BEHAVIOUR, GASTROINTESTINAL PARASITES, AND STRESS HORMONES OF THE SOUTH THOMPSON CALIFORNIA BIGHORN SHEEP (*OVIS CANADENSIS*) HERD

by

TERRI LYNN FRANCE

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Thesis examining committee:

Wendy Gardner (PhD), Thesis Supervisor and Associate Professor, Natural Resource Science, Thompson Rivers University

Thomas Dickinson (PhD), Dean of Science, Biological Sciences, Thompson Rivers University

Lauchlan Fraser (PhD), Professor, Natural Resource Science, Thompson Rivers University

Michael Borman (PhD), External Examiner, Professor and Associate Department Head in Department of Animal and Rangeland Sciences, Oregon State University

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ABSTRACT

Bighorn sheep (*Ovis canadensis*) populations are characterized by drastic all-age respiratory disease related die-offs. Conservation efforts and management are often limited by the vulnerability of bighorn sheep to a multitude of pathogens and concurrent natural and anthropogenic stressors. Furthermore, the effects of human development, infrastructure and activities on local bighorn sheep behaviour, physiology, and population demographics are not fully understood. There is an urgency to determine the mechanisms accountable for bighorn sheep population declines and to understand the dynamics of local populations in order to effectively manage sustainable populations. The South Thompson California bighorn sheep herd located in the southern interior of British Columbia has been rapidly increasing in numbers and is considered a resident herd remaining in the same general area year round. The abundance of sheep and their use of human-developed areas raise concerns regarding the effects of anthropogenic pressures, the capacity of the habitat to sustain the population, and the vulnerability of the herd to a die-off. The specific thesis objectives were: (1) determine whether behaviours are affected by habitat, season, and sex with a focus on developed landscapes; and (2) compare gastrointestinal parasitology and physiological stress levels of ewes in three areas by season and anthropogenic influence to evaluate the impacts of human development. From summer 2008 to fall 2009, behaviour observations were collected from unmarked individuals from the South Thompson herd. During the spring, summer, and fall of 2009, 90 fecal pellet samples were collected opportunistically and noninvasively from unmarked ewes. The frequency of various behavioural categories differed seasonally, among habitat types, and between sexes. The gastrointestinal parasite levels varied by season and location; whereas, stress hormones varied only by location. Based on the behavioural observation results, the urban and agricultural developed lands appear to be an integral part of the South Thompson range. Presently this may be having a positive effect on the herd health by providing high quality forage at key times. However, the population numbers are increasing and this may lead to issues associated with overcrowding. Additionally, land use changes that result in reduced access to these lands may have a major impact on the herd.

Parasites were found in all of the bighorn sheep including those in a remote area. Similar results have been reported from other bighorn sheep populations and the presence of gastrointestinal parasites alone does not appear to be a major contributing factor to die-offs. However, if the population continues to expand, or if portions of their range become unavailable, parasite loadings could contribute to health problems. This may be exacerbated if habitat use by bighorn sheep becomes concentrated in the developed areas. Stress hormones were not significantly higher for the bighorn sheep using the developed areas compared to the remote area. However, as numbers increase and more development occurs it will be important to continue to monitor gastrointestinal parasites and stress levels as they may indicate potential problem developing. The results of this study support herd-specific management efforts, help with the development of land use guidelines, aid prioritization of stewardship activities, and identify knowledge gaps for the South Thompson herd.

Keywords: California bighorn sheep, *Ovis canadensis california,* behaviour, gastrointestinal parasites, stress hormones, fecal glucocorticoid concentrations, British Columbia, habitat, urban ungulate

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CHAPTER 1 LITERATURE REVIEW

INTRODUCTION

The cornerstone of effective wildlife conservation and management is understanding the critical factors that support a population and the constraints that limit a population (Krebs 2002). However, many extrinsic and intrinsic factors can undermine the success of management strategies. These factors can operate singly, concurrently, or sequentially, making identification, interpretation and prediction of effects and interactions difficult (Miller et al. 2012). Of these factors, the association between animals and their habitat is often the basis of inquiries (Alldredge and Griswold 2006). There is a need to identify, understand and predict which habitats and resources are needed to support sustainable wildlife populations (Boyce and McDonald 1999, Manly et al. 2002). Evaluating the relationships between wildlife populations and their corresponding habitat is an integral part of wildlife management, species conservation, impact and habitat suitability assessment, population modelling, and stewardship activities (Manly et al. 2002, Strickland and McDonald 2006).

Further challenging the management of wildlife populations is the complexity of political, social, economic, and ecological values and outcomes that are manifested from competing demands where stakeholders and resource users have differing, and at times incompatible, objectives for the land base (Miller et al. 2012). Human activities inherently pose risks to species conservation and are recognized as driving the current global loss of biodiversity (Isaac at el. 2007, International Union of Conservation of Nature 2014). Consequently, understanding the biological traits that underpin a species vulnerability to human impacts is critical for conservation of populations (Cardillo et al. 2006). Urgent concerns and limited conservation funding highlights the need to prioritize and optimize allocation of funds and develop pragmatic management plans and stewardship initiatives. There is a range of strategies for setting conservation priorities which are often developed as reactive or remedial attempts for species or populations with immediate threats (Cardillo et al. 2006, Isaac et al. 2007). However, researching and addressing the limiting factors and inherent risks to populations pre-emptively may help mitigate risks and establish a baseline for monitoring.

The vulnerability of bighorn sheep (*Ovis canadensis*) populations to respiratory disease outbreaks and inconclusive causes associated with the subsequent dramatic all-age die-offs showcase the challenges of identifying, interpreting, and managing population limiting factors (Miller et al. 2012). Host factors, environmental factors, and infectious agents have been recognized as possible determinants contributing to this complex multifactoral disease. Understanding these limiting factors will be instrumental in protecting populations, addressing population concerns and developing effective management strategies.

STUDY SPECIES

Bighorn sheep populations are widespread across western North America occurring in two provinces in Canada (British Columbia (BC) and Alberta) and 15 states in the United States of America (USA) (Arizona, California, Colorado, Idaho, Montana, North Dakota, New Mexico, Nebraska, Nevada, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming) (NatureServe 2015). Although widespread, many populations lack interconnectedness due to habitat fragmentation and are prone to die-offs which may create genetic bottlenecks (Luikart and Allendorf 1996). This may lead to reduced ranges, isolated populations, and reduced genetic diversity. Habitat fragmentation, alteration, loss, and avoidance are attributed to both natural processes and anthropogenic disturbances such as shrub and tree encroachment, weed infestation, intraspecific and interspecific wildlife and livestock forage competition, fire prevention and suppression, urbanisation, agriculture development, and recreational and industrial activities (Wakelyn 1987, Shackleton 1999, Corti 2001, DeCesare and Pletscher 2006).

Accurate bighorn sheep population estimates prior to human settlement are lacking; however, major declines and extirpations have been reported since the 1800s (Shackleton 1999, Demarchi et al. 2000). Unregulated hunting, loss and degradation of habitat, and disease have been recognized as the primary drivers causing historical bighorn sheep population declines resulting in their current reduced population numbers and fragmented distribution (Buechner 1960, Valdez and Krausman 1999, Demarchi et al. 2000).

Bighorn sheep populations across western North America have been characterized by rapid increases in abundance followed by sudden all-age die-offs (Buechner 1960, Stelfox 1971, Onderka and Wishart 1984, Monello et al. 2001). These die-offs have further suppressed bighorn sheep populations (Monello et al. 2001, Cassirer and Sinclair 2007). Drastic declines of bighorn sheep populations of over 90% have been reported in the USA (Valdez and Krausman 1999) and up to 75% over one year in BC (Harper et al. 2002). Cassirer and Sinclair (2007) investigated eight populations near Hells Canyon, Idaho, USA and found pneumonia caused 43% and 86% of the mortality in bighorn sheep adults and lambs respectively. Many of the populations have reduced ranges, patchy distribution, and low numbers of individuals which creates a concern regarding long-term population viability (Sugden 1961). Berger (1990) reported that a minimum population size of 125 individuals is needed to maintain a viable population.

Bighorn sheep are designated provincially as a blue listed species by the BC Conservation Data Centre (2015). They are considered 'of special concern' due to loss of habitat, susceptibility to stress and disease, and vulnerability to population decline. Bighorn sheep are recognized as a conservation interest in the province and the BC Conservation Framework (2015) identifies the following actions which are needed for conserving bighorn sheep:

- review of resource use,
- monitor trends,
- compile status report,
- explore private land stewardship,
- utilize policy for habitat protection,
- apply habitat restoration,
- develop management plans, and
- manage species and populations.

Bighorn sheep are highly valued by the people of BC and the public participates in numerous activities related to this important, charismatic species. A survey of resident hunters' willingness to pay indicated hunters were willing to pay $83.20 per day for bighorn sheep which ranks them as the highest valued ungulate in the province (Demarchi et al. 2000). Under the *Wildlife Act* (RSBC 1996), bighorn sheep are classified as 'big game' and the provincial government has jurisdiction over the access, management, and protection of the species. Unlike in Alberta, most of the bighorn sheep populations in BC are outside of provincial and national park protected areas (Shackleton 1999).

Two of Cowan's (1940) taxonomically recognised subspecies of bighorn sheep occur in BC: Rocky Mountain subspecies (*Ovis canadensis canadensis* Shaw 1804) and California subspecies (*Ovis canadensis californiana* Douglas 1829). Genetic and morphometric analyses have indicated that California and Rocky Mountain bighorn sheep should not be recognised as separate subspecies (Wehausen and Ramey 1993, 2000). However, in BC they are still recognized as two separate ecotypes. Because of their differing ecologies, geographic range, habitat requirements, and stressors, management strategies and conservation efforts are unique to each ecotype (Figure 1.1). Bighorn sheep populations in BC serve as important donor herds for re-introduction into historical ranges and supplementation to depleted existing herds in the USA (Buechner 1960, Demarchi 2004).

In BC, 59 bighorn sheep herds have been recognized within 24 subpopulations (Shackleton et al. 1999). Bighorn sheep subpopulations are defined as herds that have a shared summer range but separate winter ranges (Luikart and Allendorf 1996). Of these 24 subpopulations, 10 are California bighorn sheep subpopulations and 14 are Rocky Mountain bighorn sheep subpopulations (Demarchi 2004). Berger (1990) reported that a minimum population size of 125 individuals is needed to maintain a viable population; therefore, only 15 of these subpopulations can be described as viable (Demarchi 2004).

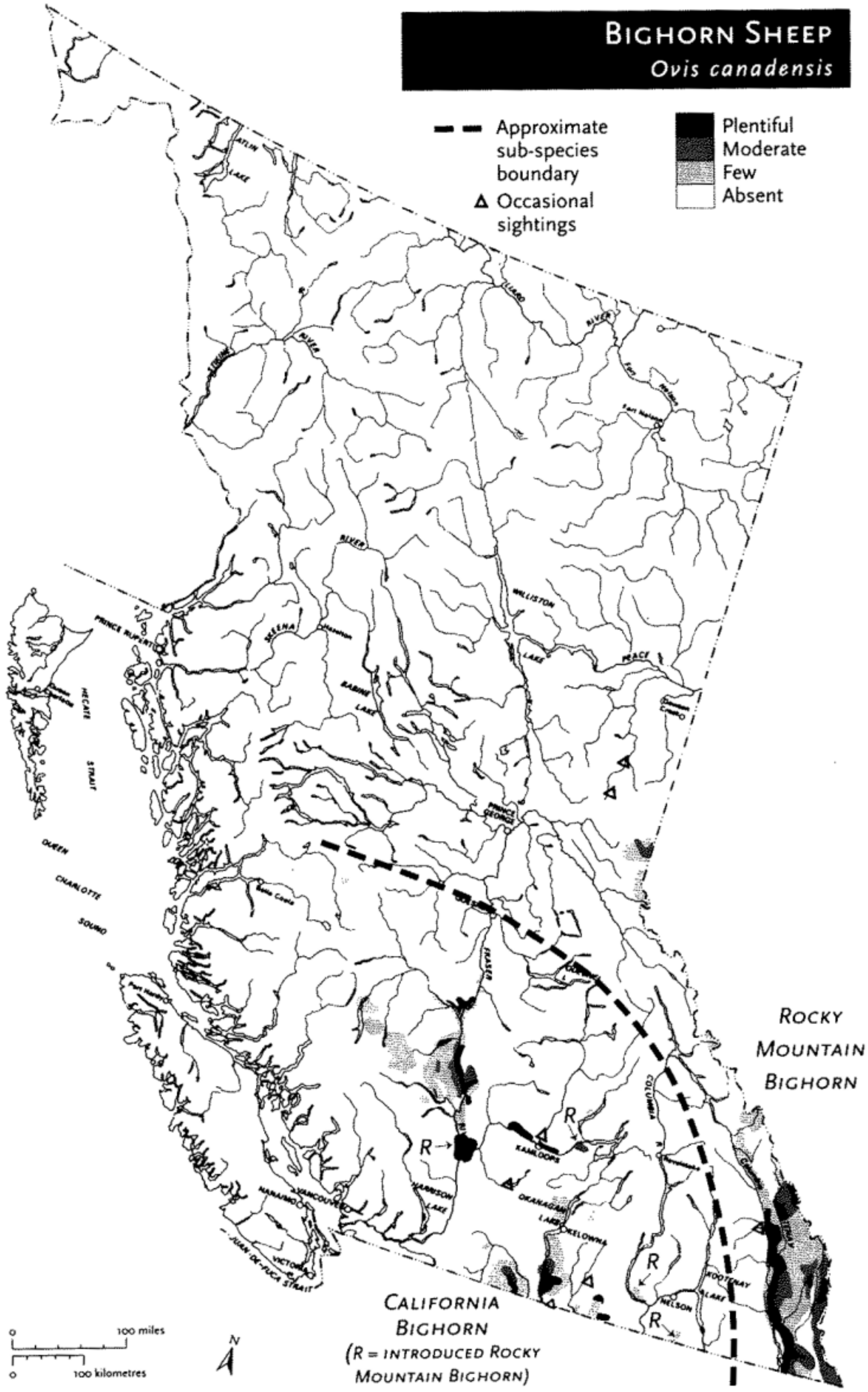

Figure 1.1Distribution of bighorn sheep (Ovis canadensis) in British Columbia showing location of the two recognized subspecies, California bighorn (Ovis canadensis californiana) and Rocky Mountain bighorn (Ovis canadensis canadensis) (Shackleton 1999).

Bighorn Sheep Life History Strategies

The life-history strategies employed by bighorn sheep affect individuals' ability to survive, grow, and reproduce, and can create resources trade-offs which may impact population performance. Bighorn sheep are gregarious, philopatric, sexually dimorphic animals (Geist 1971, Ruckstuhl 1998, Worley et al. 2004). As such, bighorn sheep live in socially hierarchically organised, family groups that are sexually and spatially segregated for the majority of the year, with the exception of the rut (Geist 1971, Main and Coblentz 1990). The optimal foraging theory (MacArthur and Pianka 1966) suggests that animals maximize their time foraging while minimizing energetic costs. By living in groups, bighorn sheep may be able to feed more effectively by decreasing individuals' vigilance thereby allowing sheep to obtain more forage (Berger 1978, Risenhoover and Bailey 1985, Bleich et al. 1997, Ruckstuhl 1998, Cassirer et al. 2013). Understanding life-history mechanisms is considered fundamental for population recovery and conservation management (Roff 2002).

Bighorn sheep have a strong fidelity to their home range and therefore do not typically expand and disperse into new range (Geist 1971, Festa-Bianchet 1986, Worley et al. 2004, Walker and Parker 2006). As a result of their group and concentrated living nature, bighorn sheep are especially vulnerable to localised disturbances and susceptible to pathogen transmission (Walker and Parker 2006). Human development and activities have the capability of impacting and altering bighorn sheep habitat use and behaviour. Walker and Parker (2006) suggest that stress incurred from anthropogenic activities could manifest in behavioural responses such as habitat avoidance or increased vigilance.

Bighorn sheep experience their highest mortality rates during their first year (Demarchi et al. 2000). Lambs are born in the spring and can have a mortality rate of over 90% during their first year due to predator pressures, poor nutrition and mothering, severe weather conditions, and/or disease (Geist 1971, Demarchi et al. 2000, Enk et al. 2001). Demarchi et al. (2000) suggested that there are multiple causes of mortality, with most correlated to habitat condition. The effects of these mortality factors depend on the quality and quantity of the range, density of the population, and suitability of the terrain to provide security from predators (Enk et al. 2001). According to Buchner (1960), a lamb:ewe ratio of

30:100 after the first winter is necessary to maintain a viable population. Generally, high lamb recruitment indicates good herd health and corresponding range condition (Lemke 2005).

Limiting Factors

There are a vast number of limiting factors for bighorn sheep populations which include: native and exotic disease and pathogens; domestic sheep and goat interaction; trace mineral and nutritional deficiencies; habitat loss, alteration, and degradation; weed invasion; poor habitat; forage quality and quantity; intraspecific and interspecific competition for forage; incompatible management strategies for sympatric species; overcrowding; inbreeding; forest encroachment; fire suppression; predation; harassment by humans and domestic dogs; severe weather conditions; and anthropogenic activities and development (Stelfox 1971, Schwantje 1988, Demarchi et al. 2000, Miller et al. 2012). Research on bighorn sheep limiting factors largely focuses on identifying agents contributing to respiratory disease outbreaks and die-offs and factors impeding post die-off population recovery (Enk et al. 2001, Miller et al. 2012). Host factors, environmental factors, and infectious agents in particular have been recognized as possible determinants contributing to respiratory disease outbreaks (Miller et al. 2012). Currently, research results are inconclusive as to whether these factors operate solely, concurrently, or sequentially (Monello et al. 2001).

Host determinants are characteristics of the host animal that directly or indirectly affect the susceptibility of the animal to disease (Miller et al. 2012). Host factors such as nutrition, age, immunity, genetics, elevated stress, and previous exposure to infectious agent may increase the vulnerability of bighorn sheep to respiratory disease. Spraker et al. (1984) hypothesized that bighorn sheep physiological response to stress triggered by extrinsic and intrinsic factors may lead to immune suppression and predispose them to disease outbreaks.

Similar to host determinants, environmental determinants may directly or indirectly affect bighorn sheep susceptibility to disease. In a review by Miller et al. (2012) the following proposed environmental determinants were identified:

- harsh environmental conditions,
- lack of suitable escape terrain,
- range and migration reductions because of human development or activities,
- limited sources of water,
- limited forage and precipitation,
- plant community succession,
- protein and mineral deficiencies,
- interspecific competition for forage by domestic and native ungulate species,
- intraspecific competition for forage,
- limited winter range, and
- competition for space.

The carrying capacity of the range is the number of animals that can be supported by the available amount of food, water, and habitat resources. These resources are needed to meet the animals' requirements for optimal growth and reproduction and to minimize mortality. Addressing how these environmental requirements relate to bighorn sheep carrying capacity is fundamental for sustaining populations and developing management strategies. Monello et al. (2001) evaluated the effects of proximity to domestic sheep, bighorn herd demographics, and environmental variables in pneumonia related die-offs for 99 herds throughout the geographic range of bighorn sheep. Their findings indicated that domestic sheep proximity and density-dependent variables such as competition, malnutrition, stress, and parasitism significantly effected pneumonia mortality; however, it is inconclusive whether these variables operate cumulatively in contributing to die-offs. They reported that 88% of the die-offs were correlated with peak numbers in the population, occurring at a peak or within 3 years of a peak. Monello et al.'s research suggests that populations increasing in size may reach a carrying capacity threshold beyond which density-dependent factors act on the population eliciting physiological stress, weakened immunity and increased susceptibility to parasitism. Stelfox (1971) reported that drastic population fluctuations in bighorn sheep in the Canadian Rockies were strongly influenced by increasing sheep numbers resulting in overgrazed range and malnourished sheep.

The importance of identifying non-pathogenic factors that may predispose populations to infection and act synergistically with epizootics resulting in pneumonia epidemics has been recognized by several researchers (Spraker and Hibler 1982, Schwantje 1988, Monello et al. 2001, Miller et al. 2012). Understanding these ecological factors that contribute to population declines is critical for successful management (Krebs 2002, Cassirer and Sinclair 2007, Miller et al. 2012). Johnson and Swift (2000) suggest habitat quality is a principal factor affecting the viability of bighorn sheep populations; therefore assessing the quality of the habitat is critical for comprehension and prediction of wildlife population dynamics and viability in changing environments. Successful bighorn sheep conservation, restoration, and management are likely dependent upon consideration of both disease and habitat. Habitat requirements and stressors need to be fully understood and population management must balance population size with habitat quality and quantity (Demarchi et al. 2000). Bighorn sheep are particularly vulnerable to declines due to their life-history strategies, numerous natural and anthropogenic stressors, and susceptibility to multitude of bacteria, viruses, parasites, and diseases (Geist 1971, Enk et al. 2001, Monello et al. 2001, Worley et al. 2004, and Walker and Parker 2006).

It has been well documented that pneumonia related all-age die-offs are endemic to bighorn sheep populations and commonly coincide with pathogen infection, particularly when novel epizootics are introduced (Schwantje 1988, Wild Sheep Working Group 2012). Though it is recognized that bighorn sheep are particularly susceptible to pneumonia, the etiology of this respiratory disease complex is not fully understood (Hobbs and Miller 1992, Gross et al.2000, Cassirer and Sinclair 2007, Dassanayake et al. 2010, Besser et al. 2012).

