Risk Assessment of Respiratory Pathogen Transmission from Domestic Small Ruminants to Thinhorn Sheep and Mountain Goats in the Yukon and Northern British Columbia

Prepared for Government of Yukon

By Shifting Mosaics Consulting

June 30, 2024

Fort Nelson, British Columbia, Canada

TABLE OF CONTENTS

Acknowledgements

We recognize that this report was developed on Treaty 8 Traditional Lands of importance to First Nations, Indigenous communities, Metis communities and long-time residents of northern British Columbia. We appreciate that we share the responsibility for the lands with Treaty 8 Nations. We also wish to recognize the many Fist Nations, Indigenous Groups, and Metis of the Yukon upon whose territory's information used for this project was collected, and who have acted as stewards for the wild sheep and goats of the north since time immemorial.

Shifting Mosaics wishes to recognize the following team members for their work on this project: Alexis Jorgensen (project lead and primary author), Dr. Helen Schwantje who shared her expertise as well as providing feedback and editorial support, Dr. John Derek Scasta, Dr. Sonja Leverkus, and Dr. Gillian Leverkus for research support and guidance, Georgina Preston for her work on the literature review and interviews and Elaine Smarch who served as our local interview lead. We also wish to thank Drs. Jane Harms and Michelle Thompson from the Government of Yukon who contributed significant time and effort to provide guidance, data, and introductions to expert contacts for interviews.

Citation: *Shifting Mosaics Consulting. 2024. Risk Assessment of Respiratory Pathogen Transmission from Domestic Small Ruminants to Thinhorn Sheep and Mountain Goats in the Yukon and Northern British Columbia. Shifting Mosaics Report 24.03. Fort Nelson, British Columbia, Canada.*

Executive summary

Thinhorn sheep and mountain goats are culturally important species in the Yukon and northern British Columbia. There is concern about the impact that respiratory pathogens, particularly *Mycoplasma ovipneumoniae*, may have on these species if introduced. Respiratory pathogens are commonly transmitted from domestic to wild sheep or goat populations and have been associated with large scale die-offs of bighorn sheep in Canada and the USA.

The Government of Yukon established Control Order 2018-001 (the Control Order) in 2018 to reduce the potential for disease to spread from domestic to wild sheep and goats in the territory. The Control Order banned domestic sheep and goats from being kept over 1,000 m in elevation and created testing, enclosure, record keeping, import, and transportation requirements. In 2023, Shifting Mosaics Consulting was hired to complete a risk assessment of respiratory pathogen transmission from domestic to wild sheep and goats in the Yukon and northern British Columbia, along with a qualitative evaluation of the success of the Control Order.

Sheep, goats, and pneumonia

It is estimated that there are 20,000 thinhorn sheep and 1,500 mountain goats in the Yukon, as well as 13,000 thinhorn (Stone's) sheep in northern British Columbia (Jex et al. 2016, Government of Yukon 2024a, 2024b). Thinhorn sheep are culturally important species to both Indigenous and non-indigenous communities and bring income to the Yukon and northern BC through activities such as guide outfitting. Approximately 40-50 premises keep domestic sheep or goats in Yukon, with ≥200 of each across the territory. Most premises keeping domestic sheep and goats are located around Whitehorse or Dawson City.

A *M. ovipneumoniae* testing program for domestic sheep and goats was established with the Control Order and *M. ovipneumoniae*-positive animals have been identified every year since

testing began in 2019. *M. ovipneumoniae* has not been found in wild sheep or goats in the Yukon or northern British Columbia. However, Yukon testing is largely of hunter harvested heads and most samples are collected in the Whitehorse area. In addition, few samples have been collected from mountain goats. Thinhorn sheep in neighbouring Alaska populations are known to carry a unique strain of *M. ovipneumoniae* which is commonly found in healthy animals.

There is limited research on the impacts of pneumonia on thinhorn sheep and mountain goats and no records of large-scale die-offs were found. However, there are recorded cases of thinhorn sheep mortality linked to respiratory disease. In addition, respiratory disease associated with *M. ovipneumoniae* has led to large scale die-offs of bighorn sheep herds in Canada and the USA along with supressed lamb recruitment for multiple years after the initial outbreak. Research from the USA suggests that *M. ovipneumoniae*-related pneumonia can have similar impacts on mountain goats.

Thinhorn sheep are considered naïve to pathogens from domestic livestock so may be especially vulnerable to respiratory diseases carried by domestic flocks. Northern mountain goats are also likely naïve to such pathogens compared to more southern populations. In addition, vulnerability to disease may be compounded by other stressors in a herd's environment. Pathogens such as Orf and lungworm have been identified in thinhorn sheep and mountain goats in the Yukon and northern BC. Population declines associated with adverse weather and climatic conditions have also been noted in both species in recent years. Given the known impact of pneumonia on bighorn sheep, the relative naïvety of northern populations to domestic pathogens, and other stressors present in their environment, we estimate potential declines of >50% in any population of northern thinhorn sheep or mountain goats exposed to respiratory pathogens of concern.

The most effective way to reduce the risk of a pneumonia outbreak in wild sheep or goats is to prevent pathogen transmission from domestic flocks. Measures such as double fencing enclosures, regular testing for respiratory pathogens, removal of *M. ovipneumoniae*-positive animals, and the provision of ongoing education to sheep and goat owners can reduce transmission risk at the farm level. Translocation of wild animals is another potential source of novel respiratory pathogens. It is recommended that source animals be tested for pathogens of concern prior to translocation and the health of receiving herds monitored afterwards.

There are currently no effective treatments nor vaccinations for respiratory disease in wild sheep or goats. Vaccines and treatments are available for some respiratory pathogens in domestic animals. While antibiotic trials have successfully cleared *M. ovipneumoniae* from certain domestic flocks, results are not consistent. *M. ovipneumoniae* has high immunological variability and treatments may not provide cross-strain immunity.

A single recommendation for how to manage active respiratory disease outbreaks in wild sheep or goat populations does not exist. However, given the lack of effective treatments, culling or removal of infected animals at some scale may be required. Research suggests that removal of *M. ovipneumoniae* carriers after the initial outbreak may be effective in purging the disease from smaller herds. Larger culls, including the removal of full herds, have been used effectively to prevent the spread of disease to neighbouring populations. However, this can be technically difficult and psychologically taxing. In some cases, respiratory disease outbreaks have simply been left to run their course.

Consequences of an outbreak in the Yukon

A serious respiratory disease outbreak in thinhorn sheep and mountain goats in the Yukon would be expected to have significant environmental, economic, and socio-cultural impacts. There is

potential for large scale declines in wild populations with uncertain consequences on predator-prey dynamics and other ecosystem processes. Such declines would also be expected to have a negative economic impact in the territory. Associated hunting closures could lead to millions of dollars in revenue being lost though the guide outfitting industry alone. Further revenue loss may occur through reductions in the sale of seals, harvest fees, hunter spending on supplies and accommodation, tourism, craft sales, and closure of the Kluane tag auction.

Significant loss of sheep or goats due to disease would restrict the legally protected harvest rights of northern Indigenous groups and could potentially lead to loss of knowledge sharing and cultural activities related to hunting and processing these animals. Die-offs of thinhorn sheep or mountain goats are expected to cause significant psychological distress to communities with cultural connection to these species (both Indigenous and non-Indigenous). In addition, loss of game species may impact food security in remote communities along with the tradition of meat sharing in the Yukon.

Assessing the Control Order

With the information available, it is not possible to confidently assess if the Control Order has prevented pathogen transmission from domestic to wild sheep and goats in the Yukon. This is largely due to a lack of baseline data. There is also no comprehensive sampling program for respiratory pathogens across sheep and goat range. However, there is no evidence that *M. ovipneumoniae* has been transferred from domestic to wild sheep or goats since the Control Order came into effect. The Control Order has also taken many positive steps to reduce the risk of a pneumonia outbreak in Yukon through the following:

- Increasing government knowledge of domestic sheep and goats.

- Testing and reducing the number of *M. ovipneumoniae* positive domestic sheep and goats in the territory.
- Upgrading enclosures.
- Increasing public and staff knowledge about the risk and prevention of disease transmission from domestic to wild sheep and goats.

Several technical experts and knowledge holders were interviewed for this project and were generally supportive of control measures. However, multiple interviewees suggested that the Government of Yukon should communicate directly with Indigenous groups and stakeholders (external government agencies, Renewable Resource Councils, Wildlife NGOs and others) about testing results and decisions related to the Control Order. Some of these groups also expressed interest in being involved in decision making. Multiple interviewees discussed the hardship that the mandatory cull of *M. ovipneumonia*e-positive animals causes sheep and goat owners. Other concerns related to the potential export of *M. ovipneumonia*e-positive animals to British Columbia and the need to ensure capacity to fulfill Control Order requirements.

Knowledge gaps

There are several knowledge gaps related to *M. ovipneumoniae* and other respiratory pathogens in wild and domestic sheep and goats in the north. There has been limited research on the influence of respiratory disease on both thinhorn sheep and mountain goats. This means there is increased uncertainty about the potential impacts of respiratory pathogens on northern wild sheep and goat populations as well as appropriate management should an outbreak occur. There has been limited *M. ovipneumoniae* testing of thinhorn sheep populations outside of the Whitehorse area (and mountain goats in general), making it difficult to determine if the pathogen is present in more remote herds. In addition, further investigation is needed on wild sheep and goat range

and connectivity in the Yukon to help assess both the probability of wild animals being exposed to domestic sheep and goats and the potential for spread of pathogens among wild populations. Research on wild sheep forays (animals making short term, often long-distance departures from their regular home range) may also help to predict where they will go, if these areas overlap with disease-carrying wildlife or livestock, and how habitat alteration may be used to prevent pathogen transmission. In addition, there are limitations to *M. ovipneumoniae* testing that may create uncertainty about the actual prevalence of this pathogen in the Yukon.

Recommendations

We recommend the following measures to reduce the risk of serious pneumonia outbreaks in thinhorn sheep and mountain goats in the Yukon:

- Continued surveillance and mitigation measures such as those currently associated with the Control Order and the testing program for wild ungulates.
- Creation of comprehensive regulations or guidelines related to grazing tenures, wildlife translocations, the use of domestic sheep or goats in non-farm settings, the export of *M. ovipneumoniae*-positive animals, and the management of domestic sheep or goats displaced due to natural disaster.
- Increased cross-jurisdictional communications and partnerships with external government agencies, Indigenous groups, Yukon communities, and other stakeholders related to the Control Order or wild sheep and goat health.
- Collaring studies of wild sheep and goats to increase knowledge about the range and habitat connectivity of these species in the Yukon.
- Increased inventory and health surveillance of wild sheep and goats across the territory.
- Development of a respiratory disease outbreak response plan.

- General habitat protection and enhancement for thinhorn sheep and mountain goats.

Short forms and acronyms

BC – British Columbia

Control Order – Control Order 2018-001 under the Yukon Animal Health Act. Established to mitigate the risk of disease transmission from domestic to wild sheep or goats in the territory

GAR: BC Government Actions Regulation under the BC Forest and Range Practices Act

M. ovipneumoniae – Mycoplasma ovipneumoniae

NWT – Northwest Territories

RRC – Yukon Renewable Resource Council

SMC – Shifting Mosaics Consulting

T. gondii – Toxoplasma gondii

WAFWA – Western Association of Fish and Wildlife Agencies

WLRS – BC Ministry of Water, Land and Resource Stewardship

WRFN – White River First Nation

YG – Government of Yukon

Introduction

Thinhorn sheep (*Ovis dalli*; including subspecies *dalli* and *stonei)* and mountain goats (*Oreamnos americanus*) are species of cultural and economic importance in the Yukon and northern British Columbia (BC) as well as other jurisdictions not covered in this report. There is significant concern about the potential impacts of respiratory disease on these species if introduced into northern populations. A variety of pathogens are reported to cause disease and pneumonia in northern ungulates with bacteria, including *Mycoplasma ovipneumoniae* (henceforth *M. ovipneumoniae*) and the *Pasteurellaceae* family considered the most commonly pathogenic and concerning in wild sheep (Jex et al. 2016). Polymicrobial bronchopneumonia associated with *M. ovipneumoniae* has caused all-age die-offs of bighorn sheep herds in the USA and Canada and is usually followed by supressed lamb recruitment for years after the initial outbreak (Bernatowicz et al. 2016, Cassirer et al. 2018). Though research is limited, a similar syndrome has been associated with mountain goat disease and die-offs in the USA (Blanchong et al. 2018, Wolff et al. 2019). Respiratory disease has also been linked to thinhorn sheep mortalities (Canadian Wildlife Health Cooperative 2016). Pneumonia outbreaks are commonly associated with pathogens passed from domestic sheep or goats to wild animals (Jex et al. 2016, Cassirer et al. 2018).

In 2015, the Government of Yukon (YG) contracted the Canadian Wildlife Health Cooperative to complete an assessment of the risk of pneumonia transmission from domestic sheep and goats to thinhorn sheep in the Yukon and northern BC. The resulting report: *Risk analysis of pneumonia-related pathogen transmission from domestic small ruminants to wild thinhorn sheep in Yukon and northern BC* was completed in 2016 and recommended proactive management to prevent contact between domestic livestock and wild sheep populations. This report supported

decision makers to enact Yukon Control Order 2018-001 (henceforth the Control Order) which banned domestic sheep and goats from being kept over 1,000 m in elevation and created testing, enclosure, record keeping, and transport requirements for all domestic sheep and goats in the territory. Under the Control Order, any domestic sheep or goat that tests positive for *M. ovipneumoniae* must be destroyed or removed from the Yukon. The Control Order is currently scheduled to expire at the end of 2024.

In late 2023, YG contracted Shifting Mosaics Consulting (SMC) to *"to produce a detailed risk assessment of respiratory pathogen transmission from domestic small ruminants to thinhorn sheep and mountain goats in the Yukon and Northern British Columbia*." This document builds on the existing 2016 risk assessment (Figure 1) through the following:

- A review of scientific and grey literature on respiratory disease in thinhorn sheep published since the 2016 review.
- A review of scientific and grey literature on respiratory disease and pneumonia in mountain goats (mountain goats were not included in the 2016 risk assessment).
- Examination of data collected by YG during the term of the Control Order.
- An assessment of the efficacy of the Control Order in reducing the risk of pathogen transmission between domestic and wild sheep and goats in the Yukon.
- Recommendations for the future.

Methods

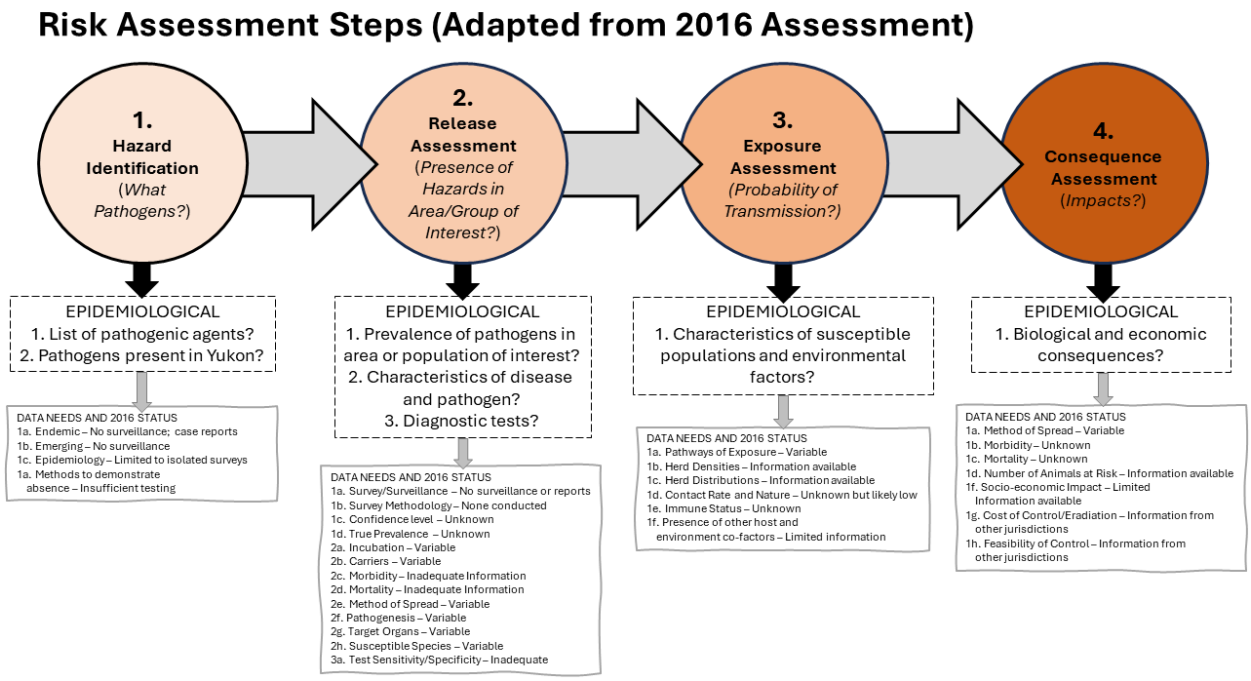

Figure 1: Risk assessment steps, epidemiological questions, data needs, and 2016 status as adapted from the 2016 risk assessment.

