FACTORS LIMITING AN ISOLATED BIGHORN SHEEP (OVIS CANADENSIS CANADENSIS) POPULATION IN SOUTH-EASTERN BRITISH COLUMBIA, CANADA:

A CASE STUDY WITH RECOMMENDATIONS

Golden Rocky Mountain Bighorn Sheep Project-Wildsight Golden
PO Box 25, Golden, British Columbia, Canada

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ABSTRACT

Bighorn sheep conservation is complicated, especially due to the numerous potential limiting factors that they face. Small populations have been found to be limited by disease, predation, competition, poor nutrition, loss of genetic variation and climate, among other variables. In this case study, we attempt to identify limiting factors on the herd of about 15 Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*), resident in the Kicking Horse Canyon, near Golden, British Columbia, using noninvasive techniques. These included fecal analysis (for genetic variability, diet quality, parasite load and cortisol level), observations, vegetation sampling, habitat evaluation and citizen reporting to inform about herd health, genetic interchange, lambing success and recruitment, habitat quality and usage levels plus possible management options. Herd health results [individual heterozygosity (mean H_{IND} = 0.667), loci heterozygosity (mean from 28 loci H_{OBS}= 0.679), protein (mean %FN=2.43) , digestible energy (mean %NDF= 47.08), digestibility (mean DAPA= 0.41), parasite load (prevalence = 88%) and baseline cortisol (mean cortisol = 45.66 ng/g) show heterozygosity at over 65% of the loci tested, good protein levels in summer and low levels in spring with low digestible energy, exposure to a range of parasites and baseline cortisol levels similar to those documented in other studies. The widespread (15 of 17 samples) presence of the lungworm, *Muellerius sp*, could be of special concern as stress levels on this herd potentially increase with upcoming highway widening. Genetic interchange results show this herd to be most similar to the Radium herd versus the other 48 herds considered. Lamb recruitment (one year) increased from one in 2018 and 2019 to three in 2020. The TransCanada Highway #1 occupies almost 20 % of the study area and BC Ministry of Transportation WARS data indicates that highway mortality is not uncommon. Seasonal habitat was identified and rated for quality, indicating that the study area contains relatively poor-quality habitat and is currently shared with white-tailed deer, mule deer and mountain goats. Plant species used by the sheep were identified along with usage levels and indicate use of shrubs, forbs, and grasses. Citizen reporting added to location data and effectively engaged the public.

The data from this case study suggests that poor diet quality, highway-related mortality, and small amounts of suitable quality habitat play important roles in limiting this group of sheep. Numerous specific actions were recommended that could improve current habitat quality; relocating the herd should also be considered. Successful management practices could result from an understanding of population-specific limiting factors which can be determined using noninvasive techniques as highlighted in this study.

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INTRODUCTION

Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) are iconic animals which have long inhabited Western Canada. Several small populations exist in the Kootenays (Poole & Ayotte 2019; Teske 2015) including one resident in the Kicking Horse Canyon, east of Golden, British Columbia (BC). This study was initiated in an effort to address concerns about the sheep in the canyon and the proposed widening of the TransCanada Highway #1 (TCH1). Bighorn sheep numbers have declined since 2009 and the list of potential limiting factors is long. Miller et al. (2012) describe many of them in detail in their effort to explain recent die-offs as have other authors (Berwick 1968; Demarchi et al. 2000; France 2005; Schwantje 1990; Stelfox 1971). Population density can determine the impacts of some limiting factors (also known as regulating factors), whereas others are density independent (for example, severe weather conditions).

Potential limiting factors can be grouped into habitat-related:

- trace mineral and nutritional deficiencies
- poor forage quality and quantity
- intraspecific and interspecific competition for forage
- overcrowding
- predation
- severe weather conditions
- lack of suitable escape terrain
- limited sources of water
- limited winter range
- inbreeding

and human-induced:

- domestic sheep and goat interaction
- habitat loss, alteration, and degradation
- fire suppression
- harassment by humans and domestic dogs
- highway mortality
- range and migration limitations due to human activities and development
- hunting pressure
- native and exotic disease and pathogens

Several of these likely limit the growth of the Golden herd which has the unique pressures of the TCH1 and the railroad, both of which pass through the length of the study area. Phase 4 of the Ministry of Transportation and Infrastructure (M o T) project to twin the TCH1 is planned to commence in early winter, 2021. With this work comes the opportunity to improve the habitat quality of the area for bighorn sheep and to ensure that structures are built that allow sheep and other wildlife to continue to use the area without gaining access to the highway (Huijser et al. 2008) as they currently do.

It is also timely to address limiting factors which may be barriers to the viability of this small herd. Many methods exist to manage wildlife and efforts continue to develop and use techniques that do not have negative impacts in individual animals. Numerous noninvasive options exist to aid in assessment of limiting factors and several are used in this study which has the following seven objectives:

- Develop baseline herd health data using noninvasive fecal collection methods to obtain measures of degree of inbreeding, diet quality, parasite loads and stress hormone levels.

- Determine the extent of genetic interchange between Golden herd and other area herds for which genetic data already exists.

- Evaluate lambing success and survival.

- Identify seasonal ranges and critical habitats including lambing areas.

- Assess current range quality and use.

- Determine most effective habitat enhancement sites.

- Engage highway user groups and tourist to share wildlife sighting along TCH1 and Highway 95

STUDY AREA

The study area is on the western extreme of the Rocky Mountains in southeastern British Columbia (BC), Canada (51°N, 117°W; 800 - 1300 m elevation) and extends east from the town of Golden (population 4,000) along the TCH1 to the Yoho Bridge (7 kms), south of the highway to the Kicking Horse River and north of the highway for approximately 300m. Due to inaccessibility to bighorn sheep of the >80° slope on the west side of Frenchman's Ridge, about 200 m west of Dart Creek, the study area includes terrain to the north of the road up to 1100 m in this section (Figure 1) and is based on where sheep were observed from the highway extended to natural barriers like the river and dense forest.

The area between the river and the highway varies from very steep (over 50° slope) with "hoodoo" formations to open SSW facing slopes of 35-45° to patches of mixed forest. To the north of the highway, the area again varies but is primarily densely forested or very steep, with occasional open SSW facing slopes (45 °) near the highway. The TCH1 bisects the entire length of the study area. This highway was built in 1962 and parts were widened and changed during Phase 3 East and West (completed in 2013).

The study area (620 ha) is classified as Columbia Dry Cool Interior Douglas-fir (IDFdk5; MacKillop et al. 2018). This ecosystem, formerly labelled Kootenay Dry Mild Interior Douglas-fir Variant (IDFd), is often found along valley bottoms and lower slopes of the Rocky Mountain Trench south of the Blaeberry River (Braumandl & Curran 1992). Much of the study area is forested with mixed stands of douglas-fir, *Psuedotsuga menzeisia*, lodgepole pine, *Pinus contorta*, and interior spruce, *Picea engelmanni x glauca*. The conifer cover surrounds patches of trembling aspen, *Populus tremuloides,* which also grows south of TCH1 on slopes of 30°-50°. Paper birch, *Betula papyrifera,* black cottonwood, *Populus balsamifera*, and Scouler's willow, *Salix scouleriana*, are found on cliffs and side-hills within the study area. Understory shrub species include Saskatoon, *Amelenchier alnifolia*, snowberry, *Symphocarpus albus*, soopalallie, *Shepherdia canadensis*, and prickly rose, *Rosa acicularis.* North of the highway is characterized by steep slopes, some vegetated with grasses, others with shrubs and trees. Where the slopes end, the relatively open edges change into denser forests. Understory plant diversity is limited with large areas of pinegrass, *Calamagrostis rubescens*, dominanting. South of the road and north of the river, both moderate and very steep slopes exist. Patches of tree cover occur on some slopes while others have little plant life (hoodoos). Vegetation in this area is affected by the highway: plantings, accidentally introduced seeds from vehicles, pollution and road dust/waste all have impacts. Several SW facing slopes are essentially monocultures of alfalfa, *Medicago sativa*, mixed with various grasses (crested wheatgrass, *Agropyron cristatum*, intermediate wheatgrass, *Agropyron intermediatum*, and foxtail barley, *Hordeum jubatum*). Forbs include Lindley's aster, *Symphyotrichum ciliolatum*, lemonweed, *Lithospermum ruderale*, among many others. The highway corridor also contains numerous non-preferred plants including knapweed, *Centaurea diffusa*, oxeye daisy, *Leucanthemum vulgare*, and tarragon, *Artemisia dracunculus,* which is especially widespread. Appendix 1 lists some of the plants found in the area.

Evidence of bighorn sheep in the study area was found near Dart Creek in the 1940s and they were seen occasionally in the area until 1986 when a small group overwintered and the Golden Rod and Gun Club began a supplementation program which lasted until 2015; by 2006, the herd had grown to 50 and 19 and 13 were moved in 2007 and 2009, respectively, to supplement other herds (Teske et al. 2011). Since

2009, the herd has remained below 20 animals and there are currently 16-17 animals (12 in nursery group) based on spring surveys conducted over the last three years and recent observations.

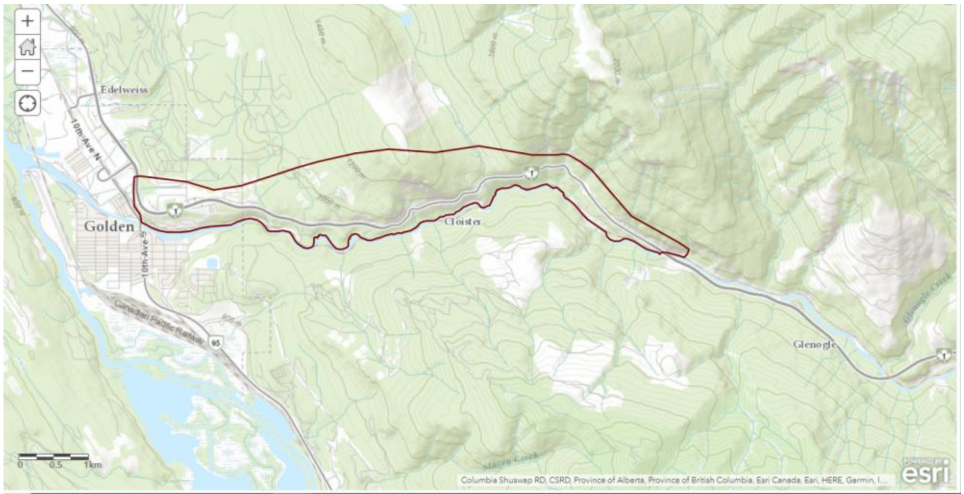

Figure 1. Study area (620 ha).

BASELINE HERD HEALTH

Objective:

Develop baseline herd health data using noninvasive fecal collection methods to obtain measures of degree of inbreeding, diet quality, parasite loads and stress hormones levels.

Introduction:

Health of herd members influences herd viability and reproductive success rates (Cahn et al. 2011) and can play a key role in survival. Assessing some aspects of the health of wild animals is possible using fecal analysis and managers can obtain important information about genetic diversity (Coltman et al. 1999; Luikart et al. 2008), diet quality (Muposhi et al. 2014; Wehausen 1995), parasite loads (Flanagan 2009) and stress hormones (Coburn et al. 2010; Miller et al. 1991; Millspaugh & Washburn 2004), all of which inform about general health.

Inbreeding, defined by a reduction of alleles and an increase in homozygous loci, can be associated with inbreeding depression (a reduction in fitness) and may significantly affect birth weight, survival, reproductive success and resistance to disease, predation and environmental stress (Keller & Waller 2002; Luikart & Allendorf 1996). In one study, inbreeding was correlated with adult soay sheep (*Ovis aries*) being susceptible to gastrointestinal parasites (Coltman et al. 1999). Low heterozygosity at loci believed to play a role in immunity against lung parasites has been linked to greater susceptibility to lungworm infection (Luikart et al. 2008). Fitzsimmons et al. (1995) found rams with more homozygous loci had smaller horns, with obvious repercussions. However, Rioux-Paquette et al. (2010) found no evidence of inbreeding avoidance in a small group of bighorn sheep despite evidence that inbreeding can lead to detrimental impacts on both individuals and populations (Rioux-Paquette et al. 2011). Inbreeding may be especially important in small, isolated or inbred populations and may impede their ability to grow (Luikart et al. 2008). Advances in genetic analysis have led to more research into the complexities of inbreeding including mapping many loci (Kardos et al. 2016). With this work comes an understanding of the bighorn sheep genome which will inform about which loci are neutral and which have specific impacts. MMP9 is a locus which has been shown to tell the body to make an enzyme which aids in lung tissue repair. Homozygosity at this locus may contribute to susceptibility to lung infection although cautious interpretation is needed as genes connected to MMP9 might also be responsible for the observed association with parasite levels (Luikart et al. 2008).

Good nutrition relates closely to diet quality, which is dependent on several factors including available forage, digestibility of the forage, digestive rate and digestive system (Baker & Hobbs 1987). Quality of forage typically changes seasonally making fecal analysis for diet quality particularly useful and it has been widely used in wildlife studies (Fecal analysis 2008; Muposhi et al. 2014; Wehausen 1995). The most useful indices of usable energy intake are diaminopimelic acid levels (DAPA), percent nitrogen (%FN) and percent neutral detergent fiber (%FNDF; Hodgman et al. 1996; McKinney et al. 2006; Parker et al. 2009). Field assessments of available forage and usage levels are also informative, but fecal analysis considers what the animals are actually ingesting and is therefore especially valuable. Due to the many variables that affect these nutritional indices, they are of greatest value within a population and require long-term monitoring to be most informative (Blanchard et al. 2003). Digestibility of proteins can be extrapolated from the number of rumen bacteria based on levels of diaminopimelic acid (DAPA) sampled in feces. Bighorn sheep host rumen bacteria which are found in higher numbers when intake of digestible energy is high (DAPA 2008; Kie & Burton 1984; McKinney et al. 2006) and levels of DAPA may inform about diet quality. A seasonal profile can be developed to track long-term changes (DAPA 2008). Protein is essential to animal growth (Mattson 1980) and levels can be evaluated from fecal nitrogen (%FN) which has been shown to correlate closely to winter diet quality (Irwin et al. 1993) and to reflect on nitrogen levels of forage (Gil-Jiménez et al. 2015; Ueno et al. 2007); higher levels of protein are generally found in forbs than in browse or grasses (McKinney et al. 2006). Because fecal nitrogen is largely produced by microbes, which also make volatile fatty acids from which ruminants derive most of their energy (Hodgman et al. 1996), higher fecal nitrogen levels should reflect greater microbial activity and fatty acid production.

