

**EXAMINING THE RISK OF DISEASE
TRANSMISSION BETWEEN WILD DALL'S
SHEEP AND MOUNTAIN GOATS, AND
INTRODUCED DOMESTIC SHEEP, GOATS,
AND LLAMAS IN THE NORTHWEST
TERRITORIES**

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The contents of this paper are the sole responsibility of the author

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EXECUTIVE SUMMARY

The global movement of domestic and wild animals by people is a major cause of emerging infectious diseases. Exchange of pathogens among introduced and native species can result in disease, often with short- or long-term consequences, for either or both species. This can have tremendous impacts on wildlife conservation, and potentially on human health. Examples include the transmission of brucellosis and tuberculosis from introduced plains bison to native wood bison in Wood Buffalo National Park and the introduction of domestic sheep diseases to bighorn sheep in western Canada and the United States; both of these events have had devastating economic, sociological, and ecological consequences.

In Canada's Northwest Territories (NWT), healthy populations of Dall's sheep, mountain woodland caribou, moose, and mountain goats are important for both subsistence and resident hunters in the Mackenzie and Richardson Mountains and are the basis for a world-class non-resident outfitted hunting industry in the Mackenzie Mountains. Outfitted hunting in the Mackenzie Mountains by non-residents annually generates at least \$1.8 million for businesses, individuals, and government in the NWT and directly employs over 100 people.

At the same time, as is evident from the *Strategic Planning Discussion Paper on Agricultural Development in the NWT* for the Territorial Farmers Association (TFA) (December 2004), there is growing interest in developing the agricultural industry, including raising domestic livestock. "The TFA believes that the agricultural potential of the north has yet to be tapped and that there is opportunity for significant growth in the industry over the next few decades... The TFA, with the support of northern

governments, must demonstrate that small- to medium-scale market gardening, land- or greenhouse-based, and livestock operations can be done efficiently and cost-effectively in the north as family or community-operated commercial enterprises” (pp. 3 and 10).

However, expansion of the livestock industry has the potential to result in pathogen exchange among domestic and wild species with negative consequences for one or both species, and subsequent impacts on the economy. For example, introduction of a domestic sheep strain of the bacteria *Mannheimia haemolytica* (a cause of pneumonia), could devastate Dall’s sheep populations in the NWT, which would in turn cripple the outfitted hunting industry. In addition, introduction of domestic goats and llamas that are increasingly used as pack animals for back-country expeditions in much of North America (including Yukon and Alaska), could also negatively impact NWT wildlife populations. Therefore, agriculture, tourism, and subsistence/resident hunting may coexist only if participants in these activities are aware of all potential negative interactions and thereby act to eliminate or minimize them.

To develop a viable and sustainable agricultural industry in the NWT, while also conserving wildlife species and ecosystem health, it is critical that we understand:

1. the risk of disease introduction with domestic livestock or exotic species
2. the risk of disease transmission between wild and domestic/exotic animals
3. how these risks can be mitigated with minimal impact on either sector

This Risk Assessment is the first step towards achieving this understanding. The objectives were twofold:

1. identify the pathogens known to infect domestic sheep, domestic goats and llamas, as well as those known to infect Dall's sheep and mountain goats
2. examine the disease risks for Dall's sheep and mountain goats, as well as for domestic sheep, goats, and llamas, associated with the possible introduction of domestic sheep, goats, and llamas to the Mackenzie and Richardson Mountains

We identified numerous pathogens in domestic sheep and goats that have had serious negative impacts on the health of bighorn sheep. Bighorn sheep (Rocky Mountain, California, and desert bighorn sheep) and thinhorn sheep (Dall's and Stone's sheep) are genetically related and may have similar disease susceptibilities. There is great concern that these pathogens would have significant and detrimental impacts on Dall's sheep and mountain goats in the NWT.

We found 9 infectious agents that are considered high risk and are likely to have negative consequences for Dall's sheep and possibly mountain goats: *Mycobacterium avium paratuberculosis*, *Mycoplasma conjunctivae*, *M. ovipneumoniae*, *Pasteurella sop.*, *Mannheimia haemolytica*, Contagious ecthyma, Parainfluenza-3, *Muellerius capillaris*, and *Oestrus ovis*. We also identified 19 infectious agents that are of unknown risk for Dall's sheep, 10 that are of low risk, 128 that have no apparent risk at this time, and 3 that are important to the NWT but that have not been reported in Dall's sheep or mountain goats in the territory. Of the risk agents identified, 11 are of potential public health concern.

Some disease agents that occur in Dall's sheep and mountain goats may infect domestic sheep, goats, or llamas. However, as a result of current management and

treatment practices of domestic livestock, we concluded that they would not be of major concern for the present or future agriculture industry in the NWT.

Our Risk Assessment indicates that contact between domestic sheep or goats and wild Dall's sheep or mountain goats would likely result in significant disease in the wild species with substantial negative and long-term effects on population dynamics and sustainability. We strongly advise that domestic goats not be used as pack animals and that domestic sheep and goats not be pastured anywhere in the vicinity of Dall's sheep or mountain goat ranges within the NWT. This recommendation is consistent with the practical experience and recommendations of bighorn sheep managers and biologists throughout Canada and the United States. Experience gained from events in the United States and southern Canada clearly highlights the substantial economic and social costs associated with trying to remedy the effects of disease introduction to wild sheep populations from domestic sheep and goats. Conversely, contact between llamas and wild Dall's sheep or goats may result in disease in wild species, but there is insufficient data available to clearly assess the role of camelids as a source of disease at this time (for additional information see *Communicable Diseases Risks to Wildlife from Camelids in British Columbia*).

This Risk Assessment provides a clear scientific basis for establishing proactive guidelines and policies to prevent negative impacts on both wildlife and domestic species associated with the possible introduction of domestic sheep, goats, and llamas to the NWT. It also highlights the critical importance for managers and agencies whose mandates include animal health to develop similar, science-based assessments for

other potential introductions or translocations of wild and domestic species in the NWT and elsewhere.

The integration of these recommendations into policy will provide a positive framework for the continued development of a healthy domestic livestock industry while promoting healthy wildlife populations in the NWT and sustainability of all forms of wildlife harvest and tourism.

INTRODUCTION

This risk assessment has been carried out following the guidelines for Health Risk Analysis entitled “Wild Animal Translocations” prepared by the Canadian Cooperative Wildlife Health Centre (<http://wildlife1.usask.ca>). It includes nine comprehensive appendices of bacterial, viral, parasitic, and fungal organisms reported from domestic sheep, goats, and llamas, and wild sheep and mountain goats. The report is a breakdown of those appendices into discussions of organisms of major concern, organisms of unknown concern, organisms of minimal concern, and those that cause no apparent disease, are not transmissible between the species of interest, or do not occur in Canada. Where possible, organisms were assigned a risk designation according to the probability of transmission as well as the effects on susceptible species.

SECTION 1: OVERVIEW OF RISK ASSESSMENT FOR INTRODUCTION OF DOMESTIC SHEEP, GOATS OR LLAMAS INTO NORTHWEST TERRITORIES

Introductions of domestic livestock species or exotic species into the Northwest Territories (NWT) for commercial or hobby farming or for use as pack animals may result in exchange of pathogens between wild and domestic species. Such exchange could lead to the emergence of clinical or subclinical disease with potentially severe detrimental impacts on wildlife and/or domestic species. Although agricultural practices in the NWT are currently minimal, there is some small-scale farming in the southern part of the territory, as well as a growing movement through the Canadian northwest to use domestic goats and llamas as pack animals (Schwantje and Stephen, 2003). There is currently no known legislation restricting the use of domestic animals in the Mackenzie or Richardson mountains in the NWT (A. Veitch, unpubl. data). There is an active resident and commercially outfitted sport hunting industry in the Mackenzie Mountains, and recent developments in the Richardson Mountains allow hunting of Dall's sheep by resident hunters from the Yukon Territory, which may increase the use of non-traditional hunting methods (D. Auriat, pers. comm.). Additionally, there is unregulated access into Dall's sheep range via the western borders of the Mackenzie and Richardson Mountains from the Yukon Territory.

Objective

The objective of this report is to proactively identify and qualitatively assess the risk of known pathogens that may be exchanged between wild Dall's

sheep (*Ovis dalli dalli*) or mountain goats (*Oreamnus americanus*), and domestic sheep (*Ovis aries*), llamas (*Llama glama*), or goats (*Capra hircus*). This will provide a practical foundation for developing management guidelines and policies regarding introduction and farming of domestic animals in the NWT.

The study area for this assessment is bordered on the west by the Yukon-NWT border, on the south by the NWT-BC border, to the east by the west bank of the Mackenzie River, and on the north by the Mackenzie Delta (Figure 1). The assessment addresses the risks associated with movement of domestic sheep, goats, and llamas to this area from western Canada. This document is intended to provide the background information required by the Government of the NWT, wildlife co-management boards, Territorial Farmers Association, Renewable Resource Councils and similar community-based organizations, and interested stakeholder groups to develop policies, guidelines, and mitigatory measures with regards to the possible introduction of domestic sheep, domestic goats, and llamas and their relatives into the NWT.

Background

The global, and often indiscriminate, movement of domestic and wild animals by people is a major cause of emerging infectious diseases. Every animal is essentially a “zoo”, bringing its own array of potential pathogens in the form of bacteria, viruses, and parasites. Exchange of pathogens among introduced and native species can result in disease, often with short- or long-term

consequences, for either or both species. This can have a tremendous impact on wildlife conservation, and potentially on human health.

We do not need to go far to find examples:

1. Movement of plains bison infected with brucellosis and tuberculosis from a farm in Wainright, Alberta to Wood Buffalo National Park in the 1920s resulted in introduction of these diseases to the native wood bison. In addition to affecting the health and dynamics of the wood bison population, this action has had significant and long-term economic, political, and sociological consequences.
2. Widespread grazing of domestic sheep on or near bighorn sheep range in the United States and southwestern Canada has had devastating consequences for some bighorn sheep herds. There have been cases where up to 90% of the wild sheep (all ages) have died as a result of pneumonia contracted from the domestic sheep. As a result, and as with the northern wood bison issue, considerable time, money, and energy are now being spent to try to remedy the situation.

Prior to the expansion of European settlement in North America, bighorn sheep were much more numerous than at present. Estimates of bighorn sheep numbers for the mid-1800s as high as 2 million have been recorded (Queen *et al*, 1994); however, Valdez and Krausman (1999) suggest it is very unlikely that the number of bighorn and thinhorn sheep combined ever exceeded 500,000 in North America. Currently, there are an estimated 70,000 Rocky Mountain,

California, and Desert bighorn sheep in North America, which is a considerable decline from the 19th century but is a significant improvement over estimates for the first half of the 20th century. This decline has been primarily attributed to the incursion of domestic cattle and sheep onto bighorn sheep range with subsequent overgrazing and/or habitat loss and to the introduction of diseases transmitted by domestic sheep and goats (Valdez and Krausman, 1999). Other factors include mining, logging, urban expansion, use of off-road vehicles, unregulated outdoor recreation, oil and gas exploration, and the disruption of water resources (Valdez and Krausman, 1999).

Domestic sheep and goats have been implicated in the transmission of primary pathogens causing epizootics in bighorn sheep. There is a long history of large-scale (>50%), sudden (<12 months), all-age die-offs in bighorn sheep across Canada and the United States, many in association with domestic animal contact (Shackleton, 1999). The proximate cause can usually be attributed to bacterial, viral, or parasitic diseases, particularly pneumonia of multifactorial etiology; however, there is often a preceding stress on the population, which is not always nutritional (Ryder *et al.*, 1992 in Shackleton *et al.*, 1999). Stressors include overcrowding on limited range, loss of escape cover, harassment by dogs, encroachment by humans, heavy snowfall, and other weather stresses (Bunch *et al.*, 1999). The resistance of bighorn sheep to disease organisms, such as opportunistic *Pasteurella* spp. bacteria, is reduced as a result of these stressors. Catastrophes, such as epizootic die-offs, represent a significant threat

to bighorn populations already diminished by habitat loss due to human disturbances (Shackleton *et al.*, 1999).

In contrast, thimhorn (Dall's and Stone's) sheep numbers and distribution across northern North America are likely very close to what they were prior to European settlement (Valdez and Krausman, 1999). The habitat of Stone's sheep (*Ovis dalli stonei*) and Dall's sheep in northern North America is such that their ranges are generally not economically viable for farming opportunities for domestic cattle and sheep, or for many of the other human or domestic animal activities that have historically created conflict on bighorn ranges. To date, there is no evidence of the catastrophic disease-related die-offs that have occurred to bighorn sheep populations; however, there are a few reports of captive Dall's sheep succumbing to diseases from natural or experimental exposure to domestic animal pathogens (Black *et al.*, 1988; Foreyt *et al.*, 1996; Smith *et al.*, 1982). It is presumed that thimhorn sheep are at least as susceptible as bighorn sheep to important pathogens (Foreyt *et al.*, 1996) and that it is the relative isolation from human settlement and activities that have kept Dall's sheep free from the die-offs that plague their southern relatives.

In Canada's Northwest Territories, Dall's sheep occur across most of the western Mackenzie Mountains (140,000 km²) and the more northern Richardson Mountains. There are an estimated 14,000 to 26,000 Dall's sheep in the Mackenzie Mountains (Veitch *et al.*, 1998) and approximately 1,000 in the Richardsons. In addition to Dall's sheep, the major large mammal species that occur within the Mackenzie Mountains are mountain-ecotype woodland caribou

(*Rangifer tarandus caribou*), moose (*Alces alces gigas*), mountain goat (*Oreamnos americanus*), grizzly bear (*Ursus arctos*), wolf (*Canis lupus*), and wolverine (*Gulo gulo*). Black bears (*U. americanus*) occur at very low density in the southern half of the range (Simmons, 1968; Veitch and Simmons, 2001). Veitch *et al.* (2002) estimated 768–989 mountain goats within the Mackenzie Mountains, most of which are located in the south and western portions of the mountain range.

In 1997, in the only known occurrence, a lone bull muskox (*Ovibos moschatus*) was reported at the northern end of the Mackenzie Mountains (K. Hougen, pers. comm.). Muskox numbers and range are expanding west of Great Bear Lake (Veitch, 1997) and animals have been seen near the bank of the Mackenzie River in 2000–2004 (now Wildlife Management, Environment and Natural Resources, unpublished files). Reports of mule deer (*Odocoileus hemionus*) have been received in the vicinity of Nahanni Butte at the south end of the range and there have been reports of mule and white-tailed deer (*Odocoileus virginianus*) within the borders of Nahanni National Park Reserve since the 1970s and 1980s. In recent years both mule deer and white-tailed deer have been moving northwards into the Yukon (Hoefs, 2001) and white-tailed deer have been seen along the Mackenzie River Valley in the Northwest Territories (Veitch, 2001). Within the last few years, elk (*Cervus elaphus*) have also been seen and harvested near the community of Nahanni Butte at the south end of the Mackenzie Mountains.

Access to Dall's sheep range in the NWT is limited. There are only two short (<20 km) active gravel roads in the Mackenzie Mountains of the NWT, both along the Yukon/NWT border. In 1943–44, the Canol Road was constructed as part of a project to move oil from Norman Wells across the Mackenzie Mountains to Alaska. In 1945, at the end of the project, the road was left to deteriorate over virtually its entire 357 km length on the NWT side of the border (Fradkin, 1977), such that the Canol Heritage Trail is considered one of the premier backcountry hikes in North America (Howe, 1996). Plans have been developed to make the trail a territorial park (Downie, 2003). On the Yukon side, the Canol Road has been maintained as a summer-use road. An all-season highway skirts the southeastern edge of the Mackenzies in the vicinity of the communities of Nahanni Butte and Fort Liard in the NWT, and another summer-use road crosses the Yukon-NWT border at the abandoned mining community of Tungsten west of Nahanni National Park Reserve (Figure 2) and continues for <20 km within the NWT.

No people live year-round within the Mackenzie Mountains; however, recently the mine at Tungsten site at MacMillan Pass near the Yukon border on the Canol Road was re-opened and approximately 100 workers live at the mine site on a scheduled rotational basis. This mine, together and the exploration at Prairie Creek north of Nahanni National Park Reserve, are the principal industrial activities within the mountains. Many other mining claims have been staked and exploration is ongoing, especially following the recent discovery of diamonds in the eastern NWT. Five communities along the Mackenzie River, with a combined

population of 1,913 (Government of the Northwest Territories, 1996), are located within 50 km of the Mackenzies in the NWT. In 1991, 63% of the residents of those communities identified themselves as Aboriginal, primarily Dene and Metis (Government of the Northwest Territories, 1996).

Recreational tourism is increasing in the mountains, consisting primarily of hunting, fishing, hiking, sightseeing (by airplane and helicopter), canoeing, kayaking, and skiing. Snowmobiles and all-terrain vehicles are used along the eastern and western fringes of the mountain range, gaining access via summer roads and rivers, and high-powered jet boats are used primarily by subsistence hunters to access the mountains through some of the larger rivers.

Unlike most other jurisdictions in North America, all Dall's sheep and mountain goat populations in the NWT are native, with no transplants to, from, or within the NWT (Veitch, 1998). At this time, no domestic sheep or goats are farmed anywhere within 50 km of the Mackenzie Mountains in the NWT (J. Colford, pers. comm.). However, it is evident from the December 2004 Strategic Planning Discussion Paper on Agricultural Development in the NWT that there is growing interest in developing the agricultural industry (anonymous, 2004). Currently, there are no proactive management guidelines or legislation preventing the introductions of these or any domestic species into or near wild sheep or goat habitat in the NWT.

The Mackenzie Mountains have been open for non-resident sport hunting since 1965 (Simmons, 1968) and hunting for Dall's sheep is the key component of what has become a \$7 million per year industry, of which approximately \$1.8

million remains with individuals, businesses, and government in the NWT (Crapo, 2000). There are 8 licenced outfitters in the Mackenzie Mountains and they employ over 100 people as guides, pilots, wranglers, cooks, and camp assistants each year (K. Hougen, pers. comm.). Harvest of Dall's sheep is relatively light, with outfitted sport hunters taking an average of 195 rams per year for the period 1991–2002 (Larter and Allaire, 2003; Veitch, 1998). Resident and subsistence harvest is considerably less, with a total harvest estimated to be 25–45 sheep per year. Currently, hunters with outfitters, occasionally accompanied by dogs, access sheep habitat on horseback, foot, or in light aircraft. No outfitter uses llamas as pack animals, nor do any other tourism-related businesses operate within the Mackenzie Mountains.

Although considered relatively pristine and isolated, the Mackenzie and Richardson Mountains are becoming exposed to an ever-expanding range of stressors, of which most are anthropogenic:

1. The NWT currently has the fastest-growing economy in Canada and is experiencing an almost unprecedented rate of growth, primarily in exploration and extraction of non-renewable resources, resulting in increased air traffic, construction of winter roads, and habitat disturbance.
2. There are ongoing and anticipated increases in tourism activities (including outfitted sport hunting), hydrological development, and agriculture.
3. Concurrently, the NWT is experiencing unprecedented rates of climate change. The mean annual temperatures in the Mackenzie and Richardson

Mountains (located in the “Mackenzie District” and North British Columbia/Yukon ecozones as defined by Environment Canada) have already increased by 1.8-2.0 °C over the last 50 years and this warming is expected to continue (<http://www.cics.uvic.ca/scenarios/index.cgi>; http://www.msc-smc.ec.gc.ca/ccrm/bulletin/national_e.cfm). Implications of this warming include changes in patterns of transmission of existing pathogens as well as range expansion of various wildlife species and concomitant introduction of new pathogens (Dobson *et al.*, 2003; Jenkins *et al.*, 2005e; Kutz *et al.*, 2005).

As these landscape-level environmental disturbances continue, ecological conditions for disease transmission in Dall’s sheep, mountain goats, and other wildlife in the NWT will be substantially altered. Similarly, introduction of domestic livestock into new regions may have unknown consequences for domestic and wildlife species. It is, therefore, imperative to strive toward proactive identification and understanding of disease risks to wildlife, domestic livestock, and people, and develop management and policy solutions to prevent the negative effects. In this Risk Assessment we specifically examine the potential disease interactions between domestic sheep, goats, and llamas, and Dall’s sheep and mountain goats.



Figure 1. Map showing region of Northwest Territories covered by risk assessment.

Methods

Information for this risk assessment was compiled using the following resources:

- Web of Science
- Pub Med
- Google Scholar
- University of Saskatchewan Libraries
- Canadian Cooperative Wildlife Health Center database servicing western Canada
- British Columbia Animal Health Center files
- Prairie Diagnostic Services database servicing western Canada
- Focus group interviews with elders and experienced harvesters from the Sahtu, Gwich'in, and Inuvialuit regions, NWT, January-April, 2005

The overall risk for each disease agent was assessed by examining the transmission probability to, and the health impacts on, the recipient species (Table 1). For those pathogens that were typical and endemic in domestic sheep, goats, or llamas, risks were assigned only for Dall's sheep and mountain goats. However, for those pathogens present in Dall's sheep or mountain goats that either were not found in the domestic species, or that could have an impact on domestic species, we defined transmission and health impact risks for domestic animals. We assumed the worse case scenario – that domestic sheep, goats, and/or llamas would overlap in space and/or time (i.e. they would use the same

range and/or have direct contact). We relied on the literature for bighorn sheep and assumed that mountain goats and Dall's sheep would be similarly impacted:

1. **Transmission probability**: This reflects the likelihood that a pathogen would be transmitted between species if domestic sheep, goats, or llamas used the same range as, or were in contact with Dall's sheep and mountain goats. In evaluating the probability of transmission we considered a number of factors, including:
 - a. pathogen characteristics such as host-specificity, mode of transmission (direct contact, aerosol, fomite, vector, etc.), persistence in the environment, prevalence and intensity of infection, patterns and length of shedding, age distribution, and R_0 as a measure of the transmission potential.
 - b. host characteristics that would influence the probability of contact among species, such as population densities, behaviour and patterns of habitat use (e.g. domestic sheep and wild sheep are closely related genetically and behaviourally and are much more likely to commingle than llamas and wild sheep, so the probability of pathogen exchange is much higher between wild and domestic sheep), management practices etc.

We found in the literature that, although there is often circumstantial evidence of transmission among wild and domestic sheep or goats

(particularly for bighorns), there is rarely irrefutable evidence because most investigations occur following a disease event. Complicating this further has been the poor historical or sometimes ambiguous identification of the pathogens and often limited knowledge of their transmission dynamics. Rather than classifying transmission potential as unknown, in these cases we have assigned a transmission probability based on the best information available, often limited to that on bighorn sheep. A discussion of the literature that forms the basis of these assignments is provided in the text for each organism. Where there was clearly insufficient information available, a risk rating of 'unknown' was assigned.

2. **Health impact:** Once an agent has been successfully transmitted to, and established in, a new animal, it is important to assess the impact of this agent on the health of the individual and population. This is a function of recipient species' prior exposure and immunity, the pathogenicity of the agent, long-term consequences for reproduction and body condition, and risk of mortality. In this assessment, we recognize that a pathogen causing subclinical and/or chronic disease may have comparable or even greater significance at the population level as a pathogen that causes acute mortality of a few individuals. Additionally, medicating wild animals is logistically difficult and largely unacceptable. This may result in more significant or widespread disease in free-ranging wildlife than observed in the more intensively managed and easily treated domestic species.

To assign a risk rating for health impacts we considered all the available literature for the host and pathogen species in question. However, as with the transmission risk ratings, in some cases there was insufficient information to assign a health impact risk rating and these were classified as “unknown”.

Criteria used to determine the transmission and health impact risk-rating for the wild and domestic species of interest are described in Table 1. Note that to be assigned to a specific category not all conditions in the category had to be met. Additionally, there was occasionally some overlap among categories, and when there was uncertainty we assigned the higher risk rating.

Table 1. Transmission and health impact risk ratings

Risk Rating	Transmission	Health Impact
Unknown ¹	Insufficient information available to evaluate the risk of transmission between wild and domestic species.	Insufficient information available to evaluate whether the disease agent causes any negative impacts to the species of concern.
Negligible	No evidence of experimental or natural transmission despite suitable conditions. The pathogen may be rare in the introduced species, have high host specificity, low environmental persistence, or be shed for short periods of time.	No disease observed in known infected animals.
Low	Limited evidence of experimental or natural transmission. High host-specificity, short duration of shedding, low environmental persistence, may require direct contact	Few individuals are affected and there are minimal health effects. Pathogen is unlikely to cause direct mortalities, long-term debilitating illness, or to have impacts at the population level
Moderate	Good evidence of experimental or natural interspecies transmission. Moderate levels of shedding and persistence in the environment.	Many animals affected. Mortalities or chronic and subclinical long-term effects limiting population productivity are probable.
High	High evidence of natural transmission, pathogen has a broad host range, high environmental persistence or does not require direct contact. May be shed for extended periods of time at high levels.	Many to all animals affected. Mortalities or severe impact on fecundity and herd production. Probable long-term consequences affecting productivity and persistence of individuals and populations

¹ Note that this does not suggest that the agent is not a risk, but indicates that there is insufficient information to assign it to a category

Disclaimers

This report is a summary of the current understanding, from published and unpublished works on the host species and the pathogens of concern. We encourage the reader to go to the primary literature for further information on specific disease agents.

Pathogen identification

There are many pathogens in wild sheep or goats that have been identified as the same species seen in domestic ruminants. With the advent of molecular diagnostic techniques and more critical morphological examination, we are becoming increasingly aware of the unique biodiversity of the pathogen fauna in northern wildlife and are now realizing that many pathogens once thought to be the same species in both domestic and wild ruminants, are in fact different species (Kutz *et al.*, 2004b). Accurate pathogen identification is critical for determining whether a pathogen is already established in a region and if it is transmissible among different species, and for epidemiological investigations. Throughout this assessment, we have indicated when species identification is uncertain. In acknowledging these limitations, we encourage managers to act conservatively, and where there is uncertainty regarding identification of the pathogen, caution should be exercised when making management decisions.

Dall's sheep

The literature on potential disease agents of Dall's sheep and mountain goats is limited; however, there is a body of literature on diseases in bighorn sheep and health issues associated with contact with domestic sheep and goats in Canada and the United States. We have assumed that bighorn and Dall's sheep have similar disease susceptibilities (Bowyer *et al.*, 2000; Valdez and Krausman, 1999), and have relied heavily on the history of transmission and disease impacts observed in bighorn sheep to determine the risk ratings for possible disease agents in free-ranging Dall's sheep. However, there may be species specific differences in susceptibility to various pathogens, and transmission to and impacts on Dall's sheep and mountain goats may differ from that reported in bighorn sheep. Since most populations of bighorns have a long history of exposure to domestic species compared to Dall's sheep in the NWT, it would be logical to expect that the latter would be far more disease naive and, therefore, more susceptible than bighorns to infectious diseases from domestics.

Mountain goats:

There is an even greater paucity of information regarding the occurrence and impact of potential disease agents in mountain goats than in Dall's sheep. There is insufficient information available to complete an accurate risk assessment for this species at this time. For this reason, mountain goats have been eliminated from the majority of the risk assessment unless otherwise stated in specific sections. All available information on agents previously identified in

mountain goats is provided in the appendices. Until further information is available regarding the disease status on mountain goats, managers are encouraged to act conservatively by treating every domestic animal agent as a potential pathogen unless specifically demonstrated otherwise. Generally mountain goat and bighorn sheep 1) have similar numbers of helminth species, 2) have many helminth species in common, and 3) are accidental hosts of a few others. We will assume that this susceptibility can be extrapolated to pathogens in a broader sense.

Risk Categories:

In order to qualitatively assess the risks for each pathogen, categories of risk were defined in Table 1. We acknowledge that many of the risk assumptions are generalizations and are necessary for the purposes of defining risk. However, because of often limited knowledge about the pathogen, there remains some level of uncertainty.

SECTION 2: IDENTIFICATION OF PATHOGENS OF HIGHEST CONCERN

Description

This section describes in detail the major pathogens of concern from Appendices 1–7. The criteria for designation to this category are as follows:

1. There is strong or confirmed evidence of transmission in either direction between domestic sheep, goats or llamas, and Dall's sheep, bighorn sheep, or mountain goats, and
2. there is strong evidence that the pathogen has resulted in significant disease in recipient populations (i.e. wild sheep and goats, or domestic sheep, goats, or llamas), and
3. it occurs in Canada.

Bacteria

***Mycobacterium avium paratuberculosis* (Johne's disease)**

Summary:

- *Mycobacterium avium paratuberculosis* is an acid-fast bacillus.
- Causes gastrointestinal disease with severe wasting and death.
- Domestic sheep, goats, and llamas are affected.
- Bighorn sheep and mountain goats affected.
- *In utero* or fecal-oral transmission.

