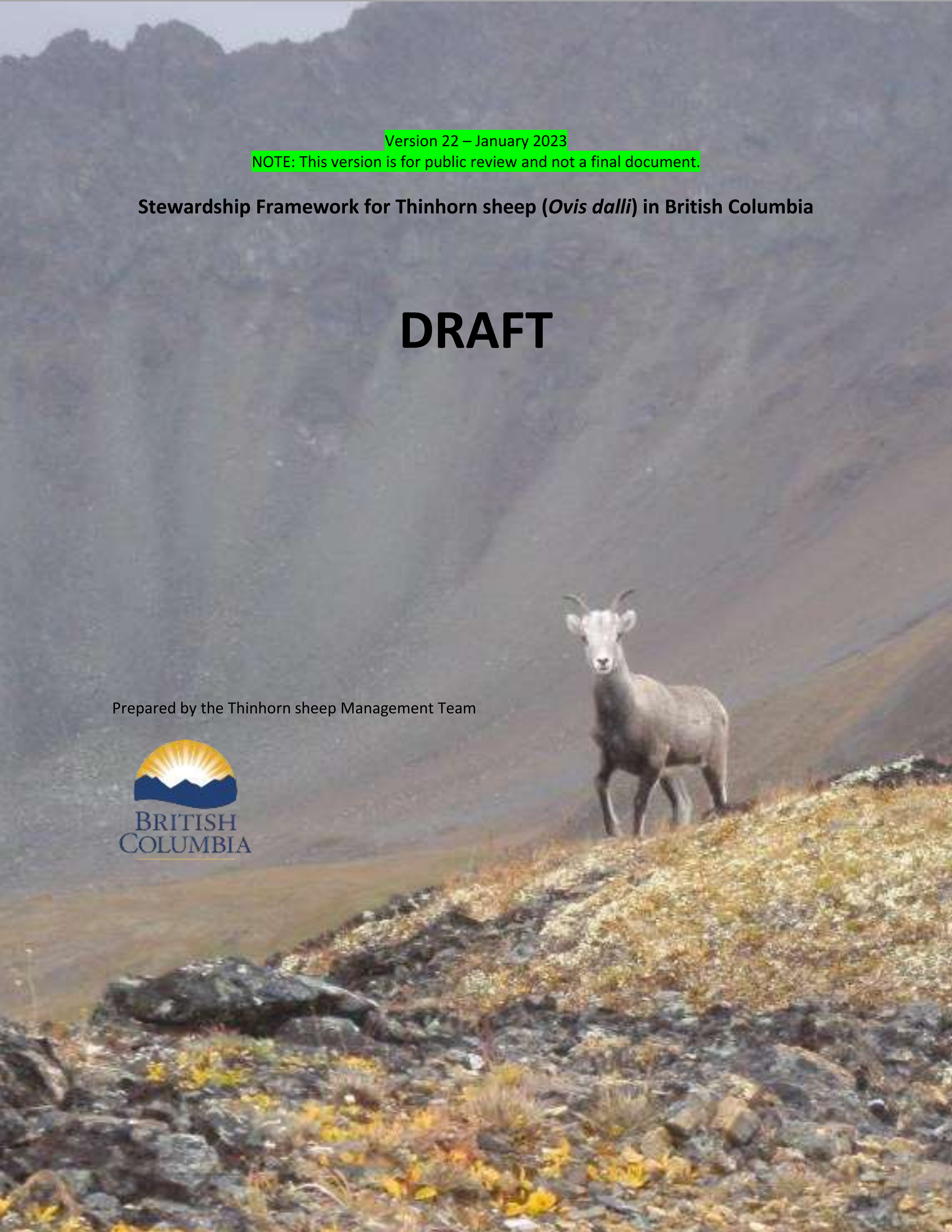


Version 22 – January 2023
NOTE: This version is for public review and not a final document.

Stewardship Framework for Thinhorn sheep (*Ovis dalli*) in British Columbia

DRAFT

Prepared by the Thinhorn sheep Management Team

BRITISH COLUMBIA

Contents

Cover Photo: Bill Jex

Purpose Statement

The Stewardship Framework for Thinhorn Sheep in British Columbia (BC) is intended to provide managers and decision makers with scientifically supported guidance for the management of Thinhorn sheep and their habitat. The Framework updates Thinhorn sheep distribution and abundance information found in the 1978 Preliminary Mountain Sheep Plan for British Columbia[1] and the 2004 Status of Thinhorn Sheep in British Columbia[2]. Provincial-level management recommendations have been developed from current science on emerging issues that affect Thinhorn sheep. The management framework and strategies that are currently in use in BC are outlined within the context of other jurisdictions to support recommendations and priorities for future management directions. These directions may be modified in response to shifting social values, emerging science, changing climates, and regional Indigenous and stakeholder perspectives. Success in the conservation of this species depends on the commitment and cooperation of many different constituencies that may be involved in implementing the directions set out in this Stewardship Framework.

Please also note that in this document, populations are described as *population groups* or *population units*. This was done to avoid confusion with the Provincial Allocation Policy that uses the term *Population Management Units*. This Stewardship Framework was not specifically developed as an allocation process tool, hence the distinctions.

Acknowledgements

We thank Jeremy Ayotte (lead-author) and Kim Poole (external science review) for their expertise and diligence in assisting with the development of this Provincial stewardship document. Thanks also to the First Nations-BC Wildlife & Habitat Conservation Forum for offering comments and suggestions that supported inclusion of Indigenous knowledge and cultural understandings, and special thanks also to those communities who shared local knowledge and their stores of cultural relationships to wild sheep (a list to First Nations contributors is provided in the Personal Communications section of this document). Finally, thanks to: Dr's Helen Schwantje and Caeley Thacker; the Wild Sheep Society of B.C., Guide Outfitters Association of B.C., the B.C. Backcountry Hunters and Anglers and the B.C. Wildlife Federation for providing editorial comments earlier on draft versions.

We also thank the Habitat Conservation Trust Foundation and the Together For Wildlife program for support funding that facilitated external supports and community engagement.

List of Authors

Authors: Jeremy Ayotte, Bill Jex, Morgan Anderson, Mike Bridger, Krystal Kriss & Andrew Walker.
Independent Reviewer: Kim Poole.
Indigenous Perspectives Authors: Bill Jex, Sydney Goward and Hunter Lampreau, with the support of the Thinhorn Sheep Indigenous Perspectives Working Group (Tom Aird, Cynthia Burke, Ryan La Pointe, Katherine Wolfenden)[3].

Suggested citation: MOF. 2022. Stewardship Framework for Thinhorn Sheep (*Ovis dalli*) in British Columbia. Thinhorn Sheep Indigenous Perspectives and Thinhorn Sheep Management Teams. Prepared for the Fish & Wildlife Branch, British Columbia Ministry of Forests, Victoria, BC. 69 Pp.

---

[1] Demarchi et al. 1978.
[2] Demarchi & Hartwig 2004.
[3] The Blueberry River First Nation was provided regular updates on the efforts of this working group.

Introduction

Alpine specialists of the most remote mountain wilderness, Thinhorn sheep (*Ovis dalli*) provide important ecological, economic, and cultural value across northern British Columbia (BC; Jex et al. 2016, WSF 2008, Kuzyk et al. 2012). The population of Thinhorn sheep in BC includes two subspecies, Stone's sheep (*O. dalli stonei*) and Dall's sheep (*O. dalli dalli*). Recent genetic research has shown that almost the entire global population of Stone's sheep are within BC's borders (Sim et al. 2016, Sim et al. 2018), elevating the already significant obligation of the Province to ensure proactive, effective and sustainable management.

Thinhorn sheep are globally considered an iconic wildlife species that symbolizes remote mountain wilderness, and are important to British Columbians as a species of social and cultural significance that can be harvested for food, and that provides both visual appreciation and trophy values. Relative to any other wildlife species, Thinhorn sheep contribute significantly to BC's northern economy through big-game hunting related revenues and tourism, offering important contributions to remote northern communities. Stone's sheep are often visible from roadsides around Muncho Lake and Stone Mountain Provincial Park off Highway 97 and around Edziza and Spatsizi Provincial Parks off Highway 37. Dall's sheep in BC are expectedly more difficult to view, although there are opportunities at Mount Mansfield along the Haines Highway and in Tatsenshini-Alsek Provincial Park.

Thinhorn sheep have very specific habitat requirements: windblown snow-free alpine plateaus and slopes as winter range, mineral licks, and steep rugged terrain that provides escape terrain for evading predators, especially during parturition and natal periods to provide safety for newborn lambs (Geist 1971, Worley et al. 2004). As with all wild sheep, Thinhorn sheep exhibit high fidelity to seasonal ranges (Geist 1971, Festa-Bianchet 1986). The behaviours and adaptations that enable Thinhorn sheep to survive the severe weather and forage limitations typically found at high elevations in northern latitudes can also make them vulnerable to anthropogenic disturbances and the effects of climate change (Kerk et al. 2020).

Bailey and Hurley (2000) identified the most significant limiting factors affecting Thinhorn sheep as severe winters, disease from domestics, motorized access, wildfire suppression/forest encroachment, and predation. Competing land-use practices such as oil and gas extraction, mineral exploration and mining, and commercial backcountry recreation in areas important to Thinhorn sheep, as described by Paquet and Demarchi (1999) continue to increase today, some 30 years later. This along with conflicting goals, strategies and legislation among government sectors with shared resource management responsibilities also hinders the effectiveness of habitat conservation and management for Thinhorn sheep (Jex et al. 2016). The cost and logistics to routinely monitor Thinhorn sheep in remote wilderness areas of BC at a scale sufficient to accurately define herd range boundaries, designate population management units (PMUs), and track demographic and population trends are prohibitive and poses a significant challenge to conservation and management. Consequently, historical management in BC has relied on sparse data to define geographic populations, range connectivity, and trends in demographics, abundance and distribution. Observations on behaviour and habitat associations have been collected in BC since the 1950's but recent technological, methodological, and analytical advances are emerging to guide and support more effective Thinhorn sheep management planning in BC.

Thinhorn Sheep, a Collaborative Initiative - relationships to Indigenous Perspectives, Governance, Worldviews, Knowledge & Laws

In 2019, British Columbia unanimously passed the Declaration on the Rights of Indigenous Peoples Act (the "Declaration Act"), which legislates the implementation of the United Nations Declaration on the Rights of Indigenous Peoples ("UNDRIP") articles. The Declaration Act aims to create a path forward that respects the human rights of Indigenous peoples, while seeking to create better transparency and predictability. In implementing the Declaration Act, the Province, in cooperation and consultation with the Indigenous peoples of BC, will take measures necessary to align the laws of BC with UNDRIP, and ensure implementation is sufficient and lasting. The Declaration Act's Action Plan (Section 4) is currently under development, and it is unknown where or when the Wildlife Act will be aligned with UNDRIP. However, the opportunity exists through this Thinhorn Sheep Stewardship Framework (the Framework) to further the implementation of the Declaration Act[4] by recognizing Indigenous governing bodies and the important role they play in the management of Thinhorn sheep, in conjunction with the development of an Ethical Space[5] between Western Science and Indigenous Knowledge.

This Ethical Space will promote learning through interactions and intersections of Western Science and its associated management processes and Indigenous Knowledge, culture and practices. Indigenous Peoples' relationships, culture, practices and knowledge have developed over thousands of years in association with wildlife populations specific to habitats, areas and watersheds within each respective Traditional Territory. The First Nations - BC Wildlife & Habitat Conservation Forum (the "Forum") identifies and expresses that, "*all of life is interconnected is a worldview that guides the way in which Indigenous Peoples see themselves as part of the Natural World*", and that "*the Earth is our Mother and that everything on Mother Earth has a spirit*"[6]. In this regard these views provide context to aid in an understanding and in identifying common ground for how Indigenous Peoples see themselves and their role in Thinhorn sheep management.

The Declaration Act's purpose also includes supporting the affirmation and development of relationships with Indigenous governing bodies (Section 2.c). Indigenous governing bodies currently exist across the Province and are in a state of reintegration as Indigenous Peoples and Nations rebuild, creating a more collaborative comprehension and recognition of Indigenous laws, authority, jurisdiction, knowledge and culture. The Declaration Act further identifies (Section 7) the ability of the Province to enter into agreements with Indigenous governing bodies for the purpose of joint decision-making and/or to identify accommodations and obtain the consent of the Indigenous governing body before enacting some statutory decisions. The Thinhorn Sheep Stewardship Framework seeks to incorporate and recognize Indigenous Peoples' role in the delivery of co-management and stewardship with respect to managing resource values within their territories. The Framework does not prescribe or propose how

---

[4] *Declaration on the Rights of Indigenous Peoples Act*, SBC 2019, c 44, articles 5, 16, 24, 26, 27, 29, 31, 32 [DRIPA].

[5] Ethical Space is defined by Scholar Willie Ermine of the Sturgeon Lake First Nation as: "Ethical Space is formed when two societies, with disparate worldviews, are poised to engage each other. It is a space in which all knowledge systems (Indigenous and Western) are validated and respected (also called 'two-eyed seeing') and where it is possible to arrive at joint decisions arising out of mutually-agreed protocols". Ermine, Willie. 2007. "The Ethical Space of Engagement." Indigenous Law Journal 6(1): 193-203. Also see "What is Ethical Space?" (2010 talk at McMaster University) www.youtube.com/watch?v=85PPdUE8Mb0

[6] Cultivating Abundance, 2019.

Indigenous governing bodies may participate in Thinhorn sheep stewardship but intends to create an example for a recognition-based approach in collaborative species management. The self-determination mechanisms Indigenous governing bodies utilize will inform the Framework and approach used by the respective Indigenous governing bodies to establish their role in a collaborative process, as decision-makers and stewards within their territories.

Indigenous laws and knowledge have developed over centuries. Indigenous stewardship varies from Nation to Nation and may even vary within a Nation across different groups (e.g., communities, house territories, etc.). The inclusion of Indigenous knowledge and stewardship into the management of Thinhorn sheep will require the species stewardship framework to be adaptable as transformations of legislation, policy and regulations occur. BC is committed to the further development and implementation of standing measures for the handling and treatment of Indigenous knowledge in collaboration with Indigenous Peoples. Best practices have been identified through relationships with Nations as well as internal procedures directing how BC administers information, advice and data provided by First Nations governments. The Province of BC has developed a document referenced as Draft Principles Regarding Indigenous Knowledge,[7] which should be considered in implementing the Thinhorn sheep framework and other species plans. The First Nations–BC Wildlife & Habitat Conservation Forum has also articulated principles to support this approach in their document titled *Cultivating Abundance.*[8] The Forum identifies that if the Crown and Indigenous governments are to undertake the development of a management strategy via Ethical Space, the parties must interact with the guiding principles of open and mutual learning.[9]

The inclusion of respectful recognition supports the Provincial wildlife management strategy, *Together for Wildlife* (the "Strategy") with a recognition that "collaborative wildlife stewardship may advance reconciliation with Indigenous governments". The Strategy further acknowledges that the relationship between the Crown and Indigenous Peoples will be essential in ensuring wildlife and habitat stewardship outcomes are achieved, consistent with the Declaration Act's intent.

Artwork by Naomi Fisher

[7] 1. Indigenous Peoples Own Their Knowledge
2. The Province will recognize and work to respect Indigenous Nations' internal requirements for the management and use of Indigenous Knowledge.
3. The Province has a responsibility to protect Indigenous Knowledge that is shared in confidence, in accordance with applicable provincial laws.
4. Indigenous Knowledge and Western Knowledge are Equal ways of Knowing.
5. The application of Indigenous Knowledge should be part of an ongoing process based on building bridges between different Knowledge systems.
6. Indigenous Knowledge is a system of Knowledge that forms and is part of Indigenous Peoples Cultural Heritage.
7. Public Servants and the Province should approach Indigenous Communities and Knowledge Holders from a place of Cultural Safety and Humility.
8. Respectful relationships should be developed for ongoing engagement with Indigenous communities and Knowledge Holders as Indigenous ways of knowing and being are integral to understanding what it means to live in a diverse, fair society committed to reconciliation.

[8] Indigenous knowledge systems and Western Science, especially when navigated in Ethical Space, should be (i) valued and respected equally, (ii) used to inform and complement each other, and (iii) integrated in a harmonized system of stewardship.

[9] citation for c.a. to Cailyn/Eduardo or to Forum.ce

The Strategy lists 24 actions under 5 goals, which are to guide the work of BC, Indigenous Peoples, Stakeholders, and interest groups in BC. The Strategy's actions identify added considerations[10] for implementation of the province's species management related to regional scale deliveries (Action 2) to support better managed wildlife and habitat. This population objective setting process will benefit from information developed with the Ministers Wildlife Advisory Council and the First Nations – BC Wildlife and Habitat Conservation Forum. Where significant decisions are required, a rationale for those decisions made by Indigenous governments and BC as governing partners, will be reported on as outlined in Action 16 of *Together for Wildlife*.

The role of Indigenous Peoples in Thinhorn sheep management will support and further the development of a collaborative management relationships, facilitating reconciliation with Indigenous governments. For the purposes of the Provincial Thinhorn Sheep Stewardship Framework, references to Nation-level or Territorial-level engagement are to be defined by the overlap of Thinhorn sheep ranges with First Nations' Traditional Territories and Wildlife Management Units. Subsequent development of Regional-level plans that explore consumptive and non-consumptive management approaches at regional and territorial scales will be informed by the provincial Framework and engagement considerations.

Indigenous Cultural Context of Thinhorn Sheep

With the creation of meaningful collaborative stewardship tools, this framework charters a new pathway of recognizing there are Indigenous Governance structures in place for the delivery of wildlife stewardship. The approach is important for relationships now and into the future. This framework creates an ethical space as a pathway for sharing and learning. Stewardship is about more than ensuring access to wild sheep, it is about managing relationships with wildlife and their habitats. Offering understandings of Indigenous cultural contexts aims to provide a bridge between Indigenous ceremony and harvest by non-Indigenous people. Respect is key – to each other and to the land and wildlife that inhabit it.

"We all share the gifts around us." – Tom Aird

Photo: Bill Jex

[10]Action 2: By 2022, we will create or expand existing Regional Wildlife Advisory Committees to represent a variety of perspectives and provide opportunities for collaboration to improve wildlife stewardship. We will tailor committees to meet the unique needs and priorities of each region and ensure the committees can influence and be involved in processes that affect wildlife stewardship (e.g., land use planning, cumulative effects assessments, wildlife and habitat monitoring, etc.) Regional Wildlife Advisory Committees will provide opportunities for dialogue with provincial government programs, industry, stakeholders, local governments, and the public that complement the government-to-government relationships the Province is committed to pursuing with Indigenous governments. Indigenous governments will be encouraged to join Regional Advisory Committees as the Province's government-to-government partners.

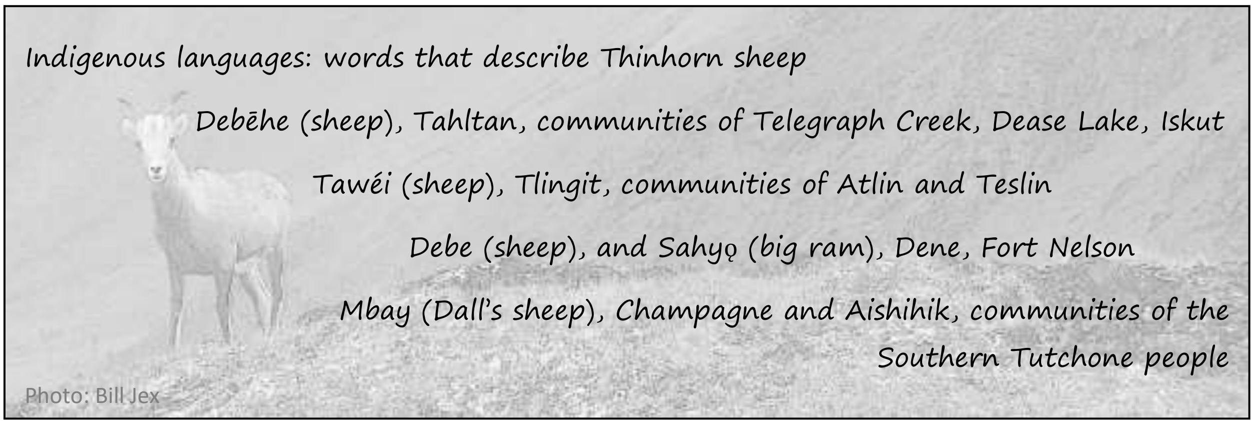
Action 8: Beginning in 2020, we will establish clear, measurable objectives for wildlife stewardship that take into consideration the interactions among species. In 2021, in collaboration with the Minister's Wildlife Advisory Council and the First Nations–BC Wildlife and Habitat Conservation Forum, we will draft a renewed approach for setting objectives and linking wildlife populations and habitat. We will implement this approach after broad engagement, by developing provincial stewardship frameworks and regional stewardship plans for priority species and populations.

Action 16: We will document and share with all British Columbians the rationale for significant decisions related to wildlife stewardship and how evidence was used to inform decisions. In 2021, we will develop an approach for publicly reporting on significant decisions, and we will implement this approach over the life of the strategy.

When using Indigenous words in reference to specific places, species or other titles the reader must understand that those singular words are not representative of the depth of meaning. Indigenous words and languages are the culmination of a relationship between the people, their territory and the living spaces around them, that has been built since time immemorial. Names often mean more than a literal translation – they describe a relationship to an animal or place (not just a name), dating 1000's of years. Relations, cultures, and spirits are substantial. Humans are a part of the ecosystem. These relationships and stories form a linguistic approach to stewardship.

> *"Language is a significant gift from the creator and sharing it is a significant gift to all those who read this." – Tom Aird*

Languages are a common thread that maintain spiritual connections between Indigenous peoples, their territory, ancestry and cultural beliefs. This often carries more significant meanings than the way we have used words in the following text, although we have attempted to describe relationships as best we could.



Indigenous languages: words that describe Thinhorn sheep

Debēhe (sheep), Tahltan, communities of Telegraph Creek, Dease Lake, Iskut

Tawéi (sheep), Tlingit, communities of Atlin and Teslin

Debe (sheep), and Sahyǫ (big ram), Dene, Fort Nelson

Mbay (Dall's sheep), Champagne and Aishihik, communities of the Southern Tutchone people

Photo: Bill Jex

The value of sheep is tied to spiritual and cultural practices that include hunting. For the Tlingit people, Tawéi is considered a 'special meat' and a delicacy for Elders. The skin was traditionally used for clothing, and hides were used for the underlay of a bed or for blankets. Horns were carved or heated and shaped to be used for ladles, spoons, knife cases and as water-carrying vessels. Bones/ribs were used as breastplates in protective armour (Ryan LaPointe pers comm.). Similar uses for sheep occur across most of the northern Indigenous communities overlapping British Columbia and the Yukon[11], manifesting into relationships between individuals, Indigenous cultures and wild sheep. This was reflected in immediate ways through the provision of sustenance, but also in intergenerational ways reflected in craftsmanship and tools that were gifted and used in trade.

Our vision: a full curl approach to knowledge & stewardship

Thinhorn sheep develop a distinct annual growth of horn, much like the annual ring of wood in a tree. This means that as sheep age, we can see how each year and even season, build on each other. Generally, by the time a male Thinhorn sheep reaches eight years of age, the horn has grown into what we describe as "full curl", and from a side profile, the horn makes a near-perfect circle. Similarly, the circle is an important shape for Indigenous people and is often referenced to reflect the sharing of

[11] McGill University has collaborated with many Nations and developed this reference material: http://traditionalanimalfoods.org/mammals/hoofed/page.aspx?id=6135

knowledge, collective healing, and teachings (such as the medicine wheel), are circle associated references.

A full curl approach to knowledge also has biological relevance to the western management of sheep populations. Research and experience have shown that from a population perspective, a full curl ram represents maturity – these sheep have a social role as knowledge keepers and biologically are the most successful breeders, passing along both ecological knowledge and genetics to the herd. In similar ways we can parallel a full curl approach to elders sharing wisdom and learnings within communities, that originate from both scientific and local knowledge. By capturing the essence of the circle, we are reminded to incorporate all ways of knowing and types of knowledge in our stewardship decisions, highlighting the interconnectedness of all, with no beginning, middle, or end. It frames this work to focus on holistic knowledge and respect as core goals, and supports the concept of adaptive management and continuous improvement.

Artwork by Naomi Fisher

In recognition of this chapter, our group has attempted to better describe some common reference terms, for example, the phrase 'Traditional Ecological Knowledge'. Please note that in this document, the terminology '*Traditional Ecological Knowledge*' has instead been replaced by *Traditional Indigenous Knowledge* (i.e., the collective, culturally-based knowledge held by Nations, Communities and/or First Nations individuals), and *Local Ecological Knowledge* (i.e., ecological knowledge held by community elders, professionals, researchers and stakeholders who may or may not be First Nations, but whose perceptions and ecological wisdom is based on a strong relationship with the environment and wild sheep). This was done respectfully to recognize that 'traditional knowledge' about the environment and our ecological relationships with it, can come from many sources and all can have equal value in contributing to better managing wild sheep.

Species Description

Distribution and abundance

Thinhorn sheep inhabit steep rugged mountain terrain in the northern third of British Columbia. Their distribution extends north from north-central BC across the Yukon and the interior of Alaska, and east into the Mackenzie and Richardson mountains of the Northwest Territories (Figure 1). BC's populations of Thinhorn sheep are generally contiguous across their historic range, shaped by past glaciations that influenced gene flow (Jex et al. 2016). Compared with most other North American large mammals, Thinhorn sheep provide a unique example of a species that occupies most of their historic range at similar ancestral population densities (Worley et al. 2004, Demarchi and Hartwig 2004) and overall population levels (WAFWA WSWG 2020). Connectivity among Thinhorn sheep populations is fragmented only by large landforms such as wide forested valleys, large lakes/reservoirs, and large rivers.