Percent neutral detergent fiber (%FNDF) correlates well with available energy in deer (Hodgman et al. 1996) and possibly in bighorn sheep; high levels of fiber in forage generally lowers digestibility (Marković et al. 2012); however, like other ruminants, bighorn sheep are able to extract a high quantity of nutrients from foods leading to a situation where, given sufficient quantities of forage, they may be able to meet their nutrient requirements (Hopcraft et al. 2010; McKinney et al. 2006).

While diet quality is important, seasonal and annual variations are normal. Parasite loads may also fluctuate seasonally (Kyriánová et al. 2017) and some level of intestinal parasites is not uncommon although elevated levels can lead to disease and death (Miller et al. 2012). Two relevant factors in determining the impacts of gastrointestinal parasites are the total number of parasite species present in the herd and how many animals are infected with multiple species (Worley & Seesee 1992). Recent die-offs of bighorn sheep in North America have been tied to parasitic nematodes (lungworms) including *Protostrongylus* spp. and *Muellerius* spp. which may be associated with deadly pneumonia outbreaks and lowered recruitment (Almberg et al. 2018; Decesare & Pletscher 2006; Ezenwa et al. 2010; Festa-Bianchet 1989; Poole et al. 2016; Spraker et al. 1987). These parasites have been studied extensively in domestic sheep and goats and can be transmitted between species easily since larvae expelled in feces infect various hosts, including snails, which are then eaten by other animals (Foreyt et al. 2009; Georgiev et al. 2003). Numerous gastrointestinal parasites have also been found in bighorn sheep and large numbers are believed to cause various health issues (Foreyt 2000; Miller et al. 2012).

High stress levels can also negatively impact bighorn sheep, leading to lowered resistance to disease. Long-term or chronic exposure to stressful events is thought to cause an increase in cortisol and a lowering of immune functions (Miller et al. 1991) with lowered lambing success (Coburn et al. 2010). Baseline stress hormone levels can be established and comparisons made as human activity changes. Fecal measures show the same information as plasma samples and are simpler to collect (Sheriff et al. 2010).

Methods:

Sixty fecal samples which appeared to have been freshly excreted were collected from locations where sheep had been seen within the previous 24 hours or less. Samples were photographed and mapped before being placed into plastic bags, labelled and stored in a cooler in the field. Samples were then refrigerated or frozen depending on the testing to be done.

In June, 2019, ten fecal samples were sent to Dr. Coltman's lab at the University of Alberta (Edmonton, Alberta) in coordination with a Parks Canada project. Extracted DNA was typed at 13 microsatellite loci following procedures described in Deakin et al. (2020). In September, 2019, ten fecal samples were delivered to Wildlife Genetics International (WGI) in Nelson, British Columbia, a lab that specializes in genetic samples using DNA extraction and microsatellite analysis (Paetkau 2003; Woods et al. 1999). Loci were selected based on previous work done by Coltman et al. (1999), Graves & Flesch (2020) and Luikart et al. (2008). All loci selected were believed to be neutral except for MMP9 (Luikart et al. 2008). Since marker loci used varied between the 2 labs, a measure of individual heterozygosity was calculated (H_I = number of heterozygous loci/total number of loci typed for each individual animal). Observed heterozygosity (H_O) was calculated for each of the loci tested by dividing the number of heterozygous individuals by the total number of individuals sampled. In July, 2019, five fecal samples were delivered to the Wildlife Habitat and Nutrition Laboratory at the Washington State University (Pullman, Washington, USA). Fecal matter was analyzed on a dry matter basis (Crocker et al. 1998) for diaminopimelic acid (DAPA), percent nitrogen (%FN) and percent neutral detergent fiber (%FNDP). Seventeen (five in July, 2019 and 12 in March, 2020) fresh fecal samples were delivered to the Washington Animal Disease Diagnostic Laboratory (WADDL) at the Washington State University (Pullman, Washington, USA). Parasite loads were analyzed using the Baermann test and the fecal flotation test (Foreyt 2001). Fecal cortisol was measured by the Toronto Zoo laboratory from samples delivered in June, 2019 (n= 22) and March, 2020 (n=12) following the procedure described in Miller et al. (1991) and Dulude-de Broin et al. (2019).

Results and Discussion:

Nine unique individuals, representing approximately 2/3 of the herd, were identified from the samples submitted. All samples performed very well except for one sample delivered to WGI. The University of Alberta analysis identified six individuals from 10 samples. WGI's analysis of these 6 animals plus 4 other samples led to identification of 3 additional individuals. Table 1 shows results for the 9 individuals: the average proportion of the 28 loci which were heterozygous (H_I) was 0.641 ± 0.102. For the 28 loci, the average # of alleles was 2.88 ± 1.05 while the observed heterozygosity (H_O) was 0.66 ± 0.25 (Table 2). The individual heterozygosity (H_I) for the 9 unique individuals for which analysis was completed was similar to that documented in other studies (Hedrick & Wehausen 2014; Hogg et al. 2006; Wehausen & Ramey 2004). The H_O for this herd is higher than expected and higher than that found in Alberta by Deakin et al. (2020) for the same 13 loci. The analysis at the MMP9 locus showed especially high H_O which may indicate less susceptibility to lung infection than in animals with low heterozygosity at this locus (Luikart et al. 2008). In contrast, the fixed allele at the MAF36 locus may warrant further study.

Table 1. Sex and individual heterozygosity (H_I) for 9 members of a small herd of Rocky Mountain bighorn sheep based on mapping of 13-28[1] microsatellite loci.

Individual	**Sex**	**# loci sampled[1]**	**H_I = Proportion of heterozygous loci**
1	F	18	0.556
2	M	28	0.714
3	M	28	0.500
4	M	28	0.821
5	M	28	0.571
6	F[2]	13	0.692
7	F	18	0.556
8	M	28	0.750
9	F	18	0.611
			mean H_I = 0.641
			SD = 0.102
			range = 0.615 - 0.846

1 - # of loci sampled varies depending on the lab (s) that did the analysis. See methods for details.
2 - based on pregnane level not genetic analysis.

The low number of alleles observed (mean = 2.88; Table 2) relative to Deakin et al. (2020) may be a result of the localized sample, however the low number could also indicate reduced variability which may contribute to reduced fitness (Hogg et al. 2006; Poirier et al. 2018). It is possible that all ewes in the herd (n=6) are impregnated by a single ram, most likely the oldest ram in the herd. As a result, sibling relationships are unlikely, but father and daughter offspring are very likely; small populations are vulnerable to losing genetic diversity, fixation of alleles and lowered fitness (Erwin et al. 2018; Frankham 1996). Increasing diversity requires mixing populations and may be necessary for the Golden herd.

Table 2. Description of 28 microsatellite loci analyzed to quantify genetic diversity in 9 members of a herd of Rocky Mountain bighorn sheep (herd size < 17), including locus name with source, # of individuals sampled (N), # of alleles (A), and observed heterozygosity (H_O = # heterozygous individuals/# of individuals sampled)

Locus^{source}	**N**	**A**	**H_O**
BM203^{1}	8	2	0.50
BM848^{13}	8	4	0.88
BM1225^{1}	9^{18}	3	0.67
BM4028^{1}	8	2	0.50
BM4505^{1}	6	4	0.83
BM4513^{1}	8	2	0.63
BM6506^{1}	8	4	0.88
BMC1009^{1}	8	3	0.63
BMC1222^{1}	9^{18}	2	0.33
BMS745^{14}	8	3	0.875
BMS1788^{14}	8	2	0.25
CRH^{15}	8	4	0.50
INRA11^{16}	8	2	0.5
INRA107^{17}	8	3	0.63
MAF209^{3}	6	3	0.67
MAF36^{4}	6	1	0.00
MAF64^{5}	6	4	0.83
MAF65^{6}	6	4	1.00
MMP9^{11}	8	4	0.88
OarAE16^{7}	6	2	0.67
OarCP26^{8}	6	4	1.00
OarFCB193^{2}	8	3	0.75
OarFCB266^{2}	6	2	0.83
Rt1^{9}	8	3	0.63
Rt9^{9}	9^{18}	2	0.67
Rt27^{9}	8	2	0.88
TGLA122^{10}	6	2	0.17
TGLA387^{10}	6	4	1.00
Mean		**2.88**	**0.66**
SD		1.05	0.25
Range		1-4	0.0-1.0

1- Bishop et al. 1994; 2- Buchanan & Crawford 1993; 3- Buchanan & Crawford 1992; 4- Swarbrick et al. 1991a; 5- Swarbrick et al. 1991b; 6- Buchanan et al. 1991; 7- Penty et al. 1993; 8- Ede et al. 1995; 9- Wilson et al. 1997; 10- Georges & Massey 1992; 11 -Luikart et al. 2008; 12- Masabanba et al. 1996; 13- Gasca-Pineda et al. 2013; 14 - Cronin et al. 2005; 15 - Cronin et al. 2003; 16 - Vaiman et al. 1992; 17 - Vaiman et al. 1994; 18 - data from two labs was combined for these loci.

SD= standard deviation calculated from STDEVPA in Microsoft Excel 2013

Results for diet quality indicate seasonal variation with higher levels of DAPA and lower % FN in the spring (Table 3). The small sample size prohibits conclusions as does the need to establish baselines for this herd. However, further analysis of existing samples and further sampling would lead to insights into diet to which this data alludes.

Digestibility, based on presence of diaminopimelic acid (DAPA), is lower than found in other studies (Fecal analysis 2008; Hodgman et al. 1996) in both seasons (spring and summer) for which samples were obtained (mean DAPA = 0.41 mg/g). Normal DAPA levels vary within a range of 0.20mg/g to 1.0 mg/g (DAPA 2008; Hodgman et al. 1996) and the DAPA levels found in the Golden sample are on the low end of this range and may indicate a less than ideal diet quality.

Protein is seasonally accessible to sheep and it is not uncommon for large herbivores to be at low levels outside of the growing season (Mattson 1980; Parker et al. 2009). Levels of fecal nitrogen (%FN) below 1.3% may indicate low protein levels for bighorn sheep, especially in the winter months (Irwin et al. 1993) as a high level would be around 3.0 % (Fecal analysis 2008). Our small sample indicates low levels of nitrogen in spring (1.5 %) and higher levels in the summer (3.1%). The high intake of alfalfa (*Medicago sativa*), prevalent along the highway, may account for the higher protein levels observed in the summer samples. The low levels in spring may highlight the need for access to critical spring range after a long winter with little to eat. As a known allelopath (Plant Profile 2020), alfalfa, *Medicago sativa*, may inhibit growth of neighboring plants and thereby contribute to the current monocultures found along TCH1. Fecal samples from the fall and winter could be analyzed to determine if protein levels may be dangerously low in winter, especially given the low spring results.

Digestible energy intake based on % NDF (Hodgman et al. 1996) was higher in spring (55%) than in summer (40%), which may correspond with the increasing maturity and associated lignification of forage species (Marković et al. 2012). The sample is too small to make conclusions but this data does indicate that winter and spring protein levels, along with digestibility, could be issues that negatively impact this herd.

Nutritional levels of plants vary both within species and between seasons and years and nitrogen fluctuations may be large enough to affect sheep numbers (Peek 2016). Various trace minerals are also crucial to sheep health which were not evaluated in the study. Selenium deficiency has been well-documented in bighorn sheep with established levels (Hebert & McTaggart-Cowan 1971; Lemke & Schwantje 2006) and it would be of value to determine both the mineral levels in the sheep and the sources that exist within the study area.

Table 3. Seasonal means for spring and summer plus overall mean, standard deviation (SD), and range for Diaminopimelic Acid (DAPA), % Nitrogen (%FN) and % Neutral Detergent Fiber (%FNDF) sampled on a dry matter basis from Rocky Mountain bighorn sheep feces.

	DAPA (mg/g)	**%FN**	**%FNDF**
Mean summer 2019, n=3	0.38	3.07	39.99
Mean spring 2019, n=2	0.46	1.51	55.39
Mean overall, n=5	0.41	2.43	47.08
SD, n=5	0.06	0.78	7.98
Range, n=5	0.299 - 0.479	1.485 - 3.304	39.329 - 59.573

SD - standard deviation calculated from STDEVPA in Microsoft Excel 2013

Parasite load results from the Baermann test found dorsal spine larvae (DSL) in 15 of the 17 samples (88.24%). Two samples believed to be from lambs reported no parasites. Table 4 shows a mean value of 14.99 ± 25.90 and a range = 1-81. The Golden herd may be susceptible to lung disease based on the prevalence of larvae. Although the DSL were not able to be identified to species, the likelihood is high that they are *Muelleris capilaris* (Laura A. Williams, personal communication, June 4, 2020). This very common parasite of domestic sheep and goats (Foreyt et al. 2009) is believed to also cause lung disease in bighorn sheep (DeMartini & Davies 1977; Ezenwa et al. 2010; Pybus & Shave 1984; Snyder et al. 2015). High numbers may be needed to cause disease and values from Baermann tests do not correlate well with infestation severity (Laura A. Williams, personal communication, June 4, 2020). However, even in the absence of lung disease, lungworms could compromise other aspects of sheep health (Ezenwa et al. 2010; Luikart et al. 2008) and warrant further study.

Dorsal spine larvae seek out a host, often a snail. This host is later ingested by sheep or goats which then become infected. The widespread prevalence of DSL in our sample indicates that the larval hosts are in the area and accessible to both the bighorn sheep and, most likely, the mountain goats with whom they share the area. While further testing using single-strand conformation polymorphism (SSCP) profile comparisons (Huby-Chilton et al. 2006) could identify the exact species of dorsal spine larvae involved, determining the host species will take further study but is necessary to break the infection cycle. Additionally, it may be worthwhile to test for the presence of the bacterium, *Mycoplasma ovipneumoniae*, which has been found in many cases of bighorn sheep pneumonia (Cassirer et al. 2017) and may allow managers to detect a potential outbreak.