Early research identified lungworms (*Protostrongylus* spp.) as the principal agent responsible for causing respiratory disease in bighorn sheep populations (Buechner 1960). However, several researchers have suggested that lungworm infection may be ubiquitous in bighorn sheep populations and the presence of lungworm may not necessarily lead to pneumonia in bighorn sheep (Cowan 1951, Blood 1963, Forrester and Senger 1964, Festa-Bianchet 1991, Goldstein at el. 2005). Blood (1963) suggested that lungworm infection is common, and reported infection rates of over 90% for most herds throughout western Canada, and Forrester and Senger (1964) found lungworm prevalence of 91% based on 900 fecal samples from 10 herds in western Montana. Samson et al. (1987) and Miller et al. (2000) suggested there is not substantial evidence to determine whether lungworm infection results in pneumonia. They speculate that bighorn sheep may be capable of suppressing parasite reproduction; however, concurrent extrinsic pressures may lead to pneumonia mortality.

Lungworms can severely damage lung tissue and high infection levels have been shown to be lethal in bighorn sheep lambs (Demarchi 2004, Walker and Parker 2006). Goldstein et al. (2005) recognized that stress response and indirect effects of lungworm infection have not been fully evaluated but suggest that infection could lead to chronic stress and reduced fitness. Furthermore, heavy lungworm load can compromise the respiratory tract and lower the sheep’s immunity which may be further compounded by concurrent assaults by other pathogens. Collectively these factors can cause prolonged stress in bighorn sheep and exacerbate susceptibility to pneumonia (Rogerson et al. 2008). Festa-Bianchet (1989) and Pelletier et al. (2005) demonstrated that both parasite suppression and reproduction are energetically costly to bighorn sheep which possibly creates a trade-off between reproductive success and parasite load. Their results suggest parasite loads are highest during lambing for ewes and rut for rams as this is the most energetically costly time in their life cycle. A better understanding of the relationship between lungworms and sheep and an evaluation the effects on the sheep’s physiological response, metabolic resources, and pathogen resistance may address management concerns regarding how endemic, high lungworm burdens contribute to the pneumonia complex (Rogerson et al. 2008).

Habitat factors that are favourable to lungworm larvae and their intermediate gastropod hosts can result in elevated lungworm loads (Demarchi 2004). Increased likelihood of lungworm ingestion can be expected when the following factors are present:

concentrated bighorn sheep numbers, isolated and nonmigratory bighorn sheep populations, high moisture or irrigated areas that attract sheep and increase the likelihood of pathogen transmission, high number of lungworm infected gastropods, and temporal and spatial overlap between the gastropods and sheep (Jones and Worley 1994, Rogerson et al. 2008).

Recent experimental and field research associates respiratory bacterial agents, particularly *Pasteurella multicoda* (Cassirer and Sinclair 2007), *Mannheimia haemolytica* (Lawrence et al. 2010), *Bibersteinia trehalosi* (Dassanayake et al. 2013) and *Mycoplasma ovipneumonia* (Besser et al. 2012), with pneumonia epidemics in bighorn sheep populations. Conversely, some studies have reported that populations where pneumonia has not been detected are known to be infected with pathogenic epizootics suggesting environmental or density-dependent factors causing chronic stress may trigger disease outbreaks (Jaworski et al. 1998, Monello et al. 2001, Jenkins et al. 2007, Rudolph et al. 2007, Miller et al. 2012). The multifactorial pneumonia complex has perplexed biologists and managers thereby limiting conservation and management efforts. Successful management is dependent on the comprehensive understanding of the population's limiting factors, habitat requirements, and carrying capacity. There is a definite need to determine the mechanisms accountable for bighorn sheep population declines and to understand the dynamics of local populations in order to effectively manage a sustainable population.

Bighorn Sheep Key Habitat Requirements

California bighorn sheep in the southern interior of BC commonly distribute along major river systems and use the associated canyons and grassland benches for security and forage respectively (Geist 1971, Wakelyn 1987, Shackleton 1999). Smith et al. (1991) defined key habitat parameters for habitat evaluation for bighorn sheep and Sweanor et al. (1996) further explained these requirements in the following table (Table 1.1). The habitat requirements included escape terrain for security from predators (Demarchi et al. 2000), quality and quantity of seasonal forage (Wikeem and Pitt 1992), horizontal visibility (Smith et al. 1991), water sources (Payer and Coblentz 1997), and suitable winter range (Tilton and Willard 1982). The availability and juxtaposition of these key parameters are a critical determinant of habitat quality (Payer and Coblentz 1997). Ruckstuhl (1998) suggested that distribution of forage and predation pressures are primary drivers affecting habitat use.

Table 1.1 Bighorn sheep habitat parameters used for GIS-based habitat evaluation in the Rocky Mountains (Sweanor et al. 1996).

Habitat Parameter	**Definition**
Escape terrain	Areas with slope > 27° , < 85°
Escape terrain buffer	Areas within 300 m of escape terrain and areas <1000 m wide that are bounded on at least 2 sides by escape terrain
Vegetation density	Areas must have horizontal visibility > 60%
Water sources	Areas must be within 3.2 km of water sources
Natural barriers	Areas that bighorn sheep cannot access, e.g., rivers > 2000cfs, areas with visibility < 30% that are > 100 m wide, cliffs with slope > 85°
Human use areas	Areas covered by human development (e.g., roads, parking lots, and buildings)
Man-made barriers	Areas that cannot be accessed due to man-made barriers, e.g., major highways, wildlife-proof fencing, aqueducts, major canals
Domestic livestock	Areas must be over 16 km from domestic sheep
Winter Range	Areas meeting above criteria, with aspect between 120° and 245°, and snow depth < 25 cm

Precipitous habitat that provides security from predators is critical for bighorn sheep (Geist 1971, Shackleton 1999, Demarchi et al. 2000, Mooring et al. 2003). Escape terrain offers security from predators because sheep can evade threat, see predators approaching from considerable distances, and camouflage into their surroundings (Geist 1971, Tilton and Willard 1982). Bighorn sheep studies have indicated that the distance to and slope of escape terrain are two critical variables which define habitat quality (Geist 1971, Tilton and Willard 1982, Johnson and Swift 2000, DeCesare and Pletscher 2006). Escape terrain is characterized by steep, continuous slopes greater than 27º (Geist 1971, Smith et al. 1991). Rugged, escape terrain is essential for evasion of predators; especially during the lambing period when the young lambs are vulnerable (Demarchi et al 2000, Enk et al. 2001). Habitat use studies indicate bighorn sheep select areas that are in close vicinity to escape terrain (Fairbanks et al. 1987, Wakelyn 1987); generally within 300 m (Smith et al. 1991). Jansen et al. (2006) indicated that use of forage areas depends on the juxtaposition of escape terrain, with bighorn sheep in their study area solely selecting forage areas which were near or bordered by escape terrain.

Vegetation obstructs bighorn sheep vision and decreases their ability to detect predators (Geist 1971, Tilton and Willard 1982, Wakelyn 1987, Smith et al. 1991, Shackleton 1999). As such, the vegetation density influences the distance sheep will move from escape terrain and which habitats types they prefer (Geist 1971, Risenhoover and Bailey 1985). Smith et al. (1991) indicated that bighorn sheep avoid areas with less than 60% horizontal visibility, where horizontal visibility is described as the amount an animal is able to see while looking straight ahead. Correspondingly, Frid (1997) suggested that increased vegetation density correlates with decreased foraging time due to increased predation risk and bighorn sheep vigilance. Bighorn sheep rarely use areas with low horizontal visibility, such as closed forests (Fairbanks et al. 1987, Smith et al. 1991, Shackleton 1999). DeCesare and Pletscher (2006) also found that bighorn sheep preferred habitats with high horizontal visibility such as grasslands, while dense habitat types were generally avoided. However, they did not attribute selection of lower cover type solely on visibility but also on predatory pressures and forage quality and quantity.

Bighorn sheep are primarily grazers (Wikeem and Pitt 1992, Demarchi et al. 2000) and grasslands provide critical foraging habitat (Shackleton 1999). However, opportunistic in nature (Wikeem and Pitt 1987), bighorn sheep will eat a variety of plant species and adapt their diets depending on the availability and seasonality of local plant species (Shackleton 1999). Bighorn sheep will also select browse species, eating the young buds, twigs, and leaves (Shackleton 1999, Wikeem and Pitt 1987). California bighorn sheep are acknowledged to browse year round and more frequently in comparison to their Rocky Mountain ecotype counterpart (Shackleton 1999).

The quality and quantity of forage is an important factor affecting bighorn sheep survival and influences sheep growth, reproduction, and behaviour (Caughley 1994, Demarchi et al. 2000). A balance between sheep nutritional requirements and plant productivity is necessary to minimize damage and degradation of forage quantity and quality (Holechek et al. 2011). Stoddart et al. (1975) suggested that palatable plants reduce with increased grazing pressure resulting in unpalatable plant species dominating. Research suggests that poor forage condition correlates with poor bighorn sheep body condition and health (Demarchi et al. 2000, Enk et al. 2001). Correspondingly, Festa-Bianchet et al. (1997) identified body mass as a critical variable affecting bighorn sheep survival. In addition, various land uses and management activities in conjunction with forest encroachment have resulted in reduced quality and quantity of California bighorn sheep habitat in BC (Demarchi et al. 2000). Ultimately, these habitat alterations may cause declines in forage quality and quantity which can negatively affect the health of bighorn sheep populations.

The condition and suitability of winter range is an important factor for bighorn sheep habitat use (Tilton and Willard 1982, Corti 2001). Buechner (1960) suggested decreases in forage quality on winter range correlates with decreased habitat use. Bighorn sheep avoid areas with snow depth greater than 25cm (Smith et al. 1991) and select slopes with a southern aspect which provide maximum sunlight exposure. Solar radiation on southern exposures provides thermal warmth for bighorn sheep and affects the availability of forage by melting the snow covering vegetation and promoting plant growth in the spring (Shackleton 1999). In the winter, habitat use is also concentrated on slopes where wind frequently exposes palatable vegetation. In some instances, open forest habitat types may be used for thermal cover in the winter.

The literature indicates some differences in opinion regarding the importance of water sources for bighorn sheep. Shackleton (1999) suggested that bighorn sheep appear capable of withstanding long periods of time without free water, meeting their primary water requirements year round from vegetation and snow during winter months. Conversely, Rubin et al. (2002) suggested that physical water sources are a critical resource for bighorn sheep and most habitat evaluation models for bighorn sheep factor proximity to water as critical criterion affecting habitat suitability (Smith et al. 1991, Sweanor et al. 1996). Ostermann-Kelm et al. (2008) indicate temperature and season may influence water requirements of bighorn sheep.

Anthropogenic development and activities, including urbanisation, forage competition via livestock grazing, domestic dog harassment, forest encroachment due to fire prevention, hunting, and habitat alterations, can have negative impacts on bighorn sheep and their range as well as increase the likelihood of human-bighorn sheep interactions (Krausman 2000). These interactions between humans and bighorn sheep can potentially cause long-term stress in bighorn sheep populations (Tremblay and Dibb 2004). Urban development has the potential of altering wildlife behaviour and habitat use (Rubin et al. 2002).

Conversely, urban areas can provide wildlife species with high quality forage and water resources; therefore attracting animals to the area. Rubin et al. (2002) found that the Northwest Santa Rosa Mountains bighorn sheep subpopulation selected urban areas. In accordance with the optimal foraging theory (MacArthur and Pianka 1966), animals will select areas that provide optimal foraging opportunities; therefore, urban areas with productive, irrigated, high quality forage may be selected over arid native grassland habitats. However, the benefits acquired from an urban area such as water sources and foraging opportunities may be counteracted by negative impacts such as decreased security cover, stressful interactions with humans and domestic dogs, disease transmission, and road collision mortalities (Rubin et al. 2002).

SOUTH THOMPSON BIGHORN SHEEP HERD AND STUDY AREA

The South Thompson California bighorn sheep herd population is currently estimated at 250 – 300 individuals and is considered to be the healthiest in British Columbia (BC) (D. Jury pers. comm.). The overwinter lamb to ewe ratio is 47:100 well above Buchner's (1960) suggested ratio of 30:100 to maintain a population. The population size varies primarily due to lamb recruitment, depredation, mortality, periodic removal for transplants, and annual hunting opportunities. The herd is an important donor population for transplants to augment populations in BC and the United States of America. Between 1996 and 2012, 150 sheep have been removed from the herd through transplants.

The South Thompson bighorn sheep range is approximately 7,600 hectares and is located north of the South Thompson River and east of the North Thompson River near Kamloops, BC. The range extends from the Mt. Paul and Mt. Peter area eastward approximately 25 kilometres to the Lionshead area near Monte Creek. The majority of the range occurs on Tk'emlúps te Secwȅpemc Indian Band (TIB) land with a small portion on public land (Figure 1.2). The Yellowhead Highway, local roads, agricultural areas, Mt. Paul Industrial Park, Sun Rivers golf course and housing development, the Spiyu7ullucw Ranch (formerly Harper Ranch), the Lafarge limestone pit and cement plant and residential areas occur within the bighorn sheep range. There are multiple stakeholders and land use activities occurring throughout the range that have the potential to negatively impact the herd. Furthermore, the South Thompson Herd is a resident herd where bands typically remain in the same general areas year round, whereas most herds migrate in elevation seasonally using lower elevation range in the winter and higher range in the summer coinciding with plant growth (Geist 1971, Van Soest 1994). These circumstances raise concerns of the capability of the habitat to support a healthy bighorn sheep population (Lemke 2005). As such coordinated land use planning and management is needed.

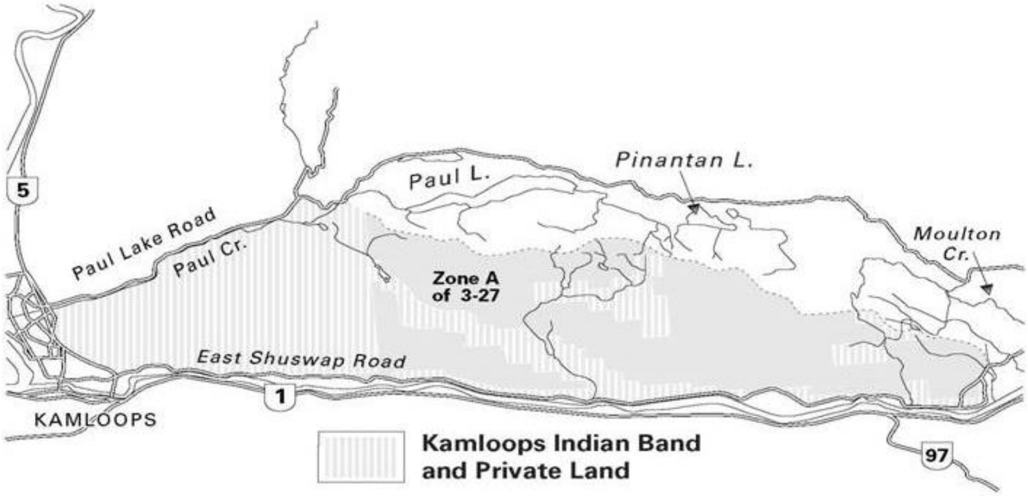

Figure 1.2 South Thompson bighorn sheep herd range located in Kamloops, British Columbia (British Columbia Ministry of Environment 2008).

In 1966, 11 California bighorn sheep from a recipient herd (Junction Herd) in the Chilcotin region of BC were released north of Kamloops Lake to re-establish a historic herd (Shackleton 1999). Twelve years later, in 1978, a founder group of 2 ewes and 2 young rams crossed the North Thompson in the Heffley Creek area and settled in the Mt. Paul area. With the aim to increase genetic diversity and persistence of the herd, 6 animals (fives ewes and one ram) were transplanted from the Junction population to supplement the small established South Thompson Herd in 1986. In order to gain permission to release sheep on to the Harper Ranch, the BC Ministry of Environment, Lands and Parks contracted that the bighorn sheep herd would not exceed 50 animals (Jury 2000).

The herd increased dramatically to approximately 150-200 animals by 1993. This increase in bighorn sheep numbers resulted in grazing damage to irrigated alfalfa fields and stored hay at Harper Ranch. The ranch insisted that the government develop a strategy to reduce numbers as per their agreement. By 1996 the population was estimated at 250 – 300 animals. In response, the Wildlife Branch of BC Ministry of Environment initiated a transplant program where bighorn sheep were transplanted from the South Thompson herd to suitable ranges throughout BC and the USA. However, target reductions of 50 animals annually did not occur due to unsuccessful baiting attempts at the ranch. The alternative of net gunning sheep from a helicopter was not justified due to its expensive and inefficient nature. In 2000, the Tk'emlúps te Secwėpemc Indian Band purchased the Harper Ranch and renamed it to Spiyu7ullucw Ranch. The new ownership provided an opportunity for a change in management direction.

The South Thompson California bighorn sheep herd population has increased rapidly since 1987. Currently the herd is estimated at 250 – 300 individuals (D. Jury pers. comm.). The location and high number of sheep in the South Thompson herd pose serious concerns regarding the effects of anthropogenic pressures, the capacity of the habitat to sustain the population, and the susceptibility of the herd to a disease outbreak. If the population continues to grow due to the high reproductive rates of the healthy herd, the herd may get larger than the area can support leading to reduced forage quality and quantity potentially making them more vulnerable to die-offs. This is supported by the research indicating die-offs may be triggered when populations approach a carrying capacity beyond which the habitat can maintain (Monello et al. 2001).

In 2005, the South Thompson Wildlife Stewardship Pilot Project was developed when staff from the BC Ministry of Environment Thompson Region and TIB Cultural Resource Management Department recognized the herd could sustain a limited annual harvest and that the concept of a stewardship enfranchisement program should be explored. The South Thompson Wildlife Stewardship Committee was formed to cooperatively develop, administer, and steer the South Thompson Wildlife Stewardship Pilot. The committee consists of representatives from the TIB, the BC Ministry of Environment, the BC Ministry of Lands, Forests and Natural Resource Operations, the BC Wildlife Federation, the Wild Sheep Society of BC, the Guide Outfitters Association of BC, the Kamloops District Fish and Game Association, and Thompson Rivers University.

The five-year pilot project met the criteria needed to explore and test stewardship enfranchisement programs of involving a private landowner, user-pay system, government policy, and a need for habitat planning and management activities (Morgan 2005). The project objectives were to create hunting opportunities through limited entry and guided hunts, generate incentives for private landowners, and establish coordinated habitat planning and stewardship activities. Enfranchisement programs aim to facilitate cooperation between government agencies, landowners and stakeholder organizations, with the goal of coordinated management.

The stewardship fund supported various initiatives. Initiatives specific to the South Thompson bighorn sheep herd included a noxious weed treatment program, highway fencing, a prescribed burning program, strategic range use planning, aerial surveys, transplants, and this thesis research. Additional projects were supported outside the South Thompson range and included bighorn sheep population inventories throughout the Thomson Region, Kamloops Lake herd transplants, moose radiocollar research, grouse lek monitoring, wetland restoration, and a Fraser bighorn sheep lamb mortality study.

STUDY PURPOSE AND OBJECTIVES

The research scope of this thesis was determined based on input from the BC Ministry of Forests, Lands, and Natural Resource Operations, the Tk'emlúps te Secwe̓pemc Indian Band, the South Thompson Wildlife Stewardship Committee, and Thompson Rivers University. This coordinated approach helped to facilitate the collection of data that supports herd specific management efforts, helps guide stewardship activities, and identifies knowledge gaps for the South Thompson herd.

This thesis research supports the proposed management initiatives aimed to maintain a healthy population. The following activities have been identified as important measures to help proactively manage a sustainable herd (Lemke 2005):

- surveying bighorn sheep numbers and distribution,
- monitoring parasite levels and disease detection,
- evaluating habitat and mortality factors, and
- measuring habitat condition.

The research findings are important in developing operational guidelines for various land use practices which aim to reduce stressors potentially deleterious to the herd. Recent research indicates causes of pneumonia related die-offs are likely multifactorial and complex.

Our research provides baseline information on the South Thompson population and investigates factors affecting behaviours, parasitology, and stress to support management decisions and resource integration.

The specific objectives of the thesis are to:

1. Determine whether behaviours are affected by habitat type, season, sex, and group size, and
2. Compare gastrointestinal parasitology and physiological stress levels among three ewe bands to assess differences across a spectrum of anthropogenic influences and seasons.

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Personal Communication

D. Jury, Senior Wildlife Biologist, British Columbia Ministry of Environment, Environmental Stewardship Division, Kamloops, BC

CHAPTER 2 HABITAT, SEXUAL, AND SEASONAL DIFFERENCES OF ADULT BIGHORN BEHAVIOURS IN THE SOUTH THOMPSON HERD

INTRODUCTION

Animal behaviour is an important consideration when designing effective management plans for conserving sustainable wildlife populations. The field of conservation behaviour is an emerging multidisciplinary approach to investigating the mechanisms behind animal behaviour (Anthony and Blumstein 2000). Human activities inherently pose risks to species conservation and are recognized as contributing to the loss of biodiversity (Isaac at el. 2007). Urban development, infrastructure, and resource use is expanding in many environments which results in wildlife populations living within or in close proximity to developed areas (Rubin et al. 2002). Human activities and disturbances have the potential of affecting and altering habitat use, wildlife behaviour, and population demographics and limiting management options (Polfus and Krausman 2012). Recognizing the fundamental role behaviour can play in population dynamics and viability will support wildlife managers in developing solutions and tools that mitigate conservation issues and help promote healthy populations in an increasingly busy landscape. Consequently, understanding the natural and human-induced causes of behavioural responses and life-history trait evolution may be instrumental in population recovery and guiding conservation management strategies for promoting a healthy population (Roff 2002, Wilson et al. 2008).

