The Wolverine Project: Evaluating Cumulative Effects Within the Land of Ktunaxa Using the One Heart Method

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Abstract

This study evaluated the cumulative effects of existing and proposed land use activities and climate change within a narrow and vital wildlife corridor considered of high value to Ktunaxa and non-Ktunaxa peoples. Cumulative alteration, degradation, and disturbance to habitat directly impacts Ktunaxa lands and waters on which the exercise of Ktunaxa rights depends. Increased access to backcountry areas are expected to substantially diminish habitat condition, increase wildlife displacement and mortality risk, and fragment wildlife populations with unavoidable population-level impacts. The effects of land use are likely to be exacerbated by accelerating climate change further limiting habitat suitability and creating additional human-wildlife interactions. This study is unique in that we applied Ktunaxa research methodology throughout all assessment stages. This iterative approach to knowledge gathering brings Ktunaxa and non-Ktunaxa together in concert with input from a diverse group of problem solvers. Further, we used this opportunity to refine our understanding of cumulative effects through a Ktunaxa linguistic perspective. Repeated interviews deepened research relationships and empowered use of Ktunaxa oral history in the evaluation of cumulative effects. Two species of key concern identified for this study were ʔaȼpu (wolverine) and kⱡawⱡa (grizzly bear). We simulated current and future habitat condition for key values using a pre-contact baseline representing the Range of Natural Variability (RONV). The assessment presented herein considered past, current, and proposed future land use activities, with a focus on recreational interests. We found combined effects of proposed recreation developments with existing land use practices within the study area to substantially negatively impact both wolverine and grizzly bear habitat condition and population connectivity. We concluded that cumulative developments of past, current and any potential future land use that includes outdoor recreational activities in ʔamak̓is Ktunaxa must be informed by regional-scale and long-term land stewardship planning to prevent further adverse impacts and to ultimately improve the habitat conditions for ʔa·kxaⱦis q̓api qapsin (All Living Things).

Keywords Cumulative effects · Ktunaxa knowledge · recreation impacts · wolverine · grizzly bear · modelling

Introduction

Ktunaxa World View and Cumulative Effects

ʔa·knumuȼtiⱡiⱡ, our Ktunaxa natural law, dictates that we have an obligation to protect and preserve the lands and resources for future generations (Ktunaxa Nation Council,

2010). Ktunaxa people adhere to stewardship principles that consider all human interactions with the land and follow best practices rooted in the goal of sustaining ʔa·kxaⱦis q̓api qapsin (All Living Things) (KNC, 2017). Ktunaxa law protects values inherent in the land: the land gives us the resources to survive, and in return, we uphold the covenant with the Creator to protect and not overuse the land. We

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understand that we are only a small part of a complex existence providing homes for the four leggeds, the wingeds, the ones that crawl on the ground, and the ones that live in the waters.

Inherent to Ktunaxa natural law, cumulative effects reflect a complex system where what effects one effects all, or yunaqałxu?mik kłaxmitiyam – many things laying around causing trouble. It can also be thought of as "for there to be many properties present that cause single/undifferentiated trouble". The traditional understanding of cumulative effects aligns closely with contemporary definitions, such as "changes to environmental, social, and economic values caused by the combined effect of past, present, and potential future human activities and natural processes" (e.g. BC Government (2024)). Managing for individual impacts in isolation without considering the synergistic interactions among multiple impacts and how these collectively manifest over space and time is counter to the long run connectedness typically found in the Ktunaxa understanding of ?a·qałikniyi?is (ecosystem services). In the Ktunaxa cultural context "long run" implies an extended dynamic, described by the terms wunikit (an extended time period) and wuq̓ma·nikit (for a timeline to take a long time). These are the dynamics of instantiating traditional knowledge gathered and actuated between ?a·qałq̓anuxwatił (when animals were the people) to ?unik kyukyit (the end of days). Further from the Ktunaxa cultural context "connectedness" refers to the interconnectedness that we typically see in elders' contributions to discussion of belongingness and identity, specifically in the term t̓i·kxawi¢ikimik (for all things to be connected) and hak̓amxuni·kin (for everything to have its purpose).

The extent of cumulative impacts is highly dependent upon spatial scale and time of reference (Foley et al, 2017). For Ktunaxa and many Indigenous peoples, impacts from contemporary and industrialized land use practices must be realized over appropriate scales that consider values of interest both locally and regionally and pre-date colonial occupation. Contextualizing and evaluating post-colonial effects within the context of the Range of Natural Variation (RNV), which excludes Indigenous land stewardship practices such as fire, from a pre-contact baseline is viewed as an appropriate means to adequately capture cumulative effects – challenging the pervasive use of shifting baselines. Projecting future conditions is required to understand the trajectory of the landscape and facilitate meaningful decision making for future generations.

Without a holistic and scale-appropriate approach to cumulative effects assessment, the combined effect of human land use, natural disturbance, and climate change will further displace us, and ?a·kxam̓is q̓api qapsin, from our shared homeland, interfering with the ability to exercise our Ktunaxa rights and responsibilities.

Cumulative Effects of Recreation

Ktunaxa have long expressed concerns for the combined impacts of 'all' land uses, including nature-based, or outdoor recreation. Like many activities humans engage in on the land, outdoor recreation can have negative consequences when occurring at intensities and frequencies that exceed disturbance thresholds of ecosystems and/or plant and animal species (Shelby and Heberlein, 1987), thereby exceeding the land's ability to remain resilient to change and support viable populations of ?a·kxam̓is q̓api qapsin (All Living Things). However, recreation has typically been viewed as a low-impact land use activity. As such, recreation is often excluded from cumulative effects assessments, those focusing on industrial impacts of urban development and resource extraction. With widespread interest in outdoor recreational pursuits, both commercial and non-commercial, impacts are now being realized at industrial levels. For example, British Columbia (BC) Parks and Protected Areas observed hiker visitation increase up to 222% in the last decade (BC Parks, 2021). Further, a local BC cycling club reported an approximate 300% increase in trail use in only four years. In response, a growing body of recreational research has found these once relatively benign activities to negatively influence biodiversity and ecosystem function. These recreational activities lead to soil compaction and erosion, alteration and loss of native vegetation structure and composition, establishment and spread of invasive alien species and reductions in forage quality/quantity, reduced water quality and aquatic health. Recreation also causes wildlife disturbance and displacement from key habitats, leading to direct reductions in animal condition and/or stress-mediated decline, culminating in reduced population fitness, and potentially population fragmentation (e.g. Hooper et al. 2005; Hammitt et al. 2015; Larson et al. 2016; Dertien et al. 2021). Climate-related changes "such as diminishing reliable snowpack for ski and snowmobile tourism" are expected to exacerbate disturbance from winter recreation on species and critical winter habitats (Steiger et al. (2019); Schepens et al 2023). This array of recreational impacts is found throughout British Columbia and ?amak̓is Ktunaxa (Ktunaxa Nation, Land of Ktunaxa). Formalizing recreation as a disturbance factor in cumulative effects assessment is therefore a priority to Ktunaxa.

