RECOVERY PLAN FOR CALIFORNIA BIGHORN SHEEP IN THE SOUTH OKANAGAN VALLEY BRITISH COLUMBIA

by

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DISCLAIMER

NOTE: The content of this report was completed in 2002 and reflects the state of our knowledge at that time. It has received limited review since 2002 and content has not been substantively updated prior to publication, thus the publication date remains 2002 although the document has not been available until now.

Statements and recommendations contained in this report are the opinion of the author and do not necessarily represent those of the Ministry.

Information on current status of native and some non-native species in British Columbia can be found through B.C. Species and Ecosystems Explorer http://www.env.gov.bc.ca/atrisk/toolintro.html

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SUMMARY

California bighorn sheep (*Ovis canadensis californiana*) in the South Okanagan have undergone two and possibly three major declines in historic times. The first was associated with unregulated overhunting between 1870 and 1906. A second possible decline was disease-related, occurring in the early 1920s, and was associated with domestic sheep brought north from the United States to graze bighorn ranges in the South Okanagan. The third and most recent major population decline occurred in winter/spring 1999/2000, and was the result of an all-age pneumonia-related die-off in which 60 to 75% of affected subpopulations died. This recovery plan is designed to hasten recovery of California bighorn sheep from this last population decline.

The South Okanagan Valley contains a variety of shrub–steppe and dry forest habitats that in combination represent a unique ecosystem recognized as one of the most threatened in Canada. A burgeoning human population and the habitat loss and fragmentation that results from agricultural, industrial, and urban development have put pressures on a variety of wildlife species, including bighorn sheep.

California bighorn sheep are included in the Ministry of Water, Land and Air Protection Blue List as a vulnerable species because of numerous and uncertain threats from disease, forest succession, access development, land alienation, housing development, and grazing competition, as well as the high vulnerability and sensitivity of bighorn sheep to human disturbance from recreation, livestock grazing, and resource extraction.

At least in recent times, South Okanagan bighorn sheep were very productive, with an average pregnancy rate of adult females (3 years and older) of 96%, and an average twinning rate of 22%. With this high pregnancy rate and propensity for twinning, the South Okanagan subpopulations should be capable of high rates of population growth if factors affecting survival of adults and lambs are controlled. Bighorn sheep are capable of exponential growth rates that can double their population every 2½ years.

Mortality factors, however, can be significant. In the nearby Ashnola metapopulation, neonatal mortality rates were calculated at 72% in the mid-1980s, with most occurring in the first 4 weeks postpartum, and all probably the result of coyote predation. Classification counts indicate that lamb production and survival was about twice as high in the early 1960s as in the 1980s and 1990s. From 1962 to 1966, the 5-year moving average was 46 lambs to 100 "ewes" compared with averages since 1980 that have been consistently less than 25 lambs to 100 "ewes."

Until the 1880s, the South Okanagan metapopulation was distributed on both sides of the Okanagan Valley. The current distribution of bighorn sheep is now almost completely on the east side of the valley, with two small exceptions—one west of Skaha Lake and another west of Vaseux Lake. The South Okanagan metapopulation is essentially nonmigratory, although short

seasonal movements between winter ranges, rutting grounds, and spring/summer ranges are typical. Bighorn sheep subpopulations in the South Okanagan have been defined on a preliminary basis. Further study of movement patterns and gene flow will be required to more accurately reflect the actual metapopulation structure of bighorn sheep populations in the South Okanagan.

Between 1977 and 1986, a total of 77 animals (mostly females) were removed from the Vaseux Lake subpopulation for translocation to other areas. Before this, 14 males were added to the Vaseux Lake subpopulation in the 1950s.

The 62-kg body mass of adult females from Vaseux Lake measured in 1984 is average compared with other bighorn sheep populations. Horn-growth curves from the South Okanagan metapopulation show average or higher-than-average horn growth rates, suggesting a “high-quality” population, at least until the early 1980s. A more recent analysis indicated a possible decline in the length of the yearling increment, from around 250 mm in the 1970s to 215 mm in the early 1990s.

Resident hunter harvest of bighorn rams from Management Units (MU) 8-01 and 8-09 increased through the 1970s and was highest from 1982 to 1989. Most of the increased harvest in the 1980s was by resident hunters, but although resident harvests dropped off in the 1990s, nonresident harvest remained relatively constant. After the disease epidemic was discovered in early 2000, the hunting season was closed and no rams were legally harvested from MUs 8-01 and 8-09 in the fall of 2000.

As part of an ecosystem classification project, potential summer and winter habitats were mapped at 1:20 000 scale in the South Okanagan. Most bighorn sheep winter ranges contain substantial areas in poor range condition, particularly for those subpopulations in the southern part of the valley. From 1974 to 1991, the Vaseux Lake subpopulation was fed during part of the winter. Peak winter feeding occurred in the late 1970s and early 1980s when more than 6000 kg of pellets and 200 bales of hay were consumed. There has been no extensive supplemental feeding since 1991.

Previous comparisons of various blood constituents between the Vaseux subpopulation and other bighorn herds indicate that Vaseux bighorn sheep were marginally deficient in selenium and had relatively high levels of inorganic phosphorus and blood urea nitrogen.

Reports of dead or dying sheep in the vicinity of Vaseux Lake were first received on 14 February 2000, and dead animals were collected for analysis through ground searches, aerial surveys, and reports from the public. It became apparent that the pneumonia outbreak began before its discovered. Necropsies of 20 dead sheep showed lesions of subacute to chronic bacterial pneumonia with varying degrees of lungworm involvement. *Mannheimia [Pasteurella] multocida* was consistently isolated from the lungs of dead sheep, and there were indications that several other organisms considered to be secondary respiratory pathogens were involved in some mortalities. Although the genus name *Pasteurella* has recently been officially changed to *Mannheimia*, for clarity, the former name *Pasteurella* will be used throughout this document.

The size of the South Okanagan metapopulation on the east side of the Okanagan Valley was estimated at 430 to 442 in 1999. As of June 2001, the population on the east side of the Okanagan Valley is estimated at 159, reflecting a 63% decline from 1999, a result of the all-age pneumonia die-off in 1999–2000. The two small subpopulations on the west side of the Okanagan Valley, the northernmost subpopulation near Penticton, and the southernmost subpopulation in the United States, appear to be unaffected by the die-off.

Experience has shown that once a pneumonia-related die-off has begun, current methods of treatment in the field or in captivity are of little value in controlling the outbreak. Control methods used in the South Okanagan die-off were limited to increasing observations to identify sick animals and euthanizing these sheep for necropsy.

Several areas in the SOK were identified where small flocks and one large commercial flock of domestic sheep (>1000) were grazed close to bighorns; such close contact and transmission of infectious organisms may have occurred before the die-off.

For many years, bighorn sheep habitats in the South Okanagan were known to be affected by many problems. Increases in the human population between 1940 and 1987 resulted in 8799 ha of native grasslands in the South Okanagan being converted to agricultural and urban development. If this trend continues, an additional 4000 ha of grassland will be lost to development in the next 20 years. Fire suppression policies over the past 50 years have altered the natural fire frequency of wildfire in grasslands, but prescribed burns are being used to restore this natural disturbance regime to native shrub–steppe and dry forest ecosystems. Although much of the damage to native plant communities caused by overgrazing livestock occurred approximately 100 years ago, many ranges still have not fully recovered. Careful range management practices are required by ranchers to maintain improving trends in range condition. One of the most significant habitat issues in the South Okanagan is degradation of native ecosystems caused by noxious weed invasion. At least 25 noxious and problem weeds have invaded native plant communities in the South Okanagan, and many are significantly reducing range carrying capacity for bighorn sheep.

The extent and impact of predation on South Okanagan bighorn sheep is unknown, but could be significant, particularly considering the depleted nature of remnant herds left after the die-off. Coyote predation would probably affect lamb survival in the first few months after birth, whereas cougar predation would affect all age classes. Collisions between bighorn sheep and vehicles on Highway 97 were the largest single source of mortality of adult females in a recent study. Human disturbance has the potential to cause indirect mortality through increased stress and lower foraging efficiency and by altering normal range-use patterns. Human activities that stress bighorn sheep include close approaches for viewing, helicopter and fixed-wing aircraft, vehicles, rock climbing on escape terrain, and domestic dogs.

Current management activities include temporarily closing all hunting of bighorn rams in the South Okanagan (MUs 8-01 and 8-09) in 2000 until populations have rebuilt sufficiently to provide a sustainable harvest. As well, in spring 2000, 25-kg bags of prescription trace minerals were made available to bighorn sheep that survived the die-off. Trace minerals were distributed to spike natural licks and other widely distributed sites to avoid concentrating animals. Volunteers confirmed the use of some of these sites. Small prescribed burns of 12 and 15 ha were accomplished in 2000 on winter/spring range used by the Vaseux subpopulation. New parks and protected areas were established in the Okanagan in 2000 and several of them include habitats used by bighorn sheep in the South Okanagan metapopulation.

This recovery plan is based on four basic principles:

1. The recovery of California bighorn sheep will be based on establishing and maintaining wild free-roaming populations in suitable habitats, within their historic range in the South Okanagan.
2. All efforts will be made to preserve the genetic integrity and diversity of bighorn sheep and to maintain their genetic distinctiveness from other subspecies of bighorn sheep.
3. To provide for continued natural evolution of California bighorn sheep, the normal interaction of free-roaming populations and their native environment will be maintained.
4. This recovery plan will support the goals and objectives of bighorn management plans for the province of British Columbia, and to the greatest extent possible, will support the objectives of management plans for adjacent bighorn populations in Washington State.

The five goals of the recovery plan for California bighorn sheep in the South Okanagan are:

1. **Reestablish a viable metapopulation of at least 400 disease-free free-roaming California bighorn sheep on suitable habitats within their original range in the South Okanagan by 2010.** This is to restore California bighorn sheep to their approximate historic distribution within the ability of habitat conditions to support viable populations. Several subpopulations are required to reduce the risk of random events affecting their entire metapopulation. Ultimately, the goal is to have a stable or increasing metapopulation of at least 400 California bighorn sheep, well distributed throughout the South Okanagan, with some subpopulations that are genetically interconnected, but not intimately connected (to arrest the spread of epidemic disease).
2. **Prevent contact between bighorn sheep and domestic sheep.** The risk of the transmission of domestic sheep diseases to wild sheep is one of the greatest obstacles to the recovery of California bighorn sheep in the South Okanagan. Every effort must be made to avoid close contact and transfers of infectious organisms from domestic sheep (*Ovis aries*) to free-

roaming bighorn sheep. There may also be risks with close contact with domestic goats (*Capra hircus*). Management will work towards the separation of domestic sheep and goats to prevent the transfer of infectious agents such as *Mannheimia [Pasteurella]* spp., contagious ecthyma.

3. **Allow the South Okanagan metapopulation to increase to a level that allows for long-term sustainable human use.** There is significant value in ecotourism, wildlife viewing, resident hunting, nonresident guide outfitting, and native subsistence use of bighorn sheep in the South Okanagan. Achieving population levels that allow human use of bighorn sheep is consistent with and supports conservation objectives.
4. **Encourage research on the South Okanagan metapopulation, particularly those studies that focus on conservation and conservation biology of bighorn sheep.** Well-designed research could be very effective in improving the ability of wildlife managers to manage both populations and habitats to achieve recovery objectives. Research directed towards evaluating the population responses to various recovery actions could determine the effectiveness and cost efficiency of management programs.
5. **Continue to continue to work with public groups, rural and agricultural communities, aboriginal peoples, and other government agencies to develop cooperative management and fund-raising programs for establishing and maintaining healthy subpopulations in the South Okanagan.** Conservation objectives are easier to achieve if local communities have a direct stake in re-establishing and maintaining viable populations of bighorn sheep in their area. Native peoples have a long history of cultural attachment to this species. The South Okanagan Sportsmen's Association has a proven ability to cooperatively sponsor and develop bighorn sheep conservation programs. The federal government recently announced a contribution of $1 million towards the conservation of habitat and species at risk as part of South Okanagan–Similkameen Conservation Program. Recovery programs are expensive, and new sources of revenue and fund-raising should be developed with various public and private partners to support implementation of this plan.

1.0 BACKGROUND AND CURRENT STATUS

1.1 Introduction

Bighorn sheep in the South Okanagan have been the subject of a high level of conservation concern for many years. This herd was among the first herds in British Columbia to be protected from overhunting, and recommendations for prohibiting grazing by domestic sheep and the appointment of game wardens to control predator populations were made in the early part of the twentieth century (Brooks 1923). Wildlife biologists recognized the importance of protecting winter range habitats from development and competing uses in the early 1950s (I. McT. Cowan 1951, quoted in Spalding and Bone 1969). Many organizations have become involved in the conservation of these herds. The South Okanagan Sportsmen's Association has conducted an annual sheep count in the central part of the winter range over the past 50 years, and the Okanagan–Similkameen Parks Society and local naturalist clubs were instrumental in purchasing substantial portions of the winter range for conservation purposes in the late 1960s. More recently, The Nature Trust of British Columbia has been very effective in purchasing private lands to be turned over for management as conservation areas. In the late 1970s, scientists from the University of British Columbia, Simon Fraser University, and the B.C. Wildlife Branch initiated a major study of the conservation biology of bighorn sheep at the Okanagan Game Farm using bighorn sheep captured from the Vaseux Lake subpopulation. In the mid-1980s, bighorn sheep captured from the South Okanagan were successfully translocated to the Grand Forks area to re-establish an extirpated population.

The South Okanagan Valley contains a variety of shrub–steppe and dry forest habitats that in combination represent a unique ecosystem recognized as one of the most threatened in Canada (Slater 2000). Pressures from a burgeoning human population and the resultant habitat loss and fragmentation resulting from agricultural, industrial, and urban development (Harper et al. 1993) have led to the listing of at least 10 animal and plant species as Threatened or Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Since 1940, more than 8000 ha of grassland in the South Okanagan have been converted to agriculture and urban development (B.C. Ministry of Environment, Lands and Parks 1998). A national Ecosystem Recovery Plan is currently under development to address these past and projected losses of biodiversity in the South Okanagan (Slater 2000). The federal government has provided a significant source of monies from the Habitat Stewardship Program to implement recovery of endangered species and ecosystems as part of South Okanagan–Similkameen Conservation Program.

Bighorn sheep are of high conservation and public value as part of this South Okanagan ecosystem. They are a key component of this ecosystem through their ecological role as a large herbivore, and through their social and economic role as a large charismatic species and game animal. In the past, bighorn sheep were often used as the featured species in habitat acquisition and restoration programs in the South Okanagan.

Bighorn sheep (*Ovis canadensis* Shaw, 1804) are members of the grand order Ungulata, order Artiodactyla, suborder Ruminantia, infraorder Pecora, family Bovidae, subfamily Caprinae, and tribe Caprini (bharal, goats and sheep) (Shackleton 1985; Eisenberg 1981). Of the six species in the genus *Ovis,* two occur in the wild in North America (*Ovis canadensis* and *Ovis dalli*) and one occurs as a domestic animal (*Ovis aries*).

Subspecific taxonomy is controversial, but at present seven subspecies of *Ovis canadensis* are recognized (Shackleton 1985). The California bighorn sheep (*Ovis canadensis californiana* Douglas, 1871) is the morph associated with the drier shrub–steppe and semi-desert in the intermontane valleys and ridges west of the Rocky Mountains. Some authors (e.g., Valdez 1982; Wehausen and Ramey 2000) question the validity of the *O. c. californiana* subspecies in British Columbia (Demarchi et al. 2000). Based on cranial morphology and mitochondrial DNA, Wehausen and Ramey (2000) assign populations of *O. c. californiana* from British Columbia and Washington to the Rocky Mountain subspecies (*O. c. canadensis*). Systematics of bighorn sheep populations will probably remain complicated because the original distribution of the different North American races has been altered by range reductions and translocations that cross over historic subspecific range boundaries. Regardless of whether British Columbia's California bighorn sheep continue to be considered a separate subspecies in future taxonomic revisions, they will probably remain an important ecotype adapted to a different environment than bighorn sheep from the Rocky Mountains (Shackleton 1999).

The goals, objectives, and management actions prescribed in this recovery plan are designed to be consistent with international, national, provincial, and regional strategic plans and agreements. These include the principles articulated in the United Nations Convention on Biological Diversity, such as to "rehabilitate and restore degraded ecosystems … through the development and implementation of plans or other management strategies" and "promote the protection of ecosystems, natural habitats and the maintenance of viable populations of species in natural surroundings" (United Nations Environment Program 1992).

At the national level, this recovery plan will support key elements of A Wildlife Policy for Canada (Wildlife Ministers' Council 1990), the Canadian Biodiversity Strategy (Biodiversity Working Group 1994), and the Ecosystem Recovery Plan for the South Okanagan currently being developed (Slater 2000).

At the provincial level, this recovery plan will support and be consistent with the Provincial Wildlife Strategy (B.C. Ministry of Environment, Lands and Parks 1994), the British Columbia Wildlife Harvest Strategy (B.C. Ministry of Environment, Lands and Parks 1995), the Okanagan Land and Resource Management Plan (LRMP), and Forest Practices Code (FPC) (Province of BC 1997, 1999b).

At the regional level, this recovery plan will support and be consistent with the South Okanagan Similkameen Conservation Program.

1.2 Conservation Status

The major decline of North American populations occurred during the last half of the nineteenth century (Krausman 2000a). The Global Ranking for bighorn sheep at the species level under The Nature Conservancy system is G4, not rare and apparently secure globally, but with cause for long-term concern (B.C. Conservation Data Centre 2001). The Provincial Ranking for bighorn sheep at the species level under The Nature Conservancy system is S2S3—between “imperiled because of rarity or because factors making it vulnerable to extirpation” (S2) and “rare and uncommon, susceptible to large-scale disturbances and/or may have lost extensive peripheral populations” (S3) (B.C. Conservation Data Centre 2001; Cannings et al. 1999b). The British Columbia Ministry of Water, Land and Air Protection includes bighorn sheep on the Blue List (Cannings et al. 1999b), which includes vulnerable species that could become a candidate for the Red List (i.e., threatened or endangered) in the foreseeable future.

Demarchi et al. (2000) recommended revising the earlier Nature Conservancy rankings of bighorn sheep upwards provincially from S3 to S2S3 to reflect concerns that many bighorn sheep populations are potentially imperiled by factors making them susceptible to extirpation. Demarchi et al. (2000) cited numerous and uncertain threats from disease, forest succession, access development, land alienation, housing development, and grazing competition, as well as the high vulnerability and sensitivity of bighorn sheep to human disturbance from recreation, livestock grazing, and resource extraction, as reasons for increased conservation concern. This proposed upward ranking of bighorn sheep was accepted by the Conservation Data Centre, but did not affect their inclusion on the provincial Blue List. A more detailed explanation of The Nature Conservancy ranking system is available in *Rare Amphibians, Reptiles and Mammals of British Columbia* (Cannings et al. 1999b).

