RESPONSES OF MOUNTAIN GOATS TO HELISKIING ACTIVITY: MOVEMENTS AND RESOURCE SELECTION

by

Becky A. Cadsand

B.Sc., University of Northern British Columbia, 2005

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OR SCIENCE
IN
NATURAL RESOURCES AND ENVIRONMENTAL STUDIES
(BIOLOGY)

UNIVERSITY OF NORTHERN BRITISH COLUMBIA

September 2012

Abstract

Heliskiing activity has increased in many areas of mountain goat (*Oreamnos americanus*) range; how this activity affects movements and resource use, however, is poorly understood. In 2007 – 2010, I examined locations and movements of 11 GPS-collared female mountain goats relative to activity of GPS-equipped helicopters in northwest British Columbia. Mountain goats exhibited anomalous movements in the 48 h following helicopter approaches within 2 km, regardless of whether helicopters were visible to the animals. Mountain goats were not displaced by the disturbances, however, and seasonal movement rates did not increase with heliskiing exposure. Animals did not avoid areas of helicopter activity, but several animals in areas of high heliskiing activity selected strongly for security terrain. When exposure to helicopter activity is <1h/month, I recommend pre-planning measures be undertaken to ensure 1,500-m separation distances between heliskiing activity and mountain goat range. At higher exposures, separation distances should extend to 2 km.

Table of Contents

List of Tables

List of Figures

Acknowledgements

This thesis was a collaborative effort that involved the expertise, dedication, and commitment of many individuals and organizations. Thinking back about the amazing people and groups I have had the privilege to work with over the course of the project, I feel truly fortunate.

Funding for this project was provided by the Habitat Conservation Trust Foundation (HCTF), B.C. Ministry of Environment, and National Science and Engineering Research Council (NSERC) with in kind support from UNBC and Helicat Canada. The B.C. Ministry of Environment and Last Frontier Heliskiing were invaluable partners in this project, providing in-kind support, expertise and enthusiasm. The B.C Ministry staff in Smithers – Bill Jex, Rick Marshall, George Schultze, and Len Vanderstar – ensured that both capture crews and mountain goats remained safe throughout the collaring process, and made ground trapping goats in the Northern Skeena Mountains possible. They were also steadfast goat-trappers themselves, and were always helpful in collar retrieval efforts. The management, guides and pilots at Last Frontier Heliskiing (with special acknowledgement to Franz Fux and Michael Brackenhofer), were a pleasure to work with throughout the project. Their dedication to helping conserve the wilderness they work in should be something all companies aspire to. The original project design and pilot studies were developed by a steering committee – Dave Butler, Mike Gillingham, Steve Gordon, Gerry Kuzyk, Rick Marshall, and Steven Wilson. Their assistance in acquiring project funding, developing partnerships, and facilitating animal captures was integral to project success.

This thesis would not have been possible without the dedication and mentorship of my thesis committee – Mike Gillingham, Doug Heard and Kathy Parker. Working with a group of such knowledgeable and passionate ecologists was a constant inspiration. Mike's enthusiasm, hard work and dedication was the single most important reason for the completion of this thesis. He consistently went above and beyond what was expected of a graduate supervisor, and was always there with support, a sense of humour, and a visual basic program when I needed it most. Kathy's insights were always valued; her perspectives on wildlife behaviour and habitat use helped shape many parts of this thesis and my own understanding of wildlife. I was fortunate enough to be taught by both Mike and Kathy while an undergraduate at UNBC, and throughout the process of this M.Sc project, my respect for them as teachers, ecologists, and all-around amazing people continues to grow everyday. Doug's extensive knowledge of the ecology of the north, and enthusiasm for wildlife was a constant inspiration. Discussions with him were always constructive and motivating, and influenced many of the management implications of this thesis. Doug and Mike also proved to be a ringer goat-trapping team. Though not on my committee, I'm indebted to both Ping Bai and Roger Wheate for their time and patience in providing GIS assistance, particularly Ping's involvement regarding the Line-of-Sight analyses.