Purpose and Objectives

Increased recreational interests and concerns about associated cumulative effects were identified within one area of the ?amak̓is Ktunaxa. To understand the current and

potential future effects of existing recreation and proposed future developments, we asked: How much recreational activity coupled with past changes to the land and existing land uses (i.e., mining, forestry, roads, other linear corridors, urban/rural development, etc.) exceeds the carrying capacity of the land and the associated tolerance limits of biodiversity components? Or rather, just how 'deep' do we want our ʔa·kɬik (foot tracks) to tread on ʔa·kxam̓is q̓api qapsin? Furthermore, what will be the realized impacts for Ktunaxa to uphold ʔa·knumuȼtiɬiɬ (Ktunaxa law outlining Ktunaxa obligation as responsible stewards of the land)? To answer these questions, we assessed cumulative effects by applying multiple ways of knowing and considered past, current, and potential future landscape conditions within one target area of concern. Guided by Ktunaxa research and problem-solving principles, our work aimed to:

- Assess cumulative impacts using xaȼqanaɬ ʔitkiniɬ (Many Ways of Working on the Same Thing), including the impacts of land use activities and climate change, from prior to colonization to projecting into the future.
- Solicit cultural information about the meaning of cumulative effects through a linguistic perspective using ʔa·kwiȼis ktunaxa (Ktunaxa Wing Model of Culture).
- Evaluate the implications of existing and proposed recreational land use activities within a portion of ʔamaƙis Ktunaxa to the health of ʔa·kxam̓is q̓api qapsin (All Living Things).

Here, we focused on understanding the impacts to two values identified based on cultural significance, available data, and understanding of species response to existing and proposed recreational land use activities: ʔaȼpu (wolverine, *Gulo gulo*) and kɬawɬa (grizzly bear, *Ursus arctos horribilis*). ʔaȼpu are considered to be one of our spiritual guides known as notoriously solitary and fierce. Harvesting a wolverine is a proud hunt for Ktunaxa, their fur valued for its frost-resistant properties. Like many populations across Canada and worldwide, wolverines in ʔamaƙis Ktunaxa are declining due to cumulative effects of climate and landscape change, increasing human disturbance (e.g., winter recreation), habitat loss, and unsustainable harvest (Heim et al. 2017; Kortello et al. 2019; Heinemeyer et al. 2019; Mowat et al. 2020; Fisher et al. 2022). kɬawɬa is considered an important link to Ktunaxa spirituality. Grizzly bear is also a wide-ranging species with a low recruitment rate. It is listed as a species of Special Concern in Canada (COSEWIC), with threats ranging from direct mortality, which can easily become unsustainable, to fragmentation of populations elevating extirpation risk resulting from increased human development and access into previously secure areas (e.g., Lamb et al. 2017, 2018; Proctor et al. 2012, 2019).

Study Area

The spatial boundary of the study area is situated within the southwestern portion of ʔamaƙʔis Ktunaxa (Ktunaxa Nation, Land of Ktunaxa) and is home to the Yaqan Nuʔkiy and Kootenay Tribe of Idaho people. The study area is situated between ʔamaƙis ʔaȼpu and ʔamaƙis miȼqaqas (Wolverine's Land and Chickadee's Land) and has offered an abundance of food and medicines that sustained

Ktunaxa since time immemorial. The study area includes all British Columbia Assessment Watersheds that intersect with two recreational tenures proposed along Highway 31A, covering an area of 5,662 km^2 bound by Kootenay Lake to the east and Slocan Lake to the west. It extends to the northernmost reaches of the Upper Arrow Lakes near qayiɬxuɬik (Beaton), and is bound by the confluence of sɬuq̓an ʔakinmituk and kɬantawsanmituk (Slocan and Kootenay rivers) just west of ʔakanukamak (Shoreacres) to the south (Fig. 2). The area is characterized by high relief, encompassing mountain peaks in the Goat Range and Kokanee Glacier massif at 2,700 m above sea level, and descending to 461 m at the confluence of the Slocan and Kootenay Rivers. There are mainly upland coniferous and mixed forests in the Interior Cedar Hemlock (ICH) and Engelmann Spruce Subalpine Fir (ESSF) biogeoclimatic zones below 2,300 m (a.s.l.). Uppermost elevations are within the Interior Mountain-Heather Alpine undifferentiated subzone, comprised of alpine meadow, heath, fellfield, talus, avalanche chutes, and, most notably Kokanee Glacier at the headwaters of Keen Creek.

The heart of the study area is bisected by what is now referred to as the Highway 31A corridor which connects wupnikɬa (New Denver) and qasɬu (Kaslo), where the snow meets the water. Ktunaxa ʔa·qaɬqanuxwatiɬ (oral histories) and archeological records accord that, prior to European contact, this route was used for travel and trade, and it is integral to distinctive Ktunaxa culture. This corridor provides critical connectivity habitat for aȼpu (wolverine, *Gulo gulo L.*) and kɬawɬa (grizzly bear, *Ursus arctos horribilis*, Proctor et al. 2015, 2023). This north to south (N-S) corridor connects regional wolverine populations, specifically within the protected areas of Goat Range and Kokanee Glacier Provincial Parks (Fig. 1). Habitats within the study area support the highest confirmed wolverine density still occurring in the region (i.e., 5–7 wolverines/1000 km^2; Mowat et al. 2020). These areas are characterized by low road density with persistent late spring snow cover, and high habitat quality characteristics preferred by sensitive breeding female wolverine (Kortello et al. 2019). This corridor connects multiple known natal denning areas protected under provincially designated Wolverine Seasonal Closure Areas, underscoring the importance of this study area for regional wolverine populations. Similarly, this corridor connects already fragmented sub-populations of

Fig. 1 ʔa·kxamis q̓api qapsin.
Ktunaxa graphical illustration depicting cumulative effects on the interconnectedness of ʔa·kxamis q̓api qapsin (All Living Things). Illustration by Marissa Phillips. Submitted to the Ktunaxa Nation Council, 2023. Excerpts from artist statement: "The center of the image starts from the singularity of spirit at the beginning of time and Spirals out. I was taught that time for us isn't linear, but instead moves in a spiral. Within the larger spiral are smaller spirals showing increasing events (or cumulative effects) and decreasing events throughout time". Each circle-window has four triangles on it to represent the four states of being- Spiritual, Emotional, Mental and Physical. If one of the states of being is effected, then the others will also be effected. I have also shown a personified version of Moon and Sun, as both of their cycles effect our environment and show us movement through time and the seasons"

grizzly bear while providing abundant ɬawiyaɬ (huckleberry, *Vaccinium membranaceum Dougl.*) patches, making it some of the highest quality grizzly bear habitat remaining in the region (Fig. 4; Proctor et al. 2012, 2015, 2023). Further, it is expected that female grizzly bears access the security of snow-covered dens within this study area (Pigeon et al. 2014). Increased recreational disturbance elevates concerns regarding anticipated and disproportionate costs to these species, particularly when nursing young in winter dens. Disturbance to species within these critical habitats and breeding periods can have long-lasting and detrimental effects that may not be realized until populations reach apparent declines.

Though not described here, many other animals, including several species at risk are found within this study area (SARA, 2023). Situated within the Kaslo River watershed and its many tributaries, the area provides important habitat for a variety of fish species, including

provincially blue-listed westslope-cutthroat qustit' (trout) and tuhuɬ (bull trout, *Salvelinus confluentus*). A key concern for local species and their habitats found within and adjacent to this corridor is the increasing popularity of both summer and winter recreational activities.

Two study area boundaries were delineated to assess cumulative effects according to appropriate scales of influence: Regional and Local (Fig. 2). The study area boundaries considered the home range and dispersal requirements of aȼpu and kɬawɬa.