1.3 Population Status

1.3.1 Population considerations

Population Dynamics

Fecundity/natality

The age of first mating in bighorn sheep females is usually at 2.5 years of age, and the pregnancy rate of breeding-age females is typically higher than 90% (Shackleton et al. 1999). Pregnancy rates of female Rocky Mountain bighorns 2 years and older averaged 93%, regardless of whether the population was increasing or decreasing due to outbreaks of bronchopneumonia (Singer et al. 2000d). From 1965 to 1983, the Vaseux Lake and South Slope subpopulations were sampled for reproductive status, and the average pregnancy rate of adult females (3 years and older) was determined to be 96% (Table 1).

Table 1. Pregnancy rates **of adult female California bighorn sheep from the South Okanagan and Similkameen metapopulations**

Subpopulation	Date	Pregnant	Not Pregnant	Pregnancy Rate (%)	Technique	Reference
Vaseux Lake	1964–65	11	1	92	Necropsy[a]	Spalding 1966
Vaseux Lake	Mar 1977	16	0	100	Observation of captives[b]	Eccles and Shackleton 1979
Vaseux Lake	Mar 1978	7	1	88	Blood hormone assay[c]	Ramsay and Sadlier 1979
South Slope	Feb–Mar 1983	11	0	100	Doppler ultrasound[d]	Harper 1984a,b
Total		46	2	96		

[a] Examination of the reproductive tracts of adult females 3–6 years old killed by vehicles on Highway 97.

[b] Observation of wild-captured females at the Okanagan Game Farm (they had bred and wintered at Vaseux Lake).

[c] Single-sample radioimmunoassay of peripheral plasma progesterone concentrations (>3 ng/ml indicates pregnancy).

[d] Circulatory sounds associated with pregnancy: fetal heart, uterine artery, placenta, and movement of the fetus (Harper and Cohen 1985).

Although twinning among North American bighorn sheep is considered to be "exceedingly rare" (Geist 1971, p. 281), this does not appear to be the case in the South Okanagan. A total of 6 pairs of twins were found in 27 pregnant females sampled from the Vaseux subpopulation, for a twinning rate of 22% (Spalding 1966; Eccles and Shackleton 1979). Although Eccles and Shackleton (1979) speculate the high rate of twinning in the Vaseux subpopulation may be genetically related, they also feel it may not confer a reproductive advantage to the population because lower predicted birth weights in twin lambs could result in higher rates of neonatal mortality.

The intrinsic rate of natural increase (r_m) for bighorn sheep has been calculated at 0.258, and occasionally is even higher (0.288–0.388; Shackleton et al. 1999). This suggests that, in the absence of any limiting factors, bighorn populations have the potential for an exponential growth rate that would double their population every 2½ years. If factors affecting survival of adults and lambs are controlled and high pregnancy rates and propensity for twinning can return to the South Okanagan subpopulations, they should be capable of high rates of population growth.

Survivorship

Based on studies elsewhere in British Columbia, survivorship of newborn lambs in the South Okanagan is currently low and was probably less than 50% before the die-off. In the nearby South Slope subpopulation, Harper (1984b) estimated neonatal mortality rates at 72% in the mid-1980s, with most deaths occurring in the first 4 weeks postpartum, and all probably the result of coyote predation. A similar pattern of low survival of newborn lambs has been found in other bighorn populations in British Columbia, such as the Fraser metapopulation near Williams Lake (Hebert 1987; Hebert and Harrison 1988).

Mortality rates of bighorn sheep, like many ungulates, decrease after the first year of life. Annual mortality estimated using marked individuals was 33% for yearlings and 18% for two-year-olds (Festa-Bianchet 1989). Annual mortality rates for adults 3 to 7 years of age can be as low as 5% in the absence of disease and high predation rates on adults. A recent study made before the pneumonia-related die-off (1997–1999) indicated a slowly declining population of 442 to 430, with high adult female mortality rates (36% of collared ewes) and high lamb mortality in some areas (Chapman 1999).

Classification counts

The best time series of classification counts comes from annual censuses conducted by the South Okanagan Sportsmen's Association (SOSA). These counts have been conducted in February each year since 1962, and data on the total number of rams, lambs, and "ewes" counted are available for each year, except 1967, 1988, and 1994 (Joan McKay, SOSA, pers. comm., 2000). These classification counts do not include all the subpopulations in the South Okanagan metapopulation, but are focused on the core of its range, which include the Vaseux Lake and Mud Lake subpopulations. Counts of "ewes" are mostly adult females (>2.5 years old), but may also include subadult (1.5 years old) males and females.

Lamb production and survival was about twice as high in the early 1960s as in the 1980s and 1990s. From 1962 to 1966, the five-year moving average was 46 lambs to 100 "ewes" compared with averages since 1980 that were consistently less than 25 lambs to 100 "ewes" (Figure 1).

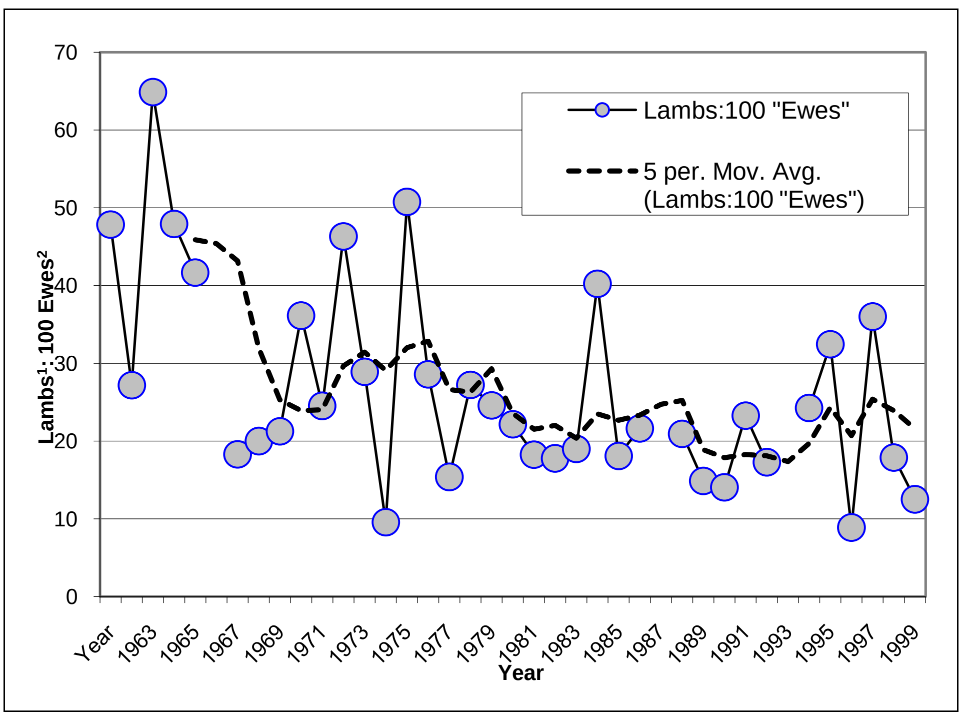

Figure 1. Ratio of Vaseux Lake and Mud Lake lambs to 100 "ewes," estimated by counts organized by the South Okanagan Sportsmen's Association 1962 to 2000. [1]"Lambs" are young of the year, typically 0.8 years old when censused in February; [2]"ewes" are adult females, subadult males (class I), and subadult females. [5 per. Mov. Avg. = 5 year moving average]

Distribution

Until the 1880s, the South Okanagan metapopulation was distributed on both sides of the Okanagan Valley (Brooks 1923). The current distribution of bighorn sheep is almost completely on the east side of the valley, with two exceptions: one group west of Skaha Lake and one west of Vaseux Lake. These two small subpopulations account for approximately 15% of the bighorn sheep in the currently depleted South Okanagan metapopulation (Figure 2).

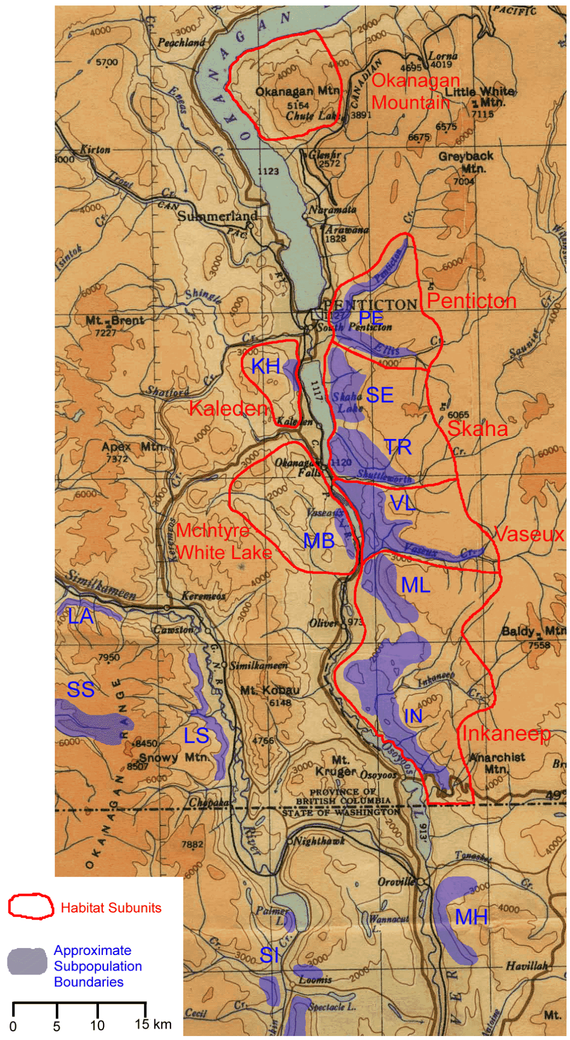

Figure 2. Approximate subpopulation boundaries and habitat subunits for the South Okanagan metapopulation.

Demarchi et al. (2000) define metapopulations, subpopulations, herds, and bands of bighorn sheep as follows:

- Metapopulation: Two or more subpopulations that have no barriers to dispersal and/or less than 15 km apart.
- Subpopulation: Two or more wintering herds that share a common summer range.
- Herd: A self-sustaining group of ewes and their progeny using a particular area and named by their discrete winter range.
- Band: A cohesive, home-range group that is a subgroup of a herd.

Based on these definitions, bighorn sheep subpopulations in the South Okanagan have been defined on a preliminary basis (Table 2). Further study of movement patterns and gene flow will be required to more accurately reflect the actual metapopulation structure of bighorn sheep in the South Okanagan.

Although some populations of California bighorn exhibit long migratory movements to summer range (e.g., the nearby South Slope subpopulation; Blood 1963), many are nonmigratory and have adapted to year-long occupation of relatively limited range with little elevational gradient (Toweill 1999). The South Okanagan metapopulation is essentially nonmigratory, but short seasonal movements between winter ranges, rutting grounds, and spring/summer ranges are typical (Chapman 1999; Spalding and Bone 1969).

Unlike some species, bighorn sheep do not readily explore and colonize new ranges (Krausman et al. 1999). This characteristic can have implications for meeting recovery objectives when range traditions are lost during an all-age die-off.

Abundance

Population estimates

The size of the South Okanagan metapopulation in the early 1800s is unknown, but it was certainly larger and more widely distributed than it is currently. According to Brooks (1923), “mountain sheep of the greater part of the dry interior were wiped out forty or fifty years ago (circa 1870–1890) by the introduction of rifles … and the introduction of domestic sheep to their range.”

Early estimates of the South Okanagan metapopulation were 100 to 300 animals (Table 3), but the apparent increase is probably the result of greater survey effort, and not necessarily due to an increase in population (Spalding and Bone 1969). The increase from the 1960s to 1980s is, however, undoubtedly real, although many consider the estimate of 600 to 900 in 1984 too high. The apparent decline from the1980s to late 1990s is also considered to be real, and is reflected in the total winter counts conducted by SOSA (Figure 3). Perhaps the most detailed population estimates were conducted by Chapman (1999)

Table 2. Preliminary delineation of bighorn sheep subpopulations in the South Okanagan metapopulation and nearby Similkameen and North Okanagan metapopulations

Metapopulation	Summer Range	Subpopulation	Code	Comment
North Okanagan	Westside	Shorts Creek	SH	Small declining remnant subpopulation completely isolated from other populations by over 80 km.
South Okanagan	Upper Penticton & Ellis Creeks	Penticton-Ellis	PE	Includes the Penticton Creek herd and Ellis Canyon herd.
South Okanagan	Skaha West	Kruger	KH	Small subpopulation initiated by escapes from the Okanagan Game Farm research herd, and isolated from other subpopulations by Skaha Lake and the City of Penticton.
South Okanagan	Skaha East	Skaha East	SE	Small subpopulation with good connection to both the Penticton-Ellis and Thomas Ranch subpopulations.
South Okanagan	Thomas-Shuttleworth	Thomas Ranch	TR	Includes the Peachbluff and Thomas Ranch herds.
South Okanagan	East of Vaseux Lake	Vaseux Lake	VL	Includes the Lower Vaseux herds and Upper Vaseux (Gallagher) herd.
South Okanagan	West of Vaseux Lake	McIntyre	MB	Small subpopulation initiated in the late 1990s by emigration from the Vaseux Lake subpopulation.
South Okanagan	East of Atsiklak Canyon	Mud Lake	ML	Located between Wolf Cub and Vaseux Creeks.
South Okanagan	East of Osoyoos Lake	Inkaneep	IN	Includes the Long Joe and Ryegrass herds.
South Okanagan	Mount Hull	Mount Hull	MH	Small U.S. subpopulation located just less than 15 km from the Inkaneep subpopulation with few barriers to dispersal.
Similkameen	Joe Lake	Lower Similkameen	LS	Located just over 15 km from the South Okanagan metapopulation at its closest point, with significant dispersal barriers in the form of urban and agricultural development, highways and Osoyoos Lake.
Similkameen	Joe Lake	South Slope	SS	Large subpopulation 25 km from the South Okanagan metapopulation.
Similkameen	Crater	Lower Ashnola	LA	Small subpopulation 25 km from the South Okanagan metapopulation.
Sinlahekin	Sinlahekin	Sinlahekin	SI	Small U.S. metapopulation considered isolated from the Similkameen metapopulation 15 km to the north and South Okanagan metapopulation to the east (Scott Fitkin, pers. comm.). Initiated in 1957 through translocation of 18 animals from the Junction Herd in the Fraser metapopulation (J. Hatter, former Dir. B.C. Fish Wildl. Br., pers. comm., 2000).

who estimated the South Okanagan metapopulation on the east side of the Okanagan Valley at between 430 and 442 based on extensive ground counts and helicopter surveys (Table 3). The current population on the east side of the Okanagan Valley is estimated by Ethier (2000) at 159, which reflects a 63% decline from 1999 that is a direct result of the all-age pneumonia-related die-off that affected most of the subpopulations in the South Okanagan in 1999/2000. Ethier (2000) estimates the entire Okanagan metapopulation in Canada at 194 (Table 3).

Classification counts by SOSA over the past 40 years are consistent with the estimates of wildlife biologists given in Table 3. The five highest of SOSA's counts in the past 40 years occurred from 1981 to 1990, with total counts of 299 to 362 (Figure 3). Total counts before 1977 suggest a stable population, but totals increased rapidly between 1977 and 1983 (Figure 3). This increase in total numbers in the late 1970s to early 1980s cannot be explained by lamb production and survival, since lamb-to-ewe ratios were declining during this period (Figure 1). The high numbers of bighorn sheep in the 1980s could be related to the artificial feeding program that occurred from 1975 to 1991 (see below).

Individual subpopulation estimates

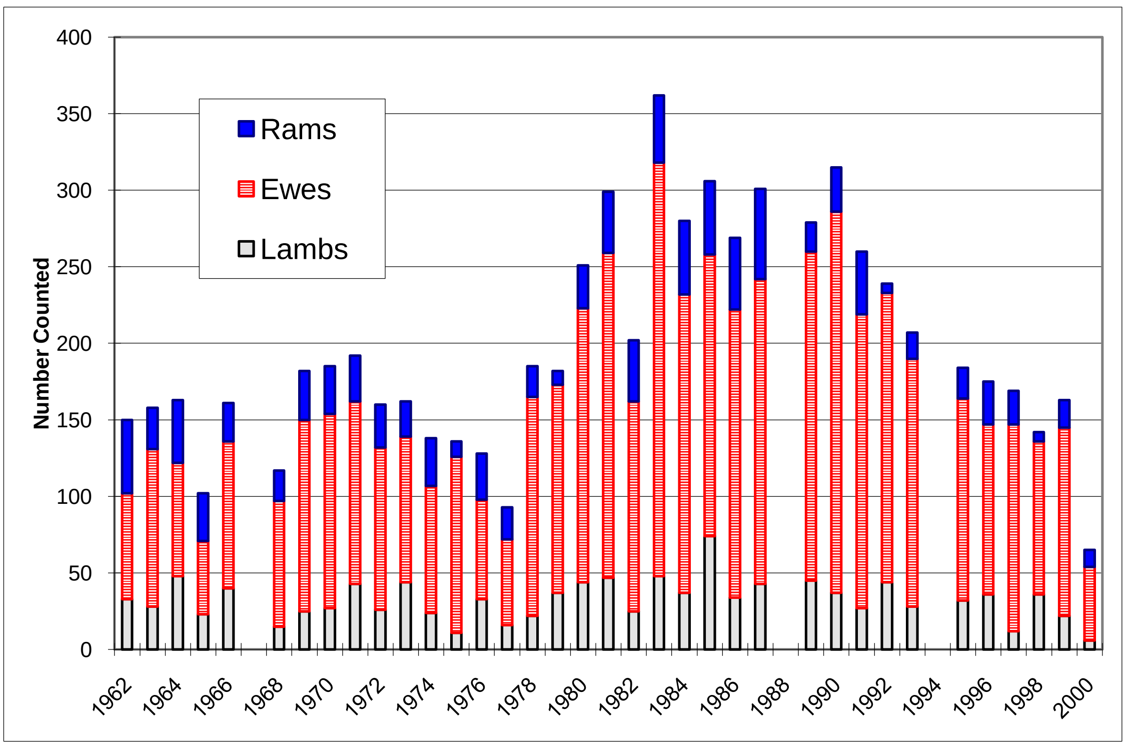

Figure 3. Classification counts of the Vaseux Lake and Mud Lake subpopulations organized by the South Okanagan Sportsmen's Association 1962 to 2000. "Ewes" are adult females, subadult males (class I) and subadult females; lambs are young of the year, typically 0.8 years old when censused; "rams" are class II, class III, and class IV males (after Geist 1971).