Literature review

SMC followed a systematic approach to reviewing the literature based on *a priori* criteria and needs identified in the planning process with YG. This approach closely followed the recommendations set forth by the Collaboration for Environmental Evidence (2024). First, a table of relevant search terms was developed including the target species, pathogens of interest, vocabulary related to health/disease, and focus locations (Table 1). Combinations of these terms were entered as keywords in Google Scholar to search for literature. Inclusion criteria were developed and used to determine whether a particular document would be reviewed (Table 2). In addition, prioritization criteria were used to guide the literature review team (See Appendix 1 for more details). Search terms, inclusion, and prioritization criteria were reviewed by wildlife veterinarians Dr. Helen Schwantje (retired provincial veterinarian - BC), Dr. Jane Harms (YG)

and Dr. Michelle Thompson (YG) prior to the main literature review. SMC also reviewed documents and sources of both scientific and grey literature recommended by YG, Dr. Helen Schwantje, and individuals from expert interviews (discussed below). In addition, team members were encouraged to seek out documents of interest referenced in other sources.

Table 1: Search terms used in systematic literature search for the 2024 risk assessment of pathogen transfer from domestic small ruminants to wild sheep or goats in the Yukon and northern BC.

Category	Search Terms
Animal	Thinhorn sheep, *Ovis dalli*, Dall's sheep, Stone's sheep, Fannin sheep, mountain goat, *Oreamnos americanus*, wild sheep, wild goat
Health/Disease	Pneumonia, respiratory, disease, mortality, epidemic, vaccine, treatment, immunity, foray
Pathogen	*Bibersteinia trehalosi* (*Pasteurella*), *Pasteurellaceae Mannheimia* (*Pasteurella*) *haemolytica*, *Mycoplasma*, *Mycoplasma ovipneumonia*e, *Pasteurella multocida*, nasal sinus tumor
Location	Alaska, British Columbia, Yukon, Northwest Territories

Table 2: Inclusion criteria for systematic literature search for the 2024 risk assessment of pathogen transfer from domestic small ruminants to wild sheep or goats in the Yukon and northern BC.

Inclusion Category	Criteria
Species	• Any variety of thinhorn sheep (Dall's, Stone's, Fannin), mountain goat, or bighorn sheep either wild or kept in a pasture or enclosure • Domestic sheep or goats in priority areas (Yukon, Northwest Territories, northern BC and Alberta, or Alaska)
Date Range	• 2015-2024 (as the last assessment was completed in 2016)
Location	• Canada or the USA
Qualifying criteria	• Studies must relate in some way to sheep/goat respiratory disease or pneumonia, mortality, range (to determine potential range overlap between wild and domestic sheep/goats) or interactions between wild and domestic sheep/goats • Studies focussing on testing methods are excluded as a separate group is exploring this subject
Exceptions to date range	• Documents about mountain goats from any date may be used as this species was not included in the 2016 risk assessment • Priority 1 documents (see Appendix 1) that were not included in the 2016 assessment

Yukon data

YG provided *M. ovipneumoniae* testing data for domestic sheep and goats for the term of the Control Order and wild sheep and goats from 2015-2023. They also provided a variety of information relating to Yukon sheep and goat range, farm size and locations, hunting revenue, and the implementation of the Control Order. This information was used alongside the scientific literature to assess local risk.

Expert interviews

To gather local and potentially unpublished expert knowledge on northern sheep, goats, and pneumonia, SMC interviewed a range of technical specialists and knowledge holders from the Yukon, BC, and other jurisdictions (Appendix 2). Interviewees included veterinarians, biologists, Yukon Renewable Resource Councils (RRCs), Agricultural Branch staff, non-government

organizations, and others. Most interviewees were recommended by either YG or Dr. Helen Schwantje. Interviewees themselves also often recommended others to speak with.

YG sent emails introducing SMC and the project to several northern contacts following which SMC reached out by phone or email to schedule an online interview. In cases where no introductory email was provided, SMC reached out directly via email, provided an overview of the project, and asked to schedule an interview. Interviews were held online via Microsoft Teams or Zoom and largely followed a standardized question list approved by YG. Separate question lists were developed for technical experts, such as wildlife veterinarians, versus RRCs and Indigenous groups to focus on the unique types of knowledge held by these groups (Appendix 3). However, the interviews were flexible to ensure that SMC staff could ask questions not included on lists or the interviewees elaborate on a particular subject of interest as desired. All interviewees were asked to read and sign a one-page consent form giving SMC permission to use information provided in the project report. Both the question list and consent form were provided to interviewees for review beforehand. Interviewers took detailed notes and interviews were recorded and transcribed provided permission was given by the interviewee.

Results: Sheep and goats in the Yukon and northern BC

Thinhorn sheep – population and value

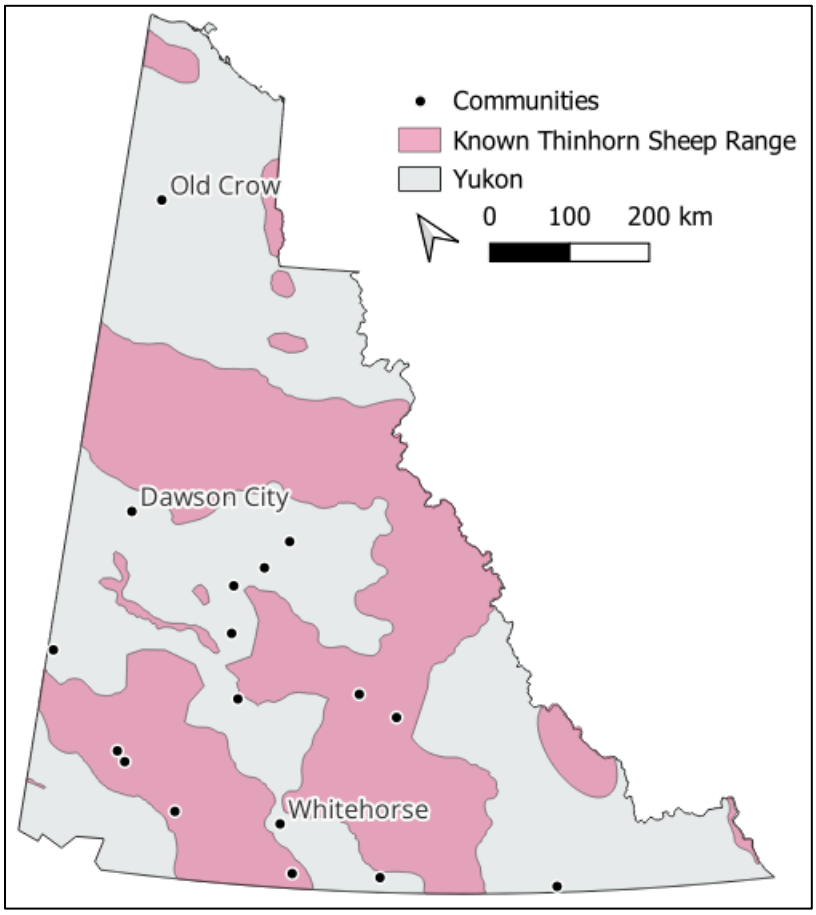

*Figure 2: Map of known thinhorn sheep (*Ovis dalli*) range relative to communities in the Yukon. Community and sheep range data from the Government of Yukon. Territorial outline from the Government of Canada.*

Thinhorn sheep are large herbivores living in rugged, mountainous terrain in northern BC, the Yukon, Alaska, and the Northwest Territories (Jex et al. 2016). They commonly live in groups and reproduce relatively slowly, ewes normally producing a single lamb per year (Canadian Wildlife Health Cooperative 2016). Two subspecies of thinhorn sheep exist: white Dall's sheep (*Ovis dalli dalli*), and grey Stone's sheep (*Ovis dalli stonei*) which also have recognized genetic differences beyond colour. Dall's sheep tend to spend most of their time in alpine meadows, whereas Stone's sheep may also use shrubby or forested areas depending on location (Canadian

Wildlife Health Cooperative 2016). Fannin sheep are a hybrid between these two subspecies and may have various grades of white and grey-coloured fur.

There are estimated to be up to 100,000 Dall's and Fannin sheep in the Yukon, Alaska, and the Northwest Territories (NWT) and around 13,000 Stone's sheep in BC (Jex et al. 2016). In the Yukon, the thinhorn population is estimated at 20,000 animals (Government of Yukon 2024a). Thinhorn sheep live in mountainous regions throughout the territory, with cross border populations reaching into Alaska, BC, and the NWT (Figure 2). They are a species of importance to Yukon Indigenous groups and non-Indigenous communities. Kluane First Nation refer to themselves as "sheep people" and have a strong cultural connection with thinhorns (C. Wong, pers. comm.). White River First Nation (WRFN) stated that wild sheep and goats are of great value to the community and are a traditional food source (WRFN Staff, pers. comm.). However, few WRFN members currently hunt these animals due to conservation concerns (WRFN Staff, pers. comm.). Thinhorn sheep appear in the legends of the Gwich'in, who live in both the Yukon and the NWT and hunt them for food and hides (Benson 2023). Traditionally, the Gwich'in also used sheep organs for medicine and carved horns into tools or carrying containers (Benson 2023). In the Haines Junction area, where thinhorn sheep are harvested by both Indigenous and non-Indigenous hunters, they are a more valued species than caribou or moose for which there are limited hunting opportunities (M. Nassiopoulos, pers. comm.). An average of 230.4 sheep were harvested by licenced hunters in the Yukon annually from 2016-2023 (YG, unpublished data). Thinhorn sheep are also a culturally important species for Indigenous groups in northern BC. They are used for food, clothing, and crafts by the Tahltan Nation and are considered an honour to hunt (Tahltan Nation Staff, pers. comm.).

Thinhorn sheep provide both direct and indirect income to Yukon residents (McDowell Group and Vector Research 2016, Jung et al. 2023). Hunters sell the harvested sheep horns, hides, or heads (Benson 2023) and several Yukon outfitters offer guided sheep hunts. Government revenue from hunting seals and harvest fees averaged $48,493.75 annually from 2016-2023 (YG, unpublished data) and hunters and outfitters provide further income to local communities through the purchase of equipment, fuel, food, or accommodations. In previous years, sheep have provided direct income to Kluane First Nation through the auction of a tag for the Kluane Game Sanctuary which sold for $230 000 US in 2022 (OnlineHuntingAuctions.com n.d.). Stone's sheep are also a valuable animal for the guide outfitting industry in BC, selling for around $100 000 US each (BC Guide Outfitting Association, pers. comm.). In addition, thinhorn sheep are charismatic animals that add significant tourism value to the Yukon and BC through wildlife viewing opportunities. Recommendations for viewing thinhorn sheep are listed on the YG website (Government of Yukon 2024a) and they are featured at the Yukon Wildlife Preserve and the Thechàl Dhâl' Visitor Centre in Kluane National Park.

Multiple sheep populations in the Yukon and surrounding jurisdictions are currently considered to be in decline. Surveys from the Kluane region show declines of 49-63% since formal population counts in 2011-2016 (Government of Yukon 2023a, 2023b). The magnitude of these reductions has led the Kluane First Nation to appeal to resident and subsistence hunters to limit or refrain from hunting sheep in related game management zones until the populations recover (Kluane First Nation Lands, Resources, and Heritage Department 2023). Populations around Haines Junction, which were previously stable, have also declined since the winters of 2020, 2021, and 2022 (M. Nassiopoulos, pers. comm.). In addition, Thinhorn sheep numbers in the Dawson area are considered low after experiencing a significant winter die-off in 2012-2013 and

ongoing, likely stress related, mortality in the years following (D. Reynols, pers. comm.). Weather-related factors (snow depth and duration, freeze/thaw events) are thought to be contributing to limited lamb recruitment and population declines as are alterations to forage quantity and quality associated with climate change (Government of Yukon 2023a, 2023b; H. Schwantje, pers. comm.). Climate related mortality and population reductions have also been noted in BC, Alaska, and the NWT (B. Jex, pers. comm.). In addition, the Tahltan Nation in northern BC has observed decreasing sheep numbers over time, with hunting and predation potentially contributing to this trend (Tahltan Nation Staff, pers. comm.). Concern for thinhorn populations in general is leading to cross jurisdictional research collaborations to better understand how to conserve the species (H. Schwantje, pers. comm.).

Mountain goats – population and value

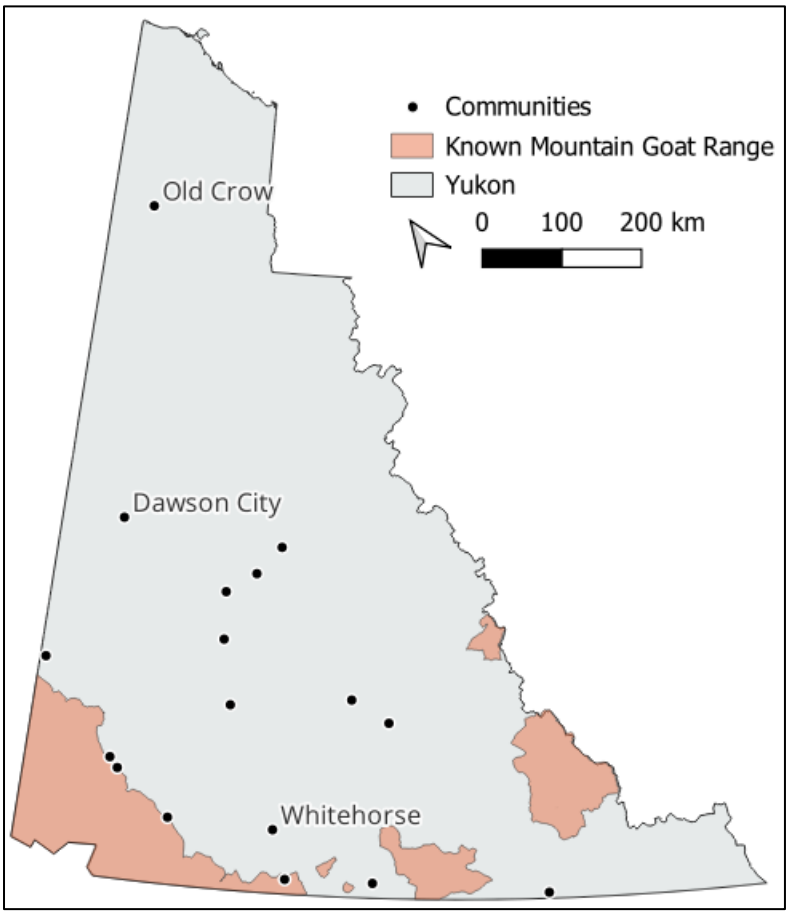

*Figure 3: Map of known mountain goat (*Oreamnos americanus*) range relative to communities in the Yukon. Community and sheep range data from the Government of Yukon. Territorial outline from the Government of Canada.*

Mountain goats are generalist herbivores which live in alpine or subalpine areas containing steep slopes or cliffs that serve as escape terrain (Mountain Goat Management Team 2010). Beyond this, their habitat varies across their wide range. Mountain goats live throughout western North America and from the Yukon to as far south as Nevada and Colorado (Mountain Goat Management Team 2010, Blanchong et al. 2018). There are an estimated 1,500 mountain goats in the Yukon, with range limited to mountainous areas in the southern half of the territory (Figure 3; Government of Yukon 2024b). Goats are a culturally significant species to Yukon Indigenous groups and have long been hunted for their horns and pelts (Barichello and Carey

1988). WRFN stated that goats are a traditional food source and valued by the community (WRFN Staff, pers. comm.).

Like thinhorn sheep, mountain goats contribute revenue to the Yukon through hunting. Multiple Yukon outfitters offer guided goat hunts and local communities may receive revenue through hunters or outfitters purchasing supplies and accommodation (McDowell Group and Vector Research 2016). However, mountain goats account for a small proportion of harvest and associated revenue in the Yukon, with an average of only 17 non-resident seals sold and 12.5 goats harvested annually by licenced hunters from 2016-2023 (YG, unpublished data). Government revenue from mountain goat seals and harvest fees averaged $14,506.25 annually during this time period (YG, unpublished data). Mountain goats may also provide revenue through acting as a draw for tourism and are one of the species featured at the Yukon Wildlife Preserve.

Though multiple goat surveys took place in the 1970s and 1980s (Barichello and Carey 1988), there is limited information available about goat populations within the last decade. A 2017 survey of mountain goats in Yukon Game Management Zone 9 suggested that populations were increasing in the area at the time (Hegel and Russell 2019). Parks Canada data from Goatherd Mountain in Kluane National Park also suggested population expansion from 2013-2018 (Wong 2018). However, there was low goat recruitment in Kluane National Park in 2021 and 2022, likely due to adverse weather events (C. Wong, pers. comm.).

Domestic sheep and goats

Most Yukon premises with domestic sheep or goats have only a small number of animals (<10) kept as pets or for milk. However, a few locations have larger herds of approximately 40-50

animals (YG Animal Health Unit, pers. comm.). Most of the premises keeping domestic sheep or goats are in the Whitehorse and Dawson areas (YG Animal Health Unit, pers. comm.).

Prior to the establishment of the Control Order in 2018, YG had limited information on the number and location of domestic sheep and goats in the territory (YG Animal Health Unit, pers. comm.). Surveys such as the Canada Census of Agriculture have voluntary participation and likely underestimate the actual numbers of animals. The 2021 Census of Agriculture (Statistics Canada 2022a) reported only 165 sheep across four farms and only six farms with goats in the Yukon (Table 3).