Methods

Ktunaxa Research Methodology

A research methodology is a system of methods directed to an area of study, or research problem, indicating the theory,

Fig. 2 Study area map with Ktunaxa place names.
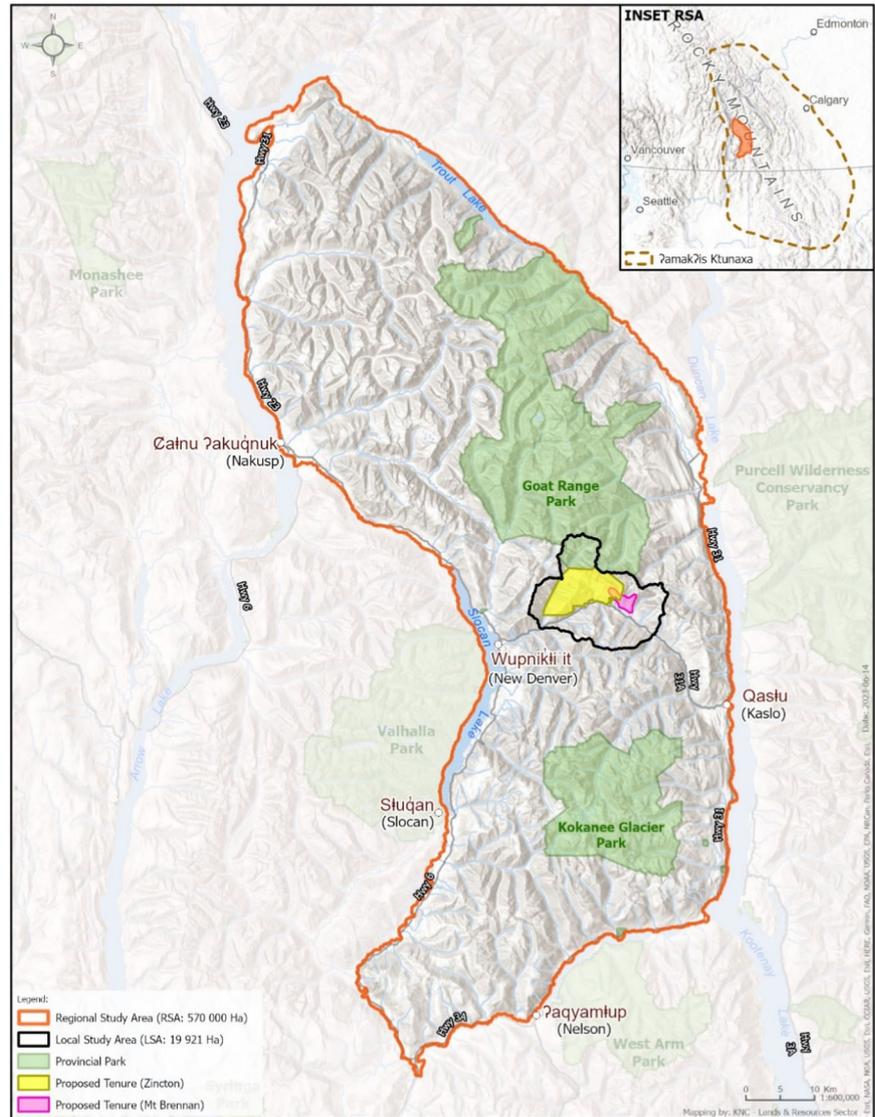
or hypotheses, in which the research is conducted (Mohajan, 2018). Research methodologies provide a substrate for identifying correlations through variation of study designs, data gathering processes, analyses, data interpretations and concluding reports which serve to harmonize meaning and measurement (Robey, 1994). However Indigenous voices have been removed from these historic processes. The result is largely exogenous data gathering and analytical processes (Horsethief, 2024a), those often rooted exclusively in western science. As a result, the emergence of Indigenous research methodologies relies heavily on the inclusion of Indigenous vision, voice, communicative protocols, practices and dissemination policies.

The Ktunaxa Nation has been at the forefront of developing a comprehensive Indigenous research methodology steeped in Ktunaxa values. As a methodology built on a specific Indigenous group's cultural, linguistic and philosophical foundations (Horsethief, 2024b), the Ktunaxa Research Methodology empowers Ktunaxa people to engage in areas of research compatible with ʔa·knumuȼtiɬiɬ (Ktunaxa cultur), ka·kɬukaqwaɬa (linguistic), and ka·kikiɬ haqwaɬa (philosophical foundations). This system of Ktunaxa methods both binds Ktunaxa people to research and affords translation of Ktunaxa ideas across contemporary research discussions. The specific methods are ʔa·kwiȼis ktunaxa (the wing model of culture), ʔukiniɬwitiyaɬa (a group thinking with one heart) and xaȼqanaɬ ʔitkiniɬ (many ways of working on the same thing) (Horsethief, 2023). These methods preserve and draw from oral tradition and collective memory, mirroring a modern literature review, and follow data gathering and collaborative problem-solving protocols. An iterative approach of clarifying questions and seeking guidance from Ktunaxa citizens refines methods and results. Used together, the Wing

Model, One Heart, and Many Ways have been applied to academic, scientific, policy and leadership research in the context of the Ktunaxa Nation (Shahram et al. (2020); Horsethief, 2020; 2021).

Integration of Ktunaxa research methods into cumulative effects research allows us to investigate cumulative impacts to ʔa·kxaⅿis q̓api qapsin (All Living Things / All Things Rooted to the Land) within an inclusive and holistic framework. xaȼqanał ʔitkinił brings non-Indigenous and Indigenous knowledge holders together as a means of reciprocal calibration, where indigenous models and western models gradually exchange information and evolve to accept each other's permeable boundaries (Horsethief, 2022). Many Ways establishes structural equivalence where scientific ideas that are accepted as rigorous and sufficient from a Western perspective are also viewed as valid and necessary from the Ktunaxa perspective— and vice versa. This approach ensures both knowledge systems and ways of collecting data are achieved in concert, are equally robust, and complimentary.

Throughout all stages of this assessment, we gathered knowledge from a diverse group of problem solvers, including subject matter experts (Ktunaxa and non-Ktunaxa), Ktunaxa citizens, and western science biologists. In turn, outcomes of this work reflect expertise and insights from various educational and cultural backgrounds spanning Ktunaxa communities, sectors, and age groups – exceeding minimum interactions needed to avoid small sample bias. This is consistent with Page's diversity conjecture (Page, 2007), where diverse groups of problems solvers often outperform a group of experts, because small sample biases cancel each other out. It is consistent and compatible with the wisdom of the crowd and indigenous notions of consensus. It also promotes capacity development by exposing Ktunaxa community members to conversations, processes, and methodologies previously beyond their common place practice. This allows for the inclusion of a nuanced and contextual description of Ktunaxa ecosystem dynamics, Ktunaxa cumulative effects, and violations of Ktunaxa sustainability or Western development incompatibilities with sustainable Ktunaxa lived practice. Knowledge was gathered through consultation with subject matter experts, Calls to Gather, focus groups and workshops, and one-on-one interviews. Outcomes engagements with greater than 50 Ktunaxa knowledge holders guided values selection and iterative review at all stages of assessment.

Linguistic Refinement of Cumulative Effects

To refine our understanding and evaluation of cumulative effects we investigated the meaning of cumulative effects through a Ktunaxa linguistic perspective. Cumulative effects is an old concept to Ktunaxa. Language teaches the origins of our understanding; how we interpret natural processes and ask questions about the impacts to these processes.

Using the wing model, we solicited cultural information including significant phrases in the Ktunaxa language to describe cumulative effects (including primary concepts). The wing model filters information through social structures in accordance with community protocols. Repeated interviews yield increased cultural and linguistic knowledge, deepening research relationships between Ktunaxa community members and non-Indigenous researchers. This iterative process prevents community members from becoming overwhelmed in recalling distant information in a static state, allowing for respectful and thoughtful elicitation of information from individual or collective memory.

Evaluating Cumulative Impacts to Ecological Values

Using Many Ways, we evaluated impacts on ecological values anticipated to be affected by local and regional land use practices and those underpinning Ktunaxa way of life. We considered impacts to habitat availability and condition, landscape fragmentation, alteration and degradation; wildlife disturbance, displacement, population fragmentation, and mortality risks; aquatic species and systems implications, and inherent uncertainties of accelerating climate change.