Table 3. Estimated size of the Canadian portion of the South Okanagan metapopulation

Year	Metapopulation Estimate	Source
1951	50–100	Cowan 1951 *in* Spalding and Bone 1969
1952	115	Martin 1952 *in* Spalding and Bone 1969
1960	200	Sugden 1961
1962	300	McLaren 1961 *in* Spalding and Bone 1969
1964/65	325	Spalding and Bone 1969
Late 1970s	350–400	I. Robertson *in* Harper 1980
1984	600–900	R. Lincoln *in* Hebert et al. 1985
1997	442	Chapman 1999
1998	436	Chapman 1999
1999	430	Chapman 1999
2000	194	Ethier 2000[a]

[a] Includes an estimated 35 animals on the west side of the Okanagan Valley not included in previous estimates.

Penticton–Ellis Subpopulation (PE)

This northernmost subpopulation in the South Okanagan metapopulation is located east of the City of Penticton. The population consists of two main bands, the Penticton Creek band along the south-facing bluffs of Penticton Creek and the Ellis Canyon band near Ellis Creek. Bighorn sheep have been present in Ellis Canyon since at least the 1960s (Spalding and Bone 1969), but there were only scattered reports of bighorn sheep in Penticton Creek canyon until January 1993 when 12 sheep were translocated there from the Thomas Ranch subpopulation. In March 1998, the Penticton Creek band was further supplemented by 14 animals from the Harper Ranch subpopulation near Kamloops (Table 4).

Because of the extremely rugged canyon habitats that this subpopulation occupies, obtaining accurate population estimates is difficult, particularly from helicopter surveys. Chapman (1999 and pers. comm.) estimated there were 43 animals in this subpopulation in late February 1999. In December 2000, a total of 47 animals were observed during ground counts. This strongly suggests the Penticton–Ellis subpopulation was not affected by the *Pasteurella*-related die-off of 1999/2000.

Kruger Hill Subpopulation (KH)

This small subpopulation is located on east-facing bluffs above Highway 97 immediately southwest of Penticton. It is one of the two subpopulations on the west side of the Okanagan Valley. It was initiated in the early 1980s by escapes from the captive research herd once kept at the Okanagan Game Farm, the original source of which was the Vaseux Lake subpopulation (Table 4). Accurate estimates of the size of this subpopulation have not been made, but it is probably no larger than 15 to 20 animals. Since it is

Table 4. Translocation of bighorn sheep into and out of the Canadian portion of the South Okanagan metapopulation

Year	Animals Added	Source	Animals Removed	Destination
1952	4 males	Fraser metapopulation (Williams Lake area)	–	South Okanagan metapopulation (Vaseux Lake)
Nov. 1957	10 males	Fraser metapopulation (Deer Park)	–	South Okanagan metapopulation (Vaseux Lake)
April 1977	–	South Okanagan metapopulation (Vaseux Lake)	16 females 3 lambs 1 yearling male	42-ha Okanagan Game Farm Research Enclosure
1978	–	South Okanagan metapopulation (Vaseux Lake)	12	Nevada
Feb. 1984	–	South Okanagan metapopulation (Vaseux Lake)	18 females 2 males	Kettle–Granby metapopulation (Pass Creek)
1985	–	South Okanagan metapopulation (Vaseux Lake)	12	Kettle–Granby metapopulation (Kettle Creek)
Jan. 1986	–	South Okanagan metapopulation (Vaseux Lake)	13	Kettle–Granby metapopulation
Jan. 1993	9 females 3 males	South Okanagan metapopulation (Thomas Ranch)	9 females 3 males	South Okanagan metapopulation (Penticton Creek)
Mar. 1998	11 females 3 males	Thompson metapopulation (Harper Ranch)	–	South Okanagan metapopulation (Penticton Creek)
Total added	28 [a]	Total Removed	77 [a]	

[a] The 12 animals moved from the Thomas Ranch subpopulation to the Penticton Creek herd in 1993 are not included in these totals.

isolated from the other subpopulations by Skaha Lake and urban development in the City of Penticton, we assume it was not affected by the *Pasteurella*-related die-off of 1999/2000.

Skaha East Subpopulation (SE)

The Skaha East subpopulation inhabits the rugged west-facing rock bluffs east of Skaha Lake. This is a difficult area to obtain accurate population estimates. A total of 29 bighorn sheep were counted in this subpopulation in 1964 (Spalding and Bone 1969) and a helicopter survey in June 1986 observed 25 animals. The highest count for this subpopulation occurred during a helicopter survey in late March 1999 when 42 animals were observed. One year later, only 16 animals were observed during a helicopter survey, suggesting a *Pasteurella*-related population reduction of 62%. The Skaha East subpopulation was the northernmost subpopulation affected by the 1999/2000 die-off.

Thomas Ranch Subpopulation (TR)

The Thomas Ranch subpopulation inhabits the southwest-facing bluffs north of McLean Creek, the southwest-facing Peach Bluff immediately east of Okanagan Falls, and the south-facing bluff immediately north of Shuttleworth Creek. Until 2000, this subpopulation was increasing its size and range. In February 1966, only 13 bighorn sheep were counted (Spalding and Bone 1969), but 30 years later helicopter surveys in 1996 counted 99 animals. During this time the subpopulation apparently expanded its range to include Peach Bluff, an area not known to support sheep in the 1960s (Spalding and Bone 1969).

Helicopter and ground counts in 2000 counted a maximum of 25 animals (6 on Peach Bluff in March 2000, 19 in the vicinity of Thomas Ranch in December 2000). This suggests a *Pasteurella*-related population reduction of about 75%.

Vaseux Lake Subpopulation (VL)

The Vaseux Lake subpopulation has the highest population of all subpopulations in the South Okanagan metapopulation. It inhabits the south- and west-facing bluffs between Shuttleworth and Vaseux Creeks east of Highway 97 and Vaseux Lake. It also includes the Gallagher Range, an area of south-facing slopes just north of Vaseux Creek. A total of 173 bighorn sheep were counted in this subpopulation in 1964/65 (Spalding and Bone 1969). Helicopter and ground counts through the 1980s and 1990s revealed similar numbers (176 in June 1986, 150 in March 1991, and 183 in January 1996). There is some indication the subpopulation may have been slowly declining after 1996; only 123 animals were counted in a helicopter survey in late March 1999. The highest count since the die-off was 44 animals in February 2000, and numbers near Vaseux Lake continued to decline through to December 2000. The population reduction of the Vaseux Lake subpopulation due to *Pasteurella*-related die-off is estimated at 65 to 72%.

McIntyre Bluff Subpopulation (MB)

The McIntyre Bluff subpopulation was initiated in the late 1990s through emigration from the Vaseux Lake subpopulation. It is one of only two subpopulations on the west side of the Okanagan Valley. This small subpopulation is estimated at less than 15 individuals and, because of its relative isolation from subpopulations on the east side of the valley, it probably was not affected by the *Pasteurella*-related die-off of 1999/2000.

Mud Lake Subpopulation (ML)

The Mud Lake subpopulation inhabits the area north of Wolf Cub Creek and south of Vaseux Creek. A total of 51 bighorn sheep were counted in this subpopulation in 1964/65 (Spalding and Bone 1969). Similar numbers were counted by helicopter in the 1990s (57 in March 1991 and 45 in February 1996). The highest count after the die-off was 18 animals in November 2000. The population reduction of the Mud Lake subpopulation due to *Pasteurella*-related die-off is estimated at approximately 60%.

Inkaneep Subpopulation (IN)

The Inkaneep subpopulation inhabits the west- and southwest-facing bluffs south of Wolf Cub Creek to Highway 3 near the International Boundary with the United States, including Ryegrass Mountain and the Inkaneep Creek watershed. According to Spalding and Bone (1969), there were no sheep in this area in the 1960s. It is not clear if this is because the subpopulation did not then exist or it was simply overlooked because of its small size. Chapman (1999) estimated the size of this subpopulation in the late 1990s as 21. In 2002, there was an estimated 14 to 20 animals in this subpopulation. The extent of reduction due to the *Pasteurella*-related die-off is unknown.

Mount Hull Subpopulation (MH)

The Mount Hull subpopulation is the most southern subpopulation of the South Okanagan metapopulation. It is located in Washington State less than 15 km south of the Inkaneep subpopulation and the International Boundary at Osoyoos. Since the last native California bighorn in Washington State was seen near Hart Pass about 1925 (Thorne et al. 1985), all bighorn sheep in Washington State are the result of translocations. The Mount Hull subpopulation was initiated in 1970 through translocation from another population in Washington State that, in turn, originated from the Junction subpopulation of the Fraser metapopulation near Williams Lake (Scott Fitkin, District Wildlife Biologist, Dep. Fish and Wildlife, Winthrop, WA, pers. comm., 2000). The Mount Hull subpopulation was considered stable at 35 individuals in 1984 (Thorne et al. 1985). The most recent estimate is 65 to 75 individuals, and this includes 11 animals translocated in January 2001 from a subpopulation near Yakima, Washington (Scott Fitkin, pers. comm., 2000). Due to its relative isolation from the Inkaneep subpopulation to the north, it is assumed that it was not affected by the *Pasteurella*-related die-off of 1999/2000, and there have been no indications of disease problems with this subpopulation in 1999/2000 (Scott Fitkin, pers. comm., 2000).

Translocations

The South Okanagan metapopulation has been both a recipient and a source of animals for translocation (Table 4). On two occasions in the 1950s, males from the Williams Lake area were released in the vicinity of Vaseux Lake (Spalding and Bone 1969). In 1998, the Penticton Creek herd was supplemented with male and female bighorn sheep from the Thompson metapopulation (Chapman 1999).

Between 1977 and 1986, the Vaseux Lake subpopulation served as a source of animals for translocation to Nevada and to establish a captive research herd at the Okanagan Game Farm. Forty-five animals from the Vaseux Lake subpopulation were also used to initiate the new Kettle–Granby metapopulation on historic ranges near Grand Forks (Table 4). Overall, 14 males were added to the Vaseux Lake subpopulation, and 77 (mostly females) were removed. The Penticton Creek herd was approximately doubled by adding 14 animals in 1998.

Physical attributes

Body Mass

Smaller adult size is often associated with reduced lamb survival; smaller lambs at high population densities experience higher winter mortality than larger lambs from lower population densities (Festa-Bianchet et al. 1997). Adult females (2.5 years or older) from the Vaseux Lake subpopulation averaged 62 kg in February 1984 (Figure 4). Vaseux Lake females, like those in other populations, appear to cease growing at 3 to 4 years of age (Shackleton et al. 1999). The 62-kg body mass of adult females from Vaseux in 1984 is the same as adult females from the South Slope subpopulation in the Ashnola (Harper 1984b), and is about average compared with other bighorn sheep populations (Shackleton et al. 1999). It was, however, almost 10 kg heavier than the average weight of adult females captured from Vaseux Lake in April 1977 and measured later that year at the Okanagan Game Farm (OKGF). Peterson and Bottrell (1978) give average weights for these adult females in September and December 1977 as 52.5 kg. Likewise, Vaseux lambs weighed in early 1984 were heavier on average (29.0 kg; Figure 4) than Vaseux lambs weighed at the OKGF in late 1977 (25.3 kg; Peterson and Bottrell 1978). The average weight of adult female roadkills collected from 1965 to April 1966 was 58.7 ± 2.1 kg (± SD, *n* = 9, Wildlife Program Files, Penticton). It is difficult to interpret the implications of these weight data, given that many of the weights were measured at different times of the year. However, it would be interesting to compare current weights in February with those collected in the early 1980s when the Vaseux subpopulation was taking advantage of supplemental feeding.

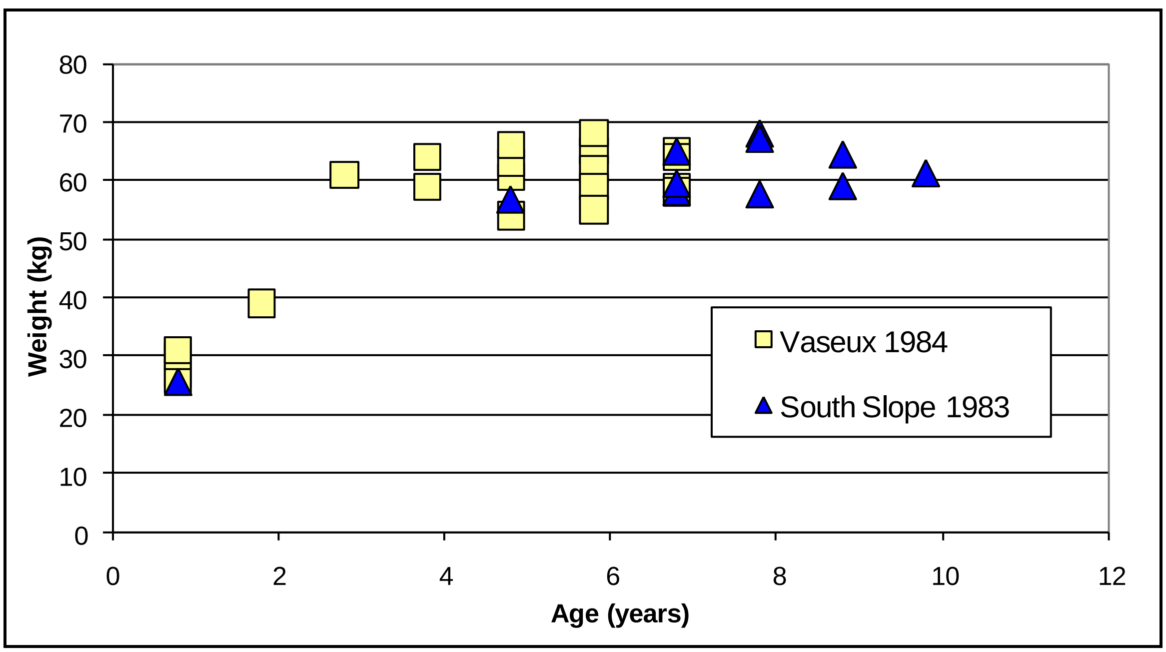

Figure 4. Age-specific weights of winter-fed females from the Vaseux Lake and South Slope subpopulations in 1983 and 1984.

Horn Growth

Patterns of annual horn growth can provide valuable information about bighorn populations. Although the general pattern of horn development is consistent among populations, deviations in horn-growth curves from the general pattern can be an indicator of environmental or nutritional conditions (Shackleton et al. 1999). Populations with greater annual horn growth are considered to be "high quality" and are typically the result of a higher nutritional plane characterized by early maturation, high milk production, increased individual growth rates, rapid population growth, and short life spans (Geist 1971; Shackleton et al. 1999). Horn-growth curves from the South Okanagan metapopulation show average or higher than average horn growth rates, suggesting a "high-quality" population, at least until the early 1980s (Harper 1980, 1984c).

More recent analysis indicated possible declines in the length of the yearling increment, from around 250 mm in the 1970s to 215 mm in the early 1990s (Lincoln 1994).

Hunter harvest

Although native Indian bands hunted South Okanagan bighorn sheep before European contact, they probably had little effect on overall population numbers. The introduction of the rifle to the South Okanagan was the factor that led to extensive and uncontrolled hunting of both sexes by natives, residents, and wealthy nonresidents (B.C. Ministry of Recreation and Conservation 1978). Hunters came from all over the world, encouraged by glowing accounts such as "the best hunting of this class (bighorn sheep) is now to be found in British Columbia" (Shields 1890). Bighorn sheep population declines began sometime in the 1870s, but it was not until 1906 that an Order of the Executive Council closed the hunting season for bighorn sheep in the Okanagan–Similkameen (Brooks 1923; B.C. Ministry of Recreation and Conservation 1978).

There was no legal hunting of bighorn sheep in the South Okanagan from 1906 to 1953. Spalding and Bone (1969) summarize hunter harvests from 1954 to1967, based on game checks in the field during the hunting season. Hunter harvest figures from 1968 to 1974 were based on hunter sample questionnaires. Because so few questionnaires were returned, this data was subject to large variances around the annual estimates. Since compulsory inspection was introduced in 1975, and all hunter-harvested bighorn sheep have been inspected at government offices, hunter-kill estimates are considered to be quite accurate.

Two wildlife management units (MUs) encompass the hunted portion of the South Okanagan metapopulation. In the south, MU 8-01 includes the Inkaneep, Mud Lake, and Vaseux Lake subpopulations. In the north, MU 8-09 includes the Thomas Ranch, Skaha East, and Penticton subpopulations (Figure 2). From mid-1960s to 1999, hunting of South Okanagan bighorn sheep has been regulated under a general open season for ¾ curl or larger rams for nine days in September.

Resident harvest of bighorn rams from MUs 8-01 and 8-09 increased through the 1970s and was highest from 1982 to 1989 (Figure 5). Most of the increased harvest in the 1980s was from resident hunters, but although resident harvests dropped off in the 1990s, nonresident harvest remained relatively constant (Figure 6). After the disease epidemic was discovered in early 2000, the hunting season was closed and no rams were legally harvested from MUs 8-01 and 8-09 in the fall of 2000.

The proportion of rams harvested by guided nonresidents averaged 38% from 1975 to 1999, but this varied considerably by year (Figure 6). As the population increased through the late 1970s and early 1980s, the proportion of nonresident harvest declined to less than 25%, but increased through 1986 to 1995 to an average 60% in the late 1990s (Figure 6).

The average age of hunter-harvested males from MU 8-01 and 8-09 was 6.1 years during the periods 1954 to 1957 (n = 39) and 1975 to 1979 (n = 60) (Harper 1980). After 1979, the average age of rams shot in MU 8-01 appears to have declined, particularly in the 1990s (Figure 7), whereas there appears to be no overall change in the average age of rams shot in MU 8-09.

