Behavioural responses of southern mountain caribou to helicopter and skiing activities

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Abstract: Helicopter- and snowcat-supported backcountry skiing is a unique industry that is widespread throughout southern mountain caribou habitat in British Columbia (BC). We analyzed records of helicopter and skier encounters with caribou collected by tourism operators under an agreement between the BC government and HeliCat Canada. Average reported encounter rates were low for helicopters (0.6%) and skiing groups (0.1%); however, encounters were likely underreported due to factors that affect caribou sightability. Helicopters encountered caribou more frequently than skiing groups, caribou were detected from helicopters at greater distances than by skiers. We used Bayesian network models to assess the independent contribution of different factors to the behavioural response of caribou to encounters. Encounter distance was the most important factor in both helicopter and skiing models. Larger groups of caribou responded strongly to skiers but not to helicopters, although the independent effect of this factor was small in both models. Larger helicopters elicited stronger reactions from caribou than smaller machines and were responsible for 25% of the modelled variation in caribou response. Encounters with helicopters at distances of 100–500m had a 78% probability of eliciting a *concerned-to-very-alarmed* response from caribou, while skiers at a similar distance had a 60% probability of eliciting the same response. The probability of *concerned-to-very-alarmed* responses dropped to <20% at encounter distances of >1000 m. These results indicate that initial encounter distance is the key variable to manage risk to caribou of helicopter and skiing encounters. Ongoing feedback on the effectiveness of management practices is critical to ensure the continued viability of industries operating in caribou habitat.

Key words: woodland caribou; adventure tourism; behaviour.

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Introduction

Woodland caribou (*Rangifer tarandus caribou*) populations living in the mountains of southern British Columbia (BC) and Alberta (hereafter "mountain caribou") are experiencing declines, having been affected by a range of threats including habitat loss, population fragmentation, and increased predation (Environment Canada, 2014). Although their status is currently recognized as 'Threatened' under Canada's Species at Risk Act, a re-designation of the current populations (COSEWIC, 2011), will likely increase scrutiny on all human activities occurring in their habitat, including backcountry skiing.

Helicopter and snowcat (hereafter "helicat") skiing are unique adventure tourism activities

that bring clients to mountain environments for a deep snow, downhill ski experience (Hamilton & Pasztor, 2009). Popular in the mountains of central and southern BC and occurring on public lands for which exclusive adventure tourism tenures are granted by the provincial government (Ministry of Environment, 2009), the winter land-base of many operators overlaps the range of mountain caribou. Forestry, mining, recreational snowmobiling, backcountry ski touring and hunting also occur in mountain caribou habitat and often overlap helicat tenures.

Mountain caribou occupy high-elevation, deep snow habitats in winter where they feed on arboreal lichens (Rominger *et al.*, 1996; The Mountain Caribou Technical Advisory Committee, 2002). This behaviour results in spatial overlap with winter recreational activities. Many studies have established that wild and semi-domesticated *Rangifer* individuals and populations respond to human disturbance (Brade, 2003; Kinley, 2008; Mitchell & Hamilton, 2007; Plante *et al.*, 2018; Reimers & Colman, 2006; Skarin & Åhman, 2014; Skarin *et al.,* 2010; Vistnes & Nellemann, 2008; Wolfe *et al.*, 2000). McKay (2007) found active behavioural responses to encounters on foot, such as fleeing (walking, trotting or running) and increased vigilance as well as evidence of habituation near trails where human presence was predictable. Lesmerises *et al.* (2018) found a strong enough individual response to skiers that habitats were abandoned by caribou. A similar individual disturbance response where snowmobiles and helicopter skiing were present resulted in elevated stress hormones in caribou as compared to areas where these activities were absent (Freeman, 2008). Threshold disturbances by people approaching on foot (skiing or hiking) suggested that reindeer (*Rangifer tarandus tarandus*) pay an energy price to avoid disturbance (Reimers *et al.*, 2003).

At the population level, Seip *et al.* (2007) concluded that snowmobiling can displace caribou from preferred habitat in BC. The negative response of barren ground caribou populations to aircraft overflight has been well established (Calef *et al.*, 1976; Harrington, 2003). The sensitivity and responses of other alpine ungulate populations to ground-based, human disturbance and overflights has also been reported (Bleich *et al.*, 1994; Brambilla & Brivio, 2018; Cadsand *et al.*, 2013; Côté *et al.*, 2013; Frid, 2003; Gander & Ingold, 1997; Schnidrig-Petrig & Ingold, 2001; Stankowich, 2008; but see Hatler, 2012).

In 2007, the Mountain Caribou Recovery Implementation Plan (MCRIP) established a mechanism for the Government of BC and the helicat industry (working through their industry association, HeliCat Canada) to develop and monitor practices for helicat businesses operating in caribou winter habitat (MCRIP Progress Board, 2007). The BC and HeliCat Canada partnership was the result of a need to address how a recreational use could continue in the habitat of a species with serious population declines (Ministry of Environment, 2009). As part of this mechanism, a protocol was developed to monitor wildlife observations made by helicat operators during training or client-guiding operations (Hamilton & Pasztor, 2009; Wilson & Nyberg, 2009). The key information collected relates how animals react to helicat activities and the conditions under which the activities are occurring (Wilson & Nyberg, 2009).