Underpinned by the Ktunaxa view of cumulative effects and the impacts to ʔa·kxaⅿis q̓api qapsin, we considered an array of ecological and cultural values predicted to be impacted by past, current and future land use activities and climate change within the study area. Here, we simulated cumulative effects using a pre-contact baseline focused on impacts to two of the identified values: ʔaȼpu (wolverine) and kławła (grizzly bear) as well as future conditions of land use, natural disturbance, and accelerating climate change.

Scenario analysis

This assessment used ALCES Online (Carlson et al. 2014) to evaluate Valued Component (VC) indicator response to pre-contact, current, and future conditions. A Pre-Contact scenario was simulated to provide a pre-colonial Range of Natural Variability (RONV) for evaluating changes to ʔaȼpu and kławła indicators. Prospective scenarios focused on the effects of new recreation proposals, specifically, Mt. Brennan Backwood Adventure Tourism (Mt. Brennan) and Zincton All Season Resort (Zincton) within the context of cumulative effects. The Scenarios were run at 100 m spatial resolution and simulated at a decadal time scale with

outputs that correspond to current condition (year 2021), and potential future condition (year 2071).

Here we use three periods (simulations) to evaluate cumulative effects of land use over time and space:

1. Pre-contact (Range of Natural Variability)
2. Current conditions
3. Future conditions

Hydrological modelling was accomplished to simulate potential future climate conditions and effects on seasonal snowpack.

Pre-contact simulation A Pre-Contact scenario was developed which removed all anthropogenic footprints from the land and replaced it with adjacent natural landcover following a nearest neighbor approach. In this context, anthropogenic footprint refers to post-colonial, or post-contact, human-mediated landscape change or and development and does not account for landscape change through the management, or stewardship, practices of Indigenous peoples (specifically Ktunaxa). A nearest neighbor approach was deemed sufficient for the study area since no large expanses of anthropogenic land cover (e.g., farmland or large towns) currently exist in the study area. Forest age subsequently changes in response to random fire events and aging during a 300-year calibration period, to produce a landscape that is consistent with expected RONV conditions in the region. The simulation of the Pre-Contact scenario is an area where traditional knowledge can be incorporated in future projects. The RONV in forest age was estimated by simulating the natural fire regime.

Pre-suppression fire rate was based on natural fire return intervals reported by natural disturbance type and biogeoclimatic subzone/variant in the Forest Practices Code of British Columbia Biodiversity Guidebook (British Columbia Forest Service and BC Environment, 1995). Fire was simulated as a stochastic process to approximate the effect of a variable fire regime on forest age and related indicators. The fire regime was simulated as random draws from a lognormal distribution, a distribution well suited for characterizing variable fire regimes (Armstrong, 1999). Drawing from a lognormal distribution required estimates of the mean and the standard deviation in annual burn area. Mean annual burn area equaled the assumed natural burn rate multiplied by the burnable area (forest and shrubland) of the region. Standard deviation in burn area was derived from the coefficient of variation in interannual burn area for the study area (104%) as calculated using historic fire data from the BC catalogue for years up to and including 1940. The year 1940 approximates when largescale fire suppression began in the province of British Columbia. A characteristic of the lognormal distribution is that it can occasionally produce very large values relative to the mean. To avoid unrealistically high fire years, the annual burn rate was truncated at the maximum annual burn area recorded for the study area (18,200 ha). Fire location and shape were random but influenced by relative burn probabilities that varied by forest type and age, and fire size was based on the size class distribution calculated using historic fire data for the study area.

Ten thousand 400-year fire simulations were generated, of which the following five were selected to capture the RONV: 5th percentile, 25th percentile, 50th percentile, 75th percentile, and 95th percentile of landscape disturbance as measured as the average forest age during the last 100 years of the simulation. Pre-contact indicator status was assessed as the average indicator value across the final 100 years of the five selected simulations. The Pre-contact scenario has been identified as an area where traditional knowledge should be incorporated through future work.

Current condition The current condition analysis required the preparation of a landcover dataset representing a continuous landscape. Multiple sources of up-to-date landscape and disturbance data were integrated into a single dataset, which formed the basis for the current condition analysis. Landscape data were obtained from open sources, specifically Vegetation Resource Inventory (VRI) for landcover, wildfire and insect outbreak data from government sources (BC Fire Perimeters – Current and Historical, BC Pest Infestation Polygons – Current and Historical), and Freshwater Atlas (FWA) for water features. Footprint datasets were retrieved from BC Ministry of Forests Lands Natural Resource Operations and Rural Development (FLRNORD) files consolidated for Kootenay Boundary wide analysis (FLRNORD Consolidated Disturbance Dataset). This dataset includes existing cutblocks (and their ages), agriculture/clearing, right of ways, mining and extraction, oil and gas infrastructure, transmission lines, dams, airfields and airports, railways, recreation, and urban development.

Future condition ALCES was used to simulate the cumulative effects of land use (including proposed recreational developments), natural disturbance, and climate change (through snowpack and fire change) on habitat condition for ʔaⱦpu and kⱡawⱡa. ALCES simulated a dynamic landscape by transitioning a cell-based representation of the current landscape to user-defined future development actions and natural disturbances. The tool is web-based to enable collaboration and facilitate dissemination of results (Carlson et al. 2019).

Potential future conditions were simulated to include: forest harvest and resource road development, urban and rural residential expansion, traffic volume increase (Highway 31 A, see Fig. 2), proposed recreation developments

(e.g. lifts, trails, lodging, ski-run glading), projected natural disturbances (i.e. fire and insect disturbance) and hydrological change as a function of climate change.

The Future Restricted scenario represents strict adherence to proposed restrictions on access and human use presented in the Zincton All Season Resort Proposal (BHA, 2021), one of the local commercial recreation proposals assessed for this study. For summer recreation, this assumes hiking and mountain biking will only occur on designated trails and within proposed lift-serviced zone. The Future Unrestricted scenario assumes hikers will extend use off designated trails and access areas outside delineated summer use zones. For winter, the Future Restricted scenario assumes that backcountry skiers will stay within the proposed backcountry ski zone. The Future Unrestricted scenario assumes that backcountry skiers will access terrain beyond the designated ski boundary.

To evaluate the impacts under varying scenarios, we discounted habitat condition using a degrading function from 1-0 based on species known sensitivity to disturbance and projected human-use levels. High 'use areas' (e.g. trails, lodges) were assumed to be the most impacted and were discounted by 1, reducing habitat condition to 0. Daily use areas were buffered to simulate the effect of species displacement near recreational use and where assumed use was unrestricted. For large distances from use areas, the concept of fuzzy logic was used to apply a gradient of discounts (Wang et al. 2010). A linear function was applied to simulate the human impact decreasing with distance from area of use. Buffer distances and habitat discounts were determined based on known species-specific responses to recreation and the existing and projected type/intensity/frequency of recreation. Values were derived from existing literature and expert knowledge.

For female wolverine, habitat condition was discounted by 1 on trails (i.e. the high human-use trail assumed to provide low to no habitat quality for female wolverines). Wolverine are known to avoid trails that exceed 10 user groups in a two-week period (Barrueto et al. 2022). In this study area, commerical tenure holders were projecting 3 to 4 client days a week, exceeding the threshold of disturbance for a wolverine. The buffer distance of 300 m of the trail was selected because wolverine were found to avoid areas within 300 m of roads and areas of both non-motorized and motorized recreation (Heinemeyer et al. 2019; Scrafford and Boyce, 2014). A buffer from 300 m to 2000 m from a main use area or trail was discounted gradually from 0.5 to 0 with distance from the trail. This buffer distance of 2 km was selected following evidence of non-motorized recreation to elicit moderate to low levels of wolverine disturbance from 1 to 2 km (B. Harrower, per comm).