Human development, infrastructure, and activities can result in habitat avoidance and/or attraction by wildlife and offers both benefits and costs to the animals. Habitat avoidance costs can include loss of habitat and foraging opportunities and increased vigilance, movement, and physiological stress (Rubin et al. 2002, Tremblay and Dibb 2004, Geist 2005). Habitat attraction is when wildlife actively seeks out urban areas for benefits such as forage and water resources, security, and shelter. Wildlife can become habituated to predictable human activity, particularly in the absence of hunting and harassment (Thompson and Henderson 1998). Habituated wildlife may accrue benefits in urban areas that improve their fitness. The scale, type, and effects of human development differ by region and as such limit our ability to directly apply research findings to the management of local ungulate populations. The impact of human development is influenced by the distance and availability of security cover, the predator and hunter pressure, livestock and native ungulate competition, and type and spatial configuration of development (Polfus and Krausman 2012). Although some work has been done related to human-wildlife interactions, the comprehensive effects of human development and activities on wildlife behaviour, physiology, and population dynamics have not been extensively studied (Polfus and Krausman 2012).

Bighorn sheep are gregarious animals and generally live in two philopatric, sexually segregated, familial groups (Geist 1971). Maternal groups typically consist of lambs, yearlings, subadult rams, and ewes. Bachelor groups consist of rams that have left their maternal group. This usually occurs when they are over 3 years of age (Geist 1971). Generally, these sexually segregated groups have spatially separate home ranges, with the exception of rut (Geist 1971, Ruckstuhl 1998). Bighorn sheep exhibit a number of anti-predator adaptations such as their gregarious nature, movement and migration patterns, and affinity for areas in close proximity to escape terrain (Geist 1971). Bighorn sheep exhibit a strong fidelity to their home range and typically do not expand and disperse into new range (Geist 1971, Festa-Bianchet 1986). Bighorn sheep possess K-selected traits, meaning they have relatively long lifespans, low reproduction rates, and high parental investment (Pianka 1970). Because of these K-selected traits, bighorn sheep populations generally exist near the carrying capacity of the area they inhabit (Geist 1971). Due to their population density, home range affinity, and concentrated group formations, mountain sheep are especially vulnerable to localised disturbances and susceptible to pathogen transmission (Walker and Parker 2006). Therefore, human development, infrastructure, and activities have the ability to affect and alter bighorn sheep habitat use, behaviour, and population demographics (Rubin et al. 2002, Walker and Parker 2006).

The South Thompson California bighorn sheep herd occupies an area that has considerable and varied anthropogenic activities. These include agricultural areas, residential development, a golf course, industrial areas, and recreational use. Some attention has been given to the effects of industrial and recreational activities on mountain sheep populations (Krausman et al. 1998, Rubin et al. 2002, Jansen et al. 2006, Walker and Parker 2006);

however, the effects of residential development have been given less consideration (Polfus and Krausman 2012). Understanding how these activities affect the behaviour of the bighorn sheep is critical in developing a management plan for the herd. If some or all of these activities are leading to behaviours that are detrimental to the long term sustainability of the herd, it will be important to develop mitigation plans to address these effects. There are two important factors to consider specific to this herd, (1) it is a resident herd remaining in the same general area year round and (2) there may be an artificially high carrying capacity due to the forage and resources contributed by the agricultural and urban areas.

This chapter focuses on research activities related to the behavioural characteristics of the South Thompson herd in reference to land use. As discussed, human development can affect habitat use, behaviour, physiology, abundance, distribution, and population demographics of wildlife. A key step in developing an effective management plan for the South Thompson herd is to document their behaviour and to determine the impacts of the anthropogenic development and activities. This research focussed on how the habitat impacts the behaviour of the herd, specifically the urban and agricultural habitat types that the herd is known to frequent. These human developed areas appear to be attracting bighorn sheep which may result in sheep spending a disproportionate time in these settings. It is important to identify what behaviours occur in these habitat types to try to determine why they are selected. Also of importance is determining if there is a particular time of year these areas are utilized. This is a key consideration because different habitat types may be seasonally important to the herd. The specific objectives of this chapter were to:

(1) Estimate the activity budgets of adult bighorn sheep,
(2) Evaluate the main effects and interactions of sex, season, or habitat types on the amount of time spent in five observable behaviours, and
(3) Assess when the bighorn sheep are using human developed land and determine the main behaviours occurring on this habitat type.

METHODS

Study Area and Herd

The South Thompson bighorn sheep range is approximately 7,600 hectares and is located north of the South Thompson River, east of Kamloops in south central British Columbia, Canada (N 50º 41', W 120º 18'). The bighorn sheep range occurs in the Thompson-Okanagan Highlands ecoprovince and the semi-arid steppe highlands ecodivision (Demarchi et al. 2000). The elevations range from approximately 345 m to 1097 m. Due to the rain shadow location, the Kamloops is semi-arid with warm to hot summers and cold winters (Meidinger and Pojar 1991). Average temperatures range from -2.8 ºC in January to 21.5 ºC in July. Annual average precipitation is 277.6 mm with two peaks occurring in June with an average of 37.4 mm as rain and in December with an average of 22 cm as snow (Environment Canada 2015). The southern exposed slopes along the river are often windswept and in combination with solar radiation can be free of snow throughout the winter. The range occurs in the following biogeoclimatic zone, subzone, and variant: Bunchgrass Very Dry Hot Thompson (BGxh2), Ponderosa Pine Very Hot Dry Thompson (PPxh2 and PPxh2a grassland phase), and Interior-Douglas-Fir Thompson Very Dry Hot (IDFxh2) (Lloyd et al. 1990).

The terrain is characterized by terraces, benches and rugged valley walls associated with the U-shaped valley along the Thompson River system (Wikeem and Wikeem 2004). The landscape is interspersed with silt cliffs, rock faces, and talus slopes which provide critical escape terrain for the bighorn sheep. A considerable amount of agricultural, residential, and industrial development occurs in the valley bottom. Plant communities are influenced by topography, climate, elevation, and disturbance regime. The lower grasslands of the Thompson-Pavilion are characterized by big sagebrush (*Artemesia tridentata*) and bluebunch wheatgrass (*Pseudoroegneria spicata*) shrub-steppe whereas the upper grasslands are dominated by rough fescue (*Festuca scabrella*) (Wikeem and Wikeem 2004). Disturbed areas are typically dominated by invasive species and noxious weeds, particularly cheatgrass (*Bromus tectorum*), Kentucky bluegrass (*Poa pratensis*), bulbous bluegrass (*Poa bulbosa)*, knapweed species (*Centaurea* spp.), and leafy spurge (*Euphorbia esula*). Open forested areas are dominated by Ponderosa pine (*Pinus ponderosa*) and Interior Douglas-fir

(*Pseudotsuga mensezii*). Common ungulates present in the study area included mule deer (*Odocoileus hemionus*) and horses. Potential bighorn sheep predators included black bears (*Ursus americanus*), cougars (*Puma triconcolour*), coyotes (*Canis latrans*), wolves (*Canis lupus*), and golden eagles (*Aquila chrysaetos*) (Demarchi et al. 2000). Predation on the South Thompson herd is considered to be relatively low (Doug Jury pers. comm.).

The majority of the range occurs on Tk'emlúps te Secwe̓pemc Indian Band (TIB) land with a small portion on public land. The Yellowhead Highway, local roads, agricultural areas, Mt. Paul Industrial Park, Sun Rivers golf course and housing development, the Spiyu7ullucw Ranch (formerly Harper Ranch), the Lafarge limestone pit and cement plant and residential areas occur within the bighorn sheep range. There are multiple stakeholders and land use activities occurring throughout the range.

The bighorn sheep range extends from the Mt. Paul and Mt. Peter area approximately 25 km eastward along the slopes and bluffs to Swain Creek and the Lionshead area (Shackleton1999, Lemke 2005). The bighorn sheep herd utilizes three distinct areas in the range resulting in three spatially separated bands in the Mt. Paul and Mt. Peter, Spiyu7ullucw Ranch, and Lionshead areas. Due to access limitations, the Lionshead area was excluded from the study area. Within each of the band areas the bighorn sheep are sexually segregated into maternal and bachelor groups except during the rut (Geist 1971). The Mt. Paul and Mt. Peter band are sexually segregated with maternal groups using the Mt. Paul area and the bachelor groups using the Mt. Peter area. Similarly, the Spiyu7ullucw Ranch band is segregated with the maternal groups using the Ewe Hill area and bachelor groups using the Ram Hill area. The Mt. Paul and Mt. Peter bighorn band frequently use urban developments, primarily the Sun Rivers golf course, and residential development whereas the Spiyu7ullucw Ranch band frequently uses modified grasslands and agricultural areas. Bighorn sheep populations typically migrate in elevation seasonally using lower elevation range in the winter and higher range in the summer coinciding with plant growth (Geist 1971); however, the South Thompson herd is considered a resident herd typically remaining in the same general area year round.

The following water sources were identified in the Mt. Paul and Mt. Peter band area: a trough established at the transplant capture site at the west end of the Sun Rivers housing development, the golf course irrigation system, landscaping ponds in the housing development, and potentially the South Thompson River where accessible. The following water sources were identified in the Spiyu7ullucw Ranch band area: Stobbart Creek, a livestock nose pump located in a pasture at the base of Ewe Hill along East Shuswap Road, hayfield irrigation systems, and potentially the South Thompson River where accessible. In both areas, ephemeral streams likely provide water seasonally.

Behavioural Observations

Behavioural observations were conducted on unmarked sheep seasonally from the Mt. Paul and Mt. Peter, Ewe Hill, and Ram Hill areas from the summer of 2008 to the fall of 2009. Seasons were delineated by weather patterns and bighorn sheep biology. The seasonal divisions were spring from March to May corresponding with the lambing period, summer from June to August, fall from September to November coinciding with pre-rut and rut, and winter from December to February (Fairbanks et al. 1987, Rubin et al. 2002, Doug Jury pers. comm.). Bighorn sheep groups were located by travelling three predetermined routes. Each route was traveled twice per week. Scan stops were made at fixed locations along the route to distribute the sampling effort throughout the area of interest and to maximize coverage of the landscape. Figure 2.1 show the Mt. Paul and Peter, Ram Hill, and Ewe Hill transects. Observations occurred during daylight hours between sunrise and sunset, as bighorn sheep are rarely active at night (Sayre and Seabloom 1994). The observation days were divided into morning, midday, and evening time periods. The number of morning, midday, and evening observations were distributed equally throughout each season. The three routes were travelled in different rotations, and start time and locations were varied to reduce observation biases (Fairbanks et al. 1987). Due to time constraints and to minimize pseudoreplication, one group observation was conducted per route. Additionally, the first group encountered was observed to reduce biases towards easily detectable groups. Large groups or certain age-sex classes may be more readily observed, therefore setting this observation rule ensured the first group regardless of size or composition was observed (Altmann1974).

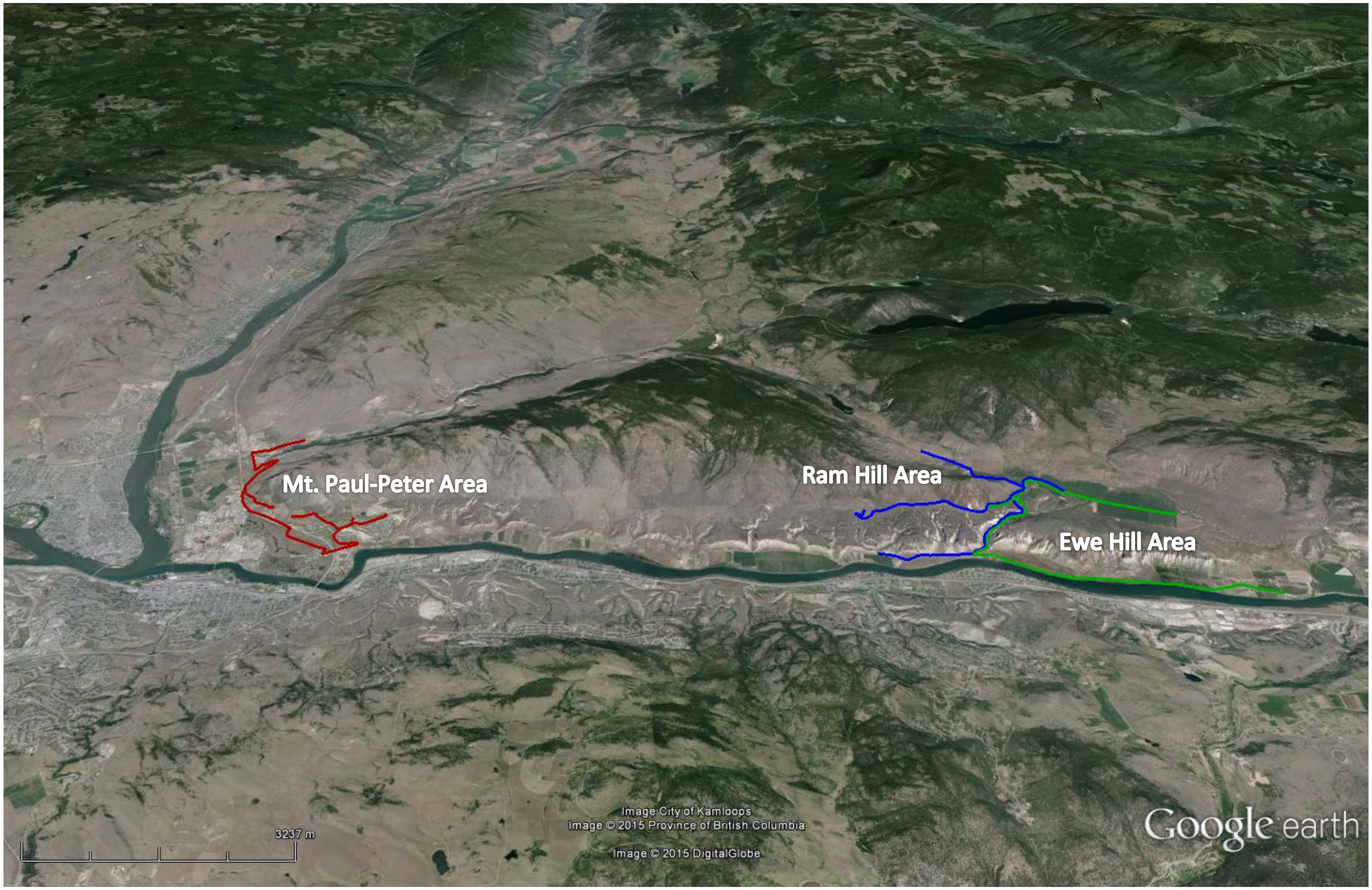

Figure 2.1 Three predetermined routes (a) Mt. Paul and Mt. Peter (red line), (b) Ram Hill (blue line), and (c) Ewe Hill (green line) travelled for bighorn sheep observations from July 2008 to November 2009 near the community of Kamloops (N 50° 40’ 34”, W 120° 20’ 27”) in the southern interior of British Columbia, Canada (image obtained from GoogleEarth, February 25, 2015).

Observations were conducted at a distance of between 100 and 1000 m with binoculars (Bushnell Excursion EX 10x42) and a spotting scope (Bushnell Legend 20-60x80mm). Observations were conducted from a distance of ≥ 100 m to avoid disrupting animals from their normal behaviours. Groups were identified by using Frid's (1997) definition "a set of individuals which, in terms of structural attributes of the environment, were under similar predation risk". Groups were defined as >1 individuals occurring in a spatially discrete area and occupying similar habitat type.

Bighorn sheep were randomly selected using a table of random numbers and were observed during five minute focal animal samples (Altman 1974, Thompson et al. 2007). Activity budgets (Ruckstuhl 1998) were collected on five randomly selected bighorn sheep and each individual was observed for 5 minutes or until the animal moved out of sight. Activities were recorded by instantaneous sampling at ten second intervals. Five exclusively observable behaviours were recorded: feeding, laying, standing, moving, and interacting. Feeding was defined as grazing, browsing, and foraging bouts where the sheep's head remained below its shoulders. Laying included ruminating bouts because it was not possible to distinguish whether sheep were ruminating when the mouth was not visible to the observer. Standing was considered still posture and included vigilant bouts. Moving was defined as walking or running with forward movement with the sheep's head above its shoulders with no evidence of foraging. There were a number of behaviours that were considered interacting, including but not limited to mating tactics such as dominance encounters and courtship (Hogg 1984), play, and nursing. Sampling sessions that were truncated by over 50% out of sight occurrences were discarded. If sheep became disturbed, observations were terminated. The mean duration of time spent in each behaviour was calculated from the activity budgets.

During each observation, the date, time, season, weather, location, habitat type, group size and composition, and observable behaviours were recorded for the first group encountered on each transect. Bighorn sheep were classified based on Geist's (1971) sex-age classification of mountain sheep defined by sex, body size, and horn size. The classification was adapted for the study to the following classes: lambs; yearlings (female, male, indistinguishable); rams (Class II – IV); and ewes. Three categories were defined for analyses: subadult (including lambs and yearlings), adult rams, and adult ewes. Subadults were excluded from the analyses because their behaviour is likely dependent on their mothers' behaviour (Shackleton and Haywood 1985, Corti and Shackleton 2002).

Habitat type was recorded for each observation. Habitat was stratified into four major habitat types: escape terrain, sagebrush-steppe grasslands, agricultural modified, and urban. Escape terrain consisted of silt cliffs, rock faces, and talus slopes. Sagebrush-steppe grasslands were dominated by bluebunch wheatgrass, big sagebrush, and rough fescue. Agricultural modified areas consisted of modified grassland pastures and hayfields. Urban areas were the Sun Rivers golf course and residential development. The relative area of each habitat types was not determined so there is potential for biases because the area of one of the habitat types may be disproportionately high and behaviours in this area may be overrepresented.

The original study was designed to concentrate on habitat selection. However, it was not possible to collar ewes due to health concerns associated with chemical immobilization. Without collar data or a sightability model (correction factors based on behavioural and environmental factors that influence detection), the assumption that bighorn sheep were visible in all habitats was deemed a major limitation to measuring habitat use. Subsequently, data analyses shifted to an evaluation of behaviour.

Pseudoreplication is expected in the behavioural observations because bighorn sheep were unmarked and identity was unknown. To minimize pseudoreplication, only one observation was conducted per route per observation day to avoid recording the same individual more than once. To address independence of observations, bighorn sheep were randomly selected from the first group encountered on the route. Routes were travelled twice per week and were separated by at least a day. Also, routes were travelled in different rotations, starting locations, and times.

Data Analysis

A four-way analysis of variance (ANOVA) was used to examine the main and interacting effects of activity, sex, season, and habitat type on the mean duration response variable. Data were tested for normality and equality of variances prior to statistical analyses. A post-hoc Tukey's Honest Significant Difference (HSD) test was used to determine differences among means. Statistical analyses were conducted using the R statistical software, version R.3.1.1 (R Developmental Core Team 2014) with significance accepted at an alpha value ≥ 0.05. Values are presented as the arithmetic mean ± one standard error (SE).

RESULTS

Behavioural data were collected from 248 individual ewes and rams from the summer of 2008 to the fall of 2009. Time spent was significantly affected by activity; whereas, sex, habitat type, and season did not have a significant main effect (Table 2.1). Activity by sex by season, activity by sex by habitat type, and activity by habitat type by season interactions were significant.

Table 2.1 Results from 4-way ANOVA for average time spent by activity, sex, season, habitat type and their interaction for adult bighorn sheep from the South Thompson bighorn sheep herd from the summer of 2008 and the fall of 2009. Asterisks denote significance.

	Degrees freedom	*F*-value	Probability	
Activity	4	107	<0.001	*
Sex	1	0.00	0.996	
Habitat Type	3	0.00	1.000	
Season	3	0.00	1.000	
Activity x Sex	4	5.17	<0.001	*
Activity x Habitat Type	12	7.32	<0.001	*
Sex x Habitat Type	3	0.00	1.000	
Activity x Season	12	2.99	0.005	*
Sex x Season	3	0.00	1.000	
Habitat Type x Season	7	0.00	1.000	
Activity x Sex x Habitat Type	12	3.84	<0.001	*
Activity x Sex x Season	12	2.50	0.003	*
Activity x Habitat Type x Season	28	1.92	0.003	*
Sex x Habitat Type x Season	4	0.00	1.000	
Activity x Sex x Habitat Type x Season	16	0.734	0.761	

The amount of time bighorn sheep spent in the 5 observable behaviours were significantly different with the greatest amount of time spent feeding followed by laying, standing, moving, and interaction, according to the Tukey post hoc comparison of the activity main effect (Figure 2.2).