I wouldn't have had any study animals if it wasn't for the many folks that braved sub-zero temperatures, white-outs and the wrath of fiery nanny goats in capture camps, so a big thanks to Jeremy Ayotte, Mike Bruns, Kim Brunt, Jack Evans, Darren Fillier, Steve Gordon, Brian Harris, Anne Hetherington, Bill Jex, Rick Keim, John Kelly, Rick Marshall, Fraser McDonald, Cliff Nietvelt, Keith Nole, Chris Proctor, Dennis Quock, Aaron Reid, Darryl Reynolds, George Schultze, Tom Smith, Ian Spendlow, Chris Schelle, Robin Temoine, Len Vanderstar, Andrew Walker, Marika Welsh, and Mark Williams. I'd also like to thank the many supervisors that contributed staff time and wages, making the involvement of these individuals in the goat trapping operations possible, and the ladies at Smithers MOE, Aly Taylor and Bonnie Zemenchik, that were our always cheerful safety check-ins throughout the project. Ministry of Forests, Telkwa and Prince George Fire staff Trever Krisher and Kelly Johnson supplied 3 base camp tents used by crews throughout the projects. Pat Rooney and the Highland Helicopters Crew were also integral to the trapping process, moving capture crews and gear safely through rugged country and often challenging weather. Nick Hawes from Lakes District Air was the expert pilot that flew telemetry flights throughout the project. The friendship of Nick, his wife Mary, and their family always made the telemetry trips an entertaining time. Collar retrievals were often challenging in this project, and were made successful and safe with the mountaineering skills of Len Vanderstar and the expertise of other folks at Smithers MOE. Sonja Ostertag, Krista Sittler, and Robin Steenweg provided much appreciated digging and technical support. I am also indebted to the expert flying and capture skills of Greg Altoft (Altoft Helicopters) and Glen Watts for retrieving those collars that weren't always as remotely releasable as anticipated. Rob D'Eon generously provided a number of collars for use in the study, and Kim Poole and Dale Seip provided use of command units used to release the collars from animals.

Sam Albers, Brenna Boyle, Lesley Dampier, Libby Williamson-Ehlers, Nick Ehlers, Faye Hirshfield, Eric Kopetski, Ian Picketts, Ty Smith, Robin Steenweg, and Brooke Wilkin ensured that any physiological stress resulting from coursework and thesis preparations were minimized through river floats, bonfires at my cabin, relevant course discussions, and interpretive dance. Krista Sittler provided not only friendship and support, but was also a partner in all things fieldwork related and was the source of many adventures I doubt I will ever forget. My family was always there with love, support, and encouragement. I will always be indebted to them for fostering my love of wildlife and the outdoors, and giving me the confidence to do whatever I put my mind to. Paul Cramer provided love, support, and understanding even during the periods of frazzled, neurotic thesis preparation when I was likely a little less than charming. Sage, Mokey, and Noodles consistently provided comic relief and general tail wagging.

I dedicate this thesis to the Northern Skeena Mountains wilderness, all of the people committed to its conservation, and of course all of the mountain goats that call it home.

Chapter 1- Introduction

BACKGROUND

Mountain goats (*Oreamnos americanus*) are an alpine-dwelling ungulate classified in the Rupicaprinae tribe within the Caprinae subfamily of the Bovidae family (Youngman 1975). The current distribution of mountain goats, including native, reintroduced, and introduced populations, ranges across western North America from Utah and Colorado extending north to the Yukon, Northwest Territories and Southeast Alaska with the majority of the population occupying British Columbia (B.C.) and Southeast Alaska (Festa-Bianchet and Côté 2008, Mountain Goat Management Team 2010). Although tolerant of a wide range of climates, mountain goats are dependent on steep, rugged terrain, which they use to avoid and escape predation (Hamel and Côté 2007, Mountain Goat Management Team 2010).