For female grizzly bear, habitat was discounted by 1 within main, or intensive human-use areas, and by 0.75

within surrounding buffer area of 300 m from mountain bike and hiking trails. In the Cabinet/Yajk and South Selkirk systems the buffers are currently set at 500 m around non-motorized trails and are being revised to a value between 250 and 300 m (US Fish & Wildlife Service review, unpublished, W. Kasworm, per comm). Five studies reviewed by Mattson (2019), found that grizzly bears avoided pedestrian trails at an average of 270 m. Recently, a study in central Alberta found grizzly bear decreased detection rates to occur within 267 m of a given trail and suggest a 300 m buffer as an appropriate management target to limit disturbance within wildlife corridors, specific to grizzly bears. (Thompson et al. 2025).

Indicators

Using best available knowledge, value indicators were selected to quantify the cumulative effects of existing and potential future land use within the study area, with a focus on the direct and indirect impacts of proposed recreational developments (Table 1). Many of the potential effects of recreational development on the values involve indirect reductions in habitat quality via human-induced wildlife disturbance and displacement, rather than direct land conversion. We assume habitat quality, or condition, as the measure of a habitat's capability to support a particular value, which is a function of disturbance and displacement impacts on that value, and considers the availability of an area to provide necessary life requisites for a given species or suite of species. Due to existing knowledge limitations related to recreational impacts, explicit indicator thresholds are generally not defined. Instead, reductions to habitat quality were used to assess the degree of impact (Heim et al. 2023).

ʔaȼ̓pu (Wolverine)

Population density Wolverine density, as modelled by Mowat et al. (2020), is dependent on overall road density and on persistent spring snow coverage. Road density was measured as the distance of roads in an area using a moving window (km/km^2) and persistent snow coverage (%) simulated with the hydrological model (Chernos et al. 2017, supporting materials). Persistent snow coverage for wolverine density was calculated by multiplying the percent snowbound for the 1990-2019 period by 17, to provide the Snow17 metric used by Mowat et al. (2020).

Snow coverage was defined for each year as whether simulated snow water equivalent (SWE; mm w.e.) was greater than 0 mm at the end of May. The percent snowbound statistic integrated these values over a 30-year period (a Historical 1990-2019 period, and two future periods; 2021-2050 and 2051-2080) as the fraction of years

Table 1 Two key species, or valued components (VC), assessed in this study, their corresponding indicators, and the equations used to simulate cumulative effects of existing and proposed future land use activities, natural disturbance and climate conditions on those indicators

Value Component	Indicator	Equation
ʔaȼpu (wolverine)	Population density	Density (index) = -0.669*ROAD DENSITY + 0.698*SNOW COVER
	Occupancy (both sexes)	Occupancy for both sexes at 10 km scale (index)= @-0.57 + 0.42*"CARIBOU 10 km"+@0.96*"MARMOT 10 km"-0.81*"FSR 10 km"+0.46*"PROTECTED 10 km")
	Occupancy (female)	Occupancy for females (index) = -1.95 + 0.65*MARMOT - 1.25*FSR
	Critical denning habitat	Criteria were used to classify critical denning habitat: Areas within 200 m above and 2 km below the treeline The upper quartile of undiscounted and unscaled wolverine female occupancy Forest patches greater than 1 ha in size
	*Habitat connectivity	n/a, based on known regional population distributions
Kⱡawⱡa (grizzly bear)	Female reproductive habitat	Reproductive habitat (index)=@0.0003*""Distance to huckleberry 10 ha \""-42.85*"Riparian 8 km" @+ 4.31*""Alpine Areas 3 km\""+ 1.5*"Secure Habitat 62%"#(4))
	High quality ⱡawiyaⱡ (huckleberry) patches	Spatial file provided by M. Proctor (Proctor et al. 2023)
	*Habitat connectivity	n/a, based on known regional population distributions

[*]Indicators evaluated using inference from available data and expert knowledge, not included in ALCES simulations

where snow coverage was non-zero at the end of May. Snow coverage and percent snowbound were calculated to derive a spatially contiguous output as an indicator.

Occupancy for both sexes Wolverine occupancy for both sexes, at the 10 km scale, was simulated based on the work by Kortello et al. (2019). This work developed an occupancy equation that was dependent on 10 km^2 moving windows of caribou range (CARIBOU; km^2), marmot habitat (MARMOT; km^2), forestry road density (km/km^2), and protected areas (Protected; km^2) as subcomponents. Forestry roads were not disaggregated in the model so "Minor Roads" serve as a proxy. The wolverine occupancy values were scaled from 0-1 with continuous distributions. Scaling of indicators was required to apply habitat discounts that were based on the percent of impact.

Female occupancy Wolverine occupancy for females was also simulated based on the work by Kortello et al. (2019), dependent on marmot habitat and forestry road density only. In a 5 km moving window, MARMOT is the density of ideal mean marmot habitat and FSR is the forestry road density.

Critical denning habitat Critical denning habitat for females was determined by combining the wolverine occupancy for females, north facing slopes, and buffers around tree line. Buffers 200 m above and 2 km below tree line were selected to favor locations with suitable talus or rock structures that are close to mature forest found within the study area. The lower boundary of the alpine habitat was used as the tree line. We included the upper quartile of undiscounted and unscaled wolverine female occupancy and patches of mature forest greater than 1 ha in size.

Habitat connectivity Wolverine is a wide-ranging species that lives in sparse densities making effective habitat connectivity another important indicator of population health and resiliency. Existing knowledge combined with expert interpretation of wolverine population density, genetic structure, and movement requirements were used to evaluate existing and potential future fragmentation effects associated with proposed recreation developments.

kⱡawⱡa (Grizzly Bear)

Female reproductive habitat Female reproductive success was selected as a suitable indicator for the grizzly bear valued component (VC), since female bear health and reproductive fitness is the most limiting component to the overall persistence of a grizzly population. Fitness was modelled based on previous work by Proctor et al. (2023), who analyzed the main variables of female reproductive success via logistic regression. Output consisted of a Resource Selection Function (RSF) equation which has then been incorporated into this work (see Table 1).

The 'Distance to huckleberry 10 ha' equation is defined as the distance to huckleberry patches 10 ha in size or greater; "Riparian 8 km" is defined as the mean area of riparian zones within a radius of 8 km; "Alpine Areas 3 km" is defined as the mean area of alpine within a radius of 3 km; and "Secure Habitat 62%" corresponds to a value of 1 if the assessment unit has greater than 62% secure habitat. Secure Habitat is determined by habitat >500 m from an open road

and trails, intensive human use areas and infrastructure (e.g. backcountry lodge), and the availability, or abundance, of preferred food sources (Lamb et al. 2018; Proctor et al. 2019). At present, benchmarks for Grizzly Bear Female Reproductive Success have not been defined.

High quality ɬawiyaɬ (huckleberry, Vaccinium membranaceum) patches Huckleberries are an important food source for grizzly bears so incremental loss of huckleberry patches due to recreational development was used as another indicator. It was simulated by intersecting trail buffers and lodge areas with huckleberry patch locations utilized by grizzly bears (modelled by Proctor et al. 2023) and calculating patch area lost (ha). The assumption is that with a high degree of disturbance bears will avoid otherwise preferred huckleberry patches.

Habitat connectivity Effective habitat connectivity is another indicator of grizzly bear population health and resiliency, particularly for this wide-ranging species in our regionally fragmented habitats. Known regional grizzly bear movement patterns and local habitat needs were used to evaluate existing and potential future fragmentation effects associated with proposed recreation developments (Proctor et al. 2012. 2015, 2023).