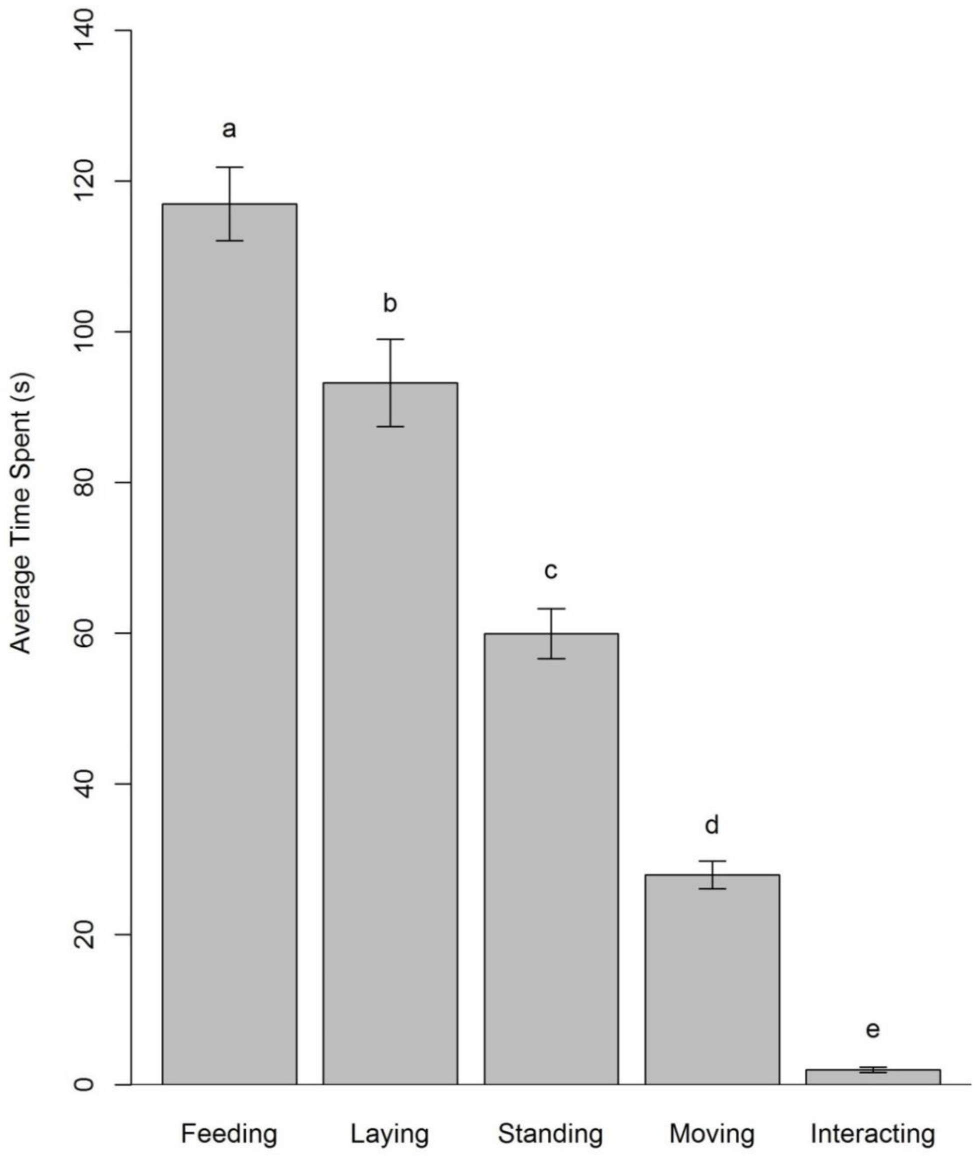

Figure 2.2 Average time adult bighorn sheep spent in seconds (s) in five activity types (feeding, laying, standing, moving, and interacting) observed during five minute samples from July 2008 to November 2009. Error bars represent ± one standard error SE and bars sharing the same letter are not significantly different as determined by Tukey's HSD test.

There was an interaction effect among activity, sex, and season (Table 2.1) (Figure 2.3). In spring, ewes stood longer than rams. In summer, rams lay more and moved and stood less than ewes. In fall, ewes fed longer than rams whereas rams stood and interacted more than ewes. In winter, activities were similar between ewes and rams.

There was also an interaction effect among activity, sex, and habitat type (Table 2.1) (Figure 2.4). Ewes did not lay or interact in agricultural areas where rams did both. In escape terrain, ewes spent more time feeding, standing, and moving than rams and less time laying than rams. Ewes spent more time laying than rams in sagebrush-steppe grasslands whereas rams spent more time standing, moving, and interacting than ewes. In urban areas, ewes spent more time feeding than rams and rams spent more time interacting than ewes.

Lastly, there was an interaction effect among activity, season, and habitat type (Table 2.1) (Figure 2.5). In spring, bighorn sheep were not observed using agricultural or urban habitats. Most of the feeding occurred in the sagebrush-steppe grasslands with some occurring in the escape terrain. In summer, significantly more feeding occurred in the urban areas than in the escape terrain. More time was spent laying in the escape terrain and sagebrush-steppe grasslands than in agricultural and urban areas. Bighorn sheep stood and moved more in agricultural areas than they did in escape terrain and in the sagebrush-steppe grasslands. Very little interacting occurred between bighorn sheep in any of the habitat types. In fall, bighorn sheep fed significantly more in agricultural areas followed by urban areas and the least in escape terrain and sagebrush-steppe grasslands. They lay more in escape terrain and sagebrush-steppe grasslands than in agricultural and urban areas. Standing occurred significantly less in agricultural areas. Moving and interacting were not significantly different for any of the habitat types. In winter, feeding was significantly different among the four habitat types and occurred most to least in the following order: urban areas, sagebrush-steppe grassland, escape terrain, and agricultural areas. Laying did not occur in agricultural areas and occurred most in escape terrain and in sagebrush-steppe grasslands. Standing and moving occurred most in agricultural areas.

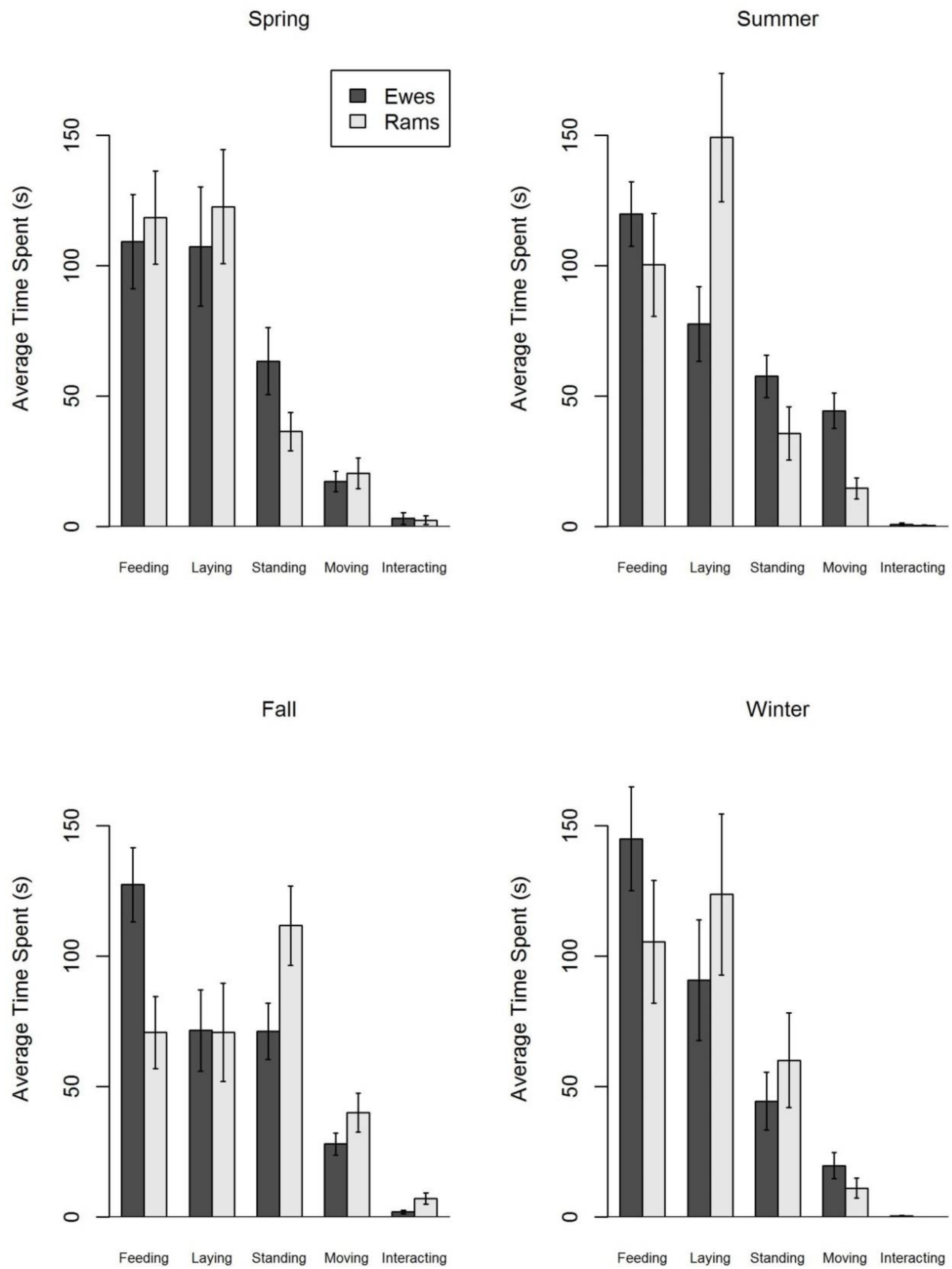

Figure 2.3 Average time adult bighorn sheep spent in seconds (s) by activity, sex, and season observed from July 2008 to November 2009. Error bars represent ± one standard error SE.

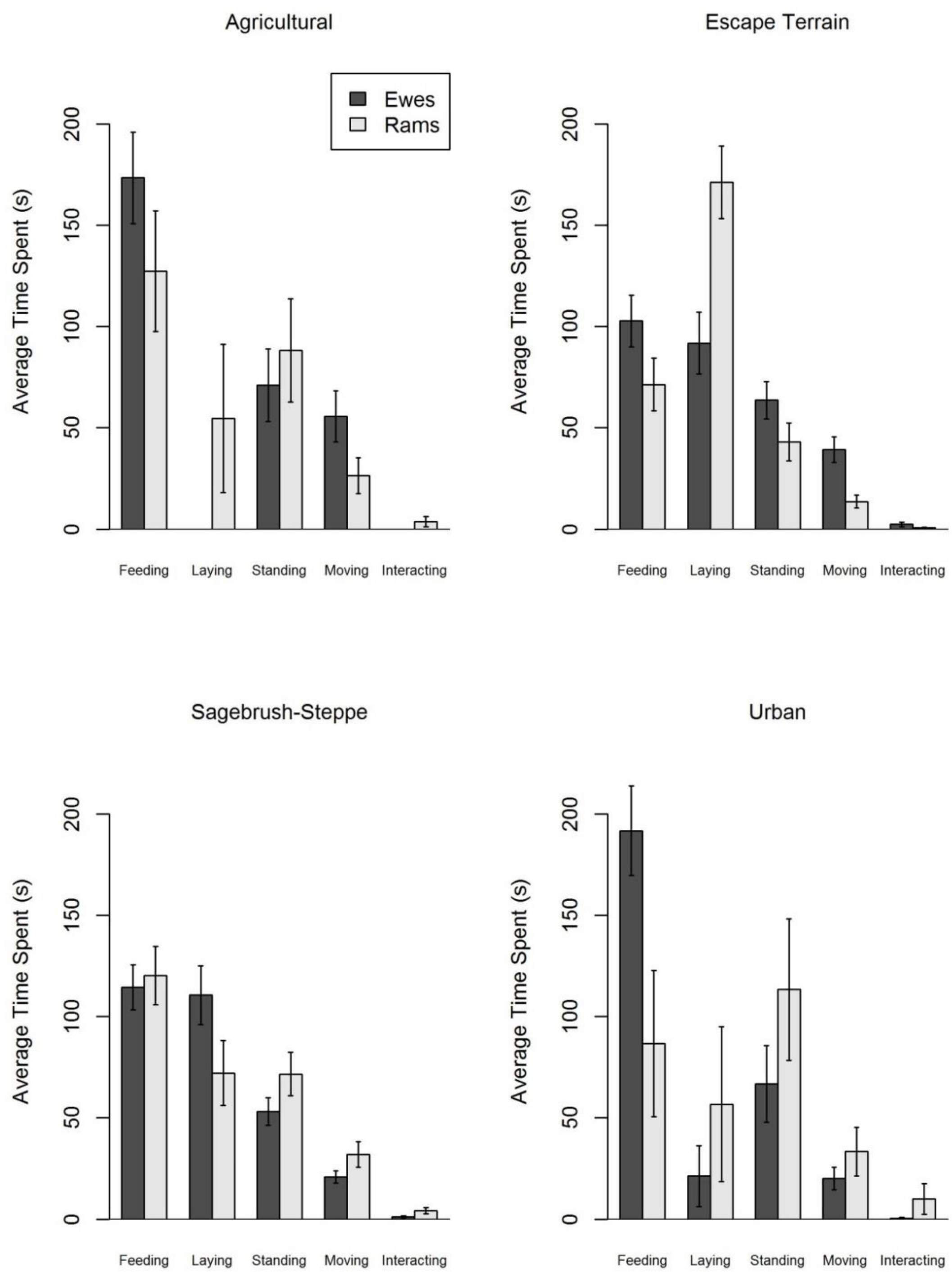

Figure 2.4 Average time adult bighorn sheep spent in seconds (s) by activity, sex, and habitat type observed from July 2008 to November 2009. Error bars represent ± one standard error SE.

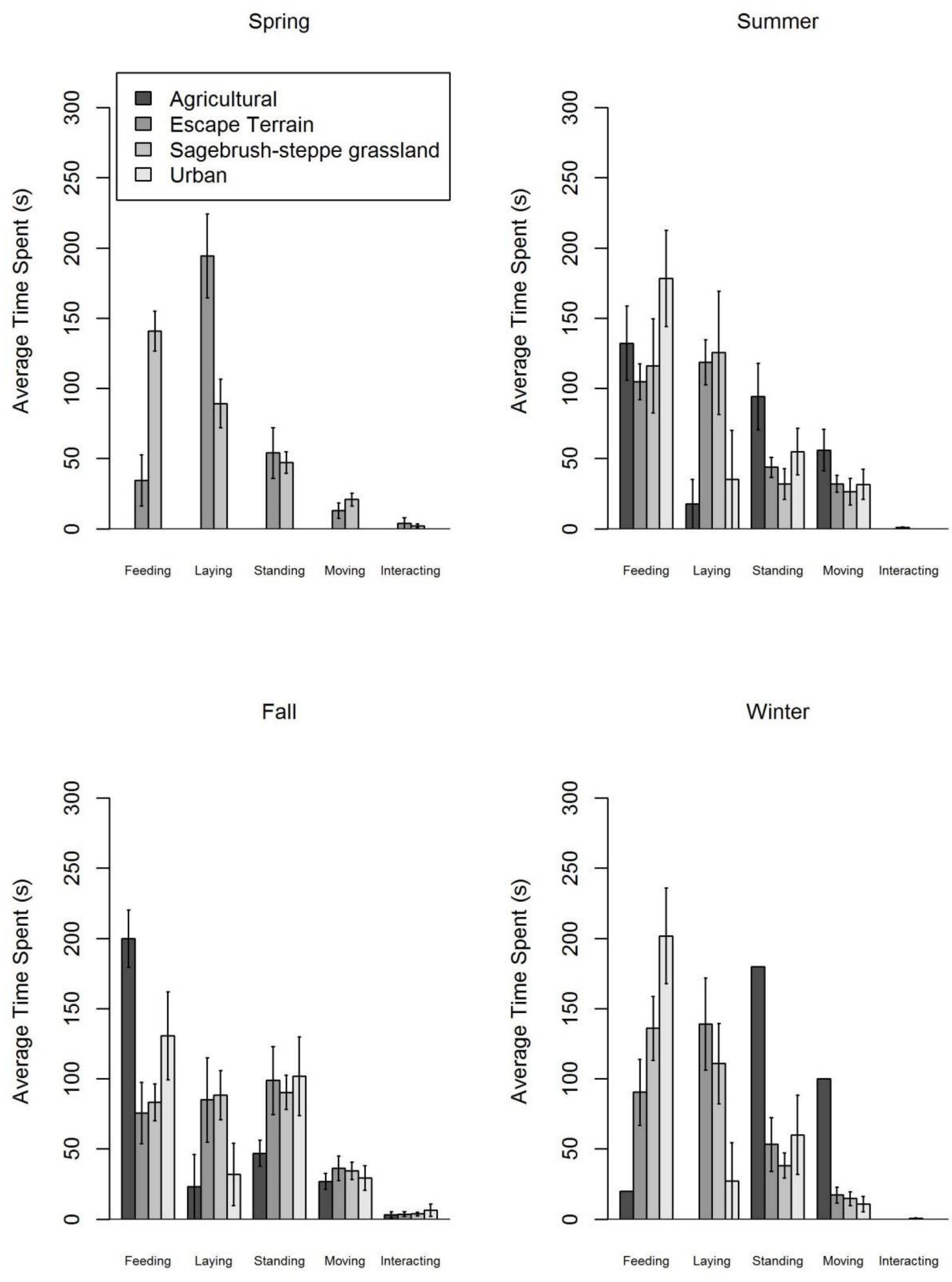

Figure 2.5 Average time adult bighorn sheep spent in seconds (s) by activity, habitat type, and season observed from July 2008 to November 2009. Error bars represent ± one standard error SE.

DISCUSSION

Grazing behaviour of ungulates is driven by numerous constraints which can affect optimal forage intake such as the morphology and physiology of the animal, forage availability and quality, characteristics of the plants that are selected, risk of predation, and social organization (Illius and Gordon 1987, Kie 1999). Behavioural responses are influenced by a decision making process where an animal selects a particular activity in relation to benefits obtained and risks avoided (MacArthur and Pianka 1966). Behavioural ecologists have the challenge of determining what drives these choices and interpreting how they affect behavioural responses.

In accordance with the first objective of this chapter, the activity budgets of adult bighorn sheep in the South Thompson herd were examined. Evaluating the duration of time devoted to particular activities is an important measure for interpreting activity budgets and the influential constraints (Altmann 1974, Belovsky and Slade 1986). The amount of time bighorn sheep spent in the 5 observable behaviours was significantly different with the greatest amount of their time spent feeding (38%) followed by laying (32%), standing (20%), moving (9%), and then interacting (1%). These data correspond with the literature which suggests that most ungulates including bighorn sheep spend the majority of their active bouts feeding (Hudson 1985, Ruckstuhl 1998). Bighorn sheep are ruminants and rumination is usually associated with alternating bouts of feeding and resting (Owen-Smith 1988). This allows animals to digest coarse materials and lessens the time they are exposed as they can consume forage relatively quickly and then ruminate in areas where they are secure from predators (Perez-Barberia and Gordon 1998). This likely explains the fact that laying was the second most common activity observed in this study.

The second objective was to evaluate the main effects and interactions of activity, sex, season, and habitat. Although activity was the only significant main effect there were significant interactions among (1) activity, sex, and season, (2) activity, sex, and habitat, and (3) activity, habitat and season. These results highlight that seasonal variations, sexual differences, and habitat associations are important considerations when evaluating the behaviours of the South Thompson herd.

Sexual segregation was observed in the South Thompson herd and there were behavioural differences among seasons and between the maternal and bachelor groups. Ungulates commonly sexually segregate spatially and temporally across feeding niches and heterogeneously distributed resources (Illius and Gordon 1987). Jarman (1974) suggested that niche separation and social organization are influenced by body size allometry, energetic requirements, and foraging ability of an animal and that synchronization of behaviour strongly influences group cohesion. Condradt (1998) and Ruckstuhl (1998) indicated synchrony in activity budgets occurred in groups of individuals of similar size as it is likely costly to synchronize activities among animals that have substantial differences in energy requirements and consequently activity budgets.

Males and females in many ungulate species are dimorphic with males being considerably larger than females (Owen-Smith 1988). Bighorn sheep are sexual dimorphic with rams typically 50 % larger than ewes (Ruckstuhl and Festa-Bianchet 2001). This is an important factor because body size influences the energetic requirements and foraging patterns of ungulates (Ruckstuhl 1998). Ungulates metabolic rate is allometric to their body weight, meaning as weight increases their metabolic rate decreases (Jarman 1974). Therefore with higher metabolic rates, smaller individuals have relatively greater nutritional needs than larger individuals. Typically animals with high nutritional needs will spend more time foraging relative to an animal with lower energy requirements (Bunnell and Gillingham 1985). Meanwhile gut capacity is proportional to body size with gut capacity increasing with additional body weight (Owen-Smith 1988). This means larger individuals have proportionally larger guts allowing for slower passage and more efficient digestion (Demment and Van Soest 1985, Illius and Gordon 1992). Mysterud (1998) suggested that the larger males in temperate, sexually dimorphic ungulates may feed less and consume lower quality forage because of their slower rumination time. Consequently, it was expected that the bighorn sheep ewes would spend more time foraging than rams in order to meet their higher nutritional demands due to their higher metabolic rate and smaller gut size. However in this study, this was only observed during the fall when ewes spent significantly more time feeding than the rams.