Since the MCRIP agreement was established in 2007, the caribou subpopulations in southern BC have continued to decline (Boutin & Merrill, 2016) and management efforts to reinforce these populations have been pursued (Hayek *et al.,* 2016). There are ten caribou subpopulations that have helicat tenures in their ranges and a number of other helicat tenures that occur outside of caribou range (Table 1, Figure 1).

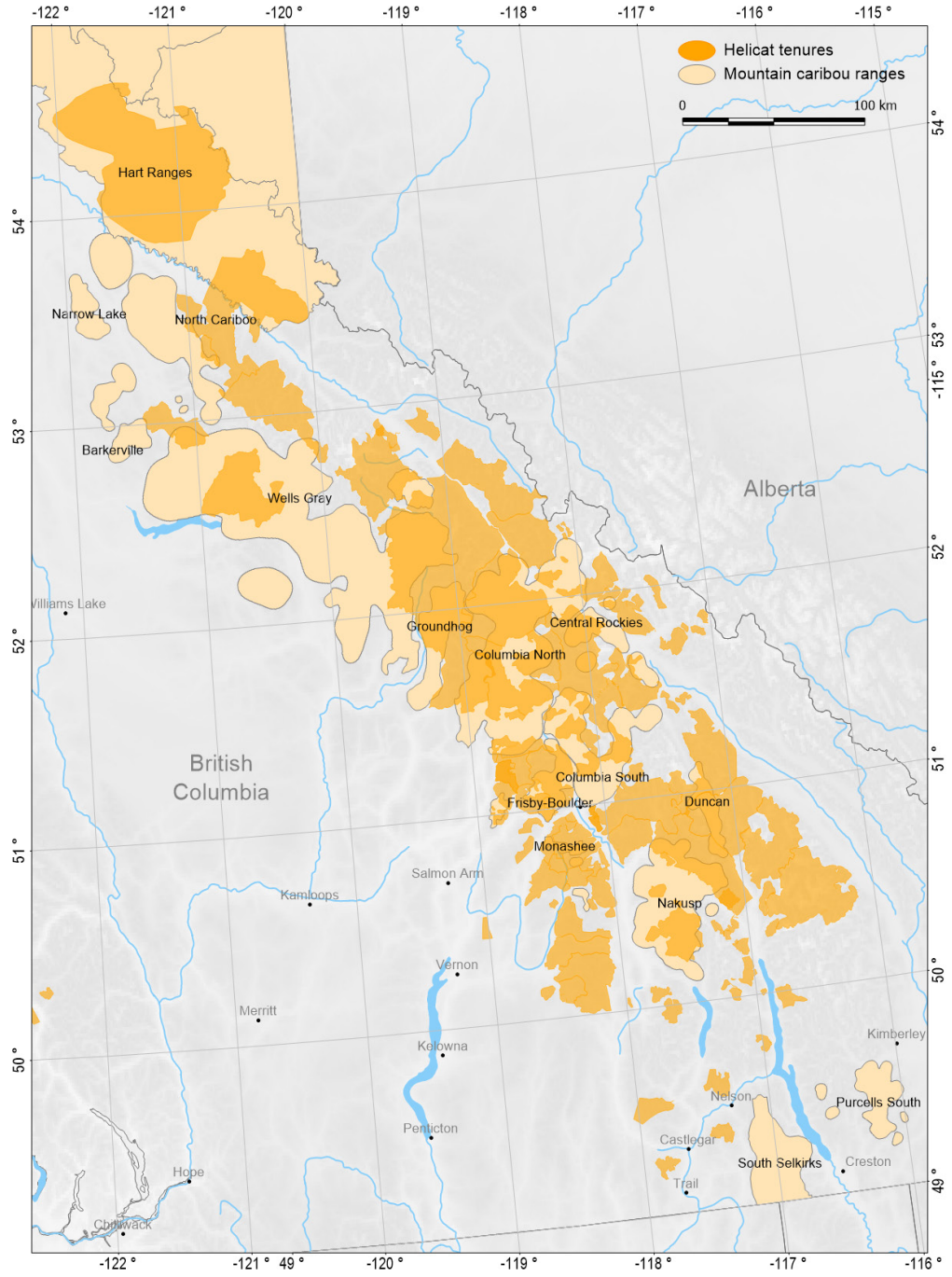

Figure 1. Mountain caribou herd boundaries interpreted from telemetry data (pale orange areas outlined in grey) and helicopter and snowcat ski tenures (dark orange areas) across southern British Columbia. Source data available from http://catalogue.data.gov.bc.ca.

Table 1: Caribou subpopulations that overlap with helicopter and snowcat ski tenure areas in southeastern British Columbia, Canada. Population estimates are from government surveys conducted and trends are updated from COSEWIC (2014).