Results

Ktunaxa Research Methodology, Knowledge Gathering

Guided by xaȼqanaɬ ʔitkiniɬ principles, we applied an iterative approach to knowledge gathering at all stages of assessment. Through reciprocal calibration non-Ktunaxa researchers and Ktunaxa people participated in several engagement sessions ranging from Calls to Gather, workshops, interviews and data review processes. From these, results of this assessment were informed by over 50 voices ranging in age, lived experience and expertise. Knowledge gathering not only contributed to the selection of focal values – kɬawɬa (grizzly bear) and ʔaȼpu (wolverine) and their associated indicators – but led to a more comprehensive understanding of the potential impacts of cumulative effects to ʔa·kxaṁis q̓api qapsin (All Living Things). Further, it offered an opportunity for reciprocal knowledge sharing and increased Ktunaxa community involvement in land use decision making.

Linguistic Refinement of Cumulative Effects

Throughout the community, crowdsourcing process research discussions repeatedly moved ecological concepts between Western and Indigenous contexts, revealing important Ktunaxa connections between collective memories to individuals' specific working memories. The overall impact continues to filter lived experiences through community social and cultural structures in such a way that they are readily available for contemporary and ongoing problem-solving strategies, including informed decision making.

Using the wing model, the team solicited cultural information and meaningful Ktunaxa language phrases. The open-ended and semi-structured questions were addressed by a sufficiently diverse group to anneal individual problem-solver bias, while also identifying minimum data elements from which to triangulate with Western ecosystem science interests. This process resulted in the following iterations associated outcomes:

- Initial discussion with smaller sample conversations; null order changes with community members exploring familiar and unfamiliar concepts, yielding a list of community members to include in the sample, a method of community consultation, suggestions for samples size and additional sources of data (written account of oral history). Other important data elements included connectedness of human beings to others, the land and the animals, and the primacy of connection with respect to community knowledge systems.
- Subsequent discussions centered on animal names, adjacent species habitation, initial guesses on locations and references to past works (e.g., Boaz, F. 1918) formalization of sample methodology compatible/consistent with the Ktunaxa culture. Important elements included information resistant to individual bias and awareness of cultural entropy, the history of researchers dispossessing Ktunaxa of traditional knowledge.
- The next iteration introduced several ideas, including animal traits, habitation patterns, cultural associations, oral histories and geographic locations. Specifically, the kɬawɬa (grizzly bear) figured prominently in several stories, with ʔaȼpu (wolverine) mentioned in the Animal War in the Sky Story. Here Wolverine's indifference had implications on the battle. This emergent knowledge represented empowered use of Ktunaxa oral history with working cultural resource use and ecological study.
- The next iterations utilized a smaller sample with linguistic specialties, including phrases for accumulation of troubles and differentiations between trouble and bad luck related to Ktunaxa understanding of and experience with cumulative effects. Discussion also centered on multiplicity and context (i.e.: the translation of "many" and the default nature of "trouble" without context to necessitate pluralization). This demonstrated living Ktunaxa ideas in the form of linguistic refinement of cumulative effects and biological consideration.
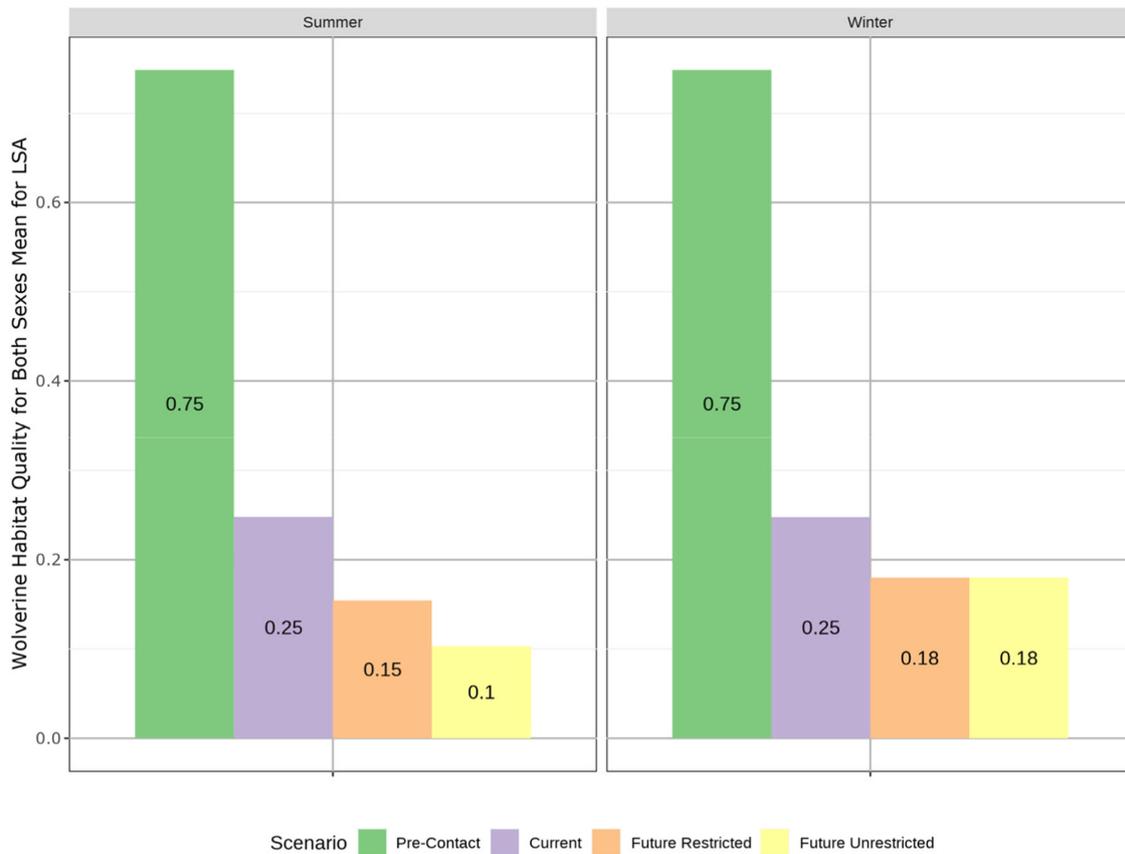
Fig. 3 Mean female ʔaȼpu (wolverine) habitat quality within the LSA (Local Study Area) for pre-contact, current and prospective future scenarios (winter and summer).

- The next iteration was with a specific linguistic expert to finalize the term "yunaqaɬxuʔmik kɬaxmitiyam", and the correct International Phonetic Alphabet script for the letters. The formal definition of "many things laying around causing trouble".

- Finally, the Ktunaxa Traditional Knowledge Advisory Committee (TKLAC) met to discuss the latest spelling and translation: "For there to be many properties present that cause single/undifferentiated trouble". Discussion also clarified the trouble could be a single concern or multiple concerns, but without specific contexts the trouble is assumed to be a single concern. TKLAC agreed to participate in future research into the role of lexical context and pluralization of troubles (e.g., essentially are there many causes that lead to many impacts, or are there many causes that lead to a single impact).

Evaluating Cumulative Impacts to Ecological Values

ʔaȼpu (wolverine)

When modelling disturbance from existing land use impacts on wolverine habitat, we found current habitat condition to be already reduced by 66.7% from pre-contact conditions for both sexes across all seasons (i.e., mean habitat quality declined from 0.75 pre-contact to 0.25 currently). Prospective simulations of cumulative effects that included existing land use activities and proposed future commercial developments predict further reductions in wolverine habitat quality. For female wolverines, habitat quality is expected to decrease another 20.9% in winter and 54.3% in summer from current condition (Fig. 3). Incremental reductions in habitat condition were higher in summer compared to winter due to existing winter tenures and non-commercial recreation activity. Habitat quality was expected to be compromised even further for all scenarios which assumed unrestricted access, or where people were assumed to stray from designated trails and outside formalized boundary areas.