Fecal flotation tests found parasites in 11 of the 17 samples (65%). The following genera were isolated: *Stongyles, Eimeria, Nematodirus, Capillaria, Wyominia, Moniezia* and *Trichuris ovis* with a prevalence of 5% - 35% each (Table 5). Although one individual had three different isolates, all other samples contained 2 or fewer. Though parasites have the ability to degrade body condition, change behavior and lower immune response (Foreyt 2001; Miller et al. 2012), levels of concern have not been established (Hoar et al. 1996; Jenkins & Schwantje 2004). Our results indicate that numerous types of gastrointestinal parasites infect the Golden bighorn sheep herd, though likely not at levels of concern. Additional sampling and analysis would allow for a better understanding of the role of parasites in this population.

Table 4. Mean, standard deviation (SD), range and prevalence (percent of positive samples) for dorsal spine larvae (possibly *Muellerius capillaris*) detected in fecal samples from Rocky Mountain bighorn sheep from Baermann tests.

	Dorsal Spine Larvae[1]
Mean, n=17	14.88
SD	25.90
Range	1-81
Prevalence	**88.24%**

1- larvae per gram
SD - standard deviation calculated from STDEVPA in Microsoft Excel 2013

Table 5. Mean, standard deviation (SD), range and prevalence (percent of positive samples) for seven gastroinstestinal parasites (*Strongyles, Eimeria, Trichuris ovis, Moniezia, Capillaria, Nematodirus)* detected in fecal samples from Rocky Mountain bighorn sheep from fecal flotation analysis.

	Stongyles[1]	**Eimeria[2]**	**Trichuris ovis[1]**	**Moniezia[1]**	**Wyominia[1]**	**Capillaria[1]**	**Nematodirus[1]**
Mean, n=17	0.29	1.06	0.06	0.06	0.06	0.06	0.41
SD	0.46	1.63	0.24	0.24	0.24	0.24	1.19
Range	0-1	0-5	0-1	0-1	0-1	0-1	0-5
Prevalence	0.29	0.35	0.06	0.06	0.06	0.06	0.18

1- eggs per gram; 2 - oocysts per gram; SD - standard deviation calculated from STDEVPA in Microsoft Excel 2013

Stress hormone results from the 34 fecal samples analyzed for cortisol showed a range of values from 15.23 ng/g to 119.08 ng/g (Table 6). From the sample of 32, stress hormone baseline levels for spring can be established and compared to data from future samples collected after highway construction begins. The higher levels documented in 2 additional samples collected during summer and fall could lead to further analysis of samples from these seasons. Results from other studies show levels between 20-50 ng/g (France 2005; Goldstein et al. 2005) making some of our values, which are much higher, of further interest. Coburn et al. (2010) suggest that numerous components of the stress response should be measured to best identify normal adaptive stress versus a health-threatening stress response to an event. Millspaugh and Washburn (2004) also point to the difficulties in interpreting fecal glucocorticoid metabolite or cortisol results although others have found that fecal cortisol accurately reflects stress in bighorn sheep (Miller et al. 1991).

Table 6. Mean, standard deviation (SD) and range of cortisol (ng/g of feces) detected in fecal samples from Rocky Mountain bighorn sheep collected in spring, summer and fall 2019 &2020.

Season and year, sample size (n)	**Mean Cortisol (ng/g)**	**SD**	**Range**
Spring 2019 & 2020, n= 32	36.76	18.52	15.23 - 119.08
Summer 2019, n=1	141.95	NA	NA
Fall 2019, n=1	245.79	NA	NA
All, n=34	45.66	42.99	15.23 - 245.79

SD - standard deviation calculated from STDEVPA in Microsoft Excel 2013

GENETIC INTERCHANGE

Objective:

Determine the extent of genetic interchange between Golden herd and other area herds for which genetic data already exists.

Introduction:

Little is known about movement of Rocky Mountain Bighorn Sheep between populations in mountainous areas and the genetic relationship of the Golden population to nearby populations is not known. Male sheep are particularly prone to foray (O'Brien et al. 2014) which may serve to introduce genetic diversity into the herd; however, the relative isolation of the Golden herd could restrict population exchange. Major river valleys and mountain ranges have been documented as barriers to gene flow and decreasing diversity of alleles was found as latitudes increase going north (Deakin et al. 2020).

No documentation exists to determine where the bighorn sheep resident in the Kicking Horse Canyon came from although some believe they came over the continental divide from Alberta, largely based on several sightings of rams to the north of Golden. Extensive DNA analysis has been done on bighorn sheep from AB and BC. Comparing the genetic makeup of members of the Golden herd to that of members of other herds will inform about interchange with BC sheep versus AB sheep (Whittaker et al. 2004).

Methods:

Fecal samples were analyzed and typed at 13 loci following procedures outlined in Deakin et al. (2020). This genetic information was compared to similar data from herds in AB and BC to establish relatedness through a principal component analysis (PCA) completed by Sam Deakin at the University of Alberta. To calculate a metric of genetic distances between the herds, FST and Nei's genetic distances were calculated. The lower the distance value the more similar are the two herds (Deakin et al. 2020).

Results and Discussion:

The degree of relatedness was greatest between the two British Columbia herds (Radium and Golden) based on DNA analysis of samples from 49 locations in BC and AB (Figure 2). It is not surprising that the Golden herd is more closely related to the Radium herd than to herds located in Alberta given that the continental divide separates the Golden sheep from Alberta. Although seemingly isolated, members of the Golden and Radium herds have most likely been in contact historically leading to the similarities in the PCA analysis results which support the conclusion that male sheep travel away from the home area and cross major rivers and highways.

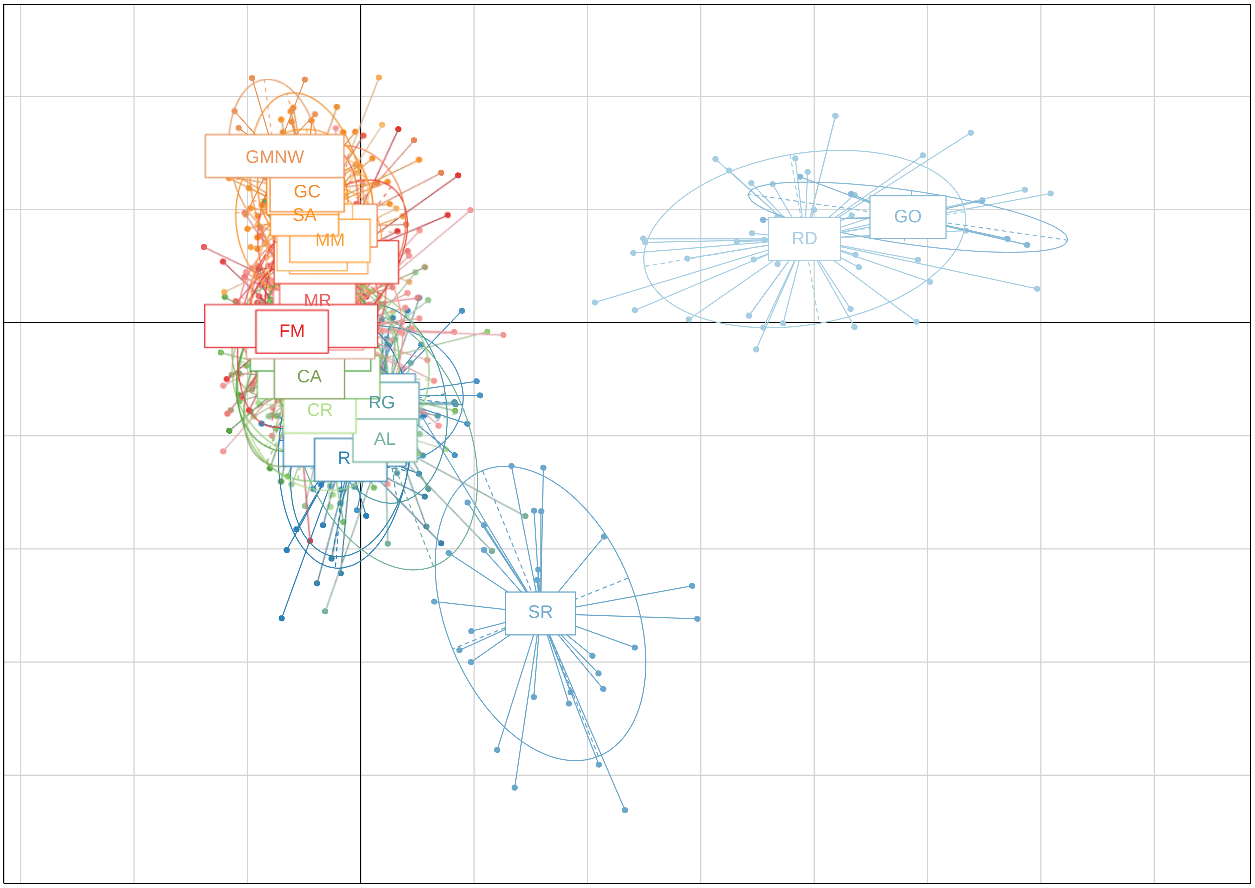

Figure 2. Results of principal component analysis (PCA) showing greater proximity to between British Columbia bighorn sheep (GO-Golden and RD-Radium) than between British Columbia and Alberta bighorn sheep (left side of image).

LAMBING SUCCESS AND SURVIVAL

Objective:

Evaluate lambing success and survival.

Introduction:

Minimum viable population (MVP) size is open to debate, especially for Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) which have a history of small populations. Most of the current BC populations of bighorn sheep are below the historically accepted MVP of 125 animals (Berger 1990; DeMarchi 2004). Several populations have survived and even increased from well below the 125 value (Wehausen 1999), and several small herds persist in British Columbia (Poole & Ayotte 2019; Teske 2015).

A population of any animal will be limited if it does not successfully recruit new members. Estimates of 30 lambs recruited (surviving to one year) per 100 ewes (30:100) have been suggested for bighorn sheep (Buechner 1960; Jorgenson 1992). Relatively high survival rates have been documented in bighorn sheep adults (Overstreet et al. 2014) and even minimal recruitment could build a herd up in number.

Single lambs are born in the spring and high mortality has been documented within the first months. Though lambs can walk on their first day of life, Cain et al. (2018) found the highest mortality in desert bighorn sheep lambs was during the first week of life and was most likely due to predation. Smith et al. (2014) found that mortality before 3 weeks was most likely from predation whereas mortality between 4 – 8 weeks was most likely due to disease. Poor nutrition and mothering, severe weather, highway mortality and falls can also contribute to reduced recruitment (Demarchi et al. 2000; Enk et al. 2001; Geist 1971; Monteith et al. 2009) though disease seems to be the most common cause (Singer et al. 2000b; Smith et al. 2014).

It is not uncommon for over 85% of females in a herd to be impregnated (Singer et al. 2000; Festa-Bianchet 1988). Pregnancy rates within a population are indicative of health and can be used to compare to known births to target the causes of low recruitment. Fecal steroid analysis is believed to hold great potential for looking at both reproductive success and disease in bighorn sheep (Borjesson et al. 1996; Schoenecker et al. 2004a) and is being used more frequently to inform wildlife managers.

Methods:

Between 2016 and 2020, the number of ewes and yearlings within the study area was documented on sighting trips through the study area (round trip = 14 kms). Additionally, in 2019 and 2020, bighorn sheep were observed daily during lambing season and much of the year to determine lambing areas, dates, success and recruitment. Animal activity was filmed and analyzed to determine lactation status of ewes, lamb numbers and survival.

In addition, thirty-three fecal samples were delivered to the Toronto Zoo for analysis of pregnane levels following methods described in Flasco et al. (2017) and Morden et al. (2011).

Results and Discussion:

Over 220 sighting trips were made between February, 2016 and July, 2020 to document bighorn sheep herd composition, location and activity. Table 7 summarizes observations between 2016 and 2020. Each year between 2016 and 2019, 1-2 lambs survived to one year of age. In 2019, 4 lambs were born from 6 ewes and 3 survived to one year. In 2020, 5 lambs were born to 6 ewes and have been observed as of July 1, 2020 (Figure 3). At least one was a highway-related mortality (Helen Shwantje, personal communication, July 22, 2020). Although the size of the herd makes lamb:ewe ratios less meaningful, our data indicates values of 33-83 lambs born per 100 ewes between 2018 and 2020 and 17 to 50 lambs surviving to one year per 100 ewes. Recruitment of the 2020 lambs will be monitored in hopes of continued improved recruitment.

Thirty –three samples were analyzed in June, 2019 and April, 2020 for pregnane levels (ng/g). Five samples came from known males and 2 from known females based on DNA analysis. The sex of the remaining samples was determined, if possible, based on observations and video from just prior to defecation. Only samples from animals whose sex could be accurately determined were used in the analysis and two very small sized samples were classed as coming from yearlings. Two samples collected after parturition were discarded leaving 27 samples in total. Table 8 shows a range of values from 130.56 to 2212.60 with a mean and standard deviation of 811.17 ± 629.88.

Morden et al. (2011) determined that levels over 2000 ng/g of progesterone metabolites indicate pregnancy in reindeer (*Rangifer tarandus*) and levels for pregnant bighorn sheep greater than 1800 ng/g have been reported (Borjesson et al. 1996). In this study, the large discrepancy between average male and average female mean values (351 ng/g vs. 1133 ng/g) may indicate that levels over 1100 ng/g are found in pregnant ewes in our sample although one sample from a presumed yearling tested at over 1900 ng/g. While female bighorn sheep can be bred as early as 10 months, 16-26 months is more common (Morgart & Krausman 1983). Since our samples were from unidentified ewes, the number of pregnant ewes could not be determined with certainty though 5 and 4 samples tested over 1100 ng/g in 2019 and 2020, respectively. While highly informative data collection is possible with this tiny population, it would be time consuming and may not be warranted based on studies indicating pregnancy rates and the ability to observe lactating ewes. That said, early fetal losses could be an issue which only this type of testing could detect and pregnane testing is easily done in conjunction with cortisol testing on samples collected in spring.

Figure 3. Three of five lambs born in 2020

Table 7. Raw numbers of bighorn sheep ewes, yearlings, lambs and rams sighted in the Kicking Horse Canyon, east of Golden, BC, during 222 sighting trips though the study area between February, 2016 and July, 2020 plus lamb:ewe ratios calculated for the peak of lambing and the following spring.

	2016	2017	2018	2019	2020
Number of sighting trips driven	23	15	15	79	90
Number of mature ewes	5	5	6	6	6
Number of lambs	no data	no data	2	4	5
Number of lambs recruited from previous year	2	2	no data	1	3
Lamb:ewe ratios[1]	NA:40	NA	33:17	67:50	83:NA
Rams older than 2 years seen during the year	5	4	4	4	4
Total number of bighorn sheep seen	14	15	12	13	17

1 - Number of lambs per 100 ewes at peak of lambing:subsequent spring.