Caribou range	Population estimate	Estimate year	Trend
Hart Ranges	459	2016	Declining
Central Rockies	0	-	Extirpated
Columbia South	4	2016	Declining
Columbia North	147	2017	Stable
Wells-Gray	345	2018	Declining
Nakusp	31	2018	Declining
North Cariboo	187	2018	Declining
Frisby-Boulder	11	2013	Declining
Monashee	0	-	Extirpated
Groundhog	23	2018	Stable

Managing activities in mountain caribou habitat requires an understanding and evaluation of associated risks, the components of which are the probability and consequence of uncertain events (Kaplan & Garrick, 1981). For helicat skiing, an event is considered an encounter between a helicopter, snowcat or skier with a caribou or group of caribou (*cf*. Wilson & Shackleton, 2001 as described for mountain goats). Given typical movement and distribution patterns for mountain caribou (Johnson *et al*. 2002), we define a group simply as the number of caribou seen in a single encounter.

Our objective was to characterize the short-term risk to caribou posed by helicat activities based on available data. We do not consider the long-term implications of these encounters to individuals or populations but focus on responses that were immediately apparent during the encounter.

Material and methods

The study area included helicopter and snowcat tenures located within mountain caribou habitat of southeastern BC (approximately 51–54° N and 116–122° W; Figure 1). This area is dominated by a series of north-south mountain ranges with peaks as high as 3500m. The region has a wet continental climate that generates high-elevation snow packs of several metres every winter. Human settlements and agriculture are common in the valleys but rare in the mountains. Lower slopes are generally covered with dense stands of Western Hemlock (*Tsuga heterophylla*), Western Redcedar (*Thuja plicata*) and a variety of other conifer species, with higher-elevation forests dominated by Engelmann Spruce (*Picea engelmannii*) and Subalpine Fir (*Abies lasiocarpa*). Vegetated and unvegetated alpine is extensive at the highest elevations.

Wildlife observation data have been collected by tourism operators since 2009 (Wilmshurst & Gordon, 2017). All observations were made by helicat ski guides either in transit to or from ski areas in a helicopter or snowcat, or while skiing. Flight guidelines require that helicopters remain at altitudes of >500m while in transit (where practicable) and descend quickly to the landing site. Thus, helicopter encounters with caribou generally occur at a distance while in transit or closer when approaching a landing site. Snowcats travel along established trails at relatively low speeds and encounters are generally rare. Skiing occurs in small groups (up to 12) in open or treed terrain. Because they are moving quickly and relatively quietly, they can come upon caribou with little warning,

particularly if visibility is limited by terrain or trees.

Although guides and pilots are trained to look for caribou, and to record their reactions when observed, observers have multiple tasks while in transit and there is no objective way to determine whether caribou were present but not observed. In addition, travel routes were not designed as systematic surveys. Hence, caribou observations are treated as opportunistic or incidental and our analyses focused only on the characteristics of caribou reactions once encounters occurred (Wilson & Nyberg, 2009). This type of data collection limits the scope of statistical analyses but does not preclude statistical data modeling (Isaac & Pocock, 2015; Krebs, 1989).

If caribou were observed, guides recorded the following data: date, number of animals observed, geographic coordinates, estimated distance between the observer and caribou, elevation (above, at or below treeline), cardinal aspect of the terrain, reaction of caribou (see below), and whether the observation was made from a helicopter (either "heavy" or "light" machines), snowcat or while downhill skiing.

The caribou response variable was recorded by observers as one of six alternatives (from mildest to strongest): *no response*, *unconcerned* (demonstrating awareness), *curious* (periodic directional alertness but no disruption of activity), *concerned* (alertness but no directional movement), *alarmed* (walking or trotting away from the stimulus), or *very alarmed* (rapid flight from the area; Penner, 1988).

Because observers were not trained biologists and were concerned primarily with client safety and experience, it was infeasible for them to collect more detailed data (e.g., age-sex composition of groups, detailed pre- and post-encounter behaviour).

Observations were entered by guides into a purpose-built database at the end of each operating day (Wilmshurst & Gordon, 2016; Wilson & Nyberg, 2009). Compiled information from each operator was sent to the BC Government at the completion of each ski season.

We aggregated operator observations from 2009 to 2010 and 2013 to 2018 ski seasons into a single database. Observations from the 2010 to 2012 operating seasons were unavailable. In total, helicat guides and pilots reported 424 encounters with caribou over the 7 years for which data were available. However, particularly in the first few years of data collection, there were incomplete records with data not recorded for machine type or caribou group size.

The probability of an encounter with caribou is a function of the number of trips and the amount of time spent in and over caribou habitat, as well as the number and distribution of caribou occupying the habitat. As an approximation, we estimated the encounter probability of skiing groups with caribou using records of skier-day data provided by operators for 2013–2018 (skier-day data were unavailable for 2009–2010 season). We estimated skier group sizes by weighting the number of passengers in light and heavy helicopters by their relative frequencies reported in the observation database. The number of skier-days was divided by the estimated mean group size of eight to estimate the number of skier-groups by season. The number of skier-groups was divided by the number of caribou encounters to derive encounter rates for each season. Encounters rates for helicopters and for skiers were calculated separately.