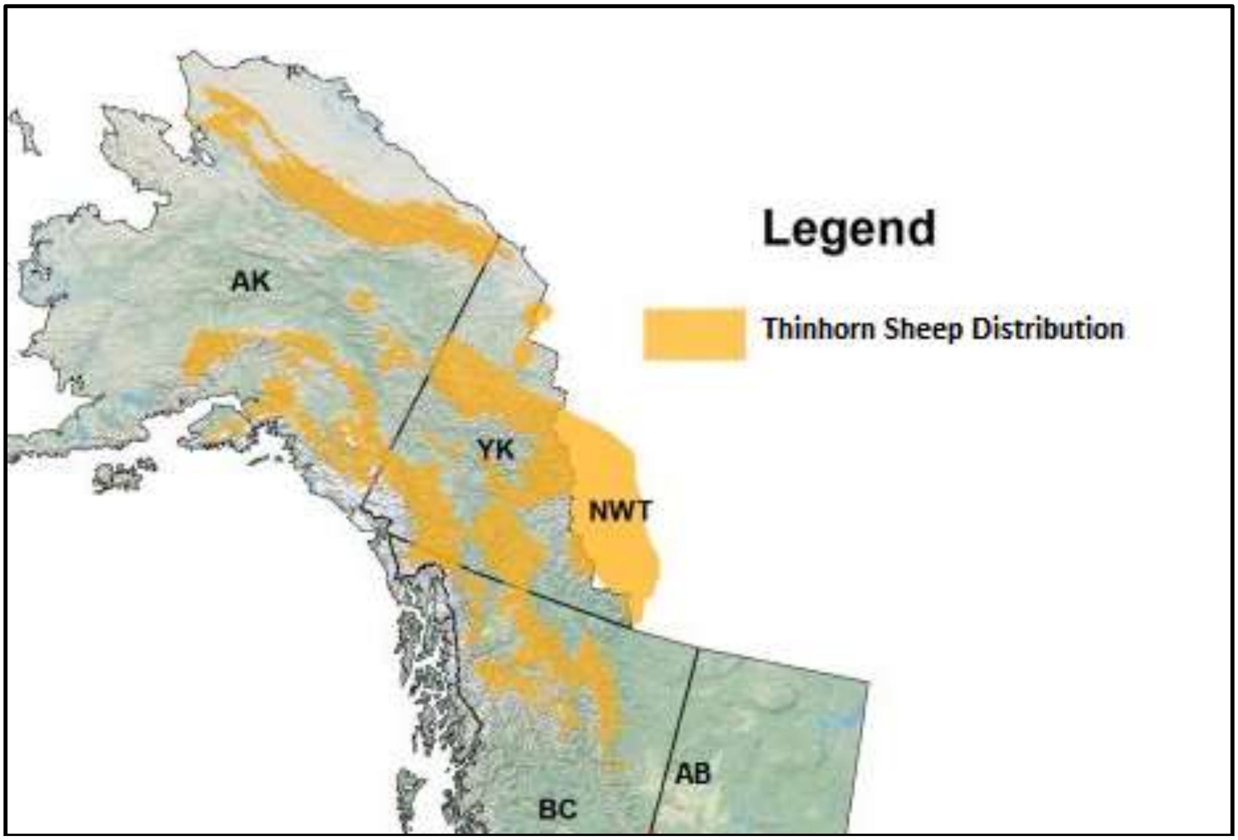


Figure 1. Thinhorn Sheep Distributions in North America (Source: Western Association of Fish and Wildlife Agencies' Wild Sheep Working Group Initiative, https://wafwa.org/initiatives/wsi/).

The nature of alpine topographies, with rugged escape terrain features and wind-blown ridges, is fundamental to the capability of these northern mountain complexes to provide quality Thinhorn sheep habitat, and directly relates to population viability and stability. The value and juxtaposition of these specific habitat attributes to seasonal range selection and use cannot be overemphasized (Jex et al. 2016). Because of these relationships and adaptations to stable, climax alpine habitats, Thinhorn sheep appear more K-selected[12] than other ungulate species (Heimer 1999). Alpine environments, however, are prone to stochastic, severe weather events, which played a key role in Thinhorn sheep population fluctuations through the mid-1980s and early 1990s in BC (Demarchi and Hartwig 2004), and across both the Yukon (Hik and Carey 2000) and Alaska (Alaska Department of Fish and Game 2008). With changing climactic patterns globally, the frequency and severity of freeze-thaw events are likely to change, altering the ability and predictability of winter ranges to provide accessible forage. These severe winter storms and icing events can result in large-scale mortality, such as those observed in the winters between 2010-11 through to 2013-14 in Alaska (ADFG 2017).

To support Thinhorn sheep population management, inventory data storage and archiving, BC has developed a relational database called the Wild Mountain Sheep Registry (the 'Registry'). The Registry is a geospatial database of Thinhorn and Bighorn herd home ranges that was implemented in 2002 and contains both historical and current information regarding the status and trends of BC Bighorn and Thinhorn sheep populations. The registry also provides ancillary information about genetics, management directions, and significant events such as disease outbreaks and translocations. With increasing concerns of contact with domestic sheep/goats, and the need to have a maintained and up-to-date repository for wild sheep range mapping, the registry is an important primary information source for researchers, managers and decision-makers.

The goals of the Wild Mountain Sheep Registry[13] are to:

1. Provide up-to-date information on the status and trend of mountain sheep populations in BC.
2. Serve as a central repository of spatial range use information.
3. Serve as the definitive source for meta-population, sub-population and herd definitions and hierarchical relationships.
4. Provide a record of significant management and natural events, such as transplants, disease outbreaks, hunting regulation changes, controlled burns or catastrophic wildfire.

The province also maintains a spatial database for wildlife inventory data called Wildlife Species Inventory, also known as SPI[14]. Thinhorn sheep population monitoring data are collected by government staff and by other researchers as required by their wildlife permit conditions. Due to the sensitive nature of the data and potential for harm, sheep data are secured and not publicly available without an established need for the data and confidentiality agreements in place. This includes the sheep registry mapping.

Taxonomy and genetic variation

Thinhorn sheep have a range of coat colours, from the pure white pelage typical in Dall's sheep to the darker grey/black and chocolate more predominant in Stone's sheep. Until recently, subspecies designation was defined by geographically associated patterns of pelage colour alone. The white Dall's sheep defined one subspecies and the dark-coated Stone's sheep another. A third subspecies designation was proposed based on a blend of the two coat colours and was described as the Fannin group of Thinhorn sheep (Figure 2). Colour-based subspecies designation is problematic, however, as

Photo: Krystal Kriss

[12] *K*-selected species exhibit relatively stable populations, with a longer gestation period that produces fewer offspring, over their longer life spans. They also inhabit relatively stable ecological communities that are often late-successional or climax habitats (https://www.britannica.com/science/K-selected-species).

[13] https://catalogue.data.gov.bc.ca/dataset/bc-wild-mountain-sheep-registry-distribution

[14] https://www2.gov.bc.ca/gov/content/environment/plants-animals-ecosystems/wildlife/wildlife-data-information

colour morphs can simply be variation across a species range, rather than defining discrete genetic populations. Genetic evidence has also been found to be inconsistent with morphology-based taxonomy in other wild sheep species (Gutierrez-Espeleta et al. 2000). Over the past two decades, Thinhorn sheep genetic analyses completed by Worley et al. (2004) using microsatellite markers, Loehr et al. (2006) using mitochondrial DNA, and Sim et al. (2016, 2018) with single-nucleotide polymorphisms (SNPs), have significantly improved our understanding of *Ovis dalli* genetic structure and subspecies range delineation. The recent work also suggests that the Fannin sheep represent a population with admixed Stone's sheep and Dall's sheep genetics, but are predominantly related to Dall's sheep origins across most of their distribution (Jex and Sim 2021).

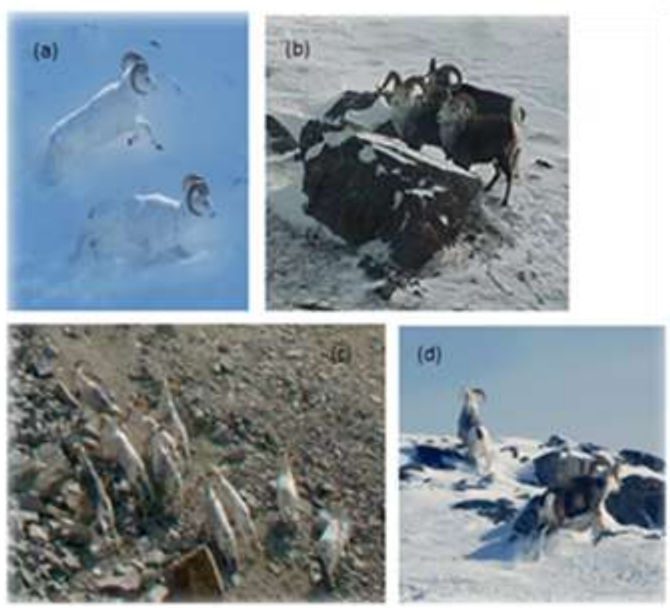


Figure 2. Representative pelage colour for Thinhorn sheep from various regions of BC: (a) Dall's sheep (*Ovis dalli dalli*), (b) Stone's sheep (*Ovis dalli stonei*), (c & d) Fannin (*O. d. dalli* x *O. d. stonei*) from Sim et al. (2016). Photos: Province of BC.

There is some consensus that there may have been multiple colonization events of ancestral sheep moving into North America, dating back as far as 1.1 M years ago (Wehausen, pers. comm.). These immigrations, along with glaciation events, helped shape patterns of Thinhorn sheep genetic variation (Sim et al. 2018). The differentiation between Dall's and Stone's sheep has been shown by previous studies to be driven by vicariance due to isolation in different Pleistocene glacial refugia (Loehr et al. 2006) that likely existed through successive glaciation events (Sim et al. 2016). Both Sim et al. (2016) and Loehr et al. (2006) identify the existence of at least one minor refugia in BC, challenging the previous hypothesis that postulated the survival of Thinhorn sheep in only the Beringian refugium (Geist 1971). Specifically, instead of surviving the Wisconsin glaciation in the ice-free Beringia refugium with Dall's sheep, Stone's sheep were likely isolated from other Thinhorn sheep in a small ice-free refugium in north-central BC as far back as 130,000 to 300,000 years ago. Postglacial recolonization allowed spatial overlap of the two subspecies, with present day genetic structure driven by historical isolation and contemporary limits on connectivity from large northern BC rivers (Sim et al. 2016). Key results from this work suggest that many dark-coloured Thinhorn populations in southern Yukon that are currently identified as Stone's sheep based on coat colour, are more correctly assigned with Dall's sheep ancestry (Sim et al. 2018). It is now recognized that Stone's sheep distributions extend only slightly into the southern Yukon from northern BC, at the northern tip of the Cassiar Mountains (Figure 3).

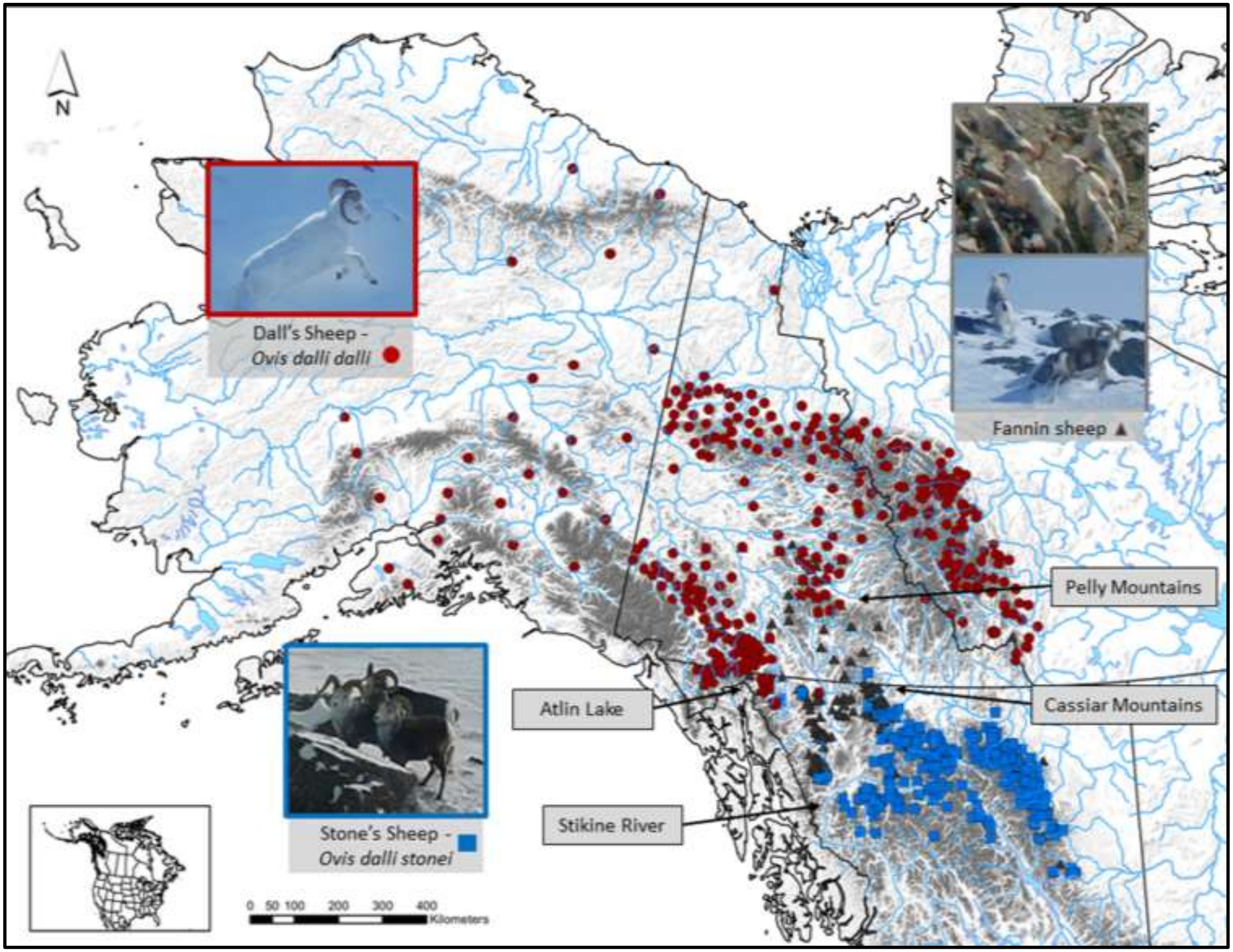


Figure 3. Sub-species-wide ranges of Thinhorn sheep (i.e., Dall's and Stone's), and Admixed (i.e., Fannin) distributions. Map from Sim et al. (2018) showing sample collection locations.

This new genetic information has been adapted cross traditional Wildlife Management Unit boundaries and used to delineate 5 large Thinhorn sheep genetic population groups in BC, that can be used to inform conservation and management planning (Figure 4). While these genetic populations will not specifically be applied to considerations related to licensed hunter harvest management (i.e., PMUs), they will be useful in land-use planning considerations and habitat management initiatives.

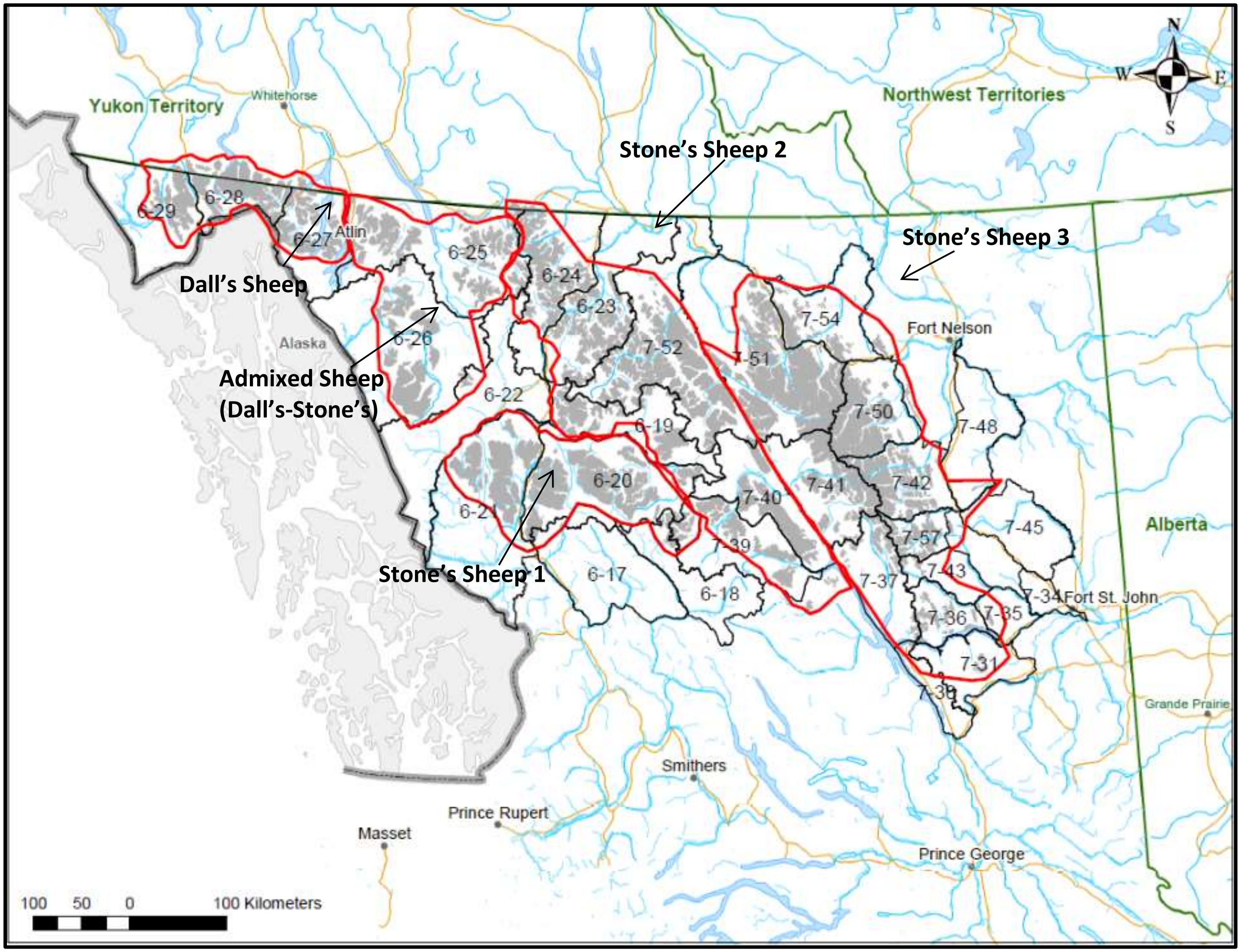


Figure 4. Distribution of Thinhorn sheep in British Columbia and proposed genetic population units (Dall's sheep, Admixed, and 3 Stone's sheep units) based on analyses by Sim et al. (2018) with historic herd range boundaries (grey polygons –BC Wild Mountain Sheep Herd Registry), and Wildlife Management Units (red outline).

Populations across North America

Although Thinhorn sheep distribution and abundance are thought to have remained historically stable across their geographic range, population estimates have changed over time, mainly due to improvements in survey methods, incorporation of measures of uncertainty, financial resourcing and First Nation/conservation stakeholder input. Broad-scale population estimates collated in 2021 indicate approximately 103,000 Thinhorn sheep in North America (Table 1, Figure 5).

Table 1. Current jurisdictional estimates and trends of Thinhorn sheep populations based on phylogeographic delineations from Sim et al. (2016, 2018) and Western Association of Fish and Wildlife Agencies - Wild Sheep Working Group (updated in 2021).

Jurisdiction	Dall's Sheep		Stone's Sheep	
Alaska	46,000	Stable across most of state; Kenai Peninsula continues decreasing trend; numbers continue to be down in western Brooks Range - severe weather, predation.	0	Outside the range of the subspecies.
British Columbia	900	Population is stable to declining across most of provincial range in Skeena region, overlapping WMUs 6-25 to 6-29 with populations estimated between 700-1300.	12,300	Population generally stable across most of its range with some localized declines. Regional estimates: Skeena = 3,400-6,400, Omineca = 300-600, & Peace = 7,000-9,000.
NW Territories	21,000		0	Outside the range of the subspecies.
Yukon	22,500	Population is generally stable across most of its range; some localized declines in central Yukon ranges	~100	Population is generally stable across most of its range.
Estimated Totals	**90,400**		**12,400**	Photo: Lance Goodwin

Despite generally stable distribution and abundance trends across Thinhorn sheep range, localized population declines have been noted. These events have been associated with, predation, population health and individual fitness. environmental productivity and habitat resilience, and anthropogenic disturbances (i.e., industrial and recreational). The exact cause(s) are difficult to assess because some declines appear to have occurred prior to population and harvest monitoring programs being initiated and that is at least partially due to the remoteness of some Thinhorn sheep ranges.

Populations within British Columbia

Dall's sheep have been Blue-listed in BC since 1995 (CDC 2018). Stone's sheep have seen changes in conservation status rankings over time, being moved from the Yellow-listed to Blue-listed in 2017 (CDC 2018), supported by new genetic research and a conservation risk assessment that identified a more comprehensive understanding of overall risks (i.e., disease, habitat loss, impacts from anthropogenic disturbances). Generally, populations of both Dall's sheep and Stone's sheep in BC have been identified as stable to slightly decreasing in some regions since the first Provincial population estimate of just over 8,000 Thinhorn sheep was generated in 1970. Earlier estimates were based largely on a consensus of expert opinion based on fixed-wing survey approaches, changing through time as more supporting inventory information was collected and improved survey techniques (i.e., standardized methodologies, use of helicopters, etc.) were used to inform that expert opinion. Kuzyk et al. (2012) identified relatively stable populations of Thinhorn sheep in BC between 1987 and 2011, with estimates ranging between 12,000-15,000 sheep (Figure 5). Updated 2021 estimates consider subspecies boundaries identified in Sim et al. (2016, 2018), and refine the estimates of Dall's sheep and Stone's sheep populations to ~12,300 Stone's sheep and ~900 Dall's sheep.

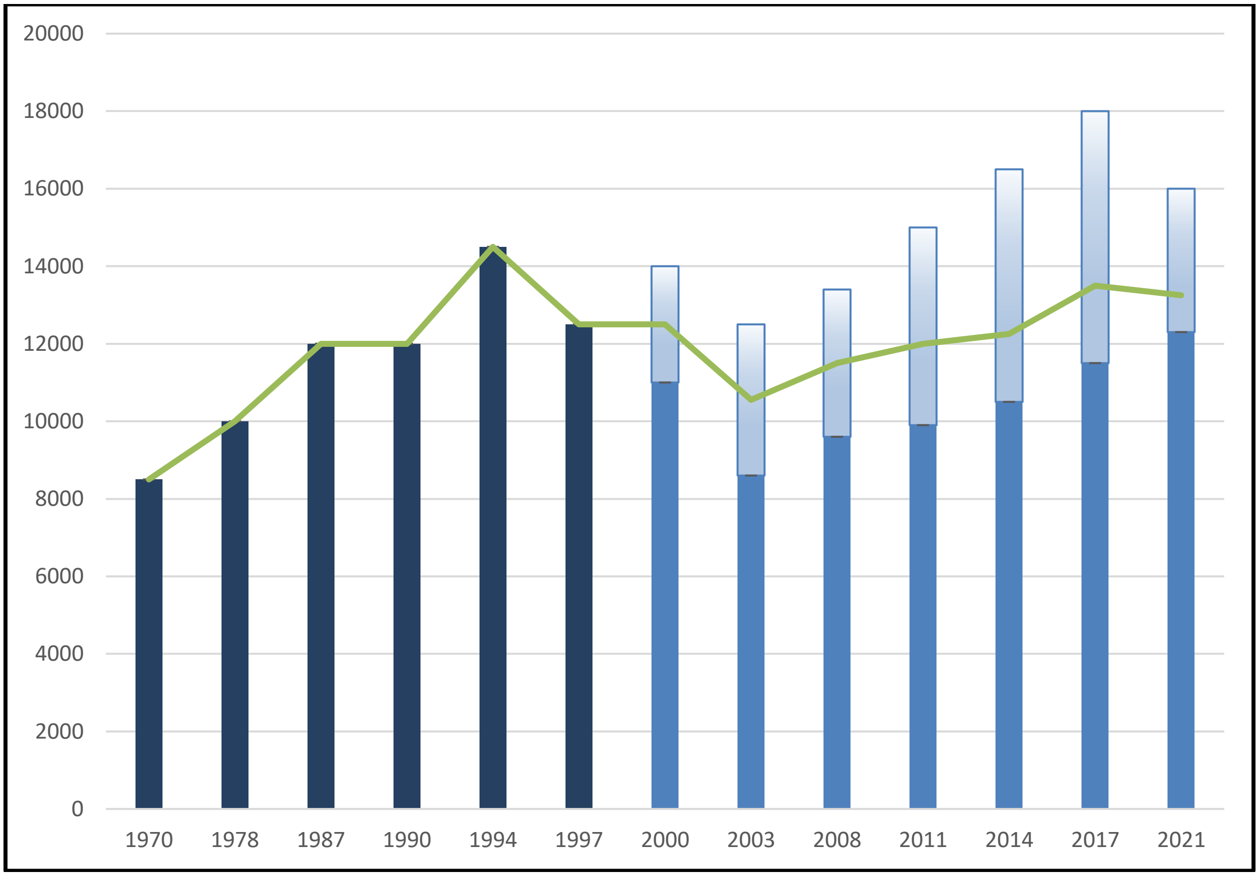


Figure 5. Estimates of Thinhorn sheep populations in British Columbia: includes Stone's sheep in the Skeena, Omineca, and Peace regions, and Dall's sheep in the Skeena Region. Provincial estimates 1970-1997 are single-value-estimates (dark bars); estimates 2000-2021 incorporated a range in the estimate from minimum (solid fill) to maximum (gradient fill) values. Solid green line represents the accepted single-value-estimate for that year.

As in other jurisdictions, reliably assessing Thinhorn sheep population trends in BC is complicated by variable survey effort, objectives, selection of survey areas (e.g., Management Unit - MU, mountain block, herd range), and methodology (e.g., minimum counts, sightability correction, demographic ratios). Population monitoring of Thinhorn sheep has always been extremely challenging due to the cost and logistics demanded by aerial surveys in remote mountainous areas. Early provincial estimates that were based on expert opinion and fixed-wing aircraft flights have become more refined with strategic helicopter-based aerial surveys and standardized inventory and classification methods (see Resource Inventory Standards Committee 2002). Recent Stone's sheep surveys in the Northern Rockies present results with an explicit measure of survey effort (min/km^2), flight paths, and sightability correction factors (Anderson and Bridger 2021), however relying on MUs or portions of MUs to define survey areas continues to complicate comparisons of survey results over time. This is particularly problematic for alpine species like Thinhorn sheep because MU boundaries often follow height of land, meaning one side of a ridge would be included in the survey area while the other side would not. Continuing to improve and refine Thinhorn sheep herd range polygon boundaries stored in the Wild Mountain Sheep Herd Registry (the provincially managed spatial database of wild sheep range) and using herd ranges to define survey areas will improve population trend assessments and help transition to more meaningful Thinhorn sheep population management units (PMUs).

Historically BC has attempted augmentations of populations to support recovery, however all the efforts failed to achieve project objectives and resulted in poor success. A total of 60 Thinhorn sheep were moved in 3 separate translocation projects within BC during 1990-1995 in the Peace and Skeena regions (Hatter and Blower 1996). Twenty-eight Stone's sheep were moved in 3 efforts between 1990 and 1993, in an attempt to repopulate unoccupied Stone's sheep habitats on Mount Frank Roy and Mount Monteith, that were separated from occupied habitat by flooding the Peace River valley (Wood 1995). A second effort in 1996 saw 8 Stone's sheep moved from the Toad River to an area approximately 25 km to the east of the source but still within the Toad River watershed. The third effort occurred near Atlin in northwestern BC in 1994 (n=14) and 1995 (n=10), where a total of 24 Dall's sheep were moved from the east side of Atlin Lake to the Table Mountain area on the west side of the lake, in an attempt to improve herd performance and expand occupancy of the habitat in that area. There have been no subsequent attempts to translocate Thinhorn sheep in BC.