Table 8. Mean, standard deviation (SD), and range of pregnane (ng) per gram of dry feces from Rocky Mountain bighorn sheep, grouped by sex.

	Females[1], **n=10**	**Males**[1], **n=15**	**Yearlings**[2], **n=2**	**Overall, n=27**
Mean Pregnane (ng/g)	1132.79	351.36	1220.66	839.55
SD	515.98	194.43	67.34	650.02
Range	747.44 - 2212.60	130.56 - 731.04	1153.32 - 1288.00	130.56- 2212.60

1- as determined either by DNA (2 females and 5 males) or observation at time of defecation.
2 - based on small size of fecal pellets.
SD - standard deviation calculated from STDEVPA in Microsoft Excel 2013

SEASONAL AND CRITICAL HABITATS

Objective:

Identify seasonal ranges and critical habitats including lambing areas.

Introduction:

Each species has requirements and habitat preferences which may vary seasonally. Suitable Rocky Mountain bighorn sheep seasonal habitats have been characterized, partly to aid in success of transplantation efforts, about half of which have historically failed (Singer et al. 2000a). Bighorn sheep use habitats characterized by access to escape terrain, defined as areas with slopes over 27° wherein sheep can avoid predators, bed down, feed and give birth. On the contrary, areas of dense vegetation restrict visibility and have been shown to be avoided by bighorn sheep (Brundige & McCabe 1986; Smith & Flinders 1991) which prefer cliffs in proximity to water. Bighorn sheep may select for areas where they feel safe over areas of high-quality forage (Smith et al. 1991) and are able to vary their diet from grasses to forbs to browse (Wagner & Peek 2006). Some populations rely on grasses over shrubs and tend to graze on grasslands, never far from escape into the mountains (Smith & Flinders 1991; Wagner & Peek 2006); others eat more browse and forbs (Rominger et al. 1988; Tilton 1977) such that the availability of a range of choices is important in all seasons.

Habitat requirements vary over the year and seasonal habitats need to be understood to ensure that wild bighorn sheep are able to access the terrain and vegetation that they require (Smith et al. 1991). Winter is arguably the "toughest" season; however, good preparation in summer and fall can ensure winter survival for animals for whom limited food resources exist (Cook et al. 2004). Some populations use distinct summer and winter ranges (Poole et al. 2016) whereas others remain in one area all year (Wagner & Peek 2006).

Winter habitat selection has been examined by numerous authors. Poole et al. (2016) found that winter habitats tended to be at higher elevations, close to escape terrain, relatively warm and vegetated with native grasses. Forested areas are not preferred (Baker et al. 2016; Dibb 2010) and forests that reach cliff edges may lead to more competition with mule deer, more risk of predation as sightlines decrease and less access to winter forage, reducing habitat quality. Snow pack can become an issue for bighorn sheep and they will occupy open, wind-swept, south facing slopes when possible (Poole & Ayotte 2019). As winter snows recede most quickly on S and SW facing slopes, these areas become important habitat for bighorn sheep during and after the winter months. Steep areas with good visibility in open ponderosa pine forests were preferred in South Dakota and bighorn sheep there were never found further than 1 km from water or 80 m from escape terrain (Brundige & McCabe 1986). Dibb (2006 & 2010) found that summer habitats selected by Radium sheep were relatively open and complex areas at high elevations and use of a variety of aspects has been documented (Smith et al. 1991). Lambing habitat was found to be a defining feature of successful sheep transplants (Zeigenfuss et al. 2000) and bighorn sheep exhibit high site fidelity to these areas (Festa-Bianchet 1986, Geist 1971; Poole 2013; Poole et al. 2016; Shackleton et al. 1999) such that minimizing disturbance, especially from mid- May to mid-July, becomes very important. Bighorn sheep have shown a preference for lambing on relatively flat spaces within rugged terrain, areas close to perennial streams, and south facing aspects, near forage, with slopes between 27 - 85°; lambing habitat includes areas used for lambing and during six- weeks post-partum (Smith et al. 1991; Smith et al. 2015; Zeigenfuss et al. 2000).

Though females typically use the same areas throughout their lives (Boyce et al. 1999; DeCesare & Pletscher 2006), males may "foray" to other areas, returning to their home range for the winter months (Hogg 2000; Poole et al. 2016). Festa-Bianchet (1986) found that older males were more likely to wander than younger ones and that site fidelity to seasonal ranges was generally high which emphasizes the importance of home range quality and, especially, high quality winter range. Sexual segregation is well documented in bighorn sheep and may be the result of differences in foraging behavior as animals share the landscape (Ruckstuhl 1998).

Urbanization and human developments impact habitat selection and have the potential to attract wildlife to high quality forage, water and possible protection from predation while also exposing them to disease transmission, stressful interactions and highway mortality (France 2005; Rubin et al. 2002). Bighorn sheep near Radium, BC preferred winter habitat close to human habitation over steeper habitat leading to a variety of management concerns (Dibb 2010), and Demarchi (2004) noted that, "roads and railways occupy habitat, dissect migration routes, and result in direct mortality. Salt used for road maintenance can attract and hold sheep in highway corridors. In some cases, significant numbers of adults have been lost in single seasons."

Critical habitats contain essential minerals needed for good health. Selenium and copper are two of several important trace minerals (Hnilicka et al. 2002; Schoenacker et al. 2004b; Schwantje 1990) and higher levels of selenium may be found in alpine plants (Hebert 1973) but be less available during wetter years depending on the soil type (Hnilicka et al. 2002). Sheep are known to regularly visit salt licks (Graves et al. 2016) and their locations in the Kicking Horse Canyon are not well-documented.

Methods:

Animal locations were recorded on targeted sighting trips through the study area, with stops at pullouts to look for wildlife. Videos and photographs were taken without leaving the vehicle and notes about individuals present, group size and composition, activity and behaviors, weather and various other details were recorded after leaving the area and watching the videos. Values were recorded for 25 variables (Appendix 2), including initial and final latitude and longitude using maps.me and GAIA GPS applications on an iPhone. Animals were photographed and filmed when possible and footage was reviewed to verify locations, herd composition and habitat use. Location information was also recorded based on observations shared by individuals travelling through the study area. Additional night-time location information was obtained using a Flir Scout III 640 thermal imaging monocular in an effort to try this noninvasive technology (Blackwell et al. 2006; Cilulko et al. 2013; Christiansen et al. 2014). Location and group size data was imported into ArcGIS for display and analysis. Lambing areas and activity were determined through daily observations from the highway between May 15 and June 30, 2019 and 2020, without disturbing the sheep.

A study area polygon was created that included places where bighorn sheep were sighted plus a buffer zone. Lambing ranges were identified based on sightings shortly after birth. The area is restricted by the Kicking Horse River to the south, which is very likely a barrier to nursery group movement (Deakin et al. 2020; Smith et al. 1991).

Results and Discussion:

Two-hundred and twenty-two sighting trips were completed between February, 2016 and July, 2020 (Table 7). Based on location data recorded on these trips, several high-use areas were identified as were seasonal ranges. Bighorn sheep were observed on the majority of trips (between 1-14 individuals). Locations were also recorded for white-tailed deer and mule deer which were often observed near the highway in the western portion of the study area. Twenty additional location reports were obtained from members of the public who were driving through the study area between June 2019 and June 2020. A thermal imaging monocular was used on 10 occasions from the rim of the Kicking Horse Canyon, south of the river. On 2 of the 10 occasions, 8 heat signatures were observed in an area where sheep were thought to be located. This confirmed video evidence that the Golden sheep sometimes bed down for the night in the steep hoodoo formation between the highway and the river and that infrared technology may be useful as a noninvasive technique for locating wildlife, especially at night.

As expected, a majority of sightings in the study area were of the resident nursery group though rams were also frequently observed. Seasonal Ranges for winter (October-March), summer (April-September) and lambing (mid-May – July) were identified based on suitable habitat (Zeinenfuss et al. 2000) overlain with seasonal animal sightings (Figures 4-6). Sheep were seen within the study area during all seasons of the year though their use of the western portion was greater during the winter months. Ranges delineated from these sightings include S and SW facing slopes with slopes between 30-50°, often in close proximity to water. Late winter and early summer habitat plus lambing habitat was identified (Figures 7-9).

Figure 4. Forty-eight bighorn sheep locations recorded during 2 winter seasons (October-March, 2018 to 2020)

Figure 5. Fifty bighorn sheep locations recorded during 2 summer seasons (April-September, 2019 and 2020), excluding ewes and lambs from mid-May through July.

Figure 6. Bighorn sheep locations recorded during 2 lambing seasons (mid-May through July, 2019-2020).

Figure 7. Extent of almost 3 ha of SW facing slopes, immediately east and west of wildlife overpass. This area is heavily used in late winter and early spring and is fenced along lower edge of shaded area.

Figure 8. Small (<0.5 ha) SW facing slope (outlined in blue) regularly used by bighorn sheep in late winter and early spring.

Figure 9. Heavily used area in eastern extreme of study area below lambing habitat in steep cliffs.

The Golden bighorn sheep use the TCH1 corridor to navigate their home range, especially during the winter. Much of their winter usage is concentrated in the western portion of the study area, where SW facing slopes are more accessible. Travel through the area is often done using the highway which is likely easier than using the adjacent steep slopes. Spring and summer habitats are also spread through the study area. Open SSW facing slopes, which are the first place to find spring food, are located in the western portion, near Golden. Lambing areas include habitat used by sheep from before giving birth through to 6 weeks post-partum. The Golden herd used the same lambing area in 2019 and 2020: the cliffs immediately W of the five-mile bridge offer ideal lambing habitat with their access to forage (especially alfalfa, *Medicago sativa*, and birch, *Betula* spp.) and water (a spring lies behind this cliff as evidenced by lush vegetation, running water and winter ice formations). Work done for M o T in 2009 identified sheep lambing sites (Appendix 3), some of which overlap the more recently used lambing area. In both 2019 and 2020, lambs were seen shortly after birth and remained in the same area for at least 6-8 weeks following parturition. This relatively small area meets all of the requirements for bighorn sheep lambing habitat despite being close to the highway and separated from the rest of the home range by the highway, railroad and associated structures.

The resident nature of nursery groups leads to the conclusion that the study area is their home throughout the year. Rams, on the other hand, leave this area and evidence that the Golden herd is more closely related to the Radium herd than to sheep in Alberta indicates that some individuals cross the Kicking Horse and/or Columbia Rivers, either in the water or on bridges. Several railroad bridges cross the canyon and two yearling sheep were recently seen very near the bridge crossing the Kicking Horse River on Highway 93 through Golden BC, indicating that they may cross this bridge, and others, to gain access to other parts of the province and other habitats. That said, the likelihood that rams also winter within the study area is high.

Habitat used by wildlife is often impacted by human development and activity. TCH1 predates this herd of bighorn sheep and is currently an integral part of their environment. The area of the highway with a 5 m buffer on each side is approximately 18% of the study area. Efforts to keep the sheep off of the road have not succeeded and WARS data (2020) and citizen reporting (Mike Nickle, personal communication, June 15, 2019) confirm sheep mortality on TCH1 with 10 documented deaths between 2000 and 2020, which likely represent many more actual fatalities (Sielecki, 2010). One or more bighorn sheep were seen on the highway side of the fencing or in the highway corridor during 60% of sightings made between September 2018 and June 2020 in this study, indicating that sheep are often on the highway. Track and observation evidence confirm that sheep go around the eastern ends of the current fencing and video documentation of sheep using one-way gates in two directions further explains how bighorn sheep are accessing TCH1. Currently, wildlife fencing is in place in the Phase 3 West portion of the highway, where a wildlife overpass also exists. The approximately 3 kms of fencing on the south side of the highway has 5 one-way gates and three one-way jump-outs, designed to allow animals to leave the highway corridor. The north side has 5 one-way gates and is broken into 2 sections, creating 4 fence ending locations. Though wildlife fencing and overpasses can be effective (Clevenger et al. 2001, Dodd et al. 2007), bighorn sheep are extremely agile and easily breach fence ends. In addition, bighorn sheep use their horns to alter one-way gates to allow them to pass through in either direction, based on filmed observations as part of this study. While this fencing was designed to keep animals off of the highway (Harper and & Morley 2012), it will require some alterations to do so effectively.

Additional concerns arise when fencing location is considered. Current fencing exists at the base of several SW facing slopes, identified as high use areas, such that these areas are only accessible from TCH1 (See Figures 7 and 8). This essentially forces the sheep to use the highway, especially in the section of highway with the wildlife overpass (3.19 km, segment 1820), and they have often been observed travelling under this structure. The sheep also travel over the wildlife overpass and changes in the current fencing could encourage them to use it more.

Given that the bighorn sheep and other wildlife are currently able to gain access to the highway, highway mortality is a serious concern. Impacts of highway mortality are well-documented and have been found to be speed related (Hardy et al. 2006; Neumann et al. 2012). Though the speed limit in some sections of the canyon is currently posted at 40 kms/hr, speeds of over 80 kms per hour are not uncommon. Lower speeds have been shown to reduce highway mortality (Bond & Jones 2013) and Hardy et al. (2006) found that variable signs with relevant messages were effective in reducing speeds, especially after dark. Jägerbrand et al. (2018) simulated impacts of various methods to reduce driving speed and found the best results from radio messages. Remote cameras with associated signage were also successful at slowing drivers for short stretches and may be useful in the Kicking Horse Canyon.

Driving speeds will likely increase after Phase 4, making it essential that wildlife can navigate the area without going onto the highway.

Several portions of the study area include train tracks which are regularly used. Bighorn sheep mortality from trains has been documented and can be significant (Goldstein & Rominge 2006). The prevalence of train-related mortality within the Golden herd is not currently known.

The Golden bighorn sheep appear to be attracted to highway deposits which may provide some of their mineral needs, otherwise met from mineral licks (Graves et al. 2016). Minerals are a critical habitat component and further work is needed to determine if this herd’s mineral needs are being met.

HABITAT QUALITY AND USE

Objective:

Assess current range quality and use.

Introduction:

The Golden herd of bighorn sheep have managed to survive in the Kicking Horse Canyon for many years. At first look, the canyon shows little promise for supporting a population of bighorn sheep. Nevertheless, the sheep have survived for over 30 years and over 5 years without supplemental feeding. Members of the Golden Rod and Gun Club recognized their low chances of survival without supplementation due to the limited quantity and quality of habitat, especially winter range and supplemented their winter diet for almost 30 years (Teske et al. 2011).