- Very persistent in environment.
- No report of clinical disease in Dall's sheep, but they can be infected.
- Natural transmission from bighorn sheep to domestic sheep confirmed experimentally.
- Natural transmission from domestic ruminants to wild sheep and goats strongly suspected.
- Possible public health implications.
- No treatment.

General overview: *Mycobacterium avium paratuberculosis* are acid-fast bacilli that stain pink to red in feces using the Ziehl-Neelsen method. *Mycobacterium a. paratuberculosis* has a wide host distribution and is ubiquitous throughout dairy farms in the United States and Canada causing significant production losses (Chi *et al.*, 2002; Matthews, 1999). The organism multiplies in the gastrointestinal system and eventually manifests as clinical Johne's disease (diarrhea, chronic wasting) on average between 2 and 6 years later (Wenger and Tait, 2001). There are also cases of subclinical infections (Kimberling, 1988) as well as asymptomatic carriers that shed the bacteria in their feces but show no clinical signs (Matthews, 1999).

The organism is extremely difficult to test for in the live animal. Strains of this bacteria are generally considered host-specific, although cross-species infection has been demonstrated among domestic and wild ruminants (Stehman, 1990). There are two sheep strains and both are notoriously difficult to culture

compared to cattle strains (Blood and Radostits, 1989). Camelid strains are thought to originate from cattle due to their similarity in culture characteristics (Fowler, 1998). Strains circulating in free-ranging wildlife are not well defined. Fecal culture for *M. a. paratuberculosis* takes 8–12 weeks. Other tests, while quicker, are difficult to interpret due to false negative results (Matthews, 1999; Williams *et al.*, 1985), although recent advances using the polymerase chain reaction show promising results. Given the long incubation and difficulties in diagnoses (Bunch *et al.*, 1999), it is understandable that control of this disease is difficult. There is no known treatment.

Clinical signs in domestic sheep, goats, and llamas: Although most commonly associated with cattle, Johne's disease is found in adult sheep, goats, and llamas. The predominant signs in small ruminants are slow, progressive wasting, with eventual death (Kimberling, 1988; Linklater and Smith, 1993); diarrhea is less common than in infected cattle (Kimberling, 1988; Williams *et al.*, 1983b). In 2001, a serological survey of 175 llamas and alpacas was done in British Columbia. Antibodies to *M. a. paratuberculosis* were found in 10% of the tested animals (Schwantje and Stephen, 2003). All animals tested were clinically healthy.

Clinical signs in wild sheep and mountain goats: Captive Dall's sheep have tested culture positive for *M. a. paratuberculosis*, but clinical signs have not been reported (P. Merchant, pers. comm.). Signs in wild bighorn sheep and mountain

goats were similar to those seen in domestic sheep and goats and included emaciation, dry rough hair coat, and diarrhea (Williams *et al.*, 1983b). Infected mountain goats shed massive amounts of bacteria and there is some evidence that they may be more susceptible to *M. a. paratuberculosis* than bighorn sheep (Williams *et al.*, 1978).

Mode of Transmission: Transmission of *M. a. paratuberculosis* usually occurs either *in utero* or in the first few months of the animal's life by ingestion of feed, water, or dust or by suckling from an udder contaminated with feces (Kimberling, 1988). The organism may also be transmitted mechanically by arthropods (Fischer *et al.*, 2004). Horizontal transmission in older animals is uncommon and those older than six months are unlikely to contract the disease (Matthews, 1999).

Environmental survival: This bacterium is persistent in the environment, surviving up to 270 days in water, 246 days in manure, and 385 days on grass and soil in a dry, fully shaded environment (Kimberling, 1988; Matthews, 1999; Whittington *et al.*, 2004)

History in wild sheep: In the spring of 2003, Johne's was reported on the Yukon Wildlife Preserve in captive Dall's sheep, Stone's sheep, bighorn sheep and mountain goats. The presence of disease has since been confirmed by culture positives in two Dall's sheep, a bighorn sheep and a muskox. The origin of the

disease is currently unknown, but it is thought that it was introduced to the facility via colostrum and milk from domestic goats.

In the spring of 2005, three reindeer on a separate facility in the Yukon were found to be positive for *M. avium paratuberculosis* by PCR. (P. Merchant, pers. comm.).

Johne's disease has been reported in many other wild ruminant species, both free-ranging and captive (Williams *et al.*, 1985). The earliest reports of Johne's disease in bighorn sheep and mountain goats were between 1972 and 1978. Six free-ranging bighorn sheep and one free-ranging mountain goat were diagnosed with Johne's disease in Colorado and an additional 20 bighorn sheep and 4 mountain goats in the herds were observed with clinical signs consistent with Johne's disease. No source of infection was ever found, but the animals showed clinical signs and post-mortem lesions similar to those reported for domestic animals. (Williams *et al.*, 1978; Williams *et al.*, 1983b). Clinical disease associated with *M. a. paratuberculosis* has been reported in a few populations of Rocky Mountain bighorn sheep in Colorado and Wyoming (Williams, 2001). Systematic sampling has not occurred across the range of bighorn sheep, therefore, the true prevalence of these bacteria is not known.

Evidence of transmission among domestic and wild species: There are no confirmed cases of natural transmission between domestic animals and free-ranging wild ruminants. However, *M. a. paratuberculosis* from bighorn sheep has been shown experimentally to infect domestic sheep and other wild ruminant

species (Bunch *et al.*, 1999). Based on this, and on the epidemiology of this disease in domestic animals, it is suspected that natural transmission can occur between wild and domestic sheep (Bunch *et al.*, 1999). The role of wild sheep as potential reservoirs as well as in dissemination of *M. a. paratuberculosis* needs further investigation (Williams *et al.*, 1983a).

In 1994, pack llamas were banned from Canyonland National Park in Utah because of the fears of environmental contamination with *M. a. paratuberculosis* leading to infection of wild desert bighorn sheep (*Ovis canadensis nelsoni*) (Fowler, 1998). There was little direct evidence behind this action and widespread infection of the United States llama population was not demonstrated. Although it is argued that animals with clinical signs of Johne's disease would be physically unable to withstand the job of packing, because of the long incubation period of this disease, animals may shed the bacteria in their feces for 15 to 18 months before exhibiting any clinical signs (Blood and Radostits, 1989). However, transmission of *M. a. paratuberculosis* from domestic pack animals (goats and llamas) to wild sheep or goats is unlikely because survival of the bacteria in dry alpine habitats is thought to be poor, healthy animals rarely excrete large numbers of bacteria in the environment, and horizontal transmission of this pathogen is unlikely, thus exposure for wild sheep or goats would be low (Williams, 2001).

Public health risk: *Mycobacterium a. paratuberculosis* may potentially pose a public health risk; a link between infection with this bacterium and Crohn's disease has been postulated (Matthews, 1999; Wenger and Tait, 2001).

Additional comments: Assessing the impact of *M. a. paratuberculosis* in free-ranging wild sheep and goats is difficult, and control of the disease would be extremely challenging (Bunch *et al.*, 1999). In regions where the bacteria has been absent for long periods of time, naive domestic sheep are very susceptible to the disease, with high mortality following infection (Kimberling, 1988). This is of great concern if naive wild sheep populations were exposed to the bacteria.

Overall Risk:

Species Interaction	Transmission	Health Impact
Sheep and goats to Dall's or mtn goats	moderate	moderate
Llamas to Dall's or mtn goats	low	moderate
Dall's or mtn goats to sheep or goats	unknown	moderate
Dall's or mtn goats to llamas	unknown	moderate

Mycoplasma conjunctivae* and *M. ovipneumoniae

Summary:

- *Mycoplasma* spp. are small, fragile bacteria causing mild to severe conjunctivitis (*M. conjunctivae*) and respiratory disease (*M. ovipneumoniae*).

- Domestic sheep and goats can be affected, while llamas are seldom affected.
- Wild sheep can be affected.
- Direct, aerosol, or mechanical transmission.
- Environmental survival is very short; organism is extremely fragile.
- *M. ovipneumoniae* causes severe disease in captive Dall's sheep.
- *M. ovipneumoniae* may predispose animals to *Pasteurella* pneumonia.
- Both *Mycoplasma* species cause disease in bighorn sheep.
- Natural transmission from domestic sheep and goats to wild sheep and goats is strongly suspected.
- No public health risk.

General overview: *Mycoplasma* spp. are a diverse group of bacteria. They are extremely small, lack a cell wall, and stain weakly gram-negative (Carter *et al.*, 1995; Whithear, 2001). They are commonly found in the respiratory tract of both healthy and diseased domestic ruminants (Al-Aubaidi *et al.*, 1972; Goltz *et al.*, 1986), but appear to be uncommon and insignificant in llamas (Fowler, 1998). Susceptibility to the bacteria is highly variable, and impacts range from subclinical to severe (Pugh, 2002) depending on the species, the dosage, and host factors (Goltz *et al.*, 1986). One of the features of *Mycoplasma* infections is that they may predispose the respiratory tract to other invaders, with *Pasteurella/Mannheimia* spp. being a major concern (St George and Carmichael, 1975).

Mycoplasma spp. can only survive inside the host cells, making culture and identification very complicated (Blood and Radostits, 1989; Stalheim, 1983). For this reason, the species identity of *Mycoplasma* found in domestic and wild sheep has often not been determined, making it difficult to interpret the role of these bacteria in disease outbreaks (Whithear, 2001). However, *M. conjunctivae* and *M. ovipneumoniae* are generally considered significant pathogens of bighorn sheep and wild goats and seem to cause more severe disease in these hosts than in their domestic counterparts (Whithear, 2001). These are discussed below. The impacts of two other *Mycoplasma* species in wild sheep and goats, *M. arginini* and *M. mycoides*, are less well understood and these species are discussed under Section 3, pathogens with unknown consequences.

Mycoplasma conjunctivae

General overview: *Mycoplasma conjunctivae* causes a highly contagious eye infection common in domestic sheep and goats, and bighorn sheep and mountain goats (Whithear, 2001). It is not found in the conjunctival sac of clinically normal llamas (Gionfriddo *et al.*, 1991).

Clinical signs in domestic sheep, goats, and llamas: Infection with *M. conjunctivae* is characterized by redness of the eyes, squinting, pain, ocular discharge and, in advanced stages, corneal opacity or even perforation leading to permanent blindness (Janovsky *et al.*, 2002).

Clinical signs in wild sheep and mountain goats: Clinical signs in bighorn sheep and mountain goats are as for domestic animals although the outcome in affected bighorn herds is usually more severe, perhaps due to the impracticality of treating wild animals. Mortality can reach 30% in wild bighorn herds, probably due to accidents resulting from blindness (Janovsky *et al.*, 2002). Ocular disease associated with *Mycoplasma* in Alpine chamois (*Rupicapra rupicapra rupicapra*) and ibex (*Capra ibex*) in Europe was more severe than that seen in domestic sheep and goats (Whithear, 2001).

Mode of transmission: *Mycoplasma conjunctivae* is thought to spread via insect vectors or direct contact (Whithear, 2001). *Psoroptes* sp. mites may serve as vectors for the bacteria (Pugh, 2002).

Environmental survival: *Mycoplasma* spp. are very fragile due to the lack of a cell wall and they do not persist outside a suitable host (Carter *et al.*, 1995).

History in wild sheep: In late 2003 and 2004, the Silver Bell bighorn herd in Arizona was reported with clinical signs of keratoconjunctivitis (KCS) caused by *M. conjunctivae*. The source was believed to be direct contact with 5,000 domestic goats released into bighorn habitat. Bighorn sheep suffered from blindness, corneal rupture, and higher predation rates or accident-related mortality. Approximately 50% of the animals in the herd were caught and treated.

The majority of animals recovered although the mortality rate was approximated at 25%. One captured domestic goat had clinical signs of KCS consistent with *Mycoplasma* sp. infection. Sixteen non-clinical domestic goats were caught and *Mycoplasma* sp. was cultured from conjunctival swabs, with a number of these later confirmed using PCR techniques as *M. conjunctivae* (Heffelfinger *et al.*, 2004).

This disease was reported in domestic sheep and in Alpine chamois in the European Alps. Bacteriological and serological analysis on both species suggested that domestic sheep maintain *M. conjunctivae* and transmit it to chamois (Janovsky *et al.*, 2002).

Evidence of transmission among domestic and wild species: In France and Switzerland, there is convincing evidence of experimental and natural transmission from domestic sheep and goats to wild sheep and goats (Janovsky *et al.*, 2002; Whithear, 2001). Preliminary laboratory results in the Silver Bell bighorn herd in Arizona indicate that goats may transmit the bacteria to bighorn sheep (J. Heffelfinger, pers. comm.).

Public health risk: none

Mycoplasma ovipneumoniae

General overview: *Mycoplasma ovipneumoniae* has been isolated from the oral cavity of healthy and pneumonic domestic sheep and goats. Domestic sheep are the primary host, and although the bacteria has been cultured in goats the significance is unknown (Whithear, 2001). It is strongly suspected that *M. ovipneumoniae* plays a role either as a primary pathogen, a predisposing agent, or as a secondary invader in pneumonia in small ruminants (Blood and Radostits, 1989).

Clinical signs in domestic sheep, goats, and llamas: Animals with *M. ovipneumoniae* present with coughing, sneezing, mucoid nasal discharge, and prominent lung sounds (Blood and Radostits, 1989). In sheep, *M. ovipneumoniae* appears to cause mild lung lesions, but when in combination with *Pasteurella/Mannheimia* spp. a much more severe pneumonia ensues (Blood and Radostits, 1989; Goltz *et al.*, 1986). *Mycoplasma ovipneumoniae* may play a role in predisposing the respiratory tract to other invaders, resembling the shipping fever complex (Black *et al.*, 1988). *Mycoplasma ovipneumoniae* should be considered in cases of chronic pneumonia in domestic sheep (St George and Carmichael, 1975).

Clinical signs in wild sheep: Clinical presentation is as for severe *Mycoplasma* pneumonia seen in domestic sheep (Black *et al.*, 1988).

Mode of transmission: Transmission is via aerosol, direct contact, or fomites (Goltz *et al.*, 1986).

Environmental survival: This bacteria is very fragile due to the lack of a cell wall and does not persist outside a suitable host (Carter *et al.*, 1995).

History in wild sheep: In 1986, *M. ovipneumoniae* was implicated in a severe pneumonia outbreak in a captive herd of Dall's sheep at the Toronto Zoo. Two Dall's ewes had been housed temporarily in a lambing barn next to domestic ewes. Although there was no direct contact between the wild and domestic sheep, they were tended by the same zookeeper. The two Dall's ewes were subsequently returned to the herd, and signs of coughing, open-mouthed breathing with severe respiratory distress and wasting developed in 7 out of a total of 10 animals. Despite aggressive treatments, clinical signs persisted for over a year. Three mortalities resulted, and *M. ovipneumoniae* was cultured from the lungs of all 3 sheep, as well as from the nasal cavities of surviving herdmates. *Mycoplasma ovipneumoniae* was also cultured from the in-contact domestic sheep, though no signs of respiratory disease ever developed in those animals. Antibody titres to bovine respiratory syncytial virus were also found in many of the Dall's sheep, but the significance is unknown (Black *et al.*, 1988).

Between 1979–1987, all of 249 free-ranging and 3 captive Dall's sheep in Alaska tested for antibody to *M. ovipneumoniae* were seronegative (Zarnke and

Rosendal, 1989). It was suggested that significant morbidity and mortality could result in the event that this bacteria were introduced to naive herds.

There was no evidence of *Mycoplasma* spp. using immunohistochemistry in the lungs of 5 wild Dall's sheep with bacterial pneumonia and septicemia from the Mackenzie Mountains (Jenkins, 2005).

During a pneumonia epizootic in California bighorn sheep in the south Okanagan region of British Columbia in 1999, *Mycoplasma* spp. were detected (using PCR) from the lungs of 7 of 12 pneumonic sheep. *Pasteurella multocida*, *Arcanobacterium pyogenes*, *Escherichia coli*, and *Mannheimia haemolytica* were also isolated from lungs of some of the sheep. The contribution of the *Mycoplasma* spp. to the pneumonia was not determined. Domestic sheep had been on a portion of the bighorn range prior to this outbreak and contact was considered likely. Since the bighorn mortality was recognized long after the domestic sheep were removed, their role in the epizootic was undetermined (H. Schwantje, unpubl. data).

Evidence of transmission among domestic and wild sheep: There is strong evidence that *M. ovipneumoniae* can be transmitted from domestic sheep to Dall's sheep by aerosol or fomites (i.e. the Toronto zoo-keeper) (Black *et al.*, 1988).

Public health risk: none

Pasteurella spp. and Mannheimia haemolytica**Summary:**

- *Pasteurella* spp. and *Mannheimia haemolytica* belong to a very large and diverse group of related gram-negative bacteria, and classification is continually changing.
- *Pasteurella multocida*, *P. trehalosi*, and *Mannheimia haemolytica* can cause pneumonia in bighorn sheep, but there are benign strains commensal in the upper respiratory tract.
- Domestic sheep, goats, and llamas have been reported with *Pasteurella* spp. and *Mannheimia* spp.
- Wild sheep and mountain goats have been reported with *Pasteurella* spp. and *Mannheimia* spp.
- Transmission is by direct contact and aerosolization.
- *Pasteurella/Mannheimia* do not persist in the environment.
- Acute to chronic die-offs occur in bighorns and can result in low to 100% mortality.
- *P. multocida* and *P. trehalosi* can be present in healthy bighorn sheep, are considered opportunistic pathogens in this species, and can result in pneumonia outbreaks.
- *P. multocida* and *M. haemolytica* can cause clinical disease in domestic sheep and goats, but they are rarely primary pathogens.

- Dall's sheep and mountain goats are affected sporadically by *Pasteurella* and *Mannheimia* spp. pneumonia, but large-scale die-offs have not been reported.
- *Mannheimia haemolytica* A2 is common in healthy domestic sheep. It is thought to be a primary pathogen in wild sheep, and is found in pneumonia die-offs.
- Experimental transmission from domestic sheep to bighorn and Dall's sheep has been demonstrated.
- Natural transmission from domestic sheep and goats to all wild sheep is strongly suspected.
- Information on transmission from llamas to wild sheep is poor.
- No public health risk.

General overview: *Pasteurella* spp. and *M. haemolytica* are gram-negative rods or coccobacilli. This group of bacteria is considered to be one of the most important causes of all-age, large-scale pneumonia die-offs in bighorn sheep and may suppress lamb recruitment and population recovery for 1 to 5 years (Foreyt and Jessup, 1982; Miller, 2001). Because of the significant economic and ecological impacts of this disease in both domestic and wild ruminants, *Pasteurella/Mannheimia* spp. have been the subject of much research for many years (Kimberling, 1988; Rudolph *et al.*, 2003).

Some strains of *Pasteurella/Mannheimia* spp. can be found in the oropharynx of many healthy wild sheep and may act as opportunistic pathogens,

causing disease when there are predisposing factors such as nutritional deficits, crowding, anthropogenic disturbance, or exposure to other disease agents, reducing the normal protective function of the immune system. On the other hand, there is increasing evidence that other strains of *Pasteurella/Mannheimia* spp. can act as primary pathogens, and exposure to these strains, even in the absence of stressors can result in pneumonia die-offs in bighorn sheep. Some of these highly pathogenic strains, such as *M. haemolytica* A2, have been found in normal healthy domestic sheep and goats, and have been implicated in large-scale bighorn sheep die-offs following contact with domestic sheep (Martin *et al.*, 1996; Ward *et al.*, 1997).

The *Pasteurella* genus is an incredibly large and diverse group of bacteria that is continually undergoing re-classification (Fig. 1). In 1999, *P. haemolytica* was subdivided into *M. haemolytica* and *P. trehalosi* based on biochemical properties (Angen *et al.*, 1999; Jaworski *et al.*, 1998; Ward *et al.*, 1997). *Pasteurella multocida*, *P. trehalosi* (formerly *P. haemolytica* type T), and *Mannheimia haemolytica* are the three bacteria of these genera most commonly cultured from the lungs of domestic and wild sheep and goats.

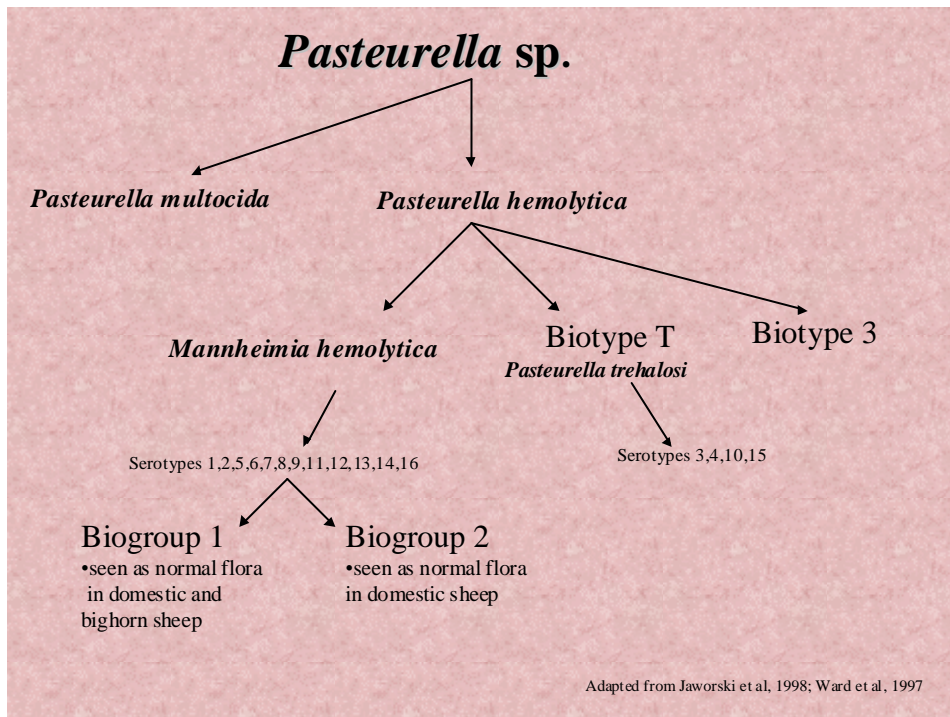


Figure 2. Current classification of *Pasteurella/Mannheimia* spp.

Mannheimia haemolytica

General overview: Strains of *M. haemolytica* (formerly *Pasteurella haemolytica*) are the organisms most frequently isolated from the lungs of pneumonic domestic sheep and goats, and bighorn sheep. Within this species, there are numerous serovars and biogroups, depending on the system of classification used. Although *M. haemolytica* is now a distinct genus, disease caused by this organism is still often referred to as “pasteurellosis”. *Mannheimia haemolytica* A1 is infrequently isolated from the upper respiratory tract of healthy bighorn sheep, and is thought to act as an opportunistic invader in much the same way as *P. multocida* and *P. trehalosi*. *Mannheimia haemolytica* A2 has been found in upper respiratory tract of healthy domestic sheep, but has not

been isolated from healthy wild sheep. It is thought that bighorn sheep are infected with *M. haemolytica* A2 through contact with domestic sheep or goats (Foreyt *et al.*, 1996; Martin *et al.*, 1996; Schommer and Woolever, 2001). This bacterium has the potential to act as a primary pathogen in bighorn sheep, resulting in all-age die-offs in herds throughout western North America. The picture is further complicated by the fact that strains currently circulating in many bighorn sheep populations may actually be of domestic animal origin.

Clinical signs in domestic sheep, goats, and llamas: *Mannheimia haemolytica* is part of the shipping fever complex in domestic ruminants. It is rarely thought to be a primary pathogen, but is associated with stresses such as shipping, crowding, weaning, and dust, or other viral or bacterial pathogens (Kimberling, 1988). Clinical signs are usually seen 1 to 3 weeks following the initiating stressor and outbreaks may begin with sudden deaths due to septicemia. Affected animals present with high fever, severe depression, anorexia, rapid weight loss, nasal and ocular discharge, respiratory distress, coughing, and weakness (Kimberling, 1988). Often 50% of the flock is affected, with mortality averaging only 10%, presumably due to successful treatment (Pugh, 2002). Recommendations for prevention of this disease include vaccination and the reduction of stress such as mixing, transport, and crowding.

In a study of pack goats in the western United States, *M. haemolytica* was cultured from the pharynx of 24 of 43 healthy animals. Based on biochemical

properties, the type of *M. haemolytica* was determined to be of high to moderate disease potential for bighorn sheep (V. Coggins, pers. comm.).

Clinical signs in wild sheep: *Mannheimia haemolytica* has been implicated as one of the major causes of mortality in bighorn sheep in North America (Foreyt *et al.*, 1996; Martin *et al.*, 1996; Ward *et al.*, 1997). The clinical presentation in wild sheep is very much like that of domestic sheep and goats. Many normal healthy bighorn sheep carry multiple biotypes/strains of *M. haemolytica* in the nose, mouth, and tonsils (Jaworski *et al.*, 1998; Onderka and Wishart, 1988; Ward *et al.*, 1997). However, *M. haemolytica* A2, commonly isolated from the oral cavity of healthy domestic sheep, may be a primary pathogen in bighorn sheep. Contact with healthy domestic sheep carrying *M. haemolytica* A2 is thought to result in all-age die-offs in bighorn sheep. In the acute phase of the disease, there can be 75–100% mortality. Recovery from these die-offs often takes years. Chronically affected animals surviving the initial outbreak perform poorly and herds may experience poor lamb survival for up to five years.

Pasteurella multocida

General overview: *Pasteurella multocida* is commonly cultured from the upper respiratory tract of healthy wild and domestic ruminants; however, the presence of these bacteria in the lungs is associated with chronic pneumonia.

Clinical signs in domestic sheep, goats, and llamas: *Pasteurella multocida* is a potential cause of pneumonia in domestic sheep and goats, playing a role in the shipping fever complex. Clinical signs are consistent with respiratory disease and include nasal discharge, exercise intolerance, coughing, depression and weight loss. Chronic manifestations of this bacterial infection are typical; outbreaks of acute disease occur, but are less common. *Pasteurella multocida* has been isolated in healthy llamas, but has never been cultured from a pneumonic animal (Fowler, 1998).

Clinical signs in wild sheep and mountain goats: *Pasteurella multocida* has been cultured from the lungs of a single Dall's sheep lamb found dead in the Mackenzie Mountains. It was suspected that it was the proximate cause of a fatal, acute fibrinous pleuropneumonia (Jenkins, 2005). Acute mortality is rare; pneumonias are usually subacute or chronic with abscessation and pleural adhesions. Animals show weight loss, ill-thrift, nasal discharge, exercise intolerance, coughing, and depression. *Pasteurella multocida* is often identified in combination with respiratory viruses such as IBR or PI3 or other bacteria such as *Arcanobacterium pyogenes* and produces a syndrome similar to shipping fever seen in domestic ruminants (H. Schwantje, unpubl. data). *Pasteurella multocida* is considered to be an important pathogen in the bighorn pneumonia complex (Martin *et al.*, 1996).

Pasteurella trehalosi

General overview: *Pasteurella trehalosi* is commonly found in the upper respiratory tract of both healthy and pneumonic bighorn (Jaworski *et al.*, 1998; Onderka and Wishart, 1988; Ward *et al.*, 1997) and Dall's sheep (Foreyt *et al.*, 1996). It is less commonly found in domestic sheep or goats (Martin *et al.*, 1996; Ward *et al.*, 1990).

Clinical signs in domestic sheep, goats, and llamas: *Pasteurella trehalosi* is found in domestic ruminants but disease is very uncommon in domestic sheep, goats, or llamas in Canada. In a study of healthy pack goats in the western United States, 33 of 43 animals had *P. trehalosi* (V. Coggins, pers. comm.).

Clinical signs in wild sheep: *Pasteurella trehalosi* has been cultured from the nasopharynx of healthy bighorn and Dall's sheep, as well as from the lungs of pneumonic sheep (Martin *et al.*, 1996). It is thought that *P. trehalosi* is a secondary invader, rarely causing disease on its own (Schommer and Woolever, 2001). Clinical signs are consistent with chronic respiratory disease, and similar to that of *P. multocida*.

The following information pertains to *P. multocida*, *P. trehalosi*, and *M. haemolytica* in general because there is considerable overlap in information regarding transmission and environmental survival etc., and in many cases

regarding outbreaks in wild sheep, the exact species of *Pasteurella/Mannheimia* was never identified.

Mode of transmission: Transmission is via direct nose-to-nose contact or aerosolized droplets. *Pasteurella multocida* bacteria remained viable after distances of up to 18 m down a wind tunnel in temperatures that simulated both winter and summer conditions, suggesting that direct contact may not be necessary for transmission (Dixon *et al.*, 2002).