Table 3: Sheep and goat numbers in the Yukon according to the Canada Census of Agriculture 2021 (Statistics Canada 2022a, 2022b, 2022c).

Number of Sheep or Goats	Number of Farms	Page
165 sheep (number uncertain)	4	Sheep inventory on farms
Goats – number not given	6	Other livestock inventories on farms
Sheep – number not given Goat – number not given	1 2	Farms classified by farm type

The Yukon Agriculture State of Industry Report 2013-2017 noted 72 domestic sheep across four farms and 90 domestic goats across six farms in the territory (Government of Yukon 2017). However, these numbers were tallied before the Control Order was established and they are low compared to those from the 2019-2023 *M. ovipneumoniae* testing program. *M. ovipneumoniae* testing reports state that 45-52 locations were identified with domestic sheep or goats annually from 2019-2023 and the number of animals tested ranged from 102 to 448 (Government of Yukon 2021, 2022a, 2023c). Considering these numbers, we estimate that a minimum of 40-50 locations have kept domestic sheep or goats in the Yukon annually since 2019 and the total number of each was likely ≥ 200 until at least 2022. In 2023, the Yukon moved to a more risk-

based approach to testing and fewer animals were sampled making population estimation more difficult. However, total sheep and goat numbers are likely similar to previous years.

Revisiting questions from the 2016 risk analysis

The sections below discuss information related to questions posed in the 2016 *Risk analysis of pneumonia-related pathogen transmission from domestic small ruminants to wild thinhorn sheep in Yukon and northern B*C (Canadian Wildlife Health Cooperative 2016). These questions were used to help guide research and make the findings of this report comparable with the 2016 risk assessment. However, SMC did not strictly adhere to the 2016 questions if other formats were considered preferable for data presentation.

Are pneumonia-causing pathogens present in the Yukon, northern BC or neighbouring jurisdictions?

Domestic sheep and goats

Answer: yes

YG established a *M. ovipneumoniae* testing program as part of the Control Order in 2019 and domestic sheep or goats have tested positive every year since the program began (Table 4; Government of Yukon 2021, 2022a, 2023c). This clearly demonstrates that *M. ovipneumoniae*, a pathogen with a known risk of transmission to wild sheep and goats, is present in the Yukon. However, *M. ovipneumoniae* appears to only occur in a minority of domestic animals as no more than 43% of sheep or 17% of goats tested had positive results. The proportion of identified premises with *M. ovipneumoniae* positive animals also has never exceeded 17% (Government of Yukon 2021, 2022a, 2023c). Animals that test positive for *M. ovipneumoniae* are either slaughtered or, in rare cases, removed from the territory at the owner's expense. It is not known whether domestic sheep and goats in the Yukon carry other respiratory pathogens of concern for

wild populations. YG staff may perform further investigations on domestic sheep or goats in the case that an animal is displaying respiratory symptoms or a mortality has occurred. However, such activities are separate from the Control Order (J. Harms, pers. comm.).

Table 4: Results of the Yukon Control Order mandatory domestic sheep and goat testing for Mycoplasma ovipneumoniae *(Government of Yukon 2021, 2022a, 2023c).*

Year	Sheep Tested	Sheep Positive (%)	Goats Tested	Goats Positive (%)	Premises Identified	Premises Tested (# and % with Positives)
1	235	101 (43%)	213	35 (16%)	52*	48 (8; 16.7%)
2	179	0 (0%)	186	17 (9%)	46	46 (5; 10.9%)
3	130	35 (26.9%)	165	28 (17%)	47	39 (4; 10.3%)
4	63	0 (0%)	39	2**(5%)	45	16 (1; 6.3%)

*Year 1 = January 2019 – March 2020 (*4 premises voluntarily depopulated)*
Year 2 = April 2020 – February 2021
Year 3 = March 2021 – March 2022
*Year 4 = March 2022 – March 2023 (**Both goats from the same premises with a history of recent imports or previously positive animals)*

Wild sheep, goats, and other ungulates

Answer: Uncertain

YG has been testing harvested thinhorn sheep rams for *M. ovipneumoniae* since 2015 and, in 2018, expanded the testing program to include other ungulates (Government of Yukon 2023d). From 2015-2022, 1,463 wild ungulates were tested in the Yukon, including 669 thinhorn sheep and 13 mountain goats (Figures 4-5). No thinhorn sheep or mountain goats have tested positive for *M. ovipneumoniae* since the program began though one case of *Mycoplasma bovigenitalium* was identified in 2015 (Government of Yukon 2023d, YG, unpublished data). In addition, five caribou have tested positive for *M. ovipneumoniae* since 2018. One was from near the Alaska border in 2018, and the others harvested from the Porcupine herd in 2020 and 2021. The

Porcupine caribou were likely not infected with *M. ovipneumoniae*, but a similar pathogen (Government of Yukon 2023d).

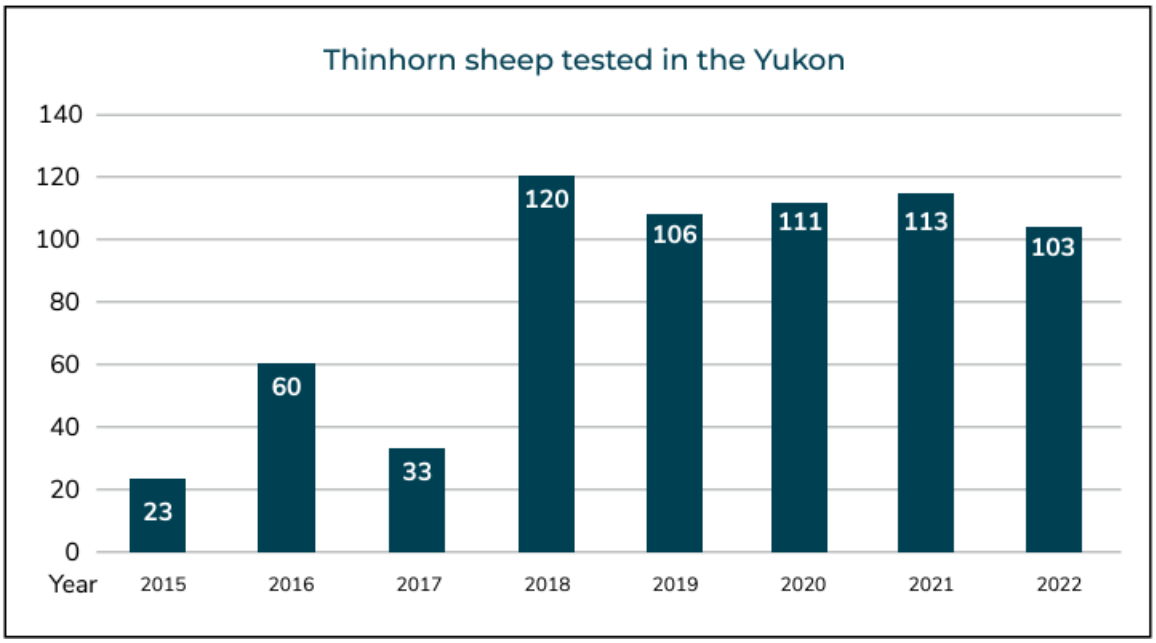

Figure 4: Number of thinhorn sheep tested for Mycoplasma ovipneumoniae *annually in the Yukon. Figure from the Yukon State of Environment Report 2023 (Government of Yukon 2023d).*

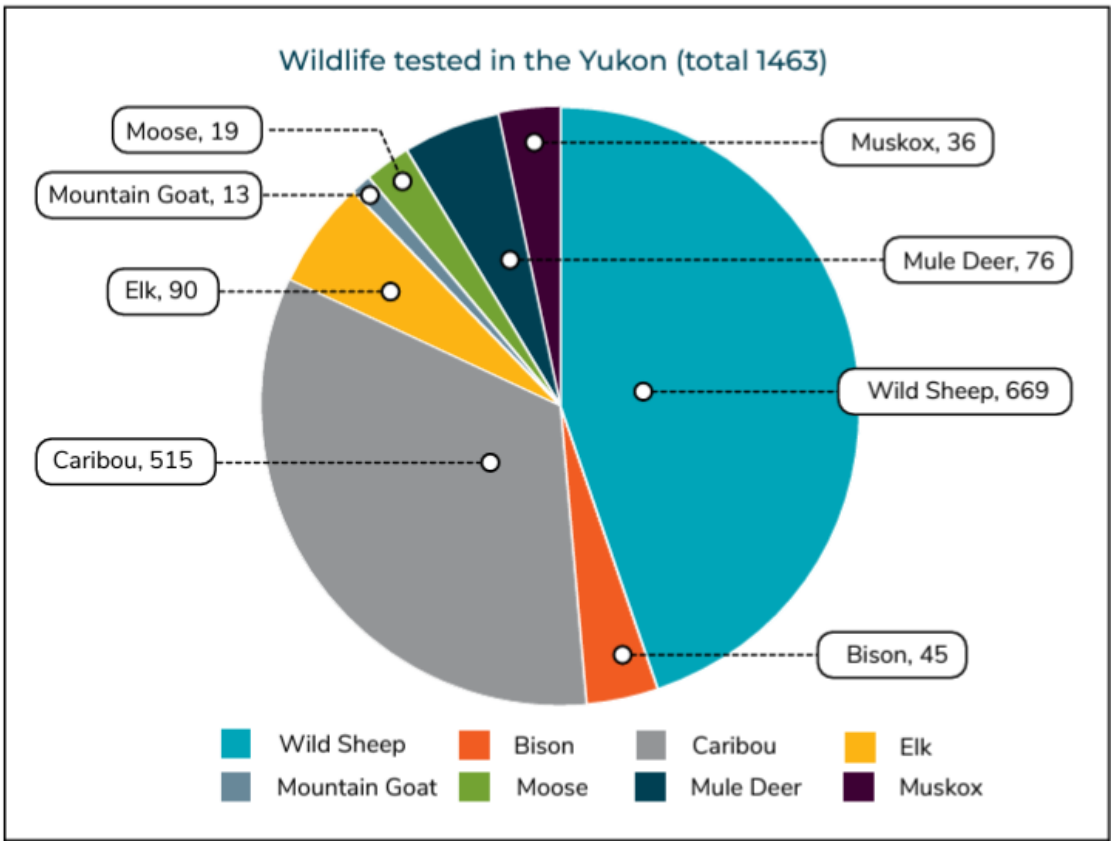

Figure 5: The number of individual free-ranging animals tested by the Yukon Animal Health Unit for Mycoplasma ovipneumoniae *between 2015 and 2022. Note: Thinhorn sheep and mountain goat testing began in 2015. Testing of other species began in 2018. Figure from the Yukon State of the Environment Report 2023 (Government of Yukon 2023d).*

SMC found only one anecdotal report of a respiratory disease outbreak in the Yukon, which occurred in the Dawson area after the winter of 2012-2013 (D. Reynolds, pers. comm.). The 2012-2013 winter was severe and associated with significant mortality in the local wild sheep population. Dan Reynolds from the Dawson RRC suggested that the stress associated with this event made surviving sheep vulnerable to pathogens that may not cause serious illness in healthy animals. He directly observed sheep coughing and several unexplained mortalities occurred in the area over the next few years. However, there was no disease investigation and no confirmation on cause of death. Reynolds has not observed similar mortalities within 4-5 years suggesting that any disease has not become chronic (D. Reynolds, pers. comm.).

There have been no reports of *M. ovipneumoniae* or other respiratory disease outbreaks in the thinhorn sheep of northern BC. Thacker (2019) performed health surveys of thinhorn sheep in multiple herds in northern BC and Alaska from 2017-2019 and detected no *M. ovipneumoniae* in BC sheep. Previous work on Stone's sheep in and around the Atlin and Williston Lake areas also identified few pathogens of concern (Wood et al. 2010; H. Schwantje, pers. comm.). In addition, staff from the Tahltan Nation are not aware of any respiratory diseases in thinhorn sheep and did not note any health problems during the recent collaring of 40 animals (Tahltan Nation Staff, pers. comm.). Culture of live sampled Stone's sheep from the Casssiar Mountains (which cross from BC into the Yukon) showed 8% positive for *Mannheimia* spp., and one sheep positive for *M. haemolytica* (Thacker 2020). However, BC has continued to test thinhorn sheep since Thacker's 2018-2019 research and to date, *M. ovipneumoniae* has not been found (Government of BC Ministry of Water, Lands and Resource Stewardship (WLRS), B. Jex, pers. comm.).

The results of the Yukon and BC *M. ovipneumoniae* testing programs, combined with the lack of confirmed thinhorn pneumonia-related die-offs supports the premise that respiratory pathogens are not currently widespread in the Yukon nor northern BC wild sheep. A summary of Gwich'in knowledge of thinhorn sheep in the Richardson Mountains supports this, including individual accounts of people finding sheep with blisters or pus on/in their lungs, but stating that it is rare to see unhealthy sheep (Benson 2023). In fact, this description is far more likely to be a hydatid cyst, a larval tapeworm common in ungulates sympatric with carnivores infected with *Echinococcus granulosus* then due to respiratory disease (H. Schwantje, pers. comm.). It is important to note, however, that the apparent absence of serious respiratory pathogens in the Yukon cannot be relied on as there has not been a comprehensive testing program across all Yukon thinhorn sheep or goat ranges. Most sampling is of hunter harvested sheep or goat heads,

relying on voluntary participation, and more than half of sheep samples (approximately 51%) have come from game management zones partially or entirely within 100 km of Whitehorse (Figure 6; YG, unpublished data; J. Harms, pers. comm.). As most licenced hunting in the Yukon occurs near Whitehorse (Jung et al. 2023), this limits the ability to detect potential outbreaks in more remote sheep or goat ranges Heads are only tested for *M. ovipneumoniae*, therefore negative results do not preclude the potential presence of other pneumonia-causing pathogens. Further investigations are performed in cases where an entire body is available to government staff, but this is less common (J. Harms, pers. comm.).

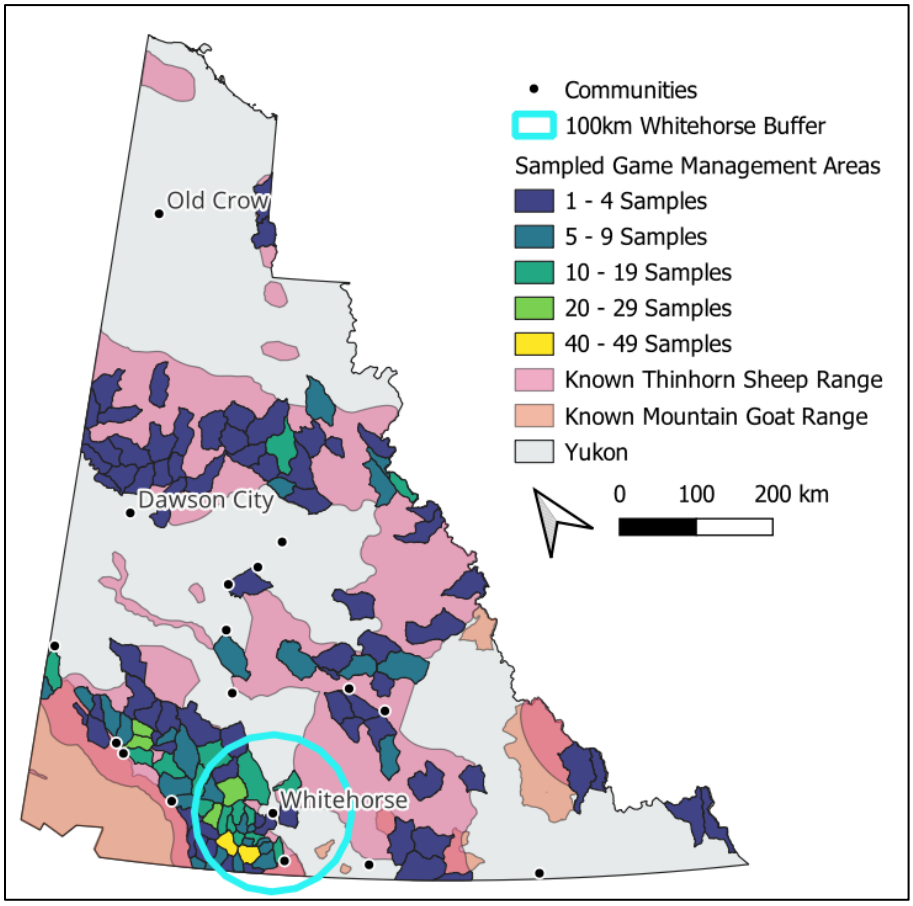

Figure 6: Map of the Yukon displaying known thinhorn sheep and mountain goat range and game management zones from which samples tested for M. ovipneumoniae have been received. Blue circle represents 100 km surrounding Whitehorse where over half (51%) of wild sheep samples originated. Data sources: Yukon outline from Government of Canada. Communities, sheep and goat range, and Game Management Areas from Government of Yukon.

