commercial recreation ventures, or agriculture. 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 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 Plans (LRMPs), 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, property covenants, 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 development and/or resource extraction. In addition, co-operative arrangements for the protection and management of important CBS habitats within provincial forests should be increased significantly. Also, commercial backcountry recreational developments must not proceed without due consideration for the protection of important CBS habitats.

The designation of key wildlife habitat as a Wildlife Management Area (WMA) is a promising way to secure that habitat to ensure its long-term viability. WMAs may be established where conservation measures are considered essential to the continued well-being of resident or migratory wildlife that are of regional, national, or global significance. Lands of strategic importance to bighorn herds and WMA relevance are the Junction Protected Area, Vaseux Lake, and the Dewdrop-Rosseau Wildlife Management Area.

WMAs should be established on some critical ranges (e.g., lambing areas and mineral licks). Some transitional ranges as well as well as certain alpine forage and/or escape habitat should receive WMA designation. The specifics of WMA location size, exposure, 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 Planning for forest harvest. 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 area. Natal times are generally between April and 15 July. However, times may vary for each species and by location. BC Environment should be consulted for species/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/salt blocks) should be implemented only after consultation with regional BC Environment and range staff.

Silviculture

- Do not use helicopters to remove timber during critical times. Consult BC Environment so a designated environment official can specify appropriate time frames.
- Prohibit the use of domestic sheep to minimize 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 diseases 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 eliminated immediately through enclosure fencing. The presence of cattle can also significantly alter the behaviour and habitat use of Bighorn Sheep (Bissonette and Steinkamp 1996). Therefore, it is recommended, where grazing allocations apply to bighorn winter range, 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 foot rot, pseudo-tuberculosis, 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 bighorn infected with domestic strains of *P. haemolytica*, drug treatment of sick bighorn is not an option. Drug treatment (*i.e.,* ivermectin, fenbendazole, or cambendazole) of bighorn experiencing high lungworm loads has not been successful in Colorado (H. Schwantje, pers. comm.). In 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 1991). 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 bighorn cannot be expected.

While CBS have not experienced the extreme die-offs of RMBS, there have been herds with high lamb mortality, which negatively affects overall herd stability. In the case of lamb mortality that increases or spreads, it would be wise to use a protocol to prevent transmission. Some of these might include the following recommendations:

1. If a die-off is experienced, 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 *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 bighorn 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 bighorn (Coggins and Matthews 1992). This precaution is paramount to the health of bighorn. In addition, by maintaining the habitat in good condition and regulating animal numbers according to habitat capability, die-offs may be avoided. Recent additions of domestic sheep and goat in proximity to the Nemaia herd may be linked to recent declines (J. Youds, pers. comm.). It is extremely important to assess this situation to ensure that contact is eliminated.

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 1927, when Rocky Mountain Bighorn Sheep were translocated from Banff; 50 to Spences Bridge and 50 to Squilax, BC. Since 1955, the Junction herd has been the major source herd for CBS translocations around BC and the western states. Sheep from this herd have re-established herds in six western states (Hebert and Harrison 1988).

The problems associated with translocations are now serious concerns for managers. Founder effect and genetic drift can occur within small re-introduced 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 reintroduced 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 it 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 from 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 but, with some modification, several of these items could be used to improve British Columbia's protocol:

- If translocation is proposed to a historic site or one with a depressed population, evaluate the habitat to determine the reason(s) for the lack of bighorn 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 bighorn 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 bighorn are not translocated to healthy populations and vice versa.
- Keep genetic strains intact as much as possible by emphasising transplants within continuous ranges.

It is possible that some mixing with introduced RMBS has already occurred within CBS herds east of the Fraser River and north of the Thompson River. Despite this serious threat, both herds are highly valued by residents of the adjacent communities as well as by other members of the public and it may not be practical or feasible to correct the situation by removing and replacing the *O. c. canadensis* population with *O. c. californiana* stock. The Wildlife Branch had one opportunity in 1989 when the Chase herd was reduced to only five animals but chose instead to augment the herd with two rams and two ewes of *O. c. canadensis* from Spences Bridge. (Hatter and Blower 1996). This herd is now estimated at about 25 animals and stable. In the event of another die-off of either the Chase or the Spences Bridge herd, serious consideration should be given to restocking with CBS from the isolated Junction Band.

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 First Nations. Spalding (1996) recommended that all four sites be considered for transplants and range improvements. Before implementing these recommendations, there is a need to develop a broader strategic plan that should include the completion of a 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 non-government 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 that are applicable to California Bighorn Sheep range. 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 (ATVs) 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, compromise, and enforcement. Communication to the public is needed regarding the importance of access management.

Commercial backcountry recreation in the form of heli-skiing, heli-hiking (e.g., at Nemaiah), 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 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 CBS population declines 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.