Since nonconsumptive use of bighorn sheep is a high priority in the South Okanagan, management of bighorn sheep hunter harvests has been designed to have minimum negative effect on total population size. Because they are trophy animals, hunting has mainly been restricted to the older age-class male component of the population. When the number of males entering the trophy-size age-class is known, then a proportion of these, spread among all trophy age-classes, can be harvested annually (Wegge 1997). However, the detailed census data and life-table analysis required to estimate this number could be difficult to obtain. As an alternative,

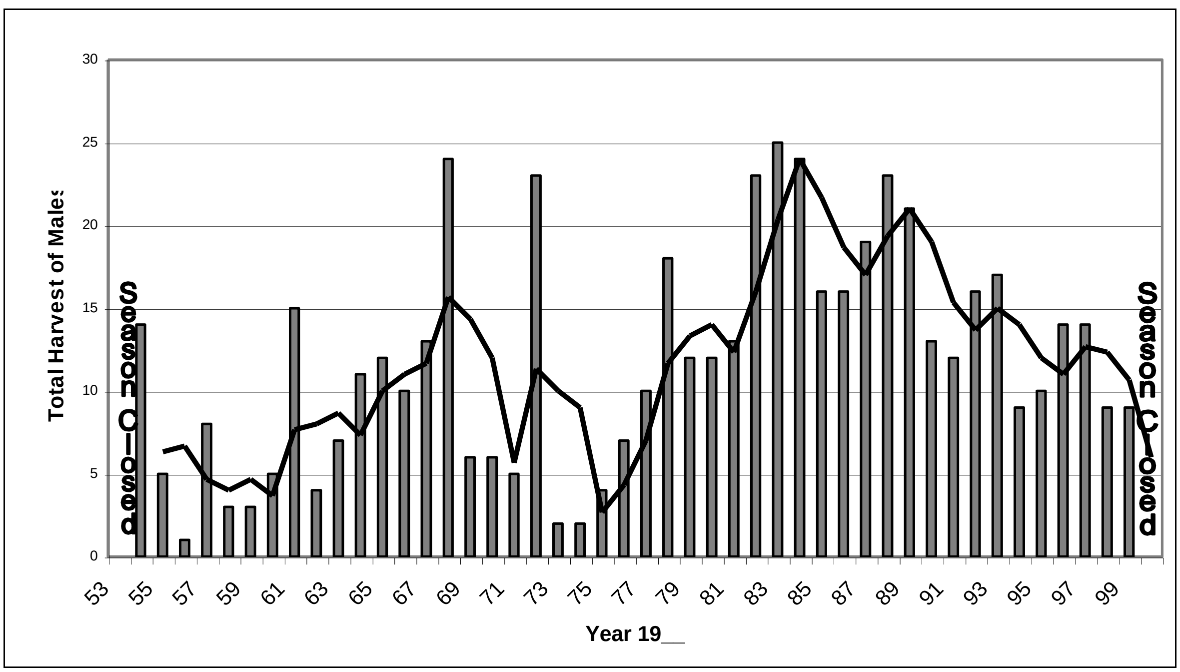

Figure 5. Total estimated harvest of rams from the South Okanagan metapopulation (MUs 8-01 and 8-09). Solid black line represents 5year moving average.

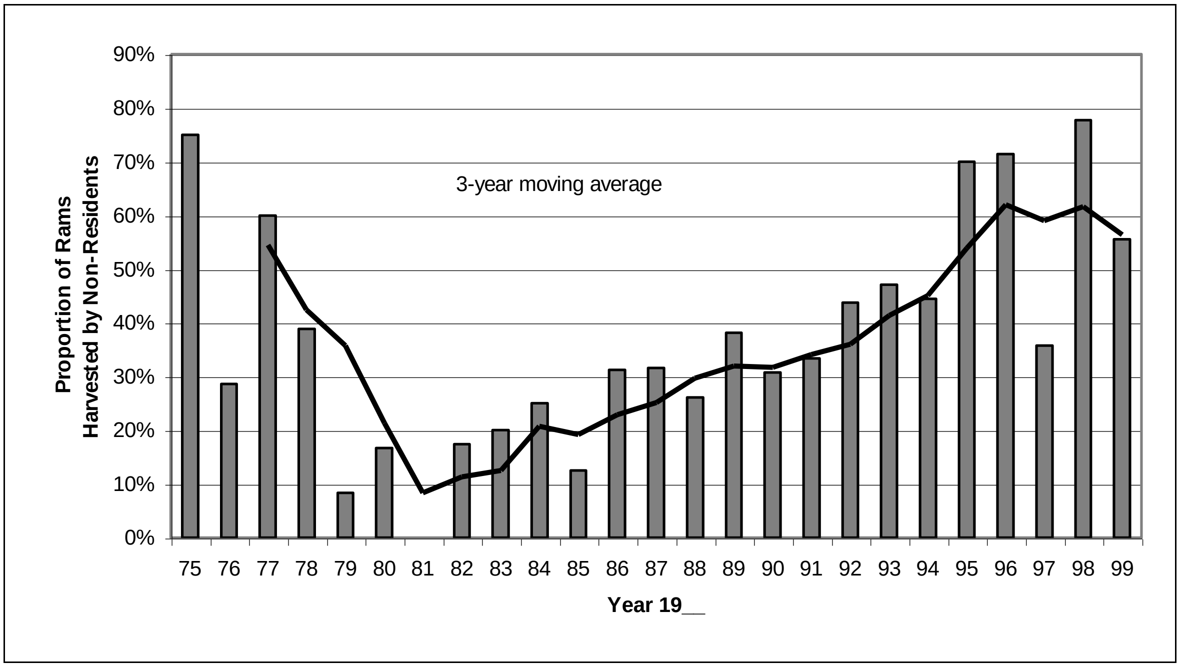

Figure 6. Proportion of South Okanagan rams harvested by nonresident hunters.

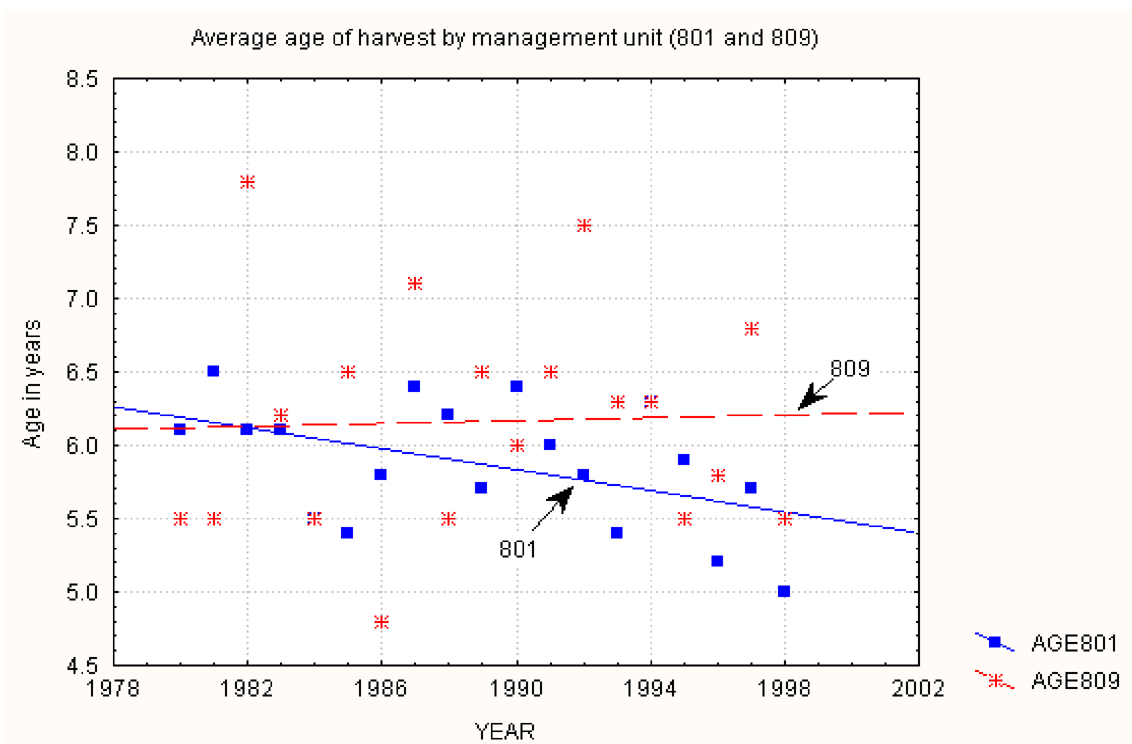

Figure 7. Trends in the average age of hunter-harvested rams in Management Units 8-01 and 8-09.

Toweill (1999) recommends ram harvests should not exceed 8% of the total number of rams (excluding lambs). In areas where herds are regularly surveyed, this guideline could be modified to allow harvest of up to 15% of observed ¾ curl rams, to achieve the same objective (Toweill 1999).

Genetic considerations

After experiencing a large but unknown population decline up to the early 1900s, bighorn sheep in the South Okanagan stabilized at some small but unknown level. There is no doubt the metapopulation went through a genetic bottleneck. Only small remnant herds of sheep remained in the early 1900s. Bighorn populations then increased naturally under protection from hunting (1906 to 1953) and termination of the practice of grazing domestic sheep on open range.

The South Okanagan metapopulation was supplemented with bighorn sheep from other areas on three occasions: 1) four males from the Fraser metapopulation near Williams Lake were translocated in November 1952; and 2) 10 males from Deer Park, an area adjacent to the 1952 source, were translocated in November 1957, both to the Vaseux Lake subpopulation (Spalding and Bone 1969). In March 1998, 12 females and 2 males were translocated from the Harper Ranch subpopulation near Kamloops to supplement a small population in the Penticton Creek canyon (Chapman 1999).

1.3.2 Environmental considerations

Distribution, abundance and quality of suitable habitats

As part of an ecosystem classification project (Lea et al. 1991; Harper et al. 1993), potential summer and winter habitats were mapped at 1:20,000 scale in the South Okanagan. Although the total area considered to be potential habitat for bighorn sheep is large (>100,000 ha), most of these habitats are not currently occupied, and many are in poor range condition or are of limited value because they lack adjacent escape terrain or are close to human developments. Although most of the potential habitat is provincial Crown land, a significant amount is on private land and First Nations Reserves. Less than 10% of potential bighorn sheep habitat in the South Okanagan is on lands purchased or managed for conservation purposes (B.C. Ministry of Environment, Lands and Parks 1998; Table 5).

In general, most winter ranges contain substantial areas in poor range condition, particularly for those subpopulations in the southern part of the valley. Winter ranges for the Vaseux Lake subpopulation are in generally poor condition, and have been since at least the 1960s. Spalding and Bone (1969) noted major infestations of diffuse knapweed (*Centaurea diffusa*) in several areas, particularly those areas in the vicinity of power transmission lines. Further south, another introduced weed species, cheatgrass (*Bromus tectorum*), was noted on the flatter parts of the Inkaneep subpopulation's winter ranges (Spalding and Bone 1969).

Table 5. Distribution of potential summer and winter bighorn sheep habitat by land status

Land Status[a]	Summer Range (ha)	%	Winter Range (ha)	%
Conservation land	10,477	9	9,439	8
Provincial land	47,747	43	42,820	37
First Nations reserve	26,873	24	26,506	23
Private land	26,465	24	38,314	33
Total	111,562		117,079	

[a] Source: B.C. Ministry of Environment, Lands and Parks (1998).

Forest encroachment on shrub–steppe habitats and an increased density of conifers in some forested communities has been documented in the Okanagan (Turner and Krannitz 2001; Parminter and Daigle 1999). This probably has had a significant effect on the suitability of these habitats to support foraging bighorn sheep.

Diet

Across their range, California bighorn sheep eat a wide variety of plants. Depending on how populations adjust to different seasons and habitat conditions, the diet can be dominated by grasses, forbs, or shrubs (Shackleton et al. 1999). Forbs are particularly important in spring and summer when they are most readily available and high in nutritional value (particularly the flower heads). Grasses are a significant component of the diet in all seasons, and shrubs can be important at various times of the year depending on location (Shackleton et al. 1999). Calculations of forage selection indices can indicate which species are being selected, and which species are being consumed in proportions that merely reflect a high availability. For example, bluebunch wheatgrass (*Agropyron spicatum*) constituted more than 20% of the annual diet at the Okanagan Game Farm Research site, but was eaten in proportions less than its availability within that habitat (Wikeem and Pitt 1992). On the other hand, selection indices for forage species of forbs and shrubs show diet selection that is higher than availability of the species (Shackleton et al. 1999).

Shrubs are an important component in the diet of many bighorn populations. For example, Douglas rabbitbrush (*Chrysothamnus viscidiflorus*) and winterfat (*Eurotia lanata*) received heavy use and made up 22% of the winter diet of bighorn sheep in Yellowstone National Park (Oldemeyer et al. 1971). In Colorado, true mountain mahogany (*Cercocarpus montanus*) leaves constituted 73 to 94% of the summer diet. Although there have been no specific studies of the diet of the South Okanagan metapopulation, bighorn sheep from the Vaseux Lake subpopulation have been observed making extensive use of antelope bitterbrush (*Purshia tridentata*) and mock-orange (*Philadelphus lewisii*).

Supplemental Feeding

Substantial supplementary feeding of the South Okanagan metapopulation began in December 1974, although some residents fed the sheep on a smaller scale in earlier years (Harper 1980). The objective of this program was both to encourage an increase in the population of bighorn sheep and to reduce roadkills on Highway 97 through intercept feeding. Both alfalfa and Buckerfield's Domestic Sheep Pellets (80-lb bags, unknown composition) were provided during the winter months, typically from December to February, but occasionally as late as early March (Joan McKay, SOSA, pers. comm., 2000). Only two feeding stations were developed initially, but this was increased to four stations by the early 1980s. All four feeding stations were within the range of the Vaseux Lake subpopulation.

The peak of winter feeding occurred in the late 1970s and early 1980s when more than 6000 kg of pellets and 200 bales of hay were consumed per year (Figure 8) (Harper 1980; Joan McKay, SOSA, pers. comm., 2000). The amount of supplemental winter feed was gradually decreased through the late 1980s and the program was discontinued in 1991.

Competition with livestock

Overgrazing by domestic livestock may result in competition for forage and deterioration of bighorn ranges. In most cases, the damage to natural shrub–steppe ecosystems caused by excessive stocking levels is difficult to document because most of it happened many years ago (livestock grazing as a significant industry in the South Okanagan began in the 1860s). By the 1960s, many bighorn ranges were

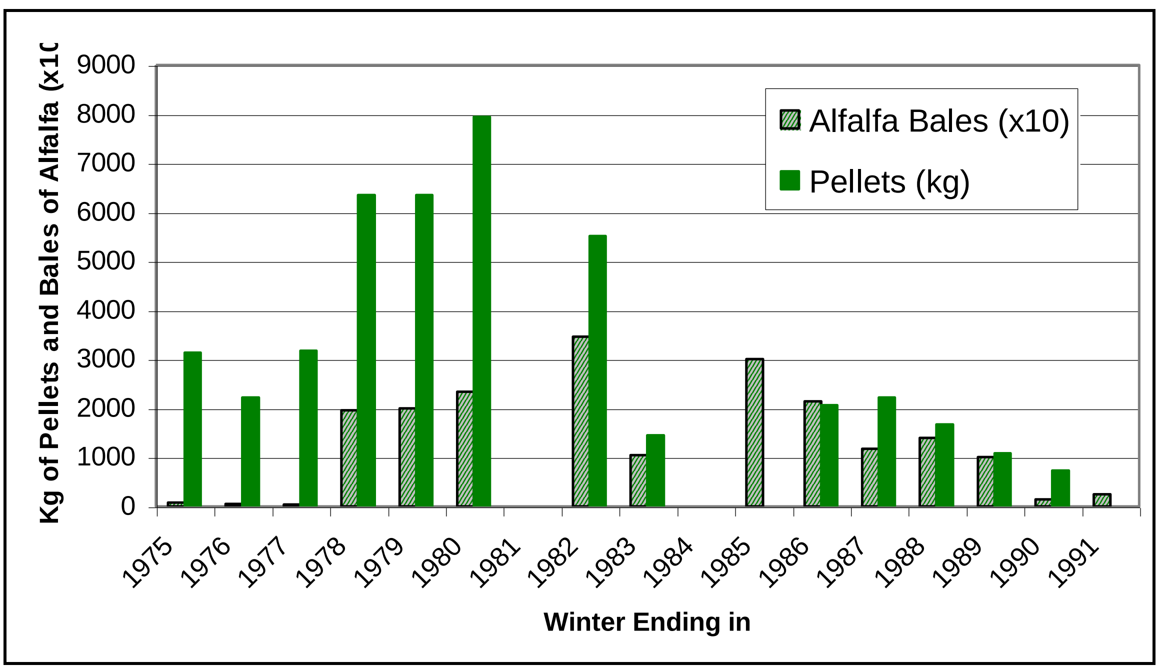

Figure 8. Winter feeding of alfalfa and pelleted rations to the Vaseux Lake subpopulation from 1975 to 1991.

in poor range condition as a result of past overgrazing (Spalding and Bone 1969). These changes in plant communities caused by historic overgrazing can have a substantial effect on bighorn sheep habitat suitability. In Nevada, for example, cattle-grazed areas supported an average of 2.3 bighorn/km^2, compared with densities of 6.6 bighorn/km^2 found in ungrazed areas (Krausman et al. 1999). Other authors suggest there is little evidence of competition between California bighorn sheep and domestic cattle, noting that cattle prefer gentle slopes and bighorn sheep prefer steep slopes (Toweill 1999).

Predator–prey relationships

Potential predators of bighorn sheep in the South Okanagan include coyote (*Canis latrans*), cougar (*Felis concolor*), lynx (*Lynx canadensis*), bobcat (*Lynx rufus*), and golden eagle (*Aquila chrysaetos*). In the nearby South Slope subpopulation (Figure 3), Harper (1984b) estimated neonatal mortality rates at 72%, primarily in the first 4 weeks after parturition, and probably the result of coyote predation. The same pattern of low survival of newborn lambs due to coyote predation was found in California bighorn sheep in the Williams Lake area (Hebert 1987). The year after extensive coyote control in Junction Wildlife Management Area, lamb-to-ewe ratios increased 2- to 3-fold (Hebert and Harrison 1988). Bighorn lambs at the National Bison Range, Montana, experienced higher than 75% mortality to coyote predation, most within 3 days of birth (Hass 1989). In Alaska, newborn Dall sheep lambs experienced a 40% mortality rate in the first year of life, almost all due to predation (Scotton 1997). Coyote predation accounted for about half of the first-year mortality rate and golden eagles accounted for about a quarter (Scotton 1997).

Cougar are an important cause of adult bighorn sheep mortality in North America, resulting in annual adult survival rates as low as 0.79 (Hayes et al. 2000) and 0.72 (Wehausen 1996) in southern California. Cougar predation by even a few cougar can affect adult survival rates (Ross et al. 1997), particularly of mature rams (Harrison and Hebert 1988).