It is unknown whether *M. ovipneumoniae* or other respiratory pathogens are present in Yukon mountain goat populations as only 13 goats have been tested for *M. ovipneumoniae* since 2018. All test results were negative, but this is an insufficient sample size to conclude that the pathogen does not exist in wild goats. There is also limited information from neighbouring jurisdictions. A study by Lowrey et al. (2018) found one respiratory pathogen, *Mannheimia haemolytica*, in a single goat during testing in northwest Alaska. This may be contrasted to the Greater Yellowstone Area of the USA where *M. ovipneumoniae* and multiple pathogens from the *Pasteurellaceae* family were detected in local mountain goat populations. Lowrey et al. (2018) states that there were likely undetected pathogens in the Alaska populations, but remote sampling and limited sample size restricted further conclusions. However, these findings suggest that Alaskan goat populations have had relatively little exposure to pathogens from domestic small ruminants. This is likely the case in the Yukon, given the small number of domestic sheep and goats in the territory compared to southern jurisdictions.

M. ovipneumoniae has been identified in several wild sheep populations in Alaska (Alaska Department of Fish and Game 2020, Thacker 2020, Lieske et al. 2022a). However, the Alaska strain of the bacteria appears to be unique to the state. The Alaska strain has been found in healthy sheep and goats and not associated with disease outbreaks, suggesting that it may not be a threat to local populations. However, it is unknown whether Yukon populations naïve to the Alaska strain would behave in a similar manner. Domestic sheep in Alaska have been found to carry *M. ovipneumoniae*, and it is not clear if domestic strains would be pathogenic to wild sheep with the unique Alaska strain (Alaska Department of Fish and Game, pers. comm.). The current NWT territorial veterinarian was not aware of any cases of *M. ovipneumoniae* or respiratory disease in wild sheep or goats in the territory (N. Jutha, pers. comm.). However, testing in the

NWT is limited to hunter collected samples of harvested rams from the Dehcho and Sahtu Regions.

Are thinhorn sheep or mountain goats in the Yukon and northern BC susceptible to the adverse effects of pneumonia and what is the potential magnitude of an outbreak?

Answer: Likely susceptible, potential population declines of >50%

Thinhorn sheep: The research since 2015

Limited research on respiratory pathogens in thinhorn sheep has been published since 2015. SMC did not find any reports of confirmed small or large scale thinhorn sheep die-offs in Canada or the USA due to respiratory disease. This is supported by statements from the Alaska Department of Fish and Game and the Western Association of Fish and Wildlife Agencies (WAFWA) Wild Sheep Working Group (Jex et al. 2016, Alaska Department of Fish and Game 2020). However, the lack of outbreaks is generally attributed to the low exposure of northern sheep to respiratory pathogens from domestic livestock rather than inherent resistance to respiratory disease. Also, due to the remoteness of most populations it is possible that disease events would not be observed (Wood et al. 2010, Jex et al. 2016, Thacker 2020). When discussing the Alaska *M. ovipneumoniae* strain, Beckmen et al. (2022) explicitly states that its presence does not suggest decreased vulnerability or predisposed immunity to respiratory pathogens. Research prior to 2015 demonstrated that thinhorn sheep are susceptible to agents associated with respiratory disease and pneumonia which have been linked to multiple mortalities (Canadian Wildlife Health Cooperative 2016). In addition, research on the closely related bighorn sheep (*Ovis canadensis*) continues to demonstrate the high risk that pneumonia outbreaks present to wild sheep populations (Cassirer et al. 2018).

Pneumonia outbreaks affect a large proportion of the individuals in bighorn sheep herds following disease transmission and commonly limit lamb recruitment for years after the initial outbreak. Bernatowicz et al. (2016) described pneumonia related die-offs in three Washington bighorn sheep herds causing declines of 35%, 36% and more than 50% (Bernatowicz et al. 2016). Werdel et al. (2020) recorded 57.9% mortality of a newly translocated bighorn sheep herd in south Dakota after being exposed to *M. ovipneumoniae*. A review of bighorn sheep mortality due to *M. ovipneumoniae* outbreaks, including herds in BC and Alberta, found a median population decline of 48% and ranging from 10-90% along with high rates of lamb mortality in many infected populations (Cassirer et al. 2018). There also appears to be limited cross strain immunity to *M. ovipneumoniae,* meaning that populations that have recovered from disease outbreaks can again be infected by a different strain of the bacteria (Cassirer et al. 2017).

Pneumonia outbreaks have the potential to spread over large areas as pathogens have been transmitted among adjacent bighorn herds in the USA (Bernatowicz et al. 2016). Bill Jex, Provincial Wild Sheep & Mountain Goat Specialist for BC, stated that thinhorn sheep range appears to be highly connected in the province's north suggesting the potential for widespread transmission (B. Jex, pers. comm.). There is also evidence of *M. ovipneumoniae* transmission from bighorn sheep to mountain goats (Wolff et al. 2019). Surveys of thinhorn sheep as well as anecdotal accounts have noted wild sheep and goats using the same areas and/or sharing mineral licks in BC and the Yukon's Kluane region (C. Wong, B. Jex, pers. comm.), demonstrating the potential for cross species contact and pathogen transfer.

Thinhorn sheep herds in BC and the Yukon may be at increased vulnerability to pneumonia outbreaks due to cumulative effects on their general health from other stressors in their environment. As referenced earlier in this report, multiple Yukon thinhorn populations are in

decline due to adverse weather or climatic events (Government of Yukon 2023b, 2023a). Long term Parks Canada monitoring of some Yukon populations suggest that fall or spring conditions may have a significant influence on sheep recruitment (C. Wong, pers. comm.). Climate caused mortality and related population declines have also been noted in BC sheep populations, with different events impacting either recruitment or ewe and juvenile ram survival (B. Jex, pers. comm.). Herd die-offs and lamb mortality due to respiratory disease could be especially devastating in populations already suffering significant recruitment or population declines.

Sheep in the Yukon or neighbouring jurisdictions are confirmed to carry pathogens that may predispose them to respiratory disease. Species of lungworm unique to wild sheep and goats (*Protostrongylus stilesi* and *P. rushi*) are present in most populations sampled (H. Schwantje, pers. comm.). These parasites have the potential to cause lung tissue damage and, when they occur with pathogenic bacteria, can be part of a pneumonia syndrome (Thacker 2020; H. Schwantje, pers. comm.). Thacker (2020) noted the presence of lungworm in both BC and Alaska sheep and the parasite has also been found in Yukon populations (J. Harms, pers. comm.). A variety of pathogens not specifically linked to pneumonia have also been detected in northern sheep populations. Several cases of sore mouth or Orf disease caused by a *Parapoxvirus* (also known as contagious ecthyma) have been diagnosed in thinhorn sheep in both BC and the Yukon (YG, unpublished data; Government of BC WLRS pers. comm.) and some sheep in the Kluane region are reported to have an unidentified skin disease causing patchy hair loss (C. Wong, pers. comm.). In addition, Thacker (2020) found a high prevalence of *Toxoplasma gondii* in Alaskan sheep. T. *gondii* is a parasite passed in wild or domestic felid feces and can cause neurological disease in wild sheep if ingested. It also has been confirmed to cause abortions in US bighorn herds (Fisk et al. 2023). *T. gondii* has been found in BC along with malignant

catarrhal fever and some samples of strep and *E. coli* (B. Jex, pers. comm.). It is unclear whether these pathogens have been recently introduced or are endemic to BC sheep populations and were simply not previously detected due to lack of testing (B. Jex, pers. comm.). There is also insufficient monitoring of BC thinhorn sheep populations to determine if such organisms are causing significant mortality (B. Jex, pers. comm.). While not always linked to respiratory disease, the presence of lungworm, *T. gondii*, *Parapoxvirus*, or other pathogens may indicate that a thinhorn population is in less-than-ideal health and more vulnerable to other disease-related declines.

Previous recorded cases of pneumonia in thinhorn sheep combined with the known impacts of respiratory disease on bighorn sheep and other stressors currently influencing thinhorn populations suggest that a pneumonia outbreak would have a serious impact on wild sheep in the Yukon and northern BC, potentially reducing populations by >50%. Thinhorn sheep may suffer worse outcomes than bighorn sheep due to their comparatively low exposure to pathogens carried by domestic livestock. Note, however, that the actual severity of an outbreak will likely depend on overall health of the affected population, additional pathogens present and, if associated with *M. ovipneumoniae*, the specific strain introduced. Recent literature indicates that the presence of *M. ovipneumoniae* does not always result in clinical disease or mortality in wildlife, likely due to the differing virulence of strains (Kamath et al. 2019). This premise is supported by the Alaskan *M. ovipneumoniae* strain which does not appear to have significant health impacts. Methods to test for virulence in *M. ovipneumoniae* strains are currently being developed and are part of the challenge in diagnostic testing and understanding the pathology of this bacteria in wild sheep (Lieske et al. 2022a).

Mountain goats

There is limited research on respiratory disease in mountain goats (Blanchong et al. 2018, Wolff et al. 2019). The BC Mountain Goat Management team states that disease transmission between domestic livestock and wild goats is a concern, but the level of threat from any disease is not well understood (Mountain Goat Management Team 2010). However, research from the USA confirms that mountain goats can be affected by respiratory disease in a similar manner to wild sheep (Wolff et al. 2019). Respiratory infections in mountain goats cause similar symptoms to those observed in bighorn sheep including coughing, lethargy, runny nose, droopy ears and loss of balance or coordination and may also contribute to kid mortality (Blanchong et al. 2018, Wolff et al. 2019). Wolff et al. (2019) stated that the impact of pneumonia on mountain goat kids and herd recruitment is similar to that seen in all-age die-offs of bighorn sheep, and that respiratory pathogens should be considered a potential limiting factor for goat populations.

Several respiratory pathogens have been detected in mountain goats in the USA including *M. ovipneumoniae* and *Pasteurellaceae* spp. among others (Table 5). A health assessment of three mountain goat herds in Montana found that all had evidence of *M. ovipneumoniae* or at least one respiratory pathogen from the *Pasteurellaceae* family (Almberg et al. 2022). Infections not specifically associated with the respiratory tract may also lead to pneumonia in mountain goats. Patton et al. (2012) described four cases of pneumonia symptoms in captive mountain goats in Oregon infected with the *Caprine arthritis encephalitis virus* (CAEv). CAEv is a multi-system disease, and respiratory symptoms are only one of the ways it can present. The infected goats were likely exposed through contaminated milk (used for feeding) and being housed with other infected animals (Patton et al. 2012). Though not specifically a respiratory pathogen, Bovine Viral Diarrhea virus (BVDv) has been indicated as a predisposing agent to bacterial pneumonia

in mountain goats (Dunbar et al. 1986). Parainfluenza-3 virus and lungworm may also predispose mountain goats to respiratory disease (Dunbar et al. 1986).

Table 5: Respiratory pathogens identified to occur in mountain goats via literature review.

Pathogen name	Location	Reference
Mycoplasma ovipneumonia	Greater Yellowstone Area (Wyoming and Idaho), Nevada, Montana, Alaska (Alaska specific strain)	Blanchong et al. 2018, Lowrey et al. 2018, Heimer 2020, Almberg et al. 2022
Pasteurellaceae spp. (various)	Greater Yellowstone Area (Wyoming and Idaho), Nevada, Montana	Lowrey et al. 2018, Wolff et al. 2019, Almberg et al. 2022
Bibersteinia trehalose	Greater Yellowstone Area (Wyoming and Idaho), Nevada	Lowrey et al. 2018, Wolff et al. 2019
Mannheimia spp.	Greater Yellowstone Area (Wyoming and Idaho), Nevada	Lowrey et al. 2018
Mannheimia haemolytica	Southeast Alaska[1], Greater Yellowstone Area (Wyoming and Idaho), Nevada	Lowrey et al. 2018, Wolff et al. 2019
Mannheimia glucosida	Nevada	Wolff et al. 2019
Pasteurella multocida	Greater Yellowstone Area (Wyoming and Idaho)	Lowrey et al. 2018
Respiratory syncytial virus	Washington	Dunbar et al. 1986
Caprine Arthritis Encephalitis virus (CAEv)[2]	Oregon (captive mountain goats)	Patton et al. 2012

1 Only one positive test in study
2 Multi system disease, pneumonia is only one possible presentation

There is limited information on recent population trends or health of mountain goats in the Yukon (or, for that matter, most northern populations). However, low mountain goat recruitment, likely due to adverse weather events, was noted in the Kluane region in 2022-2023 (C. Wong, pers. comm.). There is also evidence of respiratory and non-respiratory pathogens present in northern goat populations. Orf virus has been identified in goats in northern BC and *Mannheimia haemolytica* detected in one animal in southeast Alaska (Lowrey et al. 2018; Government of BC WLRS, B. Jex, pers. comm.). Horn rot has been reported in mountain goats around the Alaska

Panhandle, though it is unclear if this is due to disease or nutritional problems (B. Jex, pers. comm.).

Similar to thinhorn sheep, mountain goats in the Yukon may be more vulnerable to respiratory disease than southern populations due to their relative isolation and low exposure to pathogens from domestic animals. Given this, and as *M. ovipneumoniae*-related pneumonia has been observed to have similar impacts on mountain goats as bighorn sheep, we estimate potential populations declines up to >50% in Yukon and northern BC mountain goat populations if exposed to *M. ovipneumoniae* or other serious respiratory pathogens.

Do the circumstances exist for Yukon or BC thinhorn sheep or mountain goats to be exposed to pneumonia-causing organisms from domestic sheep or goats?

Answer: Yes, but the risk is low compared to more southern locations.

There are many Yukon communities within or adjacent to known wild sheep and goat ranges and some contain premises keeping domestic sheep or goats. Contact between wild and domestic sheep and goats may occur in these areas as well as when thinhorn sheep or mountain goats disperse or travel on forays (YG, unpublished data). Interviewees related stories of wild sheep observed within Haines Junction, a community which keeps a small number of domestic sheep or goats. In at least one case, a wild sheep was killed by conservation officers due to suspected contact (C. Wong, M. Nassiopoulos, pers. comm.). Whitehorse and Dawson City, around which most of the territory's domestic sheep and goats are kept, are both within 50 km of known thinhorn sheep range. Though the number of domestic sheep and goats in the Yukon is small compared to more southern jurisdictions, there is still potential for pathogen transfer to wild populations if measures to prevent contact are not in place. This is particularly important given the known presence of *M. ovipneumoniae* in domestic sheep and goats in the territory. It is also

possible that climate change will lead to more livestock being kept in northern areas over time, potentially increasing the risk of wild sheep or goats being exposed to respiratory infections (Jex et al. 2016).

Respiratory pathogens may spread to the Yukon from neighbouring jurisdictions. Alaska, BC, and the NWT share cross border wild sheep or goat populations with the Yukon and are subject to varying control regulations. The NWT does not allow domestic small ruminants to be kept within mountainous areas west of the Mackenzie River (NWT Environment and Natural Resources n.d.). Sheep habitat in the NWT is generally very remote (N. Jutha, pers. comm.), reducing the risk of contact between domestic and wild sheep and goats. Alaska does not allow the use of sheep or goats as pack animals when hunting wild sheep, goats, or muskox (Alaska Department of Fish and Game 2023). In addition, the Alaska Administrative Code prohibits the import of any animal that is known to have a communicable disease, have been exposed to a communicable disease within 30 days, or is from a designated quarantine area in another state (Alaska State Legislature 2024). Animals must receive a certificate from a qualified veterinarian (unless intended for immediate slaughter) and fulfill a range of health requirements, including, testing negative for *M. ovipneumoniae* no earlier than 60 days prior to import (Alaska State Legislature 2024). However, Alaska does not currently have a legal separation program and there are known cases of close contact between domestic and wild sheep or goats in the state (Alaska Department of Fish and Game, pers. comm.). It is possible that the Alaska *M. ovipneumoniae* strain in wild sheep will eventually be transmitted into Yukon populations with unknown impacts. The Alaska strain has been detected in cross border or neighbouring populations with the Yukon such as the Wrangle Mountains (Alaska Department of Fish and Game 2020).

Sheep and goat farming is not a regulated industry in BC meaning that the BC government does not know where all sheep and goat farms are located or how many are in the province's north (Government of BC Ministry of Agriculture, pers. comm.). Thacker (2020) noted potential contact between wild sheep and domestic goats adjacent to a study area in the Cassiar Mountains. The Cassiar mountains stretch from northern BC into the Yukon, so may act as a potential corridor for pathogen movement. Telegraph Creek is northern location where mountain goats and domestic animals occur close together (B. Jex, pers. comm.). However, SMC did not find any reports of confirmed pathogen transmission between domestic and wild sheep nor goats in northern BC. Cases of Orf observed in BC wild sheep and goats may have originated from contact with domestic flocks, but this is uncertain (Government of BC WLRS, pers. comm.).

There are programs and regulations related to preventing disease transmission to wild sheep and goats in BC. The BC Sheep Separation Program has existed for over 25 years with significant outreach, though testing and mitigation actions are voluntary in most areas. Government Action Regulations (GARs) under the BC Forest and Range Practices Act allow for the establishment of General Wildlife Measures to conserve a specified ungulate species in designated areas (Government of British Columbia 2004). Under GARs, ungulate winter range areas for Stone's sheep have been established in the Omineca and Peace Regions of BC with additional requirements for domestic sheep and goat management (Government of British Columbia n.d.). For example, U-7-28 (established 2016) includes the following requirements within Stone's sheep core winter range and other specified units (Government of British Columbia 2016):

- Domestic sheep, goats, or llamas may not be used in new or existing range tenures.
- Domestic sheep or goats may not be used for vegetation management.
- Only unused salt or mineral blocks may be placed in designated areas.