Life history

As with all northern ungulates, the natal period has evolved to optimize the availability of abundant, nutritious forage necessary to meet the energetic and nutritional requirements of lactation (Hebert 1973, Bunnell 1982, Thompson and Turner 1982 in Demarchi and Hartwig 2004). Just prior to lambing, pregnant ewes will travel to steep, rugged areas to lamb where there is a reduced risk of predation during this vulnerable time (Walker 2000, Enns 2021). The preceding gestation period lasts approximately 172 days. Thinhorn ewes will give birth to a single lamb, generally during the months of May and June with Bunnell (1980), reporting that lambing can occur as early as April 30th and as late as June 2nd. Enns (2021) established lambing dates from 19 radio-collared Stone's sheep ewes between 2018 and 2020 with parturition ranging in dates from May 3rd to June 14th.

Also similar across all mountain ungulate species is the important influence of mineral licks on spatial distributions and movements (Ayotte 2004; Ayotte et al. 2006, 2008). Elemental deficiencies and digestive disorders related to spring forage changes may be improved by soil ingestion at mineral licks (Ayotte 2004). Peak use of mineral licks by Stone's sheep coincides with the transition from low-quality winter diet to easily digestible spring forage, and the increased demands associated with lactation (Ayotte et al. 2006).

The Thinhorn sheep mating season or rut begins in early November and continues through to early December, in response to photoperiod-driven ovulation in ewes (Bunnell 1980). Rams typically begin to participate actively in rutting activities when they reach 6 years of age (Demarchi and Hartwig, 2004). Social interactions among rams establishes the dominance hierarchy in a population long before the rut, with an evolution in the social status of dominant rams at times changing throughout the rut and as a result of employing different rutting behaviours (Geist 1971). While most breeding is done by older more dominant rams within the herd, where dominance is typically based on age and horn size, younger subordinate rams (i.e., 1.5 to 7 yrs old) can collectively sire ~50% of the lambs in any given year by employing aggressive breeding tactics such as "coursing" and "blocking", to sequester oestrus ewes away from mature "tending" rams (Demarchi and Hartwig 2004, Coltman et al. 2001).

Thinhorn sheep ewes can become reproductive by 1.5 years of age. Heimer (1999) reported that examination of Dall's sheep ewe ovaries collected from 50, 1.5-year-old ewes, identified a 100% ovulation rate, yet lamb production by 2-year-old ewes was virtually absent (Heimer and Watson 1986a, and Heimer and Watson-Keller, unpub data, in Heimer 1999) potentially indicating that those ewes failed to carry a lamb full term (i.e., fetuses were aborted or resorbed), or they failed to breed in that year. Another field study identified ewes first lambing at ages 3 and 4 (Nichols and Bunnell 1999). Hoefs and Cowan (1979) reported age at first lambing in Kluane National Park, Yukon, at 3 years old. Rather than a specific age, ewes likely become reproductive based on when they reach adult body weight (>57 kg: Nichols and Bunnell 1999, Valdez and Krausman 1999). Consequently, in some populations with poor range conditions, ewes may be 4-5 years of age before their first successful reproduction (Bunnell and Olsen 1982). This was observed in BC in 2017-2019, where studies occurred in northwestern BC. Winter pregnancy sampling in the two herds showed a very different range of ages for ewes found to be pregnant, with pregnant ewes in one area being >3 years old, yet ewes in the second location were pregnant as young as 1.5 years of age. Project leads agreed that the areas varied greatly in terms of habitat productivity and quality (Jex unpublished data, pers. comm).

Reproductive frequency for ewes in some populations may occur in alternate years, rather than annual lambing (Heimer 1978, Heimer and Watson 1982). Alternate year, or non-annual, reproduction in Thinhorn ewes is likely a consequence of the environmental extremes of their habitat and the nutritional stress associated with gestation. Non-annual patterns of pregnancy and reproduction was observed in a declining Stone's sheep population in the Cassiar Mountains of BC (Enns 2021; Jex, pers. comm.), where on average only 67% of winter-captured, adult ewes were confirmed pregnant. Nichols and Bunnell (1999) reported winter pregnancy rates of Thinhorn ewes varying between 75-100%; Thacker (2020) measured pregnancy rates of sampled ewes in two different Stone's sheep populations in northwestern BC, with one population assessed at 100% pregnancy in both 2017 and 2018; the second population was found to have pregnancy rates that ranged between 67% and 91% in 2017 and 2018, respectively, however different considerations for ewe selection were made as the capture effort progressed (e.g., selecting against ewes that had a previous season's lamb at heal) and this may have resulted in the observed increase in pregnancy rate in this herd in year two (Jex unpublished data, pers. comm.). Cubberley (2009) recorded pregnancy rates of sampled Sentinel and Stone mountains Stone's sheep in northeastern BC at 89% and 88%, respectively, and work in the Williston area in northeastern BC in 2020 also found pregnancy rates of sampled ewes to be 100%.

Seasonal range use

Wild sheep are highly philopatric, with individuals using the same seasonal home range (particularly breeding, winter and natal range) each year (Geist 1971, Festa-Bianchet 1991, Enns 2021). Geist (1971) observed 88% fidelity to seasonal home range for Stone's sheep rams and 90% for ewes and Enns (2021) found 100% fidelity to seasonal home range for ewes in the Cassiar population. The Cassiar ewes migrated an average of 17.5 km during spring and fall migrations (distances ranged from 6.2-45.9 km; Enns 2021), similar to migration distances in the Stone and Sentinel mountains (Hengeveld and Cubberley 2009).

Thinhorn sheep spend spring and summer predominantly grazing on grasses, sedges, and forbs in alpine meadows; they also forage on terrestrial lichens (Seip 1983, Seip and Bunnell 1985) and will browse willow (*Salix sp.*), rose (*Rosa sp.*), aspen (*Populus sp.*) and birch (*Betula sp.*) shrubs throughout the year, but more so in April (Seip 1983). Stone's sheep in the Northern Rocky Mountains (Besa-Prophet) consistently selected for rock and dry alpine vegetation that included mountain-avens (*Dryas integrifolia*) and Altai fescue (*Festuca altaica*) dominated alpine areas on well drained sites with moderate to steep slopes all year, and selected for burn-grass (recently burned and open disturbed sites dominated by wildrye (*Elymus sp.*) in early and late winter, lambing, and fall (Walker 2000). For most Thinhorn sheep populations, summer range following green-up is primarily restricted by proximity to steep escape terrain and access to mineral licks, and bounded by large landscape features such as wide forested valleys and rivers that limit dispersal. With the onset of winter, range use shrinks to smaller high-elevation areas with limited snow accumulation. In early winter, Stone's sheep will move to steep south- and west-facing slopes and ridges where the interactions among slope, aspect, and solar radiation influences site selection (Walker et al. 2007). This same research also found that dense subalpine conifer patches are strongly avoided. As with other mountain ungulates, the amount (depth), quality (density) and duration of snow become increasingly important in influencing fine-scale site selection as the winter season progresses.

Sexual segregation of wild sheep (males and females using different seasonal ranges) is related to differences in antipredator strategies (Festa-Bianchet 1988) coupled with differences in nutritional demands and forage selection (Ruckstuhl 1998). This predation-risk trade-off occurs when males move to forage in areas that provide high nutrition, improving growth and development at a greater risk of predation, whereas females select more secure areas at the expense of forage quality (Berger 1991, Bleich et al. 1997). Intrasexual segregation by female Stone's sheep was studied by Walker (2005) in northeastern BC where ewes segregated relative to reproductive status and associated predation risk more so than based on differences in forage quality or quantity.

The trade-off between forage and predation risk has been well documented in wild sheep (Festa-Bianchet 1988, Berger 1991, Bleich et al. 1997, Walker 2000), where lambing sites are selected for terrain ruggedness, lower forage quality, and limited predator density compared to winter range (Festa-Bianchet 1988, Enns 2021). After only several hours post-birth, lambs are fully mobile, and the ewe-lamb pair will join other ewes and lambs between 2-4 weeks after parturition as they move into their summer range. Rams older than 1.5 years will usually join all-male groups and typically use different ranges than ewe-nursery groups over the summer months (Demarchi and Hartwig 2004). Some yearling rams have been observed remaining with nursery bands of sheep until the age of 2.5 years (Enns 2021). In the fall, both sexes typically will converge on the same ewe-juvenile wintering range (Demarchi and Hartwig 2004, Enns 2021).


Artwork by Naomi Fisher

BROAD MANAGEMENT GOALS AND OBJECTIVES

The broad goals and their associated objectives for the conservation and management of Thinhorn sheep in BC include:

1. Viable and ecologically sustainable populations of Thinhorn sheep throughout historical and suitable native range for ecological, cultural, economic and social benefits using science-based management, and locally relevant sources of ecological knowledge.
    a. Maintain or improve population resiliency;
    b. Maintain viable population size, distributions and connectivity at both subpopulation and larger metapopulation scales, across historical range;
    c. Maintain appropriate sex/age ratios;
    d. Maintain and improve understanding of population health. Reduce risk of respiratory disease outbreaks and the potential for contact with domestic sheep/goats.
2. Populations that provide for cultural, consumptive, and non-consumptive opportunities.
    a. Management and habitat objectives developed in consideration of this Stewardship Plan, Traditional Indigenous and Local Ecological Knowledge and Regional Management Plans, the Provincial Big Game Harvest Management Procedure and the Thinhorn Sheep Harvest Management Procedure;
    b. Manage populations and landscape connectivity and permeability to balance access to harvest opportunities while ensuring quality experiences for both consumptive and non-consumptive users;
    c. Manage harvest opportunities to ensure sufficient escapement of mature/older rams after hunting season such that mature/older rams fulfill their social and biological roles.
3. Protection of Thinhorn sheep habitat throughout the current range, considering landscape permeability/access, fragmentation and development of linear corridors and anthropogenic disturbances (commercial, recreational and industrial developments).
    a. Continue to refine range mapping and population information by incorporating accepted scientific and inventory information into the Wild Mountain Sheep Registry spatial database;
    b. Maintain and enhance habitat suitability and productivity through the use of habitat interventions or restoration actions that promote beneficial outcomes for Thinhorn sheep;
    c. Maintain integrity and connectivity of seasonal ranges, lambing and rutting areas, mineral licks and migration routes;
    d. Avoid impacts from recreation, commercial and industrial activities on Thinhorn sheep populations that may result in alienation or abandonment of important habitats, while also implementing mitigations for these activities in other areas used by wild sheep.

MANAGEMENT BACKGROUND, TOOLS, AND RECOMMENDATIONS

Population Inventory and Monitoring

Resources for ungulate inventory and population monitoring are limited, especially in northern regions where expansive and remote mountainous areas make accurate systematic surveys expensive and logistically complicated. Surveys for harvest-allocated species in BC are prioritized in response to management issues and concerns (Hatter 2017). Given the relative stability in distribution and abundance of Thinhorn sheep compared to other ungulate species, regional ungulate inventory budgets have been focused mainly on caribou (*Rangifer tarandus*) and moose (*Alces alces*) in the Skeena, Peace and Omineca regions. Consequently, Thinhorn sheep are one of few species in BC that do not have designated population management units (PMUs). Hatter (2017) recommended increased investment to support the development of PMUs for Thinhorn sheep, also noting that this was one of the most pressing issues affecting the ability of inventory and monitoring to inform effective management decisions. Ideally, repeat population monitoring should occur every 3-5 years, however many Thinhorn sheep populations have never been monitored, have been monitored far more infrequently, or have outdated information. Priority for the limited funding available for Thinhorn sheep population monitoring is given to those populations where conservation concerns are highest (e.g., declining trends, high harvest rate, increased access). Some Land & Resource Management Plans (LRMPs) such as the Cassiar Iskut-Stikine LRMP, provide specific strategies to survey and monitor Stone's sheep to achieve the objective of managing populations as a sustainable resource. As negative impacts of anthropogenic disturbance and climate change on Thinhorn sheep are expected to increase, a more structured approach that connects Thinhorn sheep inventory and monitoring to decision-making through conservation-focused management objectives will help to resolve this.

Currently, Thinhorn sheep populations are surveyed by Wildlife Management Units (WMU or MU), subzone, or groups of MUs/subzones to create a mountain block of sheep range (given that many MU boundaries are aligned with heights of land). Preliminary population units have been provided in this Stewardship Framework (Figs. 6-10, Table 2), but will require further refinement as inventory and monitoring information are improved. Defining biologically meaningful population units that minimize interchange (emigration/immigration) will likely require a combination of collar data, repeated aerial monitoring, and integration of Local Ecological and Traditional Indigenous Knowledge to understand movements and connectivity among adjacent populations.

Standardized aerial inventory flights for Thinhorn sheep in BC are primarily conducted by helicopter in winter (January – March) following provincial standards (Resource Inventory Standards Committee 2002). However, many Dall's sheep surveys in other jurisdictions are conducted during summer months, with Skeena Region adopting a similar approach. A minimum of two experienced sheep observers are required for each flight to ensure reliable inventory outcomes. Mountain blocks are surveyed systematically by helicopter, following contours between treeline and ridge top, working up-slope. Known locations of mineral licks, natal areas, or other habitat features are also surveyed. Georeferenced maps are used on iPads with GPS functionality. Air speeds are generally kept near 40-60 km/hr when inventorying sheep habitat. Reported survey effort for Dall's sheep ranges between 0.3-1.3 min/km^2 (Udevitz et al. 2006) and 2.6-3.3 min/km^2 for replicate Stone's sheep surveys (Cubberley 2008, Hengeveld and Cubberley 2011, Anderson and Bridger 2021). Survey effort between 1.3-6.1 min/km^2 did not have an appreciable effect on detectability of mountain goats on surveys in southern BC (Poole 2007).

Thinhorn sheep population monitoring in BC includes classifications of individual sheep generally following Geist (1971), including rams, ewes, yearlings, and lambs. Rams are also further classified based on horn curl: Class I (1/4 curl, age 2-5 yrs), II (1/2 curl, age 3.5-6 yrs), III (3/4 curl, age 6-8 yrs), and IV (full curl, age 8-16 yrs). Because of horn growth structure, Thinhorn sheep present a challenge to observers in correctly distinguishing between Class I rams, yearlings and adult ewes. Following a review of the accuracy of observers in differentiating among these categories, and in an effort to minimize disturbance to sheep during surveys, Class I rams, adult ewes and yearlings were all grouped into a "ewe-like" classification category. During surveys, attempts are also made to limit aircraft distances to >150 m from Thinhorn sheep with ideally one pass per sheep group; photos are often used to confirm classifications post-flight. The Yukon follows a similar classification scheme when conducting Dall's sheep population monitoring, although inventory flights are typically scheduled for post-lambing (June, July) and use a category called "nursery sheep", which include adult ewes, yearlings and 2-yr old rams that have not yet joined the ram bands (Russell and Hegel 2011).

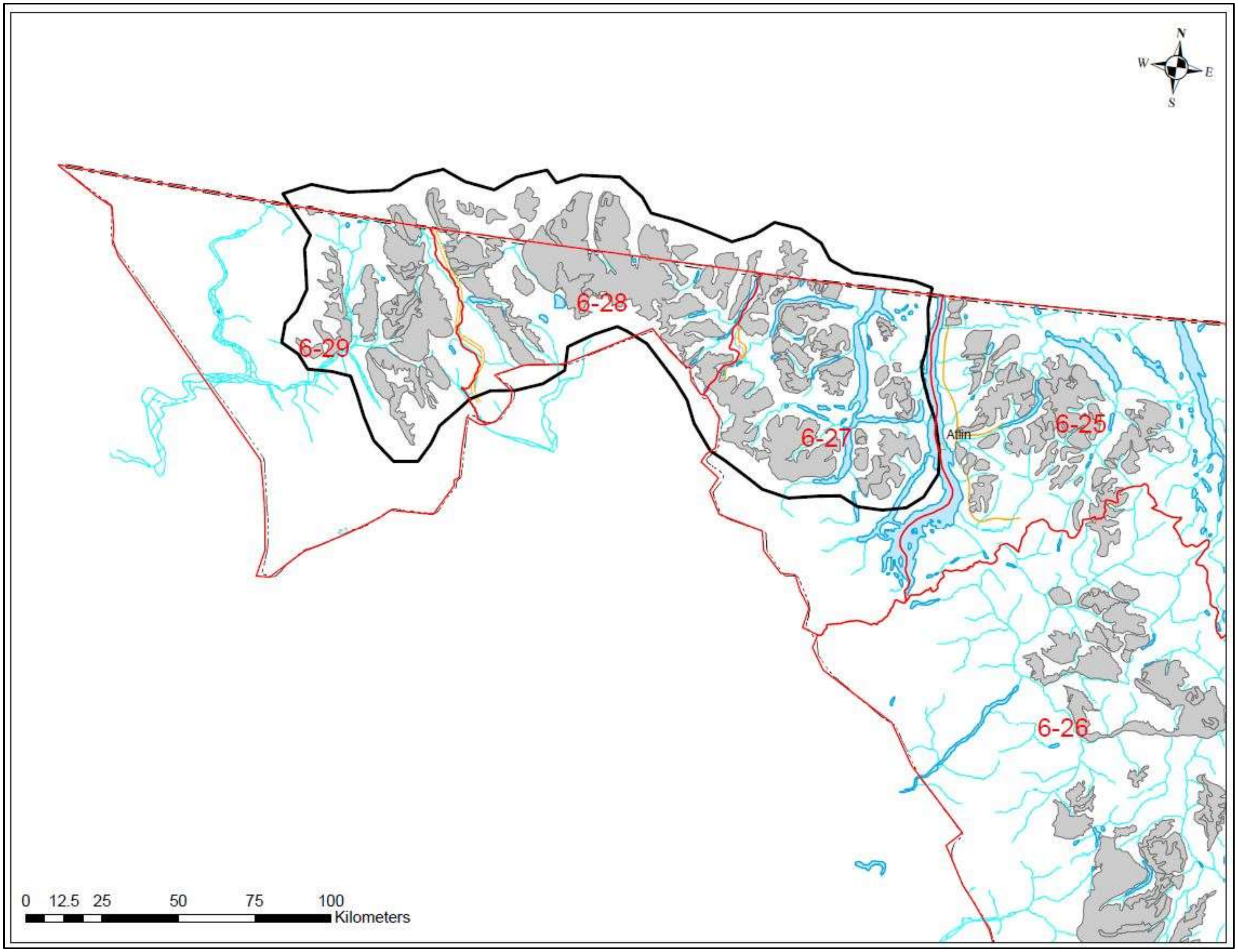
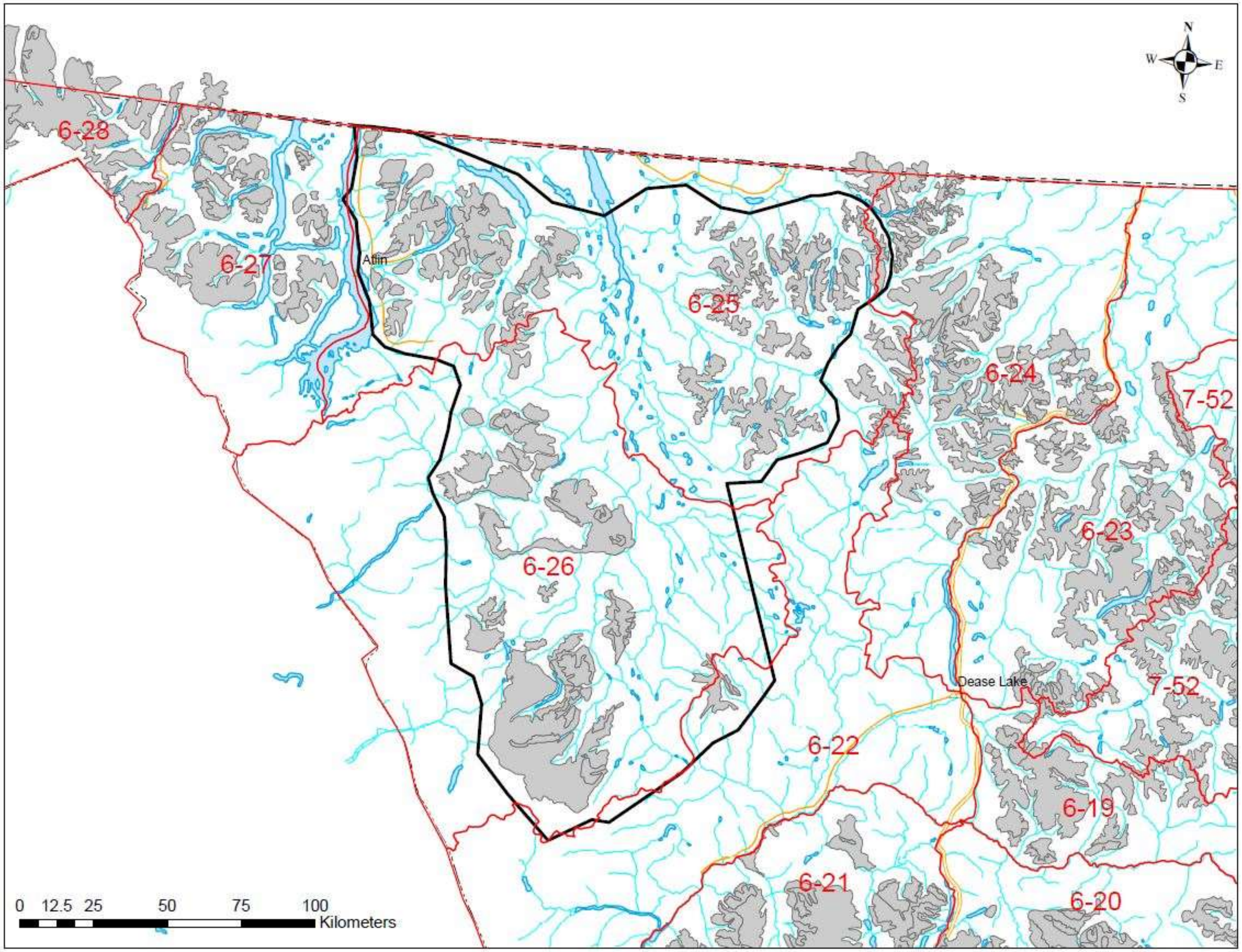


Figure 6. Proposed Population Unit of Dall's sheep (black polygon) comprised of multiple herds (grey polygons). Population Units are delineated based on genetic divisions (Sim et al. 2018), herd range boundaries (Provincial Wild Mountain Sheep Registry), landscape fracture zones, and Wildlife Management Units (red outline).

Figure 7. Proposed Population Unit of admixed Thinhorn sheep (genetically assigned with <80% alignment with either Dall's or Stone's lineage, black polygon) consisting of multiple herds (grey polygons). Population Units are delineated based on genetic divisions (Sim et al. 2018), herd range boundaries (Provincial Wild Mountain Sheep Registry), landscape fracture zones, and Wildlife Management Units (red outline).



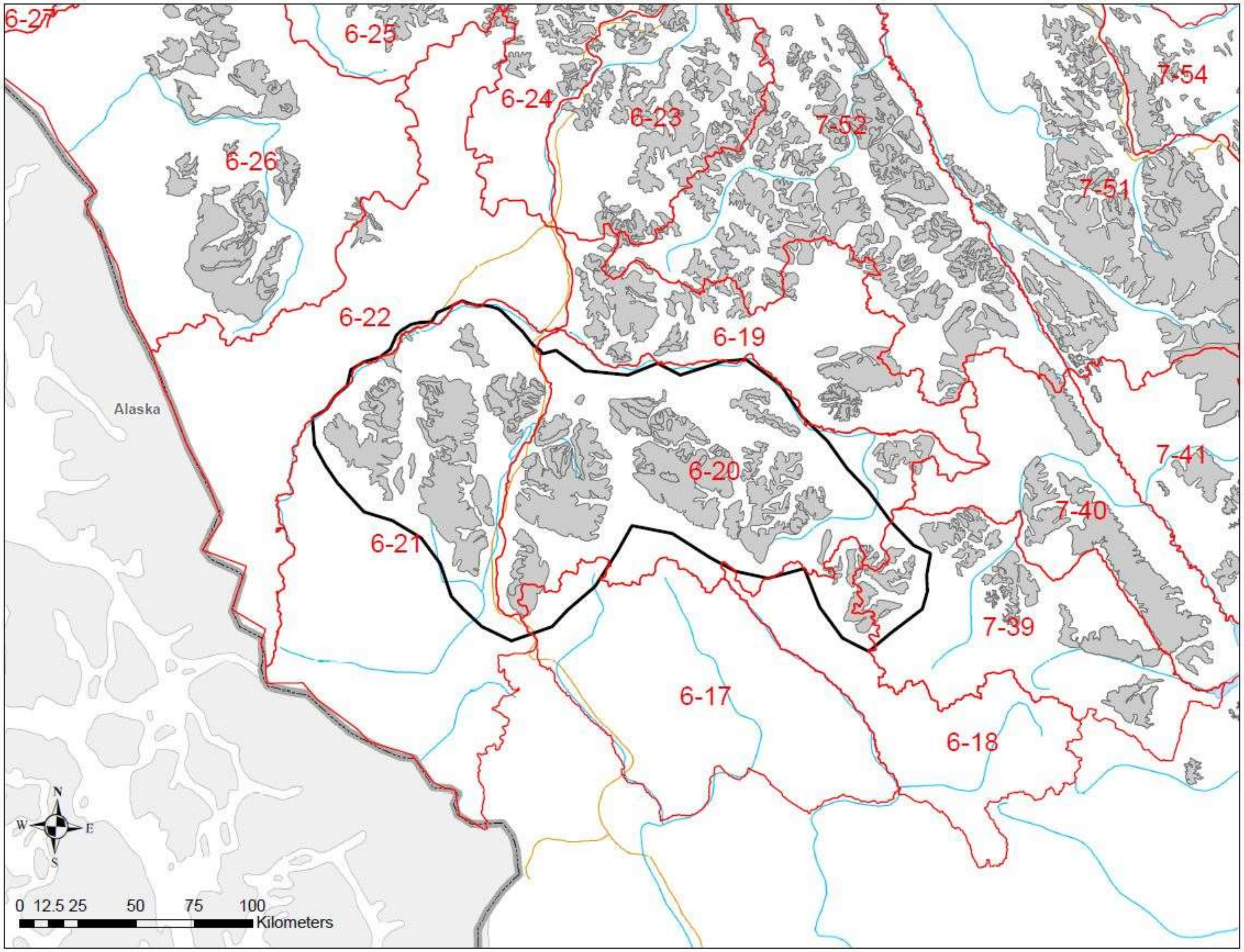
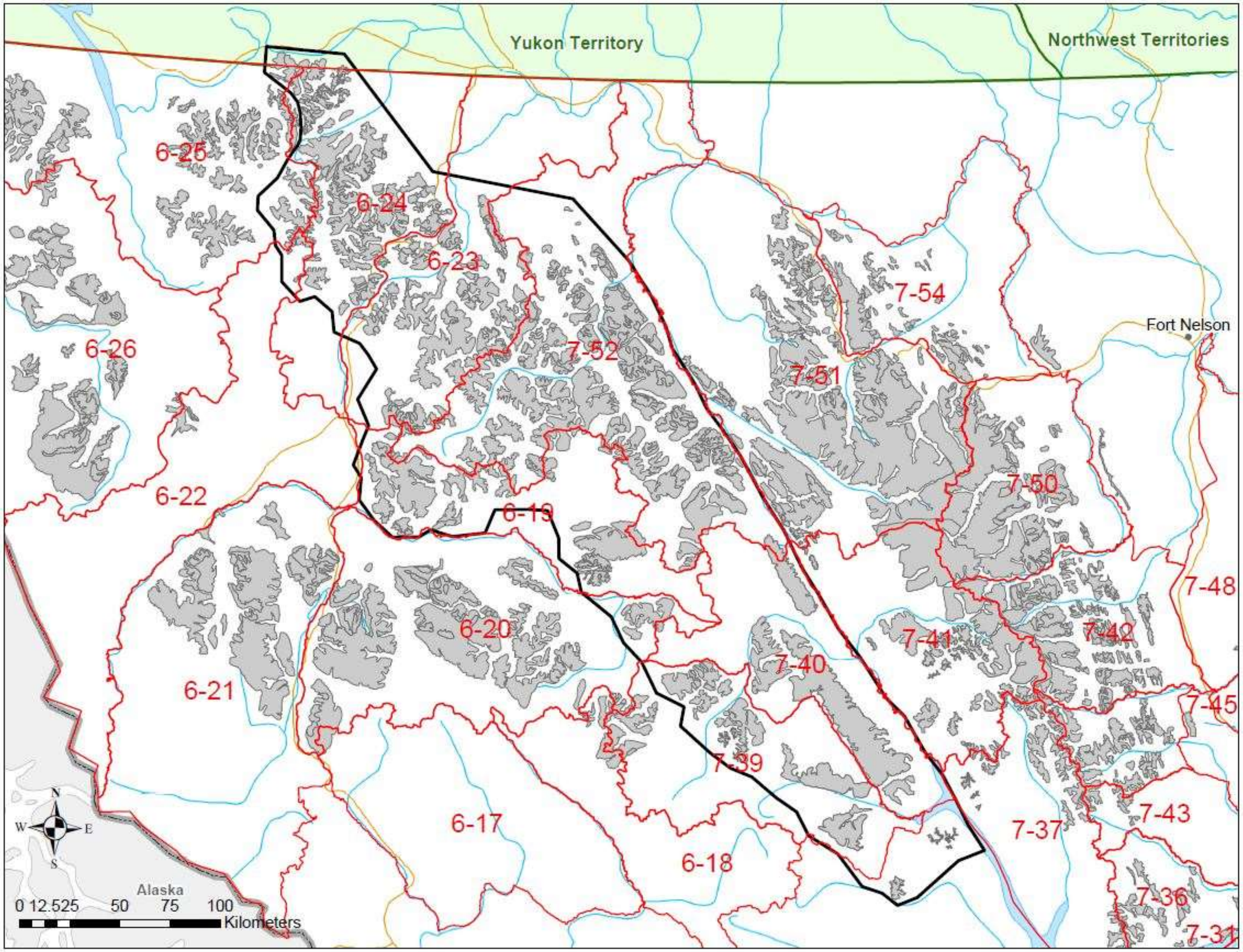


Figure 8. Proposed Population Unit of Stone's sheep 1 (black polygon) consisting of multiple herds (grey polygons). Population Units are delineated based on genetic divisions (Sim et al. 2018), herd range boundaries (Provincial Wild Mountain Sheep Registry), landscape fracture zones, and Wildlife Management Units (red outline).