Body size and sexual dimorphism are also recognized to affect vulnerability to predation and consequently foraging behaviours. Berger and Cunningham (1988) examined the effects of body size on vigilance rates for four ungulate species: bison, mule deer, bighorn sheep, and pronghorn. Their findings indicate that vigilance decreased with increasing body size, implying smaller-bodied animals are more vulnerable to predation. The presence of young also affects susceptibility to predators and behaviour. Young are at higher risk for predation than adults; therefore, mothers face a foraging versus vigilance tradeoff. Time allocated to vigilance is expected to increase predator detection and avoidance (Lima and Dill 1990). Festa-Bianchet (1988) found in their study bighorn sheep ewes with newborn lambs used areas with lower quality forage likely due to an anti-predator strategy. Berger (1990) showed bighorn sheep ewes with young compromise foraging efficiency for increased vigilance in order to protect their offspring whereas rams foraging efficiency was higher and they utilized areas with higher predation risk. Given these findings, it was expected that South Thompson ewes would be more prone to predation, particularly ewes with lambs, and therefore would be more vigilant than rams. In the study, ewes did spend more time standing than rams in the spring and summer. In bighorn sheep standing includes vigilance bouts and as such the greater time spent standing by the ewes was likely due to their greater vigilance.

Conversely, in the fall ewes fed longer than rams whereas rams stood and interacted more than ewes. These results are consistent with literature on ram behaviour associated with rut (Geist 1971, Pelletier et al. 2005, Pelletier et al. 2009). Rut occurs during the fall and during this time a number of mating tactics are employed by bighorn sheep rams (Pelletier et al. 2005). These include tending where a ram guards a ewe from other suitors and coursing where a subdominant ram physically displaces a guarding ram typically involving head butting and kicking. These tactics could result in increased standing and interacting time. In addition, rams experience rut-induced hypophagia where there is a tradeoff between foraging and mating activities (Pelletier et al. 2009). Foraging activities are reduced in favour of maximizing reproduction opportunities. Additionally, the higher time spent foraging observed in the ewes may be due to a strategy to improve body condition prior to the winter as herbivores are known to adopt foraging strategies where increased time is spent foraging to optimize forage intake and accumulate body fat in preparation for the energy demanding winters that typically have a shortage of food (Shipley et al. 1994).

During the winter, activities were similar between ewes and rams. However, differences in activity budgets may be underrepresented because ram groups in the Ram Hill area camped out at a hay storage area for the majority of the winter observations. This resulted in limited observations because this group location was less than 100 m from the predetermined route and therefore was often not captured.

The third objective of this chapter was to determine the main behaviours that are occurring on the human developed landscape and when the bighorn sheep are using these habitat types. It is important to identify what behaviours occur in these habitat types to try to determine why they are selected. Also of importance is determining whether there is a particular time of year that the developed areas are utilized. The results of the study show intersexual and seasonal behaviour differences in developed areas. It is particularly important to note the activity patterns on the developed land because this information can support herd and habitat management plans and help guide local land use guidelines.

In agricultural areas, ewes did not lay or interact whereas rams did both. This lack of laying may suggest that the ewes spend time foraging in the agricultural areas and then move off to other areas to lay and ruminate which could be a defence mechanism as ewes are more susceptible to predation and therefore may be more reliant on escape terrain (Berger and Cunningham 1988). Main and Coblentz (1990) suggest ewes choose habitats that offer safety from predators even though the forage quality and quantity may be inferior whereas rams choose habitats with higher forage quality and quantity regardless of predator pressure. Bighorn sheep stood and moved more in agricultural areas than they did in escape terrain and in the sagebrush-steppe grasslands. This may be due to the increased exposure to predators, decreased horizontal visibility due to higher vegetation density, and increased distance to escape terrain. As a result, bighorn sheep may be more vigilant in these developed habitat types. Studies report that vigilance by bighorn ewes increase with increased distance from escape terrain (Risenhoover and Bailey 1985) and vegetation density (Frid 1997).

In urban areas, such as the golf course and residential development, ewes spent more time feeding than rams, and rams spent more time interacting than ewes. Pre-rut and rut in the Mt. Paul and Mt. Peter area was concentrated on the golf course which may explain why rams spent more time interacting in this habitat type likely employing mating tactics (Pelletier et al. 2009). Rams probably fed less in urban areas because when this habitat was used they were experiencing rut-hypophagia. In this study, ewe groups were repeatedly observed frequenting the residential development and golf course throughout the year except during the lambing period. Rubin et al. (2002) also reported a subpopulation of bighorn sheep that fed and rested on urban lawns year round with the exception of spring. In their study, urban use was associated with concentrated use and contracted core activity areas, increased distance from secure escape terrain, and use of gentler slopes likely increasing vulnerability to predation. In addition, concentrated animal numbers resulted in elevated parasite transmission. Their findings illustrate tradeoffs that may occur when bighorn sheep use urban areas.

The only season bighorn sheep were not observed using agricultural or urban habitats was in the spring. Maternal groups may not have used these habitat types in the spring because during lambing they are typically found on lambing grounds characterized by precipitous terrain where they are secure from predators (Geist 1971, Tilton and Willard 1982). Rubin et al. (2002) found urban areas were used the least during spring which corresponded with peak lambing. They also reported that spring was the only season the urban and remote subpopulations selected escape terrain with the similar slope. In the South Thompson range, agricultural and urban habitat types are generally located away from escape terrain. Krausman et al. (1989) noted that proximity to escape terrain affects habitat use. In spring, most of the feeding in the South Thompson range occurred in the sagebrush-steppe grasslands with some occurring in the escape terrain. The sagebrush-steppe grasslands in the study area are often bordered by the escape terrain and the new vegetative growth in the grasslands may provide the bighorn sheep with adequate forage to meet their energetic requirements (Shackleton 1999, Holechek et al. 2011).

In the summer, significantly more feeding occurred in the urban areas than in the escape terrain. The urban areas have irrigated lawns and the availability of this high quality forage may be attracting the bighorn sheep. Native grass species in the sagebrush-steppe grasslands habitat type reach maturity and decrease in nutrient value during the summer (Holechek et al. 2011). It should be noted that both observation summers were considerably drier than normal with 12 mm and 6 mm of rain in June in 2008 and 2009, 14 mm and 19 mm in July, and 15 mm and 2 mm in August in comparison to the average of 37 mm, 31 mm, and 24 mm, respectively (Environment Canada 2015). June is typically the wettest month of the year and is associated with a flush in plant growth which could have affected vegetative growth on the native range (Holechek et al. 2011). Rubin et al. (2002) found bighorn sheep use of urban areas in southern California was the highest between August and October. Another attractant may be the water sources available in the urban areas, such as the golf course irrigation system, a water trough at the transplant bait site, and ponds in the housing development. Also in the summer, more time was spent laying in the escape terrain and sagebrush-steppe grasslands than in agricultural and urban areas. It is likely that bighorn sheep are foraging in the developed areas and retreating to escape terrain and sagebrush-steppe grasslands to ruminate in a safer environment.

In the fall, bighorn sheep fed significantly more in agricultural areas followed by urban areas and the least in escape terrain and sagebrush-steppe grasslands. These developed areas likely provided higher forage quality and quantity in fall than native environments as the regrowth on hayfields and modified grasslands and the irrigated and fertilized golf course and residential lawns would provide higher quality forage than mature native plant species growing in the escape terrain and sagebrush-steppe grasslands (Holechek et al. 2011). In the fall during the rut, sheep are concentrated in the developed areas because the golf course and a pasture along the East Shuswap Road are the primary rutting grounds for the Mt. Paul and Mt. Peter and Spiyu7ullucw Ranch band, respectively. Each fall rams return to their respective rutting areas (Geist 1971).

In the winter, there were significant differences in the time spent feeding in the four habitat types and occurred most to least in the following order: urban area, sagebrush-steppe grassland, escape terrain, and agricultural areas. Bighorn sheep tend to favour areas with low snow cover especially slopes with southerly aspect where snow accumulation reduces quickly and provides access to forage (Smith et al. 1991, Shackleton 1999). The predominant southwest exposure of the urban area and sagebrush-steppe grasslands may have resulted in less snow due to solar radiation and wind allowing access to forage. The agricultural areas in the study area generally occur on flat sites where snow may accumulate covering forage. Of note, the average snowfall for December is 22 cm and in December 2008 during the winter observations 38 cm of snow fell (Environment Canada 2015). During the winter there was only one group observation in the agricultural habitat type. The maternal group was observed in a field and were primarily standing and moving with some feeding occurring during the observation. A possible explanation is that the sheep group was passing through this area to access other habitat types. However again it should be noted that ram groups in the Ram Hill area camped out at a hay storage area for most of the winter and often observations were not captured because this location was less than 100 m from the predetermined route.

Management Implications and Recommendations

Because wildlife populations are inherently dependent upon available habitat it is essential to investigate how human development, infrastructure, and activities affect local populations (Polfus and Krausman 2012). The South Thompson herd occupies an area that has considerable and varied anthropogenic land use and activities. This study demonstrates that use of urban areas affected the South Thompson bighorn sheep herd behaviour, which is important when considering the long term impacts of human development and activities on the herd. In the study area, urban and agricultural areas appear to be attracting bighorn sheep which could significantly impact their physiology, abundance, distribution, and population demographics (Polfus and Krausman 2012). The abundance and quality of forage in these developed areas may be negating the need for the sheep to migrate higher in elevation in the summer months for continued access to high quality forage. In this manner the developed areas are likely altering the normal behaviour of the bighorn sheep.

The study findings show bighorn sheep in the South Thompson herd are using the residential development, the golf course and agriculture lands. This will be an important consideration when developing a management plan for the herd and for the management of the land base. In essence these areas have become part of their habitat and likely contribute to the high fecundity of the herd as they are likely providing high quality forage at critical times. Management plans need to account for this and assess whether this habitat will be available in the future. Factors that might limit use or access should be reviewed and addressed.

Due to the forage and resources available in the developed areas, these areas may have an artificially high biological carrying capacity relative to native range. It would be useful to calculate the carrying capacity of the native habitat without the developed land component. This would provide a target number of animals that can be supported on the natural land base. Further work should be done to try to quantify the usage of the developed land to determine the maximum carrying capacity of the total land base. Any potential loss of access to land should be also considered in this calculation. Having a target or threshold population size may be critical as overabundance has been associated with many herd die-offs reported in the literature and decreased compatibility with human populations. Defining a variety of management options and developing comprehensive contingency plans will help accommodate the balance required for ecological aspects of the herd and the opposing social conflicts that can arise.

Bighorn sheep may behave similarly in developed areas as they do in their natural habitats if the developed areas provide key habitat features (Smith et al. 1991, Sweanor et al. 2006). Jansen et al. (2006) found bighorn sheep use and behaviour were comparable between native range and an active copper mine provided the developed area encompassed similar landscape features such as highwalls that provided escape terrain and revegetated sites that provide adequate forage in close proximity to security. The substantial use of the agricultural and urban areas by the South Thompson bighorn sheep herd indicates these habitat types provide key landscape features that attract bighorn sheep. In this study, types of agricultural and urban areas were not delineated such as modified grasslands versus hayfields and golf course versus residential. However, bighorn sheep may use varying agricultural and urban areas very differently. It was noted that bighorn sheep rarely used the hayfields adjacent to the Spiyu7ullucw Ranch Headquarters. Although this area may provide superior forage, it is speculated that the distance to escape terrain discourages use. As a result, it is necessary to consider how resources are distributed to predict habitat use and activity patterns. Areas of high quality forage located in areas with high predation pressure at distance from escape terrain may be avoided as a tradeoff between forage efficiency and security.

This part of the study examines the behavioural responses of bighorn sheep to anthropogenic influences but it would be advantageous to extend this research to assess higher level population measures such as abundance, distribution, and demographics and whether these affect reproduction and survival rates (Polfus and Krausman 2012). McClure et al. (2005) found that mule deer using urban areas in northern Utah had lower fawn recruitment rates and contracted home ranges. At the present time, it appears human developed areas in the South Thompson range are supporting high lamb recruitment; however, increased number of sheep and concentrated use could lead to issues relative to nutritional stress, parasite transmission, and body condition that could make the herd susceptible to a major disease outbreak.

At the present time there are some relatively large areas within the South Thompson bighorn sheep range that appear to receive little or no use. To attempt to determine the reason for this, an evaluation of habitat selection and suitability are recommended. These analyses would help to identify key features and interpret why certain areas within their range are not presently being used. For example, is this lack of use due to limited escape terrain, lack of water in the area, or because of the herd's strong fidelity to their current range and the tendency of bighorn sheep not to expand into new areas (Geist 1971)? It is important to determine this prior to stewardship dollars being spent to promote use of areas or before excluding any developed areas. This will be beneficial for prioritizing and optimizing limited conservation and stewardship funding.

The observation that South Thompson population is considered a resident herd lacking movement to higher elevations during the summer is a key consideration. Most ungulates migrate in elevation seasonally using lower elevation range in the winter and higher range in the summer coinciding use with plant growth when forage nutritional value and digestibility are high (Van Soest 1994). Changes in bighorn physiological demands coincide with seasonal variation and affect how much energy is required for maintenance, growth, reproduction, and survival (Festa-Bianchet 1988). During the plant growing season, herbivores may adopt foraging strategies where increased time is spent foraging to optimize forage intake and accumulate body fat in preparation for the energy demanding winters that typically have a shortage of food (Shipley et al. 1994). Payer and Coblentz (1997) suggest seasonal variation in bighorn sheep behaviour and habitat use creates considerable implications for management and conservation of suitable habitats because their importance may differ throughout the year. This may be related to the availability of high quality forage on the agricultural land and the golf course/residential development within the study area. It will be important to consider this behaviour when developing a management plan for the herd especially if access to these developed areas is ever limited.

Another key consideration is that wildlife management in developed settings can be limited due to human expectations so it is essential to understand why habitats are used in order to communicate their importance to the public, land owners, and stakeholders. Currently in BC, there is increased number of conflicts related to urban habituated ungulate populations (Hesse 2010). With the increasing bighorn sheep numbers and concentrated use on developed land on the South Thompson range, there is an increased risk of human-wildlife conflicts and public concerns. Ungulate use of urban areas often coincides with concerns related to property damage, human safety, wildlife welfare, and disease transmission (Polfus and Krausman 2012). Public perceptions can limit the management options and tools in urban areas. Therefore it is of the utmost importance to encourage public education and awareness of the herd. Education programs can engage the community and raise awareness and appreciation for a species. This could encourage community involvement and a feeling of ownership and responsibility for the herd which would be beneficial for promoting both a healthy population and habitat.

A predator survey of the area would help assess the current and potential predator pressure and the possible influence on bighorn sheep behaviours. The bighorn sheep may be using urban areas as a predator-avoidance strategy; however, there is the risk ungulates using or habituated to urban areas might subsequently attract predators (Polfus and Krausman 2012). Concerns of predator presence to public safety could degrade the public's perception of the herd and create a demand for mitigation. Therefore, proactively including a discussion of predators in public education strategies may promote public awareness and support cooperative management attempts.

In conclusion, behaviours differed seasonally, among habitat types, and between sexes. Currently, the developed areas (agricultural and urban) appear to be an integral part of the South Thompson bighorn sheep range. Although at present the developed areas appear to be having a positive impact on the herd it is important to consider the implications if herd numbers continue to increase. It will be important to consider this when developing a management plan for the herd and management of the land base especially with any proposed land use changes.

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Personal Communication

D. Jury, Senior Wildlife Biologist, British Columbia Ministry of Environment, Environmental Stewardship Division, Kamloops, BC

CHAPTER 3 GASTROINTESTINAL PARASITOLOGY AND FECAL GLUCOCORTICOID CONCENTRATION DIFFERENCES AMONG EWE BANDS ACROSS VARYING ANTHROPOGENIC INFLUENCES

INTRODUCTION

Bighorn sheep have a strong fidelity to their home range, a tendency not to expand into new areas, vulnerability to numerous extrinsic and intrinsic stressors, and susceptibility to a myriad of bacteria, viruses, parasites, and diseases and as such their populations can be particularly impacted by environmental disturbances and anthropogenic influences (Geist 1971, Enk et al. 2001, Worley et al. 2004). Coping with stressors and resisting pathogen infection are energetically costly to bighorn sheep and likely result in an energy tradeoff of other life-history functions such as maintenance, anti-predator strategies, reproduction, and feeding efficiency (Breazile 1987, Festa-Bianchet 1988, Ruckstuhl 1998, Pelletier et al. 2005). These tradeoffs can potentially affect habitat use, behaviour, predator evasion, and nutritional status which may contribute to reduced overall fitness, suppressed immune response, and increased risk of respiratory disease. Respiratory disease is responsible for causing debilitating all-age die-offs that are endemic to bighorn sheep populations and are recognized as the principal limiting factor for populations and recovery efforts (Gross et al. 2000, Cassirer and Sinclair 2007).

Bighorn sheep are susceptible to numerous infectious agents including ectoparasites, endoparasites, bacteria, and viruses (Schwantje 1988). It is unclear whether infectious agents operate solely triggering respiratory disease or if the accumulating effects of a number of limiting factors working in unison to compromise the health of the animal and increase their susceptibility to infection (Miller et al 2012). The fact that infectious agents identified as the causal epizootic can be present in both healthy and pneumonic bighorn sheep provides a diagnostic challenge for interpreting the etiology of the disease (Aune et al. 1998, Miller et al. 2012). Furthermore, the concurrent infection by multiple infectious agents in combination with environmental and host factors likely have cumulative effects compromising bighorn sheep immunity. This emphasizes the need for infectious agent surveillance to understand what bighorn sheep are infected with and their potential to jeopardize animal health and contribute to the complex multifactorial respiratory disease that is recognized to cause most herd die-offs (Cassirer and Sinclair 2007). Miller et al. (2012) stress the importance of also focusing on host and environmental factors that promote animal health and suggest a risk management approach that aims at protecting populations by maintaining viability rather than determining each causal agent.

Research suggests resisting parasite infection is metabolically costly for bighorn sheep and may affect their health, behaviour, and vulnerability to secondary infection of pneumonic epizootics which may predispose sheep to respiratory disease associated with die-offs (Festa-Bianchet 1989, Pelletier et al. 2005). Parasite burdens can compromise an animal's growth, maintenance, and reproduction by increasing the energetic costly tradeoff associated with parasite immunity (Festa-Bianchet 1989, Pelletier et al. 2005). Kraabel and Miller (1997) suggested that continual environmental stressors are related to the onset of pneumonia-related epizootics in bighorn sheep populations.

Parasite presence and shedding in bighorn sheep can be evaluated using gastrointestinal parasitology surveys (Forrester and Lankester 1997a, Foreyt 2001). Fecal analyses can be used to provide an indirect measure of gastrointestinal parasite infection and can facilitate the understanding of a herd's resiliency in terms of their ability to cope with environmental changes, anthropogenic disturbances, and stressors (Festa-Bianchet 1989, Wilson et al. 2001, Goldstein et al 2005, Pelletier et al. 2005).

Difference in parasite infection and shedding may be caused by variations in (1) host susceptibility which can be affected by age, physiology, previous exposure, and stress, (2) host abundance, distribution, and activity, (3) parasite establishment and transmission which is likely impacted by season, climate, geographic location (Festa-Bianchet 1991, Forrester and Lanker 1997a, Foreyt 2000, Pelletier et al. 2005, Rogerson et al. 2008). It is important to consider these key factors when interpreting the level of parasitism.

Research has documented that lungworms (*Protostrongylus* spp.) are nearly universal in bighorn sheep populations (Cowan 1951, Blood 1963, Forrester and Senger 1964, Uhazy et al. 1973, Festa-Bianchet 1991, Goldstein et al. 2005). The ubiquitous high prevalence of lungworm in bighorn sheep populations with some populations lacking clinical signs of respiratory disease suggests lungworms are not the primary etiological agent. However, Lungworms cause lung tissue damage and potentially contribute to a weakened immune response that may predispose animals to secondary infection of opportunistic epizootics (Bunch et al. 1999). The effects of lungworm burden on the stress response of bighorn sheep have not been fully evaluated but it has been suggested that high lungworm infection could lead to chronic stress and reduced overall fitness (Goldstein et al. 2005). A better understanding of the sheep's physiological response to the presence of lungworms and the impact that lungworms have on sheep metabolic resources and pathogen resistance may help address management concerns regarding how endemic, high lungworm burdens contribute to the pneumonia complex (Rogerson et al. 2008).

Lungworm infected bighorn sheep pass first-stage lungworm larvae (L1) in their feces (Foreyt 2001). These L1 larvae subsequently infect intermediate gastropod hosts and develop into infective third-stage larvae (L3). Bighorn sheep are infected with lungworms when they inadvertently ingest the intermediate host while foraging. Lungworms migrate from the ingested gastropods to the lungs of the infected bighorn sheep where they develop into adults. Infected bighorn sheep often cough up and swallow adult lungworms which subsequently pass through their digestive system. In addition, lungworms can be transferred transplacentally resulting in lambs born with lungworm infection (Hilber et al. 1972). The prepatent period, the time lag between parasite infection and detection in the definitive host, for bighorn sheep lungworm is 5 weeks (Foreyt 2001).