Environmental survival: *Pasteurella* spp. survive less than 24 hours outside the host (Martin *et al.*, 1996; Onderka and Wishart, 1988).

History in wild sheep: *Pasteurella* sp./*M. haemolytica* have been reported as the number one cause for bighorn population declines throughout North America, both in early reports, as well as in more recent die-offs (Schwantje, 1988a). Severe, acute pneumonia in bighorn sheep is usually caused by *M. haemolytica*, but *P. multocida* and *P. trehalosi* have also been isolated during die-offs, suggesting that these species may be more pathogenic than formerly thought (Onderka *et al.*, 1988; Pugh, 2002; Weiser *et al.*, 2003).

There are many reports throughout Canada (Table 1) and the United States as early as 1927 of contact between domestic sheep and bighorn sheep followed by all-age die-offs in the bighorn population (Krausman, 1996; Schwantje, 1988a). This type of die-off usually results in 75–100% mortality

(Schommer and Woolever, 2001). For example, in the early 1980s, pasteurellosis decimated a desert bighorn herd in Utah, reducing the herd from 254 to 6 sheep (Bunch *et al.*, 1999). Over 300 bighorns died of pasteurellosis in Hells Canyon, Idaho, possibly caused by contact with one goat (Cassirer *et al.*, 1996; Coggins, 2002). Not all die-offs are caused by contact with domestic sheep or goats; however, outbreaks following documented contact with domestic animals can be very severe, affecting all ages of sheep, and have extreme outcomes. In addition to the acute impacts, surviving animals frequently develop chronic pneumonia, have low reproductive rates or sick, undersized lambs, and recovery of the population can take years (Onderka *et al.*, 1988; Onderka and Wishart, 1984). Lambs born during or following pneumonia die-offs experience poor survival rates, and this trend may continue for up to five years (Martin *et al.*, 1996).

Attempts at treatment and/or vaccinations of wild sheep have been unsuccessful. Vaccination of bighorn sheep with the bovine vaccine for pasteurellosis, resulted in disease in 100% of the animals (Onderka *et al.*, 1988). Wild sheep are difficult if not impossible to medicate effectively in the wild. Capture attempts are stressful and dangerous. Moving sheep into captivity for effective parenteral treatment regimes may create enough stress to initiate or exacerbate the disease, while the close confinement increases the chances for contact resulting in a higher rate of transmission (Bunch *et al.*, 1999). Vaccination and treatment are therefore currently considered non-viable options for controlling or preventing outbreaks in wild sheep (Callan *et al.*, 1991; Ministry of Environment, 2000).

It can be said that no single factor can be incriminated in all die-off's (Bunch *et al.*, 1999). However, there is more than enough evidence demonstrating that contact with domestic sheep or goats frequently leads to death in bighorns, and this has prompted strict regulations and recommendations around domestic sheep and goat grazing for some bighorn ranges in the United States (Schommer and Woolever, 2001). In other jurisdictions it has been repeatedly recommended that all contact between domestic sheep/goats and wild sheep be avoided (Bunch *et al.*, 1999; Foreyt *et al.*, 1994; Ministry of Environment, 2000; Onderka *et al.*, 1988).

Susceptibility of Dall's sheep and mountain goats: There are no reports of the large-scale die-offs in Canadian Dall's sheep such as those seen in bighorn sheep (Jenkins *et al.*, 2000). Between 1999 and 2003, sporadic cases of fatal bacterial pneumonia, in three instances involving *Mannheimia/Pasteurella* spp. were described in free-ranging Dall's sheep in the Mackenzie Mountains, NWT. In pneumonic and healthy Dall's sheep from this populations, there was no evidence of the strains of *Mannheimia* or *Pasteurella* spp. common in domestic sheep and goats (Jenkins, 2005). Dall's sheep are likely completely naive to pathogenic strains of these bacteria circulating in domestic sheep, although they may harbour their own unique endemic strains. Susceptibility of Dall's sheep to *M. haemolytica* carried by domestic sheep is difficult to assess given the fortuitous geographic separation of these two species at this time. *In vitro* studies demonstrate an equal or greater susceptibility to *M. haemolytica* (A2) than

bighorns, suggesting that exposure to domestic sheep carrying the *M. haemolytica* A2 could be devastating to Dall's sheep (Foreyt *et al.*, 1996).

To our knowledge, *Pasteurella/Mannheimia* related die-offs have not been reported in mountain goats. In part, this could be due to the biology of the animals. Mountain goats do not congregate in as high densities as wild sheep and do not seek out domestic sheep. Also, mountain goats are even more difficult to observe and monitor than wild sheep, so although there are reports of mountain goat herds disappearing from one year to the next, the cause is unknown.

Evidence of transmission among domestic and wild sheep: In studies looking at natural and experimental transmission of *Pasteurella/Mannheimia* from domestic sheep and goats to wild sheep, exposure resulted in severely pneumonic bighorn sheep, with most of the experimentally-infected bighorn sheep dying within 48 hours. At no time during contact do domestic sheep show clinical signs of pneumonia (Foreyt, 1988; Foreyt *et al.*, 1994; Foreyt and Jessup, 1982). Unfortunately, in natural settings, bighorn sheep and domestic sheep and goats will commingle if given the chance, particularly during the rut, increasing the chances for transmission of pathogenic strains of *Pasteurella/Mannheimia* (Onderka *et al.*, 1988; Ward *et al.*, 1997).

Public health risk: None

Overall Risk:

Species Interaction	Transmission	Health Impact
Sheep to Dall's	High	High
Goats to Dall's	High	High
Llamas to Dall's	Unknown	High

Table 2. Bacterial pneumonia related die-offs in bighorn sheep in Canada

Date	Location	Proposed Cause	Outcome
1999–2000	Okanagan Valley, BC	Bacterial pneumonia, mixed organisms, domestic contact	75% dead
1998	Elk Valley, East Kootenay, BC	Bacterial pneumonia, <i>P. multocida</i>	Low mortality, no progression
1988	Captive herd, AB	Pneumonia after vaccine trial	All died
1985–86	Sheep River, AB	<i>M. haemolytica</i> type A	60-65 BHS reported dead
1981–83	East Kootenay, BC	Multiple organisms, lungworm	approximately 65% reduction in multiple herds
1978	Sheep River Sanctuary, AB	Pasteurella/verminous pneumonia	10% died
1970s	University of BC captive herd	Pneumonia	All died
1964–66	East Kootenay, BC	Bacterial and verminous pneumonia, domestic contact	Significant mortality in multiple herds
1920s	East Kootenay, BC	Bacterial and verminous pneumonia, domestic contact	Significant mortality in multiple herds

Viruses

Summary:

- Contagious ecthyma is caused by a very contagious *Parapox* virus.
- Disease includes painful blisters and proliferative lesions on the lips and muzzle or coronary bands of lambs or udders of ewes.
- Seen in domestic sheep, goats, llamas and wild sheep and mountain goats.
- Wild and domestic sheep and goats may be natural reservoirs for this virus.
- Transmission is by direct contact and indirectly through contaminated objects.
- Virus is highly persistent in the environment in scab material.
- Confirmed in captive Dall's sheep.
- Transmission between wild and domestic ruminants is highly suspected.
- Can be transmitted to humans.

Contagious Ecthyma

General overview: Contagious ecthyma (CE) is a highly contagious *Parapox* virus of the family Poxviridae. It is also called sore mouth, orf, and pustular dermatitis (Merwin and Brundige, 2000). It is endemic in domestic herds of sheep, goats, and llamas in western Canada (Fowler, 1998; Wenger and Tait, 2001). Sheep are considered the primary reservoir host for the disease (Fowler, 1998) and the virus has been observed in domestic flocks for more than 200 years (Lance *et al.*, 1981).

Clinical signs in domestic sheep, goats, and llamas: The virus enters the host through skin abrasions. Signs of disease begin within 3 to 4 days with vesicular, blister-like lesions that quickly rupture, progressing to scabs (L'Heureux *et al.*,

1996; Samuel *et al.*, 1975). Contagious ecthyma is common in young domestic sheep, goats, and llamas (Fowler, 1998; Kimberling, 1988). Lesions are usually restricted to the lips and muzzle. The condition can be very painful, interfering with prehension and mastication of food (Samuel *et al.*, 1975), and resulting in depression and loss of body condition (Fowler, 1998; Kimberling, 1988). Clinical disease is usually seen in young animals, although in naive herds, animals of all ages may be severely affected (Wenger and Tait, 2001). There is no treatment, but sheep and goats usually recover spontaneously within 2 to 4 weeks, while camelids often show clinical signs for months (Fowler, 1998). Secondary bacterial involvement can occur, and may result in complications including gastritis, pneumonia, lameness, corneal opacity, and rupture (Kimberling, 1988; Linklater and Smith, 1993; Smith *et al.*, 1982) and even mortality (Blood, 1971; Samuel *et al.*, 1975). There is a vaccine available for CE in domestic sheep and goats (Fowler, 1998), and although immunity is incomplete, it may be useful in reducing the severity of disease during an outbreak (Kimberling, 1988; Matthews, 1999; Wenger and Tait, 2001).

Clinical signs in wild sheep and mountain goats: Clinical signs in Dall's and bighorn lambs are similar to those in their domestic counter parts. Severe disease can occur in lambs and naive adult sheep, and can involve the eyes, ears, and coronary band of the hooves; lesions have been seen covering the entire body of young lambs (Fowler, 1998; Merwin and Brundige, 2000). Infection may result in lower body weight in late summer lambs relative to uninfected

counterparts. Although lambs may continue to have lower body weights into the following year, it appears that CE rarely leads to population declines and does not appear to play a primary role in population dynamics (Clark *et al.*, 1993a; L'Heureux *et al.*, 1996), but has been implicated as a precursor to lamb-pneumonia die-offs in some herds (Bunch *et al.*, 1999).

Clinical signs in mountain goats are similar to bighorn sheep but can be much more severe. Outbreaks have occurred resulting in deafness, blindness, and death (Samuel *et al.*, 1975; Zarnke, 2000).

Mode of Transmission: Transmission occurs during close contact of affected animals. The virus can be spread among animals, farms, and regions on inanimate objects such as pails, fences and feed, as well as people and insects (Kimberling, 1988). There can be transmission of CE resulting from the communal use of salt blocks where the abrasive nature of the salt can increase transmission (Blood, 1971; Lance *et al.*, 1981; Samuel *et al.*, 1975). Affected lambs can transmit the virus to ewes during nursing (L'Heureux *et al.*, 1996). There is also evidence of asymptomatic carrier goats and sheep playing a role in disease perpetuation within flocks (Wenger and Tait, 2001).

Environmental survival: The virus can remain viable in shed scabs for years, resulting in long-term environmental contamination (Fowler, 1998; Greenwood, 2003; Zarnke, 1981).

History in wild sheep: Clinical signs of CE were reported in free-ranging Dall's sheep in Alaska as early as 1930, but the disease was not confirmed until 1976 in a captive herd near Fairbanks, Alaska. Two of the lambs were euthanized because of severe debilitating lesions (Zarnke, 1981). There was evidence that the infection originated from an infected farm labourer or from sheep on a nearby farm (Dieterich *et al.*, 1981). In a subsequent study there was a higher prevalence of CE exposure in wild Dall's sheep than in domestic sheep in Alaska, suggesting that wild sheep may be natural reservoirs for this disease and that the virus could be endemic in some herds (Zarnke, 1981; Zarnke *et al.*, 1983). Government biologists involved with studies on Dall's sheep in the Mackenzie Mountains since 1994 have only recorded a single case of a Dall's sheep showing signs of contagious ecthyma – a lamb that was observed in October 1997 (A. Veitch, unpubl. data).

Contagious ecthyma has been reported in free-ranging mountain goats (Merwin and Brundige, 2000; Samuel *et al.*, 1975) and it is present in many herds of mountain goats throughout British Columbia and Alaska (Dieterich *et al.*, 1981; Smith *et al.*, 1982).

Contagious ecthyma was first reported in bighorn sheep in 1954 in Banff National Park (Lance *et al.*, 1981). Outbreaks in bighorn sheep may be associated with herds suffering from crowding, poor nutritional condition, high interspecific competition, higher social and environmental stress, poor genetic heterozygosity, or concurrent disease, which are all thought to lower immunity and result in a higher susceptibility to disease (Kimberling, 1988; L'Heureux *et*

al., 1996; Merwin and Brundige, 2000; Samuel *et al.*, 1975). Contagious ecthyma is intermittently recognized in the East Kootenay region bighorn sheep of British Columbia. Characteristically, several young animals in one or two herds are affected with lesions, clearing within a month. There are several more reports of adult animals with more extensive oral lesions. These are invariably associated with high population density and coarse feeds. Contagious ecthyma is considered an endemic disease in this region (H. Schwantje, unpubl. data).

Contagious ecthyma was reported from the Silver Bell bighorn herd in Arizona following release of 5,000 domestic goats into their range. The bighorns initially suffered from keratoconjunctivitis (caused by *M. conjunctivae*), which was followed by a large-scale and severe CE outbreak. The overall impact was undetermined, however many lactating ewes were seen with no lambs and three stillborn lambs were reported. Additionally, three dead ewes had evidence of a recently terminated pregnancy at post-mortem examination. Some captured animals were vaccinated for ovine CE, but it appeared that the CE spread systematically through the herd (J. Heffelfinger, pers. comm.).

Evidence of transmission among domestic and wild species: Transmission between wild and domestic sheep has been demonstrated (Blood, 1971). It remains uncertain whether CE has always been endemic in wild sheep and goats, or if it was brought to North America with the introduction of domestic sheep (Bunch *et al.*, 1999; Zarnke *et al.*, 1983). Either way, transmission of CE appears to occur both ways and may pose a threat to both groups when wild

sheep and goats contact domestic sheep, goats, and camelids, particularly in the young or naive portions of the population (Samuel *et al.*, 1975; Zarnke, 1981).

Public health risk: CE is a zoonotic disease. It can be transmitted from direct contact with affected domestic and wild animals as well as from skinning and dressing affected carcasses (Smith *et al.*, 1982).

Parainfluenza 3

Summary:

- **Parainfluenza 3 (PI3) is caused by a *Paramyxovirus*.**
- **Signs of disease in cattle, sheep and goats include coughing, nasal discharge, and difficulty breathing.**
- **Infection may predispose the respiratory tract to secondary bacterial invaders like *Pasteurella/Mannheimia* spp.**
- **Clinical disease is seen in domestic sheep and goats.**
- **Antibodies to PI3 present in some llamas, but no clinical disease has been reported.**
- **Associated with die-offs in bighorn sheep in Canada and the US.**
- **Evidence of exposure in Dall's sheep.**
- **Transmission is by direct contact.**
- **Does not persist in the environment.**
- **Natural transmission between domestic and wild bighorn sheep is suspected.**
- **There are no public health effects.**

General overview: Parainfluenza 3 (PI3) is a respiratory virus of the genus *Paramyxovirus* that causes respiratory disease in domestic cattle, goats, and sheep, resulting in serious economic losses (Baker, 1990; Matthews, 1999; Rodger, 1989). PI3 rarely causes disease on its own, but predisposes the respiratory tract to secondary bacterial invaders, particularly *Mannheimia*

haemolytica, and is part of the shipping fever complex (Kimberling, 1988; Krausman, 1996; Parks *et al.*, 1972; Rodger, 1989).

Clinical signs in domestic sheep, goats, and llamas: Clinical signs include fever, loss of appetite, coughing, ocular and nasal discharge, increased respiratory rate, and laboured breathing (Baker, 1990; Zarnke, 2000). The virus can also cause sudden death in domestic sheep (Rodger, 1989). Although most infections are inapparent with greater than 70% of surveyed domestic sheep having antibody, PI3 is still the most common virus associated with bacterial pneumonias in this species (Kimberling, 1988). Antibodies to PI3 have been documented in clinically healthy llamas in British Columbia (Schwantje and Stephen, 2003) and in camelids worldwide, but the significance is unknown (Wernery and Kaaden, 2002).

Clinical signs in wild sheep: Virus has been isolated from both healthy and pneumonic bighorn sheep (Clark *et al.*, 1985) and has clearly been associated with fatalities in bighorn sheep (Parks *et al.*, 1972). Clinical signs appear to be much like those seen in domestic animals infected with PI3 virus but the incidence of pure infections is unknown.

Mode of transmission: Transmission of PI3 occurs during close contact of susceptible and stressed animals. It is a highly infectious virus and is efficiently transmitted (Van Campen and Early, 2001).

Environmental survival: PI3 is unstable in the environment.

History in wild sheep: Seroprevalence to PI3 is almost ubiquitous in wild ruminants, and for the most part, infections appear to be subclinical (Van Campen and Early, 2001). Antibody to PI3 has been reported in both free-ranging and captive, healthy Dall's sheep in Alaska, though the prevalence is very low (Dieterich, 1981; Foreyt *et al.*, 1983; Zarnke, 2000). There was no evidence of exposure to PI3 on immunohistochemistry of lungs of 7 pneumonic Dall's sheep, or on serology from 11 healthy Dall's sheep from the Mackenzie Mountains.

PI3 was reported to cause fatal pneumonia in 100% of 10 wild-caught Rocky Mountain bighorn sheep in Wyoming (Parks *et al.*, 1972). Virus was also detected through the use of PCR techniques, in pneumonic California bighorn sheep during the South Okanagan die-off where it was presumed to be one of a number of organisms responsible for a die-off (H. Schwantje, unpubl. data).

Evidence of transmission among domestic and wild species: none proven

Public health risk: none

Overall Risk:

Species Interaction	Transmission	Health Impact
Sheep to Dall's	Unknown	High
Dall's to sheep	Unknown	Moderate
Llamas to Dall's	Unknown	Unknown

Parasites – Helminths**Muellerius capillaris****Summary:**

- ***Muellerius capillaris* is a lung nematode.**
- **Occasionally causes mild respiratory disease in domestic animals.**
- **Found in domestic sheep and goats and in bighorn sheep in South Dakota.**
- **Larvae develop in gastropod intermediate hosts, and consumed by grazing sheep**
- **Long-term environmental survival.**
- **Suspicion of associated pneumonia in infected bighorn sheep, but this is unconfirmed.**
- **Evidence of transmission from domestic goats to bighorn sheep.**

General overview: *Muellerius capillaris* is the most common and perhaps least pathogenic lungworm known to infect domestic sheep and goats (Pugh, 2002). Adults, larvae, and eggs inhabit nodules in the lung parenchyma. *Muellerius capillaris* is differentiated from the other lungworms of domestic sheep by the dorsal spine on the tail of the larvae, and the characteristic corkscrew tail of the adult male nematode. It has been reported in bighorn sheep (Pybus and Shave, 1984).

Clinical signs in domestic sheep, goats, and llamas: *Muellerius capillaris* occasionally causes a mild interstitial pneumonia in goats and lung granulomas in sheep, but in both cases clinical signs are seldom observed (Kimberling, 1988; Pybus and Shave, 1984). *Muellerius capillaris* has not been reported in llamas.

Clinical signs in wild sheep: The role of this parasite in clinical disease in wild sheep is unknown. Pybus and Shave (1984) reported that infected bighorn sheep had numerous adult lungworms while domestic sheep and goats are usually infected with only 1 or 2 adults, suggesting that there is the potential for more extensive tissue damage in affected bighorns compared to that seen in domestic sheep. It is thought that the presence of large numbers of larvae and adult worms in the lung tissue of wild sheep may predispose them to bacterial pneumonia (Demartini and Davies, 1977).

Mode of transmission and lifecycle: Dorsal-spined first-stage larvae are shed in the feces, and develop into infective larvae inside the snail or slug intermediate host. The susceptible ruminant then accidentally ingests the infected gastropod and larvae are released in the gastrointestinal system to migrate to the lungs where they develop into adults.

Environmental survival: The 1st stage larvae can survive for months under a variety of environmental conditions in fecal pellets, and the 3rd stage larvae can survive inside the intermediate host for the lifetime of the gastropod.

History in wild sheep: Until identified in bighorn sheep from South Dakota in 1974, *M. capillaris* was thought to be a lungworm only of domestic sheep and goats (Pybus and Shave, 1984). In August of 1974, 20 out of 20 captive bighorn sheep died following clinical respiratory disease. On necropsy, 17 out of 20 animals had chronic verminous pneumonia associated with *M. capillaris* larvae and bacterial pneumonia was confirmed in all animals. It is thought that the tissue damage from numerous larvae may predispose animals to bacterial invasion (Demartini and Davies, 1976). The source of the lungworms in this herd is unclear, although this raises the concern of transmission from domestic sheep and goats to wild sheep (Pybus and Shave, 1984).

There are reports of larvae with a characteristic dorsal-spine on the tail resembling *Muellerius capillaris* found in fecal samples of bighorn sheep from Alberta and British Columbia (Pybus and Samuel, 1984; Pybus and Shave, 1984). Recent investigations suggest that dorsal-spined larvae (DSL) in bighorn sheep are most likely *M. capillaris*. DSL in Dall's sheep in Alaska and Canada have been identified as *Parelaphostrongylus odocoilei* and there is no evidence of *M. capillaris* in these wild populations (Jenkins, 2005; Kutz *et al.*, 2001). Molecular characterization of larvae is now possible to definitively identify DSL from fecal matter (Jenkins *et al.*, 2005a).

Evidence of transmission among domestic and wild species: In a recent study, 7 bighorn sheep were housed on the same pasture as 4 domestic goats infected

with *Muellerius* spp. Within 6 months, 2 bighorn sheep had died with pasteurellosis and all 5 surviving bighorns were shedding *M. capillaris* larvae indicating transmission from domestic goats to bighorn sheep. The role of this lungworm in the pathogenesis of pasteurellosis or other bacterial pneumonia is not known (W. Foreyt, pers. comm.). It is likely that sympatric range use of domestic sheep and wild sheep can result in transmission of this parasite.

Public health risk: none.

Additional comments: Dall's sheep in the Mackenzie Mountains are infected with the lungworm *Protostrongylus stilesi* and the muscle worm *Parelaphostrongylus odocoilei*, the latter causing considerable lung pathology which can be fatal in the end stages (Jenkins, 2005; Kutz *et al.*, 2001). Addition of a third lungworm which causes another type of lung pathology potentially could cause significant disease (Kutz *et al.*, 2004a).

Parasites – Ectoparasites

Oestrus ovis

Summary:

- *Oestrus ovis* is a nasal bot-fly.
- Causes severe sinusitis and occasionally death.
- Occurs in domestic sheep, goats and llamas, and bighorn sheep.
- Not been reported in Dall's sheep.
- Transmission is direct, adult flies deposit larvae around the nose of the sheep.
- Development to adults is positively related to temperature, adult flies live for 2-3 wks.
- Not highly host-specific, highly likely that it could infect any wild sheep.
- Historic reports of human infection.

General overview: *Oestrus ovis*, or the sheep nasal bot, is a common ectoparasite in domestic sheep. It has a worldwide distribution, with geographic expansion following the domestic sheep and goat historic movements (Colwell, 2001). It can infect llamas and wild sheep.

Clinical signs in domestic sheep, goats, and llamas: Clinical signs of *Oestrus ovis* infections in domestic sheep and goats range from minimal to severe, and include foot stamping, head rubbing, rhinitis with nasal discharge, chronic sinusitis, weight loss, and occasionally death (Blood and Radostits, 1989; Kimberling, 1988; Pugh, 2002). The presence of the adult flies is annoying, at times driving flocks into frenzied attempts to evade swarming flies. It is less

common in goats than in sheep. In goats, larvae rarely migrate via the ethmoid bones to the brain. They also may enter the eye or nasolacrimal system causing conjunctivitis (Matthews, 1999). *Oestrus ovis* also infects llamas but it is not known whether the larvae develop to the third instar in this species; clinical signs are similar to those observed in domestic sheep (Fowler, 1998).

Clinical signs in wild sheep: Clinical signs in bighorn sheep are similar to those in domestic sheep, but can be more severe. In desert bighorn sheep signs include severe and chronic sinusitis, extensive bone necrosis, open lesions on the skin of the head affecting the eyes with occasional blindness or central nervous system signs, and death (Bunch, 1978). It is postulated that the anatomy of horned sheep is such that the larvae invade the large frontal sinus, causing a deep infestation with chronic damage. This phenomenon has also been recorded in domestic horned sheep (Bunch, 1978).

Mode of transmission and lifecycle: Nasal bot flies deposit larvae around the nostrils of the host. Larvae migrate to the frontal sinuses where they develop to the third-instar (this may take 1–9 months). Once this development is complete, they migrate back to the nostrils and are sneezed out. In the environment the larvae pupate into mature adults. Newly emerged adults mate and development of infective larvae within the female takes 12–17 days at 16–20 °C. *Oestrus ovis* has low host specificity and can infect many species of both domestic and wild ruminants (Colwell, 2001).

Environmental survival: Development from larvae to adult flies in the environment is a temperature dependent process. In temperate regions this process takes about 6 weeks (Capelle, 1966). Adult flies live for 2–3 wks, depending on the ambient temperature (Colwell, 2001).

History in wild sheep: There are numerous records of *O. ovis* in wild sheep, including in Idaho, Montana, Wyoming, and Utah (Becklund and Senger, 1967; Capelle, 1966; Colwell, 2001). *Oestrus ovis* in free-ranging desert bighorn throughout Utah is thought to be responsible for high mortality rates averaging 41% in Zion National Park (Bunch, 1978). The sheep nasal bot is found in other phylogenetically or ecologically related species, and it is reasonable to suspect that it can complete the normal lifecycle in all species of wild sheep (Capelle, 1966). Recent interviews with experienced harvesters in the Sahtu Settlement Region, NWT, indicated that nasal bots had not been observed in Dall's sheep over the last 25 years (S. Kutz, unpubl. data). However there is one anecdotal report of nasal larvae seen in a hunter-killed, 12-year-old Dall's ram in the Mackenzie Mountains in August of 2001 (E. Jenkins, unpubl. data). The species of larvae is unknown, however, caribou in the region are infected with another nasal bot, *Cephenemyia* sp. and it is possible that this might have infected the Dall's sheep.

Evidence of transmission among domestic and wild species: *Oestrus ovis* occurs worldwide in almost every domestic sheep-rearing area, and is found in bighorn sheep in North America (Capelle, 1966). Although domestic sheep are suspected to be the original source of this parasite for wild sheep, with the use of more effective parasite control programs in livestock management, wild sheep may now be a reservoir for reinfestation for domestic species (Colwell, 2001).

Public health risk: There are historic reports of this parasite in humans associated with sheep tending or husbandry. Larvae are found in the nostrils and conjunctiva of the eye and ears but do not develop past the first larval state. Larvae may congregate in the nasal sinuses and cause severe pain for a period of a few days (Capelle, 1966).

SECTION 3. IDENTIFICATION OF PATHOGENS WITH UNKNOWN CONSEQUENCES

Description

This section describes in detail the pathogens of unknown concern from Appendices 1–7. These pathogens are suspected to be transmissible among wild and domestic species of concern and may have serious impacts; however, insufficient data are available to assign them to the high concern category. The criteria for designation to this category are 1) the pathogen is known to cause significant clinical disease in domestic sheep, goats, or llamas and transmission to, or effect on, wild sheep or goats are unknown, or 2) the pathogen is known to cause significant clinical disease in wild sheep or goats and transmission to, or effect on, domestic sheep, goats or llamas are unknown. Because insufficient information is available to assign transmission risks and health impacts, there are no risk tables presented in this section.

Bacteria

***Chlamydophila* spp.**

General overview: *Chlamydophila* spp. (formerly known as *Chlamydia*) are small, gram-negative, pleomorphic bacteria that occur in two different forms inside and outside of the body. Inside the body, the bacteria reside in host cells, while outside the body, the bacteria take the form of an elementary body that is able to

survive for months under ideal conditions (Flammer, 2003). In ruminants there are two *Chlamydophila* species of concern: *C. pecorum* and *C. abortus*. Both are endemic in North America (Kimberling, 1988).

Chlamydophila abortus

General overview: *Chlamydophila abortus* (formerly a *Chlamydia psittaci* strain) occurs worldwide in ruminants, and colonizes the placenta of sheep, goats, and llamas.

Clinical signs in domestic sheep, goats, and llamas: *Chlamydophila abortus* is a major cause of contagious abortion and weak neonates in domestic sheep, goats, and llamas worldwide (Everett *et al.*, 1999; Papp *et al.*, 1993). Abortions are usually late term, and rarely occur more than once in the same animal.

Clinical signs in wild sheep: To our knowledge, outbreaks of abortion associated with *C. abortus* have not been reported in wild sheep. *Chlamydophila* spp. has been reported in bighorn sheep but was not identified to species. Clinical signs of keratoconjunctivitis in affected animals were more consistent with *Chlamydophila pecorum* than of those expected with *C. abortus* (Meagher *et al.*, 1992).