Habitat requirements for bighorn sheep have been well-defined (Smith et al. 1991; Zeigenfuss et al. 2000). From this work we know that bighorn sheep prefer to be within 300 m of escape terrain (slopes greater than 27° that have occasional outcroppings) and within 1 km of water. In addition, winter range should include southern aspects (SW-SE) of 27 -85° slope with less than 25 cm of snowpack, and summer range should include slopes less than 27° within 300 m of escape terrain while lambing habitat should be 2 ha or larger, have a southern, western or eastern aspect, be close to water and forage and have a slope of 27 -85°. Habitat models usually exclude areas within 150 m of manmade structures from suitable habitat as sheep are known to avoid these areas (Demarchi 2004; Huwer 2015; Zeigenfuss et al. 2000). Vehicle collisions were found to be the main source of mortality for ewes (46% of mortalities) in Colorado (Huwer 2015) and Keller and Bender (2007) found that sheep avoided habitat in proximity to vehicles.

Habitat quality is also impacted by both competition and predation. Not only does sharing an area reduce available forage, other ungulates may attract predators leading to increased predation (Johnson et al. 2013).

Evaluating habitat quality based on known preferences and risk factors can aid in assessing the suitability of an area for any species of concern and will allow for well-founded decisions regarding habitat enhancement and highway development.

Methods:

Using established criteria (Zeigenfuss et al. 2000) and the plant preferences of the Golden herd (based on numerous observations of sheep eating and of browsed plants), a habitat evaluation tool was developed to objectively qualify the habitat in the Kicking Horse Canyon. A rating scale was developed to evaluate the quality of the study area for bighorn sheep using readily available map layers and knowledge of the local area (Table 9).

To aid in analysis, the study area was broken into 6 blocks (A-E), each approximately 100 ha (Figure 10). Each block was further broken into smaller chunks (between 3 and 8 ha each) for analysis (n=126). Each chunk was assigned a quality rating for each variable (Table 9) with higher numbers indicating better quality. The following nine variables were rated: distance to escape terrain, distance to water

(Figure 11), tree cover, slope class, aspect (Figure 12), diversity of non-preferred plants (based on evidence of browsing observed in the field), diversity of preferred plants (Appendix 1 lists plants found in the study area and observed use), level of preferred plant use (Figure 13) and human disturbance. A value for suitable habitat for each season was also calculated for comparison (Table 10).

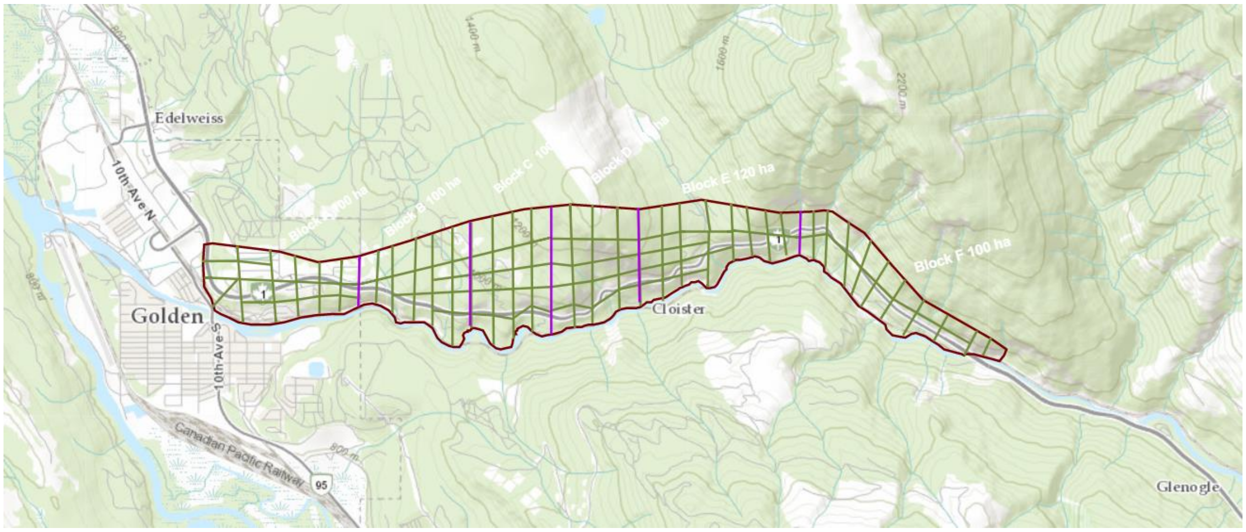

Figure 10. Map showing 620 chunks (each approximately 5 hectares) analyzed for 9 variables in Table 10 to determine habitat quality for bighorn sheep.

Table 9. Nine indicators of habitat quality and use assessed within the study area including distance to escape terrain[1], distance to water[2], tree cover[3], slope class[4], aspect[5], diversity of non-preferred and preferred plants[6] and level of preferred plant use[6] and human disturbance[7] with details used to assign quality ratings (see Table 10).

Distance to escape terrain[1] quality	**Distance to water[2] quality**	**Tree cover[3] quality**	**Slope class[4] quality**	**Aspect[5] quality**
Within 5 m = 10	Within 5 m = 10	0-10% = 10	Between 27-80° = 10	S=10
Within 50 m = 9	Within 50 m = 9	10-25% = 7	Below 27° = 5	SW= 9
Within 100 m = 8	Within 100 m = 8	25-50% = 5	Over 80° = 0	SE = 9
Within 300 m = 7	Within 300 m = 7	50-75% = 3		W = 5/7
Within 500 m = 6	Within 500 m = 6	75-100% = 1		E = 5/7
Within 800 m = 5	Within 800 m = 5			NW=3
Within 1 km =4	Within 1 km = 4			NE = 3
Within 2 kms = 3	Within 1.5 kms = 3			N=1
Within 5 kms = 2	Within 2 kms = 2			
Within 10 kms = 1	> 3.2 kms = 1			

Diversity of predominant non-preferred plants[6]	**Diversity of predominant preferred plants[6]**	**Level of preferred plant use[6]**	**Human disturbance[7]**
Aster spp.	Alfalfa	Very high = 10: damaging plant High = 8: heavy use Medium = 5: obviously used Low = 2: some evidence of use None = 1: no evidence of use	yes or no assigned to each of 126 chunks within the study area.
Crested Wheatgrass	Birch spp.		
Dandelion	Burdock		
Knapweed	Cottonwood		
Pinegrass	Wheatgrass		
Pussytoes	Red-osier dogwood		
Sow thistle	Saskatoon		
Spirea	Snowberry		
Spreading dogbane	Soopolallie		
Tarragon	Trembling Aspen		

1- escape terrain defined as slopes between 27-80° with rock outcroppings (Smith et al. 1991); 2- only yearlong water sources were used; 3- from Tree Cover 2019; 4- from Slope 2020 5- from Aspect 2020; 6- based on ground surveys 7- percent of chunks within each block that had human activity: roads, railroads and/or buildings.

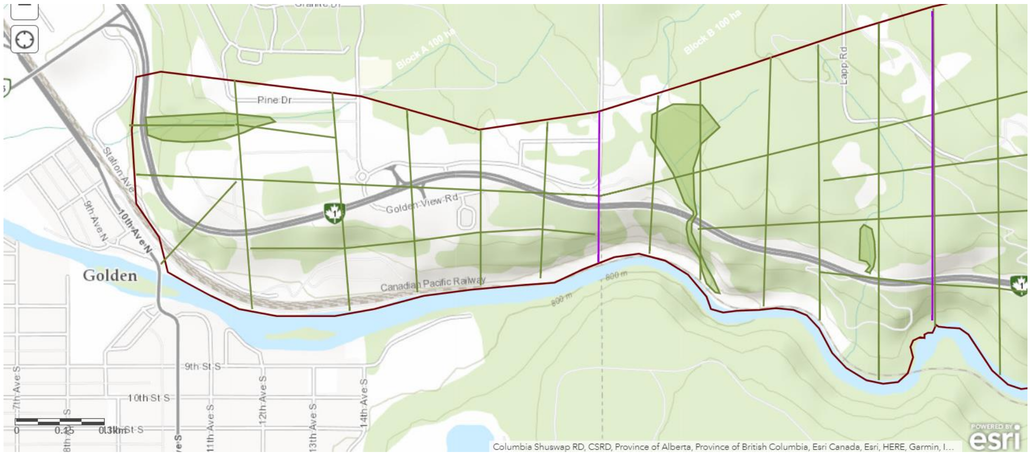

Figure 11. Map showing chunks overlaid with wet area used to calculate distance to water for each chunk. The greatest distance for any point within the chunk was used. A similar process was used to calculate distance to nearest escape terrain.

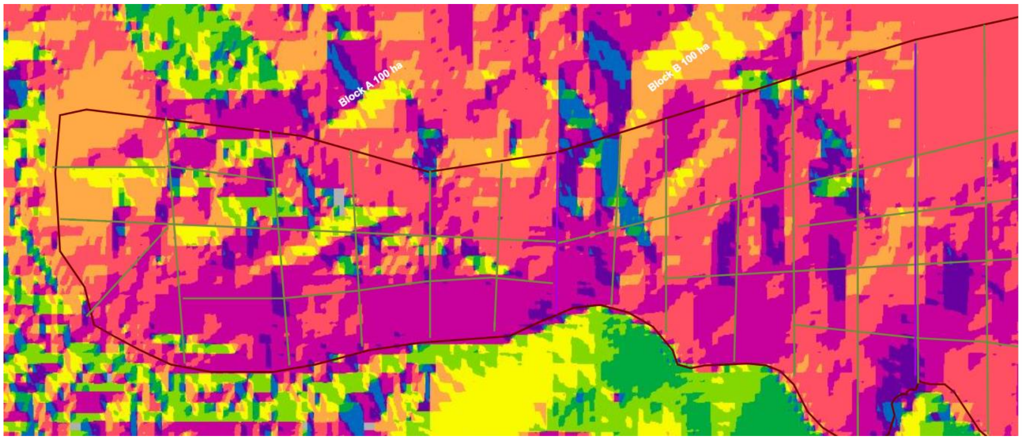

Figure 12. Map overlaying Block A and B with aspect layer in ArcGis Online. Each chunk was assigned a single numerical value to indicate the quality of the predominant aspects for bighorn sheep. The same procedure was followed for slope class and tree cover.

Figure 13. Map showing 126 chunks overlaid with satellite image, used in conjunction with knowledge of the area to estimate diversity of non-preferred plants, diversity of preferred plants and level of use of plants (see Tables 9 and 10).

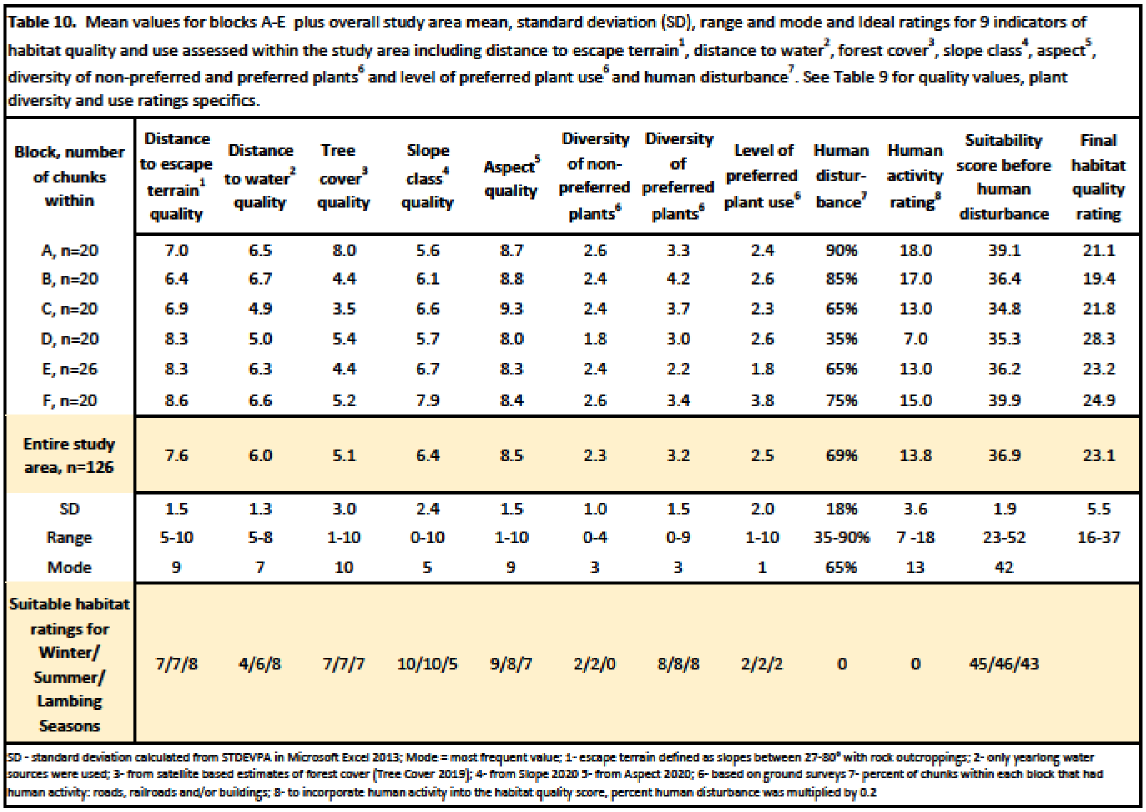

Table 10. Mean values for blocks A-E plus overall study area mean, standard deviation (SD), range and mode and Ideal ratings for 9 indicators of habitat quality and use assessed within the study area including distance to escape terrain[1], distance to water[2], forest cover[3], slope class[4], aspect[5], diversity of non-preferred and preferred plants[6] and level of preferred plant use[6] and human disturbance[7]. See Table 9 for quality values, plant diversity and use ratings specifics.