Often the lack of funding to properly assess the efficacy of past enhancement projects impairs the ability of wildlife managers to learn from their actions. Enhancement projects must be conducted as scientific experiments and monitored over time to develop an effective adaptive management program. The use of replicated experimental units and controls to monitor forage condition, abundance, and animal usage before and after treatments would allow managers to predict the results of enhancement projects at other locations.

The maintenance of climax grasslands in the Ponderosa Pine and Interior Douglas-fir biogeoclimatic zones requires repeated disturbance by low intensity fires. 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 CBS should strive to provide a mixture of forage species (Wikeem and Pitt 1992). As foraging generalists, CBS depend on 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 CBS lamb mortality, particularly near irrigated croplands and golf courses. Attempt to identify critical time periods before lamb die-offs 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 improvement, can be taken to mitigate the impact of such events.

- Research on disease transmission, how diseases are being transmitted, methods and procedures for reducing or eliminating contact with domestic sheep and goats. 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 determine fragmentation zones and viability of populations.
- Research on land use planning on sustainability of CBS metapopulations.

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.
- Identify the key predators of bighorns on a herd-by-herd basis and estimate their impacts on Bighorn Sheep. 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 metapopulations, levels of inbreeding depression and genetic drift.

10.4 Biophysical Inventory

- Complete the habitat capability/suitability mapping on all critical bighorn winter ranges at a scale of 1:20000 and by area at 1:5000. Completion of these maps will facilitate management decisions regarding enhancement activities addressing specific concerns. At present, there is a need for capability/suitability mapping to facilitate the Land and Resource Management Plans in the Kamloops Region.

10.5 Habitat Use and Enhancement

- Assess the key components of habitat use patterns by radio-tracking non-transplanted animals. This data can be used to determine the effects of habitat alteration and enhancement on habitat use and animal movement.
- Trace mineral use and needs. Inventory distribution and location of mineral licks utilized by CBS.
- Enhancement and monitoring and research.

10.6 Limiting Factors

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

11 EVALUATION

Currently, CBS 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 et al. 1994; Munro 1994). In British Columbia, Blue-listed species are considered likely to become threatened or endangered 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 American 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 that sustains or otherwise contributes to the survival of a population (Harcombe 1994). Master (undated) has developed a sequential process for ranking that is used in combination with a proposed ranking system for Canada (Harper et al. 1996).

Occurrence

An occurrence is more useful for a species that has few sightings, as an occurrence represents only one point in time (Gaston 1996). For a 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 CBS. Currently, there are 24 herds of CBS in British Columbia ranging in size from 15 to 900 individuals.

For a status evaluation, it would be more useful to use subpopulations of a metapopulation since this is the group that will have a longer persistence over time; subpopulation should be used as the basic unit for a status evaluation. A subpopulation for CBS can be defined as two or more wintering herds that share a common summer range. Harper (1992) defines eight distinct subpopulations of CBS 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 undated).

Viability

The quality, condition, viability, and defensibility of these occurrences are 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 CBS. Berger (1990) has determined that the MVP for Bighorn Sheep is probably 125. Out of the eight subpopulations of CBS, zero are extinct, one is <125 individuals, and seven are >125. While there have been extirpations of some herds, most of these were in marginal habitat and may be a normal winking out of smaller trial herds that may re-establish themselves briefly in the future. However, the remaining subpopulations are mainly of good quality and viable since they are >125.

Population Trend

The population trend for CBS has been generally upward until 1995, 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 not been the all-age die-offs of RMBS, which more dramatically affected population numbers and trends.

Population Size

The provincial population estimate of CBS exceeded 4500 in 1990. This is the largest size that inventory figures have recorded, although there may have been a larger population prehistorically, when grasslands were probably more widespread. Currently, the provincial total is estimated to be between 3030 and 3625 CBS.

Distribution Trend

The distribution trend of CBS may be somewhat smaller than its largest historic range, but it is larger than during the early part of this century because of successful recovery efforts in vacant historic habitats. CBS currently are expanding into formerly occupied (prehistoric) ranges in the Thompson, Okanagan, Kettle, and Similkameen. The capability (or potential) of the habitat has been impaired on approximately <10% in all regions, except the Okanagan, where subdivisions, highways, and agriculture have removed at least 25% of the historic capability. The suitable (or actual) habitat at present is >50% of the capable habitat within the historic distribution. The habitat is restricted but can be protected.

Threats

The threats to CBS 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

CBS 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, which may be exacerbated by the presence of alfalfa fields and golf courses, CBS are particularly sensitive to human activities.

The provincial or national ranking for CBS is currently S3, which places them on the Blue list. This status report has developed a revised ranking that includes viability of subpopulations and the fragility of

Table 11. Number code ranking for criteria used to rank California 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**

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, 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; 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). These global and trinomial ranks have been revised to G3T3 based on the information collected about North America and RMBS.

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