BC regulations also allow for the designation of restricted covenants where, for example, if a housing development is built in wild sheep and goat range, subsequent owners may not graze sheep or goats on the property (B. Jex, pers. comm.). In addition, domestic sheep or goats may not be taken hunting in BC for any reason (Government of British Columbia 2023).

Can the effects of or risk of pneumonia in wild sheep or goats be prevented, treated, or mitigated? Are there vaccines or treatments available that can be effectively delivered? Are there other mitigation strategies that can prevent pneumonia transmission to wild sheep or goats?

Answers: Prevention and mitigation – yes, vaccines and treatments – not for wild populations.

Prevention

Separating domestic sheep and goats from wild populations is currently the most effective way to prevent pathogen transmission (Jex et al. 2016, Whiting et al. 2023). The following measures are recommended at the farm level to help prevent the spread of pathogens from domestic to wild sheep and goats (Heinse et al. 2015, 2016, Nelson et al. 2016, Cassirer et al. 2018; H. Schwantje, pers. comm.):

- Double fencing, fencing or buffers that ensure that sheep or goats are physically contained and separated from potential contact with animals outside the enclosure. Heinse et al. (2016) suggests that a 20 m gap be maintained between fences to reduce the probability of disease transfer.
- Move *M. ovipneumoniae* positive animals to more distant locations when wild animals are in the area.
- Use effective livestock guardian dogs to create a buffer zone.
- Pen domestic sheep or goats at night in a fenced pasture or a building.

- Maintain high health livestock according to national standards such as the *Code of practice for the care and handling of sheep* (National Farm Animal Care Council 2013).
- Do not turn sick animals out to pasture.
- Keep rigorous counts of domestic flocks.
- Report sightings of wild sheep and goats to authorities when close to domestic livestock.
- Maintain *M. ovipneumoniae*-free domestic flocks.
- Provide ongoing outreach and education opportunities for sheep and goat owners about the risk of pathogens to their own animals, the potential risk of transmission to wild animals, and mitigation measures.
- Encourage the testing and removal of any animals with symptoms or tests confirming the presence of *M. ovipneumoniae*.

Another area where disease transmission may be mitigated is during translocations. Translocation is frequently used as a management tool for the augmentation or reintroduction of bighorn sheep or mountain goat herds. It is being investigated as a potential management strategy to create climate change-resilient herds or to replace extirpated populations (Cassirer et al. 2018, Werdel et al. 2020, Gude et al. 2022). Cassirer et al. (2018) also hypothesizes that increasing the genetic diversity of bighorn sheep populations through translocation might increase their resilience to disease. However, Werdel et al. (2020) noted that high levels of genetic diversity and heterogeneity did not appear to provide *M. ovipneumoniae* resistance to a translocated bighorn sheep population in South Dakota.

Though translocation may be a useful management tool in some situations, the movement of animals among populations creates a significant risk of spreading respiratory and other pathogens to different locations and mixing microbial communities with uncertain effects (Gude

et al. 2022). Translocations will also likely be unsuccessful in locations where there is a high probability of pathogen transmission from domestic animals (Werdel et al. 2020). Any imports of wild sheep or goats into the Yukon, or movement of animals between populations, should be treated with caution. It is recommended that managers take steps to ensure that translocated animals do not carry pathogens that may cause disease outbreaks in the receiving populations and that the health of receiving populations be closely monitored post-release (Cassirer et al. 2018, Werdel et al. 2020).

There are currently questions about the influence of populations size and density on disease outbreaks in wild sheep (Cassirer et al. 2018, Paolini et al. 2023). Populations are often at their largest just prior to outbreaks, which may indicate size or density dependent disease transmission (Cassirer et al. 2018, Paolini et al. 2023). If this is the case, limiting the size of wild sheep populations may reduce the risk of serious outbreaks. However, Cassirer et al. (2018) emphasizes that the link between population size and disease is unclear and that reducing herd sizes may not provide any benefits.

Treatment and vaccination

There are currently no effective treatments for pneumonia in wild sheep or goats (Jex et al. 2016, Maksimović et al. 2022). Expert interviewees stated that, though vaccines or treatments are available for some respiratory infections in domestics, there are no consistently effective or predictable treatments for *M. ovipneumoniae* (B. Macbeth, N. Jutha, K. Beckmen, J. Harms and others, pers. comm.). However, research is ongoing in this area. At least 19 antimicrobials have been screened for minimum inhibitory concentrations for *M. ovipneumoniae* isolates from sheep and goats (Maksimović et al. 2022). *Mycoplasmas* are inherently resistant to certain antimicrobials (such as penicillin), but some are sensitive to other antibiotics commonly used for

livestock (Maksimović et al. 2022; H. Schwantje, pers. comm.). Antibiotic trials on small, domestic BC flocks have had some success in both treating clinical symptoms and clearance of *M. ovipneumoniae* from infected animals as confirmed for over 4 years (H. Schwantje, pers. comm.). However, a recent trial using the same protocol of intranasal and systemic enrofloxacin treatment was not successful in clearing *M. ovipneumoniae* from Yukon domestic sheep (Magnusson et al. 2023). More research is needed to develop an optimal treatment regimen with pharmaceuticals approved for use (Maksimović et al. 2022). Wood et al. (2023) successfully cleared *M. ovipneumoniae* from captive bighorn lambs and yearlings with orally administered doxycycline given twice daily for eight or more weeks. However, antimicrobial use on wild sheep or goats in the field, with appropriate doses and repeated administration, is generally not possible.

Experimental vaccines for *M. ovipneumoniae* have been used with limited success, likely due to the intracellular nature and high immunological variability of Mycoplasmas in general as well as the variability of *M. ovipneumoniae* strains (Werdel et al. 2020, Maksimović et al. 2022). For example, Werdel et al. (2020) vaccinated 27 translocated bighorn sheep with an autogenous vaccine using a local *M. ovipneumoniae* strain in South Dakota. A large proportion of the population died in a pneumonia outbreak associated with a different strain a year later. It is not clear whether the vaccine did not provide adequate or lasting protection against any *M. ovipneumoniae* infection, or if it simply was not effective across strains (Werdel et al. 2020). There has also been limited success developing vaccines for other significant respiratory pathogens that are feasible for use on wild sheep or goat populations. Historic efforts to use bovine vaccines led to bighorn sheep developing fatal infections after vaccination (Onderka et al. 1988). Subramaniam et al. (2011) used an experimental vaccine that appeared effective in

protecting captive bighorn sheep against *Mannhemia haemolytica* but required multiple boosters making it impractical for use on wild herds. Batra et al. (2017) later developed a new *M. haemolytica* vaccine, partially in an attempt to eliminate the need for booster doses, but it did not prove effective.

Response

There is no single recommendation for how to manage a pneumonia outbreak in a wild sheep or goat population. However, given the lack of effective treatments, culling or removal of infected animals at some scale may be required. Research on affected bighorn sheep populations in the USA and Canada suggests that removing M. *ovipneumoniae* carriers after the active die-off phase may help purge disease from small populations or prevent transmission to neonatal lambs (Bernatowicz et al. 2016, Cassirer et al. 2018, Garwood et al. 2020; H. Schwantje, pers. comm.). Garwood et al. (2020) reported 72% reduction in lamb mortality after the removal of *M. ovipneumoniae* "chronic carriers" (animals which repeatedly tested positive for *M. ovipneumoniae*) from a bighorn sheep population in South Dakota. They did not detect *M. ovipneumoniae* nor pneumonia in the treated population after carriers were removed (Garwood et al. 2020). Bernatowicz et al. (2016) reported similar results after removal of chronic carriers from the Asotin bighorn herd in Washington. The Asotin herd appeared to be *M. ovipneumoniae* and pneumonia free and have recruitment levels equivalent to pre-outbreak by four years after the initial die-off. Similar findings occurred in BC in a multiyear "Test and Remove" experiment treating a metapopulation of bighorn sheep along the Fraser River by removing ewes which tested positive for *M. ovipneumoniae* (H. Schwantje, pers. comm.). Though results are not guaranteed, Cassirer et al. (2018) states that managing respiratory disease through the removal of carriers may be preferable for small, accessible herds which can be repeatedly tested. Note that

removal should not be limited to visibly symptomatic individuals as this strategy has failed to prevent disease in bighorn sheep in Washington (Bernatowicz et al. 2016).

In certain populations, such as large groups, acutely affected herds, or where there is a risk of affected animals spreading pathogens to neighbouring herds, more extreme culls may be required. A complete cull of a *M. ovipneumoniae*-positive bighorn herd in Washington early in an outbreak successfully prevented disease transfer to neighbouring populations (Bernatowicz et al. 2016). The removal of infected herds has also been used in locations such as Alberta and Utah to prevent the spread of pneumonia to adjacent populations (H. Schwantje, pers. comm.). However, full population culls are difficult. In the Washington case, surviving animals became increasingly wary of humans and helicopters to the point that specialized skills and equipment were needed to remove the final individuals (Bernatowicz et al. 2016). The authors suggest that trail cameras may help to locate animals during such large culls, but only if they are able to provide real-time imagery (Bernatowicz et al. 2016). In addition to technical difficulties, the killing of so many animals may be psychologically taxing on managers and subject to social opposition. In some cases, a number of infected animals may be removed to facilities where they are separated from other populations rather being culled. However, this is likely inviable in many situations.

Another example of successful management of a pneumonia outbreak comes from BC. In 2000, a bighorn die-off associated with *Mycoplasma* organisms was managed through the removal of clinically ill animals, the placement of trace mineral salts, and a moratorium on local hunting. Though lamb mortality due to pneumonia was confirmed in the population for at least two years, rapid herd and recruitment recovery was noted afterwards. This is thought to have resulted from

the death of infected ewes leading to a lack of chronic carriers in the population without the need for further management (H. Schwantje, pers. comm.).

As an alternative to culling, pneumonia outbreaks may simply be left to run their course. In Arizona, respiratory disease outbreaks in three bighorn sheep populations were left largely unmanaged (beyond predator control and hunting limitations in some areas). For two of these herds, the population and recruitment eventually recovered (WAFWA Wildlife Health Committee, pers. comm.). However, herd recovery may take many years and is not guaranteed in all cases, as evidenced by continued recovery difficulties in the third, unmanaged, herd. An interviewee from the WAFWA Wildlife Health Committee estimated that herd recruitment took around ten years to recover to pre-outbreak levels and that population recovery took even longer.

Emerging research: M. ovipneumoniae *in other species*

Research released since the 2016 risk assessment, particularly Maksimović et al. (2022) has highlighted the presence of *M. ovipneumoniae* in domestic and wild species other than sheep and goats including muskox, moose, caribou and others (Table 6). *M. ovipneumoniae*, or a closely related bacteria, has also been found in Yukon caribou (Government of Yukon 2023d). Maksimović et al. (2022) suggests three possible explanations for the occurrence of *M. ovipneumoniae* in different species:

1. There are more interactions between wild and domestic animals than previously thought.
2. Increased testing of both livestock and wildlife is providing information not previously available.
3. *M. ovipneumoniae* or a very similar organism has a much wider range of hosts than previously known.

The identification of *M. ovipneumoniae* in animals such as deer suggests that transmission of this bacteria to sheep or goats from a variety of hosts may be possible if close contact occurs. However, further research is required to quantify this risk. In particular, Paolini et al. (2023) state that research is needed on the potential for pathogen transfer between bighorn sheep and species from the Capreolinae subfamily ("New World deer"). Highland et al. (2018) suggests that, as testing methods advance, it will be important to test animals beyond the Caprinae subfamily (which includes sheep, goats, and related species).

Table 6: Wild and domestic animal species that carry Mycoplasma ovipneumoniae. *See Maksimović et al. (2022) for full reference citations from this table.*

Type	Common Name	Scientific Name	References
Wildlife	Dall's sheep	*Ovis dalli dalli*	Black et al. 1988
Wildlife	Bighorn sheep	*Ovis canadensis canadensis*	Besser et al. 2008
Wildlife	Norwegian muskox	*Ovibos moschatus*	Handeland et al. 2014
Wildlife	Mountain goat	*Oreamnos americanus*	Wolff et al. 2019
Wildlife	Desert bighorn sheep	*Ovis canadensis nelsonii*	Shirkey et al. 2021
Wildlife	Caribou	*Rangifer tarandus*	Highland et al. 2018; Rovani et al. 2019
Wildlife	Barren-ground caribou	*Rangifer tarandus granti*	Rovani et al. 2019
Wildlife	Moose	*Alces alces*	Highland et al. 2018
Wildlife	Mule deer	*Odocoileus hemionus*	Highland et al. 2018
Wildlife	White-tailed deer	*Odocoileus virginianus*	Highland et al. 2018
Livestock	Cattle	*Bos taurus*	Wolfe et al. 2010
Livestock	Sheep	*Ovis aries*	Manlove et al. 2019
Livestock	Goats	*Capra hircus*	Gonçalves et al. 2010

Potential consequences of an outbreak in the Yukon

Wild sheep, goats, and mountain ecosystems

Due to the limited amount of research and information available about northern populations of wild sheep and goats, the likelihood and severity of a pneumonia outbreak in BC and the Yukon thinhorn sheep or mountain goat populations is uncertain. However, given the relative naïvety of thinhorn sheep and northern mountain goats to domestic pathogens and the known impacts of *M. ovipneumoniae*-related pneumonia on bighorn sheep and mountain goats further south we estimate potential declines of >50% in any thinhorn sheep or mountain goat population exposed to *M. ovipneumoniae* or other respiratory pathogens of concern. Pneumonia may act cumulatively with other factors causing stress or mortality in thinhorn and mountain goat populations such as adverse winter weather and the presence of pathogens such as Orf and lungworm (Thacker 2020, Government of Yukon 2023a, 2023b).

It is not clear what large declines in wild sheep or goat populations would mean for the ecosystems they inhabit. One likely consequence is the alteration of predator-prey dynamics in the affected area. Sheep act as prey for a variety of species including black and grizzly bears, eagles, coyotes, lynx and wolverines (Jex et al. 2016). This suggests that large declines in sheep populations may lead to either reduced predator numbers or increased pressure on alternative prey species such as caribou. However, the actual effects of die-offs on predator prey dynamics, vegetation, nutrient cycling, and other ecosystem processes in uncertain.

Economic

Table 7: Revenue sources to government, businesses, and Indigenous groups related to thinhorn sheep and mountain goats in the Yukon.

Source	Estimated Annual Revenue ($)	Calculation	Data Source
Guide outfitters	2.85 million	¼ of mean annual revenue	McDowell Group and Vector Research 2016
Tags and harvest fees – sheep	48,493.75	Mean annual revenue from seals and harvest fees 2016-2023	YG unpublished data
Tags and harvest fees – goats	14,506.25	Mean annual revenue from seals and harvest fees 2016-2023	YG unpublished data
Kluane tag auction*	55,000 – 315,000 US	As reported by CBC	Tukker 2016
Licenced hunters - spending on sheep hunts	Generally, < 2,500 but up to >10,000 per person	As reported by respondents of 2022 hunter effort survey	Jung et al. 2023
Subsistence hunters - spending on sheep hunts	Unknown	-	-
Tourism/wildlife viewing	Unknown	-	-
Craft sales or workshops	Unknown	-	-

*Note that the Kluane tag was not auctioned for the 2023/2024 season.

Declines of >50% in any sheep or goat population would be expected to lead to significant hunting restrictions in the Yukon. One of the biggest economic impacts of widespread hunting closures would be through the guide outfitting industry. Yukon guided sheep hunts may sell for $40,000 US or more (McDowell Group and Vector Research 2016). Yukon outfitters reported a total revenue of approximately $11.2 million in 2014, $4.1 million of which was passed onto other businesses through the purchase of transportation, equipment, and supplies. Their clients spent another estimated $1.25 million in the Yukon beyond direct payments for their trip (McDowell Group and Vector Research 2016). From 2004-2014, an average of 151 wild sheep

were harvested by non-resident hunters annually, making up approximately 28% of mean annual harvest. Mountain goats were harvested but at much lower levels, with an annual average of four animals making up approximately 0.7% of the mean harvest (McDowell Group and Vector Research 2016). These numbers suggests that Yukon guide outfitters could lose over a quarter of their business if die-offs meant they were no longer able to offer guided sheep or goat hunts, with associated revenue losses to other Yukon businesses.

In the case of widespread hunting closures, YG would lose direct revenue from the sale of seals and hunting fees, which averaged of $48,493.75 and $14,506.25 for thinhorn sheep and mountain goats respectively from 2016-2023 (YG, unpublished data). Communities would suffer further lost income from reductions in resident hunter purchase of supplies, equipment, or accommodation. Though *Results of the 2022 Yukon Sheep (*Ovis dalli*) and Goat (*Oreamnos americanus*) Hunter Effort Survey* suggested that most respondents spent less than $2,500 on a sheep hunt (Jung et al. 2023), this is still a notable revenue source to local businesses. Kluane First Nation also stands to lose significant revenue through the annual tag auction for Kluane Game Sanctuary. Though the Kluane tag was not offered in 2023 (and will not be in 2024) due to conservation concerns, in the past it has sold for $55,000 – $315,000 US, most of which goes to the nation (Tukker 2016).