The consequences of an encounter are the immediate behavioural responses of caribou caused by the encounter (Efroymson & Suter II, 2001). We modelled the relationship between the behavioural responses of caribou and available predictor variables as Bayesian networks (BNs) *via* machine learning. A BN is a graphical model that identifies probabilistic relationships among variables. Dependencies between variables (displayed as "nodes") are cal-

culated as marginal or conditional probability distributions associated with each node (Larrañaga & Moral, 2011). In ecological applications, the conditional probabilities embedded in BNs are often derived from expert knowledge (e.g., McCann *et al.*, 2006; Nyberg *et al.*, 2006); however, in this study we "learned" the relationships from the data without any expert-based prior assumptions.

BNs are particularly well-suited to this type of problem because both the response variable (caribou behaviour) and most predictors were collected as frequencies. As a non-parametric method, BNs are also free of the assumptions (e.g., normality, homoscedasticity) that are rarely met with ecological data (Smith, 1995).

Data were binned into broader response categories in cases where the unbinned joint probability distribution had too few observations to provide stable results. Specifically, caribou behavioural responses were combined into two bins: *no response to curious* and *concerned to very alarmed*. We also combined caribou group size into two bins (1–4 and >4) and categorized encounter distances into four groups; <100m, 100–500m, 501–1000m and >1000m. Slope position (alpine, treeline, below treeline) and aspect were excluded from analyses because the resulting joint probability distributions were unreliable due to missing and sparse cells.

Analyses were stratified by helicopter and skiing encounters. For analysis of caribou responses to helicopter encounters, we omitted the <100m category because there were too few observations (n = 3). As well, because the response category *no reaction* to *curious* dominated observations, we overweighted the *concerned to very alarmed* reactions and revised the model distribution. There were insufficient observations to analyze caribou encounters by snowcats (n = 9) so our analyses were restricted to helicopter and skier encounters.

We used the tree-augmented naïve Bayes classifier to learn network topology (i.e., to link predictor and response variables). This also enabled us to identify interactions among multiple predictor variables (Friedman *et al.*, 1997). We determined the most parsimonious model structure using an information-theoretic criterion called Minimum Description Length (MDL; Lam & Bacchus, 1994). MDL balances network complexity by adding an arc between two nodes only if the relation is strong enough to compensate for the complexity added by the conditional probability table required to describe the interaction. The strength of the relationship between variables was measured by comparing their respective probability distributions using Kullback-Leibler divergence (Kullback & Leibler, 1951). Once the most parsimonious model arrangement was determined, we fit parameters using maximum likelihood estimation.

We assessed the generalizability of models via k-fold (k = 10) cross-validation (Fielding & Bell, 1997), examining the ratio of correct predictions to the total number of cases in resulting confusion matrices.

We determined the independent contribution of each factor using "likelihood matching" (Conrady *et al.*, 2014), which fixes the posterior probability distributions of variables related to the one being assessed. This allowed us to examine the effects of individual predictor variables while holding others constant.

All analyses were conducted in BayesiaLab version 7 (Bayesia S.A.S., Laval, France).

Results

Of the 424 caribou encounters recorded, data were complete for 252 encounters with helicopters and 61 with skiers. Encounter distances tended to be shorter for skiers; the mode was 100–500m for ski encounters and 500–1000m for helicopter encounters (Figure 2). The proportions of encounters occurring at distances >1km were similar for both skiers and helicopters.