Figure 9. Proposed Population Unit of Stone's sheep 2 (black polygon) consisting of 20 herds (grey polygons). Population Units are delineated based on genetic divisions (Sim et al. 2018), herd range boundaries (Provincial Wild Sheep Registry), landscape fracture zones, and Wildlife Management Units (red outline).



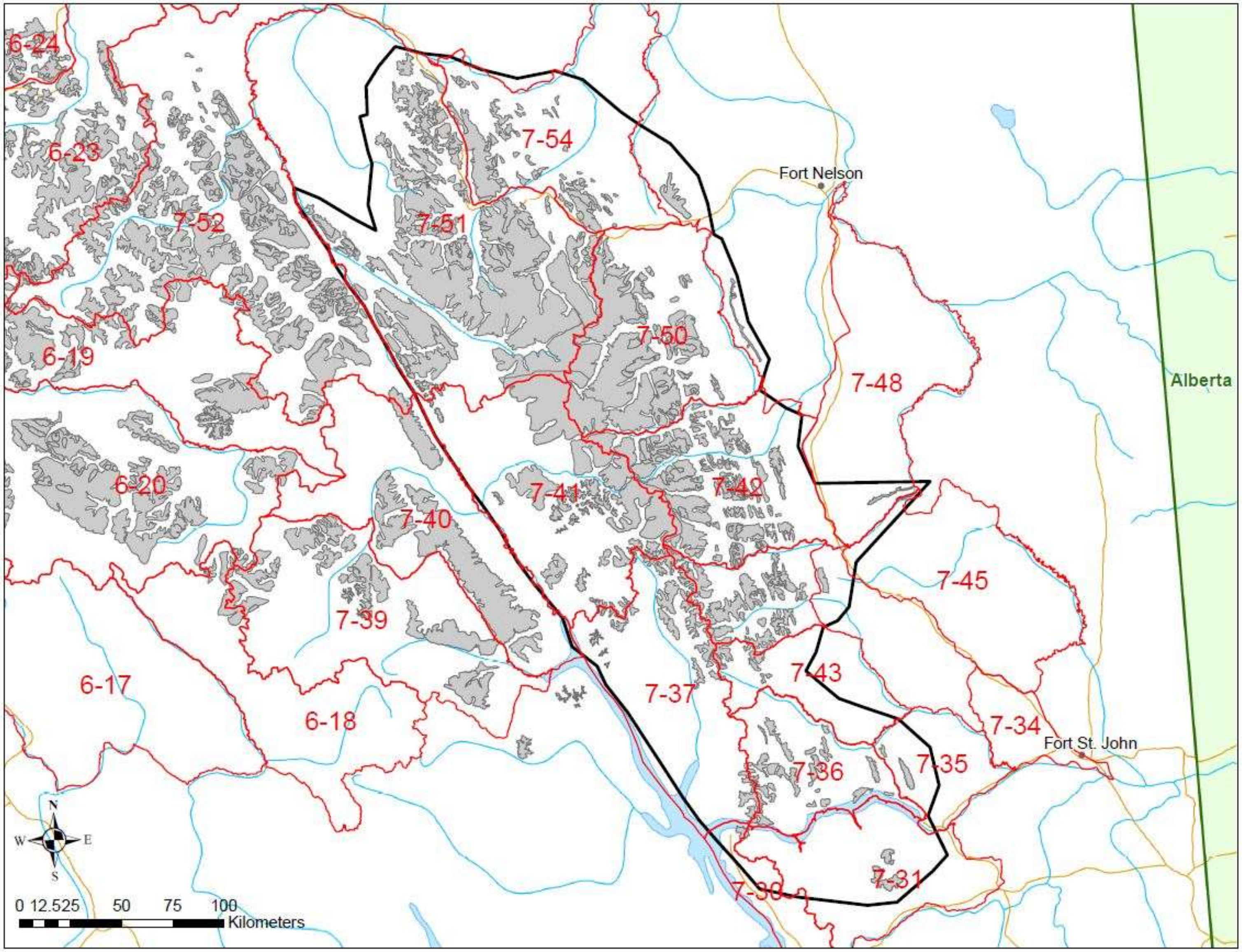


Figure 10. Proposed Population Unit of Stone's sheep 3 (black polygon) consisting of 24 herds (coloured polygons). Population Units are delineated based on genetic divisions (Sim et al. 2018), herd range boundaries (coloured polygons - Provincial Wild Sheep Registry), landscape fracture zones, and Wildlife Management Units (red outline).

Table 2. Thinhorn sheep herds by proposed Population Units (based on Sim et al. 2018). Herd names are those stored in the Provincial Wild Mountain Sheep Registry.

Dall's Sheep	Admixed Sheep (dominant ancestry)	Stone's Sheep 1	Stone's Sheep 2	Stone's Sheep 3
Tatshenshini	Atlin (Dall's)	Todagin	Jennings	Fosberg-Driftpile
Mansfield	Snowdon (Dall's)	Yehiniko	Cassiar	West Toad-Gundahoo
Primrose	Nakina (Stone's)	Spatsizi	Cry Lake	Terminus Mountain
Tutshi	Atsutla (Stone's)	Tatlatui	Horseranch	Four Mile-Eight Mile
Table	Tatsamenie (Stone's)	Klastline	West Turnagain	Stone Mountain Range
	Level (Stone's)	Edziza	Kechika Ranges	Steamboat
			Samuel Black Range	Northern Rocky Mountains
			Tucho	Wokkpash
			3 Sisters	Gataga
			Frog River	East Muskwa
			Thudaka Range	Racing River
			Lunar	Besa-Prophet
			Metsanta	Sikanni Chief Canyons
			Sifton Range	Truncate-Blanchard
			Russel Range	Akie/Pesika
			Geigerich Peak	Deception
			Cutbank Creek	Chowika
			Chase Mountain	Upper Ospika
			Ferguson	Lower Ospika
			Ross	Halfway River
				Schooler
				Dunlevy
				Mt Frank Roy
				Mt Selwyn

Population demographic composition ratios (i.e., sex and age) are also calculated using data collected during survey flights. The number of lambs per 100 ewes (or in the case of Thinhorn sheep described as ewe-like or nursery sheep) is often used to estimate reproductive success, assist with interpretation of population trend information, and describe the recruitment of wild sheep populations. Generally, 25-30 lambs per 100 nursery sheep (just after lambing) is considered the minimum ratio sufficient to maintain a stable population (Yukon Department of Environment 2017) and a ratio of 30-40 lambs:100 ewe-like sheep has been identified as adequate in maintaining stable populations when observed in mid to late-summer (Hoefs and Nowlan 1994, Whitten 1997, Demarchi and Hartwig 2004). The number of rams per 100 ewes is an additional metric used as an indication of demographic health of a population. BC's draft Thinhorn Sheep Harvest Management Procedures recommend populations be managed to maintain sufficient mature rams in the population to ensure older rams fulfill their social and biological roles (e.g., do most of the breeding, maintain traditional range utilization and subdue excessive activity by younger rams during the rut), consistent with Geist (1971). In unhunted Dall's sheep populations, ratios have been observed with >50 rams:100 ewe-like sheep (Hoefs and Bayer 1983, Nichols and Bunnell 1999). Conversely, an easily accessible Stone's sheep population in BC (Todagin Mountain) in 1972 had a ram:ewe-like ratio estimated at 20:100, as a result of high harvest pressure. Concerns about this situation prompted implementation of firearms restrictions in 1973, creating the archery-only hunting area that exists today. This returned ram:ewe-like ratios to a more sustainable level of 46:100 by 1985 (Steventon and Marshall 1985). The current draft of BC's Thinhorn Sheep Harvest Management Procedures stipulates only allowing licensed harvest in populations that have a minimum of 40 rams:100 ewe-like; this is similar to recommendations in the Science-based Guidelines for Management of Thinhorn Sheep in Yukon (Yukon Department of Environment 2017).

Demographic ratios alone may be poor predictors of recruitment and population dynamics and therefore must consider survey timing and any potential survey factors that could bias or affect observer accuracy (e.g., weather and sightability; McCullough 1994). Predator abundance and migrations (e.g., golden eagle [*Aquila chrysaetos*] spring migrations), alternate prey abundance facilitating apparent competition, as well as severe winter and spring weather (wind and precipitation, freeze-thaw/rain-on-snow events) can quickly change lamb:ewe-like ratios. While lamb mortality is typically highest during the first 2 weeks following birth (24-28% for Yukon Dall's sheep; Nichols and Bunnell 1999) it peaks again during late winter when lambs are approximately 10 months old and during golden eagle migrations. Similarly, observed ram:ewe-like ratios are sensitive to variable sightability of small, dispersed groups of rams outside of the rut or through comparisons using a combination of pre and post-harvest season ratios. Cubberley (2009) found 21% fewer rams during a March survey compared to a December survey when rams were generally more intermixed with ewes in larger groups.

Population abundance is determined by either minimum counts, or total counts requiring a correction for sightability (accounting for unseen individuals). Sightability correction factors (SCF) are typically applied after the survey, as sightability varies with group size, terrain obstructions, and vegetation cover and other survey conditions. Alaska research on Dall's sheep found that sightability can be as high as 88% (Udevitz et al. 2010) in both fixed wing and helicopter surveys. Hengeveld and Cubberley (2011) determined sightability during aerial surveys for Stone's sheep in the Sulphur/8 Mile project area in northern BC using collared individuals, but their results were drastically different when compared between their two study populations, across demographic groups and between surveys conducted in December and March, with all aspects generally ranging between 58% and 90%. The variation in estimates of detection highlights the importance of refining SCFs for Thinhorn sheep.

Photo: Bill Jex

Population Inventory and Monitoring Recommendations

1. Refine spatial Thinhorn sheep sub-population units where there is limited interchange (immigration/emigration) with other sub-populations using:
   i. Empirical information (ecotypes, genetics, inventory and GPS collar data);
   ii. Landscape features (e.g., Biogeoclimatic Ecosystem Classification [BEC], landscape fracture zones such as large rivers/lakes or wide forested valley bottoms);
   iii. Harvest data;
   iv. Expert opinion and Indigenous and Local Ecological Knowledge, supported by both published and unpublished literature.
2. Prioritize population units for inventory based on:
   i. Population viability issues/concerns (e.g., high harvest rates or pressure, harvested ram age compositions, herd recruitment, risk of contact with domestics/herd health, stochastic severe weather occurrences, or reported predation events);
   ii. Existence and/or frequency of previous inventories and current knowledge gaps;
   iii. Accessibility of the population, anthropogenic disturbances, commercial/industrial activities or development proposals;
   iv. Social and cultural considerations.
3. Develop strategies following recommendations in Hatter (2017) to create dedicated 5-year funding strategies to support an effective Thinhorn sheep population monitoring program.
4. Standardize inventory methods and timing based on management goals and objectives (e.g., lamb recruitment; habitat use/occupancy), and develop models to refine sightability correction (SCFs).
5. Refine and improve the accuracy of Thinhorn sheep herd range boundaries stored in the BC Wild Mountain Sheep Registry.
6. Develop dedicated funding sources to improve population information. Upload, store, and access population inventory data and reports in provincially managed wildlife databases.
7. Improve scientific understanding of wild sheep behavioural ecology that includes addressing knowledge gaps related to: habitat use and selection, forage nutrition, survival rates, herd health/fitness/stress hormone levels, age of first parturition and subsequent reproductive frequency, and climate change and weather effects on annual survival and subsequent harvest opportunities.
8. Promote ongoing use of Citizen Science tools and supports such as the BC Mountain Goat and Wild Sheep Natal App (https://www2.gov.bc.ca/gov/content/environment/plants-animals-ecosystems/wildlife/wildlife-conservation/wildlife-health/wild-sheep-health/bc-goat-sheep-natal-app).
9. Promote partnerships with research institutions, academia, Conservation stakeholder and other non-government organizations in implementing local projects.

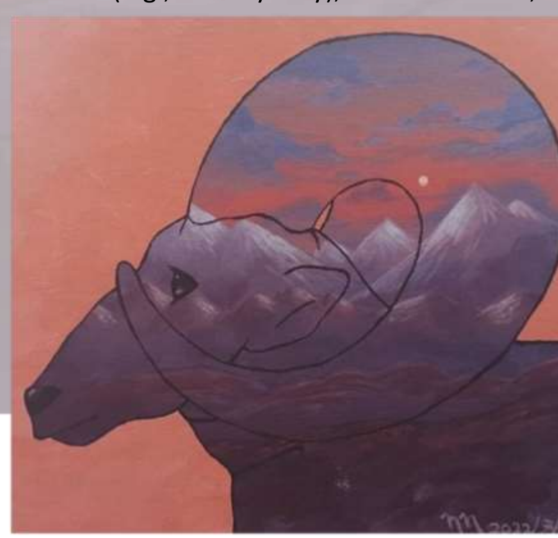
Harvest Management

Thinhorn sheep are one of the most prized big-game animals in North America, valued by both consumptive and non-consumptive users. They are harvested as part of cultural and subsistence practices by First Nations/Indigenous peoples and are important to resident as well as non-resident hunters and the guide outfitting industry. Licensed hunting has been used as a tool for conservation and for promoting sustainable use of wildlife and as such, has benefitted many species of native wildlife. This has become known as the North American model of wildlife conservation, where economic returns benefit conservation of the species. BC has generated substantial revenues through licensed hunting of both Bighorn and Thinhorn sheep, with those dollars reinvested through the Habitat Conservation Trust Foundation (HCTF) and other support funding now provided through the Together For Wildlife Strategy.

In addition to license fees and harvest royalties, BC has been issuing a resident and a non-resident Special Sheep Permit opportunity annually since 2000, which allows for the hunting of a mountain sheep ram with special concessions. These permits generate revenue that is then invested through the HCTF. Proceeds raised through these permits to date have enabled the Province and HCTF to provide over $3.5 million in support of projects benefitting BC's wild sheep and other wildlife conservation efforts. Other investments directed through government (e.g., Land Base Investment Strategy and Together For Wildlife Strategy) and non-government associations and conservation organizations (e.g., Wild Sheep Society of BC, Wild Sheep Foundation) also provide significant annual contributions toward wild sheep conservation projects in the province.

From the inception of regulated hunting of Thinhorn sheep in BC in the early 1900s, harvest has been restricted to males only, with the regulations that govern hunter opportunity and harvest shifting over time to become more restrictive based on ram age and horn curl (summarized in Demarchi 1978, Demarchi and Hartwig 2004). This trend is primarily due to increased harvest pressure coupled with a lack of population monitoring data that are required to support harvest decisions and reduce risk of overharvest. In lieu of more robust population monitoring data across BC's Thinhorn sheep range, harvest management decisions are heavily supported by compulsory inspection (CI) data from harvested rams. Harvest data provide trends in harvest age, location, horn annuli measurements, and hunter effort and success. The Yukon faces similar challenges, with limited population and demographic data in many areas insufficient to adjust the allowable harvest annually (Yukon Department of Environment 2017). Trends in regulated hunting of rams in BC have been monitored since compulsory inspection of horns from harvested Thinhorn sheep was initiated through regulation in 1975. Prior to this, sheep harvest was not formally tracked; however, some intermittent records dating back into the early 1900's do exist.

Current tools used to regulate Thinhorn sheep harvest in BC include General Open Seasons (GOS), Limited Entry Hunting Seasons (LEH), Special Management Areas (e.g., archery only), Closed Seasons, and minimum horn curl and harvest age restrictions. In the early 1900's, however, Thinhorn sheep harvest was only restricted to any male sheep, which was changed to any male sheep over the age of 1 year in 1942. Horn curl restrictions were established in 1954 and saw an evolution of changes to the degree of curl ranging from ¾ to $^{7}/_{8}$ curl in 1973, then to the original definition of 'full curl' in 1976 (Demarchi 1978). The more restrictive definition of "full curl Thinhorn ram" used today, came into effect in 1982: "*Any male Thinhorn sheep of eight years of age or whose horn tip extends upwards beyond the forehead-nose bridge*", and this remains the basis for the regulation today (Figure 11). This definition is considered by the Province, to be the most conservative in terms of potential effects on population viability and herd



Artwork by Naomi Fisher

dynamics, while offering minimally restricted, sustainable harvest opportunities and maintaining sufficient mature rams in the population to ensure older rams fulfill their social and biological roles (MFLNRO 2013).

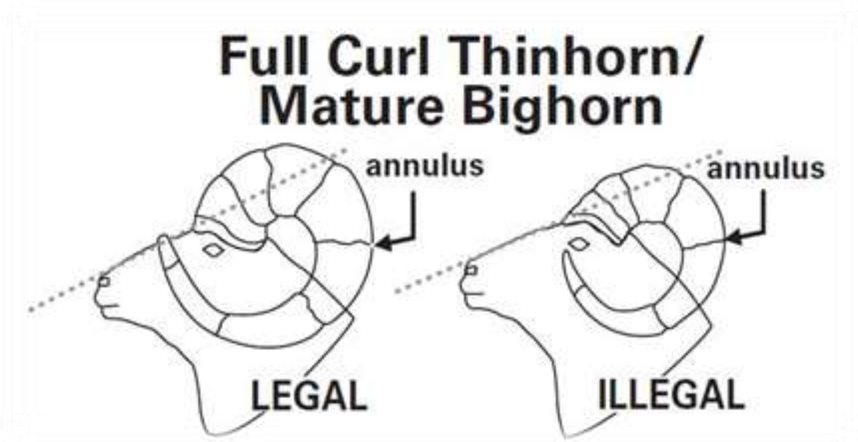


Figure 11. BC regulation on legal harvest of Thinhorn sheep requires a minimum of 8 years as evidenced by true horn annuli, or horn tip (when viewed squarely from the side at right angles to the sagittal plane of the skull) that extends dorsally beyond the nose bridge plane (Source: 2020-2022 BC Hunting and Trapping Regulations Synopsis).

Thinhorn sheep CI and horn plugging is a requirement for all Thinhorn sheep harvested by licensed hunters in BC. The CI process requires that all successful hunters must, within a prescribed timeline, present the complete upper portion of the ram's skull with horns naturally attached for inspection, measurement, installation of a horn plug and collection of harvest location and biological samples. Submission of an incisor tooth is also required to support horn aging. This process allows for assessment of compliance with harvest regulations, provides associated hunter harvest and hunter demographic data (Figures 12-15), an understanding of hunter interest/demand (Figure 16), and the horn plug discourages illegal traffic in ram heads. Biological samples collected during CIs have provided a large sample size (spatial and temporal) of material for genetic and evolutionary research and provide broad-scale health monitoring. Horn annuli lengths and ram age (by horn annuli) are also recorded during the CI process to monitor long-term trends in horn anatomy/morphology, harvest age distributions and proportions of ages of the harvested rams.

With Thinhorn sheep hunting restricted to full curl or 8+ year old rams, there is ongoing debate about the magnitude of measurable evolutionary response from selective hunting of large-horned males and the removal of a high proportion of rams with fast growing horns on the evolution of horn size in rams from within a population and the potential for negative consequences (Douhard et al. 2016, Festa-Bianchet 2017, Monteith et al 2018, Boyce et al. 2018, Festa-Bianchet et al. 2019, Boyce et al. 2019). . The general consensus is that selective harvest hunting can cause genetic change when harvest rates are high and highly selective, and when populations are isolated or occur at more localized scales. Under high harvest rates, size-based selective harvest will likely be evolutionarily relevant as it could affect the reproductive success of rams with smaller horns (Hengeveld and Festa-Bianchet 2011), but phenotypic change is complicated by individual age, genetic contribution of females, nutrition/fitness, epigenetics/phenotypic expression, patterns of mating success by individual males, gene linkage and gene flow, and other factors that can interact with harvest to impede the directional evolution of a trait (Coulson et al. 2018, Heffelfinger 2018). However, Sim and Coltman (2019) found that genetic influence on horn length, base diameter and horn volume were moderately heritable in Thinhorn sheep and accounted for approximately 33% of an individual ram's horn growth potential. In Bighorn sheep, harvest rates above 30–40% of the legal rams from within the population have been linked to shifts in the age distribution of males and to changes in horn growth of surviving males (Schindler et al. 2017). Where this level of harvest pressure occurs over an extended period of time, average ages of rams harvested under a curl restriction tend to increase as the proportion of rams with slower growing horns (i.e., those that take longer to become legal by curl) increase and the proportion of younger rams (i.e., those with fast growing horns that become legal earlier in life) decrease representation in the population. Maintaining a low harvest rate on full curl Thinhorn rams will help avoid undesirable evolutionary effects of hunter selection (Douhard et al. 2016).

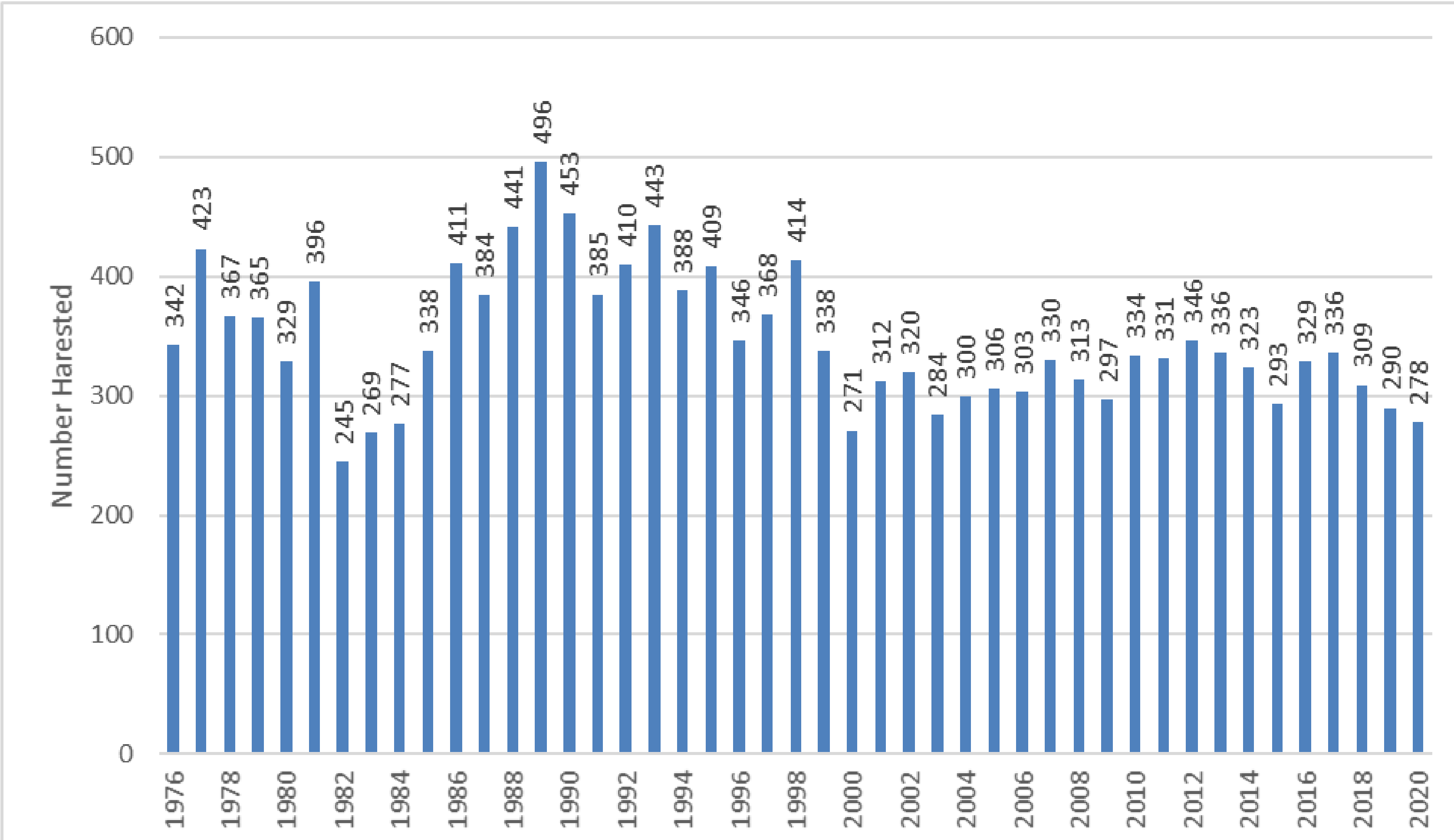


Figure 12. Total annual harvest of Stone's sheep rams in British Columbia, 1976-2020. Source: Compulsory Inspection records. Harvest in 2020 was affected by international travel restrictions.