Other potential income loss as a result of pneumonia outbreaks in wild sheep or goats is difficult to quantify. Large die-offs may lead to reductions in local tourism revenue and sales of crafts, craft supplies, or workshops. A significant pneumonia outbreak in wild sheep or goats also has the potential to impact domestic sheep and goat producers. Sheep and goat producers in BC have been subject to backlash from wild sheep and goat advocacy groups related to *M. ovipneumoniae* outbreaks (Government of British Columbia Ministry of Agriculture, pers. comm.). Social

backlash in the Yukon could lead to reduced sales of local meat, wool, or other products from domestic animals, placing financial strain on farmers. However, impacts on sheep or goat farmers may be mitigated by the presence of the Control Order, as most have readily adopted and can demonstrate measures to reduce the risk of pathogen spillover to wild populations (YG Animal Health Unit, pers. comm.).

Beyond revenue loss, a pneumonia outbreak in the Yukon could lead to significant costs to YG and other agencies for monitoring and management activities. The level of cost would depend greatly on the specific management program as well as the magnitude and location of the outbreak. However, a Test and Remove program of a bighorn metapopulation in southern BC has cost around $250,000 annually and is expected to run to at least $2.3 million by its final year (H. Schwantje, pers. comm.). While mitigation costs are rarely entirely covered by government agencies, they may be significant and affect the funds available for other environmental or wildlife projects in the territory. Costs would likely also be incurred by organizations outside of the YG involved in management efforts such as Indigenous groups.

Socio-cultural

Thinhorn sheep and, to a lesser degree, mountain goats are culturally important species. Significant loss of sheep or goats due to disease would restrict the legally protected harvest rights of northern Indigenous group and potentially lead to loss of knowledge sharing and cultural activities related to hunting and processing these animals. This may be exacerbated if population declines in certain areas lead to poaching in parks or other wild sheep or goat habitat (a concern raised by C. Wong, Parks Canada). Die-offs of thinhorn sheep or mountain goats are expected to cause significant psychological distress to communities with cultural connection to these species. This is not limited to Indigenous groups as hunting and connection to wildlife are also important

to non-Indigenous Yukon residents. Expert interviewees described the potential impact of the loss of sheep due to a large disease outbreak as “terrible” and “devastating.”

Some northern communities may rely on hunting for subsistence. This is especially true in remote or isolated areas where food prices can be very high. The Yukon does not have statistics on subsistence hunting. However, NWT communities neighbouring cross border mountain ranges (sheep range) may have a significant amount of their households consuming mostly meat harvested via hunting or fishing. For example, wild meat accounted for 75% or more of meat consumption in 44.9%, 37.5% and 50% of households in Tulita, Nahanni Butte, and Wrigley respectively in 2018 (NWT Bureau of Statistics 2019). Though it is not stated if or how much of this meat is from sheep or goats, this still demonstrates the potential for impacts to food security in remote communities if major die-offs occur. Die-offs in sheep or goat populations may reduce the tradition of meat sharing in the Yukon. Yukon guide outfitters commonly donate approximately 75% of harvested meat to local people, community organizations, or Indigenous groups and licenced hunters often share meat among 1-4 households (McDowell Group and Vector Research 2016, Jung et al. 2023). The amount of meat available for donation and sharing may be reduced if wild sheep, one of the major Yukon game species, can no longer be hunted due to pneumonia related die-offs.

Assessing the Control Order

Overview

The Yukon Sheep and Goat Control Order came into effect in 2020 and contains the following restrictions (Department of Energy, Mines and Resources and Department of Environment 2018):

- Domestic sheep and goats may not be kept on land over 1,000 m in elevation.
- An individual may only keep a domestic sheep or goat if:
    - It is kept in an enclosure approved by an inspector within the previous calendar year.
    - The enclosure is identified by a sign provided by the inspector.
    - The animal has been tested for respiratory pathogens within the previous calendar year with methods and results approved by the Chief Veterinary Officer.
    - The animal, if over four months old, has a permanent identifier in accordance with the Canadian Sheep Identification Program, Canadian National Goat Identification Program, or provided or approved by the Yukon Animal Health Unit or Chief Veterinary Officer.
- If transporting domestic sheep or goats, the owner must take reasonable steps to prevent their escape.
- The Chief Veterinary Officer must be notified immediately if a sheep or goat escapes its enclosure.
- Domestic sheep and goats must be made available for inspection and testing if requested.
- Owners must keep records of each sheep or goat's date of birth, sale, purchase, natural death, or slaughter.
- No one may transport a domestic sheep or goat into the area covered by the Control Order without a permit.

Beyond the restriction that domestic sheep or goats not be kept above 1,000 m in elevation, control requirements apply equally to all domestic sheep and goats throughout the Yukon. This was determined to be the most appropriate and comprehensive strategy for addressing the

potential risks to wild sheep and goat health when the Control Order was established. Prior to the Control Order coming into effect, little was known about the number and distribution of domestic sheep or goats in the territory. As such, geographic restrictions on Control Order requirements would have limited the ability of the order to fully quantify these animals. There are also significant gaps in the information available about wild sheep and goat occurrence and movement patterns in some parts of the Yukon. Although wild sheep and goats tend to inhabit remote areas at high elevations, they have been reported both at lower elevations and in more densely populated areas such as in or near Whitehorse and Dawson City (YG, unpublished data).

Results

Has the Control Order prevented contact/pathogen transmission from domestic to wild sheep and goats?

Answer: Uncertain

With the information available, it is not possible to confidently assess if the Control Order has prevented pathogen transmission from domestic to wild sheep and goats in the Yukon. This is largely due to a lack of baseline data on pathogen transmission rates prior to the order being enacted. A comprehensive sampling program for respiratory pathogens across the territory does not yet exist. However, there is no evidence that *M. ovipneumoniae* has been transferred from domestic to wild sheep or goats since the Control Order came into effect. There have only been two recorded incidences of wild sheep and domestic sheep interacting over the past four years, one in Haines Junction and one in Dawson, and both thinhorns involved were destroyed (Yukon Agriculture Branch, pers. comm.). No wild sheep or goat has yet tested positive for *M. ovipneumoniae* though it is identified in domestic animals every year. This does not guarantee that pathogen transfer has never occurred; however, it is a positive sign.

Has the Control Order reduced the risk of a pneumonia outbreak in wild sheep or goats?

Answer: yes

Though it is not possible to determine if the Control Order has prevented all pathogen transmission between domestic and wild sheep and goats, it has taken many positive steps to reduce the risk of a pneumonia outbreak in the Yukon through the following:

1. Increasing knowledge of domestic sheep and goats in the Yukon: A government registry of domestic sheep, goats, and their owners was established as part of the Control Order. This has greatly increased YG knowledge about the number and location of domestic sheep and goats in the Yukon, allowing for assessment of contact risk with wild animals in different locations and resulting mitigation measures. It also greatly increases the capacity of the government to monitor risk through activities such as *M. ovipneumoniae* testing and facility and enclosure inspections.

2. Testing and reducing the number of *M. ovipneumoniae* positive domestic sheep and goats in the territory: Prior to the enactment of the Control Order, there was no requirement to test domestic sheep or goats within, or to be imported into, the Yukon for *M. ovipneumoniae*. This allowed *M. ovipneumoniae* carriers to remain in the territory, increasing the risk of pathogen transmission to wild populations. The Control Order established *M. ovipneumoniae* testing requirements for local domestic sheep and goats. Animals which test positive are destroyed or, in rare cases, removed from the territory at the owner's expense. Domestic sheep and goats imported into the Yukon are immediately quarantined and tested for *M. ovipneumoniae*. Funding is available to support pre-import testing to reduce the risk of pathogen transmission. YG also compensates owners for the loss of sheep or goats which are destroyed because of positive *M. ovipneumoniae* tests.

During the first four years of the Control Order, 136 sheep and 82 goats were slaughtered or removed due to being positive for *M. ovipneumoniae*, meaning they were no longer able to spread this pathogen among domestic flocks or pass it to wild sheep or goat populations. Testing numbers suggest that these measures have been generally successful in reducing the prevalence of *M. ovipneumoniae* positive animals in the Yukon (Figures 7-8). Though there was a notable spike in positive tests between years 2 and 3 of the Control Order due to the import of a group of sheep with *M. ovipneumoniae* positive animals, the numbers decreased by year 4 (YG, unpublished data). In addition, the proportion of identified premises with *M. ovipneumoniae* positive animals has decreased annually since testing began to a low of 6.3% in March 2022 - March 2023 (Figure 9; Government of Yukon 2021, 2022a, 2023c).

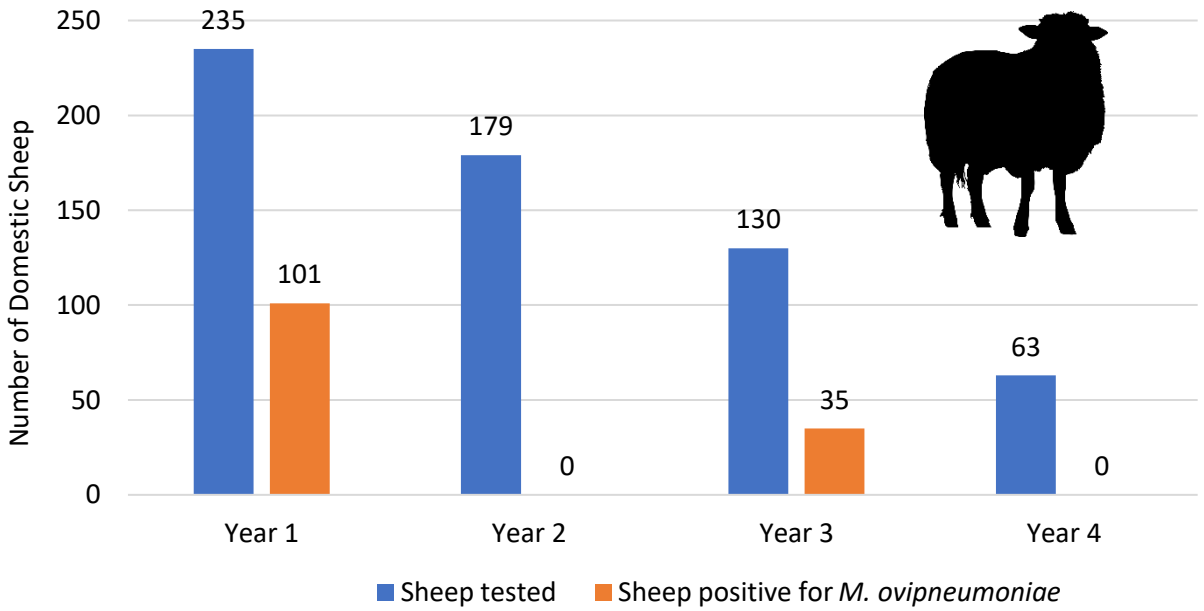

Figure 7: Number of domestic sheep tested and positive for M. ovipneumoniae *in the Yukon during the first four years of the Control Order mandatory testing program (2019-2023; Government of Yukon 2021, 2022a, 2023c). Silhouette from phylopic.org (public domain).*

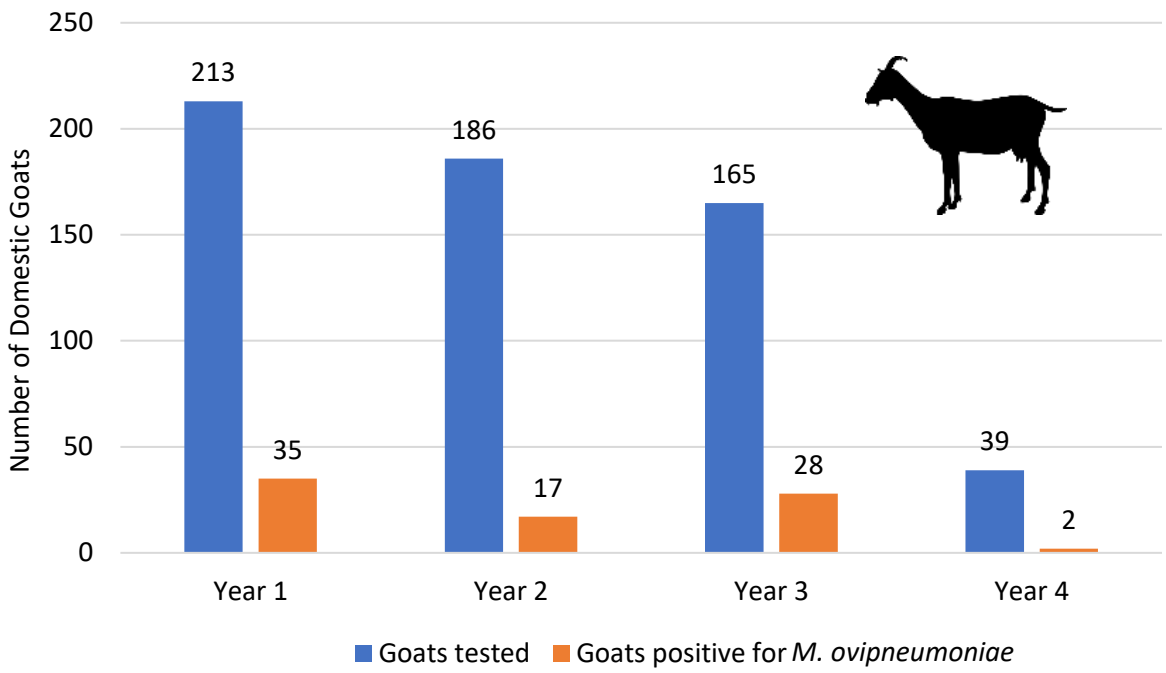

Figure 8: Number of domestic goats tested and positive for M. ovipneumoniae *in the Yukon during the first four years of the Control Order mandatory testing program (2019-2023; Government of Yukon 2021, 2022a, 2023c). Silhouette from phylopic.org (public domain).*

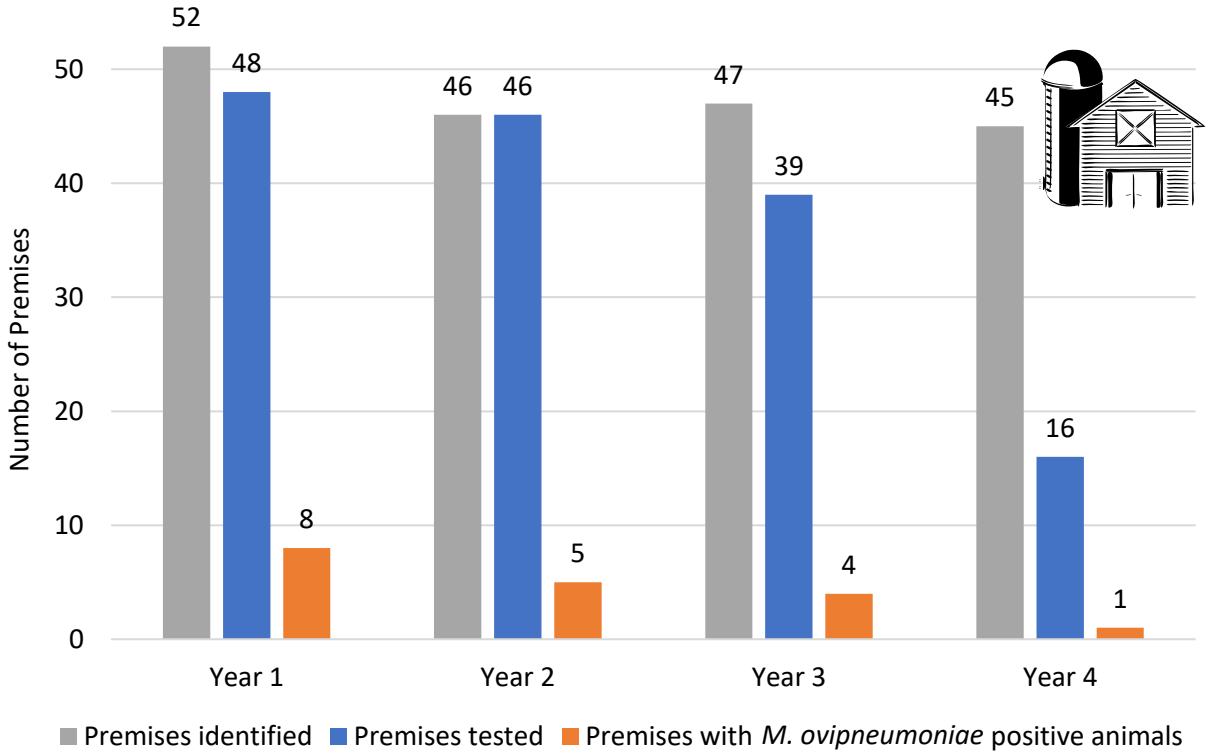

Figure 9: Number of premises in the Yukon with domestic sheep and goats where animals were tested and positive for M. ovipneumoniae *during the first four years of the Control Order mandatory testing program (2019-2023; Government of Yukon 2021, 2022a, 2023c). Image from publicdomainvectors.org (public domain).*

An important caveat to the above data is that testing numbers were not consistent across all years. This is partially due to a reduction in the number of domestic sheep and goats in the Yukon since the Control Order was enacted. However, a smaller proportion of animals were also tested in 2023, due to a more risk-based approach to which premises should be sampled (J. Harms, pers. comm.).