Block, number of chunks within	Distance to escape terrain[1] quality	Distance to water[2] quality	Tree cover[3] quality	Slope class[4] quality	Aspect[5] quality	Diversity of non-preferred plants[6]	Diversity of preferred plants[6]	Level of preferred plant use[6]	Human distur-bance[7]	Human activity rating[8]	Suitability score before human disturbance	Final habitat quality rating
A, n=20	7.0	6.5	8.0	5.6	8.7	2.6	3.3	2.4	90%	18.0	39.1	21.1
B, n=20	6.4	6.7	4.4	6.1	8.8	2.4	4.2	2.6	85%	17.0	36.4	19.4
C, n=20	6.9	4.9	3.5	6.6	9.3	2.4	3.7	2.3	65%	13.0	34.8	21.8
D, n=20	8.3	5.0	5.4	5.7	8.0	1.8	3.0	2.6	35%	7.0	35.3	28.3
E, n=26	8.3	6.3	4.4	6.7	8.3	2.4	2.2	1.8	65%	13.0	36.2	23.2
F, n=20	8.6	6.6	5.2	7.9	8.4	2.6	3.4	3.8	75%	15.0	39.9	24.9
Entire study area, n=126	7.6	6.0	5.1	6.4	8.5	2.3	3.2	2.5	69%	13.8	36.9	23.1
SD	1.5	1.3	3.0	2.4	1.5	1.0	1.5	2.0	18%	3.6	1.9	5.5
Range	5-10	5-8	1-10	0-10	1-10	0-4	0-9	1-10	35-90%	7 -18	23-52	16-37
Mode	9	7	10	5	9	3	3	1	65%	13	42	
Suitable habitat ratings for Winter/ Summer/ Lambing Seasons	7/7/8	4/6/8	7/7/7	10/10/5	9/8/7	2/2/0	8/8/8	2/2/2	0	0	45/46/43	

SD - standard deviation calculated from STDEVPA in Microsoft Excel 2013; Mode = most frequent value; 1- escape terrain defined as slopes between 27-80° with rock outcroppings; 2- only yearlong water sources were used; 3- from satellite based estimates of forest cover (Tree Cover 2019); 4- from Slope 2020 5- from Aspect 2020; 6- based on ground surveys 7- percent of chunks within each block that had human activity: roads, railroads and/or buildings; 8- to incorporate human activity into the habitat quality score, percent human disturbance was multiplied by 0.2

Results and Discussion:

The mean habitat quality rating for the study area was 23.1 with a range of 16-37, compared to an ideal rating of 45. Table 10 shows suitability scores before and after human disturbance is considered; they range from 16-52. While most values are below the suitable habitat value of 45, they indicate that the area, though much smaller than ideal (areas of 8500 ha are recommended in the Rocky Mountains by Zeigenfuss et al. 2000 and this study area is 620 ha) has potential as bighorn habitat, before the addition of the highway and railroad.

As Table 10 illustrates, the habitat evaluation tool indicates that the study area is suitable in the mean distance to escape terrain, mean distance to water and available aspects. Distance to water was calculated to sources that run all year; in numerous cases this was the Kicking Horse River along the north side of which the railroad line runs for most of the study area. The impacts of the railroad were not considered in this study but may be significant in both mortality and habitat fragmentation. If access to the river is cut off, Dart Creek becomes the principal year-round water source though several ephemeral water sources exists and may be used along with roadside accumulations (see Figure 14).

While offering some desired features, the area falls short in having too much tree cover (especially in Blocks B, C and E), too few areas between 27-80° for winter range, not enough diversity of preferred plants (mean of 3.2) and too much human disturbance. The lowest human disturbance of 35% was found for Block D whereas 90% of the chunks in Block A had human disturbance.

Figure 14. Lamb “drinking” from road side mud.

The low diversity of preferred species is another area of concern. Sheep in this study have been observed eating a variety of grasses, forbs and shrubs along with dumped grain and highway “salts.” Some vegetation has been heavily browsed whereas other areas are rarely used, possibly due to accessibility. The highway corridor has been seeded historically and this vegetation can attract sheep and other animals (Rea 2003). Non-preferred plants are also common close to the highway and have replaced other vegetation. Given the relatively low diversity and numbers of preferred food plants, the sheep may be compromised nutritionally.

The diversity of non-preferred plants was not used in the habitat analysis; however, the values in Table 10 indicate that the highway corridor contains numerous non-preferred plants and invasive weeds. Areas away from the highway have far fewer of these species. However, many of these areas are forested with over 50% cover and likely not desirable for sheep. Plant succession can dramatically affect habitat quality as can harvesting procedures. While forest succession does not seem to be a major player in the Kicking Horse Canyon, harvesting has taken place along Dart Creek, east of Frenchman’s Ridge. While these forestry activities have opened the canopy layer, they are not close enough to escape terrain to make useful bighorn sheep habitat.

Excluding various areas based on quality criteria leads to removal of almost half of the study area. Figure 14 and 15 map the remaining parts of the study area that are most suitable to bighorn sheep; these areas often border the highway. Highway accidents in the Kicking Horse Canyon appear to be a significant source of mortality for both the Golden herd and the Radium herd (Dibb 2010). While human activity may lead to reduced habitat quality and/or quantity, it may also cause sheep to abandon usage areas (Bunch et al. 1999; DeForge 1972; DeForge 1981; Hamilton et al. 1982).

That has not yet been the case with the Golden herd, members of which spend a lot of their time near, or on, the highway. Grain spills are not uncommon in the canyon and attract sheep which feed on these protein-rich grains. Planting of preferred plants like alfalfa, *Medicago sativa*, and wheatgrass, *Agropyron* spp., make roadside areas even more desirable than they already are due to their SW facing aspects. Patches of preferred shrubs like scrub birch, *Betula nana*, chokecherry, *Prunus virginiana*, and prickly rose, *Rosa acicularis*, close to the highway also attract sheep as do “road salts”.

The impacts of the TCH1 and the railroad are complicated and potentially considerable. The Golden sheep have had little choice but to use the highway and have managed to survive with both the TCH1 and a busy railroad line occupying significant portions of their home range. Nevertheless, the principal item that degrades the habitat quality in the Kicking Horse Canyon is the TCH1 and its many offshoots. While effective strategies to reduce collision rates on highways exist (Huijser et al. 2008) and could help keep the Golden herd off of the highway, direct mortality is only one impact of the TCH1. Aside from highway mortality, increased stress, decreased air quality, increased numbers of non-preferred plants and invasive weeds versus preferred native species, and habitat degradation from littering, dumping and accidental spills of both toxic fluids and organic matter all stem from TCH1.

Habitat quality is also impacted by competition with other species and predation. White-tailed deer, *Odocoileus virginianus,* and mule deer, *Odocoileus hemionis*, as well as mountain goats, *Oreamnos americanus,* use the study area throughout the year and competition may impact the habitat quality for bighorn sheep. Mountain lions, *Felis concolor*, wolves, *Canis lupus*, and black bears, *Ursus americanus*, have been documented in the study area and are known to predate on bighorn sheep; predation risk likely led to the importance of escape terrain for this species.

Figure 14. Usable bighorn sheep habitat (128 ha) within portion of study area north of TCH1.

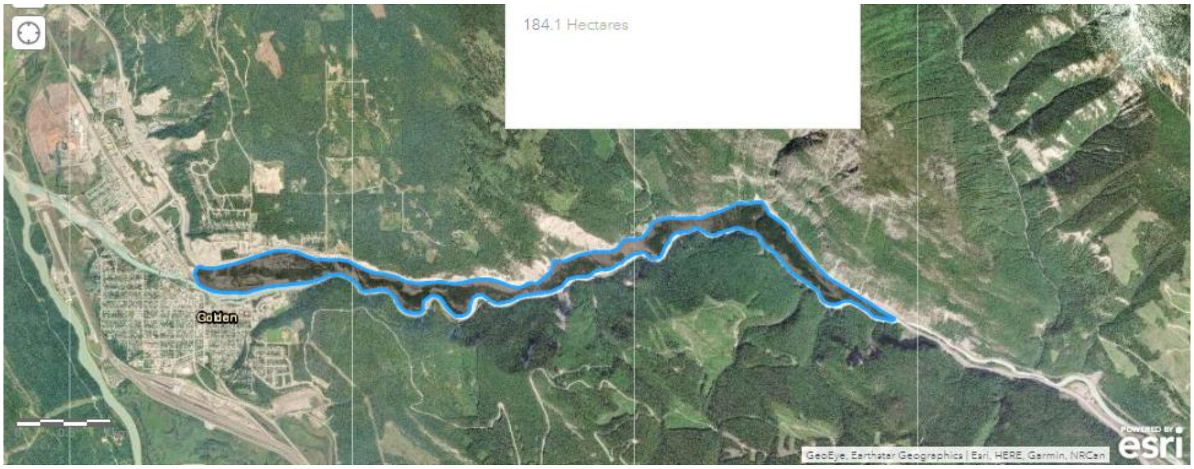

Figure 15. Usable bighorn sheep habitat (184 ha) within portion of study area south of TCH1.

HABITAT ENHANCEMENT

Objective:

Determine most effective habitat enhancement sites.

Introduction:

Successful efforts at habitat enhancement and restoration have demonstrated that it is possible for humans to make improvements to habitat for bighorn sheep (Dibb & Quinn 2006). Financial concerns may make these improvements seem impractical but the alternatives are neither humane nor desirable. Possible areas for habitat restoration have been identified (Klafki & Pezderic 2005) and several Ministry of Transportation studies have identified suitable habitat in the canyon; results of this study indicate that the area may be too small and too disturbed to support a viable population of bighorn sheep even after habitat enhancement. While small populations of sheep have been known to persist (Wehausen 1999), the likelihood of this tiny herd surviving in poor quality habitat with very high human disturbance seems low unless significant interventions are taken.

Success has been achieved with restored areas adjacent to existing home ranges and modelling tools can be used to predict the most suitable locations for enhanced sheep habitat (Dibb 2010). Enhanced habitat could keep sheep away from the highway corridor and thereby reduce chances of highway mortality while improving access to food, minerals and water.

Methods:

Habitat restoration options were assessed and areas away from the highway were considered for habitat enhancement. Maps of suitable habitat, created for the Ministry of Transportation, suggested suitable areas for consideration along with other GIS layers and knowledge of the area. Discussions with private landholders led to recommendations regarding possible areas to enhance and restoration was proposed as part of Phase 4 construction.

Results and Conclusions:

Over many years M o T has commissioned numerous studies to document potential wildlife use of the Kicking Horse Canyon. Various maps of suitable habitat have been developed including those in Appendix 3. Several Ministry of Transportation studies have recognized the limitations of the canyon for sheep habitat (Demarchi & Searing 1997) while others have relied on erroneous BEC classifications. In 2009, clear delineation of lambing habitat was made that is still relevant.

The Dart Creek drainage, recently logged, was considered and excluded as the escape terrain on the east side of the drainage is primarily west facing which is not ideal for sheep habitat. Although clear cuts create relatively open terrain, in close proximity to water, the lack of adequate escape terrain makes this area unsuitable. That said, the sheep use the open spaces near the highway at Dart Creek and a bridge over this drainage could facilitate unhindered use of this desirable area.

Private landholdings north of the highway were considered and also excluded. While the large property considered is open and has good quality forage, there is no escape terrain or lambing habitat nearby and the area is surrounded by forest. While the landowner is interested in accommodating bighorn sheep, which used the area before sheep were moved in 2007 and 2009, the likelihood that sheep would go to this area is low.

Areas south of the highway, mostly in the Ministry of Transportation Phase 3 West region, were considered and deserve further attention. Removing the accumulated garbage, planting preferred species away from the highway, and removing non-preferred species could all benefit the Golden herd. In conjunction with habitat improvement, fencing and gates should be altered to impede the current access to the highway corridor and encourage use of the wildlife overpass and bridges to be built in Phase 4.

Enticing bighorn sheep to new areas has not been explored; before investing time and money into creating new habitat, methods to ensure the sheep go to the enhanced habitat need to be established. Bighorn sheep may be unlikely to find restored habitats on their own unless these new areas are adjacent to present habitat (Dibb & Quinn 2008; Dibb 2010). That does not fit the situation in this Canyon if bighorn sheep are to be kept away from the highway making habitat restoration relatively impractical within the study area. Some evidence exists that salt licks may serve to entice animals to new areas (Hnilicka et al. 2002) which may be worth further exploration, although minimal suitable habitat exists in the immediate region.

Relocating the Golden herd may be an option for managers to consider. Successful relocation is not guaranteed but may open doors to continued survival and be more realistic than altering the study area to the degree required. About half of relocations are successful (Singer et al. 2000a), whereas the chances of long-term survival for the Golden herd are questionable. If the animals were to be moved, they should be moved to an area at a similar elevation but far from their traditional home range to resists the push of site fidelity to have them return to their previous but inadequate range.

CITIZEN REPORTING

Objective:

Engage highway user groups and tourist to share wildlife sighting along TCH1 and Highway 95.

Introduction:

Engaging vehicle passengers to record sightings of both alive and dead animals could provide data useful for understanding highway mortality and informing future highway modifications and wildlife population tracking. The Roadwatch Program has been successful in engaging the public in documenting wildlife in the Elk Valley, BC (Roadwatch 2018) and interest exists in a national system of wildlife mortality monitoring (Dean 2019). A similar concept has potential in the Golden area as various groups commute regularly including Parks Canada employees, truck drivers and tourists; a simple and free system exists for sharing locations using a smartphone application called “GAIA GPS” with minimal volunteer time required. Data of this type will be informative for future highway design, especially between Golden and Donald and for upcoming traffic diversion through Radium during Phase 4. In addition, data collection has potential to engage the public in learning about wildlife and to encourage attentiveness, which can lead to a greater desire to protect the natural world.

Methods:

Community members who regularly commute east or west on the TCH1, as well as tourists and other interested community members, were asked via email to observe and document wildlife (alive and dead) sightings near the highway. Instructions were provided for location and details sharing. Information cards were created and distributed at hotels and tourist centers, informing about wildlife and explaining the location sharing process. An informative website was created and educational sessions about Rocky Mountain bighorn sheep were offered at the local high school. Location data was uploaded to ArcGIS and shared with the M o T.

Results and Discussion:

Over one-hundred emails asking for volunteers to share sightings were sent in June 2019. Four-hundred location sharing rack cards were designed, printed and distributed to local hotels, Tourism Golden and the Yoho National Park Visitor Centre, in Radium, BC in June and July, 2019. All cards were gone when we returned to check in October, 2019. Invitation emails were also sent out monthly to invite Wildsight Golden members to volunteer. An educational session was conducted at Golden Secondary School in September, 2019. Fourteen community members responded with 2 or more sightings each. Two regular commuters shared sightings. A total of 17 sightings were received between June 1, 2019 and June 1, 2020, fourteen of live animals and three of dead animals.

