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Indigenous peoples as sentinels of change in human-wildlife relationships: Conservation status of mountain goats in Kitasoo Xai'xais territory and beyond

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Abstract

Local people can act as sentinels for change, especially for wildlife populations not monitored by centralized governments. Responding to concern expressed by the Kitasoo Xai'xais (KX) First Nation over a decline in mountain goat (*Oreamnos americanus*) sightings, our community-academic partnership assessed the conservation status of goats in KX territory and beyond in British Columbia by evaluating three independent information sources. Aerial surveys (2019 and 2020) over 542 km^2 revealed a low-density population (mean 0.25, SD 0.12 goats/km^2), typical of peripheral coastal range. Interviews with KX Knowledge Holders revealed that sightings from sea level have declined sharply over 40 years, a period during which temperatures have increased and snowpack has decreased. Finally, Kill data (1980–2018) showed that kills/hunter/day initially increased among guided hunters before plateauing, but declined among resident hunters (~70% of hunt days) in both coastal and interior BC. Convergent patterns among datasets suggest that coastal goats declined in abundance and/or reduced use of low-elevation habitat, disrupting a millennia-old relationship between KX people and goats, thereby posing a conservation concern. Broadly, our work shows that detecting threats to peripheral populations, and wildlife in general, can be informed and empowered by the knowledge of place-based peoples and associated decentralized management. Kitasoo Xai'xais First Nation mountain goat research illustrates roles of Indigenous peoples as sentinels of population and ecosystem change.

KEYWORDS

conservation status, indigenous knowledge, local ecological knowledge, mountain goat, *Oreamnos americanus*, sentinel, wildlife conservation, wildlife management

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1 | INTRODUCTION

Successful outcomes in applied ecology depend on accurate and timely information regarding species of concern. Prior to the contemporary paradigm of wildlife management, operationalized by centralized agencies of Western governments within large jurisdictional areas (e.g., countries, states, or provinces), much wildlife in North America and beyond was managed in a decentralized manner. Many Indigenous peoples had—and often maintain to this day—well-developed governance models that inform wildlife stewardship. Millennia of continued interaction through observation, experimentation, and hunting allowed for the accumulation of knowledge that continues to facilitate management by Indigenous peoples (Atleo, 2011; Ban et al., 2017; Berkes, 2018; Berkes et al., 2000; Jessen et al., 2021). Models of Indigenous management were explicitly place-based, which allowed detailed observations about populations at localized scales (Berkes et al., 2000; Berkes & Turner, 2006). Recent calls in the literature (e.g., Ban et al., 2018; Hessami et al., 2021; Jessen et al., 2021) and policies from government bodies at global (e.g., United Nations Declaration on the Rights of Indigenous Peoples; UN General Assembly 2017) to regional (e.g., Canada's Truth and Reconciliation Commission; Environics Research Group 2008) scales encourage or mandate increased consideration of local ecological knowledge (LEK) and Indigenous Knowledge (IK) in natural resource management. Incorporating Indigenous perspectives can enhance wildlife management (Ban et al., 2018; Reid et al., 2020), especially for species for which centralized management agencies have logistical or financial challenges to detect and respond to changes in the abundance, distribution, or other dimensions of population health.

Peripheral populations, which inhabit the edges of a species' distribution and are often not the focus of centralized management, tend to be vulnerable, but also of conservation value. These populations can be particularly susceptible to changes in distribution and abundance, often occupying sub-optimal habitat and occurring in small, isolated groups that have lower genetic diversity and higher demographic stochasticity than core populations (Soulé, 1973). Moreover, abiotic and biotic edge effects at range limits can increase mortality risk or competition when habitat quality deteriorates (Fischer & Lindenmayer, 2007; Goldstein et al., 2017; Kawecki, 2008; Murcia, 1995; Sexton et al., 2009). While they are typically vulnerable, peripheral populations can also be ecologically important, variously providing sources of novel species interactions, range expansions, or genetic variation (Eckert et al., 2008; Lesica & Allendorf, 1995).

Detecting declines in peripheral populations and implementing evidence-based intervention poses challenges for Western, centralized wildlife management. In this context, "centralized" refers to the dominant theme of Western resource management, where the state holds considerable bureaucratic authority over the decision-making processes that underpin wildlife and resource management (Lemos & Agrawal, 2006). In these models of management, agencies are typically responsible for vast landscapes and, given limited resources, often focus on populations within the core of a species' range where conservation concerns are pronounced or in demographically productive areas where there is high hunter participation (Larson & Soto, 2008; Lemos & Agrawal, 2006). Vital rate estimates that do exist for peripheral populations are often based on indirect measures derived from core ranges, such as extrapolations of abundance-habitat relationships, hunter surveys, or expert opinion (Bunnell et al., 2011). In these cases, management can rely on generalizations or theoretical extrapolation from data-rich to data-poor populations. When employing these approaches, however, knowledge gaps often persist. Changes in abundance or even distribution, for example, may go undetected by centralized managers (e.g., Service et al., 2014), which can delay implementation of management interventions and possibly limit their efficacy. Further, accurate assessment of the effects of ongoing or proposed resource extraction (including of the focal species) can be hindered by a paucity of specific place-based knowledge (Berkes, 2007).

Populations considered peripheral by centralized governments can hold enormous cultural and conservation value to local people for several reasons. First, species used over millennia typically engender high cultural value, especially when they offer a cultural product (e.g., Rokfar, 2014) or represent unique ecotypes with specialized behaviors or adaptations that have particular significance (e.g., Spirit Bears; *Urus americanus kermodei*; Service et al., 2020). Second, because population vulnerability can be heightened at range edges; declines in already stochastic peripheral populations may prove tantamount to extinction of important wildlife for the people living in those areas. Third, further erosion of human-wildlife interactions can compound substantial losses of nature, and associated cultural relationships, already experienced by Indigenous peoples, who have endured (and often still face) violence, land dispossession, displacement, and forced cultural assimilation since colonization (Berkes, 2018; Pierotti, 2012).

Despite any unraveling of human-wildlife relationships, we propose that people for whom human-wildlife relationships have endured over the long-term can function as sentinels of change for peripheral populations. As we explain below in this case study, regular interactions (e.g., hunting, sightings) with local peoples provide long-term baseline information with which those peoples can detect change. Moreover, powerful insight can emerge when such IK is coupled to complementary information, particularly if it draws upon independent lines of enquiry. Here, we illustrate how bringing the knowledge of Indigenous peoples (the Kitasoo Xai'xais [KX], specifically) alongside data collected by Western scientific methods can illustrate the utility of uniting these approaches in which local peoples detect and address environmental change.