3. Upgrading enclosures: Since the establishment of the Control Order, enclosures for domestic sheep and goats have been required to have both a primary and secondary barrier to keep animals contained and reduce the risk of nose-to-nose contact between domestic and wild populations (YG, unpublished data). The height and material of these barriers are not specified as needs vary

by the number and type of sheep or goats contained and other site-specific details. However, enclosures must be sufficient to prevent escape and to discourage wild sheep or goats from entering as determined by a government inspector (Government of Yukon n.d.). YG offered financial assistance to sheep and goat owners for upgrading enclosures during the first year of the Control Order. This involved the provision of funds for the purchase of fencing materials to 15-20 premises (YG Agriculture Branch, pers. comm.). Sheep and goat owners were responsible for fence installation.

YG reports that, in nearly all cases, owners have cooperated with government staff to upgrade their enclosures to the necessary standard. Identified enclosure deficiencies are usually caused by weather related events (e.g., snow damaging or piling up by a fence) and owners work with YG to resolve these issues. Since the enactment of the Control Order, there have only been two verified and 2-3 unverified incidences of domestic sheep or goats escaping containment (YG, unpublished data). The first verified case involved the escape of three domestic sheep. The owner cooperated with Conservation Officers and the Agricultural Branch to recapture the animals, which were returned to their enclosure within two days. The second case was similar, with animals returned to their enclosure on the same day they escaped. The animals from the unverified reports were likely recaptured before their escape could be confirmed. Though this suggests that some owners are not reporting escapees as required, the low number of known escapes since the Control Order was enacted suggests that enclosure requirements have been generally successful at containing domestic sheep and goats.

4. Increasing public knowledge about the risk and prevention of disease transmission between domestic and wild sheep and goats: Effective knowledge sharing is a vital part of animal health management (Paolini et al. 2023). Since 2018, YG has published simple language

summaries about pneumonia in wild sheep, Control Order requirements, and *M. ovipneumoniae* testing results (Government of Yukon 2022a, 2022b, 2023c). Guidance relating to the Control Order, keeping domestic sheep or goats, and the risks of respiratory disease transmission to wildlife is publicly available on the YG website and Yukon Agricultural Association Website (Government of Yukon 2024c, Yukon Agricultural Association n.d.). Stories about the Control Order have also been published by Yukon News and CBC.

A full assessment of public knowledge about the Control Order is beyond the scope of this report. However, the cooperation from the public, sheep owners, and conservation officers in reporting and aiding to return escaped sheep to containment, considered alongside general cooperation from sheep and goat owners relating control and testing measures, suggests that these groups have some understanding of the risk that domestic sheep and goats can pose to wild populations. Expert interviewees also stated that knowledge about the risk of pathogen transmission from domestic to wild sheep and goats has improved since the Control Order was established (S. Wallace, D. Reynolds, pers. comm.).

Considerations from the literature and expert interviews

The Control Order already includes many of the measures recommended in recent publications to prevent the transmission of pathogens from domestic to wild sheep and goats, including requirements for double fencing, reducing the prevalence of *M. ovipneumoniae* in domestic stock, keeping detailed counts of domestic flocks, and providing educational materials to sheep and goat owners (Heinse et al. 2015, Cassirer et al. 2017, 2018). Some of the other recommendations from the literature, such as sheep owners keeping livestock guardian dogs, may not be practical in all cases. A few measures not specifically addressed in the Control Order that may be useful to consider include requiring that domestic small ruminants be penned at

night and that sick animals not be turned out to pasture (Cassirer et al. 2018). In general, recent literature on pneumonia in wild sheep or goats continues to support the need for control measures to be in place (Nelson et al. 2008, Heinse et al. 2015, Cassirer et al. 2017, 2018, Lieske et al. 2022a, Paolini et al. 2023).

Individuals from expert interviews also emphasized the need for control measures to prevent pathogen transmission from domestic to wild sheep and goats. However, they raised some concerns about the Control Order. Multiple interviewees discussed the hardship that the cull of *M. ovipneumoniae* positive animals caused to sheep and goat owners. Though committed to risk reduction, they stated that they would be in support of alternate measures to manage *M. ovipneumoniae* positive animals if effective. In addition, multiple interviewees suggested that location should be considered in the Control Order, rather than having the entire territory subject to the same requirements.

Interviewees from BC noted concerns that, in cases where *M. ovipneumoniae* positive animals were removed from the Yukon rather than destroyed, they were transported to BC with potential to spread pathogens to local sheep or goat populations. If sold to farmers in northern BC, pathogens could also potentially spread from exported animals back into the Yukon through cross border sheep and goat populations. As such, it may be beneficial to regulate that any animals exported from the territory due to a positive *M. ovipneumoniae* test must be moved to locations outside of wild sheep or goat range.

Another concern raised by interviewees was the scarcity of direct involvement and communications related to the Control Order between YG and other organizations. Interviewees stated that they would like to be directly informed of test results (including the location of *M. ovipneumoniae* positive animals) and for organizations such as RRCs to be involved in planning

and decision making related to the Control Order. Two interviewees also emphasized the need to ensure that there is adequate capacity to monitor and enforce Control Order requirements across the Yukon.

Related programs: Wildlife health surveillance

Prior to 2015, there was limited data available about whether *M. ovipneumoniae* or other respiratory pathogens were present in wild sheep or goats in the Yukon. Starting in 2015, YG established a regular *M. ovipneumoniae* testing program for harvested thinhorn sheep and expanded this to include other wild ungulates in 2018 (Government of Yukon 2021, 2023d). This program is also supported by the Yukon Wild Sheep Foundation who provide test kits to their members, funding to offset testing costs, and reward a hat to anyone who submits a sample (S. Wallce, J. Harms, pers. comm.). Health surveillance of wild sheep and goats greatly increases the probability of detecting *M. ovipneumoniae* in harvested herds in the early stages of an outbreak, potentially allowing it to be contained before spreading widely though wild populations. It may also allow managers to better identify the original source of the pathogen (e.g., a local farm or cross-border spread) and respond accordingly.

Knowledge gaps

There are several unknowns related to *M. ovipneumoniae* and other forms of pneumonia in wild and domestic sheep and goats. Knowledge gaps considered especially relevant to risk assessment of northern populations are discussed below.

1. Northern knowledge and pneumonia in thinhorn sheep: Most of the recent research found relating to pneumonia in wild sheep discussed bighorn sheep in the USA (and not Alaska). Though these studies provide valuable information on the potential dynamics and severity of pneumonia outbreaks, they take place under different climatic and environmental conditions than

exist in the north. Also, though they are closely related to bighorn sheep and there are case studies suggesting their vulnerability to respiratory disease, it is not known how wild thinhorn sheep populations will respond to pneumonia pathogens. The scarcity of research on thinhorn sheep also means that there is little knowledge about how an outbreak of respiratory disease may interact with conditions such as demographics, connectivity, and environmental stressors to influence the population. Given the lack of known pneumonia outbreaks in thinhorn sheep, filling these knowledge gaps may not be currently possible. However, additional herd health assessments are important. With the remoteness of most thinhorn populations, encouraging hunters and outdoor enthusiasts to report if they find ill or dead animals, and evaluating and publishing information on thinhorns will help increase the knowledge base across the north. It is also important to partner with local communities, Indigenous groups, NGOs and neighbouring jurisdictions such as Alaska and BC to facilitate information sharing on health issues and, specifically, respiratory-related mortalities. This may also provide shared research and management opportunities for cross border sheep populations.

Another knowledge gap related to thinhorn sheep is the health and potential presence of pneumonia or other pathogens in remote populations. Most of the Yukon wild sheep tested thus far have been harvested in the Whitehorse area. It is recommended that YG target further education and provision of test kits to hunters in smaller communities and Indigenous groups (C. Wong, pers. comm.). This will allow for more comprehensive assessments of sheep health and pneumonia in the territory.

2. Mountain goats – population health and response to respiratory pathogens: Multiple documents from the literature review stated that little research is available about respiratory disease in mountain goats, or that more research is required to assess the impact of respiratory

pathogens on this species (Blanchong et al. 2018, Wolff et al. 2019, Gude et al. 2022). In addition, all of the studies found relating to pneumonia in mountain goats took place in the USA, emphasizing the need for further research on northern populations. There is also relatively little knowledge about mountain goat health and populations in the Yukon. Only 13 mountain goats have been tested for *M. ovipneumoniae* since 2018. Knowledge of mountain goats will likely benefit from the same recommendations given for thinhorn sheep; including close monitoring of populations for disease (where possible), investigation of and publication of information about pneumonia-related mortalities, and forming cross jurisdictional partnerships for management and knowledge sharing.

3. Wild sheep forays and habitat connectivity: Wild sheep, particularly males, may foray making short term, often long-distance departures from their regular home range. This provides potential opportunities for contact between wild and domestic animals and related pathogen transfer. However, there has been limited research exploring the relationship between wild sheep forays and pneumonia outbreaks (Paolini et al. 2023). Further understanding of the reasoning and timing behind wild sheep forays, in particular for thinhorns, may help to predict where they will go, if these areas overlap with disease-carrying wildlife or livestock, and how habitat alteration may be used to prevent pathogen transmission (Whiting et al. 2023). Bryan MacBeth, a Wildlife Ecologist/Veterinarian from Parks Canada also emphasized the importance of understanding the range and connectivity of wild sheep and goat populations to help manage and mitigate pathogen transfer (B. Macbeth, pers. comm.). An emphasis on population surveys and radio collaring studies of thinhorn sheep and mountain goats in the Yukon may help fill knowledge gaps related to sheep range and habitat connectivity. This may also help managers understand potential changes in range due to climate or disturbance. For example, it is unclear how the high level of

drought and wildfires across northwest Canada in 2023-2024 will influence wild sheep and goat health or risk of contact with domestic animals (Government of BC Ministry of Agriculture, pers. comm.).

4. Limitations to *M. ovipneumoniae* testing: A review of *M. ovipneumoniae* testing methods is beyond the scope of this report, as it is being explored in detail by another group. However, the subject of testing inconsistencies was raised both in the recent literature and during expert interviews. Lieske et al. (2022b) reported that detection rates for *M. ovipneumoniae* varied by laboratory and specific technique. In their study, three types of PCR assays were used to test for *M. ovipneumoniae* in Dall's sheep and mountain goats, only one of which yielded positive results (Lieske et al. 2022b). The three different assays assessed different locations and lengths along the 16S rRNA gene which may be part of the disagreement. An interviewee from the Government of BC WLRS also noted that test results from different labs may vary and that animals tested multiple times do not always have consistent results. Such inconsistencies increase uncertainty about the potential presence of *M. ovipneumoniae* in Yukon wild sheep and goat populations as well as the prevalence of this pathogen in domestic flocks.

Recommendations

Continued surveillance and mitigation measures in the Yukon

Given the potential consequences of respiratory disease in wild populations, we recommend that YG continue mitigation and control measures to prevent pathogen transmission from domestic to wild sheep and goats. The detection of *M. ovipneumoniae* in domestic sheep and goats reinforces the need for control measures to prevent pathogen transmission. We recommend that measures currently associated with the Control Order including enclosure, transport, and import requirements, testing of domestic sheep and goats, use of the sheep and goat owner registry, and

public education be continued. However, considering the increased knowledge about domestic sheep and goats in the Yukon since the establishment of the Control Order, the hardship that mandatory culling of *M. ovipneumoniae*-positive animals causes to sheep or goat owners, and the recommendation of multiple interviewees, it may be beneficial to re-evaluate whether the level of risk and related requirements should be considered equal in all locations.

Other regulations

Grazing tenures

Currently, Yukon Grazing Agreements may only be used for cattle. However, other tenure types have been discussed for the territory (YG Agriculture Branch, pers. comm.). If any new tenure types are established where domestic sheep and goats may be used, we recommend that the assessment of tenure applications include an evaluation of the risk of these animals coming into contact with wild populations. Reviewers should be provided with information about the potential for respiratory pathogen transmission from domestic to wild sheep and goats to allow for adequate consideration of risk during the assessment process. We also recommend that tenures not be granted within or adjacent to known thinhorn sheep or mountain goat range. This is supported by Jex et al. (2016) who recommend that any review of applications for land tenure use or expansion for keeping domestic sheep or goats should consider whether or not the tenure overlaps known wild sheep or goat habitat.

Translocation

We recommend that policy and procedures be established for translocations of wild sheep or goats in the Yukon. Even if there are currently no plans for translocations in the territory, establishing guidance will aid appropriate management if herds must be supplemented or reintroduced. Requirements should include actions to ensure that source and recipient

populations undergo thorough herd health assessments and monitoring following recognized standards. Organizations such as the International Union for Conservation of Nature and WAFWA have published guidelines for species translocations that may be useful sources when developing local requirements (Wild Sheep Working Group 2012, IUCN/SSC 2013).

Use of sheep or goats in non-farm settings

We recommend that YG identify and regulate any situation where sheep or goats may be kept or used in non-farm settings. Examples include:

- **Agricultural fairs**: YG should identify any agricultural fairs that take place in the territory (or are planned in future) and ensure that sheep and goats involved are required to be healthy, *M. ovipneumoniae*-negative, and kept in secure enclosures.

- **As pack animals:** Consider banning the use of domestic sheep or goats as pack animals in known wild sheep or goat habitat. Alternatively, consider putting rules in place to limit the chance of exposure between these animals and wild populations (e.g., requiring that domestic sheep or goats be kept in approved pens (potentially electrified) at campsites when not in use).
- **For vegetation management:** Sheep and goats have been used in many jurisdictions to graze clearcuts and tree plantations to reduce vegetative competition. The Control Order has largely prevented such activities from taking place in the Yukon (YG Agriculture Branch, pers. comm.). However, if there is desire to allow the use of sheep or goats for vegetation management, we recommend that YG seek guidance from other jurisdictions through documents such as the *Health Certification Protocol for Sheep and Goats Used*

for Vegetation Management in British Columbia or Alberta (Government of British Columbia 2021). This document includes requirements and recommendations such as:

  - Animals to be used for vegetation management must be inspected by a team including a licenced veterinarian within 30 days of departure to the worksite.
  - Animals may only be certified if they meet a list of requirements related to health, age, vaccinations, and parturition status (though *M. ovipneumoniae* testing is not currently required).
  - A minimum of 50 km separation must be maintained between vegetation treatment sites and known Stone's sheep range.
  - Managers must immediately report contact between wild and domestic sheep and goats.
  - Veterinary health certificates, individual animal identification records, and a livestock transportation manifest must be transported with domestic flocks.

- **As pets or emotional support animals.** YG should ensure that residents and visitors to the Yukon are made aware that they may not bring any sheep or goats into the territory unless they have tested negative for *M. ovipneumoniae* and are kept in secure enclosures for the entirety of their stay.

In general, we recommend that all government staff dealing with environmental, agricultural, or remote harvesting developments be made aware of the risk of disease transmission from domestic to wild sheep and goats. This will allow staff to flag any proposed non-farm uses of these animals for further consideration.

Export of *M. ovipneumoniae* positive animals

We recommend that any animals exported from the territory due to a positive *M. ovipneumoniae* test be required to be moved to areas outside of wild sheep or goat range (including both bighorn and thinhorn sheep range). Movement of *M. ovipneumoniae* positive animals to locations where they may come into contact with wild populations could lead to disease transmission to local wildlife or even back into the Yukon through cross border populations.

Transportation due to natural disaster

In the case of natural disasters such as flood or fire, sheep or goat owners may be required to evacuate to other communities at short notice. YG should be aware that owners in such cases may be transporting their flocks without a permit or stop in areas without approved enclosures. In addition, owners may release their animals into damaged enclosures once they return home. We recommend that YG consider establishing procedures for the identification and safe containment of domestic flocks that may have been evacuated to Yukon communities due to natural disaster.

Cross jurisdictional communication and partnerships

Individuals from expert interviews expressed concern that information about the Control Order and testing and results are not shared with them directly. Interviewees also suggested that there be communications with neighbouring jurisdictions such as Alaska to share information on management and monitoring results. Communication among the Yukon, Alaska, BC, and NWT governments and Indigenous groups may also facilitate the formation of partnerships for monitoring or management initiatives of cross border populations. Therefore, we recommend that YG establish procedures to share information related to the Control Order and related programs directly with Indigenous groups and stakeholders relating to wild or domestic sheep

and goats in the north. This includes other government organizations (such as Parks Canada), communities, RRC's, guide outfitting, tourism, and non-government organizations. Increasing the involvement of Yukon organizations such as RRCs in planning and decision making related to control measures may also aid communication, as well as giving YG ongoing access to information about sheep, goats, and the impact of control measures on communities across the territory.

Research and Monitoring

Wild sheep and goat range and population connectivity

We recommend that GPS collars be deployed on wild sheep and goat herds across the Yukon. Collaring data and a full suite of biological samples will provide useful information on herd health, mortality factors, and movement including:

- Increased knowledge of population connectivity between different herds (and between wild sheep and goat populations) and related risk of pathogen transmission.

- Increased knowledge of wild sheep and goat movements relative to domestic sheep and goats. This will help YG to identify areas where pathogen transmission is more likely to occur due to domestic and wild sheep and goats being in proximity.

- Opportunity for increased mortality investigations. If a collared animal dies, YG will be able to locate the carcass and investigate the cause of death in a timely manner. This not only allows for potential detection of pneumonia in a population, but also other health stressors that may influence vulnerability to disease outbreaks.