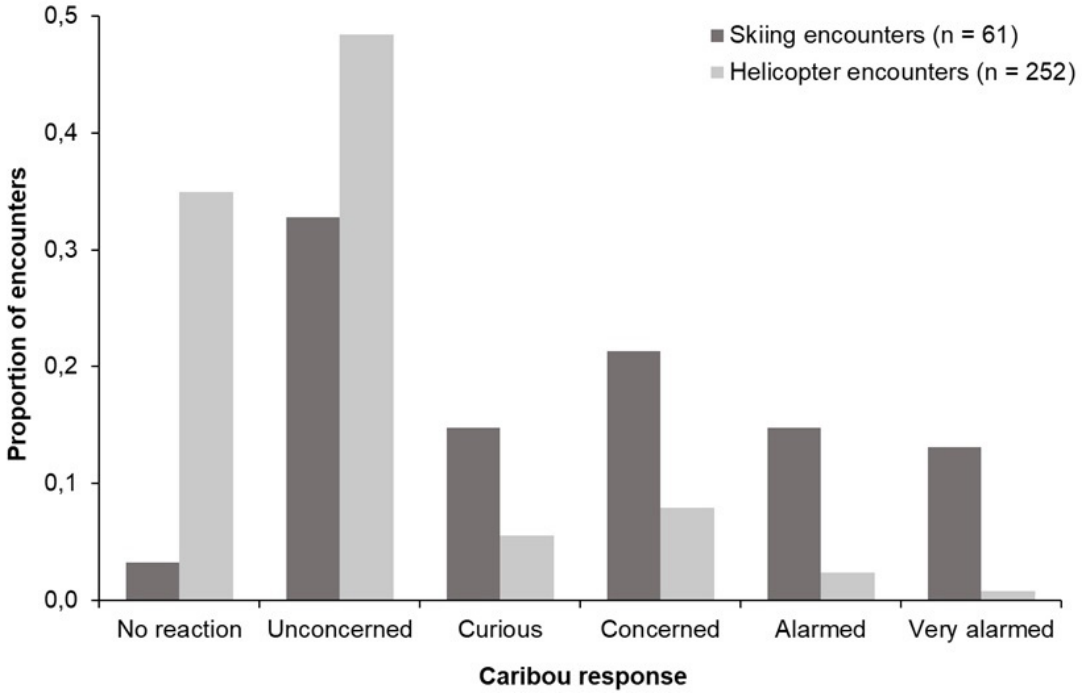

Figure 2. Proportion of caribou encounter distances by means of travel, as recorded by helicat guides and pilots. Distances were aggregated into four, discrete categories for analyses.

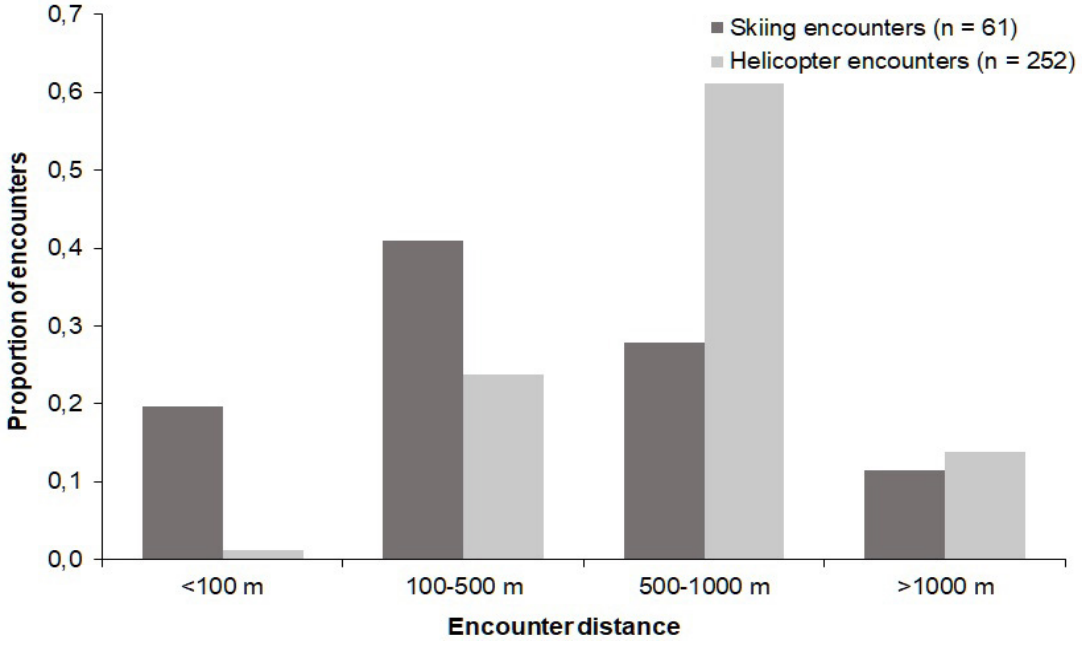

Figure 3. Proportions of different caribou reactions to encounters by means of travel, as recorded by helicat guides and pilots.

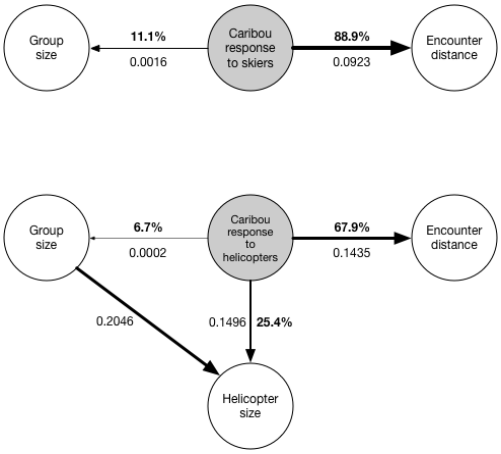

Figure 4. Bayesian Network diagrams illustrating links among predictor variables (white nodes) with the response variable (grey node) for skiing encounters (top) and helicopter encounters (bottom). Strength of pairwise interactions are reported under each link as Kullback-Leibler divergences of the nodes' respective probability distributions. Numbers above each link represent the normalized direct effect of predictor variables on the response. By convention, arrows in naïve, Bayes networks point from response variables to predictor variables.

The distribution of caribou reactions also differed between helicopter and skiing encounters, with stronger reactions *(concerned* to *very alarmed)* being recorded for skiing encounters than for helicopter encounters (Figure 3). *No reaction* and *unconcerned* were the most commonly recorded reaction categories for both skiing and helicopter encounters (Figure 3).