Predicted reductions to wolverine habitat quality are likely to reduce use and occupancy in the study area. Projected increases in human activities have the potential to limit wolverine resource acquisition, denning potential, and N-S movement. Reduced use, occupancy and connectivity have grave implications for population recovery and persistence and across ʔamakis ʔaȼpu (Wolverine's Land).

Additive to direct and indirect impacts of human disturbance on wolverine habitat quality and use patterns,

Fig. 4 Average percent snowbound across the study area in historical (1990–2019) and future conditions (2021–2050, 2051–2080) under RCP 4.5 and RCP 8.5.

Percent Snowbound
0.00 0.25 0.50 0.75 1.00
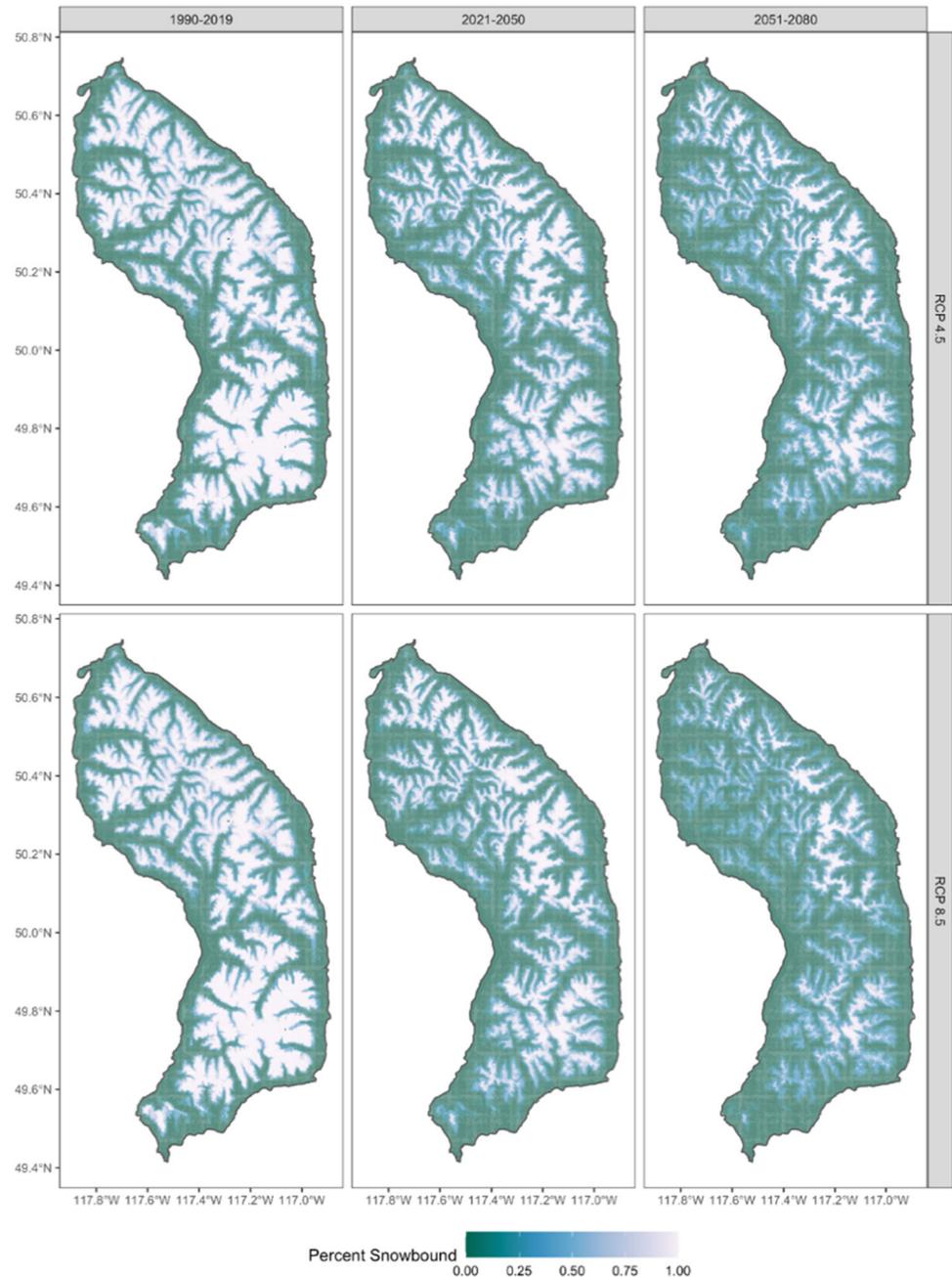
ALCES hydrological simulations (MacHydro, 2023, Supporting Material, Appendix D) predict a spatial and temporal decline in snow coverage under the future climate change scenarios. The importance of persistent spring snow for wolverine life cycle requirements (Magoun and Copeland, 1998) leaves them vulnerable to a changing climate and declining snowpacks, with greater sensitivity prior to and during the denning period (January – May). Under historical conditions (1990-2019), snow was found to persist in most alpine and subalpine areas above 2,000 m throughout the denning period and remain snow bound until late May. However, the hydrological model projects an increased likelihood of earlier snowmelt and decreased snow persistence into spring and early summer months due to warming air temperatures associated with all climate change scenarios. By 2051-2080, elevations below 2,000 m are projected to be snow free in 50% of years by the end of May (detailed further in Heim et al. 2023). Notably, scenarios project deep snowpacks to persist (i.e., Percent Snowbound >90%) at only the very highest elevations (above 2750 m) in the study area (Fig. 4). As such, ski reliability (defined as the percentage of years where the ski season extends from at least Dec 1 to May 31) is also projected to decrease under all future climate scenarios.
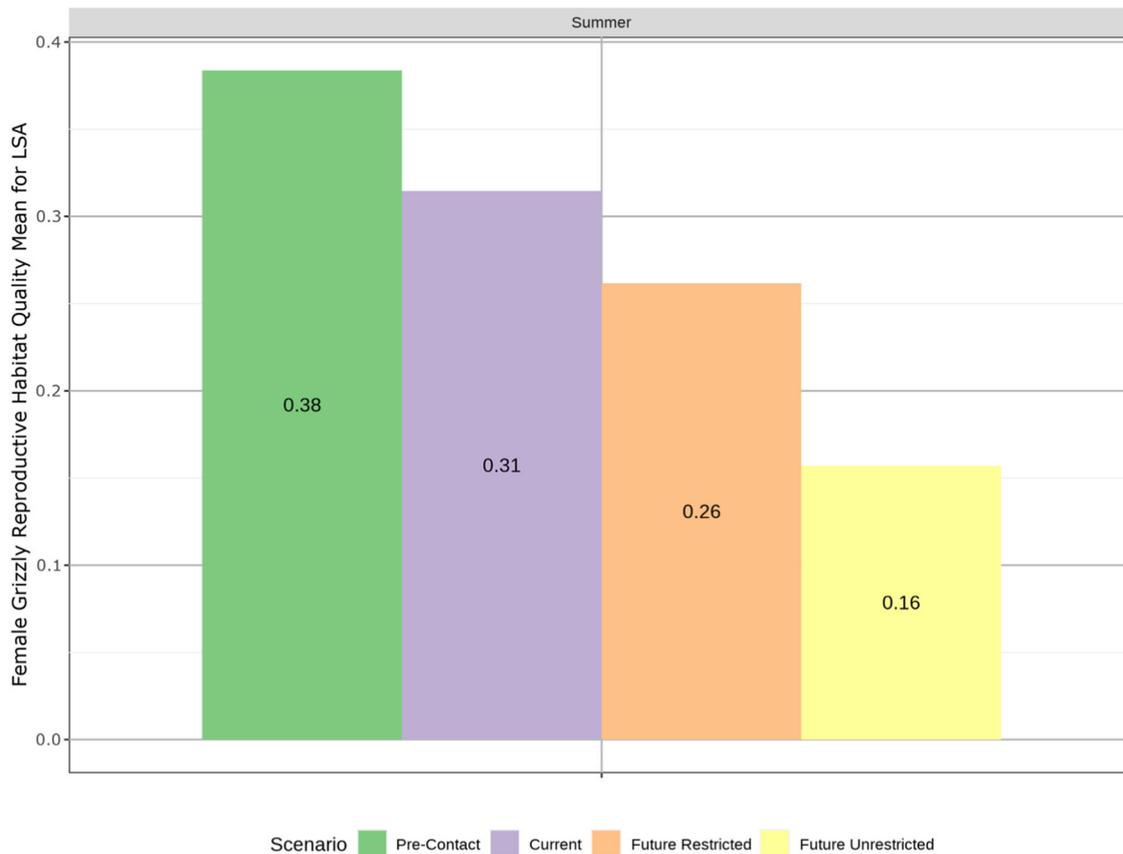
Fig. 5 Mean female kɬawɬa (grizzly bear) habitat quality within the LSA (Local Study Area) for pre-contact, current, and prospective future scenarios (summer season only).