Mode of Transmission: Aborted tissue is the major source of infection, but recent reports show that affected ewes and does continue to shed the organism during estrus following abortion (Flammer, 2003; Wenger and Tait, 2001).

Environmental survival: Bacteria can survive in elementary body form in the environment for months (Carter *et al.*, 1995).

History in wild sheep: No abortion outbreaks have been reported.

Evidence of transmission among domestic and wild species: There is currently no evidence of transmission among domestic and wild species, however, the main clinical sign, abortion, is very difficult to detect in wild populations.

Public health risk: There are sporadic reports of abortion caused by *C. abortus* in women following repeated contact with domestic sheep (Everett *et al.*, 1999).

Chlamydophila pecorum

General overview: *Chlamydophila pecorum* (formerly *Chlamydia pecorum*) has been isolated from many mammals worldwide including, but not limited to sheep, goats, and llamas (Everett *et al.*, 1999). It may be found in combination with other organisms such as *Mycoplasma arginini*, *M. ovipneumoniae*, *Acholeplasma oculi*, *Branhamella ovis*, *Moraxella bovis*, *Chlamydophila abortus* (Hindson and Winter,

2002; Linklater and Smith, 1993), and infectious bovine rhinotracheitis virus (Matthews, 1999).

Clinical signs in domestic sheep, goats, and llamas: *Chlamydophila pecorum* has been associated with abortion, keratoconjunctivitis, encephalomyelitis, enteritis, pneumonia, and polyarthritis. It is commonly associated with pink-eye or keratoconjunctivitis in domestic sheep and goats. Animals are predisposed to disease by exposure to dust, wind, bright sunlight, long grass, or flies (Matthews, 1999). Disease is usually seen in late summer or early fall (Kimberling, 1988) and can be severe, leading to temporary or permanent blindness with secondary mortality from inability to find food, water and shelter (Drew *et al.*, 1992; Hindson and Winter, 2002; Matthews, 1999; Pugh, 2002). There is poor lasting immunity to this bacteria, meaning that animals can be infected multiple times (Hindson and Winter, 2002). Affected animals can have multiple manifestations of the disease simultaneously, and have been reported with signs of concurrent polyarthritis, demonstrated by a stiff stilted gait, and upper respiratory disease (Flammer, 2003; Kimberling, 1988; Matthews, 1999).

Clinical signs in wild sheep: *Chlamydophila* sp. has been associated with signs of pink-eye, as well as concurrent polyarthritis and possibly upper respiratory disease in bighorn sheep (Meagher *et al.*, 1992)

Mode of transmission: Bacteria are generally transmitted during direct contact, exchange of tears and/or nasal secretions. Animals can also maintain the disease as asymptomatic carriers, re-infecting animals in the same herd repeatedly (Hindson and Winter, 2002). Fly vectors and fomites may play a role in spread of the bacteria (Everett *et al.*, 1999).

Environmental survival: Bacteria can survive in elementary body form in the environment for months (Carter *et al.*, 1995).

History in wild sheep: In 1982, bighorn sheep in Yellowstone National Park, Wyoming were diagnosed with *Chlamydophila* spp. causing keratoconjunctivitis. Approximately 60% of the estimated 500 sheep died as a result of this epizootic due to complications associated with blindness such as injuries and predation (Meagher *et al.*, 1992). The source of the infection was never determined. Clinical signs in all affected sheep were the same as those observed in domestic sheep and goats. Additionally, affected animals walked with a stiff stilted gait, which was attributed to the inability to negotiate terrain when blind (Meagher *et al.*, 1992), but is also suggestive of joint pain. Polyarthritis and respiratory complications were later seen in those bighorn sheep diagnosed with chlamydiosis (Meagher *et al.*, 1992). Mortality in affected animals was high, presumably due to lost ability to forage and find shelter, accidents, and a higher rate of predation. Severely affected animals were euthanized (Meagher *et al.*,

1992). *Chlamydophila* spp. have been identified in mixed infections of pneumonic bighorn sheep in BC (H. Schwantje, unpubl. data).

Chlamydophila spp. has not been reported in free-ranging Dall's sheep or mountain goats in NWT.

Evidence of transmission among domestic and wild species: *Chlamydophila* spp. are transmissible between domestic sheep and goats (Matthews, 1999). There are no confirmed reports of transmission between domestic and wild sheep or goats. Given the broad host range and environmental persistence of this genus it is probable, but not certain, that *C. pecorum* can be transmitted between domestic and wild species. *Chlamydophila* sp. has been documented in bighorn outbreaks with no evidence of prior contact with domestic sheep (Meagher, 1982), suggesting that bighorn sheep may carry this organism naturally. More study is necessary to confirm this assumption.

Public health risk: none

Corynebacterium pseudotuberculosis**Summary:**

- ***Corynebacterium pseudotuberculosis* is a gram positive bacteria.**
- **Causes abscessation of lymph nodes in domestic sheep and goats.**
- **Not reported in llamas or wild sheep.**
- **Very high prevalence of infection in domestic sheep in Canada.**
- **Transmission through contact with infective material and open wounds.**
- **Long-term environmental survival.**
- **No reports of infection in wild sheep in North America.**
- **No public health concerns.**

General overview: *Corynebacterium pseudotuberculosis* is a gram-positive coccoid bacillus bacteria causing a condition called caseous lymphadenitis (CLA) in adult domestic sheep and goats. The bacteria infect the lymph nodes and occasionally the internal organs. Infection likely occurs following invasion of the bacteria into superficial skin or oral wounds (Kimberling, 1988).

Clinical signs in domestic sheep, goats, and llamas: *Corynebacterium pseudotuberculosis* causes abscessation of superficial lymph nodes with occasional involvement of lungs or abdominal organs, weight loss, carcass condemnation at slaughter, and death in some animals (Kimberling, 1988). There is a high prevalence of this infection in domestic sheep and goats in Canada. It has been sporadically isolated from abscesses in alpacas, but there are no reports of infection in llamas (Fowler, 1998).

Clinical signs in wild sheep: There are no reports of *C. pseudotuberculosis* in bighorn or Dall's sheep in the literature, perhaps because opportunities to sample and culture lesions caused by this organism are rare.

Mode of transmission: *Corynebacterium pseudotuberculosis* is discharged from draining abscesses and contaminates soil or feed. Entry into new hosts occurs through damaged skin, ingestion or through the respiratory tract (Huang *et al.*, 1997).

Environmental survival: Bacteria are reported to survive in the environment for up to 5 months (Blood and Radostits, 1989).

History in wild sheep: This disease has never been reported in bighorn sheep, though it has been reported in mouflon sheep, white-tailed deer, and mule deer (Huang *et al.*, 1997). Since this disease may not be fatal, it is likely underreported in wild sheep (H. Schwantje, unpubl. data).

Evidence of transmission among domestic and wild sheep: None. However, the fact that this bacteria is not very host specific and the long-term survival in the environment presents some concern where domestic sheep or goat range overlaps with wild sheep and goats.

Public health risk: Human cases have been reported, but are very rare.

Coxiella burnetti (Q-fever)

Summary:

- ***Coxiella burnetti* is a rickettsial bacteria.**
- **Causes abortion and general illness in domestic sheep and goats.**
- **Antibodies found in Dall's sheep in Alaska, but the significance is unknown.**
- **Transmission is by ingestion, inhalation, contact with infected fetal materials, nose-to-nose contact, sexual transmission, and ticks.**
- **The bacteria survive for long periods of time in dry environments.**
- **Transmission between wild and domestic species is unknown.**
- **Can cause serious disease in people.**

General overview: *Coxiella burnetti* is a rickettsial bacteria and is the cause of Q-fever, a disease resulting in abortion in domestic goats and sheep in North America (Pugh, 2002). *Coxiella burnetti* can be transmitted to humans.

Clinical signs in domestic sheep, goats, and llamas: Infection with *Coxiella burnetti* is usually subclinical, but can cause abortion accompanied by anorexia, fever, and depression in does and ewes. Occasionally the majority of the herd may be affected. It has not been reported in llamas.

Clinical signs in wild sheep: Unknown.

Mode of transmission: Transmission is via ingestion, inhalation, contact with infected abortus, nose-to-nose contact, sexual transmission, and ticks (Pugh,

2002). Cattle can also carry these bacteria and are a source of infection for sheep and goats.

Environmental survival: Bacteria can survive for extended periods of time in a dry environment (Pugh, 2002).

History in wild sheep: Antibodies to *C. burnetti* were found in 12 of 15 (80%) free-ranging Dall's sheep sampled from the central Alaska Range, Alaska between 1978 and 1981. High antibody titres (1:20 or greater) were found in five of these sheep (33%). These findings suggest that the *Coxiella* may be more widespread than previously thought. Further studies are required to determine the species of *Coxiella*, possible impact on reproductive success and overall significance of this finding in Dall's sheep (Zarnke, 1983). There are no reports of *C. burnetti* in bighorn sheep or mountain goats.

Evidence of transmission among domestic and wild sheep: There are currently no reports of *C. burnetti* being transmitted between domestic and wild sheep. However, the long-term survival, multiple modes of transmission, and evidence from domestic sheep and goats warrant consideration of this bacterium as a risk for Dall's sheep.

Public health risk: People can become infected with *C. burnetti* by contaminated aerosols from infected animals. The most serious clinical signs seen in people

include inflammation of the liver and heart with influenza-like symptoms and abortion, premature birth, and low weight in newborn babies (Maurin and Raoult, 1999).

Summary:

- ***Erysipelothrix rhusiopathiae* is a gram positive bacteria.**
- **Causes chronic arthritis in domestic sheep and goats.**
- **Not reported in wild sheep in North America.**
- **Transmitted through wound contamination, ingestion and vectors.**
- **Long-term environmental survival.**
- **No evidence of transmission between wild and domestic species.**
- **Public health concern.**

Erysipelothrix rhusiopathiae

General overview: The bacteria *E. rhusiopathiae* is a gram-positive rod that causes chronic arthritis in sheep and goats in North America (Kimberling, 1988; Matthews, 1999). It is thought that bacteria are soil-borne (Kimberling, 1988) or healthy animals carry the bacteria and become clinically affected during periods of stress, leading to transient periods of environmental contamination (Leighton, 2001a). Clinical erysipelas is not as common as it once was in North America owing to the practice of disinfecting umbilical cords in newborn domestic animals (Kimberling 198,8).

Clinical signs in domestic sheep, goats, and llamas: *Erysipelothrix rhusiopathiae* causes polyarthritis characterized by lameness, stiffness, fever, depression and

weight loss and occasionally death in young lambs (Kimberling, 1988). To our knowledge there are no reports of *E. rhusiopathiae* in llamas.

Clinical signs in wild sheep: Unknown

Mode of transmission: Animals become infected via bacterial entry through contamination of wounds or umbilical stumps, ingestion, or through vectors such as lice, ticks, mites and flies (Leighton, 2001a).

Environmental survival: The bacteria can persist for long periods of time in soil, water, feces and decaying carcasses (Leighton, 2001a).

History in wild sheep: *Erysipelas rhusiopathiae* is documented in many wild mammals but has never been reported in wild sheep in North America (Leighton, 2001a).

Evidence of transmission among domestic and wild species: There is no evidence of transmission between domestic and wild sheep, however, because of the multiple modes of transmission, the wide host range, and the occurrence in domestic sheep and goats in Canada, transmission of this bacterium must be considered possible.

Public health risk: Contamination of wounds with *E. rhusiopathiae* causes skin infections. Very rarely, the infection can progress to fatal septicemia and endocarditis. Persons handling meat products are most at risk (Leighton, 2001a).

Summary:

- *Mycoplasma* spp. are small, fragile bacteria.
- Cause mild to severe respiratory disease.
- Domestic sheep and goats can be affected.
- Infection in llamas is considered insignificant.
- *M. arginini* has been isolated from bighorn sheep.
- *M. mycoides* has not been isolated from wild sheep or goats in North America.
- Direct, aerosol, or mechanical transmission.
- Environmental survival is very short - organism is extremely fragile.
- *M. arginini* reported in pneumonic wild sheep; significance unknown.
- Minor public health concerns with *M. arginini*.

Mycoplasma arginini* and *Mycoplasma mycoides

General overview of *Mycoplasma* spp.: *Mycoplasma* bacteria are a diverse group of bacteria. They are extremely small, lack a cell wall and stain weakly gram-negative (Carter *et al.*, 1995; Whithear, 2001). They are commonly found in the respiratory tract of both healthy and diseased domestic ruminants (Al-Aubaidi *et al.*, 1972; Goltz *et al.*, 1986), but appear to be uncommon and insignificant in llamas (Fowler, 1998). Susceptibility to the bacteria is highly variable, and impacts range from subclinical to severe (Pugh, 2002) depending on the species, the exposure level, and host factors (Goltz *et al.*, 1986). *Mycoplasma* infections may predispose the respiratory tract to other invaders, with

Pasteurella/Mannheimia spp. being a major concern (St George and Carmichael, 1975). The organism can only survive inside the host cells, making culture and identification very difficult (Blood and Radostits, 1989; Stalheim, 1983). The role of *Mycoplasma* spp. in pneumonia outbreaks in domestic and wild sheep is, therefore, difficult to assess (Whithear, 2001). In domestic sheep and goats in North America there are two *Mycoplasma* species of high concern, *M. ovipneumoniae* and *M. conjunctivae* (see previous section), and two of unknown concern, *Mycoplasma arginini* and *M. mycoides*.

Mycoplasma arginini

General overview: *Mycoplasma arginini* has little host specificity, and low pathogenicity (Whithear, 2001). The principal hosts are cattle, sheep, goats, horses, and domestic carnivores (Whithear, 2001). *Mycoplasma arginini* is found in the oral cavity and lungs of both healthy and pneumonic wild and domestic sheep, with significance in pneumonia questionable (Goltz *et al.*, 1986).

Clinical signs in domestic sheep and goats: Disease is seldom reported in sheep or goats (Whithear, 2001). *Mycoplasma arginini* has been isolated from the lungs of camels with chronic interstitial pneumonia (Elfaki *et al.*, 2002) but is not considered a significant pathogen in llamas (Fowler, 1998).

Clinical signs in wild sheep: This bacteria has been consistently cultured from the lungs of pneumonic Rocky Mountain bighorn sheep, usually in mixed infections; the significance as a primary disease agent remains unknown (Al-Aubaidi *et al.*, 1972; Schwantje, 1988a; Woolf *et al.*, 1970; Woolf and Kradel, 1973).

Mode of transmission: Transmission is primarily through direct contact, although short distance aerosolization may play a role.

Environmental survival: This bacteria is very fragile due to the lack of a cell wall and does not persist outside a suitable host (Carter *et al.*, 1995).

History in wild sheep: *Mycoplasma arginini* was reported from lung lesions of five pneumonic bighorn sheep (Al-Aubaidi *et al.*, 1972). There were similarities between the lesions seen in this animal and those of Dall's sheep with *M. ovipneumoniae*, and it has been suggested that the cause of pneumonia in the bighorn sheep may in fact have been *M. ovipneumoniae* which is notoriously difficult to culture (Black *et al.*, 1988).

Evidence of transmission among domestic sheep and wild sheep: None

Public health risk: *Mycoplasma arginini* has been isolated from an immunocompromised abattoir worker with fatal septicemia and pneumonia.

Additional notes: Much remains unknown about the significance of *M. arginini* in wild sheep and goats. However, because this bacterium has been isolated from pneumonic lungs of wild sheep it must be considered an important pathogen until proven otherwise.

Mycoplasma mycoides

General overview: There are a number of different subspecies of *M. mycoides*, all associated primarily with respiratory disease, although it has been cultured from domestic sheep and goats with mastitis, polyarthritis, conjunctivitis, septicemia and pneumonia (Whithear, 2001). It can cause severe disease, but has also been reported in goats with no clinical signs (Nakagawa *et al.*, 1976; Ruhnke *et al.*, 1983). The organism is widespread in the United States, and was first reported in domestic goats in Canada in 1983 (Ruhnke *et al.*, 1983).

Clinical signs in domestic sheep and goats: Disease associated with *M. mycoides* is characterized by slow onset, often subclinical for a period of time, followed by signs typical of chronic respiratory disease such as difficult breathing, thick nasal discharge, exercise intolerance and weight loss. It is presumed that the bacteria inhibit the essential function of the tracheal cilia, causing decreased clearance of mucous and debris from the respiratory tract, as well as facilitating the entry of secondary invaders such as *Mannheimia haemolytica* (Brogden *et al.*, 1998; Stalheim, 1983). In an experimental infection of sheep and goats in

Connecticut, with *M. mycoides* subsp. *mycoides* isolated from an infected goat, all 9 goats and 3 sheep infected died of septicemia within 8 days of infection (Rosendal, 1981). Camels may be susceptible to pneumonia caused by *M. mycoides*, but it is not associated with any clinical disease in llamas (Fowler, 1998).

Clinical signs in wild sheep and mountain goats: To our knowledge, *M. mycoides* has not been reported in wild sheep or mountain goats in North America. It has been isolated from three wild goat kids (*Capra aegagrus cretica*) that died of septicemia and pneumonia at a Swiss zoo (Perrin *et al.*, 1994).

Mode of transmission: The normal route of transmission is aerosol. This bacteria has also been found in the ears of ruminants as well as inside ear mites and it is suspected that ear mites may act as a mechanical vector (Whithear, 2001). It is also thought to be transmitted to young goats via infected milk from does with acute mastitis (Blood and Radostits, 1989).

Environmental survival: This bacteria is very fragile due to the lack of a cell wall and does not persist outside a suitable host (Carter *et al.*, 1995).

Evidence of transmission among domestic and wild species: None

Public health risk: None

Viruses

Adenovirus

Summary:

- **Adenoviruses are a family of DNA viruses.**
- **Found in many wild and domestic ruminants of North America.**
- **May be associated with respiratory disease in both wild and domestic sheep.**
- **Ovine adenoviruses 1-6 found in domestic sheep.**
- **Antibodies in bighorn sheep in Wyoming and Colorado, significance unknown.**
- **Not found in Dall's sheep.**
- **Virus shed in urine, feces, conjunctival secretions.**
- **Virus stable in environment.**
- **Transmission between domestic and wild species is unknown.**
- **No public health concerns.**

General overview: There are many different types of adenoviruses found in wild and domestic ruminants in North America, but their significance is often unknown (Pugh, 2002). Ovine adenoviruses 1–6 have been reported in domestic sheep (Woods, 2001) with some appearing to be associated with respiratory disease, causing a more severe pneumonia in association with *M. haemolytica*.

Clinical signs in domestic sheep, goats, and llamas: Clinical signs are typical of respiratory disease and include fever, anorexia, nasal discharge, difficulty breathing, and sneezing (Pugh, 2002).

Clinical signs in wild sheep: No known clinical signs have been observed, however, it has been suggested that adenoviruses may be involved in the pneumonia complex in bighorn sheep (Parks, 1974; Woods, 2001).

Mode of transmission: Adenoviruses are highly contagious. Virus is shed in urine, nasal and conjunctival secretions, and feces. Transmission is via direct contact or infected objects (Woods, 2001).

Environmental survival: The virus is very stable in the environment (Woods, 2001).

History in wild sheep: In a serological survey of 29 free-ranging Rocky Mountain bighorn sheep in Colorado and Wyoming, 62% had antibodies to adenovirus. Some of these animals had clinical respiratory disease (Parks, 1974). The significance of positive titres and the source of virus are unknown.

Evidence of transmission among domestic and wild species: It is unknown whether the same adenovirus can infect domestic and wild sheep and goats, however, some adenoviruses of domestic animals commonly infect similar wild species such as infectious canine hepatitis which infects both domestic dogs and wild foxes.

Public health risk: none

Additional notes: It is worthwhile to note that adenoviruses can cause a hemorrhagic disease in wild deer that has striking similarities to Epizootic Hemorrhagic Disease (EHD) or bluetongue. Outbreaks of a deer adenovirus have been responsible for the deaths of thousands of mule deer (*Odocoileus hemionus*) in California. It is suspected that unconfirmed outbreaks of EHD in wild ruminants may in fact be due to adenoviruses (Woods, 2001).

Border Disease Virus and Bovine Viral Diarrhea Virus

Summary:

- **Border disease and bovine viral diarrhea viruses are closely related viruses of the Pestivirus genus.**
- **Cause abortion, birth deformities and weak offspring.**
- **Disease is seen in cattle, sheep, goats and llamas.**
- **Antibody and virus have been isolated from bighorn sheep.**
- **Antibody to bovine viral diarrhea has been reported from Dall's sheep in Alaska.**
- **Transmission is via direct contact with infected animals and materials.**
- **Not highly persistent in the environment.**
- **No public health concerns.**

General overview: Border disease (BD) and bovine viral diarrhea virus (BVDV) are very similar diseases of the *Pestivirus* genus seen in cattle, sheep, goats (Kimberling, 1988) and llamas (Belknap *et al.*, 2000). These viruses often cross react on serological testing. BVDV is more commonly associated with domestic cattle and BD with domestic sheep. Animals can become infected *in utero* and remain infected for life. These persistently infected carriers show no clinical

signs, but shed large numbers of virus and can infect other herd members (Pugh, 2002). These viruses cause significant herd effects worldwide in domestic sheep and cattle, but there is no evidence that they have significant impacts on wild ruminant populations (Van Campen *et al.*, 2001).

Clinical signs in domestic sheep, goats, and llamas: Signs of BD in sheep and goats include abortion, birth deformities, and weak lambs. A large proportion of the flock/herd is generally affected in the first year, but as flock immunity develops, losses decline in following years (Pugh, 2002). In cattle, BVDV commonly presents as diarrhea, oral ulcerations, depression, anorexia, and occasionally a fatal form of the disease known as mucosal disease (Belknap *et al.*, 2000). This virus can also cause reproductive failure, diarrhea and weight loss. BVDV is uncommon in camelids but it has been isolated on necropsy.

Clinical signs in wild sheep: Non-cytopathic BVDV have been isolated from pneumonic bighorn sheep, and should be considered in the differentials for pneumonias of wild sheep (Van Campen *et al.*, 2003).

Mode of transmission: Transmission is primarily through ingestion or inhalation of body fluids from infected animals (Matthews, 1999). Transmission from cattle to sheep occurs when species commingle (Kimberling, 1988). Vector-mediated transmission has also been reported (Van Campen *et al.*, 2001).

Environmental survival: The virus is not highly persistent in the environment.

History in wild sheep: Antibodies to BVDV have been found in serosurveys of more than 40 wild ruminant species, including Dall's sheep in Alaska, mountain goats, and bighorn sheep (Van Campen *et al.*, 2001; Dieterich, 1981). The significance of positive titres to BVDV in wild populations is unknown and there is some question as to whether this represents species specific BVD-like virus, or if it is the same species as found in domestic cattle. BVDV was isolated from pneumonic bighorns for the first time in 2002 suggesting that it should be considered as a possible etiology in respiratory disease of wild sheep (Van Campen *et al.*, 2003). There were low levels (1:12 to 1:108) of neutralizing antibody to BVD or a related pestivirus in 3 of 11 samples from healthy Dall's sheep from the Mackenzie Mountains, NWT, but it was not detected on immunohistochemistry of the lungs of 2 pneumonic Dall's sheep from this region (Jenkins, 2005).

Evidence of transmission among domestic sheep and wild sheep: BVD has been experimentally transmitted to wild cervids, but there are no confirmed cases of natural transmission (Van Campen *et al.*, 2001). It is recommended that wild ruminants and domestic livestock remain separate to prevent transmission of this virus (Van Campen *et al.*, 2001).

Public health risk: None

Corona Virus

Summary:

- **Coronavirus is an enveloped RNA virus.**
- **Causes disease of the respiratory and/or digestive tract.**
- **Reported in domestic sheep, goats, llamas and Stone's sheep.**
- **Transmission is through direct contact with secretions.**
- **The virus survives for long periods in the environment.**
- **Evidence of natural transmission from domestic calves to Stone's sheep.**
- **No known public health concerns.**

General overview: Corona viruses are large, enveloped RNA viruses causing subclinical infections of mucosal surfaces, particularly the respiratory and digestive systems (Evermann and Benfield, 2001). They are common in most domestic mammals.

Clinical signs in domestic sheep, goats, and llamas: Clinical signs seen in domestic animals include diarrhea, pneumonia, dehydration and sometimes death. Corona virus has been reported in sheep, goats, and llamas (Cebra *et al.*, 2003; Evermann and Benfield, 2001), though it is more commonly identified as a problem in calves.

Clinical signs in wild sheep: Clinical signs in wild sheep appear to be similar to those seen in domestic animals. Hemorrhagic diarrhea was observed in 3 captive Stone's sheep (E. Jenkins, unpubl. data).

Mode of transmission: Virus is shed in mucosal secretions, and transmitted through direct contact (Evermann and Benfield, 2001).

Environmental survival: The virus is unstable in the environment.

History in wild sheep: Three captive Stone's sheep became clinically ill with depression and hemorrhagic diarrhea following natural transmission of bovine corona virus from infected calves housed nearby. Transmission was confirmed by virus isolation and fluorescent antibody test from feces, as well as demonstration of seroconversion. Supportive care led to the full recovery of the affected animals (Jenkins, 2005; Keith West, unpubl. obs.).

Evidence of transmission among domestic and wild species: To our knowledge, there is only one confirmed case of coronaviral transmission causing disease from domestic calves to wild sheep.

Public health risk: none

Epizootic Hemorrhagic Disease and Bluetongue Viruses

Summary:

- **Epizootic Hemorrhagic Disease (EHD) and Bluetongue (BT) are related, insect-transmitted, double-stranded RNA orbiviruses.**
- **Cause severe and often fatal hemorrhage.**
- **Bluetongue virus is more common in domestic ruminants.**
- **Epizootic Hemorrhagic Disease caused by one of several viral strains is more commonly seen in wild ruminants.**
- **A few Dall's sheep were seropositive to EHD and BT viruses in Alaska, but no clinical disease**
- **An intermediate host (*Culicoides* spp) is required for transmission.**
- **Virus is unstable in the environment.**
- **Both diseases are seen rarely under certain climatic conditions in southwestern Canada.**
- **Mortalities suspected to be caused by EHD in California bighorn sheep in the Okanagan Valley in British Columbia.**
- **Transmission between domestic sheep, goats or llamas to bighorn sheep is a concern, but has not been confirmed.**
- **No public health concerns.**

General overview: Epizootic hemorrhagic disease (EHD) and bluetongue (BT) viruses are closely related arthropod transmitted orbiviruses infecting wild and domestic ruminants (Jessup *et al.*, 1984; Pasick *et al.*, 2001). The two diseases caused by these viruses are collectively termed the hemorrhagic diseases (HD). The diseases are usually seen in warm, temperate climates, but outbreaks have occurred in southern Canada, and antibody to EHD has been found in wild ruminants as far north as Alaska. Bluetongue most commonly affects domestic ruminants in the southern United States, causing severe disease in sheep but often presenting asymptotically in cattle and goats. Epizootic Hemorrhagic Disease more commonly presents in wild ruminants, with white-tailed deer

(*Odocoileus virginianus*) being most susceptible (Noon *et al.*, 2002; Zarnke, 2000). Transmission of both EHD and BT between domestic and wild ruminants does occur. Bluetongue is a reportable disease in Canada and the United States, and outbreaks of either BT or EHD affect international movement of animals (Pasick *et al.*, 2001).

Clinical signs in domestic sheep, goats, and llamas: The viruses can circulate in cattle and possibly other ruminants for years without ever causing disease (Pugh, 2002). Domestic sheep suffer severe clinical disease from BT, while goats are usually asymptomatic, and disease has not been reported in llamas. Outbreaks in domestic sheep are usually seen in late summer to fall coinciding with vector availability (Lincoln, 1987). Clinical disease includes hemorrhage and sloughing of the oral mucous membranes and of the hooves, followed by ulcers and erosions of the tongue and palate, edema of the head, blood in the urine and feces, increased respiratory rate with difficulty breathing progressing to a pneumonia-like syndrome, and subsequent death (Mullens and Dada, 1992; Zarnke, 1983; Zarnke, 2000). Fetal deformities and damaged fleece can also result (Kimberling, 1988). In the southern United States, HDs are endemic and rarely cause mortality. However, outbreaks in the northern United States are sporadic and mortality can be high in these naive populations (Howerth *et al.*, 2001).

Clinical signs in wild sheep: Severe disease and mortality has occurred in bighorn sheep and captive mountain goats (Lincoln, 1987). Post-mortem findings in bighorn sheep were consistent with signs seen in domestic animals (Pasick *et al.*, 2001). Antibody to EHD has been found in Dall's and free-ranging mountain goats but clinical signs of the disease have not been reported and the significance of these findings remains unknown (Zarnke, 1983; Zarnke, 2000).