Our case study involves a peripheral population of mountain goats (*Oreamnos americanus*) in coastal British Columbia (BC). In KX territory and other regions of coastal BC, goats are a culturally and ecologically important species likely to be profoundly affected by climate change (White et al., 2018). As alpine specialists, they face increasing summer temperatures in western North America, which can induce heat stress and reduce fitness (Sarmento et al., 2019; White et al., 2018). Furthermore, increasing temperatures have pushed treelines to higher elevations and reduced snowpack, thereby degrading goat habitat and increasing exposure to predators (Festa-Bianchet & Côté, 2007). Mountain goats inhabiting coastal mountain ranges along the northwest coast of North America may be particularly susceptible to such changes, as their peripheral habitat occurs at relatively low elevation compared to interior populations.

In 2019, the KX Stewardship Authority initiated research to assess the conservation status of mountain goats in KX territory, and connected with applied academics to form the partnership that conducted this work. The project was sparked by concerns about climate change, reduced goat sightings by KX members, provincially sanctioned hunting by non-KX hunters, and high-elevation logging. These concerns occurred against a background of limited population assessment by the provincial government of BC. No data had existed on the abundance, trends, composition, or distribution of KX goats. Moreover, empirical information about goats of coastal BC in general is limited (Mountain Goat Management Team, 2010).

Our team, comprised of KX Stewardship Authority staff and collaborating scientists, assessed the conservation status of goats within KX territory and more broadly within BC. Motivated by—and emphasizing—local concerns, we used a multi-method approach to assess conservation status. To perform this assessment, we conducted aerial surveys over 542 km^2 of KX territory in August 2019 and August 2020 to estimate goat density and compared our estimates with data from published estimates of goat density in BC. To complement information from surveys, and draw inference from a larger scale, we analyzed 40 years of hunter kill data from throughout BC using generalized additive mixed models (GAMMs) to estimate how effort-corrected harvest rates might have changed over time. Finally, for detailed information at the KX scale, the KX Stewardship Authority interviewed Indigenous and non-Indigenous KX land users in 2020 to estimate changes in sightings and to characterize interactions among goats, people, and the environment over the past 40 years. Our quantitative and qualitative synthesis thus evaluates the conservation status and recent changes of the “peripheral” KX population and of other goats in BC.

2 | METHODS

2.1 | Study area spatial scales

We used overlapping and complementary study areas relevant for each of two spatial scales: local and provincial. The local study area relevant to aerial surveys and LEK interviews is bounded by the border of KX territory in the east and by the Pacific coastline of mainland BC in the west (Figure 1). The area is characterized by coastal fjords and valleys dominated by coniferous forest cover of mountain hemlock (*Tsuga mertensiana*), yellow cedar (*Cupressus nootkatensis*), and subalpine fir (*Abies lasiocarpa*). Mountainous areas are defined by steep cliffs and rugged granite complexes interspersed with glaciers. Alpine vegetation communities vary considerably with slope, soil type, moisture, and wind exposure, creating a mosaic of low-growing grasses and forbs that comprise the staples of mountain goats' diet. For the provincial hunting analysis, we used a larger study area to include both coastal and interior areas of BC. We included all BC Provincial Wildlife Management Units (WMU) in which goat hunting occurs (Figure S1). We categorized WMUs as “coastal” if they intersected the coastal ecoregions of the “Coast and Mountains” ecoprovince or the “Georgian Depression” ecoprovince (Demarchi, 2011).

2.2 | Aerial surveys

We conducted aerial surveys in August 2019 and August 2020 over a 542 km^2 study area located approximately 35–65 km northeast of Klemtu, BC (Figure 1). We based our survey design on guidelines from the Resources Information Standards Committee (RISC, 2002) and the Management Plan for the Mountain Goat in British Columbia (Mountain Goat Management Team, 2010). Specifically, we conducted aerial surveys via helicopter by traversing among 2503 hexagonal cells (each cell = 0.22 km^2) that occurred in habitat above 1000 m elevation, which we assumed provided potential goat habitat during August, when mountain goats are more