Habitats with high parasite transmission are likely those that promote both an abundance of gastropods and concentration of bighorn sheep (Boag and Wishart 1982). However, parasite transmission likely varies by season, habitat, and region. Rogerson et al. (2008) suggested that understanding the relationships, ecology, and distribution overlap of the terrestrial gastropod intermediate host and the bighorn sheep definitive host may help in measuring parasitism.

Stress, caused by various extrinsic and intrinsic stressors, signals the hypothalamus-pituitary adrenal (HPA) axis and sympathetic nervous system (SNS) of wildlife to produce adrenaline and glucocorticoids (Sapolsky et al. 2000, Reeder and Kramer 2005). These hormones help animals cope with long and short-term stress respectively (Reeder and Kramer 2005). Baseline concentrations of glucocorticoids are present in the circulatory system and contribute to homeostasis (Sapolsky et al. 2000). However, chronic or repetitive stress can cause sustained elevated secretion of glucocorticoids which can have negative effects on the health, fitness, reproduction, and immunity of bighorn sheep (Breazile 1987, Reeder and Kramer 2005, Coburn et al. 2010). Additionally, prolonged stress may render bighorn sheep more vulnerable to pathogen infection and respiratory disease.

Glucocorticoids circulating in the bloodstream are eventually metabolised by the liver and subsequently excreted into the urinary and digestive tracts (Miller et al. 1991). Physiological stress in wildlife can be measured by determining glucocorticoid concentrations in blood, urine, or fecal samples (Moberg 1987, Hunt and Wasser 2003). However, wildlife respond rapidly to capture and handling with an increase in blood glucocorticoids within 2-3 minutes which can cause inflated values that are attributed to the sampling procedure rather than stressors or environmental disturbances (Moberg 1987, Sapolsky et at. 2000). This plus the concern for the welfare of the animals associated with handling limits the value of using blood levels to measure stress. There is a temporal interval before glucocorticoids concentrations are reflected in urine and feces of animals with slow passage rates and long digestive tracts (Millspaugh and Washburn 2004). Sampling urine or feces avoids capturing the spike in concentrations that occur due to handling stress (Millspaugh and Washburn 2004). Miller et al. (1991) validated this technique of measuring physiological stress response in bighorn sheep. Measuring fecal glucocorticoids can help managers interpret average circulating glucocorticoids concentration and can provide an indication of long term stress without handling the animal (Millspaugh and Washburn 2004).

Fecal glucocorticoid concentrations are affected by numerous biological factors such as reproductive state, age, and body mass and ecological factors such as predator pressures, snow level, and temperature (Millspaugh and Washburn 2004). These confounding variables result in glucocorticoid levels being very case specific and make it impossible to state a healthy level; however, animals with similar stressors and physiology may be compared to see if there are relative differences in stress levels due to a specific treatment type such as anthropogenic influences.

Bighorn sheep respond to anthropogenic influences and disturbances behaviourally and physiologically. An increasingly busy landscape has resulted in resource development, land use practices and recreational activities impacting bighorn sheep habitat and providing increased access to bighorn sheep range. Urban development has resulted in many bighorn sheep populations using areas near or within urban settings (Rubin et al. 2002). As discussed in Chapter 2, bighorn sheep may abandon suitable habitat to avoid human activity or become habituated to these areas due to increased forage quality and quantity, presences of water sources, and shelter from predators (Adams 1994, Rubin et al. 2002, Shannon et al. 2014). Forage resources provided by developments are often irrigated and fertilized which may encourage sheep to concentrate grazing on these areas (e.g., golf courses, hayfields, landscaping ornamentals, etc.). Bighorn sheep groups may become accustomed to developed areas which can lead to high animal densities and groups that become sedentary. When animals are concentrated in an area the potential for parasite transmission is increased due to the amount of feces present (Rogerson et al. 2008). Furthermore, irrigated areas provide suitable habitat for lungworm secondary gastropod hosts. Incurred costs such as human encounters, domestic dog harassment, and domestic interspecific competition may counteract the benefits gained from developed areas. These factors can increase the likelihood of elevated stress levels and parasite transmission. Understanding how use of developed areas affects bighorn sheep populations is critical when developing management plans for the herd.

Determining gastrointestinal parasite load and fecal glucocorticoids concentrations have shown to be an effective, non-invasive technique to evaluate and monitor parasite burden and physiological stress levels in wildlife populations (Hunt and Wasser 2003, Walker and Parker 2006). These assessments of overall bighorn sheep herd health help indicate the vulnerability of bighorn sheep populations to disease epidemics (Goldstein et al. 2005). Subsequent management can be focussed on pre-emptive measures to protect bighorn sheep populations by minimising intrinsic and extrinsic stressors that could cause population declines.

The South Thompson herd has increased rapidly since the 1990s and has a high recruitment rate; therefore, the population growth will likely continue to increase. This raises the question of how many bighorn sheep the range can sustain in a healthy state and concerns about the likelihood of parasite transmission due to the increased concentration of sheep on portions of the range. It was anticipated that ewes using areas with higher anthropogenic influence would have elevated stress levels resulting in higher fecal glucocorticoid concentrations. Also, it was predicted that concentrated use of developed areas would result in higher gastrointestinal parasite shedding due to increased likelihood of parasite transmission. In addition, evaluating the effects of differing anthropogenic influences and disturbance on the herd assists with the understanding of stressors and supports proactive population management.

This chapter focuses on determining how seasons and varying levels of anthropogenic influences impact gastrointestinal parasitology and relative stress of the South Thompson herd. The specific objectives were to:

(1) Survey the gastrointestinal parasites present in the herd and their mean intensity and prevalence to establish baseline information,
(2) Evaluate the main effects and interactions of season and anthropogenic influence on lungworm larvae mean intensity,
(3) Evaluate the main effects and interactions of season and anthropogenic influence on fecal glucocorticoid concentrations, and
(4) Determine whether there is a relationship between lungworm load and relative stress.

METHODS

Study Area

This research focused on the effect of season and surrounding land use on the gastrointestinal parasitology and relative stress on bighorn sheep. To carry out this research three bands of the Thompson bighorn sheep population inhabiting different environments were sampled. The Mt. Paul and Peter bighorn sheep band frequently uses urban areas whereas the Spiyu7ullucw Ranch band frequently uses agriculturally modified areas. To provide a remote area comparison, the Dewdrop bighorn sheep band from the Kamloops Lake Herd was included (Figure 3.1).

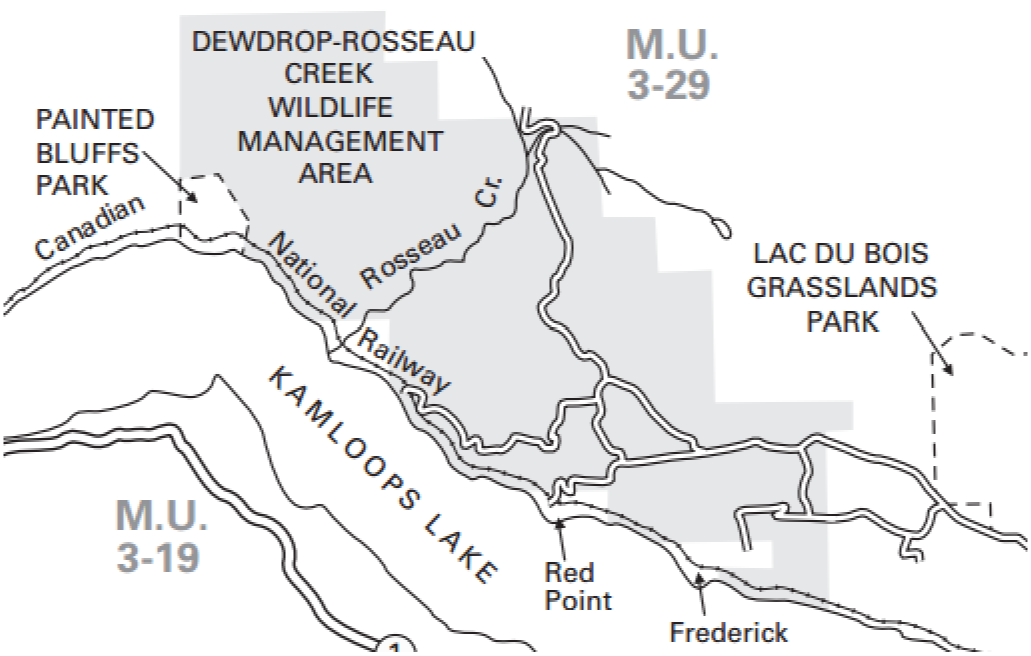

Figure 3.1 Dewdrop area within the Kamloops Lake California bighorn sheep herd range located in Kamloops, British Columbia (British Columbia Ministry of Forests, Lands and Natural Resource Operations 2014).

The Thompson bighorn sheep subpopulation range occurs in the Thompson-Okanagan Highlands ecoprovince and the semi-arid steppe highlands ecodivision of BC (Demarchi et al. 2000). There are two California bighorn sheep herds within the Thompson subpopulation; the Kamloops Lake Herd and the South Thompson Herd. The Kamloops Lake herd range is approximately 13,000 hectares and is located north of Kamloops Lake, west of Kamloops, BC (N 50 º44', W 120º 33'). The population has approximately 225 individuals (Shackleton 1999). The South Thompson Herd range is approximately 7,600 hectares in size and is located north of the South Thompson River, east of Kamloops, BC (N 50º 41', W 120º 18'). The population has approximately 250 – 300 individuals (Lemke 2005).

Average temperatures range from -2.8 ºC in January to 21.5 ºC in July. Annual average precipitation is 277.6 mm with two peaks occurring in June with an average of 37.4 mm as rain and in December with an average of 22 cm as snow (Environment Canada 2015).

Fecal Collection

Ninety fecal samples were collected non-invasively and opportunistically from unmarked ewes from 3 bands in the South Thompson and Kamloops Lake bighorn sheep herds in the spring, summer, and fall of 2009. Seasonally, 10 samples were collected for the 3 areas with differing anthropogenic influences: Mt. Paul urban development and Spiyu7ullucw Ranch agriculturally modified areas within the South Thompson bighorn sheep range and from the Dewdrop remote area within Kamloops Lake bighorn sheep range. Ewe groups were located and were observed until they defecated to ensure freshness and avoid repeat sampling of the same ewe in a single collection period (Forrester and Senger 1964). Fresh samples were collected once the ewes vacated the area to avoid disturbing the group. Collection was limited to ewes to minimise the confounding issues associated with physiological differences between classes of animals.

Samples were placed in Ziploc bags and stored in a cooler during field collection. The date, time, location, and notes were recorded on each sample bag. Each fecal sample was divided into three subsamples for the double centrifugation sucrose floatation method, modified Baermann-beaker extraction method and corticosterone ^{125}I radioimmunoassay (RIA) to determine gastrointestinal parasite ova mean and prevalence, gastrointestinal parasite larvae mean and prevalence, and fecal glucocorticoid concentration, respectively.

Gastrointestinal Parasite Ova

The double centrifugation sucrose floatation technique was used to count gastrointestinal parasite eggs/ova in fecal subsamples (Foreyt 2001). Subsamples were stored in a refrigerator and all counts were completed within two weeks of collection. Five grams of homogenised feces were double centrifuged using water and sugar floatation solution respectively. The centrifuge sediment was mounted on a glass slide and gastrointestinal parasite ova were identified and counted using a compound microscope.

Gastrointestinal Parasite Larvae

The modified Baermann-beaker method was used to count gastrointestinal parasite larvae in fecal subsamples (Forrester and Lankester 1997a). All counts were completed within two weeks of collection. The fecal pellets were slightly crushed because Forrester and Lankester (1997b) found that lungworm larvae were concentrated at the core of the pellet. Subsamples were placed in open paper bags to air dry at room temperature and were subsequently weighed. After the larvae were extracted, the Baermann sediment was poured into a gridded petri dish and larvae were counted using a dissecting microscope. Gastrointestinal parasite larvae mean intensities were expressed as the average number of larvae per gram of dried feces (LPG) and prevalence as the percentage of samples infected with larvae.

Fecal Glucocorticoid Concentration

Corticosterone ^{125}I RIA kits were used to measure fecal glucocorticoid concentrations (Wasser et al. 2000). Validation of the fecal glucocorticoid assays for bighorn sheep was completed by Miller et al. (1991). For each sample, ten fecal pellets were slightly squeezed to produce cracks in the pellets as recommended by a veterinarian parasitologist then stored in freezer at -20ºC. Samples were shipped to the University of Saskatchewan Veterinary Laboratory for the fecal glucocorticoid concentration analysis. Fecal glucocorticoid concentrations were expressed as mean corticosterone nanogram per gram of dried feces.

Pseudoreplication is expected in the fecal samples because bighorn sheep were unmarked and identity was unknown. To minimize pseudoreplication, samples were only collected from ewes observed defecating to avoid repeat sampling of the same ewe during a collection day. Additionally, collection days were separated by a minimum of one day.

Data Analysis

Two-way ANOVAs were used to examine the main and interacting effects of season and anthropogenic influences on the mean intensity of lungworm and mean fecal glucocorticoids concentrations. A linear regression was used to determine whether there was a relationship between lungworm load and fecal glucocorticoid concentrations. Data were tested for normality and equality of variances prior to statistical analyses. A post-hoc Tukey's HSD test was used to determine differences among means. Statistical analyses were conducted using the R statistical software, version R.3.1.1 (R Developmental Core Team 2014) with significance accepted at an alpha value ≥ 0.05. Values are presented as the arithmetic mean ± standard error.

RESULTS

A total of 90 fecal samples were collected from bighorn sheep ewes from the Mt. Paul, Ewe Hill, and Dewdrop areas during spring, summer, fall 2009 to estimate prevalence and mean intensity of gastrointestinal parasite ova and larvae and fecal glucocorticoid concentrations.

Gastrointestinal Parasite Ova

Five genera of gastrointestinal parasite ova were identified and are listed in order of prevalence: *Trichostongylus* spp., *Eimeria* spp., *Trichuris* spp., *Nematodirus* spp., and *Strongyloides* spp. Table 3.1 gives the mean intensity and prevalence by location and season. The mean intensity is the average number of parasite ova that were counted per gram of feces. Prevalence is the percent of samples that were infected by the identified gastrointestinal parasite ova.

Table 3.1 Mean intensity ± one standard error SE and prevalence per 5 grams of bighorn ewe feces for the five gastrointestinal parasite ova genera (*Trichostronglus*, *Trichuris*, *Nematodirus*, *Eimeria*, *Strongyloides*) identified in Mt. Paul (urban), Ewe Hill (agricultural), and Dewdrop (remote) areas in spring, summer, and fall of 2009.

Season	Location	Trichostrongylus		Trichuris		Nematodirus		Eimeria		Strongyloides	
		Intensity	Prevalence	Intensity	Prevalence	Intensity	Prevalence	Intensity	Prevalence	Intensity	Prevalence
	Urban	4.31 ± 1.25	90%	1.41 ± 0.59	60%	2.36 ± 2.21	20%	54.75 ± 20.63	90%	0.97 ± 0.73	30%
Spring	Agricultural	5.84 ± 1.21	100%	1.59 ± 0.77	40%	4.23 ± 3.88	40%	23.62 ± 7.51	100%	0.24 ± 0.11	40%
	Remote	1.67 ± 0.59	60%	0.51 ± 0.30	40%	0	0%	51.89 ± 28.08	60%	0	0%
	Mt. Paul	5.18 ± 1.97	90%	3.47 ± 0.92	100%	25.40 ± 16.40	70%	212.35 ± 104.53	100%	0.85 ± 0.31	50%
Summer	Agricultural	10.4 ± 1.52	100%	1.16 ± 0.36	70%	6.58 ± 4.29	60%	98.63 ± 42.63	100%	0	0%
	Remote	2.62 ± 0.65	90%	0.98 ± 0.44	60%	0.06 ± 0.04	20%	93.83 ± 58.62	80%	0.10 ± 0.07	20%
	Urban	10.3 ± 2.01	100%	4.16 ± 1.20	80%	16.39 ± 14.97	30%	664.12 ± 511.22	100%	2.05 ± 0.95	80%
Fall	Agricultural	8.30 ± 2.00	90%	11.30 ± 4.25	80%	37.99 ± 17.80	50%	878.40 ± 575.88	100%	0.11 ± 0.07	20%
	Remote	1.74 ± 0.67	80%	1.62 ± 0.67	50%	1.42 ± 0.84	40%	970.62 ± 963.91	70%	0.25 ± 0.17	30%

Gastrointestinal Parasite Larvae

The only larvae found in the beaker extraction method were lungworm (*Protostrongylus* spp.). In spring, lungworm larvae prevalence was 100%, 100%, and 90% for the Mt. Paul (urban), Ewe Hill (agricultural), and Dewdrop (remote) areas respectively. In summer, prevalence was 90%, 90%, and 60% respectively. And in fall, prevalence was 100%, 70%, and 100% respectively. When prevalence is 100% it means that all 10 fecal samples for the location and season were infected with lungworm larvae.

Lungworm mean intensity was significantly affected by season and location (Table 3.2). The season and location interaction was not significant. Lungworm mean intensity was significantly higher in the fall (252.8 ± 4.75 lungworm larvae per gram of feces, mean ± one standard error SE) than in the spring (96.2 ± 3.74 LPG feces) (Figure 3.2). Lungworm mean intensity was significantly lower for the Ewe Hill area (93.7 ± 3.34 LPG feces) than the Dewdrop (215.7 ± 3.88 LPG feces and Mt Paul (223.4 ± 4.67) areas (Figure 3.3).

Table 3.2 Results from 2-way ANOVA of mean lungworm (*Protostrongylus* spp.) larvae per gram of dried feces from bighorn sheep ewes with season and location as the independent factors. Fecal samples were collected from the Mt. Paul (urban), Ewe Hill (agricultural), and Dewdrop (remote) areas in the spring, summer, and fall of 2009. Asterisks denote significance.

	Degrees freedom	*F*-value	Probability	
Season	2	5.490	0.006	*
Location	2	4.720	0.012	*
Season x Location	4	2.190	0.078	

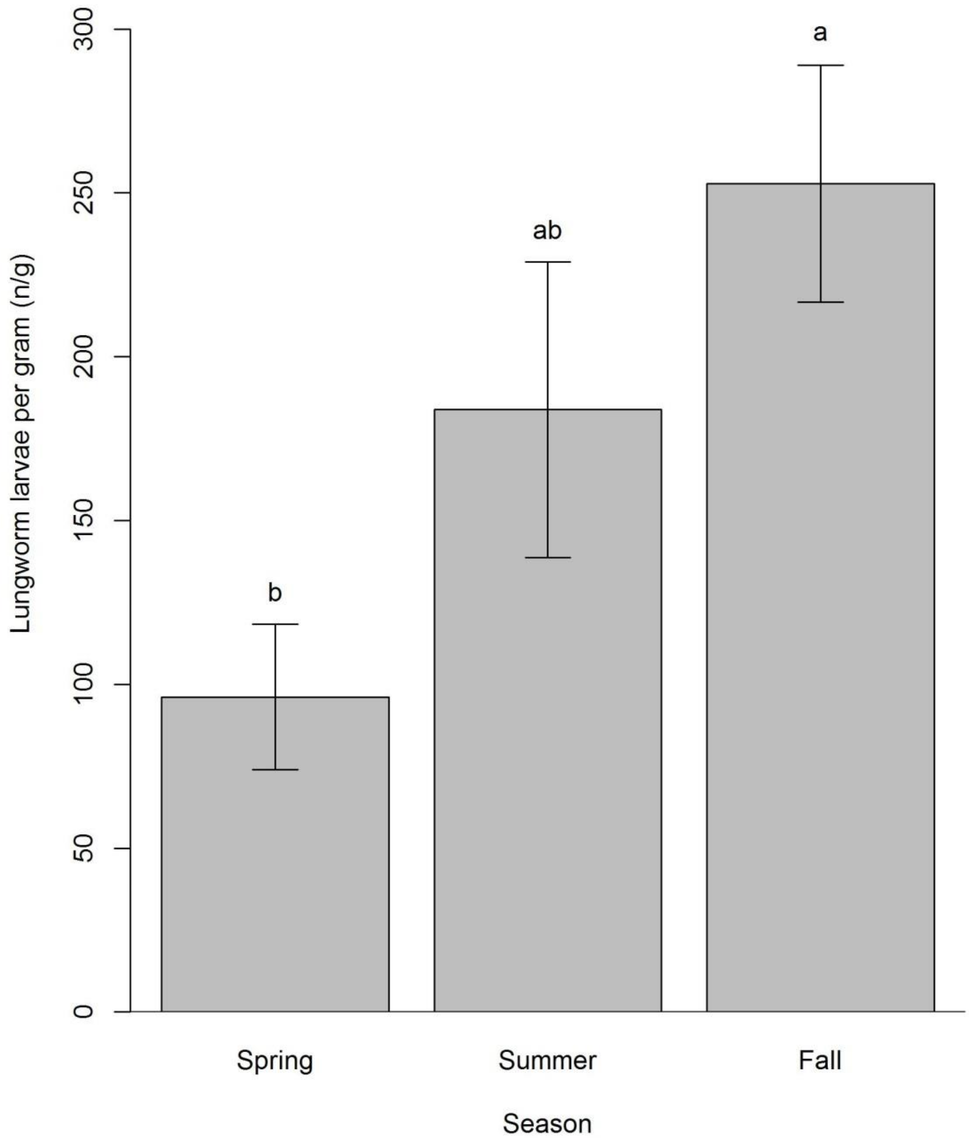

Figure 3.2 Mean lungworm (*Protostrongylus* spp.) larvae per gram of dried feces ± one standard error SE collected from bighorn sheep ewes from the South Thompson and Kamloops Lake herds in spring, summer, and fall 2009. Bars sharing the same letter are not significantly different as determined by Tukey's HSD test.