Mode of transmission: Hemorrhagic diseases are transmitted by biting flies of the genus *Culicoides*. The most common vector for transmission in North America is *Culicoides variipenni*, but other *Culicoides* spp. may serve as potential vectors (Howerth *et al.*, 2001; Mullens and Dada, 1992).

Culicoides sp. are attracted to damp, muddy areas and fecal material. The virus is picked up by the fly during a blood meal, multiplies in the fly for 7 to 10 days after which time the virus is excreted in the saliva during feeding on subsequent hosts (Kimberling, 1988). Alternate routes of transmission such as ticks, transplacentally, via semen (Kimberling, 1988; Pugh, 2002), and even oral transmission from infected animals, are suspected (Zarnke, 2000). It has been suggested that wildlife outbreaks can originate from domestic sources (Schwantje, 1988a). Outbreaks usually occur in late summer, corresponding with the presence of the appropriate insect vectors (Sellers and Maarouf, 1991).

Outbreaks of HD in Portugal, Cyprus, and Florida were caused by virus infected *Culicoides* carried to naive populations by wind. It is thought that a similar mode of transmission occurred from the United States to southern

Canada (Clavijo *et al.*, 2000; Dulac *et al.*, 1992; Sellers and Maarouf, 1991), as well as by importation of infected cattle.

Environmental survival: The virus is unstable in the environment.

History in wild sheep: In Alaska between 1972 and 1992, antibodies to EHD were found in 11 of 501 (2%) Dall's sheep and 0/91 mountain goats. Antibodies to BT were found in 2 of 506 (<1%) Dall's sheep and 2 of 88 (2%) mountain goats. There have been no reports of die-offs or animals with clinical signs related to HDs in Alaska (Zarnke, 2000). Similarly, between 1978 and 1990, 18% of bighorns tested in California were positive for antibody to EHD but there was no evidence of disease (Clark *et al.*, 1993a). The significance of these serological findings in the absence of clinical disease and virus isolation and identification are unknown (Zarnke, 1983).

Canada is generally considered free of BT and EHD, however, there is a history of sporadic outbreaks of BT type 11 and EHD type 2 in wildlife restricted to the Okanagan Valley (Pasick *et al.*, 2001), southern Alberta, and in southwestern Saskatchewan (Howerth *et al.*, 2001). Outbreaks of EHD type 2 in Canada were first seen in 1962 in southeast Alberta in white-tailed and mule deer and pronghorn. In 1987, EHD virus was isolated from a number of wildlife and domestic species in the Okanagan area of BC. This was the first report of clinical disease in bighorn sheep and seroconversion of a rocky mountain goat (Dulac *et al.*, 1992). Again in the Okanagan in 1992 and 1999, acute mortalities

in white-tailed deer and California bighorn sheep were reported, and sentinel cattle herds in the vicinity tested positive for EHD type 2 (Pasick *et al.*, 2001). No definitive diagnosis was made due to carcass conditions. There is concern that disease caused by HD viruses could predispose wild sheep that survive HD to bacterial pneumonias (Mullens and Dada, 1992; Pugh, 2002; Schwantje, 1988a). Additionally, higher susceptibility is seen in naive animals, thus introduction to a new region could have severe consequences (Kimberling, 1988; Pugh, 2002).

Evidence of transmission among domestic and wild species: It is thought that outbreaks in livestock and wildlife in Canada are caused by transportation of virus-infected vectors on air currents from the endemic south. Once the virus is established in an area, other modes of transmission may play a role (see Mode of Transmission) to maintain the virus and transmission among wild and domestic species is a possibility.

Public health risk: none

Additional notes: Based on our knowledge of the HD viruses they seem to be limited by climatic factors and possibly vector availability. The vector, *C. variipennis*, is not present in Alaska and other northern regions, but other species of the genus *Culicoides* are present in the north and may be suitable vectors for EHD and BT. Introduction of infected domestic animals together with a changing climate may increase the risk of exposure and subsequent disease in the naive

population of Dall's sheep and mountain goats (Howerth *et al.*, 2001). Additionally, there is strong evidence that a HD virus currently circulates in Dall's sheep and mountain goats in the north and may pose a risk to domestic sheep, goats, and llamas.

Infectious Bovine Rhinotracheitis

Summary:

- **Infectious bovine rhinotracheitis (IBR) is caused by a herpes virus.**
- **Virus has the potential for latency and reactivation.**
- **Causes respiratory disease, with thick discharge from eyes and nose.**
- **Disease is most common in cattle, mild disease in domestic sheep and goats.**
- **One case of bronchopneumonia was possibly associated with IBR in a llama.**
- **Antibodies to IBR have been found in bighorn sheep but not in Dall's sheep**
- **Transmission is via direct contact.**
- **IBR virus is unstable in the environment.**
- **Natural transmission from domestic sheep, goats, and llamas to wild sheep is suspected but unconfirmed.**
- **No public health concerns.**

General overview: Infectious bovine rhinotracheitis virus (IBR) is a herpes virus that causes disease primarily in cattle, but domestic sheep and goats can also be affected (Matthews, 1999). A typical characteristic of herpes viruses is latency, meaning that the virus remains inactive in the host causing no clinical signs until the animal is stressed, at which time the virus reactivates and the animal begins to shed virus and show signs of the disease (Baker, 1990; Clark *et al.*, 1985). There is serological evidence that camelids in British Columbia have been

exposed to the virus, but the implications of antibody presence are unknown (Schwantje and Stephen, 2003).

Clinical signs in domestic sheep, goats, and llamas: In cattle, infection with IBR causes a respiratory disease characterized by runny to thick discharge from eyes and nose, coughing, and difficulty breathing caused by inflammation in the upper airways; occasional abortions and reduced fertility are also reported (Baker, 1990; Clark *et al.*, 1993b). Clinical signs range from mild to severe, tending to be most severe when the disease is complicated by secondary bacterial infections, primarily *Pasteurella/Mannheimia* sp. causing pneumonia. Disease prevalence is increased when susceptible animals are crowded or stressed but the mortality rate is usually low unless complicated by bacterial pneumonia (Baker, 1990). Domestic sheep and goats infected with IBR tend to show milder respiratory signs than cattle. Clinical signs of bronchopneumonia were present in one llama testing positive for IBR virus but *Mannheimia haemolytica* was also isolated from this llama. Although the significance is unknown, there appears to be some association between IBR viral infection and clinical disease in llamas (Williams *et al.*, 1991).

Clinical signs in wild sheep: Unknown.

Mode of transmission: Transmission is typically by direct contact with oral or nasal secretions, but insect vectors and sexual transmission play a minor role (Baker, 1990).

Environmental survival: The virus is unstable in the environment.

History in wild sheep: IBR is of concern to wild sheep because of the apparent association with pasteurellosis in domestic cattle and sheep. Antibodies to IBR have been detected in bighorn sheep (Clark *et al.*, 1993a; Schwantje, 1988a), but not in Dall's sheep (n=530) or mountain goats (n=90) in Alaska tested between 1971 and 1999 (Zarnke, 2000). There was no evidence of exposure to IBR in 11 healthy and 7 pneumonic Dall's sheep in the Mackenzie Mountains (E. Jenkins, unpubl. data). IBR has also been isolated in declining populations of bighorn sheep (Clark *et al.*, 1985), however, there are no confirmed cases of respiratory or reproductive disease caused by this virus in wild sheep (Clark *et al.*, 1993b; Clark *et al.*, 1993a).

Evidence of transmission among domestic and wild species: Transmission from cattle or domestic sheep to wild sheep, though suspected, is unconfirmed (Clark *et al.*, 1993b).

Public health risk: none

Respiratory Syncytial Virus

Summary:

- **Respiratory syncytial virus (RSV) is a Paramyxovirus.**
- **Causes interstitial pneumonia with mild to severe respiratory disease, difficulty breathing and fever in domestic ruminants.**
- **The virus is reported in domestic sheep, goats, and llamas.**
- **RSV is thought to cause respiratory signs in bighorn sheep but is unconfirmed.**
- **Antibody to RSV has been detected in Dall's sheep.**
- **Antibody to RSV is widespread in bighorn sheep and mountain goats.**
- **Transmission is by direct contact.**
- **The virus is unstable in the environment.**
- **Natural transmission from domestic ruminants to wild sheep or goats is suspected.**
- **No public health concerns.**

General overview: Respiratory syncytial viruses (RSV) are paramyxoviruses that cause atypical interstitial pneumonia in ruminants. Ruminant RSV's are divided into two groups: ovine and bovine RSVs. The bovine RSV is an important and potentially severe pathogen in calves, but the significance in sheep and goats is still poorly understood (Kimberling, 1988; Matthews, 1999). Experimentally, the virus causes mild respiratory disease in domestic lambs, however the role of this virus in natural infection is unknown (Trigo *et al.*, 1984a). It is thought that the RSVs play important roles as predisposing agents to bacterial pathogens (Dunbar *et al.*, 1986; Pugh 2002).

Clinical signs in domestic sheep, goats, and llamas: The role of RSV in sheep as a primary pathogen is not fully understood. Alone it causes mild signs characterized by ocular and nasal discharge, conjunctivitis, and lung

inflammation. It is considered pathogenic for lambs and in association with *Pasteurella/Mannheimia* sp. can produce an acute and severe pneumonia in sheep (Kimberling, 1988), goats, and in cattle is clearly part of the shipping fever complex (Al-Darraj *et al.*, 1982; Trigo *et al.*, 1984b; Trigo *et al.*, 1984a). Viral diseases of the respiratory system are very rare in llamas, and disease caused by RSV is not reported (Fowler, 1998).

Clinical signs in wild sheep: Disease caused by RSVs alone is unconfirmed, but when found in combination with other respiratory viruses or bacteria, is thought to contribute to respiratory disease outbreaks in bighorn sheep (Dunbar *et al.*, 1985).

Mode of transmission: The virus is passed by direct contact and aerosol transmission.

Environmental survival: The virus is unstable in the environment

History in wild sheep and goats: Antibody to RSV was reported in 4 of 350 Dall's sheep sampled in Alaska between 1971 and 1999 (Zarnke, 2000) and in 42% of free-ranging mountain goats sampled in Washington State. The importance of this virus in the role of respiratory disease in mountain goats and Dall's sheep is unknown (Dunbar *et al.*, 1986). There was no evidence of exposure to RSV in 11

healthy and 7 pneumonic Dall's sheep in the Mackenzie Mountains (E. Jenkins, unpubl. data).

A respiratory syncytial virus has been detected in both sick and healthy free-ranging bighorn sheep, and is thought to play a role in the pneumonia complex, much like shipping fever in cattle (Schwantje, 1988a). Seroprevalence studies indicate that RSV is widespread (187 of 447) in bighorn sheep in the western United States (Dunbar *et al.*, 1985). In 1984, a bighorn herd in Colorado state was observed with clinical signs of respiratory disease. A clinically ill ewe and lamb pair was collected and necropsied, and a RSV was isolated together with *Mannheimia haemolytica* from the bighorn lamb (Spraker and Collins, 1986). In an all-age pneumonia epizootic in the South Okanagan herd in southern British Columbia in 1999, a RSV was isolated from two necropsied animals (H. Schwantje, unpubl. data).

Evidence of transmission among domestic and wild species: Both interspecies transmission and the role of domestic sheep in the epidemiology of RSV in bighorn sheep remain unknown at this time (Dunbar *et al.*, 1985; Pugh, 2002).

Public health risk: none

Parasites

Helminths – *Parelaphostrongylus odocoilei*

Summary:

- *Parelaphostrongylus odocoilei* is a muscle nematode.
- Causes pneumonia, myositis and neurological disease in Dall's sheep.
- Not reported in domestic animals.
- Not reported from llamas, but there have been no known opportunities for transmission.
- Causes disease in Dall's sheep and mountain goats.
- Widespread and abundant in Dall's sheep in the Mackenzie Mountains but not in the Richardson Mountains.
- Transmission is by consumption of larvae-infected gastropod intermediate hosts.
- Larvae survive for long periods of time in the environment.
- Unlikely to establish in domestic sheep or goats.
- No public health concerns.

General overview: *Parelaphostrongylus odocoilei* is a common muscle worm of Dall's sheep, mountain goats, and mule deer in some regions of western Canada (Jenkins *et al.*, 2005a; Kutz *et al.*, 2001; Lankester, 2001). It can cause pneumonia, myositis, and neurological disease in Dall's sheep (Jenkins *et al.*, 2005b).

Clinical signs in domestic sheep, goats, and llamas: No clinical signs were observed in experimental infections of 2 domestic sheep; few eggs were observed in lungs and few larvae were observed in feces (S. Kutz, unpubl. data). No clinical signs or first-stage larvae were observed in feces of experimentally

infected domestic goats; animals were not examined on necropsy (Pybus and Samuel, 1984)

Clinical signs in wild sheep and mountain goats: Respiratory disease associated with widespread hemorrhage with diffuse interstitial pneumonia associated with eggs and larvae of *P. odocoilei* caused the death of at least one wild 10-month-old Dall's lamb and an experimentally infected Stone's sheep. Neurological signs were observed in experimentally infected Stone's and Dall's/Stone's hybrid sheep (Jenkins, 2005). Clinical signs are expected to be greatest in heavily infected lambs and yearlings, and in spring, when high numbers of eggs and larvae pass through the lungs.

Mode of transmission: Larvae are shed year-round but there are peaks in production in the spring and fall. Larvae deposited in the feces invade gastropod intermediate hosts and develop to the infective third stage. Sheep are most likely infected on their winter ranges by ingesting these gastropods or, less likely, by ingesting larvae that emerge from the gastropods and may remain on the vegetation (Jenkins, 2005). The prepatent period in Dall's sheep is approximately 70 days (Jenkins 2005).

Environmental survival: As with most protostrongylids, first-stage larvae are quite resistant and may remain in the environment for extended periods (Shostak and Samuel, 1984).

History in wild sheep: This parasite is widespread and common in Dall's sheep in the southern part of their range in Alaska, Yukon, and NWT. It is not found in the Richardson Mountains, or in the British, Brooks, and Baird ranges in the Yukon and Alaska (Jenkins *et al.*, 2005a). Recent experimental work and field observations indicate that this is an important pathogen in Dall's sheep and is a cause of mortality and poor body condition (Jenkins, 2005; Kutz *et al.*, 2001). *Parelaphostrongylus odocoilei* has been identified in Stone's sheep in BC and mountain goats in BC and the NWT (Jenkins *et al.*, 2005a; Jenkins and Schwantje, 2004; Pybus *et al.*, 1984).

Evidence of transmission among domestic and wild species: Domestic sheep, like domestic goats, appear to be unsuitable hosts for *P. odocoilei* (Pybus and Samuel, 1984). Two domestic sheep were given 417 L3 of Dall's sheep origin. Two larvae were found in the feces of both sheep at 25 weeks post infection. Necropsy at 35 weeks post infection revealed mild peritonitis with eosinophilic tracts in abdominal muscles and a single egg in a lung section on histology (S. Kutz, unpubl. data). The susceptibility of llamas to this parasite is unknown.

Public health risk: none

Additional comments: Recent experimental research shows significant neurological and respiratory signs and pathology in thinhorn sheep. Because

nothing is known about the susceptibility of llamas to this parasite, it should be considered a potentially significant pathogen in this host, especially in light of the susceptibility of llamas and other camelids to the related neurotropic nematode, *Parelaphostrongylus tenuis* (Foreyt *et al.*, 1991).

Gastrointestinal Trichostrongylids

General overview: Gastrointestinal trichostrongylids are a family of nematode parasites found in the abomasum or intestines of wild and domestic ruminants. Left untreated, gastrointestinal trichostrongyles are a major cause of production loss for domestic sheep and cattle. It is increasingly recognized that trichostrongyles have important subclinical effects in wild ruminants as well (Albon *et al.*, 2002; Arneberg *et al.*, 2002; Kutz *et al.*, 2004b; Stien *et al.*, 2002; Worley and Seese, 1992).

The natural parasite fauna of wild sheep and goats and domestic sheep and goats differ, however, trichostrongyles tend to have a fairly broad host range (Hoberg *et al.*, 2001). As a result, in the United States and parts of southern Canada, the fauna in wild sheep and goats is a mixture of endemic and introduced species (Hoberg *et al.*, 2001). The impacts of the exchange of trichostrongylid parasite species among wild and domestic sheep have not been extensively studied. However, at the very least, the net increase in parasite abundance may be expected to have potentially negative impacts on production and survival of the recipient species.

Clinical signs in domestic sheep, goats, and llamas: Differences in pathogenicity exist among species of trichostrongylids. In general, clinical signs include anorexia, weight loss, poor hair coat, reduced fecundity, diarrhea, anemia, and protein loss.

Clinical signs in wild sheep and mountain goats: As for domestic species.

Mode of transmission and lifecycle: The general lifecycle of parasites in this family is a direct cycle. The eggs are shed in the feces, and the larvae develop to the infective stage within about 2 weeks at 20 °C. The infective larvae migrate to vegetation, and are ingested by the ruminant host. They then may develop to adult nematodes immediately or migrate into the mucosa of the abomasum (or small intestine) and enter arrested development for variable periods of time (Bowman, 1995; Kimberling, 1988; Urquhart *et al.*, 1996).

Environmental Survival: Varies according to the species.

Evidence of transmission among domestic and wild species: Many gastrointestinal trichostrongylids are generalists and have a wide host range; it is thought that many species can be transmitted among domestic sheep, goats or llamas and Dall's sheep and mountain goats (Hoberg *et al.*, 2001; Zaffaroni *et al.*, 2000).

Note: Below we discuss a number of the trichostrongylids that are considered to be significant pathogens in llamas or domestic or wild sheep or goats and that could be a concern if transmitted among species. Other trichostrongyles that are considered less of a risk are discussed in Section 4.

Haemonchus spp.

Summary:

- ***Haemonchus* spp. are large abomasal nematodes.**
- **Causes severe blood loss, stunted growth and abomasal ulcerations.**
- **Important pathogens in domestic sheep, goats and llamas.**
- **Uncommon, but reported from bighorn sheep.**
- **Not reported in Dall's sheep.**
- **Transmission is by ingestion of infective larvae.**
- **Eggs and larvae do not persist for long in the environment.**
- **No public health concerns.**

General overview: *Haemonchus contortus* is a large stomach (abomasal) nematode. It is found in domestic sheep, goats, llamas, and cattle worldwide, and a wide variety of wild cervids and bovids, including bighorn sheep having prior contact with domestic sheep (Becklund and Senger, 1967; Hoberg *et al.*, 2001; Rickard and Bishop, 1991b; Zaffaroni *et al.*, 2000). This parasite is considered a primary pathogen in wild ruminants, and is particularly common in pronghorn and deer but has not yet been reported in arctic or subarctic regions (Hoberg *et al.*, 2001). Population trends of some wild ungulates such as the white-tailed deer are correlated with the prevalence and intensity of this parasite (Worley *et al.*,

1988). It has not been reported in Dall's sheep (Kutz, 2001; Neilsen and Neiland, 1974).

Clinical signs in domestic sheep, goats, and llamas: *Haemonchus* sp. is a very important pathogen of domestic sheep in temperate regions. Infection is associated with severe blood loss, stunted growth, paleness and ulcerated stomach mucosa and can result in death (Kaplan *et al.*, 2004).

Clinical signs in wild sheep: Unknown.

Mode of transmission and lifecycle: Eggs deposited in the feces hatch and develop to infective larvae in about 3 days under optimal conditions. Development to fourth stage occurs within about 48 hours of ingestion by a susceptible ruminant. Larvae and adults feed on blood in the abomasum. The prepatent period is approximately 18–21 days (Levine, 1980 in Hoberg *et al.*, 2001). In cooler regions, *Haemonchus* overwinters as inhibited larvae in the abomasal mucosa of the host (Waller *et al.*, 2004).

Environmental survival: Eggs and larvae of *Haemonchus* do not persist for extended periods in the environment and there is no evidence of overwinter transmission in domestic sheep (Waller *et al.*, 2004).

History in wild sheep: *Haemonchus* spp. has been reported in bighorn sheep in Canada and the United States, but is not known in the subarctic and arctic regions (Hoberg *et al.*, 2001). Although clinical signs associated with the presence of this parasite are not reported in bighorn sheep, diagnosis is difficult and based on clinical signs occurring in other wild ruminants, *Haemonchus* spp. must be considered a potential primary pathogen (Hoberg *et al.*, 2001).

Evidence of transmission among domestic and wild species: *Haemonchus* spp. in North American wild bovids and cervids are all of domestic sheep or cattle origin, indicating that transmission from domestic to wild species, including bighorn sheep, occurs (Hoberg *et al.*, 2001).

Public health risk: none.

Additional comments: Historically *Haemonchus* has been considered a “warm and wet weather” nematode. However, introduced to the cooler climate of Sweden, *Haemonchus* sp. has adopted a lifecycle that relies on overwinter survival in the inhibited form and subsequent periparturient rise in egg production in the spring for maintenance in the population (Waller *et al.*, 2004). It is not known whether this life history strategy would enable it to establish and persist in domestic or wild sheep and goat populations in the NWT.

Marshallagia sp.**Summary:**

- ***Marshallagia* sp. is an abomasal nematode.**
- **Causes diarrhea, weight loss and anemia.**
- **Uncommon in domestic sheep in North America, but causes significant disease in domestic sheep and goats in Eurasia.**
- **The most common abomasal parasite in bighorn, Dall's and Stone's sheep.**
- **Evidence of negative impacts on body condition and pregnancy rates in Dall's sheep**
- **Transmission is by ingestion of infective larvae.**
- **Eggs are highly resistant in the environment.**
- **Natural transmission between wild and domestic species is unknown.**
- ***Marshallagia* sp. in Dall's sheep may represent a cryptic species.**
- **No public health concerns.**

General Overview: *Marshallagia* spp., previously named *Ostertagia occidentalis*, are common trichostrongylid nematodes in many wild ruminants, including bighorn (Hoberg *et al.*, 2001), Stone's (Jenkins and Schwantje, 2004), and Dall's sheep (Kutz, 2001; Neilson and Neiland, 1974) in BC, Yukon, NWT, and Alaska, and mountain goats in western North America (Jenkins *et al.*, 2004a). *Marshallagia* spp. in North American wild ruminants have been referred to as *M. marshalli* or *occidentalis*, however, there is evidence indicating that those in mountain goats, Dall's, and bighorn sheep may be a distinct species (Hoberg *et al.*, 2001). *Marshallagia* may affect host productivity and life expectancy at high infection intensities (Bye and Halvorsen, 1983; Kutz, 2001).

Clinical signs in domestic sheep, goats, and llamas: *Marshallagia* is present, but uncommon in domestic sheep in Canada (Lichtenfels and Hoberg, 1993). In Eurasia infection in domestic sheep and goats is much more common and causes clinical disease (Bye and Halvorsen, 1983). Signs may include watery diarrhea, chronic weight loss, and anemia (Kimberling, 1988; Myer and Taylor, 1989). *Marshallagia* sp. has been found in llamas in pockets of western United States, but there were no associated reports of disease (Fowler, 1998).

Clinical signs in wild sheep: Ulcerative lesions have been observed in the pyloric region of the abomasum in bighorn sheep and it has been suggested that these parasites “can cause reduced vigor in bighorns” and reduced body condition and pregnancy rates in Dall’s sheep (Kutz *et al.*, 1999; Uhazy and Holmes, 1971).

Mode of transmission and lifecycle: Eggs of *Marshallagia* are shed in the feces of Dall’s sheep year-round although there is a higher abundance during winter months. Transmission is by ingestion of the infective third-stage larvae and the prepatent period for *Marshallagia* is approximately four weeks in Dall’s/Stone’s sheep hybrids (S. Kutz, B. Wagner, J. Heath, unpubl. data).

Environmental survival: Eggs of this parasite are highly resistant in the environment. Evidence of year-round transmission in reindeer suggests that the infective larvae are probably quite stable in the environment as well (Halvorsen *et al.*, 1999).

History in wild sheep: *Marshallagia* spp. is widespread and abundant in Dall's, Stone's and bighorn sheep in North America. In a cross-sectional study of 105 Dall's sheep collected from the Mackenzie Mountains in the winters of 1971 and 1972, Kutz (2001) observed that sheep with higher intensities of infection with *Marshallagia* spp. were in poorer body condition and less likely to be pregnant.

Evidence of transmission among domestic and wild species: *Marshallagia* spp. appears to have a wide host range. There have been no studies to determine transmission between wild and domestic sheep, however, experimental infections of domestic sheep with *Marshallagia* of muskox origin resulted in patent infections in the sheep at 6 weeks post infection (S. Kutz, B. Wagner, unpubl. data). Additionally, it is thought that introductions of muskoxen to Spitsbergen resulted in infection of Svalbard reindeer with *Marshallagia* (Hoberg *et al.*, 2001).

Public health risk: none.

Additional comments: *Marshallagia* spp. are known to cause clinical disease in domestic and wild sheep. It is possible that there are two different species circulating, one in wild sheep and goat herds and one in their domestic counterparts (Lichtenfels and Pilitt, 1989). Consequences of the exchange of

these “wild” and “domestic” species among wild and domestic hosts are unknown.

Nematodirus spp.

Summary:

- ***Nematodirus* spp. are pathogenic nematodes of the small intestine.**
- **Causes anorexia, diarrhea, dehydration.**
- **Reported in domestic sheep, goats and llamas.**
- **Causes severe disease in young domestic sheep.**
- **Not reported in wild sheep or goats in North America.**
- **Transmission is by ingestion of infective larvae.**
- **Eggs are highly persistent in the environment.**
- **No history of transmission from wild to domestic species.**
- **No public health concern.**

General overview: *Nematodirus* spp. cause disease primarily in young domestic lambs, while adults are able to acquire some lasting immunity. In particular, *Nematodirus battus* is a serious pathogen in domestic sheep, cattle and llamas (Bishop and Rickard, 1987; Hoberg *et al.*, 2001). It is thought that the introduction of *N. battus* to Dall’s sheep could have devastating consequences.

Clinical signs in domestic sheep, goats, and llamas: *Nematodirus battus* causes explosive outbreaks of disease in domestic lambs. Clinical signs begin with anorexia, and progress to severe diarrhea and dehydration and death can result (Henderson, 1990; Hoberg *et al.*, 2001). It is also found in domestic goats. This parasite has been found in llamas, but clinical impacts are not known. Milder forms of disease may be associated with other *Nematodirus* spp.

Clinical signs in wild sheep: *Nematodirus battus* has not yet been reported from wild sheep or goats. Clinical signs associated with the other *Nematodirus* spp. have not been reported.

Mode of transmission and lifecycle: *Nematodirus* spp. have direct life cycles. Eggs are shed in the feces and larvae develop to the infective third stage and then hatch and are immediately infective.

Environmental survival: The eggs are very resistant to drying and freezing (Ash and Atkinson, 1986). Some species seem to have some plasticity in their life cycle and can hatch from 2 months to 2 years after deposition on experimental plots in a temperate environment (Thomas, 1991). *Nematodirus battus* may be limited in its northern distribution by climatic conditions.

History in wild sheep and goats: Several species of *Nematodirus* have been reported in wild sheep and goats in Alaska and the Mackenzie Mountains (see Appendix 4) (Hoberg *et al.*, 2001; Jenkins and Schwantje, 2004; Kutz, 2001; Neilson and Neiland, 1974).

Evidence of transmission among domestic and wild species: There is currently no evidence of transmission among domestic and wild species, however, domestic and wild sheep share a variety of other trichostrongyle nematodes and

there is no reason to suspect that *Nematodirus* spp. from domestic sheep and goats could not infect wild sheep. Susceptibility of wild goats is less certain.

Public health risk: None

Teladorsagia spp.

Summary:

- ***Teladorsagia* spp. are abomasal nematodes.**
- **Cause diarrhea, dull coat and weight loss and occasionally death.**
- **Found in domestic sheep, goats and llamas.**
- **Uncommon in Dall's sheep and mountain goats.**
- **Transmission is fecal-oral.**
- **Eggs do not persist for long periods of time in the environment.**
- **Impacts on wild sheep are unknown.**
- **Evidence of natural transmission between wild and domestic species.**
- **No public health concerns.**

General overview: *Teladorsagia circumcincta* is considered one of the most significant pathogens in domestic sheep worldwide, but to date there are no reports of disease in wild species attributed to infection with this parasite (Hoberg *et al.*, 2001). Range expansion of *T. circumcincta* in North American wildlife is coincident with historic introductions of domestic sheep (Hoberg *et al.*, 1999). A related species, *T. boreoarcticus* is reported as native fauna of Dall's sheep, mountain goats, caribou, and muskoxen (Hoberg *et al.*, 1999; Jenkins *et al.*, 2004a; Kutz, 2001)

Clinical signs in domestic sheep, goats, and llamas: There are two clinical syndromes caused by *T. circumcincta* in sheep and goats. Type I disease, caused by adult nematodes, usually occurs in mid to late summer. Clinical signs include profuse, watery, bright green diarrhea, dull coat, weight loss and poor-doing animals. Type II disease, seen in temperate regions, is a result of larval nematodes which enter a phase of arrested development in the abomasal mucosa during the winter. These larvae emerge synchronously in the spring and cause diarrhea, protein and blood loss, anorexia, dehydration and can lead to death in extreme cases (Urquhart *et al.*, 1996). *Teladorsagia* spp. in llamas also undergo arrested development which can cause significant pathology (Rickard, 1993).