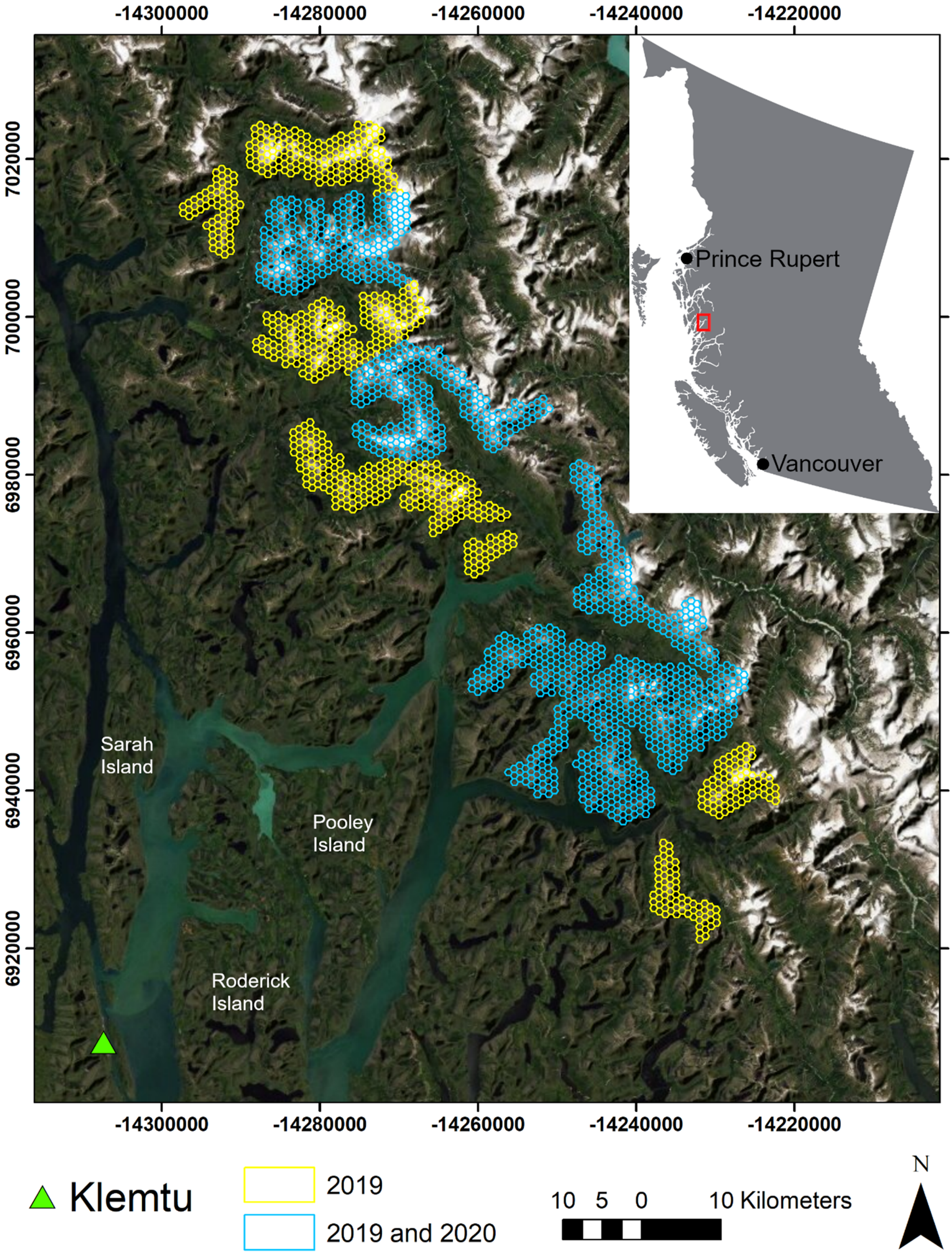

FIGURE 1 Kitasoo Xai'xais mountain goat study area (red outline in map inset) showing hexagonal cells used in aerial surveying and the location of Klemtu, the Kitasoo Xai'xais' only contemporary settlement. All cells were surveyed two times in August 2019. Cells marked in blue were surveyed three times in August 2020

readily visible above the tree line (RISC, 2002). We used the hexagonal lattice to facilitate a forthcoming occupancy analysis (not described here; Mackenzie & Royle, 2005), which also satisfied the criteria of more traditional aerial inventory survey protocols. In 2019, we surveyed each cell twice from August 13 to August 29. In 2020, we surveyed a fixed subset of cells three times from August 12 to August 27. This subset was chosen by dividing the entire study area into geographically similar ridgelines and randomly selecting ridgelines to survey.

We conducted up to two survey flights each day. Depending on weather conditions, we typically started in the late morning (0900–1100) and mid-afternoon (1300–1400) to avoid dense morning fog that would have limited visibility and compromised flight safety. We prioritized survey flight times to occur in the morning when daytime temperatures were low (when goats are more likely to be active and visible), but this was not always possible due to fog preventing navigation through lowland areas among mountain complexes. We did not conduct surveys during heavy rain or fog.

We used a consistent survey flight method within and between years. We used a Bell 206 Jet Ranger helicopter with bubble windows to maximize visibility. While on survey, the helicopter flew along a linear contour following terrain features as necessary. We typically flew contours from low elevation to progressively higher elevations in 100–150 m altitudinal increments (Figure S2), which minimizes potential stress responses in goats and improves detection (RISC, 2002). Flight survey contours were guided by a GPS map navigation system (Avenza Systems, Inc., Toronto, Canada) installed on multiple handheld computer tablets (Samsung Galaxy Table S6). Airspeed varied from 70 to 100 km/h, depending on terrain, to produce a survey effort of approximately 1 min/km^2.

Survey crews consisted of a pilot, and three observers seated in the front and rear seats. Observers included community members of Klemtu with significant experience working on, hunting on, and using the landscape. All persons, including the pilot, were considered non-independent observers who each scanned terrain out to 200 m or less for goats from different vantages. One observer was dedicated to filling out a standardized survey form for each survey conducted. When goats were sighted, we recorded the number of individuals, classifying kids and adults based on body size (Smith, 1988), as well as the location using a handheld GPS. To maintain distance from mountain goats and to minimize potential stress from helicopter noise, we recorded goat locations using a GPS point that was corrected post hoc with a distance and bearing estimate.

From a total of 34 survey flights (17 in 2019 and 17 in 2020), we estimated mountain goat population density for each survey in each year independently. Mountain goat density is commonly estimated through total counts of individuals from aerial surveys, sometimes adjusted by mark-resight modeling (RISC, 2002) or a sightability correction factor to estimate the number of animals not detected during surveys (Mountain Goat Management Team, 2010; Poole, 2007; Rice et al., 2009). We report two estimates of goat abundance: total counts per survey and counts adjusted using a conservative sightability correction factor of 0.61, the mean correction factor used for mountain goat surveys in coastal Alaska (White et al., 2016; K. White, personal communication, 2021). We then calculated density as estimated abundance divided by the study area.

2.3 | Comparisons of aerial survey data with other areas

To compare estimated densities of mountain goats in KX Territory with other areas of BC, we conducted a survey of published reports of mountain goat density. Reports were drawn primarily from the BC Ministry of Environment Species Inventory Web Explorer (http://a100.gov.bc.ca/pub/siwe/search_reset.do) and the Northern Wild Sheep and Goat Council Proceedings (http://www.nwsgc.org/proceedings.html) (Table S1). We included reports if the authors reported a population density estimate or if density could be calculated from the abundance of individuals and the size of the survey area. For consistency within the largest possible sample of studies, and because sightability does not meaningfully differ between coastal and interior areas (0.63: Poole, 2007; 0.61: K. White, personal communication, 2021) we considered only estimates without sightability correction factors (Rice et al., 2009). We categorized populations as “coastal” ($n = 34$) if they overlapped the coastal ecoregions of the “Coast and Mountains” ecoprovince or the “Georgian Depression” ecoprovince (Demarchi, 2011), and we categorized others as “interior” ($n = 30$). We assumed there were no meaningful differences in how survey areas were delineated among coastal and interior areas.

2.4 | LEK of mountain goats in KX territory

To examine comprehensively the anecdotal reports of reduced mountain goat sightings that motivated our study, the KX Stewardship Authority conducted formal interviews to assess changes in the number of sightings over time and to understand perceptions of environmental features thought to be associated with those changes.

Authorized by KX Nation between January 21 and February 5, 2020, interviews were conducted by KX Stewardship Authority staff who have decades of experience in interview methods for land and marine Traditional Use Surveys and academic studies (e.g., Service et al., 2014; Tran, 2020). These interviews, conceived, designed, approved, and conducted by KX Stewardship Authority to cover multiple wildlife species, occurred independently and without the participation of academic institution-affiliated authors and thus were beyond the scope of academic human research ethics processes. However, methods followed best practice according to KX cultural protocols and the Canadian Tri-council policy (CIHR, NSERC, SSHRC, 2018). Initial participants were identified by research staff in this small (∼350 person) community as persons with significant IK and LEK related to mountain goats. Subsequent interviewees were identified through a snowball sampling approach that allows interviewees to identify additional participants they believed would have relevant information (Davis & Wagner, 2003). Semi-structured interviews (e.g., Creswell, 2014; Eckert et al., 2018; Lee et al., 2018) were conducted independently with 17 individuals. Nine were able to provide information on trends in sightings over the last four decades. All participants (age range 30–90 years) regularly hunt, guide ecotourism operations, conduct research (e.g., salmon counting), and/or fish for subsistence and income, most often during nonwinter months. All individuals had between 10 and 40 years of experience (median = 30 years) observing mountain goats in the study area, typically from sea-level in small watercraft or from low-elevation river valleys on foot. Given the steep nature of the terrain, a sea-level observer in this landscape can observe up to an elevation of approximately 900 m, which can encompass the winter, low elevation summer, and seasonal migratory habitat of mountain goats.