Metabolic profiles

Analysis of blood metabolites and hematology parameters are typically concerned with establishing average or baseline levels for various blood constituents so they can serve as standards for comparing the nutritional and/or disease status among different populations or within the same population over time.

Comparisons of various blood constituents (Appendix 1) between the Vaseux subpopulation and sheep from other populations are confounded by a lack of consistency in the methods for capturing and handling the animals, the different seasons of sampling, and variable precision and accuracy in the various laboratory procedures used. Generally, however, the data indicate the Vaseux subpopulation was marginally deficient in selenium, but had relatively high levels of inorganic phosphorus and blood urea nitrogen in the early 1980s (Appendix 2). Baseline levels for the Vaseux subpopulation for 23 blood parameters were based on 32 animals captured in February 1984 and 11 animals captured in January 1986 (hematology only). Most of these sheep were later translocated to the Kettle–Granby area to initiate a new metapopulation (Table 4).

Disease

Many diseases are reported to occur in North American wild sheep, including pasteurellosis, verminous pneumonia, bluetongue, paratuberculosis (Johne's disease), contagious ecthyma, and mandibular osteomyelitis (Bunch et al. 1999). Among these, the most important from a conservation point of view is pasteurellosis or bacterial bronchopneumonia involving *Mannheimia* [*Pasteurella*] *multocida* or *P. hemolytica* (Bunch et al. 1999). Although the genus name *Pasteurella* recently has been officially changed to *Mannheimia,* for clear communication, the former name *Pasteurella* is used throughout this report. Because of the importance of pneumonia to bighorn sheep, a brief review follows.

Three types of pneumonia involving *Mannheimia* [*Pasteurella*] spp. are reported in bighorn sheep:

1. Peracute fibrinous pneumonia, particularly in captive sheep
2. Verminous or lungworm pneumonia, present to varying degrees in all wild sheep; may be fatal alone or in combination with other infectious organisms, and is particularly of note in lambs under 6 months of age
3. Acute to chronic bronchopneumonia of captive or free-ranging bighorns

Peracute fibrinous pneumonia is most often seen in acutely stressed animals, such as those recently moved into captivity. It is a rapidly fatal disease associated with virulent *Pasteurella* spp. and is generally refractive to treatment.

Verminous or lungworm pneumonia is caused by *Protostrongylus stilesi* and *P. rushi.* Infections with these protostrongylid parasites are considered to be virtually ubiquitous in wild sheep. Light and moderate infections may have little effect on otherwise healthy animals. Levels of infections vary with environmental and host conditions favouring transmission, such as high sheep density and conditions that increase the survival of the snail intermediate host.

The lung damage created by lungworms is ongoing and, if severe, may alone or in combination with other individual or population stresses, predispose bighorn sheep to secondary lung infections. The overall physical reactions to these stresses are believed to depress normal respiratory immune defenses, allowing the invasion of other respiratory pathogens, often regardless of the level of lungworm infection. Individual animal respiratory disease or all-age pneumonia die-offs may result.

In lambs, severe lung injury can result from the transplacental transmission of large numbers of lungworm larvae into the lungs of lambs born to ewes with high lungworm loads. The damage may predispose them to bacterial pneumonia. This syndrome has been referred to as "summer lamb mortality," because lambs usually demonstrate symptoms and may die within the first 2 to 3 months of life.

Management programs have tried to control herd lungworm infections through feeds supplemented with anthelmintic drugs. Although drugs such as fenbendazole may be effective in controlling protostrongylid lungworm infections (Jones and Worley 1997), other potential effects must be considered with this management option. In free-ranging conditions, the effectiveness of anthelmintic delivery in effective doses to all animals in the population, the possibility of development of drug-resistant parasites, the increased density and reduced movement of supplement-fed animals and, perhaps most importantly, the focus of attention away from habitat improvement must be considered.

A re-evaluation of extensive lungworm treatment programs in Colorado determined that there were no demonstrable improvements in lamb production or survival in treated populations (Miller et al. 2000). Although there are questions regarding the operational use of anthelmintics in resident herds, treatment for parasite infections is definitely warranted when animals are captured for relocation.

Acute to chronic bronchopneumonia caused by *Pasteurella* spp. or pasteurellosis, is usually associated with varying degrees of stress-causing factors, including high animal density, poor nutrition, loss of escape cover, harassment by dogs, encroachment by humans and their domestic animals, and high lungworm burdens (Bunch et al. 1999). Contact with domestic sheep has been implicated in many reported cases, suggesting the transmission of pathogenic organisms from apparently healthy domestic animals to bighorns (Foreyt and Jessup 1982). Goodson (1982) reported eight instances where declines in bighorn sheep followed contact with domestic sheep; the populations recovered once the domestics were either removed or substantially reduced.

North American wild sheep appear to be particularly susceptible to pasteurellosis. They are reported to carry several strains of *Pasteurella* spp. in their upper respiratory tracts without detrimental effects. However, Miller (2000) suggests that North American wild sheep did not coevolve with the more pathogenic strains of *Pasteurella* found in domestic sheep and rarely carry these organisms without effect. The hypothesis is probably true since cytotoxic or hemolytic *P. hemolytica* have not been identified in Dall’s or Stone’s sheep that have not been exposed to domestic animals. In addition, many bighorn *Pasteurella* isolates appear to be less pathogenic because they do not produce leukotoxin, a chemical produced by the bacteria to kill protective white blood cells. There is anecdotal information but no published studies reporting that bighorn sheep remained healthy after coming into direct contact with domestic sheep (Martin et al. 1996).

Direct evidence of disease transmission is difficult under field conditions, since disease is often recognized after the fact. It is necessary to use DNA fingerprinting to differentiate between pathogenic strains of *Pasteurella* spp. and strains that are part of the normal bacterial flora of both wild and domestic sheep (Martin et al. 1996). The conclusive demonstration of transmission requires DNA sampling of both groups before and after contact, although the presence of identical isolates is very suggestive of transmission (Ward et al. 1997). Ward et al. (1997) used DNA fingerprinting to differentiate different strains of *Pasteurella* spp. and found heterogeneous strains of these bacteria that varied among different bighorn ranges. This raises the possibility that potentially pathogenic strains of *Pasteurella* in one population of bighorn could be transmitted to immunologically naïve populations elsewhere through natural emigrations or translocations.

The first reference to disease in bighorn sheep in the South Okanagan was made by Brooks (1923): "A virulent disease that affects the heart and liver is now being introduced into the mountain sheep ranges Nos. 2 (south of Similkameen river) and 3 (east of Vaseux Lake) by domestic sheep that are brought over to graze from the state of Washington by sheep-herders. The government veterinary at Osoyoos is unable to determine this disease."

In February 1984, 32 bighorn sheep were captured from the Vaseux Lake subpopulation and translocated to the Grand Forks area to repopulate historic ranges. These animals were sampled for respiratory diseases using nasal swabs, and the Veterinary Pathology Laboratory randomly chose 10 of the 32 for bacterial analysis. All 10 of these swabs were negative for bacterial pathogens (Lewis 1984). An adult female (6 years or older) of this group was sero-positive at 1:10 dilution for bluetongue and also positive by AGID (agar gel immunodiffusion). All other samples were negative for bluetongue (Lewis 1984). Since these samples were taken, sampling and culture techniques for upper respiratory pathogens have changed. Nasal swabbing is replaced for the most part by nasopharyngeal swabs with specific transport media to increase the likelihood of the recovery of *Pasteurella* spp. with a parallel increase in recovery of the organism.

Results of necropsies of bighorns examined during the Chapman (1999) study included seven animals involved with traumatic incidents. Of these, lungworm infections were considered absent in a lamb, mild in two lambs, moderate in another lamb, and not mentioned in two adult rams. Five animals had liver selenium levels considered to be low or deficient.

In September 1999, 7 bighorn sheep in the south Okanagan were found dead at the same time as white-tailed and mule deer carcasses were found in the area. This was concurrent with a presumed epizootic hemorrhagic disease (EHD) outbreak in white-tailed deer in Washington State. There was no conclusive laboratory evidence of EHD in any wild animals from the Okanagan, but there were some similarities on necropsy.

Parasites

Arthropod ectoparasites of bighorn sheep include scabies or mange mite (*Psoroptes* spp.), the nasal botfly (Oestrus ovis), and at least three genera of ticks (*Dermacentor*, *Ixodes*, and *Otobius*) (Bunch et al. 1999). Most arthropod infestations are of little clinical significance, although epizootics of the scabies mite were correlated with population declines in the western United States in the late 1880s and early 1900s. There is no evidence of psoroptic mites anywhere in British Columbia or in the South Okanagan, but it has been documented in populations in neighbouring Washington and Oregon (Foreyt et al. 1990).

Dermacentor spp. are reported to infest bighorn sheep throughout their ranges in British Columbia. They may cause irritation and associated hair loss when present in large numbers. *D. andersoni* has been identified on South Okanagan bighorns in low-to-moderate numbers, but no significant clinical effect has been noted.

Several species of endoparasite have been identified in South Okanagan bighorns, but *P. stilesi* is considered to be the most significant.

1.4 Recovery Potential

1.4.1 Major threats

Diseases and animal health

The single greatest obstacle to restoration of North American bighorn sheep populations is epizootic outbreaks of bronchopneumonia (Singer et al. 2000d). Population models of bighorn sheep demographics have emphasized the importance of reducing the severity and frequency of epizootic outbreaks of infectious disease (Gross et al. 2000).

Reports of low population numbers and dead or dying sheep in the Vaseux Lake area were received in February 2000. Carcasses were collected through ground searches, aerial surveys, and reports from the public. Ministry of Water, Land and Air Protection (MWLAP) staff, assisted by a veterinary pathologist, performed necropsies and samples were sent to the provincial Animal Health Centre of the Ministry of Agriculture, Fisheries and Food (MAFF). The 20 gross necropsies revealed body conditions varying from moderate to poor. There were lesions of subacute to chronic bacterial pneumonia with varying degrees of lungworm involvement. A minimum of 40 carcasses and other remains were also documented in the field but were not recovered or necropsied due to poor condition or heavy scavenging. The last documented mortality was that of a young ram that was euthanized on July 28, 2000.

Pasteurella multocida was the most common organism cultured from pneumonic lungs. *Pasteurella hemolytica* was cultured from the nasal passages of an animal, but *Arcanobacterium pyogenes* was recovered from her lungs. *A. pyogenes* was present in the lungs of several animals, but was considered to be a secondary invader. *Pasteurella trehalosi* was found in the last submission in July. No viruses were cultured from the mortalities, but seven animals were positive on polymerase chain reaction analysis for *Mycoplasma* spp. and two for Respiratory Syncytial virus. Two sera converted for Parainfluenza virus at 1:24.

Lungworm infection levels were estimated by gross examination at post mortem and varied from moderate to mild. Fecal larval counts of infections in carcasses recovered during the die-off varied from 1 to 3+. Other endoparasite ova recognized during necropsies included strongyles, “whipworms,” coccidia, and tapeworms. Liver samples from necropsied animals indicated low to deficient levels of selenium and copper in most cases.

Once a pneumonia-related die-off has begun, treatment is considered to be of little value. Management has rather focused on determining and monitoring the stress factors that triggered the die-off and the initial source of the primary pathogen if they can be determined (e.g., contact with domestic sheep) (Bunch et al. 1999). Various techniques have been used to try to control the occurrence or progress of bighorn die-offs because of the intense concern generated by these events. A previous attempt in Idaho to remove sick sheep for antibiotic treatment in captivity after the onset of a pneumonia die-off was unsuccessful. Immunization against virulent strains of *Pasteurella* has not been effective in field situations to date and is unlikely to be effective as a treatment method (Foreyt and Silflow 1996). An experimental multivalent *P. hemolytica* toxoid-bacterin containing serotypes A1, A2, and T10 has produced mixed results. In some cases this vaccine resulted in elevated antibody titres to at least one *P. hemolytica* strain (Miller et al. 1997; Kraabel et al. 1998). In other cases, it stimulated only moderate and transient increases in antibody titres in treated bighorns (Ward et al. 1999), or did not provide protection against pneumonia for animals exposed to domestic sheep (Foreyt 1998). A vaccine has also been developed for *P. trehalosi* serotype 10, but the lack of a practical delivery system limits its use in the field (Miller 2000), and experimental inoculation with this vaccine failed to increase lamb survival in study populations (Cassirer et al. 1998, 2001). To date, bacterins protective against *P. multocida*, the bacterium involved with the South Okanagan die-off, have not been developed. In addition, immunization methods have not yet been developed to include protection against all of the mixed organisms usually present during a bighorn sheep die-off. Future research may better define the role of immunization in controling the spread of specific organisms.

Oral treatment of free-ranging sheep showing symptoms of bacterial pneumonia with anthelmintic or antibiotic-laced supplements is not recommended. Sick animals are reluctant to eat, particularly unfamiliar feeds, therefore are unlikely to consume treated feeds. Ruminants do not absorb antibiotics effective for respiratory disease by oral dosing, and there is no method to ensure that animals receive effective doses of the most effective medications, especially animals that have poor appetites. In addition, any concentration of animals resulting from supplemental feeding will probably increase the spread of infectious organisms (Bunch et al. 1999).

Parenteral (injectable) treatment is the most effective method of antibiotic treatment of respiratory disease, especially in ruminants. This method applied in the field is not only difficult and expensive, since a diagnosis must be made and the appropriate antibiotic chosen, but each individual must be captured to be treated, which is very stressful in most capture methods. The stress of capture may then counteract any positive effect of treatment. Coggins and Matthews (19981) had apparent success with this method after hand injecting sheep conditioned to a permanent corral trap and several sheep captured by netgun, but individual animal treatment is usually considered to be too expensive, stressful, impractical, and labour intensive to apply to most wild populations.

Other control methods include monitoring and attempting to control sheep movement by range riders on horseback and by killing obviously affected sheep. The hazing of bighorns is not believed to be possible without well-defined geographical barriers and is difficult to guarantee even then. The culling of affected animals may assist in preventing the spread of disease, but is probably most useful for collecting pathological and disease data.

Lamb recruitment is reported to be usually depressed for several years after an all-age *Pasteurella* die-off. This type of lamb mortality occurs during the summer (Festa-Bianchet 1988; Akenson and Akenson 1992; Coggins and Matthews 1992). In Oregon, the Wenaha herd of Rocky Mountain bighorn experienced a die-off in 1996 as part of the widespread Hell's Canyon die-off that started in late 1995. Akenson (1998) monitored this herd in 1997 to assess summer lamb mortality as part of a vaccine trial. Of 14 lambs observed, five died at less than 7 weeks of age, and three of these were collected for necropsy and tissue culture within 24 hours of death. *Pasteurella hemolytica* was cultured from all three animals, an organism also identified during the die-off. Foreyt (1990) found post die-off mortality of captive bighorn lambs occurred a little later than those noted by Akenson (1998), when they were 6 to 11 weeks old.

Cassirer et al. (1998) worked in the same general area as Akenson (1998) and reported low lamb survival after a die-off (November lamb-to-ewe ratios of less than 7:100). This low survival was presumed to be due to the transfer of pathogenic strains of *Pasteurella* spp. from ewes to lambs. Bailey (1986) reported on the 1980 die-off of the Waterton Canyon herd in Colorado. He found lamb survival was reduced, with pneumonia causing deaths of lambs for 1 to 3 years after the initial die-off. An estimated 72% (13 of 18 sampled) of surviving bighorn from the Lostine herd die-off of 1986/87 (Wallowa Mountains, Oregon) continued to carry *Pasteurella multocida* in October of the next year (Coggins 1988). Adult sheep surviving the initial stages of a die-off are postulated to carry virulent bacteria or higher numbers of bacteria in their respiratory tracts, especially if chronic nonfatal lesions are present. These organisms may then be transferred to lambs.

Lamb production in the South Okanagan bighorns was negligible in 2000. On June 6, a ram lamb was observed "falling from the sky" after presumed eagle predation. Examination of the carcass revealed a subacute bronchopneumonia with a pure culture of *P. multocida*. Few other lambs were observed in 2000. The South Okanagan sheep are expected to follow a similar pattern of poor lamb survival for several years.

Because residual disease may still be present for an indeterminate time after a die-off, wildlife managers should not translocate healthy bighorn sheep to the South Okanagan until it is clear they will not be exposed to survivors of the die-off that still carry and shed pathogenic strains of *Pasteurella* bacteria. This can be accomplished either (1) by translocating bighorn sheep only to more isolated areas where they will not come into intimate contact with other herds (e.g., Okanagan Mountain Park), or (2) by waiting until previously infected herds no longer harbour pathogenic strains of *Pasteurella* bacteria. In the second case, discussions of the Disease Working Group (B.C. Ministry of Environment, Lands and Parks 2000) indicate that a return to "normal" fall lamb-to-ewe ratios would be a reasonable indicator that the pathogenic strains of *Pasteurella* bacteria are no longer in a herd. The assessment of the nutritional and health status of bighorn sheep in the South Okanagan through opportunistic necropsy and tissue samples of roadkill and other mortalities should continue to be monitored for residual disease and general herd health.

Techniques are available to conduct disease risk assessment based on probability of contact and probability of transmission (Mitchell et al. 2000). Mitchell et al. used friction modelling to create a digital resistance landscape based on biophysical and local ecological knowledge of animal movements. Such an approach could be useful in predicting the most likely areas where disease could spread from domestic sheep or among bighorn sheep populations so that preventative measures could be planned.

Habitat issues

Between 1940 and 1987, 8799 ha of natural shrub–steppe ecosystems in the South Okanagan were converted to agricultural and urban development (B.C. Ministry of Environment, Lands and Parks 1998). If this trend continues, an additional 4000 ha of grassland will be lost to development in the next 20 years (B.C. Ministry of Environment, Lands and Parks 1998), and much of this lost grassland will probably be current or potential bighorn sheep habitat.

Fire suppression policies over the past 50 years have altered the natural frequency of wildfire in grasslands in the Bunchgrass biogeoclimatic zone (approximately every 5 to 15 years; Parminter 1992). Prescribed burns undertaken by the Ministry of Water, Land and Air Protection are efforts to restore this natural disturbance regime to shrub–steppe and dry forest ecosystems in the South Okanagan.

Although much of the damage to native plant communities caused by overgrazing livestock occurred approximately 100 years ago, many ranges still have not fully recovered. Careful range management practices are still required by ranchers to maintain improving trends in range condition. One of the greatest habitat issues is degradation of native ecosystem caused by noxious weed invasion. At least 25 noxious and problem weeds have invaded natural plant communities in the South Okanagan (B.C. Ministry of Environment, Lands and Parks 1998).