Clinical signs in Dall's sheep and mountain goats: *Teladorsagia* is uncommon in Dall's sheep and mountain goats (Jenkins *et al.*, 2004a; Kutz, 2001; Neilson and Neiland, 1974). There are no studies examining the impact of this parasite in these hosts.

Mode of transmission and lifecycle: *Teladorsagia* spp. have a direct life cycle as described above. Larval development to infective third-stage larvae for *T. circumcincta* takes 3–10 days at room temperature (Pandey *et al.*, 1989; Salih and Grainger, 1982). For *T. boreoarcticus*, development to L3 takes approximately 10–12 days at room temperature (J. Heath, B. Wagner, and S. Kutz, unpubl. data).

Environmental survival: Eggs of *T. boreoarcticus* do not survive extended freezing (Kutz and Heath, unpubl. data).

History in wild sheep and goats: *Teladorsagia boreoarcticus* is present, but uncommon in Dall's sheep in the Mackenzie Mountains and Alaska (Kutz, 2001; Neilson and Neiland, 1974). In the Richardson Mountains "trichostrongyle" eggs, either of *T. boreoarcticus* or a related nematode common in caribou, *Ostertagia gruehneri*, are common and abundant in Dall's sheep in mid to late summer (J. Nagy, E. Jenkins, S. Kutz, unpubl. data). This range is heavily used by the Porcupine Caribou herd and these may be *O. gruehneri* spilling over from the caribou; the impacts on the sheep are not known. *Teladorsagia circumcincta* probably circulates in wild sheep populations in the United States wherever there has been contact with domestic sheep or goats (Becklund and Senger, 1967; Blood, 1963; Hoar *et al.*, 1996; Uhazy and Holmes, 1971), yet the impact remains unknown (Becklund and Senger, 1967; Blood, 1963; Hoar *et al.*, 1996; Uhazy and Holmes, 1971).

Teladorsagia spp. (possibly *T. boreoarcticus* or another cryptic species) is reported from mountain goats in Canada and the United States (Hoberg *et al.*, 2001; Jenkins *et al.*, 2004a).

Evidence of transmission among domestic and wild species: *Teladorsagia* from domestic ruminants have been transmitted to bighorn sheep and probably

mountain goats where these species have shared range (Becklund and Senger, 1967; Blood, 1963; Hoberg *et al.*, 2001; Kistner *et al.*, 1977). *Teladorsagia boreoarcticus* of muskox origin orally administered to two domestic sheep in early September underwent arrested development and subsequently developed to adult parasites the following March. Adult *T. boreoarcticus* were recovered on necropsy and severe abomasal pathology was observed (S. Kutz, B. Wagner, unpubl. data).

Public health risk: none

Additional comments: With the possible exception of Dall's sheep in the Richardson Mountains, *T. boreoarcticus* tends to be uncommon in this species and probably does not pose much of a risk for transmission to domestic sheep, goats, and llamas. *Teladorsagia* spp. appears to be more common in mountain goats and may represent a source of infection for domestic species. In contrast, *T. circumcincta* in domestic sheep and goats is common and it is probable that this parasite could be introduced to wild sheep and goat range – the impacts of such an introduction are unknown.

Trichuris spp.

General overview: *Trichuris* spp. or whipworms, are present as adults in the caecum and colon of many ruminants including domestic sheep, goats, llamas,

Dall's sheep and mountain goats. They can be pathogenic in domestic lambs and calves (Kimberling, 1988; Knight, 1974; Knight and Uhazy, 1973; Matthews, 1999; Rickard and Bishop, 1991a). *Trichuris schumakovitschi* is present in wild sheep (Rickard and Bishop, 1991a). *Trichuris* sp. now assumed to be *T. oreamnos*, is reported from mountain goats in Canada and the United States (Boddicker *et al.*, 1971; Brandborg, 1955; Kerr, 1966; Knight, 1974). *Trichuris ovis* is most common in domestic sheep and goats (Kimberling 1988), while *T. tenuis* is found in llamas (Rickard and Bishop, 1991a). Uncertainty regarding cross-species transmission warrant continued consideration of this parasite.

Clinical signs in domestic sheep, goats, and llamas: In young sheep, goats, and llamas, infection has been associated with poor weight gain, anemia and diarrhea, while clinical signs in adult animals are uncommon (Kimberling, 1988).

Clinical signs in wild sheep and mountain goats: No clinical disease associated with this parasite has been reported in wild sheep. However, adult Dall's ewes collected from the Mackenzie Mountains had small white raised nodules in the mucosa of the caecum (S. Kutz, A. Veitch, unpubl. data). Nielsen and Neiland (1974) reported similar observations in Dall's sheep in Alaska. In some animals, the caecal mucosa, and in some cases the mucosa of the anterior colon, was dotted with small nodules. These round nodules were firm, ranged in size from two to seven millimeters in diameter and were elevated from one to three millimeters above the mucosa. It was suggested that these nodules were

associated with an immune response to the developing *Trichuris* and found that there was an inverse relationship between nodule density and number of *Trichuris* individuals in four of five sheep.

Mode of transmission and lifecycle: Under favourable environmental conditions, the eggs reach infective stage in three weeks. Ingested larvae migrate through the mucosa of the caecum and anterior colon where they mature in 1–3 months (Monnig, 1971).

Environmental survival: Eggs of *Trichuris* spp. are resistant to environmental extremes and persist for extended periods in the environment (Monnig, 1971).

History in wild sheep: *Trichuris* spp. are common in bighorn, Stone's and Dall's sheep as well as in mountain goats (Jenkins and Schwantje, 2004; Jenkins *et al.*, 2002; Kutz, 2001; Neilson and Neiland, 1974; Samuel *et al.*, 1977; Worley and Seese, 1992). The identification of *Trichuris* spp. from bighorn and Dall's sheep have been ambiguous and include *Trichuris* sp. *T. ovis*, and *T. discolor* (Becklund and Senger, 1967; Boddicker and Huggins, 1969; Neilson and Neiland, 1974; Uhazy and Holmes, 1971). In 1973, specimens identified as *T. ovis* in a collection of bighorn sheep in Alberta, Canada (Uhazy and Holmes, 1971) were re-described as *T. schumakovitschi* by Knight and Uhazy (1973), leaving some question as to the identity of *Trichuris* spp. in other bighorn sheep populations. It is probable that the *Trichuris* sp. from the Nielsen and Neiland

1974 collection are also *T. schumakovitschi*. The impact of *Trichuris* spp. on naive lambs/kids, and the cost associated with mounting an immune response for adult animals are unknown for wild sheep and goats.

Evidence of transmission among domestic and wild species: *Trichuris schumakovitschi* has been reported from domestic sheep (Knight and Uhazy, 1973). Prior to the redescription by Knight and Uhazy in 1973 *T. ovis* had been reported in bighorn sheep; however, it is now thought that these may have been *T. schumakovitschi*.

Public health risk: none.

Additional comments: There is insufficient information to evaluate the potential impacts of cross-species transmission of *Trichuris* spp. among wild and domestic hosts. However, *Trichuris* spp. are important pathogens in young domestic animals and may be important in young and mature wild sheep and goats as well. The genus appears to be well adapted to survival under harsh conditions. It is, therefore, important to treat this nematode as a potentially important pathogen for both wild and domestic hosts.

Ectoparasites

Linognathus pedalis

Summary:

- *Linognathus pedalis* is a sucking louse of domestic sheep.
- Clinical signs include feet-stamping, rubbing, self-mutilation and weight loss.
- Not reported in wild sheep.
- Reported in mountain goats, though clinical signs are unknown.
- Transmission is by close contact.
- Lice do not survive for long periods of time off the host.
- Usually considered host-specific.
- No public health concerns.

General overview: *Linognathus pedalis* is a sucking louse of domestic sheep.

Lice are generally host-specific, but can infect other similar species. These lice reside on the legs and feet of the host, and infestations are most severe in winter and early spring (Kimberling, 1988).

Clinical signs in domestic sheep, goats, and llamas: Clinical signs may include stamping the feet, rubbing and self-mutilation, wool damage, reduced time spent feeding with subsequent weight loss, and occasionally anemia.

Clinical signs in wild sheep: *Linognathus pedalis* has not been reported in bighorn or Dall's sheep. This louse has been identified on mountain goats, though no associated clinical signs were reported (Durden, 2001).

Mode of transmission: Transmission is via close contact with infested animals.

Environmental survival: The lifecycle is usually spent entirely on the host, with poor survival away from the host, although with *L. pedalis* the lice are able to crawl short distances across pasture to infest new hosts (Durden, 2001).

History in wild sheep: No reports in wild sheep.

Evidence of transmission among domestic and wild species: Since lice are usually host-specific (Durden, 2001) and this species of lice has not been reported in wild sheep, it is thought that the introduction of domestic species would not contribute to lice infestations in the wild sheep population, but this remains unknown.

Public health risk: None.

Additional comments: Louse infestation is considered normal in wild mammals. Severe infestations may cause clinical signs, but are rarely implicated in serious pathology (Durden, 2001). However, as with any introduced pathogen, the effects of a novel agent on a naive population are unknown.

Otobius megnini (Spinose ear tick)

Summary:

- ***Otobius megnini* is an ear tick.**
- **Causes painful bites resulting in rubbing, scratching and ulceration of the ear pinnae.**
- **Found on domestic sheep, goats and llamas.**
- **Reported in bighorn sheep and mountain goats.**
- **Not reported in Dall's sheep.**
- **Transmission is through close contact.**
- **The tick survives for long periods of time in arid to semi-arid climates.**
- **No obvious clinical signs reported in infected bighorn sheep.**
- **Will bite people.**

General overview: *Otobius megnini*, also called the spinose ear tick, is a soft-bodied tick that attaches deep in the ear canal of the host. This tick is native to North America. It infects domestic sheep, goats, mountain goats, bighorn sheep, white-tailed deer, mule deer, rabbits, and coyotes as well as numerous introduced species including domestic livestock and pets (Allan, 2001; Demarchi *et al.*, 2000a; Howard and Livingston, 1986). *Otobius megnini* has not been reported in llamas.

Clinical signs in domestic sheep, goats, and llamas: Painful bites and deep ear invasion result in head shaking, self-mutilation from rubbing and scratching, and ulceration of deep ear structures with accompanying deafness (Gregson, 1973 in Allan, 2001). In domestic animals, *Otobius* sp. can cause irritation and agitation, muscle spasms, hemorrhage and even death (Allan, 2001).

Clinical signs in wild sheep and mountain goats: Similar to domestic species, but with less severity.

Mode of transmission and lifecycle: Larvae of *O. megnini* enter the ears of hosts, feed, and then molt to a first-stage nymph. This feeds and molts to a second stage nymph which then feeds and drops to the ground where it molts to an adult. Mating and oviposition occur on the ground with approximately 1500 eggs deposited (Hoogstral, 1982 in Allan, 2001). Close contact with infested animals or environmental contamination promotes transmission between animals.

Environmental survival: These ticks can resist long periods of starvation (up to 2 years) and tolerate lower humidities and higher temperatures than hard ticks (Allan, 2001). The range of this *O. megnini* is generally limited to arid or semi-arid climates in southern and Pacific regions including BC.

History in wild sheep: *Otobius megnini* has not been reported in Dall's sheep in Alaska or Canada. It has been reported in bighorn sheep in British Columbia in low numbers, without obvious clinical signs (H. Schwantje, unpubl. data).

Evidence of transmission among domestic and wild species: *Otobius megnini* has successfully colonized domestic sheep, goats, cattle, and other domestic species.

Public health risk: *Otobius megnini* bites people. This may be very painful, can result in intense local irritation, swelling and subcutaneous nodules that persist for several months. It may serve as a vector of diseases such as Q-fever (see *Coxiella burnetii*) and tick paralysis (Allan, 2001).

Additional notes: Although clinical signs have not been reported in bighorn sheep, severe signs in domestic species, and the potential for severe disease in a naive herd of domestic or wild species, warrant considering it an important parasite.

Protozoa

Eimeria spp. ("Coccidiosis")

General overview: *Eimeria* spp. are protozoan parasites of the gastrointestinal tract in wild and domestic ruminants worldwide. Most animals become infected in their first few weeks of life, and disease is usually self-limiting, unless stressed or immunosuppressed (Matthews, 1999).

Clinical signs in domestic sheep, goats, and llamas: Clinical disease, known as coccidiosis, is caused by many different species of *Eimeria*. Clinical signs vary depending on species of *Eimeria*. Severely affected lambs and kids suffer from hemorrhagic diarrhea, weakness, listlessness, dehydration and weight loss,

causing great economic losses (Kimberling, 1988; Matthews, 1999). *Eimeria* oocysts are commonly encountered from fecal flotation of camelids, however clinical illness is rare in these species in North America (Fowler, 1998).

Clinical signs in wild sheep: Clinical disease in wild populations is rare and generally occurs only when animals are brought into captivity or when habitats are poor quality with overgrazing and crowding (Duszynski and Upton, 2001). When present, clinical signs in wild ruminants are similar to those in domestic animals (Kimberling, 1988).

Mode of transmission: Oocysts sporulate in the environment. Transmission is by ingestion of these sporulated oocysts.

Environmental survival: Oocysts are very resistant to cold temperatures, and can overwinter on pasture (Matthews, 1999).

History in wild sheep: *Eimeria* spp. are present in free-ranging Dall's, Stone's and bighorn sheep, particularly in the young lambs (Clark and Colwell, 1974; Jenkins and Schwantje, 2004; Kutz, 2001; Uhazy *et al.*, 1971) as well as in mountain goats (Jenkins *et al.*, 2004a; Shah and Levine, 1964).

Evidence of transmission among domestic and wild species: Although *Eimeria* are generally considered host specific (Fowler, 1998), there are examples of

these protozoa being shared between closely related species (Duszynski and Upton, 2001). There appears to be an overlap of reported *Eimeria* spp. among domestic and wild sheep and goats, but the significance is unknown (Appendix 1). Studies on cross transmission are required to determine potential infectivity between Dall's sheep and mountain goats and domestic sheep and goats (Uhazy *et al.*, 1971).

Public health risk: None

Neospora caninum

Summary:

- ***Neospora caninum* is a protozoon parasite with a wide geographic distribution.**
- **Causes neurologic disease and abortion.**
- **Domestic sheep, goats and llamas can be affected.**
- **Infection in wild sheep is unknown.**
- **Transmission is transplacental and possibly through canine definitive hosts.**
- **Environmental survival is unknown.**
- **No reports in wild sheep or goats.**
- **Transmission from domestic sheep, goats or llamas to wild species is unknown.**
- **No known public health concerns.**

General overview: *Neospora caninum* is a recently identified protozoon parasite that is closely related to *Toxoplasma gondii*. Until 1988, this parasite had been misidentified as *Toxoplasma gondii* (Dubey and Odening, 2001). It has been

reported in Canada and the United States in cattle, sheep, goats, llamas and alpacas, horses and one wild deer in California (Dubey, 1999).

Clinical signs in domestic sheep, goats, and llamas: Infection with *Neospora caninum* can cause neurologic signs and abortion in domestic sheep, goats, and llamas (Dubey, 1999).

Clinical signs in wild sheep and mountain goats: *Neospora caninum* has not been reported in wild sheep and mountain goats, however, this is a recently recognized parasite and testing for it in these species has been limited.

Mode of transmission: Ruminants serve as the intermediate host for this parasite and domestic dogs are the only known definitive host. Transplacental transmission can occur in ruminants; other modes have been described experimentally (Dubey and Odening, 2001).

Environmental survival: Unknown (Dubey, 1999).

History in wild sheep and mountain goats: No history in wild sheep and mountain goats. Neurologic disease has been reported in association with *N. caninum* in two deer: one free-ranging black-tailed deer (*Odocoileus hemionus columbianus*) in California and one zoo-reared deer in France (Dubey and Odening, 2001).

Evidence of transmission among domestic and wild species: None.

Public health risk: None known.

Sarcocystis sp.

Summary:

- ***Sarcocystis* spp. are protozoon muscle parasites.**
- **Cause fever, stiffness, anorexia and weight loss.**
- **Domestic sheep, goats, llamas, wild sheep and mountain goats are all endemically infected with *Sarcocystis* spp.**
- **May cause clinical disease in infected wild and domestic animals, but often present with no obvious signs.**
- **Significance of infection in wild sheep and mountain goats is unknown.**
- **Oocysts are released in the feces of predators and ingested by grazing prey, where they migrate and encyst in muscle tissue.**
- **Very resistant in the environment.**
- **Evidence that domestic and wild sheep are susceptible to the same species of *Sarcocystis*.**
- **People may be infected through consumption of raw meat; clinical signs are rare.**

General overview: *Sarcocystis* sp. are intracellular parasites with prey species intermediate hosts and predator species definitive hosts. Domestic sheep and goats (Matthews, 1999), camelids (La Perle *et al.*, 1999), Dall's sheep in Alaska and the Mackenzie Mountains (Neiland, 1980; S. Kutz and E. Jenkins, unpubl. data), bighorn sheep and mountain goats (Dubey and Odening, 2001) are endemically infected with *Sarcocystis* spp. Domestic sheep are commonly infected with *S. tenella*, domestic goats with *S. capracanis*, bighorn sheep with *S. ferovis* (Dubey, 1983); the species in Dall's sheep (Neiland, 1980) and mountain goats remain unknown (Dubey and Odening, 2001; Foreyt, 1989). There is

suspicion of overlap between the *Sarcocystis* sp. infecting wild and domestic species, but this is currently unconfirmed.

Clinical signs in domestic sheep, goats, and llamas: Domestic sheep, goats, and llamas are infected with *Sarcocystis* spp. Only some species of *Sarcocystis* are pathogenic for the intermediate host (Dubey and Odening, 2001). Domestic sheep showing signs of sarcocystosis develop fever, stiffness, anorexia, depression and weight loss, though mortality is low (Kimberling, 1988).

Clinical signs in wild sheep and mountain goats: Little is known about the life cycle and clinical significance of *Sarcocystis* in wild sheep and mountain goats.

Mode of transmission: Infective sporocysts are released in the feces of the predator and accidentally ingested by the intermediate host or prey species, in which the parasite migrates to skeletal muscle to complete its development (Dubey and Odening, 2001; Kimberling, 1988). Interestingly, species of *Sarcocystis* are generally more specific for the intermediate host than for the definitive host (Dubey and Odening, 2001).

Environmental survival: Sporocysts survive in the environment for many months, and are resistant to freezing and disinfectants (Dubey and Odening, 2001).

History in wild sheep and mountain goats: Neurologic disease in association with *Sarcocystis* sp. has been identified in raccoons, mink, skunk, seals and otters (Dubey and Odening, 2001), but no clinical disease associated with the finding of *Sarcocystis* in wild sheep or mountain goats has been reported.

Evidence of transmission among domestic and wild species: There is evidence that both domestic sheep and wild sheep are susceptible to the same species of *Sarcocystis* (Dubey and Odening, 2001).

Public health risk: *Sarcocystis* spp. usually infect closely related host species. People eating raw meat infected with a *Sarcocystis* spp. may become infected, but rarely is infection associated with clinical disease (Fayer, 2004).

Other Agents

Scrapie

Summary:

- **Scrapie is a transmissible spongiform encephalopathy caused by prion proteins.**
- **Causes a slowly progressive neurological disease characterized by incoordination, weight loss and intense itching.**
- **Seen in domestic sheep and goats.**
- **Not reported in wild sheep or mountain goats.**
- **Transmission is not fully understood.**
- **Prion proteins are highly resistant in the environment.**
- **No evidence for transmission from domestic sheep and goats to any wild species.**

General overview: Scrapie is a serious disease in domestic sheep and occasionally goats. It is a transmissible spongiform encephalopathy (TSE) related to bovine spongiform encephalopathy and chronic wasting disease. TSEs are apparently caused by an infectious protein particle called a prion (Pugh, 2002). This disease was first reported in Canada in 1938 and continues to be a reportable disease under the *Health of Animals Act* (Wenger and Tait, 2001).

Clinical signs in domestic sheep and goats: The disease is slowly progressive, affecting the nervous system, causing changes in behaviour, incoordination, profound weight loss, and intense itching causing affected animals to self-mutilate (Pugh, 2002).

Clinical signs in wild sheep: There are no reports of scrapie in wild sheep.

Mode of transmission: The route of transmission is unclear, but it is thought to occur horizontally via contact with infective material as well as *in utero* (George, 1990; Pugh, 2002).

Environmental survival: Scrapie prion is extremely resistant to physical and chemical destruction and may persist in the environment for months to years (Smith and Sherman, 1994).

History in wild sheep: Scrapie has never been reported in North American wild sheep or mountain goats. An undiagnosed disease resembling scrapie occurred in a mouflon (*Ovis musimon*) in the United Kingdom (Williams *et al.*, 2001).

Evidence of transmission among domestic and wild species: None known.

Public health risk: None known although another TSE, bovine spongiform encephalopathy, does cause disease in people.

Additional comments: Although this disease has never been reported in North American wild sheep, it was suspected in the mouflon sheep (*O. musimon*), and because of its severity it should be treated as a potentially important disease for wild sheep and goats.

SECTION 4. IDENTIFICATION OF HEALTH HAZARDS OF LOWER CONCERN

Description

This section describes the pathogens of lower concern from Appendices 1–7. The criteria for designation to this category are as follows: 1) the agent may cause disease in any of the species of interest but is probably endemic in the population and introduction is unlikely to increase the prevalence or severity of the disease, OR 2) the pathogen may cause significant disease but the probability of introduction or establishment is negligible because of limiting environmental conditions or it is rare in domestic sheep in Canada.

Bacteria

Arcanobacterium pyogenes

Arcanobacterium pyogenes is a gram-positive, pleomorphic rod found as part of the normal flora in the oral cavity of many species of ruminants. It can cause suppurative lesions or abscesses in ungulates (Wobeser, 2001), and in wild sheep it has been isolated from lesions of lumpy jaw and from pneumonic lungs (Hoefs and Bunch, 2001; E. Jenkins, unpubl. data). To our knowledge, there are no confirmed reports of *A. pyogenes* in mountain goats. Bacteria may be transmitted between wild and domestic sheep at mineral licks, but this point is controversial (Hoefs and Bunch, 2001) and it is more commonly accepted that *A. pyogenes* is normal flora of the oral cavity in wild sheep.

In wild sheep, oral trauma from abnormal tooth wear, eating coarse feed, or tooth eruption, allows bacteria to invade the mucosa and subsequently bony tissues leading to osteomyelitis and lumpy jaw (Hoefs and Bunch, 2001). In contrast, in domestic sheep, goats, and llamas, *A. pyogenes* is often cultured from foot abscesses, and *Actinomyces* sp. is the organism more commonly cultured from lumpy jaw lesions (Fowler, 1998; Hoefs and Bunch, 2001; Kimberling, 1988). Although lumpy jaw has been implicated in mortality of bighorn sheep in Banff National Park, there is no evidence that it affects bighorn sheep at a population level (Hoefs and Bunch, 2001). In 1907, lumpy jaw was first described in Stone's sheep in the Stikine River valley in northern BC. In subsequent surveys, lumpy jaw was observed in Dall's sheep in Alaska in 1944, and again in the Yukon Territory between 1979 and 1985, where the overall prevalence was 37%, and in 1987 in the Northwest Territories where 28% were affected (Kutny and Stenhouse, 1991). Compared to southern populations, the bighorn sheep in more northern regions and thinhorn sheep have a higher prevalence of lumpy jaw (Hoefs and Bunch, 2001).

Actinomyces pyogenes was recovered from 7 pneumonic Dall's sheep in the Mackenzie Mountains. It appears to play a role as an opportunistic pathogen, and may have acted as a primary pathogen in two cases of acute fibrino-necrotizing pneumonia where adult rams died acutely in good body condition (E. Jenkins, unpubl. data).

It is thought that this *A. pyogenes* is endemic in wild sheep, and the introduction of domestic sheep into Dall's sheep range would not affect the prevalence in wild sheep.

Fusobacterium necrophorum

Fusobacterium necrophorum, an anaerobic, gram-negative rod, is found as part of the normal flora of most ruminant species (Kimberling, 1988). Infections with this bacteria involve the mouth and feet, occasionally spreading to internal organs (Leighton, 2001b). These bacteria have a synergistic effect with *A. pyogenes*, and mixed infections are common in ungulates (Wobeser, 2001).

Foot infections with *F. necrophorum* cause weight loss, severe pain, and lameness from abscesses. Oral infections cause salivation, reduced ability to masticate or swallow, and weight loss. Occasional mortalities result from systemic involvement (Leighton, 2001b).

Transmission has occurred when animals congregate at high densities in wet weather resulting in environmental contamination. Contributing factors include stress, crowding, high fecal contamination, and contact with domestic ruminants. Outbreaks have also been observed when domestic sheep travel over crusted snow, damaging the interdigital skin.

Both sporadic and herd outbreaks have been documented in Canada and the United States in mule deer (*Odocoileus hemionus*), white-tailed deer (*Odocoileus virginianus*), pronghorn (*Antilocapra americana*), and elk (*Cervus elaphus*), particularly where animals congregate around feed or watering areas

and are in association with domestic ruminants. Although there are no specific reports of outbreaks in wild sheep, there is no known limit to the ruminant hosts in which it can be found both as normal flora and as a disease-causing agent (Kimberling, 1988; Leighton, 2001b). The introduction of domestic sheep, goats or llamas into Dall's sheep range is not thought to have an effect on the incidence of *F. necrophorum* disease because it is found in the normal oral cavity of most ruminants and disease is usually a result of environmental factors. It would be prudent, however, to sample wild Dall's sheep and mountain goats to determine if this bacterium is part of the native flora.

Viruses

Malignant Catarrhal Fever

Malignant Catarrhal Fever (MCF) is a fatal and multisystemic disease caused by ovine herpes virus-2 (OHV-2), that affects many domestic and wild ungulates worldwide (O'Toole *et al.*, 2000). MCF was described in domestic cattle as early as the 1700s in Europe and the 1920s in North America (Berezowski, 2000; Li *et al.*, 1996; Woodbury, 2002). The actual virus remains elusive, and to date has not been isolated in tissue culture. Evidence of the OHV-2 is, therefore, detected through a positive reaction of antibody to the wildebeest herpes virus (Heuschele and Reid, 2001).

OHV-2 is non-pathogenic in 90–95% of domestic sheep in Canada (Wenger and Tait, 2001) and healthy goats are commonly seropositive (Berezowski, 2000). Llamas do not appear to be carriers of this virus (Li *et al.*, 1996). Domestic sheep and goats could be potential carriers to other highly susceptible ruminants such as bison and cattle. In cattle and bison, malignant catarrhal fever is usually characterized by sudden onset with severe clinical signs and death (Schultheiss *et al.*, 1998; Woodbury, 2002). There is no satisfactory treatment for MCF (O'Toole *et al.*, 2000). There are no reports of clinical disease caused by MCF virus in any captive or free-ranging wild sheep or mountain goats (Zarnke *et al.*, 2002). In a study of free-ranging Dall's sheep in Alaska from 1997 to 2000, MCF-like viral antibody seroprevalence was 95% in the 222 animals sampled. Likewise, exposure to MCF has been identified in BC bighorn sheep

(H. Schwantje, unpubl. data). These animals had no known contact with domestic sheep or goats (Frolich *et al.*, 1998; Zarnke *et al.*, 2002). Seroprevalence in 54 mountain goats sampled in the United States, from 1990 to 1995 was zero (Li *et al.*, 1996). Wild sheep may carry their own or a very similar form of the sheep herpes virus that gives a false positive result when testing for OHV-2 from domestic sheep (Li *et al.*, 1996), however this remains controversial. Based on the high antibody seroprevalence in Dall's sheep, it has been recommended to keep susceptible species such as cattle, separate from Dall's sheep (Zarnke *et al.*, 2002).