Surveys were conducted as part of a broader interview series including cultural use and practice, though we report here only on perceptions of goat abundance and habitat quality. Participants were asked nonleading questions about the sightings of mountain goats and goat habitat within KX Territory (Appendix 1). Participants were first asked to estimate their average number of days out of 10 spent working or living in the study area (i.e., beyond the community) during which at least one mountain goat was observed. Participants were asked for this estimate for 1980–1989, 1990–1999, 2000–2009, and 2010–2019, with the earliest decade for which they could provide information being their "baseline." They were also asked for a point estimate of sightings for the most recent year (2019). Finally, participants were asked open-ended questions about biotic or abiotic changes (if any) that they observed that they believe were related to mountain goat sightings.

2.5 | Hunting data analysis

To draw inference about trends in goat abundance across a larger spatial scale, we analyzed hunting data from an independent data set that spanned all of goat range across BC and from 1976 to 2018. We interpret these catch-per-unit-effort (CPUE) kill data as providing a relative index of population size, scaling observed kills by hunting effort. All else being equal, changes in kills that are disproportionate to changes in hunt effort can be used to infer population change over time (Seber, 1986). Such data are regularly used to assess potential changes in population sizes (Chagaris et al., 2015; Rist et al., 2010). We acquired hunting data from BC's "Big Game Harvest Statistics" database (https://catalogue.data.gov.bc.ca/dataset/big-game-harvest-statistics-1976-2018), which includes information on total goats killed in each year, kill locations, sex, age class, and total hunt days (which we used as an index for hunting effort). Initial data inspection revealed that data density was lower from 1976 to 1979 compared to the rest of the period (mean = 109.25, SD = 6.42 calculations of kills per day per year [KPD/year] compared to 160.31, SD = 15.30). Data during this period also had no information regarding the number of hunt days for nonresident hunters, precluding calculations of CPUE. Accordingly, we restricted our analysis to start at 1980, which corresponded to the first decade of interview-derived observations.

We analyzed CPUE data to describe trends over time and estimate the effects of hunter residency and broad-scale hunt location within BC. We initially fit linear mixed-effects models to the CPUE data, but residuals showed temporal trends, necessitating nonlinear analysis (Table S2; Figure S3). To accurately describe trends in CPUE without presupposing temporal patterns, and while accounting for dependencies in the data, we used nonlinear GAMMs which are commonly used in the analysis of CPUE data (e.g., Tian et al., 2009; Winker et al., 2013). To assess the effects of hunter residency and hunt location (coastal or interior), we considered five candidate model forms (Table S3). For these models, we estimated kills per hunt day as a nonlinear function of year, treating WMU as a random intercept to account for nonindependence among repeated samples from the same local sub-population. Depending on the candidate model, we allowed the shape of the nonlinear year effect to differ by residency status of hunters (resident of BC or nonresident, guided hunter from outside BC), region (coastal or interior), and the combination thereof. Our null model included only the nonlinear effect of year and the random effect of WMU. The remaining models effectively considered the effects of residency status, hunt region, and an interaction between the two on the nonlinear temporal trends in CPUE. We treated resident and non-resident hunters separately because we anticipated that nonresident hunters would have greater, potentially even increasing, success over time. In particular, given the participation of experienced guides, we predicted that the success of nonresident hunters might be less sensitive to any potential population variation. We also treated coastal and interior locations separately to assess differences in CPUE trends between the coastal and interior ecotypes of goats. We fit GAMMs assuming Poisson-distributed count data, for which the rate parameter (kills per day) varied according to our candidate models such that the expected number of kills scaled with the number of hunt days. We used a standard log-link function. We performed model selection using an information-theoretic approach, with Akaike's Information Criterion (AIC; Akaike, 1973) used to assess model parsimony. All analyses were performed with R (R Core Team, 2021) and the *mcgv* package (Wood, 2021), using the *gamm4* function suited to random effects modeling.

3 | RESULTS

3.1 | Aerial surveys in KX territory

Across the two survey years, we observed 507 goats in 239 sightings (mean group size = 2.12 goats, SD = 1.66). Of 507 goats observed, we classified 341 as adults and 166 as kids, yielding a kid/adult ratio of 48.7 kids/100 adults. For the two survey rounds in 2019, mean goat density, calculated from the total number of goats observed per round (without a sightability correction factor) and the corresponding area surveyed, was 0.18 goats/km^2 (SD = 0.14). Mean density across three survey rounds in 2020 was 0.33 goats/km^2 (SD = 0.05). The overall mean density across all surveys in 2019 and 2020, calculated as the average of individual survey round densities, was 0.25 goats/km^2 (SD = 0.12). To provide coarse abundance estimates for the surveyed area, we report the number of goats observed as well as an estimate using a conservative sightability correction factor of 0.61 (Table 1).

3.2 | Comparisons of aerial survey data with other areas

Across 64 density estimates of mountain goats in BC, mean population density estimated for coastal goats (0.45 goats/km^2, SD = 0.47) was lower than the density estimated for interior goats (0.80 goats/km^2, SD = 0.56; Figure 2). The mean density estimate derived from the 2019 and 2020 KX aerial surveys was only slightly lower than the mean density of coastal goats derived from our literature survey (0.25 and 0.45 goats/km^2, respectively).

3.3 | LEK of mountain goats in KX territory

3.3.1 | Trends in sightings over time

All interviewees described overall declines in goat sightings over the period of inquiry. Patterns were similar

TABLE 1 Goat population estimates for surveyed area in KX territory, separated by year, all goats, adults only, and survey round

Survey	Survey round	Area surveyed (km^2)	Count	Corrected count
All Goats 2019	1	542	43	70
All Goats 2019	2	542	151	248
All Goats 2020	1	318	123	202
All Goats 2020	2	318	101	166
All Goats 2020	3	318	89	146
Adults 2019	1	542	29	48
Adults 2019	2	542	103	169
Adults 2020	1	318	90	148
Adults 2020	2	318	73	120
Adults 2020	3	318	46	75
Mean All Goats 2019		542	97	159
Mean All Goats 2020		318	104	171
Mean Adults 2019		542	66	108
Mean Adults 2020		318	70	114

Note: Shown are actual counts as well as estimated number of goats using a sightability correction factor of 0.61.