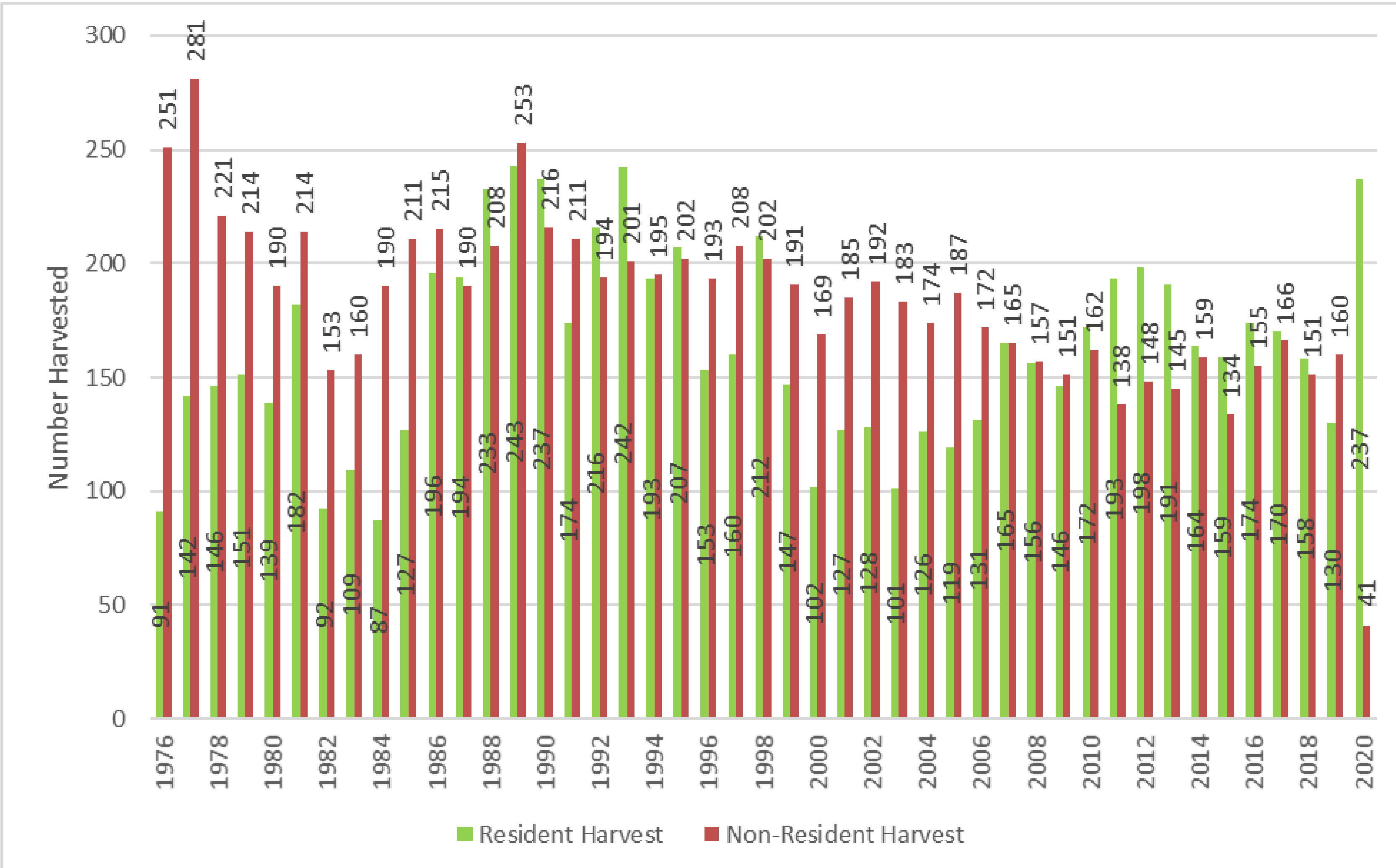


Figure 13. Annual harvest of Stone's sheep rams in British Columbia by residency, 1976-2020. Source: Compulsory Inspection records. Note that international border travel restrictions impacted Non-Resident Hunter attendance and harvest in 2020.

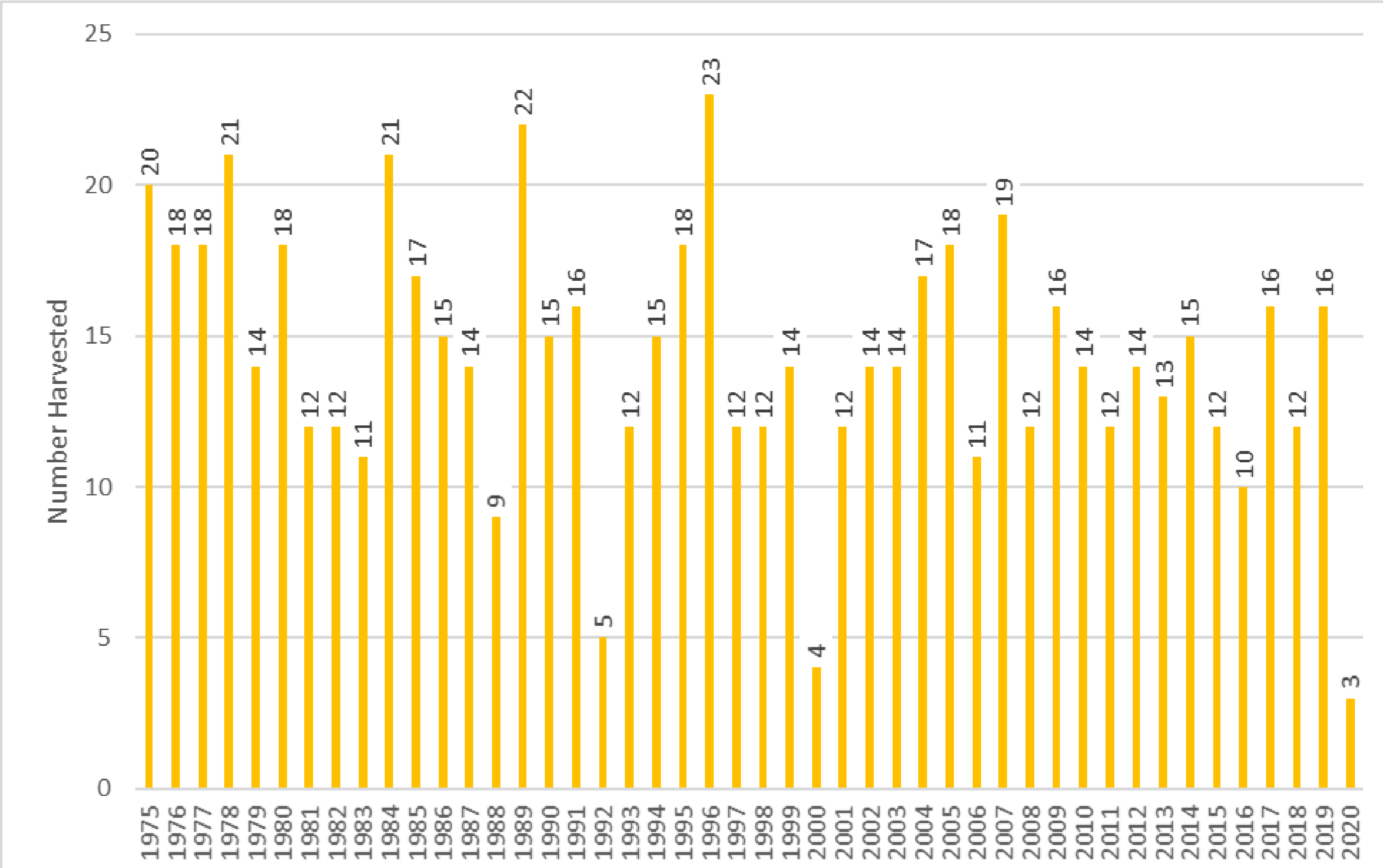


Figure 14. Total annual harvest of Dall's sheep rams in British Columbia from core range in MUs 6-27, 6-28 & 6-29, 1975-2020. Source: Compulsory Inspection records. Harvest in 2020 was affected by both international and provincial travel restrictions.

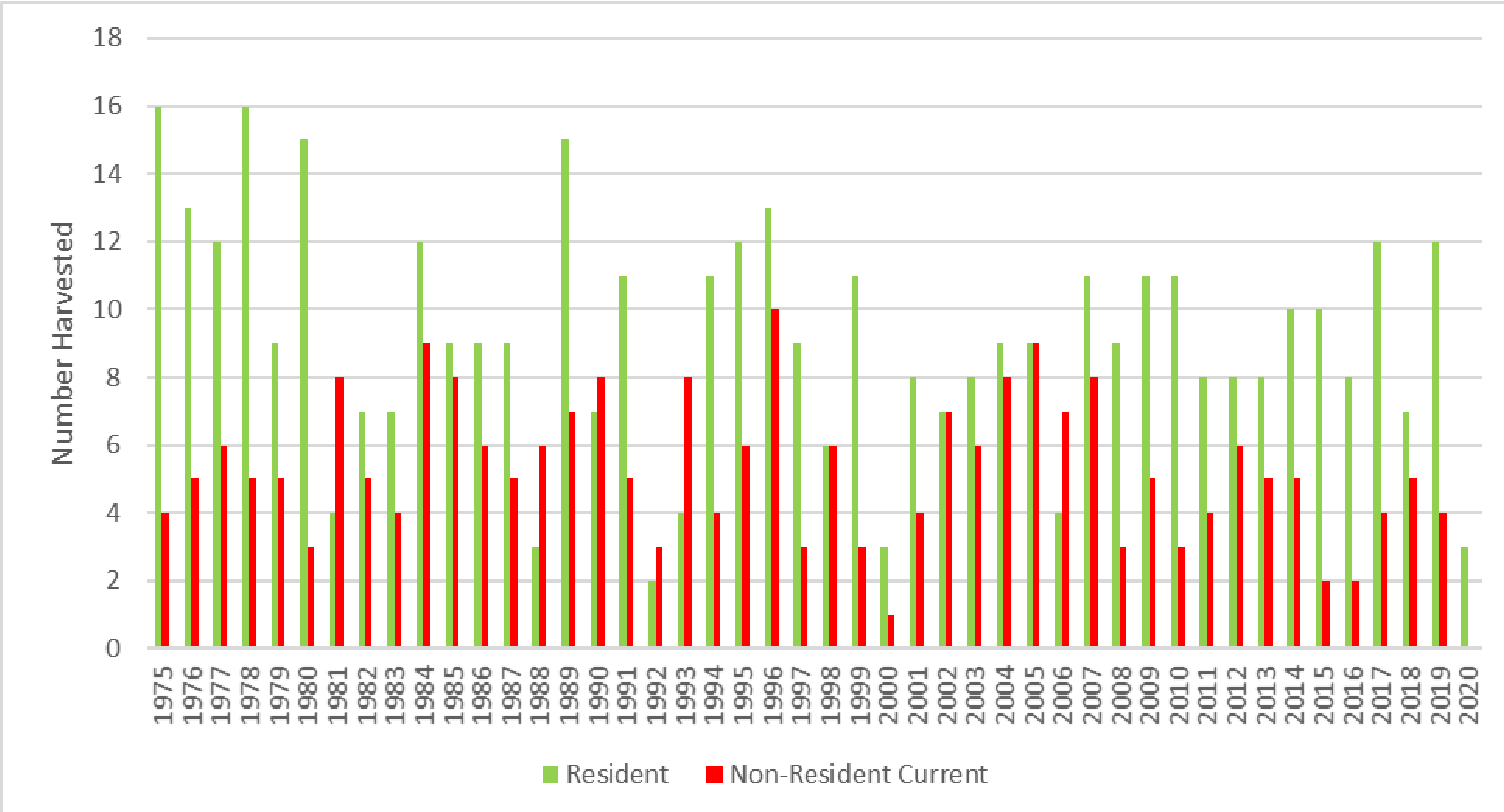


Figure 15. Total annual harvest of Dall's sheep rams in British Columbia from core range in MUs 6-27, 6-28 & 6-29, 1975-2020, by residency. Source: Compulsory Inspection records. Harvest in 2020 was affected by both international and provincial travel restrictions.

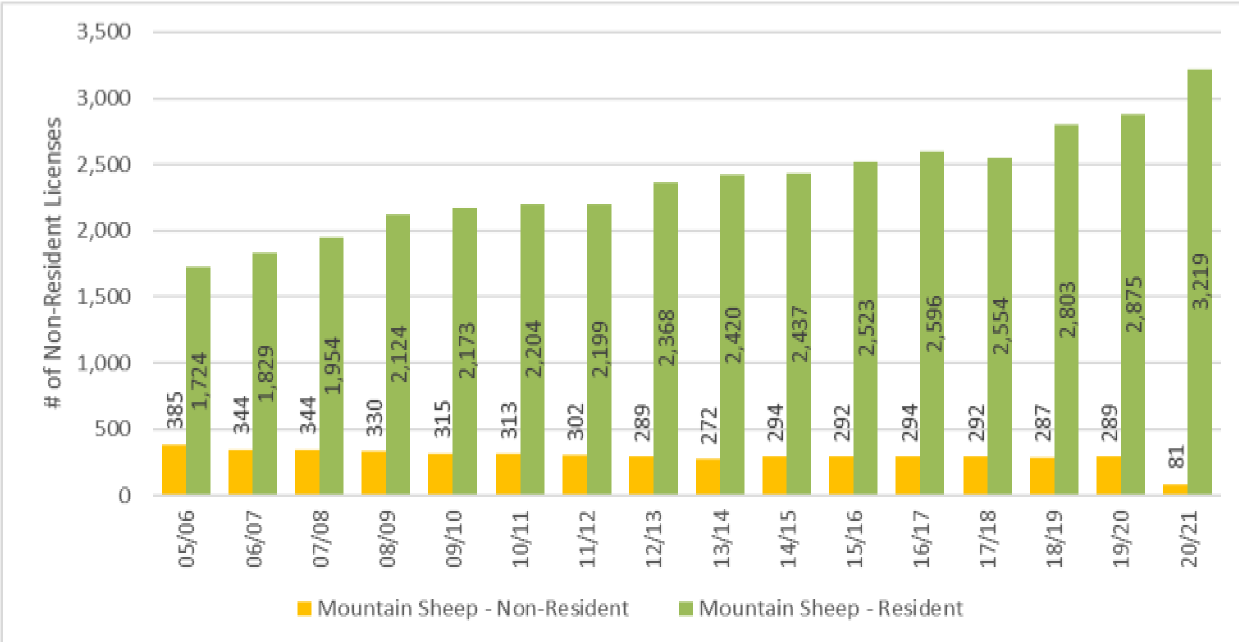


Figure 16. Total annual sales of all sheep hunting licenses (Bighorn & Thinhorn) in British Columbia, 2005-2020, by residency. Source: BC Hunting License Sales Reports. Sales of non-resident licenses in 2020-21 were affected by international travel restrictions.

Thinhorn sheep are not considered an *allocated species,*[15] nor are they designated as a *category A species* across much of their range. For all hunted Thinhorn sheep populations, however, managers describe conservation needs and include an estimate of First Nations harvest, then administer the remaining allowable annual harvest between resident and non-resident hunter opportunities. First Nations hunters have traditionally harvested animals of either sex and any age for cultural and subsistence purposes, however with new understanding of low ewe productivity, population impacts associated with female harvest, and other options for addressing food security, some Nations are asking their hunters to restrict their constitutionally-based food, social and ceremonial harvesting to males. The Province considers licensed hunter harvest as recreational hunting opportunity, consistent with the *Hunting and Fishing Heritage Act*. Standardized harvest management procedures that pre-set conditions (e.g., minimum population size, demographic ratios, trends in ram age at harvest, etc.) and that trigger corrective actions are necessary to improve clarity and transparency in harvest management of Thinhorn sheep in BC. These also support adaptive management by incorporating variability in recruitment rates, hunting vulnerability, human access, and winter severity across populations and over time. Other anthropogenic sources of mortality must also be considered for effective harvest management including non-hunting human-caused mortalities (e.g., vehicle collisions/mortalities), and illegal harvest.

Draft Harvest Management Procedures were developed for Thinhorn sheep in 2012 by the Ministry's Thinhorn Sheep Working Group. The harvest procedure is intended to improve clarity and transparency in the development of Thinhorn sheep harvest regulations province-wide. The Thinhorn sheep harvest

[15] Licensed harvest is implemented through the Provincial Harvest Allocation Policy (4-7-01.03) for all hunts identified as Category A hunts by the Harvest Allocation Procedure (4-7-01.03.1) and for species of hunted wildlife designated as Category A species under the procedure. See: https://www2.gov.bc.ca/assets/gov/environment/natural-resource-policy-legislation/fish-and-wildlife-policy/4-7-0103_-_harvest_allocation_policy_-_january_30_2019_-_signed.pdf

procedures generally align with the province's 2010 Big Game Harvest Management Procedures[16] (4-7-1.07.1). A key population management objective for hunted Thinhorn sheep populations is to ensure that older rams do most of the breeding, maintain traditional range utilization and subdue excessive activity by younger rams during the rut (MFLNRO 2013). Rominger (2008) reported a range in minimum huntable population sizes used in wild sheep harvest management in the western states and provinces of between 50 and 100 sheep. The current provincial guideline for the minimum Thinhorn sheep population size to support a ram hunt is 75 observed sheep (similar to the BC Bighorn Sheep Harvest Procedures[17]), however given expanding understandings of lower reproductive rates, population dynamics, anthropogenic effects, chronic lack of population inventory and in the face of changing climates the significance of severe stochastic winter weather events on populations, some consideration of increasing the minimum huntable population to 100 animals may be warranted. Work referenced by Demarchi and Hartwig (2004) suggested that minimum viable populations for mountain sheep in the literature generally ranged between 100-125 sheep, or possibly >150 sheep if the goal to ensure that no impact to genetic variability was a priority. Currently, licensed hunter harvest of Thinhorn sheep lambs and/or ewes is not permitted in BC.


Photo: Clint Walker

The Draft 2013 Thinhorn Sheep Harvest Management Procedures offer two models for managing licensed hunter harvest: the Population Inventory Model and the Harvest Age Structure Model. There is also an overarching recommendation supporting calculation of an Annual Allowable Harvest (AAH) when setting harvest thresholds for a given Thinhorn sheep population. Calculating the AAH requires access to sufficient population inventory and demographic data and use of the Population Inventory Model. If adequate population/demographic data are not available, the AAH can be determined using the Harvest Age Structure Model. The Harvest Age Structure Model considers adjustments to the allowable harvest in the context of a 5-year allocation period, where the allowable licensed harvest can be increased or decreased based on the proportion of rams that are ≥ 8 years of age, represented in the harvest. Whichever method is used, the intent is to ensure that the maximum harvest rate of Thinhorn sheep rams in any population does not exceed 3% of the estimated population. This harvest rate is similar to other jurisdictions with wild sheep in North America, where ram harvest rates range from 1.5% to 3.6%, with an average of 2.5% (Rominger 2008), although the companion implementation of minimum horn curl requirements in those Bighorn and Thinhorn sheep populations varied across those same jurisdictions. Several jurisdictions employ different approaches, such as supporting calculations of allowable harvest with data on the representation of >40-inch rams (i.e., > full curl) in the previous year's harvest (e.g., Alaska), or the proportion of rams with various horn curl classes or ages (Cox 2018). In the Yukon, (who use a slightly different definition of full curl than BC), harvest is managed to allow a full curl harvest rate of 4% of the non-lamb population, considering it sustainable for those populations that have been

[16] https://www2.gov.bc.ca/assets/gov/environment/natural-resource-policy-legislation/fish-and-wildlife-policy/4-7-01071_-_big_game_harvest_management_-_procedures.pdf
[17] https://www2.gov.bc.ca/assets/gov/environment/natural-resource-policy-legislation/fish-and-wildlife-policy/4-7-01075__Bighorn_sheep_harvest_management_-_procedures.pdf

surveyed (Yukon Department of Wildlife 2017). Cox (2019) reports that the net harvest outcomes for Thinhorn sheep jurisdictions align closely with those rates described by Rominger (2008).

Currently, Thinhorn sheep harvest in BC is restricted to rams that are a minimum of 8 years old or that meet the definition of a full curl Thinhorn ram (Figure 11). Hatter (in Demarchi and Hartwig 2004) suggested that a minimum of 75% of harvested rams should be ≥ 8 years old in order to maintain a sustainable harvest, and that harvest of full curl rams is considered the most conservative and effective strategy for ensuring that licensed harvest does not lead to population declines while still providing hunting opportunity. The strategy is generally effective because horn curl is an identifiable characteristic that hunters can use in the field, and it generally ensures that rams should reach the age of 8 years old before they are harvested, lessening the impact on population, breeding and age structure. By restricting the harvest to older Thinhorn rams, social structures within the male cohort of the population should be maintained, and mature rams should have at least one year of active participation in the rut. There is also a greater likelihood that very old rams killed during the hunting season could represent more compensatory than additive mortality, where the harvest is dominated by rams >8 years of age. As well, younger rams with higher survival rates or those with fast growing horns that are less selected for by hunters due to their age, may reach maturity and participate in the rut prior to becoming vulnerable or desirable for legal harvest. Based on 37 years of horn growth data, Stone's sheep rams may become legal (i.e., full curl) at a minimum of 4 years of age, with most reaching full curl by ages 7 or 8, and can live up to 14 years with some records identifying rams as old as 16 in BC (Douhard et al. 2016). Yukon data suggests that full curl age ranges between 4-11 years of age, with 55% of rams reaching full curl in their 7th or 8th year, and 85% before their 9th year (Environment Yukon, unpublished data); the Yukon does, however, use a less restrictive definition of full curl rams than BC, potentially resulting in rams becoming available for harvest up to 1 season earlier than those same individuals would if they were hunted in BC. Age-specific mortality research on Dall's sheep in the southwest Yukon and Northwest Territories suggests that once rams reach full curl, annual mortality rates average 10-15% per year (Hoefs 1981), and once older than 10 years, successive years of involvement in the rut can increase mortality rates in that cohort by >50% (Yukon Department of Environment 2017). Mortality rates of subdominant Stone's rams in BC (i.e., between the ages of 4 and 6 years, or Class 2 and Class 3 rams), may be similar to those reported for Bighorn sheep by Loison et al. (1999), who found that 19-27% of 4-year-old rams died of natural causes before they reached age 6. Although this has not yet been specifically studied in BC, a review of findings from the Sulphur-8 Mile project in NE BC by Hengeveld and Cubberley (2011), identified an approximate annual mortality rate of 17% in study rams who ranged in age between 3 and 11 years old. A review of Thinhorn sheep herd compositions estimated from winter aerial surveys completed in Skeena region between 1996 and 2020 showed that on average, Class 2, Class 3 and Class 4 rams comprised 10%, 11% and 5% of the surveyed populations, respectively, loosely supporting the conclusion that the natural mortality rate in Class 3 rams appear higher than for other ram classes, as evidenced by the significant decline in recruitment into the Class 4 category.

Harvest Management Recommendations

1. Improve the accuracy and quality of harvest data collection (e.g., Compulsory Inspection, Hunter Sample, etc.) to facilitate reliable comparisons between WMU and/or LEH zone harvests and across herd ranges; understanding of hunter effort and participation; and harvested ram age trends, to inform harvest management decisions (e.g., hunter effort/success, proportional representation of harvested ram ages, number of years a ram was legal prior to harvest).

2. Retain Thinhorn sheep as predominantly non-Category A status as per the Harvest Allocation Policy, but finalize the Draft Thinhorn Sheep Harvest Management Procedures to support implementation of conservative regulatory harvest framework, and to inform harvest management and allocation decisions.
3. Set specific thresholds that trigger review/adjustments to harvest regulations, such as when:
    a. ≤75 sheep are observed or ≤100 sheep are estimated in a population or population unit;
    b. ≤70% of harvested rams are 8 years of age or older (within a biologically meaningful population unit);
    c. <40 rams:100 ewe-like sheep (observed in one or more repeated post-hunt surveys in the same population unit); and
    d. <25 lambs:100 ewe-like sheep (observed during one or more repeated surveys in the same population unit).
4. Examine ram horn growth and age to determine what proportion of rams become legal to harvest based on curl size (i.e., full curl), at what age they become full curl vs their age at harvest, and use this information to inform harvest management and an understanding of harvest pressure.
5. Use population demographic information to better understand the effects of weather on cohort survival and potentially forecast trends in populations and ram abundance; being able to reliably forecast trends in harvestable ram availability as a tool to help inform harvest allocation setting.
6. Development partnerships with First Nations governments that improve the collection of Indigenous harvest data that can be used to inform harvest management decisions.

Health and Disease

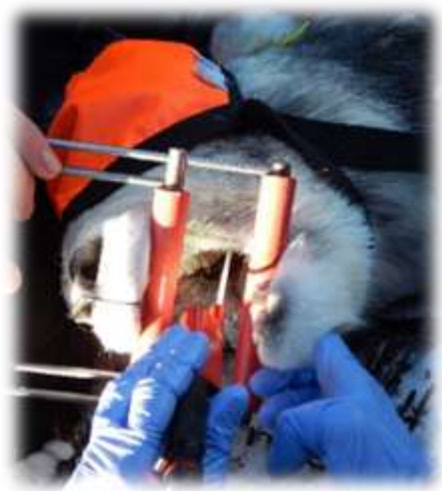
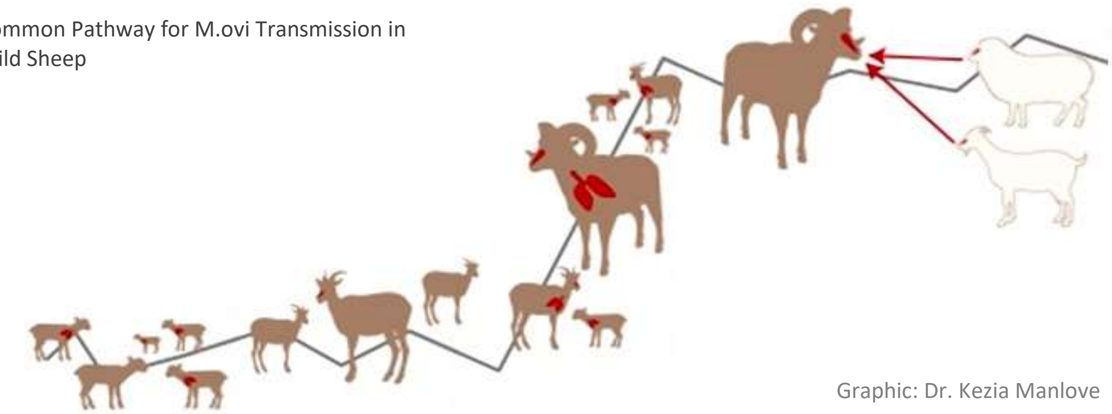


Photo: Bill Jex

Wild sheep in North America are susceptible to a variety of native and introduced infectious organisms, including bacteria, viruses and parasites that can impact individual and population health. Wild sheep and mountain goats are particularly vulnerable to introduced pathogens commonly carried by domestic sheep and goats (Jex et al. 2016, Wolff et al. 2019). The long process of domestication allowed the selection of livestock able to exist at high density in association with some types of pathogens without significant health consequences, however wild sheep and mountain goats evolved in small, isolated populations with a different suite of pathogens (Dubay et al. 2003). Wild sheep also exhibit differences in cellular immune responses to some pathogens when compared to domestics, all which results in a much more significant health risk to wild sheep. The most important pathogens crossing from domestic to wild sheep are a group of bacteria infecting the upper and lower respiratory systems. In Bighorn sheep infections can result in pneumonia outbreaks causing 30-90% mortality followed by years of low lamb recruitment, a pattern of die-offs and chronically sick herds documented in over 70 peer-reviewed publications (The Wildlife Society 2015). Decades of research investigating the epidemiology of Bighorn pneumonia has provided several theories, but it is now confirmed that the bacteria, *Mycoplasma ovipneumoniae* (M.ovi), is the most significant initiating agent of Bighorn pneumonia.