Parasites – Helminths

Dictyocaulus filaria

Dictyocaulus filaria is a common and pathogenic lung nematode of the Trichostrongylid family found in domestic sheep, goats, and llamas and causes verminous pneumonia in young animals (Kimberling, 1988). Signs include coughing, increased respiratory rates, nasal and ocular discharge, weight loss and anorexia. Secondary bacterial infections may result. This parasite is more common in younger sheep; older sheep develop some immunity. *Dictyocaulus* spp. have not been reported from wild sheep or goats (Dau, 1981; Kerr and Holmes, 1966; Kutz *et al.*, 2001; Kutz *et al.*, 2002; Matthews, 1999; Uhazy and Holmes, 1971).

Larvae are shed in the feces and develop to infective third-stage larvae within 6 to 7 days under favourable conditions. When ingested by the ruminant host the larvae migrate to the lungs where they develop to adults in about 35 days and reside in the bronchi, or they may remain in an inhibited stage in the lung parenchyma and mature at a later date (usually spring) (Kimberling, 1988). Larvae are shed in the feces for about 3 months. Third stage larvae are highly susceptible to desiccation but can withstand some freezing and can overwinter in temperate regions, particularly where they are covered with snow (Dunn, 1969). In general the larvae of *Dictyocaulus* spp. are not as freeze tolerant as the protostrongylids.

Susceptibility of wild sheep and goats to *D. filaria* is unknown. However, given disease associated with this parasite in young domestic sheep and goats, precautions should be taken to prevent translocation of this nematode to wild sheep range.

Fascioloides magna

Fascioloides magna, or the giant liver fluke, was reported in cattle in Alberta in 1998 (<http://www1.agric.gov.ab.ca>). It is present in many wild and domestic ruminants primarily in North America, and is now common in the west along the northern Pacific coast and the Rocky Mountain trench (Pybus, 2001). Infection occurs naturally in cattle and cervids and is typically subclinical. In contrast, domestic sheep, goats and wild sheep are aberrant hosts and signs include lethargy, weight loss, depression, anorexia and distended abdomen

(Pybus, 2001). Severe and usually permanent damage of the liver results in mortality within 6 months. Natural infections in bighorn sheep are rare, however experimental infections resulted in 100% mortality within 197 days post-infection (Foreyt, 1996). One wild bighorn died acutely of blood loss when a fluke ruptured a major pulmonary blood vessel (T. Shury, pers. comm.). Llamas are dead-end hosts: the flukes reach the liver, but rarely mature, and disease is not as severe as in domestic sheep (Foreyt, 1996).

Eggs are shed in the feces, hatch in water and penetrate snail intermediate hosts to multiply then emerge and encyst on aquatic vegetation to be consumed by the host (Pybus, 2001).

Although domestic sheep, goats and wild sheep are very susceptible to *F. magna* infection, rarely do they become patent and, therefore, they are presumed unimportant in the spread of this parasite (Kimberling, 1988; Pybus, 2001).

Parelaphostrongylus tenuis

Parelaphostrongylus tenuis, a protostrongylid nematode, is the meningeal worm of white-tailed deer (WTD) (*Odocoileus virginianus*). It's distribution in Canada is limited to east of the Saskatchewan-Manitoba border (Lankester, 2001). Transmission requires a gastropod intermediate host for development of the first-stage larvae shed in feces to the third stage larva that is infective to the definitive host. Suitable gastropod species for development are present in the NWT (S. Kutz, E. Jenkins, unpubl. data). Infection of abnormal hosts, including bighorn sheep, and domestic sheep, goats, and llamas, results in severe

debilitating neurological signs (Kimberling, 1988; Lankester, 2001). However, these hosts rarely become patent, and it is unlikely that they would introduce *P. tenuis* to Dall's sheep or mountain goats in the NWT.

Protostrongylus stilesi

This protostrongylid lungworm is a common and widespread parasite in bighorn sheep (Uhazy and Holmes, 1973), Stone's and Dall's sheep; prevalence in Dall's sheep in the NWT approaches 100% (Kutz *et al.*, 2001; Kutz, 2001; Veitch *et al.*, 1998). Most wild sheep populations show no clinical signs. Under conditions of environmental stress, concurrent disease, poor nutrition or crowding, the lung damage caused by *P. stilesi* may predispose to pneumonia (Forrester, 1971; Uhazy and Holmes, 1973).

Protostrongylus stilesi larvae are shed in the host feces. They require an intermediate slug or snail host to develop into third stage infective larvae. When the infective intermediate host is accidentally ingested by the sheep host, the larvae emerge from the digested snail and migrate to the lungs where they develop into adults.

To our knowledge, *Protostrongylus stilesi* has not been reported in domestic sheep or goats. Nevertheless, because parasites of the same genus can infect domestic sheep and goats, these parasites certainly warrant consideration in these species.

Parasites – Trichostrongylids

Note: the Trichostrongylid family comprises a number of nematode parasites with varying pathogenicity. There are some trichostrongylids for which little is known but that are of potential concern and they were presented in Section 3. The following trichostrongylids are thought to be of lower concern. To be complete, the general overview, clinical signs, lifecycle and transmission are presented in both sections.

Gastrointestinal trichostrongylids are a family of nematode parasites found in the abomasum or intestines of wild and domestic ruminants. Left untreated, gastrointestinal trichostrongyles are a major cause of production loss for domestic sheep and cattle. It is increasingly recognized that trichostrongyles have important subclinical effects in wild ruminants as well (Albon *et al.*, 2002; Arneberg *et al.*, 2002; Kutz *et al.*, 2004b; Stien *et al.*, 2002; Worley and Seese, 1992).

The natural parasite fauna of wild sheep and goats and domestic sheep and goats differ, however, trichostrongyles tend to have a fairly broad host range (Hoberg *et al.*, 2001). As a result, in the United States and parts of southern Canada, the fauna in wild sheep and goats is a mixture of endemic and introduced species (Hoberg *et al.*, 2001). The impacts of the exchange of trichostrongylid parasite species among wild and domestic sheep have not been extensively studied. However, at the very least, the net increase in parasite

abundance may be expected to have potentially negative impacts on production and survival of the recipient species.

Clinical signs in domestic sheep, goats, and llamas: Differences in pathogenicity exist among species of trichostrongylids. In general, clinical signs include anorexia, weight loss, poor hair coat, reduced fecundity, diarrhea, anemia, and protein loss.

Clinical signs in wild sheep and mountain goats: As for domestic species.

Transmission and lifecycle: The general lifecycle of parasites in this family is a direct cycle. The eggs are shed in the feces, and the larvae develop to the infective stage within about 2 weeks at 20 °C. The infective larvae migrate to vegetation, and are ingested by the ruminant host. They then may develop to adult nematodes immediately or migrate into the mucosa of the abomasum (or small intestine) and enter arrested development for variable periods of time (Bowman, 1995; Kimberling, 1988; Urquhart *et al.*, 1996).

Environmental Survival: Varies according to the species.

Evidence of transmission among domestic and wild species: Many gastrointestinal trichostrongylids are generalists and have a wide host range; it is thought that many species can be transmitted among domestic sheep, goats or

llamas, and Dall's sheep and mountain goats (Hoberg *et al.*, 2001; Zaffaroni *et al.*, 2000).

The following members of this family, listed alphabetically, are considered minor risks and will be discussed in brief: *Camelostrongylus mentulatus*, *Cooperia* spp., *Ostertagia* spp., and *Trichostrongylus* spp.

Camelostrongylus mentulatus is a pathogenic nematode of llamas. It causes gastritis, chronic emaciation, and death (Rickard and Bishop, 1991a). Introduced to the United States, this parasite is circulating in free-ranging herds of African bovids and llamas but has not been reported from Canada (Hoberg *et al.*, 2001). It has been shown experimentally that it can infect domestic sheep and goats (Thornton *et al.*, 1973 in Hoberg *et al.*, 2001) and it is possible that wild sheep and goats could also be susceptible.

***Cooperia* spp.** There are six known species of *Cooperia* in North America. These nematodes are primarily parasites of domestic cattle and sheep, but are found in various wild bovids and cervids (Hoberg *et al.*, 2001). They reside as adults in the small intestine. When present in high numbers in domestic kids and lambs these parasites result in hemorrhage, anemia, diarrhea and malnutrition (Kimberling, 1988). Llamas are also infected with *Cooperia*, though a different species (Hoberg *et al.*, 2001). *Cooperia* spp. are rarely found in bighorn sheep and occur in large numbers only when conditions are favourable for

reinfection from another species (Neilson and Neiland, 1974; Worley and Seesee, 1992). Their significance is unknown. This genus is considered to occur only in warm climates (Neilson and Neiland, 1974) and is therefore unlikely to establish at northern latitudes.

***Ostertagia* spp.** are abomasal nematodes occasionally found in domestic sheep and goats (Lichtenfels *et al.*, 1988). *Ostertagia* spp. has been reported in llamas, and in one report 3 of 3 affected animals died (Windsor, 1997). *Ostertagia ostertagi* was reported in Alaskan Dall's sheep that shared range with bison (Neilsen and Neiland, 1974) and has been reported from mountain goats in Alberta and South Dakota and bighorn sheep in the United States as well as British Columbia (Hoberg *et al.*, 2001). *Ostertagia gruehneri* is reported, though uncommonly, in Dall's sheep in the Mackenzie Mountains. It has been shown to reduce fecundity of Svalbard reindeer (Albon *et al.*, 2002). The susceptibility of domestic sheep to *O. gruehneri* is unknown. Given the low prevalence of *O. gruehneri* in wild sheep and of *O. ostertagi* in domestic sheep, goats, and llamas, interspecies transmission of either parasite is unlikely.

***Trichostrongylus* spp.** are small nematodes of the abomasum or small intestine. They are found in domestic sheep, goats, and llamas, wild bighorn sheep, horses, and rarely in mountain goats (Hoberg *et al.*, 2001). They have not been recorded from Dall's sheep (Kutz, 2001; Neilson and Neiland, 1974). Clinical disease is similar to that seen for other trichostrongyles. Infection of wild

ruminants is thought to be from domestic species (Hoberg *et al.*, 2001). Free-living stages of this genus are not adapted to surviving cold, arid conditions, which may explain its rarity at subarctic to arctic latitudes (Kates in Neilson and Neiland, 1974).

Ectoparasites

Psoroptes sp.

Psoroptes are small, non-burrowing mites that live on the body and in the ears of susceptible hosts. These cause severe disease in domestic sheep (Kimberling, 1988), goats (Matthews, 1999) and llamas (Foreyt *et al.*, 1992), and wild sheep and goats. *Psoroptes* is reportable in Canada and has not been reported in this country for at least 10 years (L. Polley, pers. comm.). *Psoroptes ovis* occurs more commonly in sheep and lives primarily on the body, while *Psoroptes cuniculi* occurs more frequently in goats and resides in the ears (Pugh, 2002). *Psoroptes* sp. occurs very rarely in llamas, but the species is presently unknown (Fowler, 1998).

Clinical signs seen in domestic animals are most common in late fall or winter, and include intense itching, self-trauma, head-shaking, and crusty scabs either on the body or in the ears (Pugh, 2002). Infection spreads rapidly through herds and flocks. Treatment of domestic animals is possible, although mites can survive 7–9 days on the host following treatment (Foreyt, 1985). There are also

periods of latency during which time clinical disease is inapparent, posing a possible risk to other animals in contact (Boyce *et al.*, 1991)

Psoroptes ovis has a 2-week lifecycle consisting of 5 different stages of development occurring entirely on the host. During the fall, the mite multiplies rapidly, causing severe damage to the host. In the spring and summer, the mites are inactive, but remain on the host. The mite can survive off the host for up to 3 weeks.

Psoroptes sp. is widespread in bighorn sheep in parts of the United States (Bunch *et al.*, 1999; Norrix *et al.*, 1995) but is not reported in Canada. It is thought that this parasite was introduced into bighorn sheep populations in the 1800s by domestic sheep, however the taxonomy is confusing, so the original source, as well as the exact species of *Psoroptes* in wild sheep, remains unknown (Boyce *et al.*, 1991; Bunch *et al.*, 1999). An alternative hypothesis is that *Psoroptes* mites were introduced with wild sheep migrating to North America across the Bering land bridge during the Pleistocene, but no evidence of exposure to this mite has been found in Dall's sheep, which is incompatible with this theory (Boyce and Zarnke, 1996).

Infection in wild sheep presents as either lesions on the body, in the ears or both. Often infection is restricted to the ears (Bunch *et al.*, 1999). In severe cases ears can be completely occluded with crusty exudates; this is thought to cause hearing loss resulting in impaired awareness, identification and localization of predators (Lange *et al.*, 1980; Norrix *et al.*, 1995). Lesions covering a large percentage of the body in some animals have been reported, particularly in naive

herds, resulting in significant hair loss and emaciation, and devastating mortality and extirpation of some bighorn herds (Bunch *et al.*, 1999; Foreyt, 1997; Lange *et al.*, 1980; Schwantje, 1988a). Greater than 90% of the bighorn herd in the San Andres National Wildlife Refuge was lost due to *Psoroptes* infection from 1979 to 1989 (Bunch *et al.*, 1999; Lange *et al.*, 1980; Mazet *et al.*, 1992).

Transmission from infected bighorn to Stone's sheep in captivity has been documented (Foreyt, 1997). There are no reports of infection of free-ranging thornhorn sheep (Bunch *et al.*, 1999). Experimental attempts to transmit *Psoroptes* mites from infected bighorn sheep in New Mexico to domestic sheep and cattle failed (Wright *et al.*, 1981). Until more is known about the source and cross-species transmission, mite infections in domestic and wild sheep and goats should be considered as a serious potential threat for two-way transmission (Bunch *et al.*, 1999; Mazet *et al.*, 1992). However, because psoroptic mange is not present in Canada at this time, this parasite is of low concern for animals in this country.

Protozoa

Cryptosporidium sp.

Cryptosporidium is an intestinal protozoon found in most mammals world wide, including domestic sheep and goats and llamas. *Cryptosporidium parvum* is the species most frequently reported in domestic and wild mammals (Duszynski and Upton, 2001). Adults may carry and shed the oocysts in low

numbers showing no clinical signs (Duszynski and Upton, 2001), consequently new additions to any flock or herd are a potential source of environmental contamination (Matthews, 1999).

Most animals become infected in the first 3 weeks of life. Many do not show signs, and the infection is usually self-limiting (Kimberling, 1988). However, it can cause mild to severe diarrhea, dehydration, weakness, anorexia, weight loss and depression, and occasionally death, particularly from mixed viral or bacterial infections (Pugh, 2002). Clinical signs usually last for a few days (Blood and Radostits, 1989), followed by immunity in the exposed animal. There is no treatment for this disease (Blood and Radostits, 1989). This protozoon is zoonotic, and can cause severe disease in human beings, particularly those who are immunocompromised. The oocysts are shed in the feces, and are immediately infective to subsequent hosts via the fecal-oral route (Blood and Radostits, 1989).

Outbreaks of disease have been reported in many captive wild ungulates in crowded settings. Outbreaks are most common in the spring when there is increased precipitation and high numbers of young susceptible animals (i.e. lambing) (Duszynski and Upton, 2001). There is evidence that this organism is widespread in wildlife populations worldwide (Duszynski and Upton, 2001) and that contact with domestic animals infected with *C. parvum* would not change the occurrence of disease in either wild or domestic species. However, *Cryptosporidium* has not yet been reported in free-ranging bighorn or Dall's sheep or mountain goats.

Toxoplasma gondii

Toxoplasma gondii is a protozoon tissue parasite. Sheep, goats and possibly llamas and many other vertebrates (Fowler, 1998) are intermediate host and felids are the only known definitive hosts. Abortion, stillbirth, and neonatal deaths are the most common form of disease in the intermediate host, and should be considered in flocks of sheep, goats, and possibly llamas with high rates of reproductive failure (Fowler, 1998). Domestic sheep can be affected with encephalitis, ocular disease, or reproductive forms. If ewes carry lambs to term, they are usually stillborn or weak, often dying shortly after birth. Ewes with encephalitis are found circling with incoordination and muscle rigidity. With the ocular form, animals have impaired vision with abnormal papillary reflexes (Kimberling, 1988).

The parasite is excreted in wild or domestic feline feces, consumed by grazing ruminants, and becomes encysted in muscle tissue. Ingestion of contaminated materials by the definitive host completes the lifecycle (Kimberling, 1988). *Toxoplasma gondii* oocysts are very resistant and can survive for over a year in soil or on pasture (Matthews, 1999).

Antibodies to *T. gondii* were detected in bighorn sheep in the western United States, and Dall's sheep in Alaska (Dubey and Foreyt, 2000; Zarnke *et al.*, 2000). Encephalitis caused by *T. gondii* was reported in one free-ranging Rocky Mountain bighorn juvenile in Washington (Baszler *et al.*, 2000). Although the significance of this protozoa in causing abortions and other clinical signs is

unknown in wild sheep and goats, it should be considered in populations with low fecundity and recruitment (Dubey and Foreyt, 2000). Because this protozoon parasite appears to be endemic in both wild and domestic ruminant populations as well as in wild and domestic cats, it is unlikely that contact between Dall's sheep or mountain goats and domestic sheep, goats or llamas would affect the prevalence of *T. gondii* in any of these species.

SECTION 5. ORGANISMS POSING NO APPARENT RISK.

Description

According to our current understanding, the following list of organisms from appendices 1–7 appear to pose no additional risk to either domestic sheep, goats, and llamas, or wild sheep and goats when in potential contact. Note, however, that as our understanding of the biology, effects, and geographic distribution of these organisms increases, that some may be found to be of greater concern. Criteria for this category include: 1) the organism is not present in the species of interest in Canada, OR 2) the organism causes no known disease in any of the above species, OR 3) there are no records or suspicions of any transmission between the above species. For these reasons, the following organisms will not be discussed further.

Bacteria

Acholeplasma oculi

Actinobacillus lignieresii

Actinomyces lamae

Actinomyces bovis

Actinomyces sp.

Anaplasma ovis

Anaplasma sp.

Bacillus piliformis

Bacillus sp.

Bacteroides fragilis

Bordetella sp.

Branhamella ovis
Burkholderia pseudomallei
Campylobacter fetus
Campylobacter jejuni
Clostridium botulinum
Clostridium chauvoei
Clostridium haemolyticum
Corynebacterium renale
Dermatophilus congolensis
Enterococcus sp.
Escherichia coli
Francisella tularensis
Histophilus sp.
Hemophilus ovis
Hemophilus somnus
Klebsiella pneumoniae
Leptospira spp.
Listeria monocytogenes
Moraxella bovis
Moraxella lacunata
Moraxella lacunata
Moraxella liquefaciens
Mycobacterium avium
Mycobacterium tuberculosis
Mycoplasma agalactia
Mycoplasma bovis
Mycoplasma capricolum
Neisseria sp.
Nocardiosis sp.
Rhodococcus equi
Salmonella sp.

Salmonella typhimurium

Staphylococcus sp.

Streptococcus sp.

Streptococcus zooepidemicus

Ureaplasma

Yersinia enterocolitica

Yersinia pseudotuberculosis

Viruses

Akabane virus disease

Bovine adenovirus

Bovine herpes virus 1

Bovine parvovirus

Camel pox

Caprine arthritis encephalitis virus

Caprine herpes virus

Cache Valley virus

Corona virus

Equine herpes virus type 1

Influenza A virus

Influenza B virus

Louping ill encephalomyelitis

Ovine herpes virus 1

Ovine lentivirus (ovine progressive pneumonia)

Papilloma virus

Rabies virus

Rift Valley fever

Vesicular stomatitis

Fungal

Absidia corynebifor

Aspergillus sp.

Microsporum canis

Trichophyton canis

Trichophyton gypseum

Trichophyton mentagrophytes

Trichophyton verrucosum

Parasitic

Helminths:

Bunostomum sp.

Capillaria sp.

Coenurus cerebralis (*Taenia multiceps*)

Dicrocoelium dendriticum

Dictyocaulus viviparous

Echinococcus granulosus (hydatid cysts)

Elaeophorosis schneideri

Fasciola hepatica

Graphinema aucheniae

Moniezia benedini

Moniezia expansa

Moniezia sp.

Muellerius minutissimus

Oesophagostamum sp.

Oesophagostamum venulosum

Onchocerca sp.

Pelodera strongyloides

Protostrongylus rufescens

Protostrongylus rushi

Strongyloides papillosus

Strongyloides sp.

Taenia hydatigena

Thelazia californiensis

Thelazia rhodesii

Thelazia sp.

Thysaniezia giardi

Thysanosoma actinoides

Protozoa:

Eperythrozoon sp.

Giardia sp.

Pneumocystis carinii

Trichomonas sp.

Trypanosoma sp.

Ectoparasites:

Cephenemyia sp.

Chorioptes caprae

Chorioptes bovis

Chorioptes ovis

Chorioptes sp.

Damalinia breviceps

Damalinia caprae

Damalinia oreamnidis

Demodex caprae

Demodex ovis

Linognathus ovillus

Linognathus stenopsis

Microthoracius cameli

Microthoracius mazzai

Microthoracius praelongiceps

Psoroptes cuniculi

Sarcoptes scabiei

Vermipsylla sp.

SECTION 6. ORGANISMS OF CONCERN IN THE NORTHWEST TERRITORIES.

Description

The organisms in this category pose no risk in our species of interest, but are of concern in the Northwest Territories and thus are presented for the sake of completeness. Criteria for diseases in this category are: 1) present and of concern in Northwest Territories in indigenous species AND 2) no evidence of these diseases in domestic sheep, goats or llamas in western Canada and wild sheep or goats.

Anthrax

Anthrax is a federally reportable disease infecting wild and domestic animals caused by a gram-positive bacillus, *Bacillus anthracis*. This bacteria is found throughout the world, and is of particular concern in bison (*Bison bison*) in Northwest Territories. The bacteria reside in the soil and infect the host while grazing or during activities that disturb the soil, causing aerosolization of bacterial spores, resulting in severe and usually fatal septicemias. Infection is attributed to geographic location (environments where soil is contaminated with *B. anthracis* spores) rather than by direct transmission between species (Gates *et al.*, 2001). Although domestic sheep, goats, and llamas and Dall's sheep and mountain goats are all susceptible to anthrax, it is only sporadically reported in domestic sheep and goats in Canada.

Brucellosis

Brucellosis is caused by gram-negative cocci, coccobacilli or short rods resulting in reproductive disease in susceptible species. Infected animals suffer from abortion, birth of non-viable young, infections of the reproductive tract, and infertility. In Canada, *B. abortus* is reportable, and is currently found only in wood bison in the NWT and northern Alberta. This disease is important for its economic impacts on the national livestock industry, as well as for its zoonotic potential (Dubay *et al.*, 2003; McCorquodale and DiGiacomo, 1985). There have been no cases of brucellosis infection (*B. ovis*) in domestic sheep in Canada in the past 10 years. Out of 73 Dall's sheep caught near Tok, Alaska, three animals had positive titres to *Brucella* sp. (Foreyt *et al.*, 1983). *Brucella suis* is common in northern caribou herds and there is substantial overlap between Dall's sheep and caribou range, posing some potential for transmission to Dall's sheep (Tessaro and Forbes, 1986; Brett Elkin, unpubl. data). Brucellosis has never been confirmed in wild sheep in Canada (Dubay *et al.*, 2003) and it is suggested that wild ungulates are of little importance as a disease reservoir for domestic animals (McCorquodale and DiGiacomo, 1985).

Tuberculosis

Tuberculosis is a federally reportable disease caused by the gram-positive bacteria *Mycobacterium bovis*, characterized by granulomatous lesions of the lymph nodes and the lungs causing weakness, debilitation, and death. Tuberculosis is present in wood bison in Wood Buffalo National Park in

Northwest Territories, and elk and white-tailed deer in Riding Mountain National Park in Manitoba (Joly and Messier, 2004; Lees *et al.*, 2003). It is transmitted through inhalation or ingestion of infective particles (Clifton-Hadley *et al.*, 2001). The disease has been eradicated in the rest of Canada and is not considered a risk associated with the species of interest.

Discussion

General

The objective of this report was to identify known pathogens for domestic sheep, goats, and llamas, and wild sheep and goats, for the purposes of assessing the potential health risks to these species associated with the introduction of domestic species into the western NWT. Perhaps the most profound finding of this risk assessment is the identification of numerous infectious agents for which we know very little concerning the identity, geographic distribution, transmission dynamics, and impacts in Dall's sheep and mountain goats. According to the Canadian Cooperative Wildlife Health Centre guidelines for preparing risk assessments (<http://wildlife1.usask.ca/ccwhc2003/>), the great number of unknowns should have precluded the continuation of the assessment. However, given the importance of infectious diseases, particularly introduced pathogens, in severe population die-offs in bighorn sheep, combined with the growing interest in developing the domestic livestock industry in the NWT (anonymous, 2004), we felt it prudent and timely to develop this proactive

assessment using the available information for Dall's sheep and mountain goats but also relying heavily on the bighorn sheep literature.

History of bighorn sheep in North America

Prior to European settlement in North America, bighorn sheep were much more widespread and numerous than today (Dubay *et al.*, 2003). Numbers of bighorn sheep in the mid-1800s were estimated at 1.5 to 2 million (Queen *et al.*, 1994). Since the turn of the century, bighorn sheep numbers in North America have dropped substantially (Festa Bianchet, 1988; Jones and Worley, 2004; Schommer and Woolever, 2001). The most important disease affecting bighorn sheep survival in Canada is pneumonic pasteurellosis (Foreyt, 1994) but in many cases, just as in domestic animals, stress is a factor predisposing sheep to other diseases. Probable stressors for bighorn sheep are parasitism, poor nutrition, inclement weather, multiple parasite burdens, overcrowding, predation (Jones and Worley, 2004), and human disturbances such as road construction, habitat degradation, harassment by people or dogs, loss of escape cover, noise, and high dust levels (Festa Bianchet, 1988; Jenkins *et al.*, 2000). Bighorn sheep numbers in the United States are now estimated at less than 1% of what they were prior to human settlement (Martin *et al.*, 1996).

Disease susceptibility of bighorn sheep appears to be very different from that of domestic sheep. Bighorns did not co-evolve with the same set of pathogens as domestic sheep (Dubay *et al.*, 2003). Domestic animals, reared in high density flocks and herds, have been selected for disease resistance and are

subjected to regular treatment with anthelmintics and vaccines (Jessup, 1985). Additionally, results of in vitro studies comparing immune function of wild versus domestic sheep found profound differences, demonstrating a reduced capacity of bighorn immune cells to kill bacteria (Dubay *et al.*, 2003). Dall's sheep are also thought to have a reduced ability to respond immunologically to bacteria and viruses commonly seen in domestic sheep (Foreyt *et al.*, 1996). Bighorn sheep have exhibited lower tolerance to habitat destruction, competition, and other stressors than other North American wild ungulates (Martin *et al.*, 1996; Schommer and Woolever, 2001). We have assumed that Dall's sheep may exhibit similar disease susceptibility and expression to bighorn sheep.

There are numerous cases demonstrating the susceptibility of naive populations of wild sheep to respiratory pathogens of domestic animals. Dall's sheep in the Mackenzie Mountains appear to be naive to respiratory pathogens commonly implicated in pneumonia in both domestic and bighorn sheep (Jenkins, 2005). In naive populations, disease would be more severe than that of an adapted population (Zarnke and Rosendal, 1989).

Many bighorn sheep die after direct contact with domestic sheep, while domestic sheep appear to be refractory to most wild sheep pathogens (Martin *et al.*, 1996; Schommer and Woolever, 2001). Unfortunately, wild and domestic sheep and goats demonstrate similar social behaviours, and will commingle when on shared range (Dubay *et al.*, 2003). Bighorn rams have even been known to breed domestic ewes during rut (Aune *et al.*, 1998; Spraker and Adrian, 1990).

Bighorn sheep management

In attempts to keep bighorn and domestic sheep separated, managers in some regions have instituted buffer zones. Suggested buffers of 15 or 25 km have been thought to be adequate; however, when the biology of a ram in rut is taken into consideration, these distances may not suffice. In 1984, Festa-Bianchet reported 100 km movements of radio-collared rams during rut (Onderka and Wishart, 1984).

Domestic sheep are also known to travel long distances. In one case, a stray ewe traveled a minimum of 48 km from private land to bighorn range. This journey took the ewe through very rugged terrain, heavy timber, and at least one river crossing (Coggins, 2002). In 1998, the Bureau of Land Management in Idaho recommended buffer zones of 13.5 km between domestic sheep and bighorn sheep, unless natural barriers prevented contact. However, bighorns in that same area have been documented traveling up to 80 km through towns, and crossing major rivers (Coggins, 2002). Currently, in BC, a 16 km or natural barrier buffer is recommended, but not legislated (Demarchi *et al.*, 2000b).