In the United States, habitat suitability models have been useful in predicting areas used by Rocky Mountain bighorn sheep, but accuracy was population-specific (Zeigenfuss et al. 2000). In 12 of 13 populations, the accuracy of predicting radiotelemetry and observations of bighorn sheep in suitable habitat ranged from 56 to 97% (Zeigenfuss et al. 2000). The predictive ability of these types of models depends on refining criteria and parameters to meet local conditions and ensuring that the model is applied at a scale appropriate to the available data (Johnson and Swift 2000). Studies in the United States found that population growth rates were correlated with amount of suitable habitat and the proportion of that habitat that was rugged lambing terrain (Zeigenfuss et al. 2000). As well, nutritional-constraint modelling can be used to evaluate seasonal habitat carrying capacities using data on the quantity and quality of available forage (DeYoung et al. 2000).

Predation

Predator swamping is an important factor in early survival of ungulate neonates. In Colorado, coyotes were a significant predator of both mule and white-tailed deer fawns, but because mule deer had a numerical advantage over white-tailed deer, survival to 30 days was almost twice as high (66%) for mule deer than for white-tailed deer (34%) (Whittaker and Lindzey 1999). This was attributed to predator swamping with the more numerous and later-fawning mule deer. With the population substantially reduced after the die-off, there is potential for both coyotes and cougars to have a greater impact on population dynamics than they did in previous years because there will be less opportunity for bighorn lambs to swamp their predators.

Highway collisions

Collisions between bighorn sheep and vehicles on Highway 97 near Vaseux Lake have been an ongoing problem. In 1963/64, heavy snows forced wintering bighorn sheep close to the highway with the result that 13 ewes were killed by highway traffic from late November 1963 until late March 1964 (Spalding 1966). Vehicles on Highway 97 killed only two ewes the next winter, 1964/65.

Four bighorn sheep were reported killed by vehicles in 1997 according to the provincial Wildlife Accident Reporting System (WARS) (Sielecki 1999). Roadkills picked up and reported through WARS are considered to be only a fraction of the actual numbers of animals killed in animal–vehicle collisions, and the typical correction factor is to multiply reported roadkills by a factor of five (Sielecki 1999). This suggests that collisions with vehicles on Highway 97 are a significant source of mortality (perhaps up to 20 per year), particularly for the largest subpopulation at Vaseux Lake. This was confirmed by Chapman (1999) who found bighorn sheep–vehicle collisions were the major source of adult bighorn mortality in his study.

Human disturbance

Bighorn sheep are known to be sensitive to human disturbance, particularly direct approaches off-road, and when accompanied by a dog (MacArthur et al. 1982). The human population in the South Okanagan almost quadrupled between 1940 and 1996 and is projected to increase to 112 000 by 2021 (B.C. Ministry of Environment, Lands and Parks 1998). Concomitant with the human population increase will be increased levels of human disturbance on all but the most remote bighorn sheep herds.

Bighorn sheep appear to be more sensitive to human activities than forest-dwelling ungulates, as might be expected of a species living in open habitats. In addition to habitat needs generally described for hoofed mammals, wild sheep have additional needs for escape terrain on rugged cliffs, especially during lambing. Human activities that prevent bighorn sheep from accessing escape terrain or that increase the

Table 6. Manufacturer's guaranteed analysis of custom-made bighorn sheep mineral supplement

Constituent	Concentration
Salt (NaCl)	50%
Calcium (actual)	8%
Phosphorus (actual)	8%
Iron	8,000 mg/kg
Zinc	5,000 mg/kg
Copper	2,000 mg/kg
Manganese	2,000 mg/kg
Cobalt	200 mg/kg
Iodine	200 mg/kg
Selenium	45 mg/kg
Vitamin A	350,000 IU/kg
Vitamin D	88,000 IU/kg
Vitamin E	1,000 IU/kg

time bighorn sheep spent in these escape terrain probably increases stress, and may lower foraging efficiency. Human activities that stress bighorn sheep include viewing, helicopter and fixed-wing aircraft (Frid 1998; Legg 1998), vehicles, and domestic dogs (MacArthur et al. 1982). Although occasional exposure to these activities probably has minimal effect on bighorn sheep, chronic exposure potentially reduces foraging efficiency (Bleich et al. 1994) and can lead to range abandonment. Reductions in the effectiveness of bighorn sheep habitat can lead to changes in growth and survival, and can result in chronic stress, which, in turn, can lead to compromised immune systems and increased vulnerability to diseases.

1.4.2 Translocation considerations

Management actions

All hunting of bighorn rams in the South Okanagan (MUs 8-01 and 8-09) was temporarily closed in 2000 and remains closed until populations have rebuilt sufficiently to provide a sustainable harvest.

In the spring 2000, 25-kg bags of specially blended mineral salt were made available to bighorn sheep that survived the die-off (Table 6). Mineral salt was distributed through the volunteer efforts of the South Okanagan Sportsmen's Association and others.

Small prescribed burns of 12 and 15 ha were accomplished in 2000 on winter/spring range used by the Vaseux subpopulation. A substantial number of new parks and protected areas were established in the

Okanagan in 2000 and several include habitats used by bighorn sheep in the South Okanagan metapopulation (Figure 9).

Singer et al. (2000b) outlined a seven-point program for restoring bighorn sheep populations that involves (1) surveying existing populations, (2) identifying suitable habitat through GIS, (3) convening a scientific advisory panel to review habitat assessments, (4) convening an interagency panel to discuss metapopulation management and plan the restoration, (5) drafting interagency restoration and management plans, (6) conducting the translocation, and (7) monitoring the population. Although translocations of bighorn sheep are expensive, labour intensive, and logistically and politically challenging, more than half of all North American populations are the result of these efforts (Krausman 2000a). Successful translocations between 1923 and 1997 occurred when indigenous stocks were moved into large patches of habitat where domestic sheep were more than 6 km away (Singer et al. 2000a). High dispersal rates and rapid occupation of large areas can occur when there are few water barriers, lots of rugged broken terrain, and no domestic sheep present (Singer et al. 2000c). Past restoration projects that did not meet these criteria have contributed to populations that are insular and fragmented with little observed dispersal and colonization of unoccupied habitats. Translocations were more successful the further they took place from domestic sheep. In the United States, unsuccessful transplants averaged 5 km from domestic sheep, marginally successful transplants averaged 12 km from domestic sheep, and very successful transplants averaged 23 km from domestic sheep (Zeigenfuss et al. 2000).

Founder group size in successful translocations (populations of 100 to 350) was significantly larger than that of less successful translocations (populations of less than 100), suggesting that the number of individuals translocated to establish new populations should be at least 40 (Singer et al. 2000a). Although demographic stochasticity in small populations is probably the driving factor, it is important to avoid severe genetic bottlenecks (i.e., effective population sizes of less than 10) in translocated populations (Ramey et al. 2000).

2.0 RECOVERY

Recovery of California bighorn sheep populations in the South Okanagan will require a multi-pronged approach that includes intensive management of both habitats and populations. A recent special issue of *Restoration Ecology* (Krausman 2000b) addresses many of the concepts and techniques currently used to restore bighorn populations elsewhere in North America. Recovery of the South Okanagan metapopulation to its approximate historic distribution will require the cooperation of various levels of government and the public to enhance and protect habitats, control the spread of infectious diseases, and monitor the effects of management actions.

2.1 Principles

The recovery plan is based on four basic principles:

1. The recovery of California bighorn sheep will be based on the establishment and maintenance of wild free-roaming populations in suitable habitats, within their historic range in the South Okanagan.
2. Every effort will be made to preserve the genetic integrity and diversity of bighorn sheep and to maintain their genetic distinctiveness from other subspecies of bighorn sheep.
3. To provide for continued natural evolution of California bighorn sheep, the normal interaction of free-roaming populations and their native environment will be maintained.
4. This recovery plan will support the goals and objectives of bighorn management plans for the Province of British Columbia, and to the greatest extent possible, will support the objectives of management plans for adjacent bighorn populations in Washington State.

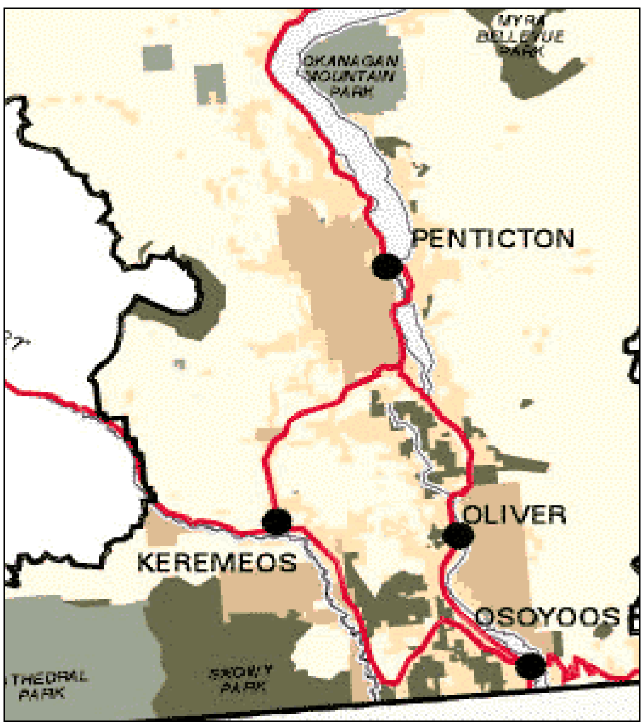

Figure 9. Existing (grey) and new (dark brown) protected areas in the South Okanagan Valley (in dark green).

2.2 Recovery Goals

The five goals of the recovery plan for California bighorn sheep in the South Okanagan are:

1. **Re-establish a viable metapopulation of at least 400 disease-free, free-roaming California bighorn sheep on suitable habitats within their original range in the South Okanagan by 2010.**

   This is to restore California bighorn sheep to their approximate historic distribution within the ability of current habitat conditions to support viable populations. Several subpopulations are required to reduce the risk of random events affecting their entire metapopulation. Ultimately, the goal is to have a stable or increasing metapopulation of at least 400 California bighorn sheep, well distributed throughout the South Okanagan, with some subpopulations that are genetically interconnected, but not intimately connected. The population target of 400 or higher will apply only to the Canadian range of the South Okanagan metapopulation and does not include the Mount Hull subpopulation in the United States. The population target includes all adult males and females, but does not include lambs less than 1 year of age. This population target should be reevaluated, once detailed habitat use and habitat suitability mapping is available, to more closely align the habitat carrying capacities of various bighorn sheep ranges with population targets. The population target of 400 or more is based on sheep range that was occupied by the eight Canadian subpopulations before the die-off, and does not include currently unoccupied areas such as Okanagan Mountain Park.

2. **Prevent contact between bighorn sheep and domestic sheep.**

   The risk of transmission of domestic sheep diseases to wild sheep is one of the greatest obstacles to the recovery of California bighorn sheep in the South Okanagan. The Disease Working Group at the Workshop for the Recovery of Bighorn Sheep in the South Okanagan agreed that contact with domestic sheep is the single most important disease risk factor in bighorn sheep management (B.C. Ministry of Environment, Lands and Parks 2000). Every effort must be made to avoid close contact and transfer of infectious organisms from domestic sheep (*Ovis aries*) to free-ranging bighorn sheep. There may also be risks with close contact with domestic goats (*Capra hircus*). Management will work towards the segregation of domestic sheep and goats to prevent the transfer of infectious agents such as *Pasteurella* spp. and contagious ecthyma.

3. **Allow the South Okanagan metapopulation to increase to a level that allows for long-term sustainable human use.**

   There is significant potential for ecotourism, wildlife viewing, resident hunting, nonresident guide outfitting, and native subsistence use of bighorn sheep in the South Okanagan. Achieving population levels that allow human use of bighorn sheep is consistent with and supports conservation objectives.

4. **Encourage research on the South Okanagan metapopulation, particularly studies that focus on conservation and conservation biology of bighorn sheep.**

   Scientific research directed towards answering the right questions can be very effective in improving the ability of wildlife managers to manage both populations and habitats to achieve recovery objectives. Research directed towards evaluating the population responses to various recovery actions can help determine the effectiveness and cost efficiency of management programs.

5. **Continue to work with public groups, rural and agricultural communities, aboriginal peoples, and other government agencies to develop cooperative management and fund-raising programs for establishing and maintaining healthy subpopulations in the South Okanagan.**

Conservation objectives are easier to achieve if local communities have a direct stake in re-establishing and maintaining viable populations of bighorn sheep in their area. Native peoples have a long history of cultural attachment to this species. The South Okanagan Sportsmen's Association has a proven ability to cooperatively sponsor and develop bighorn sheep conservation programs. Translocation and habitat acquisition programs are expensive and are not a long-term solution on their own. Land acquisitions play an important role in preserving critical habitats; the support and participation of adjoining landowners is vital to maintaining movement corridors and overall habitat integrity. This can be achieved through local stewardship initiatives such as the South Okanagan–Similkameen Stewardship Program (Bryan and Austen 2000) and by offering expertise and funding assistance. Broader community involvement and outreach can facilitate an attitude of caring and direct participation that includes both volunteer action and fund-raising.

New sources of revenue and fund-raising should be developed with various public and private partners to support implementation of this plan. The federal government recently announced a contribution of $1 million towards the conservation of habitat and species at risk as part of South Okanagan–Similkameen Conservation Program. The new funding will come from the federal government's Habitat Stewardship Program funds, and will be used to implement conservation actions with nongovernment organizations and private landowners, conservation groups, and local governments in an effort to maintain and restore habitats critical to species at risk. Since there is considerable overlap in the range of bighorn sheep with the range of nationally threatened and endangered species, it will be important to coordinate the goals and objectives of this plan with those of the South Okanagan–Similkameen Conservation Program.

2.3 Recovery Objectives and Actions

Each of the five goals of the recovery plan has objectives that are designed to directly support the achievement of that goal. This section outlines the specific objectives and management actions that are required to achieve these recovery goals.

Goal 1: Restore the Metapopulation by 2010: Objectives and Actions

Goal #1 is to "Re-establish a viable metapopulation of at least 400 healthy, free-roaming California bighorn sheep on suitable habitats within their original range in the South Okanagan by 2010."

Objectives and Actions

The 11 objectives and associated actions under this goal are:

1. Manage South Okanagan subpopulations to increase to a total metapopulation target of at least 400 animals in Canada by 2010.

   A. Develop size targets for each subpopulation based on the optimum density that current habitats can sustainably support in balance with other components of the ecosystem.

   B. Periodically, at appropriate times of the year, determine the size, distribution, and demographics of each subpopulation using standard species inventory and research methods (e.g., RIC 1997a, 1997b).

   C. Ensure that population objectives for the South Okanagan metapopulation continue to be input into various land-use and land management planning initiatives (e.g., LRMP, PAS, and FPC).

   D. Implement intensive population management programs, including translocation and predator management if and when required to achieve metapopulation recovery objectives (see below).

2. Consider a tightly controlled and limited predator management program as appropriate and necessary to recover the South Okanagan metapopulation.

   A. Determine the nature and extent of coyote predation on neonates and its effect on population growth and demographics.

   B. Determine the nature and extent of cougar predation on adults and its effect on population growth and demographics.

   C. Evaluate the potential for temporary and area-focused predator control programs to increase individual subpopulation growth rates to achieve recovery objectives.

   D. If necessary, implement an initial predator control program on a test subpopulation using adaptive management experimental protocols to determine its effectiveness.

   E. Implement temporary and area-focused predator-control programs on those subpopulations with high levels of predation that prevent recovery objectives from being attained.

3. Translocate bighorn sheep to establish new subpopulations as appropriate and necessary to recover the South Okanagan metapopulation. New subpopulations would not contribute to the recovery target of 400 animals.

   A. Identify potential translocation sites within the known or suspected historic range of bighorn sheep, based on the general habitat attributes at potential translocation sites using the most recent terrestrial ecosystem mapping (TEM), forest cover mapping, satellite imagery, aerial photography, and local knowledge. Potential sites include Okanagan Mountain Park, Eneas Creek, Nkwala Mountain, Mount Keogan, the White Lake Basin, Mount Kobau, and Mount Kruger.

   B. Evaluate and set priorities for potential translocation sites based on a detailed evaluation of habitat and potential land-use conflicts.

C. Classify and inventory habitat types at potential translocation sites using standard techniques for terrestrial ecosystem classification and knowledge of life requisites of the South Okanagan metapopulation.

D. Measure and estimate standing biomass of bighorn sheep forage available for winter and summer use.

E. Measure and predict the maximum expected snow depths on potential winter ranges during severe winters.

F. Calculate theoretical carrying capacity of bighorn sheep range using forage biomass estimates, 1:20,000 habitat mapping (B.C. Ministry of Environment, Lands and Parks 1998), and predicted snow depth information to ensure bighorn sheep are re-established in areas with sufficient habitat to support viable subpopulations.

G. Evaluate the potential for genetic interchange with other bighorn sheep herds.

H. Check historic records of translocation source herds to confirm bighorn sheep used to augment or initiate South Okanagan subpopulations are from herds of pure *O. c. californiana* subspecies.

I. Evaluate the potential for improving the genetic diversity of the South Okanagan metapopulation by translocating genetic stocks of *O. c. californiana* different from those used previously.

J. Perform disease risk assessments to avoid disease introductions from bighorn source herds or contact with domestic sheep or goats.

K. Evaluate the potential for predators to hamper herd establishment.

L. Evaluate potential conflicts of a bighorn sheep populations with other land uses and other wildlife species, at both the translocation site and in adjacent areas.

M. Finalize potential bighorn sheep translocation sites using the detailed information gathered above.

N. Initiate a program of formal agency and public consultation to obtain feedback on the highest priority bighorn sheep reintroduction sites.

O. Perform a health assessment of source stock of bighorn sheep according to standard testing protocols for bighorn sheep.

4. Augment existing subpopulations through translocation as appropriate and necessary to recover the South Okanagan metapopulation. Augmented subpopulations would contribute to the recovery target of 400 animals.

A. Evaluate the necessity of augmenting subpopulations to hasten achievement of population targets.

B. Monitor the health of bighorn subpopulations on an ongoing basis to confirm the presence or absence of residual or ongoing disease. Document lamb production and survival in all herds and the causes of any losses.

C. Calculate theoretical carrying capacity of bighorn sheep range using forage biomass estimates, 1:20,000 terrestrial ecosystem mapping (B.C. Ministry of Environment, Lands and Parks

1998), and predicted maximum snow depths to ensure that bighorn sheep are translocated into areas with sufficient habitat to support viable subpopulations.

D. Initiate a program of formal agency and public consultation to obtain feedback on subpopulation augmentation.

E. Perform a health assessment of source stock of bighorn sheep according to standard testing protocols for bighorn sheep.