M.ovi is a genus of bacteria of the class Mollicutes that lack a cell wall around their cell membranes, making them naturally resistant to many antibiotics. There are many other Mycoplasma species and many strains of M.ovi and it is present in many domestic sheep and goat populations and is considered the pathogen of highest risk to wild sheep. The transmission of M.ovi from domestic sheep to Bighorns is a population-limiting disease that has been well documented in southern grassland ecosystems. M.ovi

Common Pathway for M.ovi Transmission in Wild Sheep



Graphic: Dr. Kezia Manlove

infection results in reduction of the efficiency of upper respiratory immune function by paralyzing tracheal mucosal cell cilia (hairs on the inside of the trachea that remove foreign material) and while it can lead to M.ovi infection of the lungs, it more commonly allows multiple bacterial species to colonize the lung tissue and death as a result of a polymicrobial bronchopneumonia (e.g., *Pasteurella, Mannheimia*). Besser (2013) examined 36 herds of Bighorn sheep that had recently experienced pneumonia outbreaks, and found that all 36 herds had serological evidence of M.ovi exposure (i.e., antibodies in serum). Following acute pneumonia outbreaks, many Bighorn herds will experience residual effects with surviving ewes carrying M.ovi in their nasal sinuses transmitting the bacteria to newborn lambs that die of pneumonia before 2 months of age. This chronic disease situation can lead to further herd declines and even extirpation[18].

Thinhorn sheep are susceptible to M.ovi with one published outbreak documented in a zoo (Black et al. 1988). Thacker (2020) and Wood et al (2010) completed comprehensive baseline health assessments of Stone's and Dall's sheep in B.C. and Alaska. Thacker's recent work included M.ovi testing and demonstrated M.ovi exposure in Alaska Dall's sheep, but no exposure in BC Stone's sheep; ongoing sampling efforts find no evidence of exposure to M.ovi in BC Thinhorn sheep. Thacker (2020) also found parasite loads were at levels similar to Woods et al (2010) and confirmed winter tick infestations in the southern extent of Stone's sheep range near the Williston Reservoir. There was minimal evidence of exposure to other bacterial and viral respiratory pathogens in sampled Thinhorn sheep, confirming that BC Thinhorns are relatively naïve to diseases carried by domestic ruminants (Thacker, 2020, Wood et al., 2010).

Recent research in Alaska in 2019-2020 detected M.ovi in ~5% of Dall's sheep tested (ADF&G 2020). Despite this, there have been no observed mass mortality events linked to M.ovi infections in Alaskan wildlife. Strain-typing of the M.ovi found a single strain which appears to be unique to Alaskan Dall's sheep, when compared to other strains of M.ovi found in other states (ADF&G 2020). The single, low virulent M.ovi strain in Alaskan wild ungulates is suggested to have originated from domestic sheep imported to Alaska during the early 1900's gold rush period. Sampling of Alaskan domestic sheep and

[18] https://www2.gov.bc.ca/gov/content/industry/agriculture-seafood/animals-and-crops/animal-production/sheep-and-goats/mycoplasma-ovipneumoniae

goats has found 6 different strains of M.ovi, none of which were closely related to the strain found in wild sheep. Due to the preference of Thinhorn sheep for high elevation habitat and the general lack of suitable large-scale domestic sheep and goat farming areas in northern regions in Alaska and BC, the risk of potential contact between wild and domestic Caprinae species is lower in the north. Although the likelihood of contact between Thinhorn sheep and domestic sheep may be comparatively low, the risk of disease and subsequent transmission to other populations is predicted to be catastrophic and far-reaching, due to their naïve status and contiguous range.

Warming climates may lead to an eventual increase and expansion in domestic sheep or goat farming in northern regions. Due to the concerns of pathogen transmission from domestic sheep and goats to Thinhorns, BC has initiated a package of regulatory-based solutions delivered through the *Wildlife Act* and the Government Actions Regulations (GAR), supported by various Land & Resource Management Plans (LRMPs) such as the Cassiar-Iskut Stikine LRMP and other government best practices documents (e.g., 2021 Domestic Sheep & Goat Health Protocol[19]). The *Wildlife Act* prohibits hunting for Thinhorn sheep or mountain goats while being accompanied by domestic sheep, goats or camelids used as pack animals. The GAR regulations prohibit the permitting, use, and ranging of domestic sheep, goats and camelids on Crown Lands and/or in the forest industry for use as silvicultural tools in most areas across the north of BC. Provincial government biologists, the Wildlife Health Program, the BC Sheep Separation Program and several non-government organizations (e.g., Wild Sheep Society of BC) have supported the development of a comprehensive provincial policy with additional regulatory strategies that could be delivered in partnership with the B.C. Ministry of Agriculture, and applied on private lands that either exclude or regulate domestic sheep and goat farm practices within Thinhorn sheep range. The Yukon developed and implemented a territorial policy (Control Order 2018-001) in 2020 that is intended to reduce the risk of pathogen exposure to Thinhorn sheep by domestic sheep and goats. The Yukon Control Order requires government-approved separation enclosures (fencing), annual testing of domestics for a suite of respiratory pathogens that includes M.ovi and the exclusion of any domestic sheep or goats from areas above 1,000 m elevation (considered to be Thinhorn sheep range). While the Yukon Order has likely protected Yukon wild sheep, an unintended consequence of the initial implementation of the Control Order was the export of several M.ovi positive domestics to BC prior to development of any similar policies to protect BC's Thinhorn sheep.

Warming climates may also shift geo-climate regulated reproductive-cycle adaptations in some species of gastrointestinal nematodes such as *Marshallagia marshalli*, common to wild sheep across North America. Research suggests that nematodes from northern environs develop at a faster rate than individuals of the same species from more southern latitudes (Aleuy et al. 2018). In a warmer climate scenario, multiple reproductive cycles in parasite populations within a single year may lead to significant fitness-related impacts to sheep populations since *M. marshalli* is reported to cause diminished fitness and body condition in Dall's sheep (Aleuy et al. 2018). Conversely, a higher rate of reproduction could result in the parasite developing too fast, with the nematode missing peak winter transmission when most eggs are shed. In this scenario, there would be a high level of larvae mortality and transmission could decrease. Patterns of parasite reproductive cycling will continue to evolve with climates changing as will our understanding of the effects on Thinhorn sheep individual fitness and population health, and will be re-evaluated into the future.

Risk assessments have been completed to examine the potential for South American camelids (alpacas, llamas) to transmit pathogens to wild ungulates in BC, (see Stephen and Schwantje 2003, and Centre for Coastal Health 2017). The Yukon and Northwest Territories have also developed similar assessments

[19] https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/wildlife-wildlife-habitat/wildlife-health/wildlife-health-documents/sheep_and_goat_health_protocol.pdf

(see Canadian Wildlife Health Cooperative 2016 and Garde et al. 2009). Stephen and Schwantje (2003) defined high risk pathogens that can be shed in the feces, excreted via respiratory secretions, urine, or saliva and persist in the environment, or those which may be perpetuated or magnified outside of camelids through a secondary host. Garde et al. (2009) identified 9 infectious agents as high risk. The Centre for Coastal Health (2017) ranked 12 infectious agents by risk of transmission to wild ungulates and the magnitude of impact in the event of transmission, including several newly emerging pathogens. No pathogens were ranked as high risk, although the report cites several sources of uncertainty in this risk assessment. Overall, the Centre for Coastal Health (2017) assessed the risk posed to wild ungulates by camelids accessing the backcountry as medium-high with a medium level of uncertainty. This result was driven primarily by the risk posed by respiratory pathogens (e.g., M.ovi) and contagious ecthyma. Ongoing re-assessments of risks potentially posed by camelids will be important in better quantifying any risks to Thinhorn sheep or mountain goat populations.


Photo: Bill Jex

There is new interest and accessible technology able to define the relationships between stress hormones and health, including individual fitness, reproductive outcomes and herd health, resiliency and sustainability. Downs et al. (2018) observed no relationship between cortisol levels during mating and pregnancy success in Alaska Dall's sheep; however, there was marginal support for a negative relationship between maternal cortisol levels and neonate birth weights. Low birth weights, resulting from high maternal cortisol, may result in low survival or low fecundity for the neonate later in life, which could result in overall population decline. Downs et al. (2018) also observed a negative relationship between pregnancy and an individual ewe's immune response and ability to kill potentially harmful bacteria while pregnant. In conclusion, the authors noted that interpretation of the results was limited by the complexity and difficulties of studying a natural system in rough terrain and harsh weather conditions, however, studying immunological defenses in free-ranging animals may be important in understanding dysfunction in immune systems. Similarly, Dulude-de Broin et al. (2019) identified that predation risk had a direct positive effect on the average annual faecal glucocorticoid concentration in a population of mountain goats, which in turn, negatively affected the proportion of reproductive females. These studies present initial evidence that stress-mediated fitness and breeding suppression can occur in wild ungulates following sustained increases in stress hormone levels and increased predation risk. In an environment where anthropogenic disturbances are increasing and predator assemblages remain intact with increasing levels of abundance, as is the case in some areas of Thinhorn sheep range in BC, understanding non-consumptive effects of predation and resulting disturbance-triggered stress hormone responses will become increasingly important in fully understanding the productivity and resiliency of some populations. Where stress responses are further compounded as a result of human activities, similar to those measured in a study developed by the Tahltan Guide Outfitters and Tahltan Central Government (TGOA 2021), understanding the mitigating role that habitat productivity and individual fitness may play in some populations, could be critical to understanding the true nature of the effects from stress on naïve wild sheep herds.

Health and Disease Management Recommendations

1. Consider provincial directives (i.e., policy and regulation) that includes:
    a. an action plan to monitor small ruminant farming within Thinhorn sheep range with the support of the BC Sheep Separation Program to deliver both directed and general outreach, and education support; and
    b. reduce the risk that Thinhorn sheep will be exposed to pathogens (e.g., M.ovi, contagious ecthyma) that can be carried by domestic sheep or goats, similar to other jurisdictions (e.g., Yukon, Northwest Territories, Alaska).
2. Support standardized assessment of Thinhorn sheep herd health to allow for early detection of disease and other health-limiting factors by:
    a. developing datasets from regular and ongoing monitoring of specific high priority/high risk-of-contact herds;
    b. surveillance health monitoring conducted during wildlife capture efforts, or during examination of harvested wild sheep through the Compulsory Inspection program; and
    c. including stress hormone and other developing methodologies (e.g., gene transcription) across ranges and seasons associated with predator dynamics and anthropogenic disturbances (through directed or opportunistic sampling). These can be completed when handling wild sheep or mountain goats, since understanding home range and fitness dynamics through assessing gut microbiomes (Wolf et al. 2021) could also become an important tool in future.

Habitat

Thinhorn sheep are found in mountainous regions of northwestern North America and occupy some of the most expansive, rugged, and picturesque landscapes on the continent. The challenges of surviving in these habitats include extreme weather events such as winter rain-on-snow and prolonged cold spring rain events, wide ranges in seasonal and daily temperatures, heavy snowfalls and avalanche hazards, and severe windstorms. The intensity of these conditions varies both with geographic location and the effects of marine weather systems. All of these are influenced by global climatic events, such as the Pacific Decadal Oscillation (Jex et al. 2016). As a result, Thinhorn sheep have adapted to exploit very specific habitats that include windblown, southern-aspect grassy slopes as winter range; steep rock slopes to evade predators and provide natal habitats and safety to newborn lambs; unobstructed seasonal migration and movement corridors; and mineral licks often located at lower elevations.

Habitat protection and enhancement efforts in BC have been focused on optimizing the quality and quantity of Thinhorn sheep winter range habitat and, where possible, implementing industrial activity timing windows and protection of natal range and mineral lick micro-sites. The availability of quality winter range has been deemed the most critical to survival, especially considering the anticipated effects of climate change in northern environments. Thinhorn sheep winter range and habitat features have been protected using land use designations under the *Forest and Range Protection Act* (FRPA); higher level plans such as LRMPs (e.g., Cassiar Iskut-Stikine LRMP); under the *Park Act* as a *park*, *conservancy* or *recreation area*; and through Wildlife Management Area designations under the *Wildlife Act* (e.g., Muskwa Kechika Management Area, Todagin Wildlife Management Area). In addition, Federal statutes such as the *Species At Risk Act* (SARA) include specific directives for managing habitats for SARA-listed species. Each of the designations establishes limits and offer guidance on the types of habitat interventions that may be used to benefit wild sheep that may be consistent with the purpose of that land designation, and this can both streamline and complicate the implementation of some types of projects.

Photo: Alicia Woods (Woods, 2022)

Habitat enhancement for Thinhorns in BC has historically focused on prescribed burning of sub-alpine habitats with the intention of enhancing nutritional quality and availability of forage, and removing deciduous shrubs, aspen and conifer in-growth. Tied closely to varied delivery approaches for introducing and containing target burn areas, these efforts have had mixed results. For example, Seip and Bunnell (1985) compared sheep populations with and without access to recently burned ranges, and found that forage nutritional quality did not differ, and that while burned sites produced more forage it was generally not available during winter and early spring periods when forage was limiting. Neither intake rate nor ram lifetime horn growth differed between populations. The same research identified one positive outcome from burning and an apparent reduction in parasites (e.g., lungworm), as burning appeared to reduce parasite load and improve lamb survival. Sittler et al. (2019) assessed Stone's sheep responses to vegetation change associated with prescribed fire, concluding that Stone's sheep appeared to select for burned sites based on forage quality at a fine scale, and recommending that prescribed fire interventions with a goal of enhancing habitat and forage to benefit Stone's sheep should be comprised of smaller fires, with burn intensities high enough to remove much of the existing shrub cover, situated on westerly slopes that have a good interspersion of rocky outcrops and talus scree (i.e., areas less frequented by elk [*Cervus canadensis*]). This same research showed that following prescribed fires completed in the spring of the year, forage digestibility increased significantly in the summer of the burn. In winter, biomass and available digestible matter increased to pre-burn levels by one year after burning. This work's findings were consistent with

Photo: Krista Sittler (Sittler, 2019)

other research in showing that a short-term post-fire nutrient flush occurred, but that the benefits to ungulate forage may only be short-lived (i.e., ≤2-3yrs).

Prescribed burning continues to be considered an appropriate natural disturbance that provides an effective way to improve attributes of Thinhorn sheep range. However there continues to be some disagreement as to the long-term effect of changes in the natural fire return intervals reflected in natural disturbance patterns in specific BEC zones and in some areas that have had frequent prescribed fire interventions applied to them. Current studies across BC are examining these outcomes and will better inform understandings as to the benefits and limitations of prescribed fire as an enhancement tool in Thinhorn sheep range. As such, prescribed burning now requires complex planning and coordination among several land management agencies to ensure clear objectives and an appropriate burn plan including an assessment of burn outcomes and resulting effects on other wildlife such as mountain goats who are often located in similar, nearby habitats. Multi-year burn plans have been developed for areas in the Peace Region (i.e., the Peace-Liard Burn Program) and other smaller initiatives are being explored (e.g., Todagin Mountain); First Nations governments have also assigned staff to identify potential candidate areas in the coming years. Costs of prescribed burns are high and include thorough baseline habitat assessments to support enhancement prescriptions for prescribed burns to help ensure the desired outcomes are achieved. Management planning within Parks and Protected Areas generally provides for the conservation of undisturbed populations and ecosystems.

Apart from changing habitat directly, prescribed fire and other human interventions and actions may have other resulting outcomes. Peck and Currie (1992) documented a significant decline in Stone's sheep populations following extensive burning as part of an elk enhancement program in Northeastern BC in the 1970s and 1980s. The decline in Stone's sheep was not a direct result of fire on sheep habitat, but rather the apparent competition effect that resulted from a massive increase in elk distribution and abundance, and consequently wolf (*Canis lupus*) populations reaching higher densities (Bergerud and Elliot 1998). Considering this, Jex et al. (2016) described competition in this way:

> "*Exploitative competition occurs when two species utilize a resource that is in short supply (e.g., food, water, mineral licks, or cover) to the extent that occupation and use of the site or resource benefits one of those species at the expense of the other. Interference competition occurs when one species excludes another from, or limits access to, a particular resource, and thus inhibits survival, reproduction, or other parameters as a result of behavioral interactions. In both cases, the degree of competition depends on the resource and the competitors involved. A third type of competition, termed apparent competition, occurs when one species (e.g., thinhorn sheep) indirectly competes with one or more others, but each serves as prey of a predator. This situation is common when one (or more) species increases in number(s), and results in an increase in predator numbers in a particular area. As a result, there are more predators hunting for individuals belonging to the initial group (i.e., thinhorn sheep) occupying that area*".

Following ongoing study across the range of wild sheep, a new type of apparent competition has been described by Dr. Vernon Bleich (pers. comm.), referred to as *facilitated predation* or *manufactured competition*. This occurs where a human intervention or habitat manipulation improves conditions or enhances a target species (e.g., prescribed fire or desert water guzzler installations for wild sheep), which also alters the distribution, density, or behaviour of other sympatric species, leading to increased predation rates on the target species. In some situations, there may actually be a net-negative impact to the target species despite the original intent to improve outcomes through the intervention activity. The cost of predation and interspecific competition may outweigh the anticipated benefits of open habitat and improved forage quality that could be created by habitat interventions such as prescribed burns.

The benefits of prescribed burning for Stone's sheep would improve if burns were targeted to small patches of high-elevation south/southwest facing grass-shrub complexes, which are spatially separated from elk and moose and would reduce concerns of forage competition (Sittler 2013, Woods and McNay 2017) and *facilitated predation*.

Habitat Management Recommendations

1. Ensure that where Thinhorn sheep-specific habitat burn interventions are planned, they target small patches of mid to high elevation south/west aspect slopes near escape terrain and natal areas, separated from elk, bison and moose habitats. These fire-based interventions should include a pre and post fire monitoring plan that assesses burn effectiveness, as well as forage quantity and nutritional outcomes; population responses and wild sheep use should also be monitored to provide an evaluation of effect that can inform other projects.
2. Use GPS collar data, remote cameras and other wildlife monitoring technologies to map movement/migration corridors/trails, stop-over sites, habitat use and locations of sensitive habitats (e.g., natal sites, mineral licks) to support establishment of land base designations and conservation objectives. Inclusion of Traditional Indigenous and Local Ecological Knowledge can broaden the understanding of location information and greatly benefit outcomes associated with this recommendation, supporting establishment of habitat protection consistent with co-management endorsements.
3. Continued investigation of the potential and effectiveness of other habitat-focused interventions (e.g., alpine plant community fertilization on winter ranges, mechanical vegetation alterations or removals, enhancing natural mineral lick locations with the addition of supplemental trace minerals, etc.) on improving Thinhorn sheep nutrition and population growth.

Anthropogenic Disturbance

With increasing mineral and petroleum exploration across northern BC, as well as increasing interest in backcountry recreation, Thinhorn sheep are experiencing more disturbance and habitat impacts from human activity. Economic growth, technological advances, and social/societal factors may also have increased the number and success of hunters accessing more remote areas in northern regions. Because Thinhorn sheep are habitat specialists with low recruitment rates, high fidelity to seasonal and natal range areas, they are considered especially vulnerable to human disturbances and perturbations. Outcomes from the increased exploration activities, resource development and other anthropogenic disturbances in northern BC will have responding impacts from cumulative effects, likely influencing the behaviour and movement of Thinhorn sheep at both local and seasonal geographic and temporal scales. Concurrent expansion of jet boat and all-season off-road vehicle access into areas that previously provided refugia from motorized disturbances has also increased. As landscape permeability increases and wilderness areas are fractured, negative impacts on Thinhorn sheep behaviour are more likely to occur.

Photo: Lance Goodwin

The presence of humans in Thinhorn range, whether by aircraft, off-road vehicles, horse, skiing or on-foot, can trigger behavioural responses in Thinhorn sheep that can lead to loss of foraging time due to increased vigilance, displacement from optimal habitat, alienation and temporary abandonment of important seasonal range, and interruption of seasonal migrations. Human disturbance can be energetically costly to Thinhorns (MacArthur et al. 1982), and chronic disturbance may reduce individual fitness with potential population-level consequences (Wiedmann and Bleich 2014, Jex et al. 2016). Although the human disturbance footprint across Thinhorn range is arguably small relative to other areas of BC, the effects can be disproportionately large at a local scale for some herds or herds particularly naïve to disturbance stresses. For instance, low-level flights by fixed-wing aircraft and helicopters will disrupt behaviour of Thinhorn sheep causing them to flee to nearby steep escape terrain where they may remain vigilant without foraging for significant periods of time (Frid 2003). Energetic costs of aerial disturbances include increased movement rates, lower foraging and resting rates, increased stress reflected in stress hormone levels, displacement from and abandonment of optimal habitat, and accidental injury during overt flight responses. In addition, the popularity of recreational aerial drone use and wildlife filming is an emerging concern for wildlife managers and conservation stakeholders; so much so that most jurisdictions now have regulations in place to prohibit these activities. Still, there are few regulations or coordinated management and policy tools in place to address and mitigate this impact. Many non-government conservation organizations have adopted position statements supporting restrictions on some types of activities (e.g., WSF 2021, NWSGC 2020).

Photo: Lance Goodwin

Although long term studies on the fitness or demographic effects of human disturbances are expensive and logistically complex, especially in remote mountainous terrain (Beale 2007), there have been several studies that have examined aircraft flight characteristics (height and approach) and corresponding behaviour of wild sheep to develop management recommendations and mitigation guidelines (MacArthur et al. 1982, Stemp 1982, Frid 2003). Fixed wing aircraft generally cause less disturbance to wild sheep than helicopters and unmanned aerial drones, and for all types of aerial disturbance more direct approaches (as determined by aircraft elevation and horizontal distance from sheep) are more likely to trigger energetically costly responses (Frid 2003). To help mitigate the impact of aerial disturbance to Thinhorn sheep in BC, Regional least-risk timing windows (Table 2) have been developed for use as advice to industrial/commercial tenure holders, highlighting periods and classifications of level of risk during those periods, where groups or specific species of wildlife can be affected by human-caused disturbances. Commercial backcountry recreation tenures are also guided by the draft Commercial Backcountry Recreation Policy (2006[20] and currently in update in 2022), which defines limits for helicopter and fixed wing flights to a minimum of 1,500 m horizontal or 500 m vertical distance (line of sight) to wild sheep and mountain goats (a species found to have similar sensitivities to human activities as wild sheep); and flights also should remain a minimum 2,000 m horizontal distance from known sensitive sites (e.g., natal areas, mineral licks) if they are to be effective at avoiding disturbance

[20] https://www.env.gov.bc.ca/wld/twg/documents/wildlife_guidelines_recreation_may06_v2.pdf

effects. Effectiveness monitoring of these measures is challenging, but where compliance monitoring of management plans and operations has occurred related to the impacts of heli-skiing on mountain goats, varying levels of non-compliance were commonly observed (Vanderstar, pers. comm.).

Table 3. Least risk timing windows for Peace and Skeena Regions (Source: Peace Region Technical Report 2009).

Species	Season	Risk Category	Timing	Management Direction
All Species	Late winter and Lambing	Critical	January 15 - July 15	Development activities are not appropriate during this timeframe. Aerial activities should adhere to guidelines. In the event that working within a critical window is unavoidable, proponent should contact Ministry of Environment, to discuss alternatives, and potential mitigation and monitoring plans
Sheep and Goat	Early winter	Caution	November 1 to January 14	Proponents should minimize development activities during these timeframes
Sheep	Summer	Low	July 16 - November 14	Restrictions would not normally apply. Where ground conditions permit, plan development activities within these timeframes

Management planning that considers the specific needs of Thinhorn sheep has not been widely undertaken in BC. Recent work in the Dease Lake area examined potential effects generated from both industrial and recreational vehicle access into Thinhorn sheep range. This study found vehicle traffic along a resource/industrial trail (i.e., the Jade-Boulder Road) that bisects seasonal sheep home ranges, at levels as low as 2 vehicles per day (VPD), resulted in altered cross-valley transit times, changes in movement path trajectories, increased risk of predation and significantly elevated stress levels (indicated by fecal cortisol concentrations) (TGOA 2021). The outcomes of this multi-year study on anthropogenic disturbance and Thinhorn sheep response behaviours identified a suite of mitigation and management directives linked to specific habitat features and vehicle traffic along the Jade-Boulder Road (TGOA 2021). These directives establish timing windows at a very localized scale, for various types of resource development and motorized activities, and include no activity zones around mineral licks, timing windows and setbacks from specific habitats for helicopter use, speed controls and vehicle limitations, and protection of areas outside designated travel rights-of-way.

Industrial disturbance has been addressed in other Thinhorn sheep jurisdictions. For example, guidelines to minimize the effects of aircraft on Dall's sheep in the Yukon were developed as guidance for mining related activities by the Mining Environment Research Group (MERG 2006). Those mitigations include:

- Whenever possible, flying more than 3.5 km from known Thinhorn sheep range,
- Planning routes to avoid sensitive areas (lambing cliffs and mineral licks) between May 1 and June 15,
- Adjust flight course to place a ridge between the aircraft and the sheep,
- Fly below sheep,
- Concentrate flying time to a single session rather than spaced out over several days,
- Fly in the mornings when sheep are typically more active (avoid flying 11 am – 3 pm),
- Avoid flying directly toward sheep, approach at an angle from below,
- Proceed on course, avoid temptation to get a "closer look".