In 1995, the United States District Court in Oregon examined the issue of incompatibility between domestic and bighorn sheep, and Magistrate Judge Donald C. Ashmanskas found that scientific research supported the conclusion that an incompatibility exists, and the only way to avoid the associated die-offs is to keep the two species separate (Schommer and Woolever, 2001). Although there is more evidence implicating domestic sheep in association with bighorn

die-offs, domestic goats should be considered just as dangerous to bighorn sheep (Coggins, 2002), and should be managed away from wild sheep range. Based on the vast experience of wildlife managers, veterinarians and researchers specializing in the domestic sheep and bighorn sheep compatibility issue, contact between domestic sheep and wild sheep is not recommended (Adams and Zehnder, 2002; Coggins, 2002; Demarchi *et al.*, 2000a; Demarchi *et al.*, 2000b; Festa Bianchet, 1988; Foreyt *et al.*, 1996; Jessup, 1985; Krausman, 1996; Martin *et al.*, 1996).

Dall's sheep and mountain goats in the north

Thinhorn sheep and mountain goats in the NWT reside in remote and rugged landscapes, largely uninhabited and unaltered by human activities. They are valuable components of the ecosystem as well as important for the local tourist economy. In the future, disturbance of these species will increase as a result of a greater human footprint associated with resource exploration and extraction, road construction, and tourism in these remote regions (Blood, 2000; Case, 1989; Ferguson *et al.*, 1985). Concurrently, rapid and unprecedented climate change is having physical and biological effects on the ecosystem which may impact the health of wildlife in these regions (Kutz *et al.*, 2004; Kutz *et al.*, 2005; Jenkins *et al.*, 2005c).

Mountain goats are the least studied ungulate in NWT, research being limited by the difficulty in access and the high costs involved in surveying this remote region (Veitch *et al.*, 2002). Very little is known about the health status of

free-ranging mountain goats in the NWT (and elsewhere), and with reports of groups of mountain goats in the Yukon Territory recently disappearing, either due to mortality or dispersal (Veitch *et al.*, 2002), managers should be conservative about assumptions regarding disease susceptibility in this species.

In contrast to bighorn sheep, no large-scale disease-related die-offs have been reported in Dall's sheep. Numerous skulls were collected from a suspected "population crash" in Mount McKinley National Park in Alaska in 1944, but the cause remains unknown (Simmons *et al.*, 1984). These Dall's sheep are exposed to stressors similar to those experienced by bighorns, such as predation, human harvest, high parasite loads, and long and severe winters (Heimer *et al.*, 1992). A key distinction between healthy wild sheep populations and those experiencing population-level mortality events appears to be contact with people and domestic animals (Schwantje, 1986; Schwantje, 1988b). The absence of large-scale disease-related die-offs in Dall's sheep is presumably attributed primarily to: 1) the limited anthropogenic stressors compared to those experienced by bighorn herds in the more populated south and 2) the absence of contact with domestic sheep and goats and therefore no introduction of their associated pathogens (Foreyt *et al.*, 1996; Jenkins *et al.*, 2000).

It is difficult at this time to envision domestic sheep in the Northwest Territories; however, near Palmer, Alaska, domestic sheep were translocated into Dall's sheep winter ranges without knowledge of, or permission from, state wildlife authorities (Heimer *et al.*, 1992). Fortunately, no ill effects were reported

for Dall's sheep, but this emphasizes the need for proactive management and local restrictions prohibiting domestic sheep in wild sheep range.

Sheep, goat, and llama farming in the NWT is currently minimal. However there is a move to expand domestic livestock production in the NWT. Farming boosts local economies, is an important part of our heritage and provides large tracts of land as habitat for many wildlife species (Schommer and Woolever, 2001). As well, climate warming and habitat alterations mean that agriculture may someday be a more feasible industry in the north.

Simultaneously, wildlife managers are striving to maintain the ecological balance of the Mackenzie and Richardson Mountains, and to prevent the problems associated with human development and translocation of wild and domestic animals. However, changes in the distribution of wildlife, possibly in response to climate change or habitat alterations, may also lead to northward shifts in the pathogens normally associated with central and southern North America. Within the last few years, there have been reports of mule deer and white-tailed deer in the Mackenzie River Valley (Veitch *et al.*, 2002) and the Yukon Territory (Hoefs, 2001), presumably bringing new parasitic, bacterial and viral fauna that may pose threats to native species.

Management recommendations

It is unfortunate that studies on such valued resources are often initiated following a die-off or decline. In North America, billions of dollars have been spent on retroactive management of the wild sheep/domestic sheep and goat

issue (H. Schwantje, I. Adams, V. Coggins, pers. comm.). In 2000 and 2001, BC biologists visited 19 sheep farms in the East Kootenays. Despite the fact that these farms are in the region of high profile bighorn sheep die-offs, few were well informed and all expressed both great concern and a desire to come to a solution that prevented further disease outbreaks in bighorn sheep (Adams and Zehnder, 2002). This is encouraging information for northern managers, because the intent is not to thwart all farming efforts in NWT, but rather to have both resources thrive compatibly.

Given the value of northern ungulates, and our knowledge of wild sheep and domestic sheep issues, it is prudent to manage the risks proactively to Dall's sheep and mountain goats in the NWT. We recommend the development and implementation of strong proactive policy in an effort to decrease the risks of preventable disease outbreaks in Dall's sheep and mountain goats.

Conclusion

Our results indicate that there are potentially a number of important pathogens of domestic sheep, goats, and llamas that pose a real and significant disease risk for Dall's sheep and mountain goats. Conversely, we found few pathogens of concern for domestic sheep, goats, and llamas.

This risk assessment suggests that although there are many variables and unknowns regarding disease susceptibility and risk in Dall's sheep, there are substantial risks associated with the introduction of domestic sheep, goats, and llamas near Dall's sheep range in the NWT. Unfortunately there is less known

about mountain goats, and based on the literature, we were unable to state clear risks associated with contact between this species and domestic sheep, goats, and llamas. However, given the naive state of both Dall's sheep and mountain goats, we suspect that any contact between these species and domestic sheep, goats, and llamas could result in disease with serious outcomes for populations of these valuable game animals.

There are countless changes occurring at the ecosystem level on a global scale. In the north, although it remains relatively unspoiled, there are irreversible changes occurring such as climate change, encroachment of invasive species, loss of biodiversity and ongoing renewable and non-renewable resource development. Although we cannot prevent some of these changes, we can, through policy and forward thinking, develop proactive guidelines, policies, and mitigative measures to prevent negative impacts of agriculture on both wildlife and domestic/exotic species. Such action will promote healthy wildlife populations in the NWT and subsequent sustainability of subsistence harvest and tourism (including sport hunting). It will also provide a positive framework for the growth of a healthy domestic livestock industry while reducing potential conflicts with wildlife.

Appendix 1. Infectious bacterial agents reported in domestic sheep, goats, and llamas, and wild Dall's sheep and mountain goats.

Below is a compilation from all sources in the Reference List of this document and includes reports of natural and experimental infections where the organism was detected as well reports where antibody to the organism was detected in both captive and free-ranging animals.

(S: domestic sheep, G: domestic goats, L: llamas, D: Dall's, BH: bighorns, SS: Stone's sheep, MG: mountain goats, X: present, U: unknown)

Bacterial agents:	S	G	L	D	BH	SS	MG
<i>Acholeplasma oculi</i>	X	X					
<i>Actinobacillus capsulatus</i>			X				
<i>Actinobacillus lignieresii</i>	X						
<i>Actinomyces lamae</i>			X				
<i>Actinomyces bovis</i>	X	X					
<i>Actinomyces</i> sp.	X	X	X	X	X	X	X
<i>Anaplasma ovis</i>	X	X					
<i>Anaplasma</i> sp.	X	X	X		X		
<i>Arcanobacterium pyogenes</i>	X	X	X	X	X	X	
<i>Bacillus anthracis</i>	X	X	X				
<i>Bacillus</i> sp	X	X	X		X		
<i>Bacteroides fragilis</i>			X				
<i>Bordetella</i> sp.					X		
<i>Branhamella ovis</i>	X	X					
<i>Brucella abortus</i>	X	X	X		X		
<i>Brucella melitensis</i>	X	X	X				
<i>Brucella ovis</i>	X	X			X		
<i>Brucella</i> spp.		X		X			
<i>Burkholderia pseudomallei</i>			X				
<i>Campylobacter fetus</i>	X	X					
<i>Campylobacter jejuni</i>	X	X					
<i>Chlamydophila abortus</i>	X	X					
<i>Chlamydophila pecorum</i>	X	X					
<i>Chlamydophila psittaci</i>	X	X			X		
<i>Clostridium botulinum</i>	X	X	X				
<i>Clostridium chauvoei</i>	X	X	X				

Bacterial agents:	S	G	L	D	BH	SS	MG
<i>Clostridium haemolyticum</i>	X	X					
<i>Clostridium novyi</i>	X	X	X				
<i>Clostridium perfringens</i>	X	X	X		X		
<i>Clostridium sordelli</i>			X		X		
<i>Clostridium septicum</i>	X	X	X				
<i>Clostridium tetani</i>	X	X	X				
<i>Corynebacterium pseudotuberculosis</i>	X	X	X				
<i>Corynebacterium renale</i>	X	X					
<i>Coxiella burnetii</i>	X	X		X			
<i>Dermatophilus congolensis</i>	X	X	X				
<i>Dichelobacter nodosus</i>	X	X					
<i>Enterococcus</i> sp.			X				
<i>Eperythrozoon ovis</i>	X	X					
<i>Erysipelothrix rhusiopathiae</i>	X	X					
<i>Escherichia coli</i>	X	X	X	X	X		
<i>Francisella tularensis</i>	X						
<i>Fusobacterium necrophorum</i>	X	X	X	X	X	X	
<i>Histophilus</i>	X						
<i>Hemophilus ovis</i>	X				X		
<i>Hemophilus somnus</i>	X	X					
<i>Hemophilus</i> sp.			X				
<i>Klebsiella pneumoniae</i>	X	X	X		X		
<i>Leptospira icterohaemorrhagica</i>			X				
<i>Leptospira interrogans</i> subsp <i>Bratislava</i>	X						
<i>Leptospira interrogans</i> subsp <i>grippotyphosa</i>	X	X	X		X		
<i>Leptospira interrogans</i> subsp <i>hardjo</i>	X	X			X		
<i>Leptospira interrogans</i> subsp <i>icterohaemorrhagica</i>	X	X	X				
<i>Leptospira interrogans</i> subsp <i>pomona</i>	X	X			X		
<i>Listeria innocua</i>			X				
<i>Listeria monocytogenes</i>	X	X	X				
<i>Mannheimia haemolytica</i>	X	X	X	X	X	X	X
<i>Moraxella bovis</i>	X	X					
<i>Moraxella lacunata</i>			X				
<i>Moraxella liquefaciens</i>			X				
<i>Mycobacterium bovis</i>	X	X	X				
<i>Mycobacterium avium</i> <i>paratuberculosis</i>	X	X	X	X	X		X
<i>Mycobacterium tuberculosis</i>			X				

Bacterial agents:	S	G	L	D	BH	SS	MG
<i>Mycoplasma agalactiae</i>	X	X					
<i>Mycoplasma arginini</i>	X	X			X		
<i>Mycoplasma bovis</i>	X	X					
<i>Mycoplasma capricolum</i>		X					
<i>Mycoplasma conjunctivae</i>	X	X					
<i>Mycoplasma mycoides</i>	X	X	X				
<i>Mycoplasma ovipneumoniae</i>	X	X		X			
<i>Mycoplasma</i> sp.	X	X	X	X	X		
<i>Neisseria</i> sp.					X		
<i>Nocardiosis</i> sp.			X				
<i>Pasteurella multocida</i>	X	X	X	X	X		
<i>Pasteurella trehalosi</i>	X	X		X	X	X	
<i>Rhodococcus equi</i>	X		X		X		
<i>Salmonella abortus ovis</i>		X					
<i>Salmonella choleraesuis</i>			X				
<i>Salmonella dublin</i>		X					
<i>Salmonella</i> sp.			X				
<i>Salmonella typhimurium</i>	X	X					
<i>Staphylococcus</i> sp.	X	X	X		X		
<i>Streptococcus</i> sp.	X	X	X		X		
<i>Streptococcus zooepidemicus</i>			X		X		
<i>Ureaplasma</i>	X	X					
<i>Yersinia enterocolitica</i>		X					
<i>Yersinia pseudotuberculosis</i>		X	X				

Appendix 2. Infectious viral agents recorded in domestic sheep, goats, and llamas, and wild sheep and mountain goats.

Below is a compilation from all sources in the Reference List of this document and includes reports of natural and experimental infections where the virus was detected as well reports where antibody to the virus was detected in both captive and free-ranging animals.

(S: domestic sheep, G: domestic goats, L: llamas, D: Dall's, BH: bighorns, SS: Stone's sheep, MG: mountain goats, X: present, U: unknown)

Viral agents:	S	G	L	D	BH	SS	MG
Adenovirus	X	X	X				
Akabane virus disease	X	X					
Bluetongue	X	X	X		X		
Border disease virus	X	X	X				
Bovine adenovirus			X				
Bovine coronavirus			X			X	
Bovine enterovirus			X				
Bovine herpes virus 1		X	X				
Bovine viral diarrhea virus			X	X	X		X
Camel pox			X				
Caprine arthritis-encephalitis virus		X					
Caprine herpes virus	X	X					
Cache Valley virus	X						
Contagious ecthyma	X	X	X	X	X		X
Coronavirus	X	X	X				
Epizootic hemorrhagic disease	X	X		X	X	X	X
Equine herpes virus type 1			X				
Infectious bovine rhinotracheitis	X	X	X		X		
Influenza A virus			X				
Influenza B virus			X				
Louping ill encephalomyelitis		X					
Malignant catarrhal fever	X	X		X		X	
Ovine herpes virus 1	X						
Ovine lentivirus (ovine progressive pneumonia virus)	X	X					
Papilloma virus	X	X					

Viral agents:	S	G	L	D	BH	SS	MG
Parainfluenze Type 3	X	X	X	X	X		
Rabies virus	X	X	X	X	X		
Respiratory syncytial virus	X	X	X	X	X		
Rift valley fever			X				
Rotavirus	X	X	X				
Vesicular stomatitis		X	X				

Appendix 3: fungal agents recorded in domestic sheep, goats, and llamas, and wild Dall's sheep and mountain goats.

Below is a compilation from all sources in the Reference List of this document and includes reports of natural and experimental infections where the fungus was detected in both captive and free-ranging animals.

(S: domestic sheep, G: domestic goats, L: llamas, D: Dall's, BH: bighorns, SS: Stone's sheep, MG: mountain goats, X: present, U: unknown)

Fungal agents:	S	G	L	D	BH	SS	MG
<i>Absidia corynebifora</i>			X				
<i>Aspergillus</i> sp.			X				
<i>Blastocystis</i> sp.			X				
<i>Microsporum canis</i>	X	X					
<i>Trichophyton canis</i>	X						
<i>Trichophyton gypseum</i>	X						
<i>Trichophyton mentagrophytes</i>	X	X	X				
<i>Trichophyton verrucosum</i>	X	X	X				

Appendix 4: Helminths recorded in domestic sheep, goats, and llamas, and wild Dall's sheep and mountain goats.

Below is a compilation from all sources in the Reference List of this document and includes reports of natural and experimental infections, where the adult parasites, cysts, eggs, oocysts, or larvae were detected in both captive and free-ranging animals.

(S: domestic sheep, G: domestic goats, L: llamas, D: Dall's, BH: bighorns, SS: Stone's sheep, MG: mountain goats, X: present, U: unknown)

Helminths:	S	G	L	D	BH	SS	MG
<i>Bunostomum</i> sp.	X	X	X				
<i>Camelostrongylus mentulatus</i>			X				
<i>Capillaria</i> sp.			X		X		
<i>Chabertia ovina</i>	X	X	X		X		
<i>Coenurus cerebralis</i> (<i>Taenia multiceps</i>)		X					
<i>Cooperia oncophora</i>					X		
<i>Cooperia</i> spp.	X	X	X		X		
<i>Cooperia surnabada</i>					X		
<i>Dicrocoelium dendriticum</i>			X				X
<i>Dictyocaulus filaria</i>	X	X	X				
<i>Dictyocaulus viviparus</i>			X		X		
<i>Echinococcus granulosus</i> (hydatid cysts)		X	X				X
<i>Elaeophorosis schneideri</i>	X	X					
<i>Fasciola gigantica</i>			X				
<i>Fasciola hepatica</i>	X	X	X				X
<i>Fasciola magna</i>	X	X	X		X		
<i>Graphinema aucheniae</i>			X				
<i>Haemonchus contortus</i>	X	X	X		X		
<i>Haemonchus placei</i>					X		
<i>Haemonchus</i> sp.			X		X		
<i>Marshallagia marshalli</i>				X	X		X
<i>Marshallagia</i> sp.	X	X		X	X	X	X
<i>Moniezia benedeni</i>					X		X
<i>Moniezia expansa</i>					X		X
<i>Moniezia</i> sp.	X	X	X	X	X	X	X

Helminths:	S	G	L	D	BH	SS	MG
<i>Muellerius capillaris</i>	X	X	X		X		
<i>Muellerius minutissimus</i>							X
<i>Nematodirella antilocaprae</i>							X
<i>Nematodirus abnormalis</i>					X		
<i>Nematodirus archari</i>				X	X		
<i>Nematodirus battus</i>	X	X	X				
<i>Nematodirus becklundi</i>							X
<i>Nematodirus davtianii</i>				X	X		X
<i>Nematodirus filicollis</i>				X	X		X
<i>Nematodirus helvetianus</i>					X		X
<i>Nematodirus lamae</i>			X				
<i>Nematodirus lanceolatus</i>					X		
<i>Nematodirus maculosus</i>				X	X		X
<i>Nematodirus odocoilei</i>					X		
<i>Nematodirus oiratianus</i>				X	X		X
<i>Nematodirus sp.</i>				X	X	X	X
<i>Nematodirus spathiger</i>				X	X		
<i>Oesophagostomum spp.</i>	X	X	X		X		X
<i>Oesophagostomum venulosum</i>					X		X
<i>Onchocerca sp.</i>	X	X					
<i>Ostertagia gruehneri</i>				X			
<i>Ostertagia lyrata</i>					X		
<i>Ostertagia ostertagi</i>	X	X	X	X	X		X
<i>Ostertagia sp.</i>	X	X	X		X		X
<i>Parelaphostrongylus odocoilei</i>				X		X	X
<i>Parelaphostrongylus tenuis</i>	X	X	X		X		
<i>Pelodera strongyloides</i>	X	X					
<i>Protostrongylus rufescens</i>	X	X					
<i>Protostrongylus frosti</i>					X		
<i>Protostrongylus rushi</i>				X	X		X
<i>Protostrongylus spp.</i>				X		X	X
<i>Protostrongylus stilesi</i>				X	X		X
<i>Pseudostertagia bullosa</i>					X		
<i>Setaria cervi</i>					X		
<i>Skrjabinema oreamni</i>							X
<i>Skrjabinema ovis</i>				X	X		X
<i>Skrjabinema sp.</i>					X	X	
<i>Strongyloides papillosus</i>	X	X					
<i>Strongyloides sp.</i>			X				X
<i>Taenia hydatigena</i>	X	X		X	X		X
<i>Taenia krabbei</i>					X		
<i>Teladorsagia boreoarcticus</i>				X	X		X
<i>Teladorsagia circumcincta</i>	X	X	X	X	X		X
<i>Teladorsagia davtianii</i>							X

Helminths:	S	G	L	D	BH	SS	MG
<i>Teladorsagia trifucata</i>	X	X					X
<i>Teladorsagia</i> sp.			X				
<i>Thelazia californiensis</i>			X				
<i>Thelazia rhodesii</i>	X	X					
<i>Thelazia</i> sp.			X				
<i>Thysaniezia giardi</i>			X				X
<i>Thysanosoma actinioides</i>					X		X
<i>Trichostrongylus axei</i>			X		X		X
<i>Trichostrongylus colubriformis</i>					X		X
<i>Trichostrongylus rugatus</i>					X		
<i>Trichostrongylus</i> spp	X	X	X		X	X	X
<i>Trichuris oreamnos</i>							X
<i>Trichuris ovis</i>	X	X			X		X
<i>Trichuris schumakovitschi</i>				X	X		X
<i>Trichuris</i> sp.			X	X	X	X	X
<i>Trichuris tenuis</i>			X				
<i>Wyominia tetoni</i>				X	X		

Appendix 5: protozoal agents recorded in domestic sheep, goats, and llamas, and wild Dall's sheep and mountain goats.

Below is a compilation from all sources in the Reference List of this document and includes reports of natural and experimental infections, where the oocysts were detected in both captive and free-ranging animals.

(S: domestic sheep, G: domestic goats, L: llamas, D: Dall's, BH: bighorns, SS: Stone's sheep, MG: mountain goats, X: present, U: unknown)

Protozoal agents:	S	G	L	D	BH	SS	MG
<i>Cryptosporidium parvum</i>	X	X	X				
<i>Eimeria</i> spp. (see App. 9 for detail)	X	X	X	X	X	X	X
<i>Eperythrozoon ovis</i>	X	X	U				
<i>Eperythrozoon</i> -like			X				
<i>Giardia</i>	X	X	X				
<i>Neospora caninum</i>	X	X					
<i>Pneumocystis carinii</i>		X					
<i>Sarcocystis ferovis</i>					X		
<i>Sarcocystis</i> sp.	X	X	X	X	X		
<i>Sarcocystis tenella</i>					X		
<i>Toxoplasma gondii</i>	X	X	X	X	X		
<i>Trichomonas</i> sp.			X				
<i>Trypanosoma</i> sp.			X	X			

Appendix 6: ectoparasitic agents recorded in domestic sheep, goats, and llamas, and wild Dalls sheep and mountain goats.

Below is a compilation from all sources in the Reference List of this document and includes reports of natural and experimental infections where the parasites were detected in both captive and free-ranging animals.

(S: domestic sheep, G: domestic goats, L: llamas, D: Dall's, BH: bighorns, SS: Stone's sheep, MG: mountain goats, X: present, U: unknown)

Ectoparasites:	S	G	L	D	BH	SS	MG
<i>Bovicola jellisoni</i>					X		
<i>Bovicola ovis</i>					X		
<i>Cephenemyia</i> sp.			X				
<i>Chorioptes caprae</i>		X					
<i>Chorioptes bovis</i>			X				
<i>Chorioptes ovis</i>	X						
<i>Chorioptes</i> sp.			X				
<i>Damalinia breviceps</i>			X				
<i>Damalinia caprae</i>		X					
<i>Damalinia oreamnidis</i>							X
<i>Damalinia ovis</i>	X						
<i>Demodex caprae</i>		X					
<i>Demodex ovis</i>	X						
<i>Dermacentor albipictus</i>					X	X	X
<i>Dermacentor andersoni</i>	X	X			X		X
<i>Dermacentor hunteri</i>					X		
<i>Dermacentor variabilis</i>	X	X					
<i>Lignonathus ovillus</i>	X						
<i>Lignonathus pedalis</i>	X						X
<i>Lignonathus stenopsis</i>		X					
<i>Melophagus ovinus</i>	X						
<i>Microthoracius cameli</i>			X				
<i>Microthoracius mazzai</i>			X				
<i>Microthoracius praelongiceps</i>			X				
<i>Oestrus ovis</i>	X	X	X		X		
<i>Otobius megnini</i>			X		X		X
<i>Psoroptes cuniculi</i>		X					
<i>Psoroptes equi</i> var <i>cervinus</i>					X		
<i>Psoroptes ovis</i>	X		X				

Ectoparasites:	S	G	L	D	BH	SS	MG
<i>Psoroptes</i> sp.			X		X	X	
<i>Pthiraptera</i> spp.			X				
<i>Sarcoptes scabiei</i>	X	X	X				
<i>Vermipsylla</i> sp.			X				

Appendix 7: other agents recorded in domestic sheep, goats, and llamas, and wild Dall's sheep and mountain goats.

Below is a compilation from all sources in the Reference List of this document and includes reports where the agent was detected in both captive and free-ranging animals.

(S: domestic sheep, G: domestic goats, L: llamas, D: Dall's, BH: bighorns, SS: Stone's sheep, MG: mountain goats, X: present, U: unknown)

Agent:	S	G	L	D	BH	SS	MG
Scrapie	X	X					

Appendix 8: selected disease-causing agents identified in wild and domestic sheep and mountain goat submissions to the Canadian cooperative wildlife health centre (1970–2002).

Category	Diagnosis	Agent	Species	Geographic location
Bacterial	Oral necrobacillosis	<i>Fusobacterium necrophorum</i>	Bighorn	Saskatoon, SK
	Pneumonia	<i>Arcanobacterium pyogenes</i>	Rocky mountain goat	Calgary, AB
		<i>Arcanobacterium pyogenes</i>	Bighorn	Calgary, AB
		<i>Arcanobacterium pyogenes</i>	Bighorn	Cranbrook, BC
		<i>Mannheimia haemolytica</i>	Bighorn	Cranbrook, BC
		<i>Mannheimia haemolytica</i>	Bighorn	Cranbrook, BC
		<i>Pasteurella multocida</i>	Bighorn	Cranbrook, BC
	Enteritis	<i>Escherichia coli</i>	Mouflon	Saskatoon, SK
	Septicemia	<i>Klebsiella pneumoniae</i>	Rocky mountain bighorn	Saskatoon, SK
	Splenic abscessation	<i>Listeria monocytogenes</i>	Dall's	Inuvik, NWT
	Valvular endocarditis	<i>Bacillus sp.</i>	Barbados sheep	Saskatoon, SK
Parasitic	Coccidiosis	<i>Eimeria sp.</i>	Bighorn	Vancouver, BC
		<i>Eimeria sp.</i>	Bighorn	Victoria, BC
		<i>Eimeria sp.</i>	Bighorn	Saskatoon, SK
	Parasitic myositis	<i>Cysticercus (Taenia krabbei or hydatigena)</i>	Bighorn	Edmonton, AB
	Sarcocystosis	<i>Sarcocystis</i>	Bighorn	Cranbrook, BC

Category	Diagnosis	Agent	Species	Geographic location
	Strongylosis	<i>Strongyle sp.</i>	California bighorn	Vancouver, BC
	Tapeworm	Probable <i>Wyominia tetoni</i>	Bighorn	Cranbrook, BC
	Tick infection	<i>Dermacentor albipictus</i>	Bighorn	Cranbrook, BC
	Verminous pneumonia	<i>Protostrongylus sp.</i>	Bighorn	Cranbrook, BC
		<i>Protostrongylus sp.</i>	Dall's	Whitehorse, YT
Viral	Contagious ecthyma	Probable pox virus	Dall's	Whitehorse, YT
		Pox virus	Dall's	Whitehorse, YT

Appendix 9. Comparison of coccidia of wild sheep, mountain goats, camelids and domestic sheep and goats

Species affected	<i>Eimeria</i> sp.
Dall's sheep	<i>E. ahsata</i> *
	<i>E. crandallis</i> *
	<i>E. dalli</i>
	<i>E. ninakohlyakimovae</i> *
	<i>E. parva</i> *
	<i>E. spathiger</i>
Bighorn sheep	<i>E. ahsata</i> *
	<i>E. arloingi</i> *
	<i>E. crandallis</i> *
	<i>E. faurei</i> *
	<i>E. granulosa</i> *
	<i>E. intricate</i>
	<i>E. ninakohlyakimovae</i> *
	<i>E. ovinoidalis</i> *
	<i>E. parva</i> *
	<i>E. spathiger</i>
Mountain goats	<i>E. ahsata</i> *
	<i>E. crandallis</i> *
	<i>E. faurei</i> *
	<i>E. granulosa</i> *
	<i>E. intricate</i>
	<i>E. ninakohlyakimovae</i> *
	<i>E. ovina</i> or <i>E. arloingi</i> *
	<i>E. parva</i> *
Camelids	<i>E. alpaca</i>
	<i>E. lamae</i>
	<i>E. macusaniensis</i>
	<i>E. punoensis</i>
	<i>E. peruviana</i>
Domestic sheep	<i>E. ahsata</i> *
	<i>E. crandallis</i> *
	<i>E. faurei</i> *
	<i>E. gonzalezi</i>
	<i>E. granulose</i> *
	<i>E. intricate</i> *
	<i>E. ovina</i>
	<i>E. ovinoidalis</i> *
	<i>E. pallida</i>
	<i>E. parva</i> *
	<i>E. punctata</i>
	<i>E. weybridgei</i>

Species affected	<i>Eimeria</i> sp.
Domestic goat	<i>E. arloingi</i> *
	<i>E. caprina</i>
	<i>E. christensen</i>
	<i>E. hirci</i>
	<i>E. ninakohlyakimovae</i> *

*suspected overlap of *Eimeria* sp. between domestics and wild sheep

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