F. Release animals in areas where bighorn sheep are concentrated to help imprint animals to the release site.

Population augmentation is an effective way to increase both total numbers and genetic heterozygosity in small populations. Augmenting a small population with mostly females will have the greatest effect on population demographics, and augmenting a population with mostly males will have the greatest effect on the genetic structure of a population. However, the genetic advantages of augmenting with males must be carefully weighed against the greater risk of disease transmission, because males wander greater distances than females (Ramey et al. 2000).

5. Manage habitats of the South Okanagan metapopulation to support a total metapopulation target of at least 400 animals in Canada by 2010.

A. Develop habitat "mini-plans" for each of the seven habitat subunits identified in Figure 3 (Inkaneep, Vaseux, McIntyre–White Lake, Skaha, Kaleden, Penticton, and Okanagan Mountain). Establish specific objectives for range condition, forage production, and protected status for each habitat subunit. Local stewardship initiatives such as the South Okanagan–Similkameen Stewardship Program (Bryan and Austen 2000) have an important role to play in the development and implementation of habitat "mini-plans."

B. Within each habitat subunit, monitor and evaluate the distribution and condition of seasonal habitats and habitat use.

C. Within each habitat subunit, monitor changes in natural and disturbed ecosystems associated with use by bighorn sheep, other native ungulates, and domestic livestock.

D. Use vegetation sampling techniques employed on bighorn sheep ranges elsewhere in Canada, along with standard methods for vegetation sampling (RIC 2000), ecosystem mapping (RIC 1998), and habitat monitoring (RIC 1996).

E. Ensure habitat objectives for the South Okanagan metapopulation continue to be input into various land-use and land management planning initiatives (e.g., LRMP, PAS, and FPC).

F. Protect and manage bighorn sheep habitats within the various land-use tenures consistent with bighorn sheep recovery objectives and other conservation plans such as the South Okanagan Ecosystem Recovery Plan (Slater 2000; Cannings et al. 1999a), the South Okanagan–Similkameen Stewardship Program (Bryan and Austen 2000), and the Vaseux Lake Habitat Management Plan (Bryan 1996).

G. Implement intensive habitat management programs, including prescribed burning, forest thinning, and weed control where required to achieve metapopulation recovery objectives.

6. Use prescribed fire to improve the quantity and quality of bighorn sheep forage.

A. Refer to individual habitat subunit “mini-plans” for area-specific objectives for range condition and forage production.

B. Identify potential sites for treatment with prescribed fire, based on the general habitat attributes, the most recent terrestrial ecosystem mapping (TEM), forest cover mapping, satellite imagery, aerial photography, and local knowledge.

C. Evaluate potential sites for the risk of escape of fire and ability of prescribed burns to contribute to overall recovery goals and habitat subunit objectives.

D. Avoid prescribed burns that reduce the distribution of antelope bitterbrush (*Purshia tridentata*) and mock-orange (*Philadelphus lewisii*) because of their importance as a browse species for bighorn sheep and as a component of rare ecosystem assemblages in the Okanagan (Atwood and Osoyoos Desert Society 2000).

E. Prioritize potential prescribed burns based on a detailed evaluation of recovery objectives, consistency with ecosystem restoration programs (e.g., Scudder 2000), habitat conditions, and potential land-use conflicts.

F. Initiate a program of formal agency and public consultation to obtain feedback on the highest priority prescribed burning sites.

G. Develop burning plans for high-priority potential sites that include season of ignition (fall or spring), method of ignition, size of burn, necessity for construction of fire-breaks, contingency plans for dealing with escapes, weed control techniques, and methods for monitoring results.

H. Before and after ignition, monitor permanent sample plots within and adjacent to prescribed burn areas to document changes in vegetation communities (RIC 1996).

I. Monitor responses of bighorn sheep to plant communities altered by prescribed fire, both behaviourally and demographically.

7. Use various silvicultural techniques, including forest thinning, to improve the quantity and quality of bighorn sheep forage.

A. Refer to individual habitat subunit “mini-plans” for area-specific objectives for range condition and forage production.

B. Identify potential sites for silvicultural treatments, based on the general habitat attributes, the most recent terrestrial ecosystem mapping (TEM), forest cover mapping, satellite imagery, aerial photography, and local knowledge.

C. Evaluate the ability of potential sites to contribute to overall recovery goals and habitat subunit objectives.

D. Set priorities for potential silviculture treatments based on a detailed evaluation of recovery objectives, consistency with ecosystem restoration programs (e.g., Atwood and Osoyoos Desert Society 2000; Scudder 2000), habitat conditions, and potential land-use conflicts.

E. Initiate a program of formal agency and public consultation to obtain feedback on the highest priority silvicultural treatment sites.

F. Develop silviculture treatment plans for high-priority potential sites that include current and target stem-density estimates, methods of treatment, size of treatment area, necessity for construction of trails and roads, weed control techniques, and methods for monitoring results.
G. Before and after treatment, monitor permanent sample plots within and adjacent to treatment areas to document changes in vegetation communities (RIC 1996).
H. Monitor responses of bighorn sheep to plant communities altered by silviculture treatments, both behaviourally and demographically.

8. Use various weed-control techniques, including chemical and biological agents, to improve the quantity and quality of bighorn sheep forage.

A. Refer to individual habitat subunit "mini-plans" for area-specific objectives for range condition and forage production.
B. Identify potential sites for weed control, based on the general habitat attributes, the most recent terrestrial ecosystem mapping (TEM), forest cover mapping, satellite imagery, aerial photography, and local knowledge.
C. Evaluate the ability of potential sites to contribute to overall recovery goals and habitat subunit objectives.
D. Prioritize potential weed control sites based on a detailed evaluation of recovery objectives, consistency with ecosystem restoration programs (e.g., Atwood and Osoyoos Desert Society 2000, Scudder 2000), habitat conditions, and potential land-use conflicts.
E. Initiate a program of formal agency and public consultation to obtain feedback on the highest priority weed control sites.
F. Develop weed control plans for high-priority potential sites that include current and target vegetation community composition, methods of treatment, size of treatment area, and methods for monitoring results.
G. Before and after treatment, monitor permanent sample plots within and adjacent to weed control areas to document changes in vegetation communities (RIC 1996).
H. Monitor responses of bighorn sheep to plant communities altered by weed control, both behaviourally and demographically.

9. Explore the potential for intensively managing agricultural fields and pastures specifically for the production of bighorn sheep forage rather than domestic forages.

A. Refer to individual habitat subunit "mini-plans" for area-specific objectives for range condition and forage production.
B. Identify potential agricultural fields and pastures for intensive management, based on current land ownership (e.g., Nature Trust properties), cooperative agreements with private landowners, and the presence of bighorn sheep and adequate security cover.
C. Evaluate the ability of potential agricultural fields and pastures to contribute to overall recovery goals and habitat subunit objectives.

D. Prioritize potential agricultural fields and pastures based on a detailed evaluation of recovery objectives, habitat conditions, and potential land-use conflicts.

E. Initiate a program of formal agency and public consultation to obtain feedback on the highest priority fields and pastures.

F. Develop agricultural management plans for high-priority potential sites that include current and target agronomic species composition, methods of treatment, size of treatment area, and methods for monitoring results.

G. Before and after treatment, monitor treated areas to document changes in agronomic plant communities.

H. Monitor responses of bighorn sheep to agricultural areas managed for forage production, both behaviourally and demographically.

10. Reduce bighorn sheep–vehicle collision mortalities along Highway 97.

A. Identify areas with high rates of vehicle collisions with bighorn sheep.

B. Install ungulate fencing in areas with the highest collision rates.

C. Consider alternative mitigation strategies such as wildlife reflectors in areas with moderate or low collision rates.

D. Reduce bighorn sheep attractants immediately adjacent to unfenced highway rights-of-way.

E. Concentrate habitat improvement activities away from the unfenced highway rights-of-way.

F. Explore nontoxic alternative de-icing compounds to replace road salt along strategic locations (e.g., high-probability bighorn sheep occurrence zones (BOZs).

G. Evaluate the potential for highway fencing to increase predation rates, and consider mitigation strategies such as increasing the visibility of fencing.

H. Consider placing mineral supplements and salt blocks at strategic locations to keep bighorn sheep away from highways.

11. Provide trace mineral supplements with the goal of improving the health of subpopulations affected by the pneumonia epidemic.

A. Locate and map suitable sites for placing mineral supplements (e.g., existing mineral licks, late winter and early spring concentration areas).

B. Place mineral supplements (Table 6) in multiple dispersed locations at least partially protected from rain to minimize leaching.

C. Monitor use of mineral supplements at least monthly to determine the level of use by bighorn sheep and other animals. Monitor tissue levels of trace minerals opportunistically.

Goal 2: Prevent Pneumonia Epizootics: Objectives and Actions

Goal #2 is to "Prevent physical contact between bighorn sheep and domestic sheep."

This is the highest priority goal, since all other efforts under this recovery plan become moot if Goal 2 is not achieved and the metapopulation is subjected to further pneumonia epidemics as a result of contact with domestic sheep and goats. Achievement of this goal will require parallel actions in both the short term (e.g., Objective 3) and long term (e.g., Objective 2 and 4).

Objectives and Actions

The six objectives and associated actions under this goal are:

1. On Crown land, apply *Guidelines for the Use of Domestic Sheep for Vegetation Management in BC* (Province of BC 1999a http://www.for.gov.bc.ca/hfp/forsite/sheep/).

   A. Establish "bighorn sheep occurrence zones" (BOZ) for the entire South Okanagan Valley that delineate areas with a high, low, and nil probability of the presence of bighorn sheep.

   B. Communicate the location and purpose of these BOZs to other agencies and the general public through brochures, press releases, public meetings, and standard government communication channels.

   C. Prevent domestic sheep and goat grazing on Crown land in both high- and low-probability BOZs.

   D. Apply Health Protocol for Sheep Used in Vegetation Management in BC (Province of BC 1999a) on all domestic sheep and goats grazing Crown land in all BOZs in the South Okanagan regardless of probability of occurrence.

2. On private land, work with domestic sheep and goat producers and private landowners to educate them about the disease issue and to improve livestock stewardship practices.

   A. Establish and implement an outreach program geared to both large and small producers to educate them about the disease issues.

   B. Involve Ministry of Agriculture and Fisheries and Food (MAFF) and Ministry of Water, Land and Air Protection (MWLAP) staff and include both formal public presentations and informal "kitchen-table" discussions about private property issues.

   C. Establish prompt "two-way" notification and reporting between private landowners and MWLAP staff about stray bighorn and/or domestic sheep located in areas that might allow physical contact.

   D. Encourage self-regulation and self-monitoring of domestic sheep and goat producers, particularly in low-probability BOZs.

   E. Supplement self-regulation and self-monitoring of domestic sheep and goat producers in high probability BOZs with appropriate levels of government monitoring and assistance.

   F. Encourage domestic sheep and goat producers in high-probability BOZs to consider alternative livestock species.

   G. Develop a cooperative agreement among MAFF, MWLAP, and appropriate regional district and municipal governments to address the roles and responsibilities of the various agencies and domestic sheep and goat producers in preventing contact between bighorn sheep and domestic sheep and goats.

   H. Annually update information on the seasonal distribution and size of domestic herds of sheep and goats with high- and low-probability BOZs.

3. Install ungulate exclusion and additional livestock fencing at strategic locations.

A. Install ungulate exclusion fencing where necessary to keep bighorn sheep away from domestic sheep and goats.

B. Section 703 (e) of the *Local Government Act* allows local governments to prohibit sheep straying off the owner's land or sheep grazing on unfenced land. If not already enacted, local governments should enact bylaws to effect such regulations and require all livestock to be fenced. In particular, these regulations should be applied if there is seasonal use of vineyards by domestic sheep.

C. Cooperate with MAFF and domestic sheep and goat producers to develop special standards for fencing and gating in high- and low-probability BOZs that prevent contact between bighorn sheep and domestic sheep and goats.

D. Work towards a policy that makes these special fencing standards mandatory for all domestic sheep and goat producers in high- and low-probability BOZs.

E. Consider double fencing of domestic sheep in strategic locations using electric fences and secondary game fencing to prevent nose-to-nose contact.

F. Encourage the use of guardian dogs for domestic sheep to keep out wild sheep and keep domestics from wandering off property.

G. Encourage culling of sick sheep from domestic flocks and control the general health in domestic flocks.

H. Investigate subsidized fencing or compensation to provide additional fencing for domestic sheep beyond that required under the *Local Government Act.*

4. Enact municipal and regional district bylaws to keep domestic and wild sheep separated if local producers do not self-regulate.

A. Monitor self-regulation of local sheep and goat producers in high- and low-probability BOZs.

B. As necessary, establish "no domestic sheep or goat zones" in high-probability BOZs.

C. As necessary, establish mandatory double fencing of domestic sheep and goats in low-probability BOZs.

D. Continue information and education programs aimed at separating domestic and bighorn sheep

5. Establish new municipal and regional district bylaws to keep domestic and wild sheep separated if existing bylaws are insufficient and local producers do not self-regulate.

A. Monitor self-regulation of local sheep and goat producers under the new high- and low-probability of contact BOZ bylaws.

B. As necessary, introduce new bylaws establishing "no domestic sheep or goat zones" in high-probability BOZs.

C. As necessary, introduce new bylaws establishing mandatory double fencing of domestic sheep and goats in low-probability BOZs.

6. Consider extraordinary disease-prevention actions in certain circumstances.

   A. Cull bighorn sheep from low- and nil-probability BOZs if there has been high probability of contact with domestic sheep or goats (e.g., domestic sheep or goats were unfenced or bighorn sheep were observed immediately adjacent to fenced domestic sheep).

Goal 3: Allow Sustainable Human Use: Objectives and Actions

Goal #3 is to "Allow the South Okanagan metapopulation to increase to a level that allows for long-term sustainable human use."

Objectives and Actions

The five objectives and associated actions under this goal are:

1. Monitor changes in subpopulation distribution, size, and demographics.

   A. Develop estimates of the optimum density of bighorn sheep that habitats can sustainably support in balance with other species and components of the ecosystem.
   B. Periodically throughout the year determine the size, distribution, and demographics of individual subpopulations using consistent and standard (i.e., Resources Inventory Committee) species inventory methods.
   C. Coordinate population censuses with wildlife managers responsible for surveys of the Mount Hull subpopulation in the United States.
   D. Continue to support the annual winter census of bighorn sheep conducted by the South Okanagan Sportsmen's Association.

2. Optimize opportunities for residents and visitors to view California bighorn sheep in their natural habitat.

   A. Monitor the seasonal distribution and abundance of individual subpopulations and herds of bighorn sheep.
   B. Evaluate potential viewing sites or corridors where viewers can observe bighorn sheep without disturbing their normal activity patterns.
   C. Evaluate access to the viewing site or corridor, and the potential for access use or development to interfere with established range-use patterns.
   D. Develop safe, accessible viewing sites or corridors that will not disturb the animals or disrupt normal range-use patterns.
   E. Encourage private entrepreneurs, including guide outfitters, to provide ground viewing opportunities to the public on a fee-for-service basis.

3. Reinstitute a conservative hunting season for rams in the South Okanagan metapopulation as soon as possible.

   A. A priori, determine specific subpopulation targets for size, trend, and distribution within each Management Unit that would be sufficient to support a hunting season.

B. On an annual basis, evaluate data on subpopulation size, trend, and distribution within each Management Unit.

C. Confirm that conservation goals are being met, that subpopulations are recovering, and that there is a harvestable surplus of animals.

D. Once conservation goals and population targets are being met, propose hunting seasons and guide quotas consistent with the British Columbia Wildlife Harvest Strategy (B.C. Ministry of Environment, Lands and Parks 1995).

E. Determine the appropriate level of harvest required to continue population recovery or to maintain bighorn sheep numbers at estimated optimum levels.

F. Once lamb production and survival is sufficient to support positive population growth (e.g., average winter census of more than 25 lambs to 100 "ewes") a conservative full-curl permit-only hunting season for rams should be considered.

G. After three consecutive winters of lamb production and survival sufficient to support positive population growth, a less conservative hunting season should be considered. Toweill (1999) recommends ram harvests should not exceed 8% of the total number of rams (excluding lambs). In areas where herds are regularly surveyed, this guideline could be modified to allow harvest of up to 15% of <u>observed</u> ¾ curl rams, to achieve the same objective.

H. Allocate hunter harvest of rams among residents, natives, and nonresidents according to current policy.

I. Manage native hunter harvest through cooperative agreement with local First Nations.

J. Manage nonresident hunter harvest through quota allocations to licenced guide outfitters.

K. Manage resident hunting through Limited Entry Hunting (permit authorizations issued on a draw basis), conservative curl regulations, and/or area closures as appropriate to stay below 8% maximum harvest.

4. Consider using some South Okanagan subpopulations as a source of animals for translocation.

A. A priori, determine specific subpopulation targets for size, trend and distribution within each subpopulation that would be sufficient to support the capture and removal of females and young males for translocation.

B. On a regular basis, evaluate data on subpopulation size, trend, and distribution within each subpopulation.

C. Confirm that conservation goals have been met, that the potential source subpopulation has recovered, and that there is either a harvestable surplus of animals, or there is the need to reduce the size of the subpopulation to regulate density and lower the risk of pneumonia epizootics.

D. Evaluate the conservation merits of translocating animals both among South Okanagan subpopulations and to other metapopulations.

E. Determine the appropriate number of animals to be removed from the source subpopulation level. Toweill (1999) recommends the annual harvest should not exceed 20% of the total number of adult females.

5. Consider a hunting season for ewes in the South Okanagan metapopulation if population densities increase to a level that exceeds habitat carrying capacity.
    A. A priori, determine specific subpopulation criteria for size, trend, density, distribution and habitat condition that would justify a hunting season for ewes.
    B. On a regular basis, evaluate data on subpopulation size, trend, density, distribution, and habitat condition within each subpopulation.
    C. Confirm the necessity of reducing the size or rate of growth of a subpopulation based on the criteria mentioned above.
    D. Once conservation goals and population targets are decided, propose hunting seasons for ewes consistent with the British Columbia Wildlife Harvest Strategy (B.C. Ministry of Environment, Lands and Parks 1995).
    E. Determine the appropriate level of ewe harvest required to maintain bighorn sheep numbers at estimated optimum levels (just below habitat carrying capacity). Wishart et al. (1998) suggests that the optimum ratio to maintain a herd ratio of 1:1 was 20 lambs to 40 ewes to 40 rams.
    F. Allocate hunter harvest of ewes among residents, natives, and nonresidents according to current policy.
    G. Manage native hunter harvest through cooperative agreement with local First Nations.
    H. Manage nonresident hunter harvest through quota allocations to licenced guide outfitters.
    I. Manage resident hunting through Limited Entry Hunting and area closures as appropriate to achieve population stabilization.