Most of the variation in caribou response explained by the model was due to encounter distance (89%); caribou group size explained only 11% (Figure 4). We found no evidence of an interaction between distance and group size. Shorter encounter distances were more likely to elicit stronger reactions. For encounters with skiers at <100m, the model predicts a 67% probability of a *concerned to very alarmed* response by caribou, declining to 60% at 100–500m, and then a steeper decline in probabilities at longer encounter distances. Stronger reactions were more likely to come from caribou in larger groups, although the independent effect size of this factor was very small (Figure 5).

The Bayesian model for skiing encounters correctly classified 76.7% of *concerned to very alarmed* observations, but only 54.8% of *no reaction to curious* observations. This indicates that our model tends to over-predict stronger caribou reactions.

As with the skiing encounter model, there was an inverse relationship between encounter distance and caribou reactions, with encounters at 100–500m predicted to result in a 78% probability of a *concerned to very alarmed* response by caribou, dropping to 39% at 500–1000m and then levelling off slightly at longer encounter distances.

We found a positive, independent relationship between caribou reactions and helicopter size and a weak negative relationship with caribou group size (Figure 6). There was also evidence of an interaction between caribou group size and helicopter size, with encounters with

Table 2. Caribou encounters and encounter rates by travel mode (helicopter or ski) and year. Skier encounter rates assume that there are eight skiers per encounter.

	2013	2014	2015	2016	2017	2018	Mean
Heliskier days	52795	54263	50190	60459	62224	65529	57577
Helicopter encounters	82	48	46	29	39	38	47
Skier days (heli and snowcat)	64628	66378	61233	73151	75428	78928	69958
Ski encounters (heli and snowcat)	9	18	17	5	18	4	11.8
Helicopter encounter rate (%)	1.24	0.71	0.73	0.38	0.50	0.46	0.62
Ski encounter rate (%)	0.11	0.22	0.22	0.05	0.19	0.04	0.11

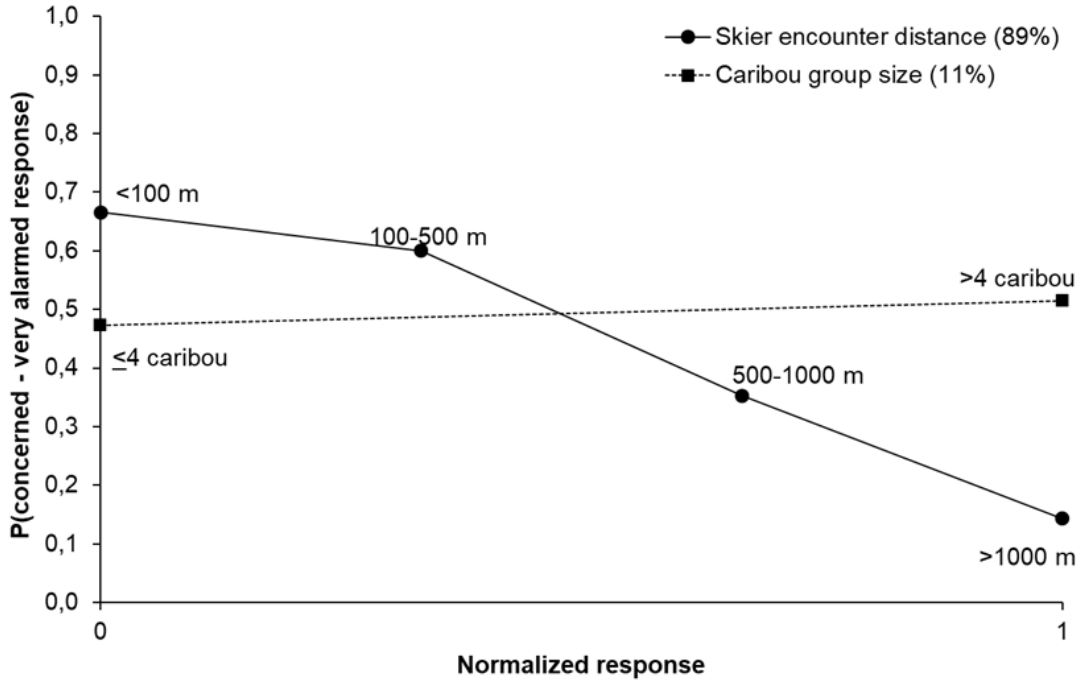

Figure 5. Probability of *concerned to very alarmed* responses by caribou in relation to caribou group size categories (and encounter distance categories) based on the skiing encounter Bayesian Network model.