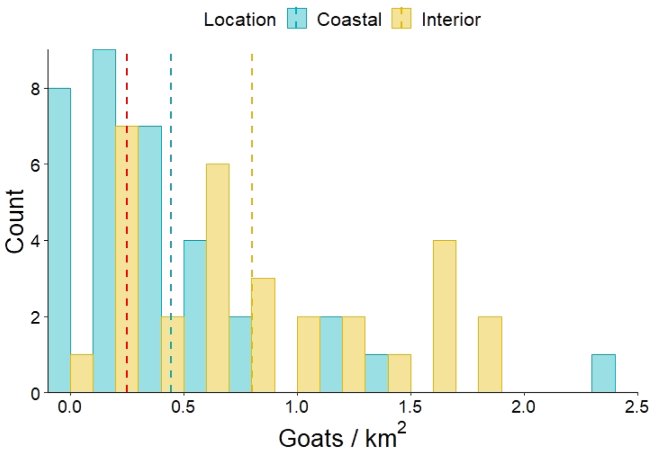

FIGURE 2 Population density estimates without a sightability correction factor for mountain goats in coastal (blue; $n = 34$) and interior (yellow; $n = 30$) habitat in British Columbia, drawn from reported goat surveys. Mean density estimates are indicated by the blue line for coastal areas (0.45 goats/km^2, SD = 0.47) and the yellow line for interior areas (0.80 goats/km^2, SD = 0.56). Mean density estimate for our Kitasoo Xai'xais surveys is shown in red (0.25 goats/km^2, SD = 0.12). Count (y-axis) refers to the number of estimates of density in the reports (x-axis)

in direction and magnitude, with interviewees generally reporting a decline in sightings over each decade (Figure 3). Treating all estimates as independent observations, the number of days out of 10 with a goat sighting across all decades had a slope of −0.21 ($R^2 = 0.54$, $F_{1,31} = 36.15$, $p < .0001$). The number of days out of 10 with a goat sighting declined by a mean of 6.67 from each participant's starting decade to the point estimate in 2019. Two interviewees described no change in mountain goat sightings until the 2010s, with the direction of change being negative thereafter. In 2019, all interviewees reported 0 days out of 10 with an observation.

3.3.2 | Qualitative descriptions—trends over time

All interviewees perceived an overall decline in mountain goat populations from 1980 to 2019. Below we share representative comments from interviewees, using their own words:

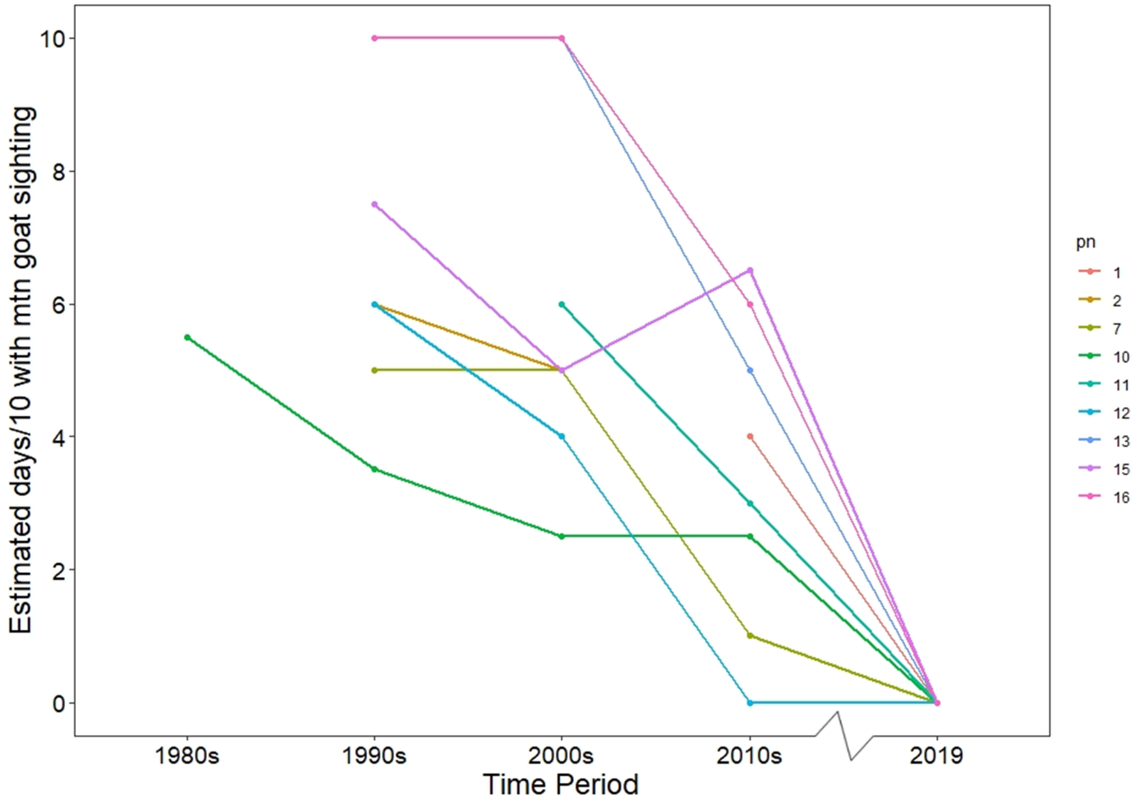

FIGURE 3 Estimated number of days out of 10 with a mountain goat sighting in Kitasoo Xais'xais territory for each decade from 1980 to 2019. Patterns derived from interviews with nine local ecological knowledge holders from Kitasoo Xai'xais territory. "Pn": participant number of interviewee participants who provided estimates over time. Adjustment of scale in x-axis, which permits straightforward visualization

> “They're [mountain goats] disappearing so fast it's not anywhere close to what it was.” Interview participant (age 77).
> I could not count there's too many of them. Every mountain you look and see them, and now there's nothing. Yeah growing up there were lots and lots and now there's nothing.” Interview participant (age 90).

3.3.3 | Changes in habitat and environmental conditions over time

Interviewees reported changes to mountain environmental conditions during their period of observation. Specifically, participants commonly mentioned reduced snowpack throughout the winter and the entire year. For example:

> “…there's a lot less snowpack ….” Interview participant (age 48).
> “There was [in the past] a heck of a lot more snow, which drove all the wildlife down.” Interview participant (age 77).

> “…We used to get a lot more snow and it used to be a lot colder as well back in the day. So things often freeze so we would get … enough snowpack that it would freeze and it would stay there all through the fall.” Interview participant (age 38).