Increased inventory and health surveillance of sheep and goats across the Yukon

We recommend that *M. ovipneumoniae* testing and general herd health surveillance of wild sheep and goats be continued across the Yukon. We recommend that YG perform targeted outreach, enhancing training and test kit provision to hunters and Indigenous groups outside of the Whitehorse area to expand sampling of harvested populations. We also suggest a targeted effort to expand sampling of mountain goats as, to date, far fewer tests have been performed on this species than thinhorn sheep. Expanding the range of testing will increase the probability of early detection of *M. ovipneumoniae* in mountain goats and remote thinhorn populations. We also recommend regular baseline health and population surveys of both thinhorn sheep and mountain goats.

Development of an outbreak response plan

We recommend that YG develop a comprehensive plan for response and management of a respiratory disease outbreak in wild sheep or goats. This plan should include procedures to monitor and control disease spread, whether detected in a single animal or as part of a larger outbreak. The plan should clearly describe a command structure and communications procedures from the time that pneumonia is detected throughout management and population recovery. Some questions to consider include:

- Who should be contacted if *M. ovipneumoniae* or respiratory symptoms are identified in wild sheep or goats in the Yukon?
- What further investigations are required to determine the best course of management?

- What are the procedures if an animal tests positive for *M. ovipneumoniae*? What are the procedures if someone reports wild sheep or goats displaying symptoms of respiratory disease (coughing, runny nose etc.) or unusual mortalities in local herds?

- Who is responsible for communications and leading management actions?

The appropriate response to a pneumonia outbreak will depend on factors such as the identification of the pathogen(s) involved, the size and location of the impacted population, how many individuals appear to have been infected, and whether they are likely to contact neighbouring herds. Information from the research and monitoring activities suggested above, particularly collaring studies, may help inform managers as to the best response to an outbreak. In the case of a serious outbreak, culling at some scale may be required to prevent widespread mortality and persistent suppression of lamb recruitment. Having response plans in place will help YG and other agencies quickly establish the necessary programs and communications for such action.

General habitat protection and enhancement

Multiple interviewees discussed the need for general protection or enhancement of wild sheep and goat habitat. Though not specifically connected to respiratory disease, having access to a range of high-quality habitat will increase the health and resiliency of sheep and goat populations in the Yukon and northern BC. It will provide greater opportunity for sheep and goats to move to alternative locations if stressors such as predation or low forage levels are present in certain regions. As such, we recommend that YG have programs in place to limit development and fragmentation of high-quality sheep and goat habitat and consider actions for habitat enhancement (e.g., prescribed fires) in areas of concern.

Conclusion

Given the small population of domestic sheep and goats in the Yukon and mitigations established through the Control Order, the likelihood of pathogen transmissions from domestic to wild sheep and goats is considered low compared to more southern jurisdictions. However, the potential severity of a pneumonia outbreak in wild sheep or goats in the Yukon or northern BC is considered high. The naïvety of northern wild sheep and goat populations to pathogens from domestic small ruminants, considered alongside significant pneumonia related die-offs recorded in bighorn sheep in southern Canada and the USA, suggests potential population declines of 50% or greater in populations exposed to respiratory pathogens of concern. So far, *M. ovipneumoniae* has not been detected in thinhorn sheep or mountain goats in the Yukon nor northern BC but has been identified in domestic sheep and goats. There is potential for *M. ovipneumoniae* or other respiratory pathogens to be transferred to wild sheep or goat populations from local domestic flocks or from cross border or neighbouring wild populations in Alaska, BC or the NWT.

The Control Order has reduced the risk of pathogen spread between domestic and wild sheep and goats in the Yukon via reducing the number of *M. ovipneumoniae* positive animals in the territory, increasing government and public education about the risk and prevention of disease transfer between domestic and wild populations, and establishing requirements related to enclosures, import, testing, and transportation of domestic sheep and goats. Information from both literature review and expert interviews strongly supports the need for ongoing mitigation measures. Research such as GPS collaring studies to determine habitat extent and connectivity, continued health and population monitoring of wild sheep and goats, creation of an outbreak response plan, and development of regulations or policies related to translocations, grazing agreements, the export of *M. ovipneumoniae*-positive animals, management of domestic flocks

displaced due to natural disaster, and the use of domestic small ruminants in non-farm settings may help decrease the risk of a respiratory-disease outbreak in Yukon thinhorn sheep and mountain goats in the future as well as the ability to detect and manage one if it occurs.

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Appendix 1: Additional Methods – Literature prioritization and data collection

Given limited project hours, SMC considered it prudent to develop a system for prioritising documents for review. Documents were sorted into three main categories (Table 8):

- Priority 1: Documents directly relating to respiratory disease in thinhorn sheep and mountain goats in the Yukon, northern BC, Alaska, or the NWT (the main study area). Recent population trends or other health threats in the Yukon.
- Priority 2: Documents discussing respiratory pathogens in bighorn sheep in Canada. Any studies of respiratory disease in mountain goats in Canada or the USA given the small amount of scientific literature available on this subject.
- Priority 3: Documents relating to thinhorn sheep, or bighorn sheep outside of the main study area. Also, literature not specifically related to respiratory disease, such as habitat selection and other threats.

Note that project team members were not restricted to the prioritization scheme if they deemed that further information on any particular subject was necessary. In addition, researchers were free to find information on related subjects (such as the value of thinhorn sheep to northern Indigenous groups) as required.

Table 8: Prioritization categories and criteria for systematic literature search for the Risk Assessment of Respiratory Pathogen Transmission from Domestic Small Ruminants to Thinhorn Sheep and Mountain Goats in the Yukon and Northern British Columbia (2024).

	Priority 1	Priority 2	Priority 3
Species	• Thinhorn sheep (any subspecies) • Mountain goat	• Bighorn sheep • Mountain goat	• Thinhorn sheep • Mountain goat • Bighorn sheep
Location	• Yukon • Alaska	• Yukon • Alaska	• All of Canada or the USA

	• Northwest Territories • Northern BC • Northern Alberta	• Northwest Territories • BC • Alberta	
Subject	• Any variety of pneumonia in wild or domestic sheep and goats (including treatments and risk factors) • Interactions between wild and domestic sheep or goats • Disease spread between domestic and wild sheep or goats. • Range overlap between wild and domestic sheep and goats • Suggested mitigation measures to prevent disease transmission or manage outbreaks	• All priority 1 subjects but with reference to bighorn sheep rather than thinhorn sheep or mountain goats • Wild sheep mortality (thinhorn or bighorn) not specifically linked to pneumonia • Respiratory disease in mountain goats from anywhere in Canada or the USA*	• All priority 1 subjects but outside of the target study area • Sheep or goat population trends and threats to the species (not related to pneumonia)

*There has been little research on respiratory disease in mountain goats and none was found from the priority study area. To ensure that information on mountain goats was included, any literature on respiratory disease in this species was considered priority 2, regardless of study location.

Appendix 2: Interview list

Table 9: Individuals interviewed as part of the Risk Assessment of Respiratory Pathogen Transmission from Domestic Small Ruminants to Thinhorn Sheep and Mountain Goats in the Yukon and Northern British Columbia (2024). Names listed as "credit to organization" if the interviewee requested that the information shared to be credited to their organization, rather than by name. Note that SMC reached out to several other individuals or groups that either declined or did not reply to interview requests.

Name	Position	Organization	Date
Credit to organization	Program Veterinarian	YG Animal Health Unit	April 2, 2024
Carmen Wong	Ecologist, Team Leader	Parks Canada – Kluane National Park	April 11, 2024
Spencer Wallace	President	Yukon Wild Sheep Foundation	April 13, 2024
Naima Jutha	Chief Veterinary Officer	Government of the NWT	April 17, 2024
Bryan Macbeth	Wildlife Ecologist/Veterinarian	Parks Canada – Banff National Park	April 18, 2024
Credit to organization	Mammalian Pathologist	Government of BC Ministry of Agriculture	April 22, 2024
Credit to organization	Wildlife Veterinarian	Government of BC WLRS	April 25, 2024
Dan Reynolds	Co-chair	Dawson RRC	April 25, 2024
Sian Williams	Co-chair	Dan Kay RRC	April 27, 2024
Jeremy Ayotte	Program Coordinator	BC Sheep and Goat Separation Program	May 1, 2024
Credit to organization	CEO	BC Guide Outfitters Association	May 13, 2023
Mark Nassiopoulos	Co-Chair	Alsek RRC	May 15, 2024
Credit to organization	Wildlife Veterinarian	Alaska Department of Fish and Game	Provided written feedback
Credit to organization	Grazing Management Coordinator	YG Agriculture Branch	May 27, 2024
Bill Jex	Provincial Wild Sheep & Mountain Goat Specialist	Government of BC WLRS	May 27, 2024
Credit to organization	Member	Western Association of Fish and Wildlife Agencies - Wildlife Health Committee	May 30, 2024
Credit to organization	Wildlife Administrator	Tahltan Nation	June 10, 2024

Credit to organization	Staff	White River First Nation	Provided written statement
Jane Harms	Program Veterinarian	YG Animal Health Unit	June 12, 2024
Helen Schwantje	Retired Provincial Veterinarian	Government of BC	NA*

*Dr. Schwantje was never formally interviewed as she was part of the project team. However, she provided a variety of information from her personal experience and expertise for this report.

Appendix 3: Standard question lists for interviews

Below are the standard question lists used for expert and knowledge holder interviews. Note that the actual question lists varied based on interviewee knowledge, interest, and experience at the discretion of the interviewer. For example, several interviewees discussed bighorn rather than thinhorn sheep and interviews with the department of agriculture focussed mostly on domestic sheep and goats.

Technical specialists

Introduction:

In 2024, the Yukon Government hired Shifting Mosaics Consulting to perform a risk assessment of the transmission of pneumonia causing pathogens from domestic sheep and goats to wild thinhorn sheep (*Ovis Dalli*) and mountain goats (*Oreamnos americanus*) in the Yukon and northern British Columbia. This project is also intended to assess the efficacy of the Yukon Sheep and Goat Control Order in preventing the spread of disease between domestic and wild sheep and goats. It expands on a similar risk assessment from 2016.

Below is a question list for knowledge holder interviews related to the 2024 risk assessment. This list is intended for individuals with technical training or expertise in the area of wild or domestic sheep or goat health and epidemiology such as veterinarians, biologists, and government staff.

Question #1: Are pneumonia-causing pathogens, or other diseases and health risks to wild sheep and goats present in the Yukon or northern BC?

- Are you aware of any outbreaks of pneumonia or other diseases in wild sheep or goats in the Yukon or northern BC? Where and when?
- What pathogens are causing these diseases (if you know)?

- Are you aware of any other die-offs or occurrences of unusual mortality in wild sheep or goats in the Yukon or northern BC since 2015? Where and when?
- Do you know what are causing these mortalities?
- Can you direct us to any documentation about these outbreaks or unusual mortalities?

Question #2: Are thinhorn sheep in the Yukon or northern BC susceptible to adverse effects of pneumonia? Is there anything else affecting the health of wild sheep and goat populations?

- How do you think pneumonia could affect wild sheep and goat populations?
- What factors may influence the severity of pneumonia to thinhorn sheep or mountain goats?
- Do you know of any other factors impacting the health of wild sheep or goat populations in the Yukon or northern BC?

Question #3. Do the conditions and circumstances exist for the Yukon or northern BC thinhorn sheep or mountain goats to be exposed to pneumonia-causing organisms from domestic sheep or goats?

- Do you know of anywhere that thinhorn sheep or mountain goats are known to occur close to domestic sheep or goats in the Yukon or northern BC?
- Do you know of any specific incidences where wild sheep or goats have had close contact with domestic sheep or goats?
- Are you aware if there has been transmission of pathogens from domestic sheep or goats to wild sheep or goats?

Question #4: What is the potential magnitude of effects of a pneumonia outbreak in thinhorn sheep or mountain goat?

- How interconnected are thinhorn sheep and mountain goat populations in the Yukon or northern BC? Are mountain goats and thinhorn sheep likely to come into contact?
- What impact do you think that an outbreak of pneumonia in wild sheep or goats would have on:
    - Yukon or northern BC tourism and economy
    - First Nations
    - The environment, particularly mountain ecosystems
    - Hunters and guide outfitters
    - Domestic sheep and goat farmers

Question #5: Can effects of or risk of pneumonia in wild sheep or goats be prevented, treated, or mitigated?

- Are there vaccines or treatments available for pneumonia that can be effectively delivered to free-ranging wild sheep and goats?
- Are there vaccines or treatments available for pneumonia that can be effectively administered to domestic sheep and goats?
- Are there other mitigation strategies that can prevent pneumonia transmission from domestic sheep or goats to wild sheep or goats?
- What control measures are there for preventing pathogen transmission between wild sheep and goats in the Yukon or northern BC?
    - Do you think that it is effective in preventing exposure of wildlife to pathogens from domestic sheep and goats?

- Is there anything that you would change?

Question #6: What are the uncertainties in estimating probability of exposure of thinhorn sheep or mountain goats to pneumonia-causing pathogens from domestic sheep and the potential impacts from transmission?

- Can you think of any knowledge gaps about pneumonia in thinhorn sheep and mountain goats? For example:
  - Estimating exposure of wild sheep and goats to domestic sheep and goats in the Yukon or northern BC.
  - Impacts of disease transmission (what would you expect pneumonia to do to the population?)
  - Impacts of reduced wild sheep or goat population on social factors (hunting, tourism etc.)

Other

- Is there anything else that you think we should know about thinhorn sheep, mountain goats and pneumonia?
- Is there anyone else that you recommend we talk to?
- Do you have any data or documents that you can refer us to or are willing to share?

Indigenous groups and Renewable Resource Councils

Introduction:

In 2024, Yukon Government hired Shifting Mosaics Consulting to perform a risk assessment of the transmission of pneumonia-causing pathogens from domestic sheep and goats to wild thinhorn sheep (*Ovis Dalli*) and mountain goats (*Oreamnos americanus*) in the Yukon and northern British Columbia. This project is also intended to assess the effectiveness of Yukon Sheep and Goat Control Order in preventing the spread of disease between domestic and wild sheep and goats. It expands on a similar risk assessment from 2016.

Below is a list of questions for interviews with representatives of Indigenous groups or Renewable Resource Councils. The intent of interviewing these groups is to:

- Help assess the cultural, economic, and subsistence significance of thinhorn sheep and mountain goat to indigenous groups.
- Gather information on changes in northern thinhorn sheep or mountain goat populations over time.
- Gather on-the-ground observations of thinhorn sheep health (disease presence, body condition etc.).
- Help assess the impact that an outbreak of pneumonia in thinhorn sheep/mountain goats may have on Indigenous groups.

Information for Interviewees:

The information that you share will be used in the project report looking at this risk of disease transmission between domestic and wild sheep and goats, and what this would mean for the Yukon and northern BC. This report will be available to the public. However, we will not use

your name or exact words without permission. Recordings will be transcribed, stored in Shifting Mosaics and Yukon Government files, then provided to your community (or RRC) once the project is complete.

Intro Questions:

- What is your name?
- What community are you from?
- What is your position with the Renewable Resource Council (if applicable)?
- Are you ok with having your voice recorded? Shifting Mosaics and Yukon Government will use information shared in the recording for the final report of this project.
- Are you ok with having your name or exact words used in the project report? Or would you rather the information you share be used anonymously?

Objective 1: Help assess the cultural, economic, and subsistence significance of thinhorn sheep and mountain goat to indigenous groups.

- How important are wild sheep and goats to your community?
- How do people in your community use wild sheep and goats?
- Do your community members hunt wild sheep or goats for food? Is it a major source of meat or other supplies?
- Are any of your community members guide outfitters who guide sheep hunts?
- Do people from outside of the Yukon ever stop or stay in your community on their way to see or hunt wild sheep or goats?
- Do any of your community members sell wild sheep or goat crafts (from bone, hide etc)?
- Do you have any stories about wild sheep or goats that you are willing to share?

Objective 2: Gather first-person observations of thinhorn sheep or mountain goat populations over time.

- Are there any domestic sheep or goats herds around your community?
- Have you or other community members noticed wild sheep or goat populations changing over time? Which herd/where have you seen this?
    - Are the populations bigger or smaller?
    - Do they live in different places?
    - Why do you think that is?
- Have you or other community members ever seen wild sheep and wild goats spending time together? When and where?
- Have you or other community members ever seen wild sheep or goats close to or in contact with domestic sheep or goats? Where and when?
- Has anyone told you that they have seen wild sheep or goats in or near your community?

Objective 3: Gather first-person observations of thinhorn sheep health (disease presence, body condition etc.).

- Do you know of any sicknesses in wild sheep or goats recently? Have you or other people seen wild sheep or goats with runny noses, coughs, or other symptoms? Where and when?
- Do you know of any unusual deaths of wild sheep or goats in the last few years? Where and when?
- Do you know what caused these animals to die?

Objective 4: Help assess the impact that an outbreak of pneumonia in thinhorn sheep/mountain goats may have on Indigenous groups.

- What do you think a large disease outbreak in wild sheep or goats would mean for your community or Nation?

Other

- Is there anything else that you think we should know about wild sheep and goats or wildlife disease?
- Are there any other questions we should have asked?