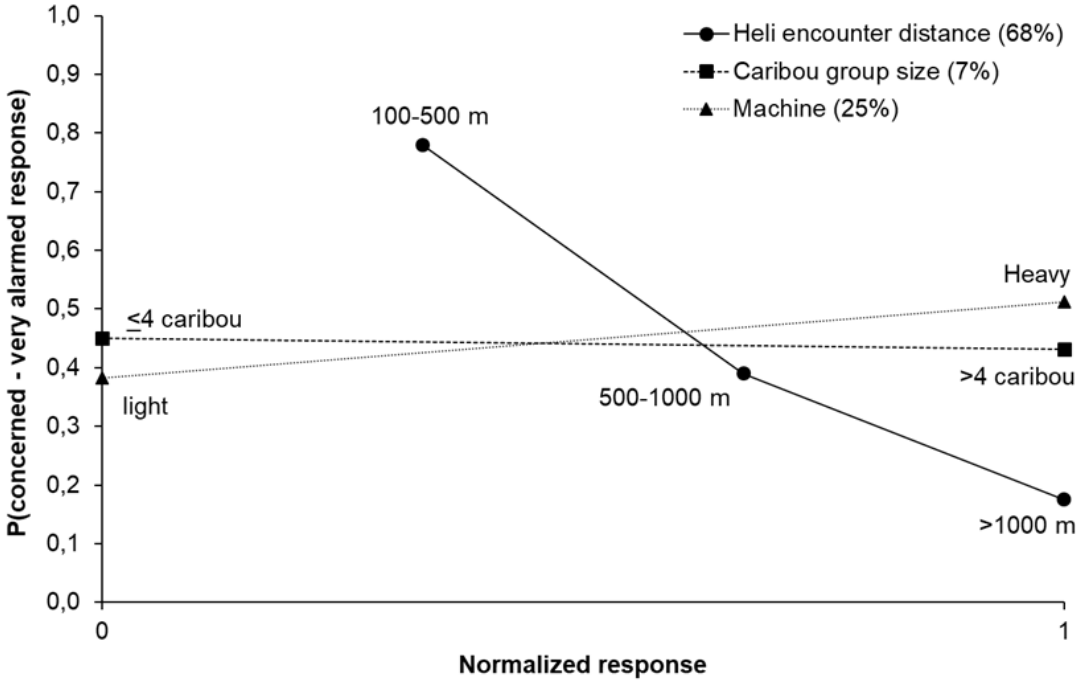

Figure 6. Probability of *concerned to very alarmed* responses by caribou in relation to encounter distance, helicopter size and caribou group size, based on the helicopter encounter Bayesian Network model.

larger caribou groups being more likely from heavy helicopters.

The probability of encounters by skiing groups with caribou varied both by means of encounter (helicopter or ski) and among years, with geometric mean rates of 0.62% for helicopters and 0.11% for skiers between 2013 and 2018 (Table 2). Caribou encounters with helicopters have declined over time, while those with skiers have varied without a clear trend.

The helicopter encounters model correctly classified 64.3% of *concerned to very alarmed* observations and 74.7% of *no reaction to curious* observations. Again, distance was the strongest explanatory variable for caribou reaction, accounting for 68% of the variance explained by the model. Helicopter size accounted for 25% of the variation while caribou group size explained 7% (Figure 4).

Discussion

Ours is the first study to analyze behavioural responses of mountain caribou to helicopters and downhill skiers collected using standardized methods. While encounters between barren-ground *Rangifer* and helicopters, Nordic skiers, snowmobiles and hikers have been well-studied (e.g., Calef *et al.*, 1976; Miller & Gunn, 1979; Reimers & Colman, 2006, Reimers *et al.,* 2003), studies reporting mountain caribou are lacking. This is because mountain caribou are relatively rare and occur in small groups in remote and rugged forested habitats. This has restricted observations to chance encounters and anecdotal accounts.

Because of where mountain caribou are found, we were required to use an approach that relied on trained, non-experts to collect data. This necessarily affected the types of data that could be collected and analysis methods, but without this, the interaction between backcountry tourism activities and mountain caribou would remain relatively unstudied.

The HeliCat Canada caribou observation dataset was sufficient to generate "dose-response" curves that are important to identify encounter thresholds used to improve heliskiing operating practices. We were also able to estimate the independent contribution of different factors affecting caribou behaviour during encounters. Animal reactions depended primarily on the distance between animal and observer, followed by whether the observer is in a helicopter or on skis. Interestingly, animal group size and the size of the helicopter also interact with animal response.

Caribou reaction to encounters with helicopters and skiers strengthened as the initial observation distance declined. This is consistent with previous reports for close snowmobile approaches (Powell, 2004) and for approaches on foot towards barren ground *Rangifer* in Greenland (Aastrup, 2007). Although summary statistics indicated that caribou reacted more strongly to skiers than to helicopters, this was confounded by skiers tending to encounter caribou at shorter initial distances. According to ski guides, close encounters with caribou while skiing are primarily a function of visibility in forested habitats. Skiers often descend through treed terrain and caribou are not visible until they are very close. In contrast, caribou are more visible from the air and more easily avoided by helicopters at longer distances. When controlling for initial encounter distance in the models, we found that caribou react more strongly to helicopters than to skiers.