Energy development (including hydro-electric and wind generation), mining, gas and petroleum exploration, and backcountry recreation often require the development and maintenance of linear corridors and infrastructure in remote mountainous areas (Jex et al. 2016). The geographic extent of the numerous resource developments has increased significantly over recent decades. Each development can be preceded by years or even decades of exploration activity. The cumulative disturbance resulting from the various phases of a site's development have the potential to elevate mortality risk and displace Thinhorn sheep from important habitats such as lambing areas, seasonal migration and movement corridors, and mineral licks (TGOA 2021, Enns 2021). For some projects such as the Red Chris mine located on the Todagin Plateau in northern BC, assessment of the long-term effects on wild sheep habitat use have been studied. Hatler and Beal (2021b) observed that winter surveys in the Red Chris project area that have been undertaken since 1985, have mostly documented sheep occurrences at 10 km or more from the location now occupied by the mine pit (assumed to be the centre of potentially disturbing activity within the mine footprint). While a compendium report has not yet been completed specifically linking mine site activity to changes in the Stone's sheep distributions (Hatler and Beal 2021a), there is some speculation based on historical observations of Stone's sheep recorded prior to 1985, that at least some traditionally occupied seasonal habitats may have been alienated from use on the Todagin Plateau. Additionally, Hatler and Beal (2017) monitored areas with high mountain goat use located near this same mine site, finding that short term impacts on mountain goat numbers did occur following mine blasts with fewer mountain goats being observed in an important foraging area. The report suggests that the fewer number of mountain goats observed after mine site blasting was more a temporary shift in occurrence rather than full abandonment of range related to mine effects. Regardless, the ongoing monitoring of Stone's sheep and mountain goat habitat use adjacent to this project appears to show at least temporary alienation of habitats identified as seasonally important.


Photo: Cat Lee, Dease River First Nation

In recognition of disturbance effects, several LRMPs have helped identify important habitats for Thinhorn sheep and prescribed strategies to protect and manage these areas, especially winter and natal ranges. The LRMP process provides guidelines for a variety of resource management purposes that include parks, forestry, livestock grazing, oil and gas exploration, and mining. The Fort Nelson LRMP included approximately 34 km^2 of Stone's sheep habitat in special management and protected areas by establishing the Muskwa-Kechika Management Area (MKMA). The MKMA Management Plan provides specific guidance for managing access and minimizing negative effects on Stone's sheep and their habitats.

Additional access management restrictions have been implemented under the *Wildlife Act* to limit the use of motorized vehicles for hunting in portions of MUs, or above an elevational cut-off. This is particularly important in areas where historical or contemporary roads and trails provide easy access to Thinhorn sheep habitats.

Non-government organizations such as the Northern Wild Sheep and Goat Council (NWSGC) have also developed guidance documents that provide science-based recommendations to inform mitigation measures. Although the NWSGC recommendations primarily focus on mountain goats, due to the sympatric nature of habitat use by both mountain goats and Thinhorn sheep, initial implementation of those recommendations would be preferable to having no mitigation (see NWSGC 2020).

Anthropogenic Disturbance Management Recommendations

1. Identify important seasonal habitats (e.g., winter range, natal range) used by Thinhorn sheep in each of the Population Units and establish land base protections to avoid impacts from industrial and commercial tenures.
2. Support development of Access Management Plans that consider mitigating impacts on Thinhorn sheep populations across their range.
3. Quantify relative anthropogenic disturbances affecting Thinhorn sheep in each of the Population Units and where baseline or long-term data sets exist, undertake an evaluation of potential effects on Thinhorn sheep habitat use and behaviour.
4. Establish blanket elevational or seasonal motorized activity prohibitions (includes all types of off-highway vehicles) in areas overlapping and adjacent to important seasonal Thinhorn sheep range.
5. Develop, refine, and require application of industrial and recreational activity timing windows and setback distances for both ground-based and aerial activities, especially adjacent to and overlapping important habitat features and ranges.

Photo: Province of British Columbia

Predation and Mortality

Predation on Thinhorn sheep involves a broad complement of predators including wolverine (*Gulo gulo*), golden eagle, black bear (*Ursus americanus*), grizzly bear (*U. arctos*), lynx (*Lynx canadensis*), wolves, and coyotes (*Canis latrans*). Cougar (*Puma concolor*) population density is considered low throughout most of Thinhorn range, however cougar abundance and distribution are expanding northward in BC and southward from Yukon, and this may increase predation on sheep. Beyond the obvious impact of predation, there are also behavioural impacts from both successful and unsuccessful predation events (e.g., increased vigilance, decreased foraging, range abandonment) as well as stress-related physiological impacts such as stress-induced breeding suppression, which has been documented in mountain goats (Dulude-de Broin 2019).

Photo: Bill Jex

The effect of predation on Thinhorn sheep populations will vary with geographic area, terrain, predator densities, winter severity, snow depth/density, and habitat quality. Milakovic and Parker (2011) found that Stone's sheep were an important prey species for several wolf packs in the Northern Rocky Mountains, contributing 29-40% of diets in the spring. Hengeveld and Cubberley (2011) documented that wolf predation accounted for approximately 30% of adult sheep mortalities in the Stone Mountain population in their study. Conversely, Hayes et al. (2003) did not find any evidence that wolf predation limited either Dall's sheep recruitment or adult sheep abundance in the Yukon following a 5-year wolf reduction experiment. Scotton (1998) and Arthur and Prugh (2010) found that coyotes, followed by eagles and then wolves, accounted for the highest levels of predation on Dall's sheep lambs; coyotes had double the level of predation effect than that caused by wolves, even when wolf populations increased significantly (i.e., level of predation of lambs by wolves did not increase). Both Scotton and Arthur and Prugh speculated that coyote populations increased during or after periods of wolf removal and/or high snowshoe hare (*Lepus americanus*) cycles. Arthur and Prugh (2010) recorded that coyotes and eagles were responsible for killing 78% of 65 collared lambs. Dixon (2014) noted significant differences in lamb:ewe ratios between two surveys conducted in the Atlin area in March 2013 and February 2014; corresponding with the timing of eagle migrations and increased spring predation and the survey timing. In Alaska, Gasaway et al. (1983) concluded that wolf predation had a relatively small effect on sheep populations and found no increase in lamb survival when wolves were reduced. In contrast, Bergerud and Elliott (1998) found predation by wolves was a major factor limiting population growth of Stone's sheep where wolf reductions of 60-86% of packs resulted in increased recruitment of Stone's sheep. However, benefits to sheep population growth during wolf reduction periods have not been fully studied in recent years and may be quickly offset when wolves repopulate removal areas (Bergerud and Elliot 1998, Bridger, pers. comm.). Removal efforts during the 1980's and 1990's noted recolonization densities that approached or exceed pre-removal numbers with the start of the wolf population recovery beginning in the year immediately following the removals; more recently Bridger (2019) documented wolf removals associated with caribou population management, noting that depending on the initial level of wolf removal from an area and whether the effort was continued through consecutive years, recolonization by wolves following removal of approximately 80% of the pre-treatment population, saw an annual recolonization rate back into treatment areas of 45-70% in as little as 1 year following the wolf removal. In association with the wolf removal actions Bridger noted incidental observations of lamb:ewe-like ratios appeared higher in treatment areas versus adjacent non-treatment areas in the winter following wolf removals. Bridger (pers. comm.) also observed numerous wolf-killed sheep in the Prophet-Besa-Muskwa area prior to wolf removal, but no wolf-killed sheep during the two years following wolf removal from that area.

Predation may be less prevalent a limiting factor for Thinhorn sheep in areas where weather and avalanches contribute more significantly to mortality rates. Lohuis (pers. comm.) reported an average adult mortality rate of approximately 13% in collared adult sheep in Alaska, similar to findings by Arthur (2012). However, unlike Arthur's works, Lohuis associated the main cause of adult ewe mortality with accidental death (i.e., avalanche and landslides), with predation by grizzly bears and wolverine accounting for only 2% of mortalities. Lohuis also studied lamb survival and predation between 2009 and 2013 in Alaska and reported that eagles (11%) and avalanches (10%) were the main causes of lamb mortality, with grizzly and wolverine predation each responsible for 6% loss and cumulatively wolves, coyotes and black bears caused a 3% loss (Lohuis, pers. comm.). Hengeveld and Cubberley (2011) assessed the mortalities of 41 collared Stone's sheep ewes in northeast BC with 19 killed by predation and 22 by environmental factors (i.e., avalanche, snow conditions, trauma from falls and poor body condition). They found more than 40% of mortalities occurred in late winter, particularly April and May and suggested that higher precipitation in May resulted in greater ewe mortality. The majority of collared Stone's sheep in a northeast BC study died during late winter and summer (between April 13 and August 5), resulting in an average of 18.5% annual adult mortality, although the causes were not determined (Walker 2005). Other observations from Freeman (pers. comm.) and Jex (pers. comm.) in northwest BC noted initial mortality rates similar to Lohuis and Walker, however three years after collaring, mortality rates had climbed to approximately 70% and 63% of collared study ewes, respectively, predominantly from environmental factors. The timing and magnitude of these losses aligns with other observations in the NW portion of the province; Hatler and Beal (2022) reporting a 50% population decline occurring in the Todagin area between 2018 and 2022.

The regulated wolf harvest in BC is already liberalized, and there remains a lack of empirical data to suggest that licensed hunting or trapping alone would be an effective enhancement tool benefitting Thinhorn sheep, particularly where wolf predation does not appear to be a primary driver of population recruitment or adult ewe survival. Predator control as a management option for Thinhorn sheep must be considered and applied carefully to avoid shifting predation opportunities to other species. Two studies in Alaska (Scotton 1998, Arthur and Prugh 2010) demonstrated high levels of mesocarnivore predation (i.e., coyote and wolverine) when wolf populations were removed or at low levels of abundance. After years of wolf control in Alaska, the vacant predator niche allowed the expansion of coyote populations (of which wolves are a predator), resulting in higher levels of lamb predation than pre-wolf cull levels (Prugh and Arthur 2015). Prugh and Arthur (2015) concluded that while a 60% reduction in wolf population could be expected to result in an increase sheep numbers by approximately 4%, should a resulting increase in coyote populations and densities occur, predation of lambs by coyotes could decrease the population by 3%. This underscores the importance of ensuring management actions are applied holistically and target the correct predator species and consider potential interactions with other species to be effective. Although it is often singled out as a priority management issue, and included in some high-level land use plans, there are highly polarized views on using predator management/culling to benefit big game. Implementation of a predator management program for use in reducing predation on Thinhorn sheep would require approval for that management action, supported through the Control of Species policy and procedures (4-7-04.01.3).

Predation Management Recommendations

1. Support research on the roles and effects of predator species and predation effect on Thinhorn sheep, especially in association with habitat enhancement projects (e.g., prescribed burns and apparent/manufactured competition).
2. Consider research opportunities to understand the short and long-term effects on Thinhorn sheep population trends where wolf reduction is occurring to support caribou recovery in areas overlapping with Thinhorn sheep range.
3. Improve the understanding of the potential effects of intermediate predator/mesocarnivore release (i.e., coyote and wolverine) on Thinhorn sheep lamb survival and population trends in areas where wolf removal is occurring.
4. Investigate the potential for primary prey species resource use and habitat competition in responding populations where predator control is/has occurred, along with implications and associations resulting from apparent competition.

Photo: Krystal Kriss

Climate

Climate plays a critical role in the availability of forage and energetic costs for Thinhorn sheep, particularly during winter and spring. Warmer winters, cycles of melting and freezing, and rain-on-snow events can produce hard crusts that sheep are unable to dig through. Large population declines have been attributed to these icing events (Nichols and Bunnell 1999). Alaska Fish and Game reported a loss in the western Brooks Range in winter 2013-14 of an estimated 80% of a Dall's sheep population as a result of starvation and diminished access to escape terrain to avoid predators due to ground-fast ice (Brunning, pers. comm.). Similar observations of ice-fog and ground-fast icing were observed during winter inventories conducted in northwest BC in March of 2013 (Jex, pers. comm.). Follow-up surveys conducted in adjacent areas in BC and southern Yukon undertaken in 2014 and 2015 noted apparent declines in Dall's sheep numbers from previous inventory efforts coincidental with the occurrence of severe winter weather conditions (Jex, pers. comm.). Sivy et al. (2018) studied the effects of snow on Dall's sheep movements, foraging and energetics costs, also identifying that future climate-affected snow conditions (i.e., warmer, wetter and denser snow-pack) may better facilitate predator pursuit and capture. Cosgrove et al. (2021) also documented early snowfall, and snow depth and condition, as having negative effects on lamb survival and recruitment in Dall's sheep in Wrangell-St Elias National Park and Preserve. In addition, prolonged snowfall events late into the spring during parturition have been linked to poor lamb survival, translating into lower populations and lower availability and hunter harvest of rams in subsequent years (i.e., 6-8 years post severe spring events). This has been documented in Alaska (Wendling et al. 2021) and BC (Jex, pers. comm.) originating from severe winter and spring conditions in both jurisdictions between the winter/spring of 2010-11 and 2013-14. A similar pattern of weather events occurred between 2018 and 2022 (Figure 17), although the outcomes of these yet remain to be observed and evaluated in terms of full effects on Thinhorn sheep populations.

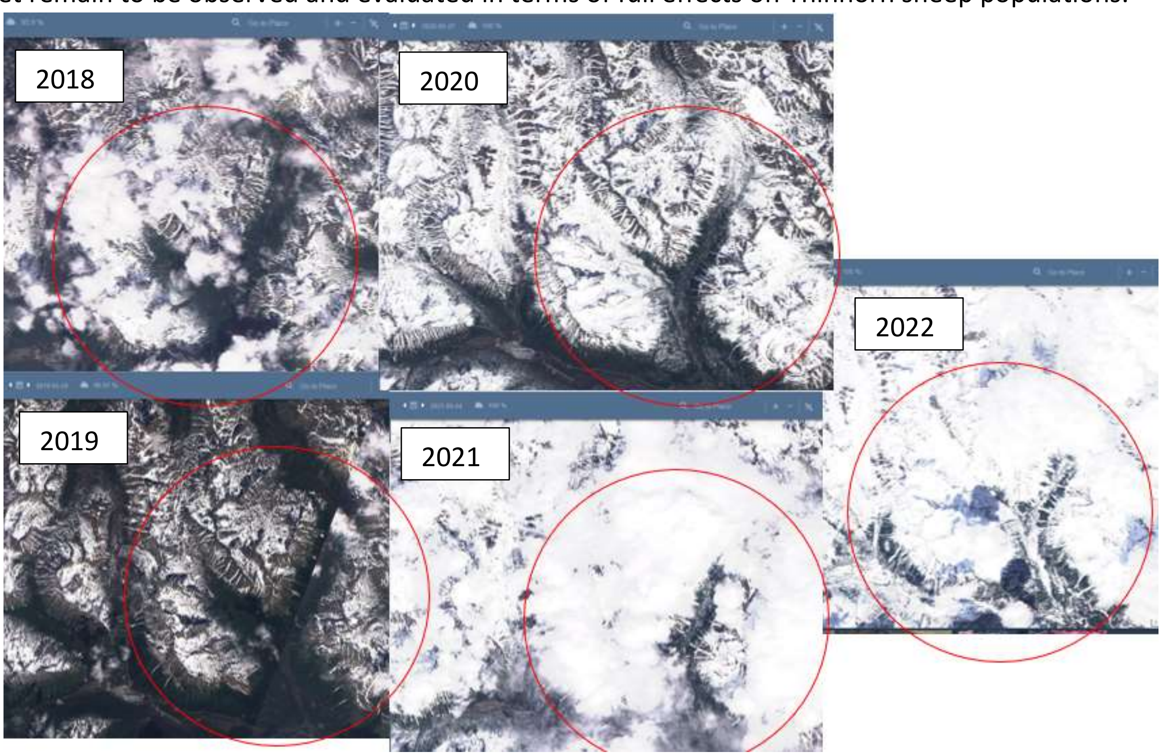


Figure 17. Timelapse satellite imagery showing natal habitats identified during the Cassiar Thinhorn sheep study. Images selected based on lowest cloud cover with dates ranging between May 25 and June 4, 2018 and 2022, showing on-the-ground snow cover; images obtained from Sentinelhub website.

Several authors including Enns (2021) have found that ewes selected spring and summer seasonal ranges in alpine and sub-alpine zones at both home range and fine scales, likely to access new forage growth while maintaining proximity to escape terrain. These areas can occasionally be vulnerable to years with higher snowfalls or late green-up that can reduce forage availability and reduce nutritional fitness of lactating ewes. Snow can also impact energetic costs associated with movements (Sivy et al. 2018), and this can be highly advantageous in improving the search area, success and reducing energetic costs of some predators (Droghini and Boutin 2018), having the potential to compound the negative impacts on Thinhorn sheep associated with snow conditions.

In a meta-analysis of Dall's sheep habitat use and recruitment data, Kerk et al. (2020) found that summer vegetation productivity was the most influential variable affecting lamb survival, whereas the previous winters' freeze-thaw frequency had the strongest effect on adult Dall's sheep survival. This research also indicated substantial variability in climatic conditions at local scales, which may confound climate impact assessments at larger, regional scales (e.g., Pacific Decadal Oscillation) where Thinhorn sheep are not uniformly affected across their range. The frequency of freeze-thaw events is predicted to increase and affect a larger spatial extent (Intergovernmental Panel on Climate Change 2013). This variability could mean that any climate effects that result in improved summer forage growth and therefore increased lamb survival, may be just as likely to occur in winter and result in negative effects on adult survival. Given that Thinhorn sheep population trend is most sensitive to adult ewe survival, severe stochastic winter and spring weather systems could result in significant impact to populations. Compounding this is the expected emergence of new diseases and parasites, or changes in endemic parasite life-cycles that effect Thinhorn sheep fitness, with climate-influenced changes in sheep-parasite-disease dynamics being unlikely to benefit Thinhorn sheep (Kutz et al. 2009, Altizer et al. 2013, Aleuy et al. 2018).

Weather pattern changes will continue to have a profound effect on winter and spring severity, adult fecundity and survival, and lamb survival and recruitment. Thinhorn sheep management will need to consider weather history and habitat condition when developing harvest objectives and setting sustainable harvest opportunities for populations with no or outdated survey information. Identifying key climate variables and their effect on Thinhorn sheep survival and demographics will help managers anticipate and respond to population impacts, prioritize population units for monitoring investments and adapt conservation strategies at both local and meta-population scales.

Climate Recommendations

1. Establish a network of population-relevant weather station/data sources to identify climate variables and timing of weather events that affect Thinhorn sheep survival, such as winter or spring severity measurements similar to those used for other species (e.g., temperature, wind, precipitation and patterns of precipitation falling as rain or snow, and the timing and duration of weather systems).
2. Investigate any climatic variables that exist across entire population units (Figures 6-10) and use those to inform broader conservation and management strategies by population unit.
3. Anticipate the role of a changing climate in management actions that affect the long-term sustainability of Thinhorn populations in BC, including connectivity among populations, habitat enhancement activities and outcomes, disease prevention, and shifting species assemblages. For example, forecasting harvestable ram abundance 6-7 years post-severe spring/poor winter survival conditions could inform decisions that effect and moderate harvest pressure impacts on mature ram abundance in those population units.

Closing

Successful and sustainable management of BC's globally significant Thinhorn sheep resources, in the presence of expanding and unknown pressures from both human activities and climate change, will require active effort on the part of BC citizens. Effectively harnessing the power and wisdom of conventional science and harmonizing that with Traditional and Local Ecological Knowledge and Cultural Practices is fundamental in achieving this, and is further mandated through implementation of the BC DRIPA. We know that environmental change is occurring at rates more rapidly than some species can adapt; however, Thinhorn sheep may be able to overcome some of those changes if investments are made into addressing the knowledge gaps and management needs summarized in this framework. The extent to which landscape, habitat and population stressors and impacts are recognized as critical drivers that affect population resiliency and overall ecosystem health, are considered when land managers are making socio-political land-use decisions, will ultimately determine the future of Thinhorn sheep in BC.

REFERENCES

Alaska Department of Fish and Game. 2008. Dall sheep management report of survey-inventory 1 July 2004–30 June 2007. P. Harper Editor, Juneau, Alaska.

Alberta Government. 2015. Management Plan for Bighorn Sheep in Alberta (Draft). Wildlife Management series Number, Wildlife Management Branch. 137Pp.

Aleuy, O.A., K. Ruckstuhl, E.P. Hoberg, A. Veitch, N. Simmons and S.J. Kutz. 2018. Diversity of gastrointestinal helminths in Dall's sheep and the negative association of the abomasal nematode, *Marshallagia marshalli*, with fitness indicators. PLoS ONE 13(3): e0192825. https://doi.org/10.1371/journal.pone.0192825

Altizer, S., R. S. Ostfeld, P. T. J. Johnson, S. Kutz, and C. D. Harvell. 2013. Climate change and infectious diseases: from evidence to a predictive framework. Science 341:514-519.

Anderson, M., and M. Bridger. 2021. Kwadacha, Muskwa, and Tuchodi Stone's Sheep Inventory (WMUs 7-41 and 7-50), February 2020. BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development.

Arthur, S.M. 2012. Effects of snowshoe hare population cycles on demography of Dall sheep and their predators. Fed. Aid Research Performance Final Rep. Proj 6.14, Grant: W-33-10. Alaska Department of Fish and Game. Juneau, Alaska. 101 pages.

Arthur, S.M. and L.R. Prugh. 2010. Predator-Mediated Indirect Effects of Snowshoe Hares on Dall's Sheep in Alaska, Journal of Wildlife Management 74(8), 1709-1721, (1 November 2010). https://doi.org/10.2193/2009-322

Ayotte, J. B., K. L. Parker, and M. P. Gillingham. 2008. Use of natural licks by four species of ungulates in northern British Columbia. Journal of Mammalogy 89:1041–1050.

Bailey, J.A., and K.P. Hurley. 2000. Management of wild sheep in North America. Proc. North Am. Wild Sheep Conf. 2:335-458.

Beale, C. M. 2007. The behavioral ecology of disturbance responses. International Journal of Comparative Psychology 20:111–120.

Berger, J. 1991. Pregnancy incentives, predation constraints and habitat shifts: experimental and field evidence for wild bighorn sheep. Animal Behavior **41:** 61-77.

Besser, T., F. Cassirer, M. Highland, P. Wolff, A. Justice-Allen, K. Mansfield, M.A. Davis, W. Foreyt. 2013. Bighorn sheep pneumonia: Sorting out the cause of a polymicrobial disease. Preventive Veterinary Medicine. 109:3-4

Besser T.E., Cassirer E.F., Potter K.A., Foreyt W.J., 2017. Exposure of Bighorn sheep to domestic goats colonized with *Mycoplasma ovipneumoniae* induces sub-lethal pneumonia. PLoS ONE 12(6).

Bergerud, A.T., and J.P. Elliott. 1998. Wolf predation in a multi-ungulate system in northern British Columbia. Can. J. Zool. 76:1551-1569.

Black SR, Barker IK, Mehren KG, Crawshaw GJ, Rosendal S, Ruhnke L, Thorsen J, Carman PS (1988), An epizootic of Mycoplasma ovipneumoniae infection in captive Dall's sheep (Ovis dalli dalli). Journal of Wildlife Diseases 24: 627-635

Bleich, V.C., Bowyer, R.T., Pauli, A.M., Nicholson, M.C., and Anthes, R.W. 1994. Mountain sheep (*Ovis canadensis*) and helicopter surveys: ramifications for the conservation of large mammals. Biological Conservation 70: 1-7.

Bleich, V.C., Bowyer, R.T. and Wehausen, J.D. 1997. Sexual segregation in mountain sheep: resources or predation? Wildlife Monographs 134: 1-50.

Boyce, M.S., T.Coulson, J.R. Heffelfinger, P.R. Krausman. 2018. Mountain Sheep Management Must Use Representative Data: A Reply to Festa-Bianchet. Journal of Wildlife Management. 83(1):9-11.

Boyce, M., T. Coulson, J.R. Heffelfinger and P. Krausman, Paul. 2019. Mountain sheep management must use representative data: A reply to Festa-Bianchet (2019): Science for Mountain Sheep Management. The Journal of Wildlife Management. 83. 10.1002/jwmg.21617.

Bridger, M. 2019. Predator Management Planning and Decision Support Tools for Caribou Recovery – Northeast Region. BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development. Resource Management. Northeast Region. 37 Pp.

British Columbia Ministry of Environment. 2006. Wildlife Guidelines for backcountry tourism/commercial recreation in British Columbia. Victoria, BC., 57Pp.

British Columbia Ministry of Environment. 2000. Thinhorn sheep in British Columbia Ecology, Conservation and Management. B.C. Ministry of Environment. 6 Pp.

Bunnell, F.L. 1980. Factors controlling lambing period of Dall's sheep. Can. J. Zool. 58: 1027- 1031.

Bunnell, F. L. 2005. Thinhorn sheep. Wildlife Afield 2:22–30.

Bunnell, F.L. and N.A. Olsen. 1976. Weights and growth of Dall's Sheep in Kluane Park Reserve, Yukon Territory. Can. Field-Nat. 90:157-162.

Burles, D.W., and M. Hoefs. 1984. Winter mortality of Dall's Sheep, Ovis dalli dalli, in Kluane National Park, Yukon. Can Field-Nat. 98(4):479-484.

Canadian Wildlife Health Cooperative. 2016. Risk Analysis of Pneumonia-Related Transmission from Domestic Small Ruminants to Wild Thinhorn Sheep in Yukon and Northern BC. Prepared for the Animal Health Unit, Environment Yukon, Government of Yukon. 60pp.

CDC, B.C. Conservation Data Centre. 2018. Species Summary: *Ovis dalli stonei*. B.C. Ministry of Environment. Available: http://a100.gov.bc.ca/pub/eswp/ (accessed May 8, 2018).

Centre for Coastal Health. 2017. Risk Assessment on the Use of South American Camelids for Back Country Trekking in British Columbia. Prepared for the British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development and the Division of Wildlife Conservation, Alaska Department of Fish and Game. 52pp.

Coltman, D.W., D.R. Bancroft, A. Robertson, J.A. Smith, T.H. Clutton-Brock and J.M. Pemberton. 1999. Male reproductive success in a promiscuous mammal: behavioural estimates compared with genetic paternity. Molecular Ecology, 8, 1199-1209.

Coltman, D.W., M. Festa-Bianchet, J.T. Jorgenson and C. Strobeck. 2001. Age-dependent sexual selection in bighorn rams. Proc. Royal Society. (2002) 269, 165-172.

Cosgrove, C. L., J. Wells, A. W. Nolin, J. Putera, and L. R. Prugh. 2021. Seasonal influence of snow conditions on Dall's sheep productivity in Wrangell-St Elias National Park and Preserve. PLoS ONE 16(2): e0244787. https://doi.org/10.1371/journal.pone.0244787

Cox, M. 2018. Wild Sheep Ram Hunting Permit Setting Process and Metrics for Western States and Provinces. Western Association of Fish and Wildlife Agencies - Wild Sheep Initiative. https://wafwa.org/wp-content/uploads/2020/07/WestwideRamQuotaSettingProcessfinal.pdf

Cox, M. 2019. Wild Sheep Population Estimates-Licensed Harvest-1990-2018. Western Association of Fish and Wildlife Agencies - Wild Sheep Initiative. https://wafwa.org/wp-content/uploads/2020/07/Wild-Sheep-Pop-Est-License-Harvest-1990-2018-ver-5_21_2019.pdf

Cubberley, J.C. 2009. Stone's Sheep Demographics in the Sulphur / 8 Mile Project Area, Northern British Columbia, Winter 2006/2007. Biennial Symposium Northern Wild Sheep and Goat Council 16: 106-121.