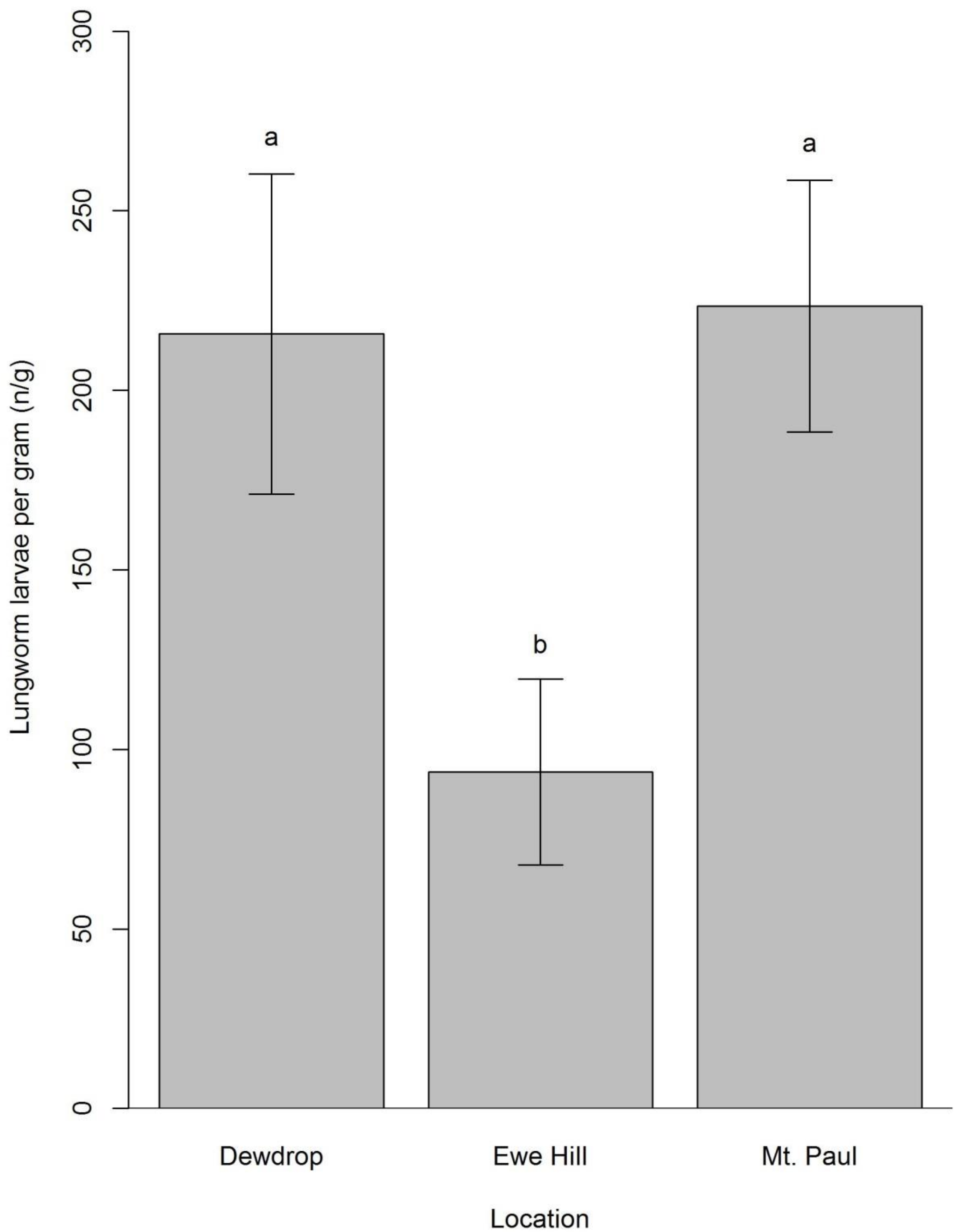

Figure 3.3 Mean lungworm (*Protostrongylus* spp.) larvae per gram of dried feces ± one standard error SE collected from ewe in bands in the Mt. Paul (urban), Ewe Hill

(agricultural), and Dewdrop (remote) areas from spring to fall in 2009. Bars sharing the same letter are not significantly different as determined by Tukey's HSD test.

Fecal Glucocorticoid Concentration

Fecal glucocorticoid concentrations were affected by location (Table 3.3). Season did not have a significant effect on fecal glucocorticoid concentrations. The season and location interaction was not significant. Mean fecal glucocorticoid concentration was significantly higher in Dewdrop (47.5 ± 3.86 corticosterone ng/g feces, mean ± one standard error SE) area than Ewe Hill (40.6 ± 3.69 corticosterone ng/g feces) area (Figure 3.4).

Table 3.3 Results from 2-way ANOVA of mean corticosterone concentration per gram dried feces from bighorn sheep ewes with season and location as the independent factors. Fecal samples were collected from the Mt. Paul (urban), Ewe Hill (agricultural), and Dewdrop (remote) areas in the spring, summer, and fall of 2009. Asterisk denotes significance.

	Degrees freedom	*F*-value	Probability	
Season	2	2.08	0.131	
Location	2	4.10	0.020	*
Season x Location	4	1.70	0.159	

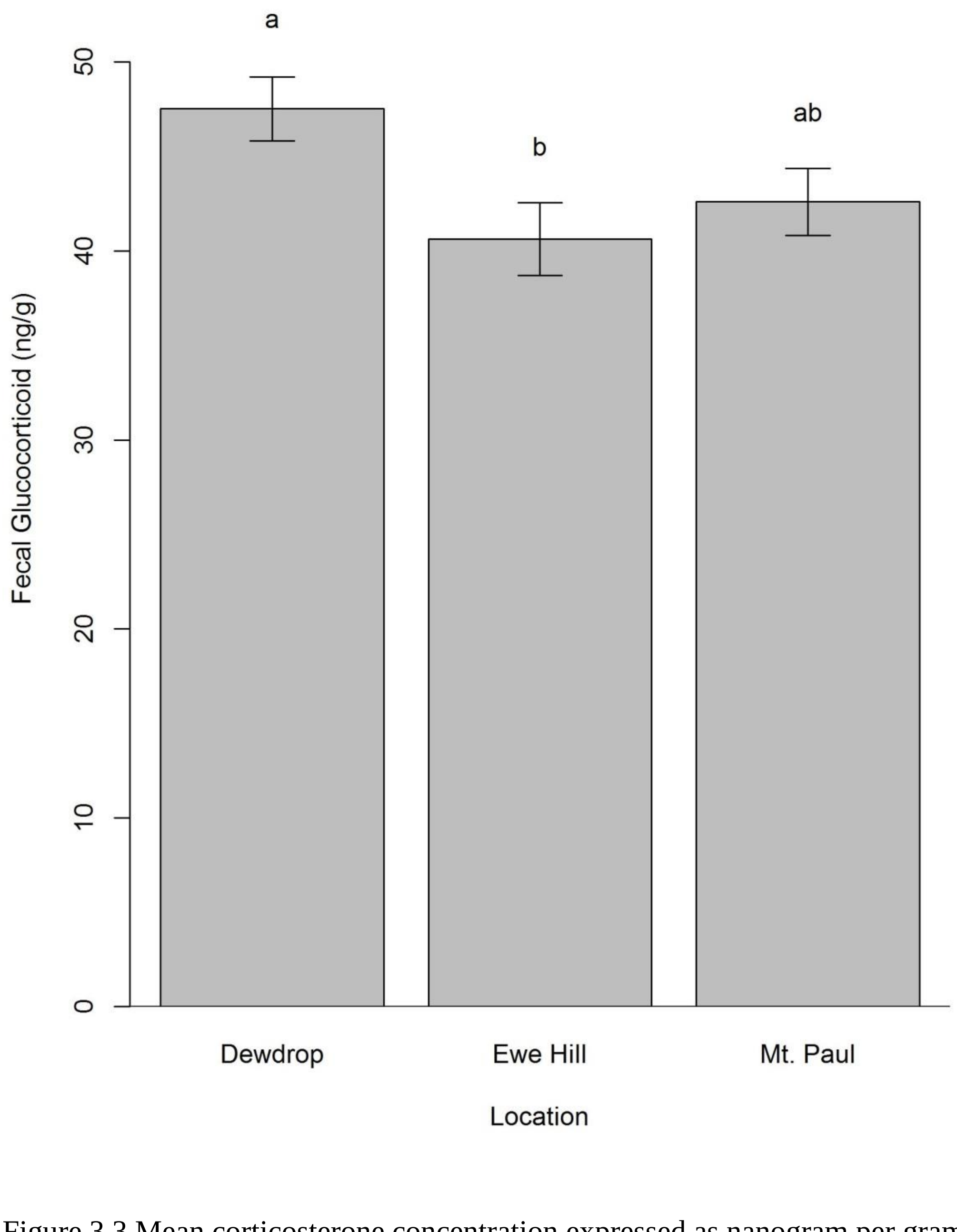

Figure 3.3 Mean corticosterone concentration expressed as nanogram per gram dried feces ± SE collected from ewe bands in the Mt. Paul (urban), Ewe Hill (agricultural), and Dewdrop

(remote) areas from spring to fall in 2009. Bars sharing the same letter are not significantly different as determined by Tukey's HSD test.

Relationship between Lungworm mean intensity and Fecal Glucocorticoid Concentrations

A linear regression of the lungworm mean intensity and fecal glucocorticoid concentrations was not significant ($p = 0.25$, $R^2=0.004$) (Figure 3.4).

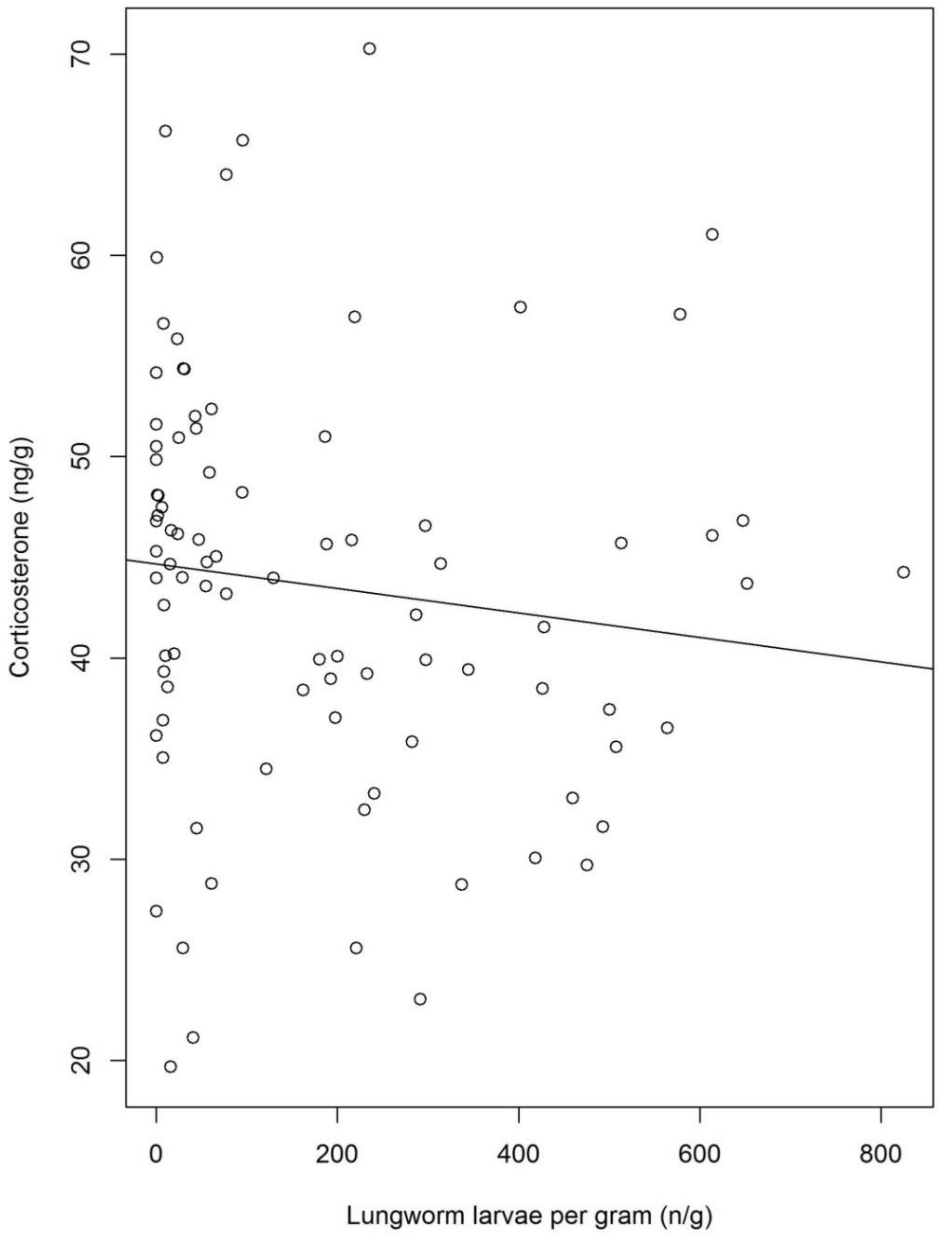

Figure 3.4 Linear regression of fecal glucocorticoid concentration measured in corticosterone per gram of dried feces (ng/g) and lungworm larvae per gram (LPG) per gram of dried feces.

DISCUSSION

A gastrointestinal parasite ova survey was conducted to provide a picture of parasite shedding in South Thompson and Kamloops Lake herds and to support future work. This gastrointestinal parasite surveillance helps establish a baseline for parasite presence, prevalence, and mean intensity. Five genera of gastrointestinal parasite ova were identified in the fecal examination *Trichostongylus* spp., *Eimeria* spp., *Trichuris* spp., *Nematodirus* spp., and *Strongyloides* spp. Although, these parasite species are considered subclinical (Garde et al. 2005) they do have the potential, if they reach high numbers, to alter behaviour, impact body condition, suppress immunity, and increase risk of respiratory disease (Miller et al. 2012). There could also be cumulative effects of these parasites in combination with other stressors. In addition, anthropogenic influences may affect what parasites are present. Rubin et al. (2002) found that ewes using urban areas were infected with parasites species that were not found in nearby bighorn sheep populations. Currently, thresholds indicating dangerously high levels of parasites have not been defined (Jenkins and Schwantje 2004). However, there have been reports of these parasites affecting body condition, appetite, weight, reproductive rates, and disease susceptibility (Foreyt 2001, Jenkins and Schwantje 2004).

Lungworm prevalence or percent of samples infected varied between 60 to 100% among the three ewe bands and seasons. Fecal samples from the Mt. Paul (urban) area had the highest lungworm prevalence each season with the exception of the fall when Dewdrop (remote) samples also had 100% prevalence. Bighorn sheep in the Mt. Paul area were frequently concentrated on the irrigated golf course year round with the exception of the spring. Rogerson et al. (2008) suggested the likelihood of lungworm transmission increases in mesic habitats where the gastropod flourish and bighorn sheep select for water and forage resources, such as riparian areas. Bighorn sheep in the Mt. Paul area were observed drinking from a trough at the transplant bait site, residential landscaping ponds, and golf course irrigation system. Also, high lungworm infection is expected in areas that attract bighorn sheep resulting in concentrated numbers and in populations that are residents due increased risk of transmission and reinfection (Jones and Worley 1994). It is possible that the bighorn sheep in the Mt Paul area had higher prevalence due to concentrated use of irrigated lawns and water developments. In spring and summer, the Dewdrop area samples had the lowest prevalence. This may be attributed to the limited amount of irrigated habitats or developed water sources in the remote Dewdrop area. This area is primarily composed of arid native range. In addition, bighorn sheep groups in the Dewdrop area did not appear to camp out on developed areas as observed in the Mt Paul area. Although the prevalence was high overall, the ewe bands did not have unusual levels of parasitism in comparison to other wild sheep populations (Blood 1963, Festa-Bianchet 1991, Rogerson et al. 2008). Forrester and Senger (1964) surveyed lungworm prevalence in 10 western Montana bighorn sheep herds and found 91% prevalence out of 900 fecal samples.

Seasonal variation in fecal lungworm output may be attributed to physiological or ecological mechanisms that affect an individual's immunity or susceptibility (Wilson et al. 2001). Numerous factors have been implicated in influencing seasonal differences lungworm shedding include environmental factors such as forage type, habitat type, environmental and anthropogenic stressors, precipitation, and geographic location; host factors such as nutritional level, reproduction effort, sex-related immunity, age-related immunity, and animal densities; and infectious agent factors such as the biological characteristics and parasitic strategy of lungworms (Forrester and Senger 1964, Uhazy et al. 1973, Olsen 1974, Forrester and Littell 1976, Festa-Bianchet 1989, 1991, Ball et al. 2001, Wilson et al. 2001, Jenkins and Shwantje 2004, Goldstein et al. 2005, Pelletier et al. 2005, Rogerson et al. 2008). The identified causes often conflict among studies making interpretation of lungworm levels challenging. Regardless of the numerous factors that may cause variations, the fluctuations themselves should be monitored and taken into consideration when interpreting parasitism levels in populations.

The lungworm mean intensity was significantly higher in the fall than in the spring. These findings are contradictory to a number of other studies (Forrester and Senger 1964, Pelletier et al. 2005, Rogerson et al. 2008) which found fecal output of lungworm in ewes peaked in the spring likely associated with the energetic costly reproductive events of late gestation and lactation, commonly termed spring or periparturient rise. The spring rise phenomenon is thought to be associated with decreased host immunity related to end of winter nutritional stress and gestation in ewes and parasite developmental strategy of increasing abundance and distribution prior to summer which is peak season of larvae development outside the hosts (Jenkins and Shwantje 2004). Many studies found sex-specific seasonal variation that corresponded with allocation of energy to reproductive effort with peak fecal output occurring in spring for ewes associated with lambing and in fall for rams associated with rut (Festa-Bianchet 1989, Pelletier et al 2005, Rogerson et al.). These findings indicate there is likely a tradeoff in bighorn sheep between reproduction and parasite immunity (Festa-Bianchet 1989). Pelletier et al. (2005) found there was fecal output variation among individual bighorn sheep with higher levels corresponding with lactation in ewes and mate searching in rams. These finding suggest physiological mechanisms affect host parasite susceptibility.

Although cyclic seasonal patterns in lungworm levels appear to be present in bighorn sheep populations it is reported that these patterns can be highly variable geographically even in similar environments (Uhazy et al. 1973). This implies environmental mechanisms may impact parasite transmission. Seasonal variation has been attributed to precipitation (Forrester and Littell 1976) and the gastropod secondary host density patterns (Forrester and Senger 1964). Conversely, Festa-Bianchet (1991) reported precipitation did not affect lungworm levels in bighorn sheep in Sheep River Provincial Park, Alberta. It should be noted that the summer of 2009 was considerably drier than normal with 6 mm of rain in June, 19 mm in July, and 2 mm in August in comparison to the average of 37 mm, 31 mm, and 24 mm, respectively (Environment Canada 2015). Rogerson et al. (2008) suggested that in semiarid environments that increased precipitation results in water availability in springs and it is the concentrated number of bighorn sheep frequenting the springs that increase transmission rather than the direct effect of the precipitation. Goldstein et al. (2005) found a bighorn population in South Dakota had high season variation in fecal lungworm intensity with winter having the highest levels and lowest in summer. They predicted that body condition was greater in the summer which resulted in suppression of lungworm reproduction. The importance environmental effects such as precipitation, habitat types and timing of lungworm transmission likely vary among geographic regions.

Another possibility is that cyclical lungworm fluctuations may not be related to environment or host changes but rather to parasite ecology (Goldstein et al. 2005). Fecal outputs are considered an indirect measure of lungworm burden and may not reflect actual parasite loads (Wilson et al. 2001). Parasites may be shed in high numbers seasonally as part their lifecycle independent from the bighorn sheep host (Ball et al. 2001). *Protostrongylus* species in caribou (*Rangifer tarandus caribou*) in Newfoundland are reported to peak in the fall with minimal shedding for the rest of the year (Ball et al. 2001). Olsen (1974) reported that an adult lungworm can live up to seven years in their bighorn sheep host and cyclical seasonal patterns may be attributed to the lungworm reproductive rate. This is an important consideration as high fecal lungworm output may not be due to environment or host factors rather just the nature of the parasite.

Ewe Hill (agricultural) had significantly lower lungworm mean intensity than Dewdrop (remote) and Mt Paul (urban). As mentioned, the intermediary gastropod host thrives in moist conditions and Rogerson et al. (2008) found lungworm load was higher in bighorn sheep that frequented riparian areas and water features because the wet environment promoted gastropod numbers. As such, it would be expected that an irrigated golf course and a concentration of sheep would result in higher numbers of gastropods and likely lungworm infection. Although hayfields in the Ewe Hill area are irrigated, there were minimal observations of ewes using these areas. Their use appeared to be focused on modified and sagebrush steppe grasslands. Bighorn sheep in the Ewe Hill were not as concentrated but they did frequent a nose pump and Stobbart Creek. An explanation for the Dewdrop levels is not readily apparent. As mentioned, the numerous and often contradictory causes of varying lungworm shedding levels make understanding parasitism in the Thompson population difficult. As such, one should be cautious in applying this data to wildlife and habitat management as numerous factors affect fecal output of lungworm and may not be directly related to bighorn sheep infection levels.