The behavioural responses of ungulates to encounters by humans can be influenced by a number of factors, including habitat characteristics, habituation/sensitization, season, reproductive status and distance to safety (Stankowich, 2008). While we were unable to test all of these factors with the available dataset, encounter distance explained most of the variation in caribou reactions for both downhill skiers and helicopters. Current operating guidance calls for maintaining distances between caribou and

skiers of >100m and between caribou and helicopters of >500m. In addition, after observing caribou in an area, operators are obligated to close nearby runs to skiing for 48 hours or until reconnaissance can confirm that no caribou appear to be in the area. Our analyses suggest that these practices are appropriate.

Existing guidance can reduce, but not eliminate the likelihood of close encounters with caribou because animals can be difficult to detect, particularly in forested habitats. In addition, industry guidance recognizes the paramount importance of human safety and circumstances can arise where maintaining recommended distances from caribou can create unsafe conditions due to weather, visibility, avalanche or other hazards. Twenty percent of encounters by skiers and 25% by helicopters occurred at distances shorter than those recommended by the guidelines, although observations of helicopters encountering caribou at <100m were very rare.

The modelled probability of a *concerned to very alarmed response* was 7% lower at the minimum recommended distance of 100–500m than at <100m for skiing groups, and 39% lower for helicopters at 500–1000m than at <500 m. Probabilities at larger distances were lower still. Again, this supports the current practice of maintaining minimum encounter distances by helicat operators.

While our analysis of the observation dataset provided important insights into the behavioural consequences of encounters with caribou, the probability of encounters provides important context for assessing the risk posed by helicat activities. Recorded encounters in relation to the number of skiing groups using caribou habitat suggested that caribou encounters are rare events. However, as noted above, caribou can be difficult to spot, and pilots and guides must maintain awareness of a variety of factors to ensure guest safety and assess snow conditions (for example). As a result, encounter rates are almost certainly under-reported, but no data are currently available to assess the degree of under-reporting. Because both caribou and backcountry tourism activities occur at low densities, it is unlikely that encounters could ever be considered common or could result in significant habituation of caribou to helicopters or skiers. McKay (2007) and Huebel (2012) both found that mountain caribou can habituate to common or predictable encounters, such as by hiking trails or ski runs, but less to rare or unexpected encounters away from usual human travel routes. As mountain caribou populations continue to decline, encounter rates are also expected to fall, paradoxically reducing the overall risk to caribou of these activities.

We found a weak positive relationship between helicopter size and caribou reaction severity, which may simply suggest that larger and noisier helicopters trigger a stronger response from caribou. The factors that contribute to caribou disturbance responses are complex, but some of the mitigations for operations in habitats with sensitive species like caribou are straightforward (Reimers & Colman, 2006). Operators already use best management practices that appear to have contributed to reduced caribou encounters, although this is confounded by ongoing caribou population declines (Table 2). Awareness that larger helicopters can trigger stronger responses can further improve this record if operators using heavier machines use extra caution when flying over caribou habitat.

Our analysis of possible confounding factors was limited by sample size. While information on the aspect and elevation of observed caribou provided useful information to operators to inform required adjustments in their operating practices, it is unlikely that it will be subject to quantitative analyses until many more years of data are available.

Annual summary reports have been prepared since the beginning of the program (Heard, 2016; Pasztor, 2011, 2012, 2013; Wilmshurst

& Gordon, 2016, 2017; Wilson, 2010). They have analyzed collected information and have provided recommendations to improve operational practices. Analyses have shown that caribou are most often encountered below the treeline on north facing slopes (Heard, 2016; Pasztor, 2011), but that the number of reported close encounters is declining (Heard, 2016; Wilmshurst & Gordon, 2016) either due to improvement in practices or fewer caribou. Following performance monitoring, most recommendations (Pasztor, 2011, 2013; Plante *et al.,* 2018; Wilson, 2010) have been acted upon, including improvements to data collection and reporting (Wilmshurst & Gordon, 2016, 2017) and improved compliance to management practices (Pasztor, 2012, 2013). Our models and risk analysis have added value to this information already reported.

Bayesian modelling is an effective way to evaluate risk using observational data to develop precautionary approaches for wildlife management (Hilborn, *et al.,* 2001). Assessment of risk requires that information be collected on the probability of an event occurring and the consequences of that event (Kangas & Kangas, 2004; Kaplan & Garrick, 1981). While the immediate consequences of caribou encounters with helicopters and/or skiers (animal reaction) are adequately monitored in this program, the probability of encounter is more difficult to measure and could benefit from detailed analysis of ski group sizes, ski locations and flight paths in relation to current caribou distribution.

Finally, it is important to note that the goal of precautionary approaches to resource management include both the ecological needs of the wildlife species plus the industries and communities dependent upon them (Hilborn *et al.,* 2001). Whether the estimated probabilities and consequences of heli-ski encounters with caribou are acceptable is a management decision that depends on specific conservation and economic objectives, as well as the degree of precaution applied by a decision-maker. Our study is restricted to the immediate behavioural response of caribou and we do not know whether observed and modeled responses are sufficient to cause more serious consequences, such as displacement from preferred habitats or demographic decline. The principal finding is that animals react more strongly to close encounters than to distant encounters both for helicopter and skiers.

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