Limited success was achieved in engaging the public to share wildlife sightings and highway mortality and sightings were not shared by enough highway users to be of value. However, community engagement was increased through the volunteer opportunity to share locations and through the community presentations. Some respondents did not use smart phones and others found the process too complicated. The people who shared sightings mentioned being pleased to have somewhere to share what they saw and some continue to share sightings. While the “maps.me” app is very useful, a recent change to “GAIA GPS” simplifies the process and may lead to more sharing. Location information from targeted interviews with drivers who have travelled the route hundreds of times provided some "hot spots" of activity that will also be shared with the M o T.

CONCLUSIONS

The Golden Rocky Mountain Bighorn Sheep Project set out to use noninvasive methods to learn more about the low number of animals in the herd, resident east of Golden in limited habitat. Several limiting factors of particular importance were identified as follows: poor diet quality, small amounts of suitable quality habitat and highway-related mortality, including stress-related concerns.

Phase 4 of highway development will commence in the near future and activity in the canyon has already increased substantially with drilling operations and surveyors gathering needed information. The Golden bighorn sheep are therefore increasingly faced with a choice between proximity to humans and vehicles and getting needed resources.

There is a lot that can be done to improve the situation faced by these sheep although substantial resources and effort will be required. Hopefully government and government contractors will see fit to do so as outlined in the recommendations from this study.

RECOMMENDATIONS

High Priority Recommendations:

1. Improve winter and spring range quality by cultivating highly digestible and high-protein shrubs, forbs and grasses and removing garbage and invasive weeds.
2. Document sources of required minerals within the study area and ensure access to mineral licks without interaction with highway
3. Ensure lambing area immediately west of Yoho bridge experiences limited to no disturbance from May 10 to July 30, annually
4. Alter fencing to encourage use of wildlife overpass, critical spring ranges and areas away from the TCH1
5. Alter one-way gates and jump-outs to impede two-way use.
6. Create level to slightly sloping travel routes for sheep and other wildlife to use to move east to west through the canyon
7. Install speeding cameras and lighted signage in the canyon near areas of high use by wildlife
8. Place movable signage used during traffic diversion periods based on wildlife locations data
9. Determine species of dorsal spine larvae present using molecular techniques

Additional Recommendations:

Herd Health:

1. Explore avenues for increasing genetic diversity by increasing the number of alleles available:
    - Consider relocation options
    - Further document likely impacts of low allele number

2. Track and identify parasites:
    - Determine and census dorsal spine larvae host species

3. Monitor stress levels:
    - Continue sampling for cortisol in spring 2021, 2022 and 2023.

Genetic Interchange:

1. Facilitate genetic interchange:
    - Support Yukon to Yellowstone (Y to Y) initiative
    - Add “wildlife lanes” to bridges over major east-west flowing rivers

Lambing Success and Survival:

1. Track lambing success and recruitment:
    - Continue to monitor recruitment and herd structure

Seasonal and Critical Habitats:

1. Reduce driving speeds:
    - Create and use radio messages to slow driving speeds.
    - Increase police enforcement of speeding in the canyon

2. Protect lambing habitat during Phase 4 of TransCanada Hwy. #1 widening project:
    - Properly identify lambing area currently being used
    - Reduce activity around lambing area between May 1 and July 31
    - Use previous work from M o T (Appendix 3) and current information for lambing area guidelines

3. Determine impacts of railroad:
    - Monitor highway and train-related mortality
    - Ask CP rail to report incidences

4. Continue to explore non-invasive techniques:
    - Purchase and employ high quality infra –red technology for further testing as non-invasive technology

Habitat Quality and Use:

1. Improve the habitat quality in the Kicking Horse Canyon
    - Plant preferred plant species
    - Remove invasive plants from study area

2. Further document herd health and habitat quality:
    - Check Selenium levels
    - Analyze diet with isotopes (see Whitaker 2010)
    - Use NDVI information to monitor habitat quality (see Hamel et al. 2009)

3. Otherwise, consider moving Golden sheep to good quality habitat given probability of eventual die-off on current range.
    - Identify good quality range to which sheep could be moved.
    - Trap and relocate entire nursery group, currently 11 animals

Habitat Enhancement:

1. Enhance habitat within the study area:
    - Plant preferred species away from highway
    - Remove non-preferred species
    - Determine numbers and distribution of white-tailed deer that currently use study area and nearby landfill
    - Consider thinning in one or more areas where current tree density may discourage use by bighorn sheep

2. Investigate enticing herd to areas away from the highway and consider relocation options.

Citizen Reporting:

1. Reduce highway mortality:
    - Continue to recruit members of the public to share wildlife sighting locations via GAIA GPS
    - Contribute to national dialogue about wildlife mortality monitoring

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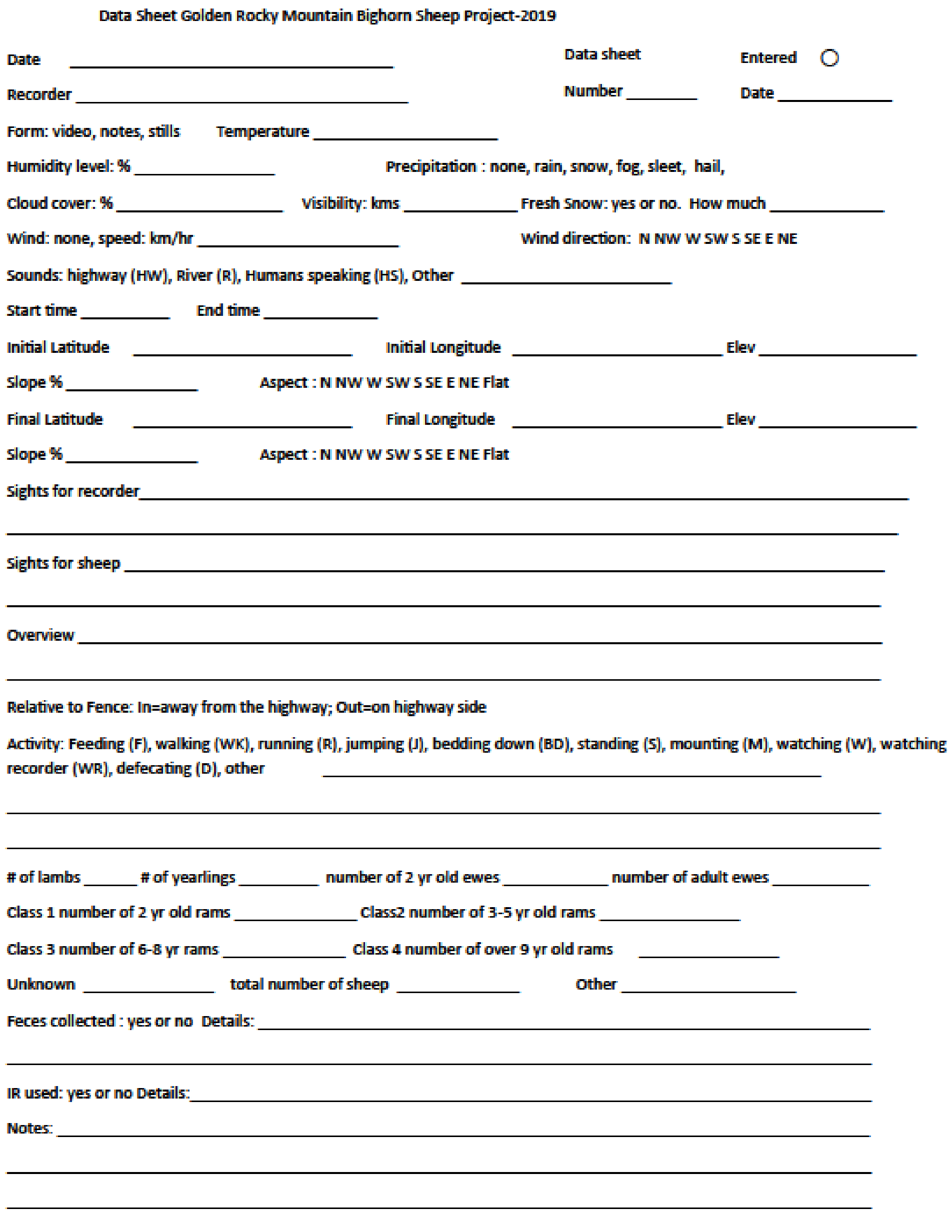
Appendix 1

Common Name	***Scientific name***	**observed use by sheep[1]**
Forbs		
Yarrow	*Achillea millefolium*	1
Pearly Everlasting	*Anaphalis margaritacea*	1
Pussytoes	*Antennaria howellii*	1
Burdock	*Arctium lappa*	2
Common burdock	*Arctium minus*	3
heart-leaved arnica	*Arnica cordifolia*	1
Tarragon	*Artemisia dracunculus*	1
Diffuse knapweed	*Centaurea diffusa*	1
Canada thistle	*Cirsium arvense*	2
Yellow lady's slipper	*Cypripedium parviflorum*	1
Mountain avens	*Dryas spp*	1
Fireweed	*Epilobium angustafolium*	1
Horse tail	*Equisetum spp.*	1
Wild strawberry	*Fragaria virginiana*	1
Yellow hedysarum	*Hedysarum sulphurescens*	1
Oxeye daisy	*Leucanthemum vulgare*	1
Lemonweed	*Lithospermum ruderale*	1
False salomon -seal	*Maianthemum racemosum*	1
Alfalfa (lucerne)	*Medicago sativa L.*	3
Thimbleberry	*Rubus parviflorus*	1
Lindley's aster	*Symphyotrichum ciliolatum*	1
Dandelion	*Taraxacum officinale*	1
Red clover	*Trifolium pratense L.*	2
Common mullein	*Verbascum thapsus*	1
American Vetch	*Vicia americana*	1
Tufted vetch	*Vicia cracca*	1
Grasses		
Crested Wheatgrass	*Agropyron cristatum*	1
Bentgrass	*Agrostis spp*	1
smooth brome	*Bromus inermis*	2
Cheatgrass	*Bromus tectorum*	1
Pinegrass	*Calamagrostis rubescens*	1
Rocky Mountain fescue	*Festuca saximontana*	2
Foxtail barley	*Hordeum jubatum*	1
rough-leaved ricegrass	*Oryzopsis asperifolia*	1
Needlegrass	*Stipa* spp.	1
Tall wheatgrass	*Thinopyrum intermedium*	3

Common Name	***Scientific name***	**observed use by sheep**[1]
	Shrubs	
Mountain alder	*Alnus incana*	1
Saskatoon	*Amelanchier alnifolia*	3
Spreading dogbane	*Apocynum androsaemifolium*	1
Kinnikinnick	*Arctostapholis uva-ursi*	1
Oregon grape	*Berberis aquifolium*	1
Scrub birch	*Betula nana*	3
Red-osier dogwood	*Cornus stolonifera*	3
Common juniper	*Juniperus communis*	2
Rocky Mountain juniper	*Juniperus scopulorum*	2
Chokecherry	*Prunus virginiana*	2
Prickly rose	*Rosa acicularis*	2
Scouler's willow	*Salix scouleriani*	2
Soopolallie	*Shepherdia canadensis*	3
Birched-leaved spirea	*Spireae betufolia*	1
Snowberry	*Symphocarpus albus*	1
	Trees	
Douglas maple	*Acer glabrum*	3
Paper birch	*Betula papyrifera*	1
Interior spruce	*Picea engelmannii* x *glauca*	1
Lodgepole pine	*Pinus contorta*	3
Limber pine	*Pinus flexilis*	2
Trembling aspen	*Polpulus tremuloides*	1
Black cottonwood	*Populus balsamifera*	1
Douglas-fir	*Pseudotsuga menseizia*	2
Western redcedar	*Thuja plicata*	3

1- use use level: 1=none, 2= some, 3= alot

Appendix 2



Data Sheet Golden Rocky Mountain Bighorn Sheep Project-2019

Date ____________________ Data sheet Entered ○

Recorder ____________________ Number ________ Date ____________

Form: video, notes, stills Temperature ______________

Humidity level: % ____________ Precipitation : none, rain, snow, fog, sleet, hail,

Cloud cover: % ____________ Visibility: kms __________ Fresh Snow: yes or no. How much __________

Wind: none, speed: km/hr ______________ Wind direction: N NW W SW S SE E NE

Sounds: highway (HW), River (R), Humans speaking (HS), Other ______________

Start time ________ End time __________

Initial Latitude ______________ Initial Longitude ______________ Elev ____________

Slope % ___________ Aspect : N NW W SW S SE E NE Flat

Final Latitude ______________ Final Longitude ______________ Elev ____________

Slope % ___________ Aspect : N NW W SW S SE E NE Flat

Sights for recorder____

Sights for sheep ____

Overview ____

Relative to Fence: In=away from the highway; Out=on highway side

Activity: Feeding (F), walking (WK), running (R), jumping (J), bedding down (BD), standing (S), mounting (M), watching (W), watching recorder (WR), defecating (D), other ______________________________

# of lambs ______ # of yearlings ________ number of 2 yr old ewes __________ number of adult ewes __________

Class 1 number of 2 yr old rams ____________ Class2 number of 3-5 yr old rams ____________

Class 3 number of 6-8 yr rams ____________ Class 4 number of over 9 yr old rams ____________

Unknown ____________ total number of sheep ____________ Other ______________

Feces collected : yes or no Details: ____

IR used: yes or no Details:____

Notes: ____

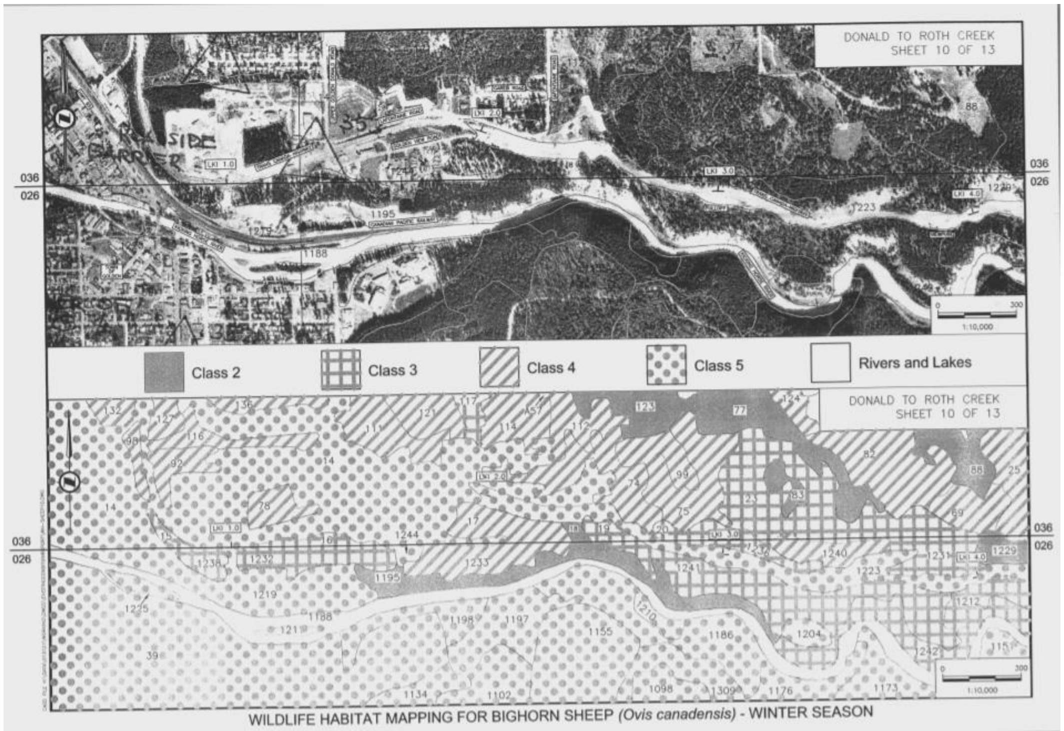
Appendix 3

Ministry of Transportation and Infrastructure commissioned work can be useful in directing the Phase 4 development. The reports vary in accuracy and need to be looked at on an individual basis. The link below leads to links to all of the reports mentioned.