> “What's happened to them [mountain goats] I think is that the snowpacks that usually hit the ground, that'll stick around all summer, have gone. …When we [my dad and Charlie] would go on the boat and they'd tell me that those mountains up there they should be white, it should be completely white with snow and he was trying to explain to me what they used to call the everlasting snow… They had a name for it in my language, but I just refer to it as everlasting snow because it's supposed to be there all year round…” Interview participant (age 36).

Additionally, interviewees cited increased temperatures (both annual and winter) compared with their baseline decade. They also spoke of the new contemporary conditions of regular summer drought, which were not observed in previous decades.

> “We've had a lot more milder winters over the past number of years and a lot more drier summers….” Interview participant (age 77).

> “July is supposed to have the peak precipitation at that time of year [summer]… the last five years have been extremely dry, you know, compared to what we've grown up with. The weather was very different then, you know. It was very common to have rain all throughout August, […] and not even be able to see the sun…. It was very different back then, so that must be challenging for those goats wearing thick coats.” Interview participant (age 38).

3.4 | Hunting data results

We found evidence of changes in CPUE among hunters, and patterns differed by residency status. Of our five candidate GAMMs, the most parsimonious model included region, residency status of hunters, and their interaction (Tables 2 and S2). Province-wide, nonresident hunter success increased from the 1980s to the mid-1990s, where it remained relatively constant through 2018 (Figure 4). By contrast, resident hunter success has slowly but steadily declined since 1980. The number of kills per day was slightly higher in coastal WMUs compared with interior WMUs.

TABLE 2 Comparison of 5 candidate models by AIC

Model	Estimated *df*	−log(likelihood)	ΔAIC
Region_x_Residence (interaction)	13	13,856.83	0
Region_ + _Residence (no interaction)	10	13,876.87	34.07
Residence	7	13,907.31	88.95
Region	7	16,227.68	4729.68
Null	4	16,248.25	4764.82

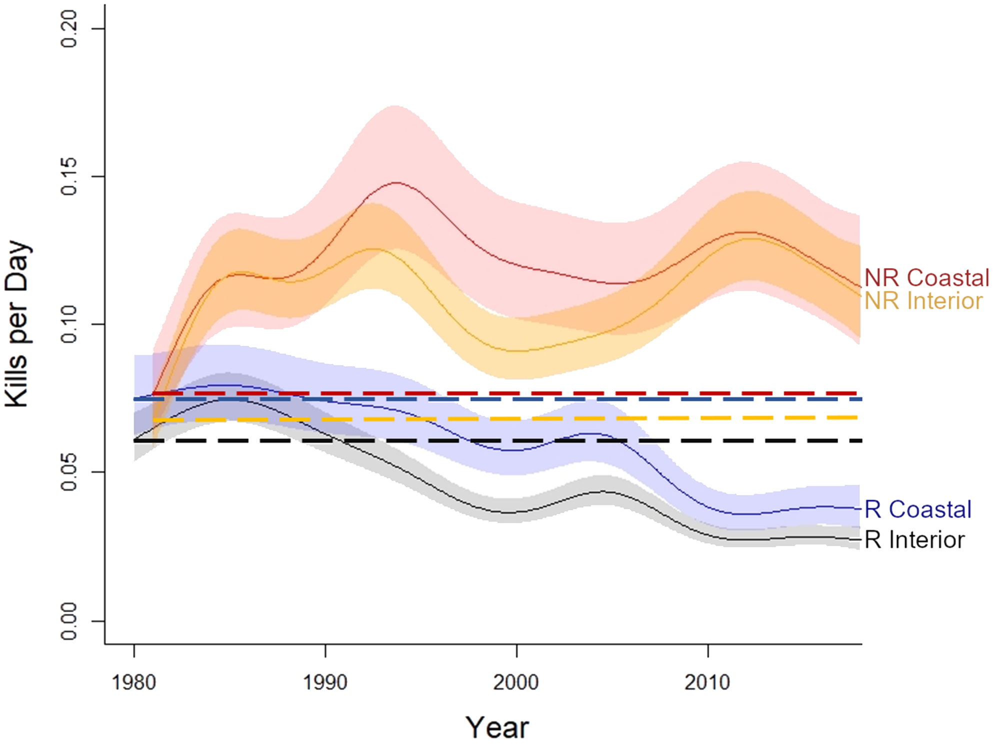

FIGURE 4 Mountain goat kills per day in British Columbia for nonresident (NR) interior hunters (yellow), nonresident coastal hunters (red), resident (R) interior hunters (black), and resident coastal hunters (blue). Curves show estimates from a generalized additive mixed model with shading indicating 95% confidence regions. Dashed horizontal lines show no significant change in catch per unit effort when the lines of same color overlap confidence regions

4 | DISCUSSION

Evidence from three independent data sets suggests that mountain goats of coastal BC comprise a low-density population, with the two data sets designed to reflect trend suggesting a population decline in abundance and/or sightings over recent decades. This observed trend could be due to an actual decline in population density, shifts in elevational distribution, or both. Density estimates from our aerial surveys in KX Territory were similar to others in peripheral range of coastal BC, and lower than estimates from the interior. Information from knowledge holders from KX First Nation Territory described a pronounced decline in sightings since the 1980s. Finally, at a broader provincial scale, we showed that although nonresident hunter success initially increased since 1980, resident hunter success—a proxy for abundance unaffected by the influence of professional hunting guides—has declined since the 1990s. In the context of these data, we weigh support for the change in abundance and change in distribution hypotheses, consider KX goats in a conservation assessment framework, and illustrate the roles of local peoples as sentinels of change in data-poor areas.

4.1 | Biological interpretation

Our multi-method approach offers support for both working hypotheses, which are not mutually exclusive. Our data suggest that interactions with mountain goats, whether through resident hunting or observation, have declined since at least 2000, a result consistent with other observations from communities and hunters within the Skeena region of northern BC (G. McQuaid, personal communication, 2021). Owing to the absence of professional guides operating in familiar areas declines in resident hunter success may provide a more reliable signal of potential population change. Additionally, resident hunters account for more than 51% of kills, more than 70% of total hunters, more than 69% of hunter days, and more than 60% of hunt outings, making it a more data-rich measure. Other independent data similarly suggest that population decline may be the most likely scenario: repeated small-scale aerial surveys indicated that populations within the nine management “regions” in BC are either stable or decreasing, with decline most prevalent in southern and southern coastal areas (Mountain Goat Management Team, 2010).