Several authors have suggested that lungworms are present in virtually all bighorn sheep populations (Blood 1963, Forrester and Senger 1964, Festa-Bianchet 1991, Rogerson et al. 2008) and this appears to be true for the Thompson bighorn sheep population. Location and seasonal differences in lungworm fecal outputs were observed in this study. It is recommended that lungworm shedding continues to be monitored to identify trends. In addition, reviewing the habitats in each area to evaluate which sites likely promote the intermediary host abundance and therefore parasite transmission would be useful. Furthermore, when developing water sources consideration should be taken regarding the potential of increasing gastropod abundance (Rogerson et al. 2008). However with the literature being fairly consistent in the conclusion that lungworms by themselves are not likely to cause clinical health concerns, it may be more important to continue to periodically monitor lungworm shedding to note any major increases in infection levels as these may predispose the sheep to respiratory disease if other infectious agents and host and environmental factors are cumulatively negatively impacting the sheep.

There was some seasonality to the lungworm levels with fall levels being significantly higher than the spring levels. Again this should be followed in any further monitoring as higher loads going into the winter may be a problem when nutrition levels are low. Continuing to collect seasonally, including winter, could help provide data on seasonal variations and perhaps clues why ewe lungworm shedding was highest in spring in this population.

Fecal glucocorticoid concentrations were significantly higher in Dewdrop area than the Ewe Hill area. Bighorn sheep using the Ewe Hill area may be buffered from anthropogenic influences because this is Tk’emlúps te Secwèpemc Indian Band land and access is restricted possibly resulting in lower physiological stress. Possibilities for the higher stress levels found in the Dewdrop area may be higher predator pressure and unpredictable human presence in comparison to South Thompson herd. It was observed during the collections that the Dewdrop bighorn sheep were noticeably more flighty than the other two areas. During the time of the study the Kamloops Lake herd had approximately 225 bighorn sheep on a range of approximately 13,000 hectares whereas the South Thompson herd had approximately 250 – 300 individuals on a range of approximately 7,600 hectares (D. Jury pers. comm.). Therefore, the Kamloops Lake herd was spread over an area twice the size of the South Thompson range. This lower population density may lead to smaller bighorn sheep groups. Data from other work suggests that sheep living in small groups are more vigilant which may increase stress levels (Frid 1997). Fecal glucocorticoid levels in the Mt. Paul area were not significantly different than in the Dewdrop and Ewe Hill areas. Even though fecal glucocorticoid concentrations were not significantly different, the Mt. Paul area by observation appears to have the highest anthropogenic influence. Bighorn sheep in the area may have become accustomed to the human activity and stress may be counterbalanced with the benefits obtained from these areas. Walker and Parker (2006) found that fecal glucocorticoid concentrations in Stone sheep in northern BC were similar regardless of anthropogenic disturbances. Because normal levels have not been established it is difficult to interpret whether these stress levels are elevated; however, it does allow assessment between the three bands. The stress hormone level data is very interesting and perhaps somewhat surprising. Of the three levels sampled the Ewe Hill area had the lowest levels.

Fecal lungworm outputs were not related to fecal glucocorticoid concentrations. Goldstein et al. (2005) also reported a lack of relationship between lungworm load and stress hormones. In addition, Rogerson et al. (2008) found no differences in stress hormones between bighorn sheep that were treated with dewormer to those that were not. However, it is likely that prolonged physiological stress will likely impact immune function (Klein 2000). Pelletier and Festa-Bianchet (2004) found bighorn rams that had higher lungworm larvae excretion would forage less; therefore implying parasite infection can alter foraging behaviour. It appears lungworm level can affect sheep behaviour and likely will impose some stress.

Management Implications and Recommendations

In this study, baseline data on gastrointestinal parasites and stress hormones were established. Gastrointestinal parasite shedding varied by season and location; whereas, stress levels only varied by location. The differences by location could be due to anthropogenic effects. This baseline information can support specific population management as well as address stakeholder considerations. Baseline data is crucial for assessing the effects of localized factors and risk management. These findings also support the understanding of the tolerance of bighorn sheep to anthropogenic disturbance. However, future work is needed to estimate disturbance thresholds and potential risks.

The data from this study may be best used as baseline data to support further investigation. Currently, there are no danger thresholds defined for parasite shedding or fecal glucocorticoid concentrations. Therefore, it is recommended for the viability of the herd and to understand variations the gastrointestinal parasites and fecal glucocorticoid concentrations for the South Thompson herd continues to be monitored periodically. It would also be useful to continue to sample the Dewdrop band for comparative purposes. It is not absolute values of parasite and stress hormone levels but significant changes between samplings that should elicit further investigation. Often this type of information is gathered reactively during or after a die-off but continuing to monitor the herd will likely provide valuable information on the effects of anthropogenic pressures and environmental changes such as wet or drought years or harsh weather that affect respiratory disease susceptibility. Ultimately, this information should support the development of guidelines for effective habitat management aimed to promote a healthy viable bighorn sheep population and reduce the risk of a die-off.

Monitoring the infectious agents and the physiological stress levels in the herd is recommended. Although the literature indicates that parasites alone do not necessarily lead to respiratory disease, they can contribute to reduced health and immunity. For this reason, ongoing monitoring of parasite levels and other infectious agents such as bacteria and virus would be beneficial. Additionally, stress alone may not be a major cause of respiratory disease but may contribute to the overall health of the herd. It is recommended that periodic monitoring be undertaken so that managers can be alerted to increased stress levels and potential negative effects of anthropogenic influences.

Future assessment of ram and lamb lungworm shedding would be valuable. Bachelor and maternal groups are often spatially segregated using different habitat types which could lead to differences in parasitism levels. Also, rams tend to migrate more (Geist 1971), possibly encountering additional parasite species. Rogerson et al. (2008) reported high prevalence of lungworm in lambs. This is an important consideration because pneumonia has been identified as the leading cause of lamb mortality and recognized as key factor population viability (Cassirer et al. 2013, Smith et al. 2014).

In conclusion, adaptive management promoting healthy bighorn sheep populations may be critical in their defence against respiratory disease. Pre-emptive herd specific measures that aid in the abatement of local stressors and conservation of seasonal critical habitat features may help reduce risk. This baseline information can support specific population management as well as address stakeholder considerations. Baseline data is crucial for assessing the effects of localized factors and risk management. These findings also support the understanding of bighorn sheep's tolerance to anthropogenic disturbance but future work is needed to estimate their disturbance threshold and potential risk.

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Personal Communication

D. Jury, Senior Wildlife Biologist, British Columbia Ministry of Environment, Environmental Stewardship Division, Kamloops, BC.

CHAPTER 4 CONCLUSIONS, MANAGEMENT IMPLICATIONS, AND RECOMMENDATION FOR FUTURE RESEARCH

The foundation of effective wildlife conservation and management is understating the principle factors that support a limit a population (Krebs 2002). Numerous extrinsic and intrinsic factors can undermine the effectiveness of habitat and population management plans. These factors may operate solely, concurrently, or sequentially, making identification, interpretation and prediction of effects and interactions difficult (Miller et al. 2012). The vulnerability of bighorn sheep populations to respiratory disease outbreaks and inconclusive causes associated with the subsequent severe, all-age die-offs showcase the challenges of managing and maintaining healthy populations (Miller et al. 2012). The importance of understanding limiting factors is instrumental in protecting populations, addressing habitat concerns and developing effective management strategies.

The relatively high productivity of bighorn sheep can result in rapid population growth and concerns of overabundance. The potential for rapid growth is credited to the high fecundity and survival of bighorn sheep (Shackleton1999, Demarchi 2004). Wishart et al. (1998) indicated that bighorn sheep that have been introduced into an area are capable of doubling in numbers over three years. The pregnancy rates of adult bighorn ewes are high with reports of healthy populations above 90% (Jorgenson 1992). Ewes typically start mating at 2.5 years. Bighorn sheep are also relatively long lived with an average life expectancy of 10 years (Demarchi et al. 2000). Furthermore, the California ecotype of bighorn sheep is known to occasionally have twins (Shackleton1999). Due to these factors, bighorn sheep populations can increase to the point that they exceed the carrying capacity of their habitat. This may be considered the biological carrying capacity (Ellingwood and Caturano 1988). Overabundance can result in decreased range health from over grazing and browsing which limits the forage resources available to the animals and increased competition between animals. Lack of adequate forage availability can lead to decreased herd health manifested by lower body condition. Animals in poor body condition have lower reproductive rates, and winter survival. These animals are also more susceptible to parasitism and disease (Ellingwood and Caturano 1988). Therefore, monitoring the condition of bighorn sheep ranges is critical to ensure the population is not outgrowing its habitat and becoming susceptible to major disease outbreaks.

Biological capacity is not the only issue that needs to be considered in bighorn sheep herd management plans. Currently in BC, there are an increased number of conflicts related to urban habituated ungulate populations (Hesse 2010). Ungulate populations are often attracted to urban environments because of the enhanced habitat and foraging opportunities, reduced predator pressure, humans feeding wildlife, and hunting restrictions. Therefore, an important concept in wildlife management is the concept of cultural carrying capacity which is defined as the maximum number of animals that can coexist with the human population in an urban area (Ellingwood and Spignesi 1985). The cultural carrying capacity is related to the sensitivity of human populations to the presence of animals in urban areas and can depend on animal densities, land use and resource activities, human perceptions and priorities, and negative interactions (Ellingwood and Caturano 1988). Overabundance can result in damage to developed areas, increased aggression towards humans, vehicle collisions, disease transmission, and human complaints. As a result, the cultural carrying capacity can be substantially lower than the biological carrying capacity. The compatibility between wildlife and human populations is typically related to the acceptance of the local human population to the consequences of animal presence, public opinion of various management options, the involvement of stakeholders, and the willingness of the community to participate with the establishment of management objectives. Because of the location of the South Thompson bighorn sheep herd both the biological and cultural carrying capacity need to be considered in management plans.

The South Thompson California bighorn sheep herd population has been rapidly increasing and is considered a resident herd typically remaining in the same general area year round. There are multiple stakeholders and land use activities occurring throughout the bighorn sheep range that have the potential to negatively impact the herd. However, the local bighorn sheep population appears to be attracted to the developed areas in their range. These circumstances raise concerns regarding the biological and cultural carrying capacity. As such coordinated land use planning and management is needed. The results of this study provide some of the information needed to develop a management plan that considers both the biological and cultural carrying capacity.

The data collected in this research project provides baseline data that supports herd specific management efforts, helps guide stewardship activities, and identifies knowledge gaps for the South Thompson herd. This was a coordinated project involving the BC Ministry of Forests, Lands, and Natural Resource Operations, the Tk'emlúps te Secwe̓pemc Indian Band, the South Thompson Wildlife Stewardship Committee, and Thompson Rivers University. The research findings are important in developing operational guidelines for various land use practices and activities which aim to reduce stressors potentially deleterious to the herd.

This research provides baseline information on the South Thompson population and investigates factors affecting behaviours, parasitology, and stress to support management decisions and resource integration. The key findings of the thesis are:

- Behaviours of the South Thompson herd differed seasonally, among habitat types, and between sexes. This is a key consideration because different habitat types may be seasonally important to the herd. In addition, this seasonal variation differs for ewes and rams and likely corresponds with their varying reproductive events. Developed areas (agricultural and urban) currently appear to be an integral part of the South Thompson bighorn sheep range. It will be important to consider this when developing a management plan for the herd and management of the land base especially with any proposed land use changes.
- Baseline data on gastrointestinal parasites and stress hormones were established. Gastrointestinal parasite shedding varied by season and location; whereas, stress levels only varied by location. The differences by location could be due to anthropogenic effects. This baseline information can support specific population management as well as address stakeholder considerations. Baseline data is crucial for assessing the effects of localized factors and risk

management. These findings also support the understanding of bighorn sheep's tolerance to anthropogenic disturbance but future work is needed to estimate their disturbance threshold and potential risk.

MANAGEMENT IMPLICATIONS

When developing a management plan for South Thompson bighorn sheep herd key management questions should be considered which will help guide the development of the plan. These include:

- What are the biological and cultural carrying capacities of the herd? Because of the forage provided in the developed area, it is assumed the herd has an artificially high biological carrying capacity relative to native range. It would be useful to calculate the carrying capacity of the native habitat without the developed land component. This would provide a target number of animals that can be supported on the natural land base if the cultural carrying capacity is exceeded and portions of the developed land are ever excluded. Further work should be done to try to quantify the usage of the developed land to determine the maximum carrying capacity of the total land base. Any potential loss of access to land should be also considered in this calculation. Having a target or threshold population size may be critical as overabundance has been associated with many herd die-offs reported in the literature and decreased compatibility with human populations. Defining a variety of management options and developing comprehensive contingency plans will help accommodate the balance required for ecological aspects of the herd and the opposing social conflicts that can arise.
- Will this herd continue to be a major donor herd for other areas? In fact this could be one of the key functions of the herd and would help control population size in respect to both biological and cultural carrying capacities. If so, promoting a healthy population and habitat is critical. The importance of this healthy herd locally, provincially, and jurisdictionally justifies consideration of conservation funding. An investment is already in place with the establishment of a permanent corral used for

transplants. However, limited conservation funding highlights the need to prioritize and optimize allocation of funds and develop pragmatic management plans and stewardship initiatives.

- Will the auctioned and limited entry hunts continue? If so is it possible for a portion of the funds raised to be dedicated specifically to the management and monitoring of this herd? The two areas recommended to have the highest priority are the follow-up monitoring and evaluation habitat suitability and selection. Although baseline data was collected during the study the findings are only a snapshot and further monitoring is needed to determine plausible factors that are causing variations in behaviour, gastrointestinal parasite shedding, and stress hormones. Results from the habitat selection and suitability should be used when prioritizing enhancement projects. For example, there is approximately 8 km of south facing native range between Mt. Peter and Ram Hill that does appear to be used by the bighorn sheep (D. Jury pers. comm.). In the past this area has been included in the prescribed burn program in an attempt to encourage use by decreasing the sagebrush density and promoting new forage growth. These analyses would help determine if lack of use is due to limited escape terrain or water in the area, or because of the herd's strong fidelity to their current range and the tendency of bighorn sheep to not expand into new areas (Geist 1971). It is important to determine this prior to spending stewardship dollars promoting use of this area or before excluding any developed areas.
- Can access to the residential area and golf course be guaranteed in the future? As reported in the behaviour portion of this study the sheep use these heavily at certain times of year and they are likely providing important nutrients to the bighorn sheep. If these areas are excluded and no alternative forage is available the exclusion could have a major impact on the herd.
- Can access to the agricultural lands be guaranteed in the future? Also reported in the behaviour portion of the study the sheep use the agriculture land during certain times of the year. Therefore, any major change to the agriculture lands either in crop grown or land use could impact the herd. Further delineation of agricultural habitat types would be beneficial. In this study agricultural areas included a variety of types such

as hayfields and modified grassland pastures. Identifying the agricultural types that sheep select for would be important in any land use planning initiative.

This study has provided some baseline data on behaviour, gastrointestinal parasite shedding, and stress hormone levels. It would be beneficial to develop a system to periodically check these levels to monitor any changes. It is important to do this on an ongoing basis rather than a reactive basis. As the literature reviewed indicate reactive sampling has too often been the approach in other areas and can potentially limit the survival of the herd. Fecal and blood samples taken during transplants would complement the baseline data reported in this study and could be used to continue to monitor herd health.

The behaviour portion of this study indicates that the herd is using the residential development, the golf course and agriculture lands to a fairly large degree. In essence these areas have become part of their habitat and likely contribute to the high fecundity of the herd. A management decision needs to be made as to whether this will continue in the future. Factors that might limit this access should be reviewed and addressed. In conjunction with determining carrying capacities, available land base, and habitat suitability, it is important that possible loss of access to developed lands be noted and the potential effect on the sheep evaluated. There are several potential reasons for loss of habitat and access:

- The agriculture land could be converted to crops that may not be used by sheep (e.g., corn, grain, etc.). Recently a winery has been established adjacent to the hayfields in the Ewe Hill area and this could alter available range.
- Agricultural land could be converted to other uses that may not be compatible with bighorn sheep use.
- Some forms of residential development could discourage or prevent sheep from using areas (e.g., high density residential developments with limited greenspace).
- There are several examples of urban ungulate conflicts in BC (Hesse 2010). With increasing bighorn sheep numbers and concentrated use on developed land there is an increased risk of human-wildlife conflicts. The extent of conflicts and damage that is considered acceptable by the local community significantly influences the cultural

carrying capacity and the need for animal management options. It is plausible that high animal densities may negatively affect the attitudes of residents, golf course users, recreationalists, and agricultural producers towards the local herd. As a result, they may be considered a nuisance and pressure to exclude them from developed areas to mitigate conflicts and damage may occur. There is concern from some residents with respect to damage to their gardening and landscaping. Although the community seems to highly value the presence of the bighorn sheep herd and want to see them persist on the landscape. Also in the past there have been concerns raised by agriculture operators regarding the sheep grazing on forage stands and accessing stored feed. Encouraging stakeholder involvement in urban wildlife management can result in public support of the population and increased participation in promoting healthy animals and range.

Although the developed land provides a considerable amount of foraging opportunities to the herd, there should be a focus on the native land base and it should be managed to promote use. In conjunction with the range carrying capacity evaluation, the habitat should be assessed for possible range improvement projects. The South Thompson Wildlife Stewardship Committee has funded numerous stewardship activities; however, a management plan that identifies critical areas and herd limiting factors would guide stewardship fund allocation to maximize the value of initiatives.

It is recommended that resources be allocated to public education and awareness of the importance of this herd. Information kiosks in key areas including viewing areas could outline the importance of the herd to the North American bighorn sheep population and also outline the potential negative effects of human activity. Stress caused by people approaching too closely, travelling through sensitive areas, allowing dogs to run loose are a few of the concerns that could be addressed in such a program. Two beneficial outcomes that could result from this strategy are: (1) reduced negative interactions with sheep that cause prolonged physiological stress and (2) reduced public pressure to exclude sheep from developed areas. Education programs can engage the community and raise awareness and appreciation for a species. This could encourage community involvement and a feeling of ownership and responsibility for the herd which would be beneficial for promoting both a healthy population and habitat.

A survey of predator pressure is also recommended. Periodic consultations regarding predator levels in the immediate area should be held. Cougars, black bears, and wolves have been reported in the area. In addition to depredation, bighorn sheep using the urban areas may draw in predators which may lead to human-predator concerns. A predator response strategy should be prepared in the near future. With the public sensitivity to predator control, particularly with wolves, it is imperative that this plan be done soon. The plan should outline how predators will be dealt with if they become a threat to the bighorn sheep herd and public safety. By having a plan in place mitigation can be undertaken as soon as predators become a threat to the herd. This plan should also be part of the public information efforts.

Bighorn sheep management has often been based on managing populations during die-offs and recovery and has often focused on identifying the principal causal agent. As outlined by Miller et al. (2012), an overall management program that manages the health of the bighorn sheep and minimizes disease risk may be a more efficient and effective approach. It is clear from the literature that there are multiple factors that need to be addressed in a management plan. These should include:

- Determining the key limiting factors. Understanding the localized extrinsic and intrinsic factors that support or constrain the bighorn sheep herd is critical. This should include further investigation of the effects of the varying anthropogenic influences.
- Determining the availability of forage resources. Many of the die-offs reported in the literature have occurred in herds due to density dependent factors such as nutritional stress (Monello et al. 2001). Therefore monitoring the quality, quantity, and health of the habitat along with population numbers is essential.

- Monitoring infectious agents. Although the literature indicates that parasites alone do not necessarily lead to respiratory disease they can contribute to reduced health and immunity. For this reason, ongoing monitoring of parasite levels and other infectious agents such as bacteria and virus is recommended.
- Monitoring physiological stress levels. Again stress alone may not be a major cause of respiratory disease but may contribute to the overall health of the herd. Baseline data is provided in this study and it is recommended that ongoing monitoring be undertaken so that managers can be alerted to increased stress levels and potential negative effects of anthropogenic influences.
- Evaluating predator pressure. At present, predator pressure does not appear to be a major issue but this can change. There is ample evidence in other areas that predator numbers can increase to the point that wildlife populations are threatened.
- Evaluating domestic livestock impacts. Currently there are no domestic sheep operations in close proximity to the South Thompson bighorn sheep range. However, maintaining an effective buffer between bighorn and domestic sheep should be considered (Miller et al. 2012). Also, minimizing forage competition between bighorn sheep and domestic livestock is recommended. Approximately 125 free-roaming horses utilize the sheep range and their impacts should be evaluated.

In conclusion, this thesis contributes data to support the development of management options targeted to maintain a healthy bighorn sheep herd. A coordinated management approach with community involvement and continued herd health monitoring are key considerations for ensuring a viable population resilient to die-offs.

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Personal Communication

D. Jury, Senior Wildlife Biologist, British Columbia Ministry of Environment, Environmental Stewardship Division, Kamloops, BC.