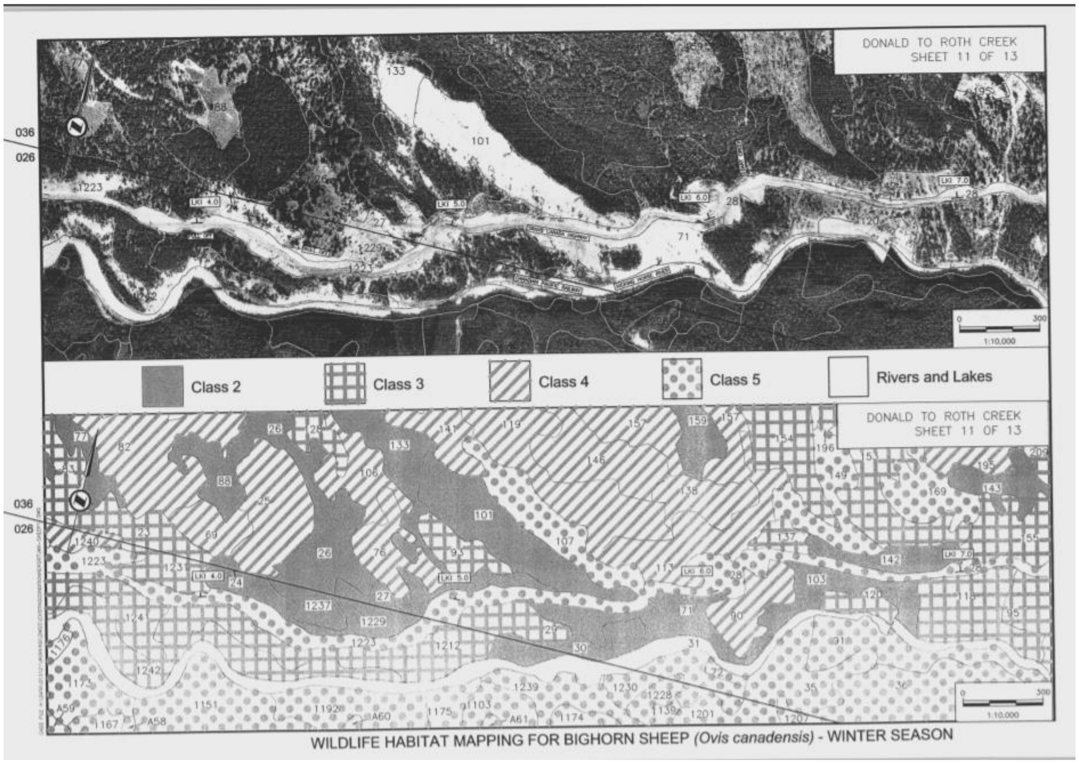
https://www2.gov.bc.ca/gov/content/kicking-horse-canyon-project/kicking-horse-canyon-document-library/environment-documents

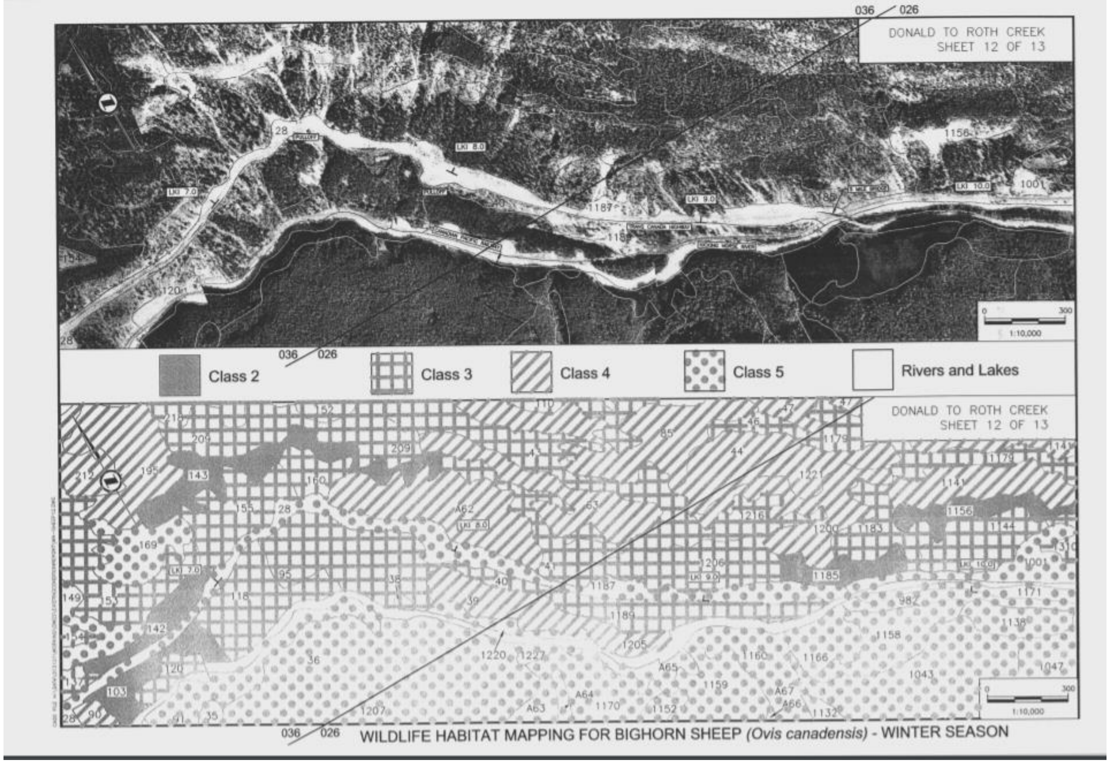
Relevant images from some of them are shown below the name of the report they came from.

2000- Trans Canada Highway Cache Creek to the Rockies Wildlife Habitat Mapping Glacier National Park to Yoho National Park Section 2: Donald to Roth Creek



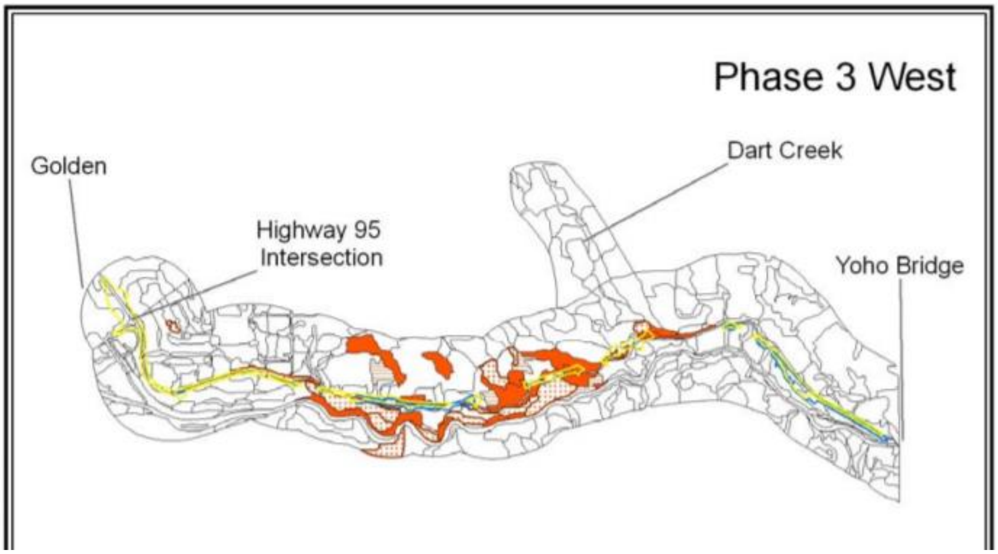
WILDLIFE HABITAT MAPPING FOR BIGHORN SHEEP (*Ovis canadensis*) - WINTER SEASON





2006- Vegetation and Wildlife Habitat Mapping Kicking Horse Canyon Project, Phase Three East and West Trans Canada Highway Golden to Yoho Bridge and Brake Check to Yoho National Park

Figure 9 Area Rated as High Habitat Suitability for Bighorn Sheep within the Kicking Horse Canyon Project Area.



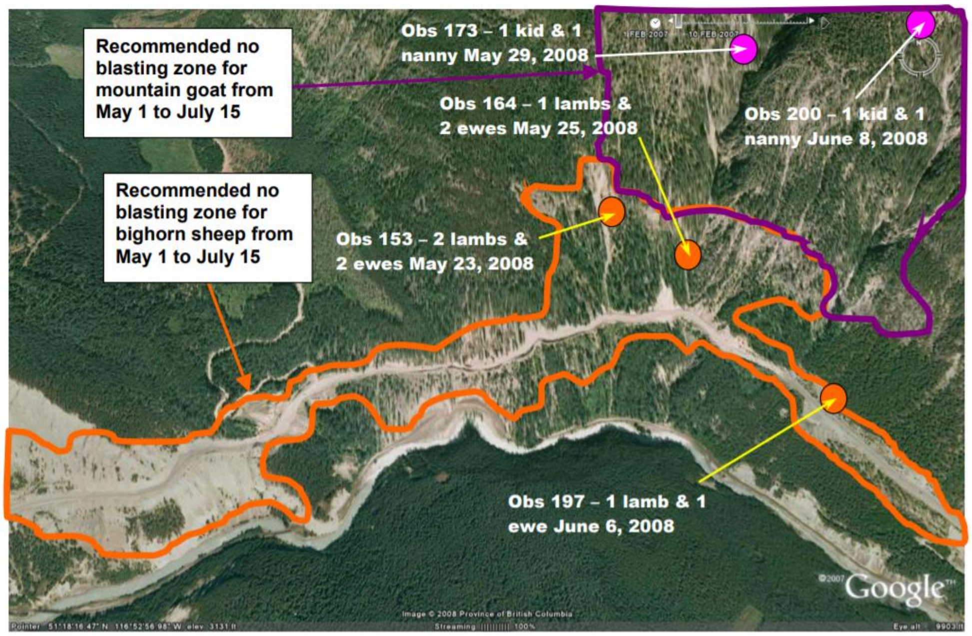


Figure 3. Bighorn sheep and mountain goat recommended no blasting zones and observations of neonates in the vicinity of Blackwall Bluffs.

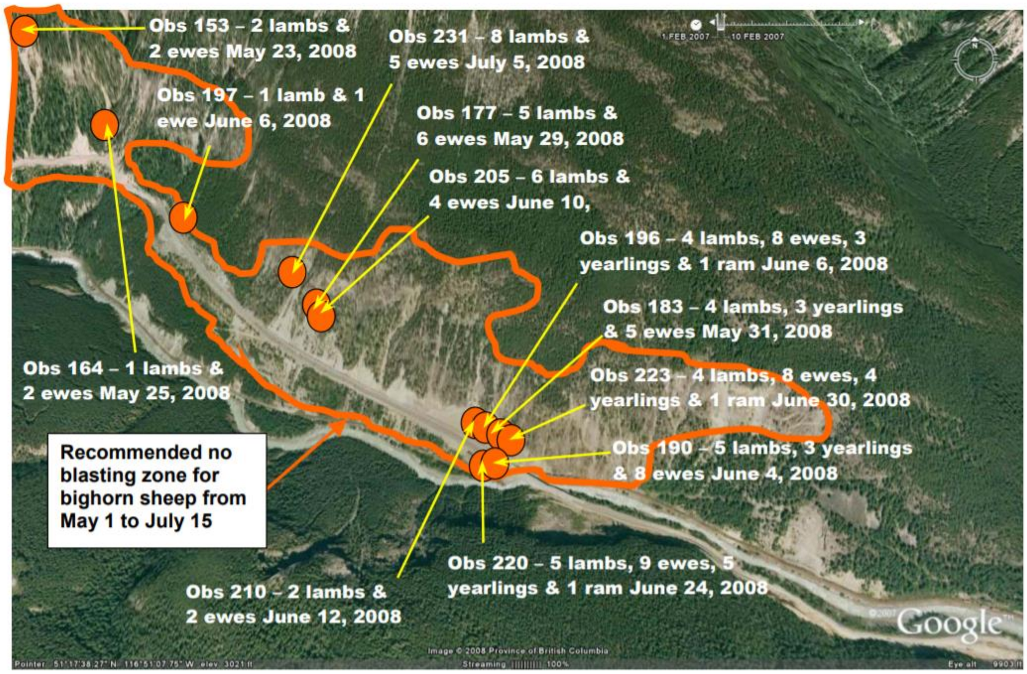


Figure 4. Bighorn sheep recommended no blasting zones and observations of neonates in the vicinity of Yoho Bridge east of Golde BC.