These projections align with the findings of a climate change risk review of ski tourism across 27 countries (Steiger et al. 2019). The spatial overlap in wolverine and skier use is likely to increase with improved access from proposed recreation developments and the diminishing future snow coverage, thereby exacerbating human-wolverine interactions and displacement potential. As such, increasing recreational disturbance with diminishing snow refugia is a growing concern for wolverine management (e.g., Schepens et al. 2023).

kɬawɬa (grizzly bear)

Like ʔaȼpu (wolverine), there has already been an estimated 20% reduction in grizzly bear habitat effectiveness since pre-contact (i.e., mean female grizzly reproductive habitat quality declined from 0.38 at pre-contact to 0.31 currently, Fig. 5). Current levels of recreation suggest partial avoidance of trails and adjacent habitats by grizzly bears (detailed further in Heim et al. 2023). All future scenarios are predicted to cause incremental reductions in habitat quality and habitat use by reproductive female grizzly bears (Fig. 5). Using a pre-contact baseline and assumed unrestricted human access, we predicted up to a 68.4% decline in

effective habitat condition for female grizzly bears into the future.

Proposed future development areas supported a significant quantity of important huckleberry patches utilized seasonally by female grizzly bears, which contributed to the predicted disturbance to habitat condition (Proctor et al. 2023). Approximately 35% of these patches are currently compromised by human disturbance within the study area. The location of the remaining undisturbed, or "secure", huckleberry patches are concentrated within 300 m of a proposed hiking trail, and within 1–2.5 km of a proposed backcountry ski lodge considered to be hike-able terrain. The overlap of hiking terrain with important huckleberry patches increases the likelihood of bear displacement from these patches with increased human use over time. Future projections suggest a significant decrease in the value of these patches to grizzly bears for reproduction and overall bear density due to human use (Proctor, pers. comms., 2022, based on results from Proctor et al. 2023). Such compromised habitat quality and security may further contribute to decreased ecological function of the area as a connectivity corridor, linking a peninsular population to the larger and healthier regional population (Proctor et al. 2012). Further, increased disturbance to ɬawiyaɬ

(huckleberry) has the potential to impact effective opportunity for Ktunaxa harvest and traditional use and ceremonial practices.

Lastly, though data limited modelled disturbance factors to female grizzly bear reproductive habitat to summer recreational activity, activities anticipated to disturb winter den selection and use during should be considered. Like wolverine, the winter period is a particularly vulnerable time for hibernators as they do not have the benefit of other mechanisms to avoid disturbance and resulting negative impacts. Disturbance to pregnant and nursing grizzly bear females can result in den abandonment, with consequences to individual fitness (Swenson et al. 1997, Linnell et al. 2000).

Conclusions

By following Ktunaxa research methods in conjunction with western science, with novelties such as recreational land use and hydrological modelling, this work contributes to the advancement of cumulative effects evaluations needed to responsibly steward ecological values vital for the health and well-being of ʔa·kxaṁis q̓api qapsin (All Living Things).

Here, we applied an iterative approach to knowledge gathering for assessment and explored the meaning of cumulative effects from a linguistic perspective in both Western and Ktunaxa contexts, with significant morpho-syntactic and lived acculturation experience. Several iterations of names, describing the notion of cumulative effects were advanced, discussed, adapted and transcribed. With each discussion new considerations were realized from both western and Indigenous modes, and both sides were better able to understand each other, viewed through scientific, post-colonial Indigenization strategies. Throughout the process inconsistencies were noted and explored, and where possible insights were identified to unify ideas or to update the transliteration of phrases by advanced Ktunaxa speakers. We encourage non-indigenous researchers to seek long-term, forward thinking and human capital building relationships with Indigenous researchers— western research institutions and indigenous governance bodies. This may include further developing understandings of nuanced Western notions of ecosystems, resilience outcomes, and cumulative effects—AND understanding notions of Ktunaxa cultural change in and out of the context of larger colonial structures, such as western administration, English only discussions, the Indian act and missionary education, as well as indigenous, traditional ecological knowledge, post-colonial/Indian research practices and contemporary treaty and governance developments.

Interviews with ktunaxaniṅtik confirm that the study area (situated between ʔamaḱis ʔac̓pu (Wolverine's Land) and ʔamaḱis mic̓qaqas (Chickadee's Land)) is a place of historical and current use and has cultural importance. Our assessment revealed that a significant portion of this area is already impacted by extensive land use including non-commercial and commercial recreation. Using a pre-contact baseline, augmented by an analysis of potential effects of accelerating climate change, we found current habitat condition to be already compromised and proposed activities to pose significant threats to population connectivity and reproductive success for two key values: wolverine and grizzly bear. With cumulative effects of proposed developments, summer habitat quality for both species is projected to decline by an estimated ~/>50% relative to current condition. This is because of an unavoidable loss in habitat security and functional connectivity for both species.

Case studies on recreational impacts provide strong evidence that recreational users often spread out, cover vast areas, and do not confine their activities to existing trails and/or designated use areas. Such access into local back-country areas was predicted to substantially diminish habitat quantity and quality for selected values of high importance to Ktunaxa. This includes disturbance and displacement from remote habitat that supports secure foraging and critical denning opportunities for both wolverine and grizzly bear. Located within an important connectivity corridor, indirect disturbance from increased recreational activities is predicted to compromise movement and exaggerate existing fragmentation effects. Further, current and projected climate change impacts are predicted to exacerbate human-wildlife interaction and displacement potential. Specific to wolverine, this may present as incremental competition for a limited resource due to increased spatial overlap between denning females and winter enthusiasts, both seeking persistent snow found on north facing slopes.

Concerns expressed by Ktunaxa regarding increased access into backcountry areas are reflected in the results of this assessment which predicts substantially diminished habitat condition. These changes are expected to have unavoidable population-level impacts on selected values of high importance to Ktunaxa and the needs of ʔa·kxaṁis q̓api qapsin which include connected landscapes.

Following a precautionary approach and guided by yakaɬ hankatiɬiɬki na ʔamak (our people care for the land, the land cares for our people), we suggest further cumulative developments and associated land management decisions are informed by Indigenous and western knowledge that extend to appropriate spatial and temporal scales. As land use and natural disturbance patterns shift with accelerating climate change, it is imperative that our assessments adapt with them. New approaches to assess cumulative effects (direct and indirect) support a better understanding of the

breadth of existing and potential future impacts. Only such a comprehensive approach will ensure the cultural and environmental values and rights of Ktunaxa are respected and honored into the future – as we collectively consider: "just how deep do we want our footprint" (Chad Luke, Yaqan Nuʔkiy).

Data Availability

No datasets were generated or analysed during the current study.

Compliance with Ethical Standards

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