Many historical declines in mountain goat populations have been attributed to hunting, though available data make such a link uncertain in BC. Permissive hunting regulations across much of BC during the 1960s and 1970s have been suggested as a cause of past goat declines, primarily in the southern portions of BC (Phelps, 1983). Despite regulatory changes, hunting still comprises a major source of mountain goat mortality in some areas (e.g., Festa-Bianchet & Côté, 2007; Hamel et al., 2006; Rice & Gay, 2010). Mountain goats are characterized by low fecundity (i.e., a low reproductive rate) compared to most ungulates, owing to their late age at maturity, low twinning rates, and relatively high incidence of reproductive pauses (Festa-Bianchet & Côté, 2007). Killing of mature (>5 year old) females, which are difficult to sex in the field, can have large impacts on population fecundity (Hamel et al., 2006). Moreover, the effects of hunting can be additive to natural causes of mortality, such as avalanches, climate change, and predation (Côté et al., 2006; Kuck, 1980; Mountain Goat Management Team, 2010). Finally, effects of hunting can also be magnified for small, isolated populations, such as those at the edge of their range. Past modeling indicates that kill rates of mountain goats in Alberta should not exceed 1% of the total population for many populations, with high extinction risk (18–82%) for small- (<25 individuals) and medium-sized (<50 individuals) populations if this threshold is exceeded (Hamel et al., 2006).

In KX territory, kill data do not allow for robust inference on whether this has contributed to current conservation risk. On one hand, hunting has been modest, and kills have been especially limited in the past decade (Figure S4). On the other hand, kills have included a moderate to high proportion of females (Figure S4). Moreover, goats in KX territory apparently occur at low density and inhabit isolated mountain-top complexes separated by oceanic inlets and other significant waterways, which are known barriers to goat movement (White et al., 2021). Future research could examine population sub-division, permitting estimates of associated sizes of constituent populations (e.g., White et al., 2021; Wolf et al., 2020). Ultimately, our analysis cannot provide a clear causal link between declines in sightings and hunting mortality, but we have identified steady changes in human-goat interactions that warrant additional monitoring.

A second and possibly concurrent reason for the patterns we document is a changing distribution of goats, relative to their historical elevational range. Conceivably, sightings and resident hunting success have declined because goats that avoid lower, warmer elevations are less accessible. Similarly, declines in observations could be a result of altered space use by goats due to changing phenologies of forage species or predator distribution. Climate change is profoundly affecting the distribution of species worldwide, and its effects are particularly pronounced for alpine areas and alpine specialists (Aublet et al., 2009; Brivio et al., 2019; Lovari et al., 2020; White et al., 2018; Yoccoz et al., 2010). Heat stress associated with warming can reduce mountain goat fitness, and shifting to higher elevations where thermal refugia remain has been proposed as an adaptation mechanism (Festa-Bianchet & Côté, 2007; Sarmento et al., 2019). Alpine warming may also induce elevational shifts in the range of species via climate-mediated shifts in vegetation (and plant phenologies) and predators (Cannone et al., 2007; Lovari et al., 2020). These changes may result in direct population declines via phenological mismatch dynamics and novel predation opportunities (Miller-Rushing et al., 2010). The coastal temperate rainforests of western North America conform to these predictions, having experienced an elevated snowline, reduced snowpack, and contracted alpine habitat (Shanley et al., 2015). Indeed, such explanations were independently advanced by KX interviewees. These suggestions may be particularly relevant in KX territory, which occurs at the extreme range edge of goats (i.e., westernmost portion of Coast Mountain Range) where available elevation is modest and habitat is not well connected (Figure S5) (mean = 667 m ASL). Lack of high elevation refugia create conditions for a climate inflection (i.e., "tipping point") where habitat loss and degradation may trigger a nonlinear reduction in goat abundance (Lenton, 2011). Further, human activity on the landscape may exacerbate climate change-induced elevational range contractions. For example, mid to high elevation logging can reduce available habitat and displace goats, given their sensitivity to noise disturbance (Goldstein et al., 2005).

Although we cannot discriminate between a change in abundance or a change in distribution, any effects they impose may be complementary. Climate change, for example, could cause direct mortality and induce range shifts in a population simultaneously. Although the effects of warming winters may reduce overwinter mortality, the detrimental effects of warming summers outweigh the benefits of warming winters for mountain goats in coastal Alaska (White et al., 2018). The decline in sightings and hunter success we observed could be a result of both declines in abundance and shifts to higher elevations occurring in concert, though baseline information on goat abundance and distribution is lacking in KX territory. We note that interviews with hunters and guides that hunt in nearby northern BC suggested a perception of decline in goat abundance at all elevations (G. McQuaid, personal communication, 2021).

4.2 | Limitations

Our study had a number of limitations. LEK was constrained to KX Territory, a small portion of the total coastal range of goats and was restricted to sightings from sea or ground level. We note, however, the common use of binoculars, which allow for reliable sightings up to ~900 m in the steep-sided inlets of the area (C Service *pers. obs.*; Figure S6). Moreover, aerial surveys can provide quantitative estimates of trend, but our surveys did not occur over a long enough period to estimate any potential changes over time. Indeed, given that aerial surveys have not previously been conducted in this region, this method cannot provide insight into population trend. Kill data and CPUE analysis, while covering a larger area, provided a coarse index of population trends (Maunder et al., 2006; Seber, 1986) at large (coastal and interior) scales.

4.3 | Conservation assessment

Collectively, three independent information sources (aerial surveys, LEK surveys, and CPUE analyses from hunt data) indicate that the mountain goat population within KX territory is of conservation concern. First, our aerial surveys confirm that this population is of low-density, typical of coastal mountain goat populations. This low density, and consequently lower number of individuals, makes this population especially susceptible to known risk factors for mountain goats, such as reduced summer habitat due to climate change (White et al., 2018), harvest (Hamel et al., 2006), and the erosion of genetic diversity (Frankham, 1996). Additionally, our LEK interviews suggest a declining population and/or an elevational shift, both of which warrant conservation attention; although peripheral to the Province of BC, and might be considered sinks at a larger scale, these goats are the only goats with which the KX have a relationship. Finally, patterns from our CPUE analysis suggests the possibility of declines, at least at large spatial scales. A declining population may signal broadly unfavorable changes in ecological conditions (e.g., climate change) and/or improperly managed human activities (e.g., hunting, industrial development). In addition, predation and disease are known causes of decline in mountain goat populations (Blanchong et al., 2018; Dulude-de Broin et al., 2020). Moreover, given the low elevation of the coastal region, goats being forced to shift to higher elevations would most likely result in their eventual population decline due to constricted summer habitat (White et al., 2018).