Goal 4: Encourage Applied Research: Objectives and Actions

Goal #4 is to “Encourage research on the South Okanagan metapopulation, particularly those studies that focus on conservation and conservation biology of bighorn sheep.”

Objectives and Actions

The five objectives and associated actions under this goal are as follows:

1. Determine which vital rates are most responsible for changes in population size.
    A. Document age-specific survival rates.
    B. Evaluate long-term population implications of demographic factors that are limiting population growth.

2. Assist in evaluating disease management programs.
    A. Assist in developing and modifying BOZs used in disease management programs.
    B. Document any bighorn sheep–domestic sheep/goat interactions.
    C. Evaluate the effectiveness of producer self-regulation and fencing programs in preventing bighorn sheep–domestic sheep/goat contact.

3. Assist in determining the effectiveness of habitat management programs by documenting changes in bighorn sheep foraging behaviour in response to prescribed burning and forest thinning treatments.

A. Document pretreatment foraging behaviour on a seasonal basis in both control and treatment areas.

B. Document post-treatment foraging behaviour on a seasonal basis in both control and treatment areas.

C. Evaluate long-term population implications of habitat management efforts.

4. Assist in determining the effectiveness of ungulate exclusion fencing in preventing bighorn sheep–vehicle collisions on Highway 97.

A. Determine the seasonal rate of roadkills along fenced and unfenced portions of Highway 97.

B. Determine if highway fencing alters home-range use patterns.

C. Determine if fencing increases the rate of predation.

5. Assist in determining the necessity for a predator-management program to achieve population objectives by documenting predator–prey interactions.

A. Determine the seasonal timing and rate of coyote predation and its effect on bighorn sheep demographics.

B. Determine the seasonal timing and rate of cougar predation and its effect on bighorn sheep demographics.

C. Determine the seasonal timing and rate of golden eagle predation and its effect on bighorn sheep demographics.

Goal 5: Develop Cooperative Management Programs: Objectives and Actions

Goal 5 is to "Continue to work with public groups, rural and agricultural communities, aboriginal peoples, and other government agencies to develop cooperative management and fund-raising programs for establishing and maintaining healthy subpopulations in the South Okanagan."

Objectives and Actions

The four objectives and associated actions under this goal are:

1. Involve government agencies, stakeholders, public groups, rural communities, and native groups in developing population- and habitat-management plans (e.g., translocation, hunter harvest, prescribed burning, forest thinning).

A. Ensure that local communities, First Nations, and local industry have input to decisions on bighorn sheep population management.

B. Recognize the special interest of First Nations in the recovery of bighorn sheep in the South Okanagan.

C. Ensure that consultation is broad and includes all public interest groups, stakeholders, and affected government agencies.

2. Consider the development of long-term cooperative management programs with federal and municipal governments, regional districts, and native bands to further recovery goals and objectives.

A. Explore the potential for developing common objectives for land-use planning and land-use management of bighorn sheep habitats that lie within federal, municipal, regional district, and Indian Reserve boundaries.

3. Continue to consult wildlife managers in Washington State on development and implementation of land-use plans and bighorn sheep management policies.

A. Seek comment from Washington State on recovery plans, land-use plans, and population management policies that affect the South Okanagan metapopulation.

B. Keep Washington State wildlife managers informed of significant changes in the status of Canadian subpopulations of the South Okanagan metapopulation.

C. Cooperate with their research and management programs.

4. Explore new sources of funding to implement and support recovery actions.

A. Develop cooperative funding proposals with partners in other government agencies, stakeholders, public groups, rural communities, and First Nations.

B. Pursue local fund-raising initiatives to generative funds and raise awareness.

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4.0 APPENDICES

Appendix 1. Blood chemistry and hematology of bighorn sheep from the Vaseux Lake subpopulation in the mid-1980s compared with other populations sampled from various locations and seasons.

Comparisons of various blood constituents (see #1 – 23 below) between the Vaseux subpopulation and other herds indicate that the Vaseux subpopulation is marginally deficient in selenium, but has relatively high levels of inorganic phosphorus and blood urea nitrogen.

The animals from other herds include 10 bighorn sheep sampled from the South Slope subpopulation in the Similkameen (Harper 1984b), 20 bighorn sheep from the Okanagan Game Farm (OKGF) research herd sampled in December 1977 (Peterson and Bottrell 1978), 11 desert bighorn sheep from an 80-acre enclosure at Zion National Park, Utah (Bunch et al. 1978), and a captive group of Rocky Mountain bighorn sheep maintained on a natural rangeland diet that simulates migratory and nonmigratory forage conditions (Hebert 1972, 1978). Bottrell et al. (1978) looked at blood metabolites of bighorn lambs born into captivity that were fed alfalfa with supplements. Kock et al. 1987 summarized data from 634 bighorn sheep captured in various western United States and various seasons between 1980 and 1986.

1. Selenium – Vaseux adult females had somewhat higher levels of selenium (0.121 vs. 0.090 ppm) than Ashnola adult females (Harper 1984b), but much lower levels than the western U.S. average of 0.25 ppm (Kock et al. 1987). This indicates a marginally deficient level of serum selenium.
2. Copper – Similar levels of copper were found in adult females from Vaseux Lake and South Slope subpopulations (0.85 and 0.69 ppm, respectively) (Harper 1984b).
3. Zinc – Zinc was present at much higher levels in adult females from Vaseux Lake than from South Slope (1.42 vs. 0.52 ppm; Harper 1984b).
4. Iodine – Similar levels of iodine were found in adult females from Vaseux Lake and South Slope subpopulations (7 and 5 mcg%, respectively; Harper 1984b).
5. Calcium – With averages from 8.2 to 9.8 mg%, calcium levels were similar in Vaseux Lake lambs to captive-fed lambs (Bottrell et al. 1978), adult desert bighorns potentially infected with sinusitis (Bunch et al. 1978), captive OKGF bighorns (Peterson and Bottrell 1978), and adult females from South Slope (Harper 1984b).
6. Inorganic phosphorus - Vaseux bighorn sheep inorganic phosphorus levels were lower (4.5–5.0 vs. 7.4 mg%) than captive-fed lambs (Bottrell et al. 1978), similar to desert bighorns and Rocky Mountain bighorns (Bunch et al. 1978; Hebert 1972), and higher (4.5–5.0 vs. 3.6 and 3.3 mg%) than captive OKGF bighorns and South Slope adult females, respectively (Peterson and Bottrell 1978; Harper 1984b).
7. Magnesium – Magnesium levels in Vaseux adult females were similar to levels in South Slope adult females (2.35 vs. 1.95 mg%; Harper 1984b).
8. Glucose – Vaseux glucose levels were similar to captive-fed lambs (Bottrell et al. 1978), captive OKGF bighorns (Peterson and Bottrell 1978), and the western U.S. average of 130 mg% (Kock et al.

1987), but lower (138 vs. 226 mg%) than adult desert bighorn potentially infected with sinusitis (Bunch et al. 1978).

9. Blood Urea Nitrogen – Vaseux blood urea nitrogen levels were similar to captive-fed lambs (Bottrell et al. 1978), but higher (30 vs. 17, 25, 24 and 21 mg%, respectively) than the western U.S. average (Kock et al. 1987), captive OKGF bighorns (Peterson and Bottrell 1978), captive Rocky Mountain bighorns (Hebert 1978), and adult desert bighorns potentially infected with sinusitis (Bunch et al. 1978).

10. Uric Acid - Vaseux bighorn sheep uric acid was lower (0.2 vs. 0.5 and 0.7 mg%, respectively) than captive-fed lambs (Bottrell et al. 1978) and adult desert bighorns potentially infected with sinusitis (Bunch et al. 1978). These comparisons should be treated with caution, however, since the level of precision for the Vaseux samples was ±0.3 mg%. Uric acid levels at Vaseux were similar to captive OKGF bighorns tested in December 1977 (Peterson and Bottrell 1978).

11. Cholesterol – Vaseux cholesterol levels were similar to captive-fed lambs (Bottrell et al. 1978) and captive OKGF bighorns (Peterson and Bottrell 1978), but lower (47 vs. 61, 73, and 87 mg%, respectively) than adult desert bighorns potentially infected with sinusitis (Bunch et al. 1978), and nonmigratory and migratory Rocky Mountain bighorns (Hebert 1978).

12. Total Protein – Total protein levels were similar to captive-fed lambs (Bottrell et al. 1978), the western U.S. average (Kock et al. 1987), and adult desert bighorns potentially infected with sinusitis (Bunch et al. 1978). Levels of total blood protein for the Vaseux subpopulation in February (average, 6.9 g/dL) were similar to OKGF animals in September but higher than the 6.2 g/dL found in December at the OKGF (Peterson and Bottrell 1978).

13. Albumin – Vaseux albumin levels averaged 3.6 g/dL, which was similar to captive-fed lambs (Bottrell et al. 1978), adult desert bighorns potentially infected with sinusitis (Bunch et al. 1978), and captive OKGF bighorns in December 1977 (Peterson and Bottrell 1978). Peterson and Bottrell (1978) found a strong seasonal effect with albumin levels rising from 2.8 to 3.6 g/dL from September to December.

14. Bilirubin - Vaseux bighorn sheep bilirubin was lower (0.2 vs. 0.4 and 0.6 mg%, respectively) than captive OKGF bighorns in December 1977 (Peterson and Bottrell 1978) and adult desert bighorns potentially infected with sinusitis (Bunch et al. 1978). These comparisons should be treated with caution, however, since the level of precision for the Vaseux samples was ±0.15 mg%.

15. Alkaline Phosphatase –Vaseux bighorn sheep alkaline phosphatase levels were lower (119 vs. 318, 356, and 373 IU/L, respectively) than the western U.S. average (Kock et al. 1987), captive-fed lambs (Bottrell et al. 1978), and adult desert bighorns potentially infected with sinusitis (Bunch et al. 1978).

16. Lactate Dehydrogenase – At 767 IU/L, adult female levels from Vaseux Lake were similar to the western U.S. average of 619 IU/L (Kock et al. 1987), but were lower than adult females from South Slope (1128 IU/L, Harper 1984b).

17. Serum Glutamine Oxaloacetate Transaminase – At 82 IU/L, Vaseux bighorns were much lower than the western U.S. average of 176 IU/L (Kock et al. 1987), and adult desert bighorns potentially infected with sinusitis (285 IU/L, Bunch et al. 1978).

18. White Blood Cells – Vaseux bighorns had average white blood cell counts that were lower (8.6 vs. 10.5 thousand per ml) than adult desert bighorns potentially infected with sinusitis (Bunch et al. 1978), but higher than the average of 7.3 thousand per ml in 464 bighorns captured in the western U.S. (Kock et al. 1987).

19. Red Blood Cells – Vaseux bighorns had red blood cell counts that averaged 10 million per millilitre, which is slightly lower than the average of 12 million per millilitre in 466 bighorns captured in the western U.S. (Kock et al. 1987).

20. Hemoglobin – At 16 grams per 100 ml, Vaseux hemoglobin levels were similar to the western U.S. average (Kock et al. 1987) and captive-fed lambs (Bottrell et al. 1978).

21. Hematocrit – Hematocrit levels in Vaseux adult females were lower (42% vs. 47, and 48%, respectively) than the western U.S. average (Kock et al. 1987), and migratory Rocky Mountain bighorns (Hebert 1978). Hematocrits in Vaseux bighorns were, however, higher than the 39% found in Hebert's (1978) nonmigratory group.

22. Mean Red Blood Cell Volume – The average volume of red blood cells of Vaseux animals was 41 cubic microns.

23. Mean Cell Hematocrit – The average cell hematocrit levels of Vaseux animals was 40 grams per 100 ml.

Appendix 2. Blood chemistry and hematology of bighorn sheep from the Vaseux Lake subpopulation in the mid-1980s.

	Lambs[a] 1984			Adults[a] 1984 and 1986			Both Age Classes and Years		
Blood parameter	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*N*
Selenium (ppm)[b]	0.100	0.013	12	0.121	0.025	17	0.113	0.023	29
Copper (ppm)[b]	0.98	0.48	13	0.85	0.11	18	0.90	0.32	31
Zinc (ppm)[b]	1.29	0.42	13	1.42	0.19	18	1.36	0.31	31
Iodine (mcg%)[b]	8	2	12	7	2	18	7	2	30
Magnesium (mg%)[b]	2.43	0.35	13	2.35	0.33	18	2.38	0.33	31
Calcium (mg%)[b]	9.4	1.4	13	8.2	0.8	18	8.7	1.2	31
Calcium (mg%)[c]	9.8	0.2	5	9.2	0.6	16	9.4	0.6	21
Phosphorus (mg%)[b]	5.0	1.2	13	4.0	1.2	17	4.5	1.3	30
Phosphorus (mg%)[c]	5.6	1.1	5	4.8	1.3	16	5.0	1.3	21
Glucose (mg%)[c]	150	82	5	138	36	16	141	48	21
BUN (mg%)[c]	32	1	5	29	5	16	30	4	21
Uric Acid (mg%)[c]	0.2	0.00	5	0.2	0.05	16	0.2	0.04	21
Cholesterol (mg%)[c]	43	11	5	48	12	16	47	12	21
Total Protein (g/dL)[c]	6.5	0.7	5	7.0	0.4	16	6.9	0.5	21
Albumin (g/dL)[c]	3.4	0.1	5	3.6	0.4	16	3.6	0.3	21
Bilirubin (mg%)[c]	0.2	0.0	5	0.2	0.05	16	0.2	0.06	21
Alk. Phos. (IU/L)[c]	132	26	5	114	59	16	119	53	21
LDH (IU/L)[c]	1216	243	5	767	142	16	874	256	21
SGOT (IU/L)[c]	118	49	5	71	19	16	82	34	21
WBC ($x10^3$/ml)[d]	8.9	1.9	13	8.4	1.9	29	8.6	1.9	42
RBC ($x10^6$/ml)[d]	9.57	1.23	12	10.76	1.26	16	10.25	1.36	28
HGB (g/dL)[d]	15.2	1.7	13	16.4	1.5	29	16.0	1.6	42
HCT (%)[d]	36.8	4.5	12	42.1	4.5	26	40.5	5.1	38
MCV (μm^3)[d]	40	1	13	42	2	29	41	2	42
MCH (µµg)[d]	15.7	0.5	12	15.9	1.0	25	15.8	0.9	37
MCHC (g/dL)[d]	41.1	1.8	11	39.1	1.8	26	39.7	2.0	37

[a] Most samples came from 32 bighorn sheep live-captured in a baited corral-type trap near Vaseux Lake on February 17, 1984. This sample consisted of 8 male and 5 female lambs (0.8 years old), 18 adult females (mostly 3 to 5 years old), and 1 adult male (2.8 years old). Additional samples for hematology only (WBC, HGB, etc.) came from 11 adult females captured on January 4, 1986, at the same location.

[b] From frozen blood sera analyzed by the Veterinary Pathology Laboratory in Abbotsford, B.C.

[c] From frozen blood sera analyzed by B.C. Biomedical Laboratories in Burnaby, B.C.

[d] From fresh uncoagulated whole blood analyzed by the Regional Hospital Laboratory, Penticton, B.C.

Techniques and precision of data on blood chemistry and hematology of bighorn sheep from the Vaseux Lake subpopulation.

1. **Selenium** (Se) **-** atomic absorption spectroscopy, milligrams per kilogram or parts per million (ppm).
2. **Copper** (Cu) - atomic absorption spectroscopy, milligrams per kilogram or parts per million (ppm).
3. **Zinc** (Zn) - atomic absorption spectroscopy, milligrams per kilogram or parts per million (ppm).
4. **Iodine** (I) - micrograms per 100 ml or microgram percent (mcg%).
5. **Calcium**[2] **-** milligrams per 100 ml or milligram percent (mg%), Veterinary Pathology Laboratory.
6. **Calcium**[3] **-** cresolphthalein complexone method, ±0.3, milligrams per 100 ml or milligram percent (mg%), BC Biomedical Laboratory.
7. **Inorganic Phophorus**[2] **-** milligrams per 100 ml or milligram percent (mg%), Veterinary Pathology Laboratory.
8. **Inorganic Phosphorus**[3] (mg%) **-** Fisk and Subbarow method, ±0.4, milligrams per 100 ml or milligram percent (mg%), BC Biomedical Laboratory.
9. **Magnesium** - milligrams per 100 ml or milligram percent (mg%).
10. **Glucose** - hexokinase method, ±8, milligrams per 100 ml or milligram percent (mg%).
11. BUN or **Blood Urea Nitrogen -** diacetyl monoxime method, ±1.5, milligrams per 100 ml or milligram percent (mg%).
12. **Uric Acid -** phosphotungstic acid method, ±0.3, milligrams per 100 ml or milligram percent (mg%).
13. **Cholesterol -** Trinder enzymatic method, ±10, milligrams per 100 ml or milligram percent (mg%).
14. **Total Protein -** Biuret method, ± 0.3, grams per 100 ml or grams per decilitre (g/dL).
15. **Albumin** - BCG dye method, ± 0.2, grams per 100 ml or grams per decilitre (g/dL).
16. **Bilirubin -** Jendrasik and Groff method, ±0.15, milligrams per 100 ml or milligram percent (mg%).
17. Alk. Phos. or **Alkaline Phosphatase -** PNP method, ±22, international units per litre (IU/L).
18. LDH or **Lactate Dehydrogenase -** NAD L to P method, ±24, international units per litre (IU/L).
19. SGOT or **Serum Glutamine Oxaloacetate Transaminase** - malate dehydrogenase method, ±4, international units per litre (IU/L).
20. WBC or **White Blood Cells -** Coulter Counter Model S, thousands per millilitre (10^3/ml).
21. RBC or **Red Blood Cells -** Coulter Counter Model S & IV, millions per millilitre (10^6/ml).
22. HGB or **Hemoglobin -** Coulter Counter Model S & IV, grams per 100 ml or grams per decilitre (g/dL).
23. HCT or **Hematocrit -** Coulter Counter Model S & IV, percent (%).
24. MCV or **Mean Red Blood Cell Volume -** Coulter Counter Model S & IV, cubic microns or micrometres cubed (μm^3).

25. MCH or mean cell **Hemoglobin -** Coulter Counter Model S & IV, picograms or micro-micrograms (μμg).
26. MCHC or **Mean Cell Hematocrit -** Coulter Counter Model S & IV, grams per 100 ml or grams per decilitre (g/dL).