Demarchi, R.A. 1978. Evolution of Mountain Sheep Horn Curl Regulations in British Columbia. Proc. First Bienn. Symp. North. Wild Sheep and Goat Council 1978. 29 pages http://media.nwsgc.org/proceedings/NWSGC-1978/1978-DeMarchi.pdf

Demarchi, R.A., D.M. Hebert, D.S. Eastman and W.G. Macgregor. 1978. Preliminary Mountain Sheep Plan for British Columbia. B.C. Ministry of Recreation and Conservation, Fish and Wildlife Branch, Victoria, B.C.. 29 pp.

Demarchi, R.A., and C.L. Hartwig. 2004. Status of Thinhorn Sheep in British Columbia. Wildlife Bulletin No. B-119. B.C. Ministry of Water, Land and Air Protection, Biodiversity Branch, Victoria, B.C.. 109 pp.

Dixon, K. 2014. LEH Zone 6-25C/D Sheep, Goat and Caribou Composition Survey: February 2014. British Columbia Ministry of Forests, Lands, and Natural Resource Operations. Smithers, BC. 14pp.

Douhard, M., M. Festa-Bianchet, F. Pelletier, J.-M. Gaillard and C. Bonenfant. 2016. Changes in horn size of Stone's sheep over four decades correlate with trophy hunting pressure. Ecological Applications, 26(1), 2016, pp. 309-321.

Downs CJ, Boan BV, Lohuis TD and Stewart KM (2018) Investigating Relationships between Reproduction, Immune Defenses, and Cortisol in Dall Sheep. Front. Immunol. 9:105. doi: 10.3389/fimmu.2018.00105

Droghini, A., and S. Boutin. 2018. Snow conditions influence grey wolf (Canis lupus) travel paths: the effect of human-created linear features. Canadian Journal of Zoology. 96(1): 39-47. https://doi.org/10.1139/cjz-2017-0041

Dubay S, Schwantje H, de Vos J, McKinney T (2003), Bighorn sheep (Ovis canadensis) diseases: a brief literature review and risk assessment for translocation. Unpublished report. 20pp.

Dulude-de Broin, F., S. Hamel, G.F. Mastromonaco and S.D. Cote. 2019. Predation risk and mountain goat reproduction: Evidence for stress-induced breeding suppression in a wild ungulate. Functional Ecology. https://doi.org/10.1111/1365-2435.13514

Eamer, C. 2014. Yukon Thinhorn Sheep Horn Growth, Genetics, and Climate Change. Government of Yukon. Department of Environment.

Enns, G. E. 2021. Seasonal habitat use, habitat selection, and migratory behaviours of Stone's sheep(Ovis dalli stonei) in northern British Columbia, Canada. MSc Ecology Thesis, University of Alberta. 123pgs.

Festa-Bianchet, M. 1986. Site fidelity and seasonal range use by bighorn rams. Canadian Journal of Zoology. 64:2126-2132

Festa-Bianchet, M. 1988. Seasonal range selection in bighorn sheep: conflicts between forage quality, forage quantity and predator avoidance. Oecologia: 75: 580-586.

Festa-Bianchet, M. 2017. When does selective hunting select, how can we tell, and what should we do about it? Mammal Review 47:76–81.

Festa-Bianchet, M. 2019. Mountain Sheep Management Using Data Versus Opinions: A Comment on Boyce and Krausman (2018). The Journal of Wildlife Management, vol. 83, no. 1, 2019, pp. 6–8. JSTOR, https://www.jstor.org/stable/26609705.

Frid, A. 2003. Dall's sheep responses to overflights by helicopter and fixed-wing aircraft. Biological Conservation 110: 387-399.

Frid, A., Dill, L.M. 2002. Human-caused disturbance stimuli as a form of predation risk. Conservation Ecology 6: http://www.consecol. org/Journal/vol6/iss1/art11/print.pdf.

Garde, E., Kutz, S., Schwantje, H., Veitch, A., Jenkins, E., and Elkin, B. 2009. Examining the risk of disease transmission between wild dall's sheep and mountain goats, and introduced domestic sheep, goats, and llamas in the Northwest Territories.

Gasaway, W.C., R.O. Stephenson, J.L. Davis, P.E.K. Shepherd, and O.E. Burris. 1983. Interrelationships of wolves, prey and man in interior Alaska. Wildlife Monographs. 84.

Geist, V. 1971. Mountain sheep: a study in behavior and evolution. Univ. of Chicago Press, Chicago. 383pp.

Geist, V. 2006. The North American Model of Wildlife Conservation: a means of creating wealth and protecting public health while generating biodiversity. Pages 285–293 in D. M. Lavigne, editor. Gaining ground: in pursuit of ecological sustainability. International Fund for Animal Welfare, University of Limerick, Limerick, Ireland.

Gutiérrez-Espeleta, G.A., Kalinowski, S.T., Boyce, W.M., Hedrick, P.W. 2000. Genetic variation and population structure in desert bighorn sheep: implications for conservation. Conservation Genetics (2000) 1: 3-15.

Hayes, R.D., R. Farnell, R.M.P. Ward, J. Carey, M. Dehn, G.W. Kuzyk. A.M. Baer, C.L. Gardner, M. O'Donoghue. 2003. Experimental reduction of wolves in the Yukon: Ungulate responses and management implications. 67:3

Harrison, S. and D. Hebert. 1988. Selective predation by cougar within the Junction Wildlife Management Area. Bienn. Symp. N. Wild Sheep and Goat Counc. 6:292-306.

Hatler, D.F and A.M. Beal. 2017. Red Chris Wildlife Management Program Annual Report 2017. Unpublished report. 60 Pp.

Hatler, D.F and A.M. Beal. 2021a. Aerial Survey of Mountain Goats and Incidental Observations of Stone's sheep in the Newcrest Red Chris Project Area, 18 July 2021. Unpublished report. 7 Pp.

Hatler, D.F and A.M. Beal. 2021b. Aerial Survey of Stone's sheep in the Newcrest Red Chris Study Area, March 2021. Unpublished report. 11 Pp.

Hatler, D.F and A.M. Beal. 2022. Newcrest Red Chris Stone's sheep Aerial Survey, March 4 & 7, 2022. Unpublished report. 15 Pp.

Hatter, I.W. 2017. Towards a Big Game Inventory and Monitoring Strategy for British Columbia: Background Report. Version 1.0. Fish and Wildlife Branch BC Ministry of Forests, Lands, Natural Resource Operations. Victoria, BC.

Hatter, I.W. and D. Blower. 1996. History of transplanting mountain goats and mountain sheep - British Columbia. Biennial Symposium of the Northern Wild Sheep and Goat Council 10:158–163.

Heffelfinger, J. 2018. Inefficiency of evolutionarily relevant selection in ungulate trophy hunting. Journal of Wildlife Management 82:57-66. doi:10.1002/jwmg.21337

Hegel, T. 2015. Identifying sustainable harvest rates for Sheep in Yukon. Draft report, Environment Yukon, Whitehorse, Yukon.

Heimer, W.E. 1984. Interior sheep studies. State of Alaska Department of Fish and Game. Juneau, Alaska.

Heimer, W.E. 1999. A Working Hypothesis for Thinhorn Sheep Management. Alaska Department of Fish and Game. Juneau, Alaska. Unpublished Report. 20 pages.

Heimer, W.E. and S.M. Watson. 1986a. Comparative dynamics of dissimilar Dall sheep populations. Fed. Aid in Wildl. Rest. Final Rep. Proj W-22-1 through W-22-4. Job 6.9R. Alaska Department of Fish and Game. Juneau, Alaska. 101 pages.

Heimer, W.E. and S.M. Watson. 1986b. Time and Area Specific Variations in Dall Sheep Lamb Production: An Explanatory Hypothesis. Proc. Fifth Bienn. Symp. North. Wild Sheep and Goat Council 1986. 24 pages

Hengeveld, P.E. and J.C. Cubberley (eds). 2011. Stone's sheep population dynamics and habitat use in the Sulphur / 8 Mile oil and gas pre-tenure plan area, northern British Columbia, 2005 - 2010. Synergy Applied Ecology, Mackenzie, BC. 167 pp plus appendices.

Hengeveld, P. E. and Festa-Bianchet, M. 2011. Harvest regulations and artificial selection on horn size in male bighorn sheep. Journal of Wildlife Management. 75189-197. https://doi.org/10.1002/jwmg.14.

Hik, D.S. and J. Carey. 2000. Patterns of cohort variation in horn growth of Dall sheep rams in the southwest Yukon, 1969–1999. Biennial Symposium of the Northern Wild Sheep and Goat Council 12: 88–100.

Hoefs, M. 1981. The Dall sheep population of Sheep Mountain, Kluane National Park. Yukon Renewable Resources Dept. Whitehorse, YT.

Hoefs, M. and I. McT. Cowan. 1979. Ecological investigations of a population of Dall sheep. Syesis 12(1):81pp.

Hoefs, M. and M. Bayer. 1983. Demographic characteristics of an unhunted Dall sheep (Ovis dalli dalli) population in southwest Yukon, Canada. Canadian Journal of Zoology 61:1346–1357.

Hoefs, M., and U. Nowlan. 1994. Distorted sex ratios in young ungulates: the role of nutrition. J.Mammal. 75(3): 631-636.

Hogg, J. T. 1984 Mating in bighorn sheep: multiple creative male strategies. *Science* **225**, 526–529.

Hogg, J. T. 1987 Intrasexual competition and mate choice in Rocky Mountain bighorn sheep. *Ethology* **75**, 119–144.

Hogg, J. T. & Forbes, S. H. 1997 Mating in bighorn sheep: frequent male reproduction via a high-risk 'unconventional' tactic. *Behav. Ecol. Sociobiol.* **41**, 33–48.

Intergovernmental Panel on Climate Change. 2013. Climate change 2013: the physical science basis. Pages 1029-1136 in T.G. Stocker, D. Qin, G.-K Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley, editors. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK.

Jex, B. A., J.B. Ayotte, V.C. Bleich, C.E. Brewer, D.L. Bruning, T.M. Hegel, N.C. Larter, R.A. Schwanke, H.M. Schwantje, and M.W. Wagner. 2016. Thinhorn sheep: Conservation challenges and management strategies for the 21st century. Wild Sheep Working Group. Western Association of Fish and Wildlife Agencies, Boise, Idaho. USA.

Jex, B.A. & Z. Sim. 2021. A rare phenotype of thinhorn sheep - The Dark Phased Dall's: New Genetic Analysis Tools Help Re-Map Thinhorn Sheep Subspecies Distributions in North America. Caprinae news: Newsletter of the IUCN/SSC Caprinae Specialist Group. http://iucncaprinaesg.weebly.com/

Joslin, G., 1986. Mountain goat population changes in relation to energy exploration along Montana's Rocky Mountain Front. Biennial symposium of the Northern Wild Sheep and Goat Council 5, 253–271.

Kerk, M., S. Arthur, M. Bertram, B. Borg, J. Herriges, J. Lawler, B. Mangipane, C. Lambert Koizumi, B. Wendline, and L. Prugh. 2020. Environmental influences on Dall's sheep survival. Journal of Wildlife Management 84(6) 1-12.

Krausman, P. R., and R. T. Bowyer. 2003. Mountain sheep. Pages 1095–1115 *in* G. Feldhammer, and J. Chapman, editors. Mammals of North America. John Hopkins University Press, Baltimore, Maryland, USA.

Kutz, S. J., E. J. Jenkins, A. M. Veitch, J. Ducrocq, L. Polley, B. Elkin, and S. Lair. 2009. The Arctic as a model for anticipating, preventing, and mitigating climate change impacts on host-parasite interactions. Veterinary Parasitology 163:217–228.

Loehr, J., K. Worley, A. Grapputo, J. Carey, A. Veitch and D. W. Coltman (2006). "Evidence for cryptic glacial refugia from North American mountain sheep mitochondrial DNA". Journal of Evolutionary Biology 19: 419–430.

Loison, A., M. Festa-Bianchet, J. M. Gaillard, J. T. Jorgenson, and J.-M. Jullien. 1999. Age-specific survival in five populations of ungulates: evidence of senescence. Ecology 80:2539–2554.

MacArthur, R.A., Geist, V., and Johnston, R.H. 1982. Cardiac and behavioural responses of mountain sheep to human disturbance. Journal of Wildlife Management 46: 351-358.

Mahoney, S. P., and J. J. Jackson. 2013. Enshrining hunting as a foundation for conservation the North American Model. International Journal of Environmental Studies 70:448–459.

McCullough, D.R. 1994. What do herd composition counts tell us? Wildlife Society Bulletin 22:295–300.

MFLNRO (Ministry of Forests, Lands and Natural Resource Operations). 2013. DRAFT Thinhorn Sheep Harvest Management Procedures, 4.7.01.07.6. Victoria. 10Pp.

Milakovic, B., and K.L. Parker. 2011. Using stable isotopes to define diets of wolves in northern British Columbia, Canada. Journal of Mammology. 92(2) 295-304.

MERG. 2002. Mining Environment Research Group – Flying in Sheep Country: How to minimize disturbance form aircraft. MERG Report 2002-6. Geoscience Information and Sales, Yukon Government Room 102, Elijah Smith Building, Whitehorse, Yukon. Unpublished Report 12Pp.

Montana Fish, Wildlife and Parks. 2010. Montana Bighorn Sheep Conservation Strategy. Wildlife Division, Helena, MT (pages 39-40).

Monteith, K., R. Long, T. Stephenson, V. C. Bleich, R. T. Bowyer, and T. LaSharr. 2018. Horn size and nutrition in mountain sheep: can ewe handle the truth? Journal of Wildlife Management 82(1):67-84. doi:10.1002/jwmg.21338

Nichols, L. and F.L. Bunnell. 1999. Natural history of Thinhorn Sheep. Pp. 23-77 in R. Valdez and P.R. Krausman, eds. Mountain sheep of North America. Univ. Arizona Press, Tucson, AZ.

NWSGC. 2020. Northern Wild Sheep and Goat Council position statement on commercial and recreational disturbance of mountain goats: recommendations for management. Proceedings of the Biennial Symposium of the Northern Wild Sheep and Goat Council, 22: 1-15.

Peace Region Technical Report. 2009. Peace Region Least-Risk Timing Windows: Biological Rationale. 49Pp.

Poole, K.G. 2007. Does survey effort influence sightability of mountain goats Oreamnos americanus during aerial surveys? - Wildl. Biol. 13: 113- 119.

Province of British Columbia. 1978. Preliminary Mountain Sheep Plan for British Columbia. Ministry of Recreation and Conservation Fish and Wildlife Branch. 29Pp.

Prugh, L.R. and S.M. Arthur. 2015. Optimal predator management for mountain sheep conservation depends on the strength of mesopredator release. Oikos 124: 1241-1250, 2015.

RISC (Resource Inventory Standards Committee). 2002. Aerial-based inventory methods for selected ungulates: Bison, mountain goat, mountain sheep, moose, elk, deer, and caribou. Standards for components of British Columbia's biodiversity No. 32. Pp.105

Robinson, D.J. 1987. Wildlife and the law. Pp. 43-58 in A. Murray, ed. Our wildlife heritage: 100 years of wildlife management. Centennial Wildl. Soc. B.C., Victoria, BC.

Ruckstuhl, K.E. 1998. Foraging behaviour and sexual segregation in bighorn sheep. Animal Behaviour 56: 99-106.

Russell, K. and T. Hegel. 2011. Dall's Sheep Survey: Southern Lakes Region, 2009. Fish and Wildlife Branch. Yukon Government. 17 Pp

Rominger, E. 2008. Ram Harvest Strategies for Western States and Provinces—2007. Biennial Symposium of the Northern Wild Sheep and Goat Council 16: 92-98.

Schindler, S., M. Festa-Bianchet, J.T. Hogg, and F. Pelletier. 2017. Hunting, age structure, and horn size distribution in bighorn sheep. Journal of Wildlife Management 81.5 (2017): 792-799. DOI: 10.1002/jwmg.21259

Scotton, B.D. 1998. Timing and Causes of Neonatal Dall Sheep Mortality in the Central Alaska Range. M.Sc. thesis, University of Alaska Fairbanks. 50 Pp.

Seip, D.R. 1983. Foraging Ecology and Nutrition of Stone's Sheep. Fish and Wildlife Report, ISSN 0701-581X; No. R-9. Ministry of Environment, British Columbia.

Seip, D.R., and F.L. Bunnell. 1985. Nutrition of Stone's sheep on burned and unburned ranges. Journal of Wildlife Management. 49:397-405.

Shackleton, D. 1999. Hoofed mammals of British Columbia. University of British Columbia

Press, Vancouver, British Columbia, Canada.

Sim, Z. 2014. Year One Summary Report for Landscape Genetic Assessment of British Columbia – South Yukon. Department of Biological Sciences, University of Alberta.

Sim, Z., J.C. Hall, B. Jex, T.M. Hegel, D.W. Coltman. 2016. Genome-wide set of SNPs reveals evidence for two glacial refugia and admixture from postglacial recolonization in an alpine ungulate. Molecular Ecology.

Sim, Z., C.S. Davis, B. Jex, T. Hegel, D.W. Coltman. 2018. Hierarchical analysis of population genetic structure reveals the influence of historical glacial vicariance on patterns of contemporary genetic variation in thinhorn sheep. Conservation Genetics. https://doi.org/10.1007/s10592-018-1123-2

Sim, Z. and D.W. Coltman. 2019. Heritability of Horn Size in Thinhorn Sheep. Frontiers in Genetics. https://doi.org/10.3389/fgene.2019.00959

Sittler, K.L. 2013. Influence of prescribed fire on stone's sheep and rocky mountain elk: Forage characteristics and resource separation. MSc Thesis. University of Northern BC. 201 Pp.

Sittler, KL.. 2019. Health Status and Habitat Enhancement of British Columbia's Southern Most Stone's Sheep (Ovis dalli stonei). Wildlife Infometrics Inc. Report prepared form the Wild Sheep Foundation. Wildlife Infometrics Inc., Mackenzie, British Columbia, Canada.

Sittler, K.L., K.L. Parker, and M.P. Gillingham. 2015. Resource separation by mountain ungulates on a landscape modified by fire. J. Wildl. Manage. 79:591–604.

Sittler, K.L., K.L. Parker, M.P. Gillingham. 2019. Vegetation and Prescribed Fire: Implications for Stone's Sheep and Elk. J. Wildl. Manage. 83(2):393-409. DOI: 10.1002/jwmg.21591

Sivy, K.J., A.W. Nolin, C.L. Cosgrove and L.R. Prugh. 2018. Critical snow density threshold for Dall sheep (*Ovis dalli dalli*). Canadian Journal of Zoology Volume 96, Number 10, October 2018.

Stephen, C. and H. Schwantje. 2003. Communicable disease risks to wildlife from camelids in British Columbia. Nanaimo, BC.

Steventon, D. and R. Marshall. 1985. March 1985 inventory of the Todagin sheep population. BC Ministry of Environment and Parks, Skeena Region. 17Pp.

Stockwell, C.A., Bateman, G.C., and Berger, J. 1991. Conflicts in national parks: a case study of helicopters and bighorn sheep time budgets at the Grand Canyon. Biological Conservation 56: 317-328.

TGOA. 2021. Tahltan Guide Outfitter Association and Tahltan Central Government Jade-Boulder Sheep Project. TCG Fish and Wildlife Newsletter - September 2021. Unpublished report. Pages 27-31. https://tahltan.org/wp-content/uploads/2021/11/TCG_FishWildlifeNewsletter2021_Web.pdf

Thacker, C. 2020. Health surveillance of thinhorn sheep (Ovis dalli) herds in British Columbia and Alaska. M.Sc. thesis, University of Calgary, Calgary.

The Wildlife Society and American Association of Wildlife Veterinarians. 2015. Domestic Sheep and Goats Disease Transmission Risk to Wild Sheep. Joint Issue Statement.

Udevitz, M.S., B.S. Shults, L.G. Adams, C. Ckeckner. 2010. Evaluation of aerial survey methods for Dall's sheep. Wildlife Society Bulletin. 34:3. 732-740

Valdez, R., and P.R. Krausman. 1999. Description, distribution, and abundance of mountain sheep in North America. Pp.3-22 in R. Valdez and P.R. Krausman, eds. Mountain sheep of North America. Univ. Arizona Press, Tucson, AZ.

Walker, A.B.D. 2005. Habitat Selection and Behavioural Strategies of Stone's sheep in Northern British Columbia. M.Sc. thesis, University of Northern British Columbia, Prince George. 218 Pp. https://web.unbc.ca/~parker/Student%20Theses/WalkerThesis.pdf

Walker, A. B. D., K. L. Parker, M. P. Gillingham, D. D. Gustine, and R. J. Lay. 2007. Habitat selection by female Stone's sheep in relation to vegetation, topography, and risk of predation. Ecoscience 14:55–70.

Wendling, B., Want, J. and Lohuis, T. 2021. Recent Dall's Sheep Harvest Data Summary and Population Concerns, Alaska – November 2021. Alaska Department of Fish and Game. Unpub. report. 3 pages.

Western Association of Fish and Wildlife Agencies (WAFWA) Wildlife Health Committee (WHC). 2014. Bighorn Sheep Herd Health Monitoring Recommendations. 29 Pp.

Western Association of Fish and Wildlife Agencies (WAFWA) Wild Sheep Working Group (WSWG). 2016. Jurisdictional Wild Sheep Population Estimates 2016.

Western Association of Fish and Wildlife Agencies (WAFWA) Wild Sheep Working Group (WSWG). 2020. Jurisdictional Wild Sheep Population, License, Harvest Demand Estimates, 1990-2019.

Whitten,K.R. 1997. Estimating population and composition of Dall Sheep in Alaska: assessment of previously used methods and experimental implementation of new techniques. Fed. Aid in Wildl. Restor., Res. Final Rep., Grants W-24-3, W-24-4 and W-24-5, Study 6.11, Juneau. in M.V. Hicks, ed. Dall Sheep. Alaska Dep. Fish and Game, Juneau, AK. Fed. Aid in Wildl. Restor. Manage. Rep.: Survey-Inventory Activities, 1 July 1995 – 30 June 1998, Grants W-24-4, W-24-5 and W-27-1, Study 6.0.

Wolf, J.F., K.D. Kriss, K.M. MacAulay, K. Munro, B.R. Patterson and A.B. Shafer. 2021. Gut microbiome composition predicts summer core range size in two divergent ungulates. FEMS Microbiol Ecol. 2021 Apr 13;97(5):fiab048. doi: 10.1093/femsec/fiab048. PMID: 33729507.

Wolff P, Blanchong J, Nelson D, Plummer P, McAdoo C, Cox M, Besser T, Muñoz-Gutiérrez J, and Anderson C, (2019) Detection of Mycoplasma ovipneumoniae in Pneumonic Mountain Goat (Oreamnos americanus) Kids, Journal of Wildlife Diseases: January 2019, Vol. 55, No. 1, pp. 206-212.

Wood, M. 1995. Mount Frank Roy Stone's Sheep Transplant. Peace Williston Fish and Wildlife Compensation Program. BC Hydro. 6 Pp.

Wood, M.D., B.A. Culling, D.E. Culling, and H.M. Schwantje. 2010. Ecology and health of Stone's Sheep (*Ovis dalli stonei*) in the Dunlevy/Schooler area, north-eastern British Columbia. Peace/Williston Fish and Wildlife Compensation Program Report No. 342. 106 pp plus appendices.

Woods, A.D. 2020. Prescribed burns for wild sheep habitat enhancement in Northeastern BC: supplemental information 2020. Ridgeline Wildlife Enhancement Report #008, Ridgeline Wildlife Enhancement, Fort St. John, BC.

Woods, A.D. 2022. Stone's Sheep Habitat Enhancement Newsletter – August 2022. Ridgeline Wildlife Enhancement, Fort St. John, BC.

Woods, A.D. and R.S. McNay. 2017. Prescribed burns to enhance ungulate habitat N. Central BC. Wildlife Infometrics Inc. Report No. 578a. Wildlife Infometrics Inc., Mackenzie, British Columbia, Canada.

Worley, K., Strobeck, C., Arthur, S., Carey, J., Schwantje, H., Veitch, A. and Coltman, D.W. 2004. "Population genetic structure of North American thinhorn sheep Ovis dalli" (PDF). Molecular Ecology 13 (9): 2545–2556.

WSF. 2021. Wild Sheep Foundation Position Statement: Effects of Recreational and Commercial Use of Drones on Wild Sheep. https://www.wildsheepfoundation.org/cache/DOC391_DronePolicy_1.pdf?20211027020139

Yukon Department of Environment. 2017. Science-based guidelines for management of thinhorn sheep in Yukon. Yukon Department of Environment Fish and Wildlife Branch. MR-17-04. 33Pp.

PERSONAL COMMUNICATION/UNPUBLISHED DATA REFERENCES

Bridger, Michael C. 2021. BC Ministry of Forests, Lands, Natural Resource Operations, Northeast Region Wildlife Biologist.

Brunning, Darren. 2014. Alaska Department of Fish & Game, Delta Junction, Regional Biologist.

Freeman, Shaun D. 2020. SDF Environmental Consulting. Proprietor and Senior Wildlife Biologist.

Jex, Bill. 2021. BC Ministry of Forest Land Natural Resource Operations, Provincial Wild Sheep and Mountain Goat Specialist.

Lohuis, Tom. 2021. Alaska Department of Fish & Game, Dall's sheep Research Biologist.

Peard, Dean. 2018. BC Ministry of Environment, Skeena Region, Information Specialist.

Thacker, Dr. Caeley. 2018. Provincial Wildlife Veterinarian, BC Ministry of Forest Land Natural Resource Operations.

Schwantje, Dr. Helen. 2018. Provincial Wildlife Veterinarian, Emeritus, BC Ministry of Forest Land Natural Resource Operations.

Wehausen, Dr. John D. 2019. Associate Research Scientist, University of California, retired.

Photo: Province of British Columbia

First Nations Governments and Community Engagement:

Acho Dene Koe First Nation
Blueberry River First Nations
Dene Tha' First Nation
Doig River First Nation
Fort Nelson First Nation
Halfway River First Nation
Horse Lake First Nation
North Peace Tribal Council
Prophet River First Nation
Saulteau First Nations
Treaty 8 Tribal Association
West Moberly First Nations
Dease River First Nation
Kaska Dena Council
Kwadacha Nation
McLeod Lake Indian Band
Nak'azdli Whut'en
Takla Nation
Tsay Keh Dene Nation
Carcross-Tagish First Nation
Liard First Nation
Tahltan Central Government
Taku River Tlingit First Nation
Teslin Tlingit Council
Champagne and Aishihik First Nations
Nisga'a Nation
Gitxsan- Upper Skeena Watershed
Gitxsan- Sustut Watershed
Tsetsaut Skii Km Lax Ha Nation.

Photo: Province of British Columbia