Because mountain-goat data are scarce in KX territory, we argue that our evidence of a declining trend, in combination with known population-level risk factors (reduction in low elevation habitat in the face of climate change; White et al., 2017), warrants a precautionary approach to mountain goat management. This concern does not align, however, with the current approach of centralized management in northwestern North America. Provincial and state policy in BC, Alaska, and Washington typically restricts hunting when the estimated number of adults in a population falls below a predefined threshold value. In BC, that number is 50 (Mountain Goat Management Team, 2010). We propose that this current approach requires an unrealistic availability of data for most populations. For example, accurately defining the spatial bounds of a 'population' requires detailed surveys of collared animals and, likely, genetic analyses. More broadly, factors such as demographic stochasticity over time, marginal habitat conditions, and intrinsic population factors such as low genetic variation are not widely considered in these policies (Mountain Goat Management Team, 2010). Yet these characteristics can be common in peripheral populations. Finally, the current centralized management approach currently disregards local knowledge, the richest and most comprehensive data source for many understudied remote, peripheral populations. Incorporating and proactively acting upon LEK information might provide better conservation outcomes, because actions can be taken when populations may still be large enough to be resilient (Hamel et al., 2006). In the face of uncertainty and data limitations (conditions commonly faced by mountain goat managers), precautionary management has been encouraged and discussed at length in the scientific and environmental policy literature (e.g., Cooney & Dickson, 2012; Dovers et al., 1996; Foster et al., 2000; White et al., 2019). We note too that precautionary management is not only a KX Stewardship Authority principle but also commonly a hallmark of Indigenous stewardship (Berkes et al., 2000).

What might precautionary management look like? Exercising rights of self-determination, the KX have made several changes in the way they manage goats. Notably, KX members voluntarily stopped hunting goats over the last two decades. Other interventions currently considered and negotiated with the BC government by the KX Nation include the suspension of activities potentially detrimental to goats including hunting by non-KX hunters, high-elevation logging, and helicopter tourism (e.g., heli-hiking, fishing).

Globally, losses in human-animal relationships have resulted in the loss of IK and associated practices that were once common (Gómez-Baggethun et al., 2013; Reyes-García et al., 2013). Despite uncertainty in the cause of reduced mountain goat sightings, longstanding relationships between KX people and goats are now considered threatened by the KX First Nation. Although considered peripheral (part of only two wildlife management units at the edge of the province's jurisdiction), KX mountain goats are the only goats available to the KX people and hold immense cultural value. Reductions in access, distribution, and abundance from climate change can have the effect of reducing the overall availability of wildlife to people. Such effects are known to adversely impact Indigenous communities with cultural practices or food security that depends on wildlife (Brinkman et al., 2016). Ultimately, restricted distribution or declines in abundance of mountain goats have a similar outcome: the severing of millennia-old human-animal relationships, as well as connections of community members to their alpine and subalpine territory. In the absence of intervention, such losses can limit the potential for Indigenous and local peoples to monitor and respond to ecological changes.

4.4 | Local/Indigenous sentinels of change

Our study highlights how KX members, drawing on LEK and IK, serve as sentinels for wildlife, catalysts for multimethod approaches, and agents for change in wildlife management. Combined approaches that use data alongside LEK or IK are growing and have been shown to enhance management and conservation outcomes (Ban et al., 2018; Berkes, 2004; Berkes et al., 2000; Popp et al., 2020; Reid et al., 2020). Harnessing such knowledge for data-poor populations in particular is important. Scientific research often requires years to build robust datasets, but extant LEK has already been generated over many years of experience and observation (Thompson et al., 2020). Such information can enhance management by extending historical baselines (e.g., Eckert et al., 2018; Lee et al., 2018) and rapidly detecting change (e.g., Service et al., 2014). Although social (e.g., Nadasdy, 1999) and analytical (e.g., Wohling, 2009) challenges exist, examples of interlinked approaches to research and management are growing and include the practice of science by Indigenous peoples (e.g., Housty et al., 2014; Reid et al., 2020). Finally, we note that early warnings of change by Indigenous peoples in one area can uncover processes potentially occurring at larger scales. In this case, early concerns by the KX triggered investigations that revealed evidence of potential decline in goats well beyond KX territory. These patterns had remained undocumented, despite long-term and abundant CPUE data being managed by the provincial government and publicly available.

As Indigenous governments reassert their authority to manage the lands, waters, and wildlife in their territories, the applications of IK and LEK to wildlife management are moving beyond mere contributions of information (e.g., Frid, McGreer, & Stevenson, 2016). Such resurgence of decentralized management is well suited to apply local knowledge and agency to manage peripheral populations. Indeed, the benefits of decentralized management more broadly have been gaining wider recognition (Lemos & Agrawal, 2006; Ribot et al., 2006; Larson & Soto, 2008; but see Hohbein et al., 2021). Indigenous lands can be remote, biodiverse, and lacking in Western scientific research; yet in these same areas Indigenous monitoring and stewardship may be strong (Garnett et al., 2018). Integrated approaches towards research and management, informed and guided by the knowledge of local peoples, can offer unique insight that is place-based and tailored towards areas or species that might otherwise be ignored or deprioritized. Examples of such approaches are becoming abundant in both research (e.g., DeRoy et al., 2019; Gavin et al., 2015; Housty et al., 2014; Reid et al., 2020; Thompson et al., 2020) and management (e.g., Frid, McGreer, Haggarty, et al., 2016; Houde, 2007) contexts. Especially in landscapes inhabited by peripheral wildlife populations, LEK and IK observations can serve as early warnings and an important source of information to guide applied research and management.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

AUTHOR CONTRIBUTIONS

Tyler D. Jessen, Christina N. Service, and Kim G. Poole participated in the conceptualization, field work, analysis, and writing of the article. Christina N. Service conducted the community interviews. A. Cole Burton, Andrew W. Bateman, Paul C. Paquet, and Chris T. Darimont contributed to the conceptualization, analysis, and writing. Chris T. Darimont provided funding for the field work and analysis.

DATA AVAILABILITY STATEMENT

Hunting data for British Columbia is freely available in the "Big Game Harvest Statistics" database (https://catalogue.data.gov.bc.ca/dataset/big-game-harvest-statistics-1976-2018). Mountain goat reports are available from the BC Ministry of Environment Species Inventory

Web Explorer (http://a100.gov.bc.ca/pub/siwe/search_reset.do) and the Northern Wild Sheep and Goat Council Proceedings (http://www.nwsgc.org/proceedings.html). Interview data are held by the Kitasoo Xai'xais Stewardship Authority.

ETHICS STATEMENT

Aerial surveys were authorized by the Kitasoo Xai'xais Stewardship Authority, the University of Victoria Animal Care Committee (protocol number: Darimont, 2019-012 (2)), a British Columbia Parks Use Permit (protocol number: 100310783), and a British Columbia General Wildlife Research Permit (protocol number: 100311000). Interviews in Klemtu, BC, were conducted by Kitasoo Xai'xais Stewardship Authority staff and beyond the scope of institutional research ethics.

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