As of 2012, core populations, including those inhabiting the central coastal and northwest regions of B.C., were large and stable, but numerous herds occupying the southern and southwest regions of the province, as well as several herds within the Rocky Mountains and Columbia Mountains, showed evidence of decline, with many populations under 50 animals (Poole and Adams 2002, Gonzalez-Voyer et al. 2003, Hamel et al. 2006, Mountain Goat Management Team 2010). The decline of these populations has been met with considerable concern from wildlife managers and the public because recent work indicates that small mountain goat herds (<50 animals) have a high extinction risk (18% – 82% over 40 years) even in the absence of harvest (Hamel et al. 2006). Understanding and managing for the factors underlying these population declines is critical for the recovery of threatened populations and the pro-active conservation of those that are currently stable.

One of the factors thought to contribute to declines in mountain goat populations is repeated disturbance (Joslin 1986, Wilson and Shackleton 2001, Festa-Bianchet and Côté

2008). In some areas of mountain goat range, including B.C., this disturbance is largely related to the expanding helicopter-supported recreation industry (Denton 2000, Wilson and Shackleton 2001, Festa-Bianchet and Côté 2008). Several studies have shown helicopter disturbance to cause short-term stress responses in mountain goats including fleeing, decreased foraging, and increased vigilance (Foster and Rahs 1983, Côté 1996, Goldstein et al. 2005). These short-term impacts on behaviour could translate to consequences to movement rates, range use and ultimately survival and population productivity (Wilson and Shackleton 2001, Festa-Bianchet and Côté 2008).

Although there has been no rigorous study of the effects of disturbance on mountain goat demographics, there have been anecdotal reports of decreased productivity and reduced population size of herds inhabiting areas of high helicopter activity (Joslin 1986, Denton 2000). Several heliskiing operators, however, contend that the animals inhabiting their tenure areas have become habituated to heliskiing activity (Wilson and Shackleton 2001), referring to the persistence of mountain goat populations in established operating areas as evidence of a non-effect of heliskiing on populations.

In light of the abovementioned concerns and the continued expansion of helicopter-based industry, the B.C. government established Wildlife Guidelines for Backcountry Tourism/Commercial Recreation (Government of British Columbia 2006). The Wildlife Guidelines bring attention to the impacts of backcountry recreation on wildlife, and define measures to minimize the disruption and displacement of wildlife by commercial recreation. Within the guidelines, mountain goats are identified as a species particularly sensitive to aerial disturbance, necessitating additional restrictions, including a 1,500-m, line-of-sight avoidance of occupied mountain goat habitat by helicopters, and when outside of restricted areas, the avoidance of any visible mountain goats within 1,500 m. The government also acknowledged, however, the significant knowledge gaps surrounding helicopter-mountain goat interactions, and the impediment they present in establishing effective and meaningful regulations.

The largest knowledge-gap affecting management is the lack of understanding of the longer-term effects of disturbance. The effects of disturbance are complex, and are often considered at 3 spatial-temporal scales: short-term, medium-term, and long-term. Because there is often a lack of standardization in their measurement across the literature, for the purposes of my thesis, short-term responses refer to the reactions of animals to helicopters that occur directly following helicopter approaches and are verified by observer-based studies. The temporal scale of reactions observed in these studies range from 15 minutes following disturbance (Goldstein et al. 2005) to several hours following disturbance (Côté 1996). Medium-term responses are the responses to helicopter activity that are evident when observing the daily to seasonal behaviour patterns and habitat use of animals that have been exposed to helicopter activity (e.g., changes in movement behaviour, temporary displacement). Long-term responses are those effects that result in demographic changes to reproduction and population size over years.

Our knowledge to date regarding mountain goat-helicopter interactions is largely limited to short-term movement responses, and suggestions of how these responses may translate to medium- and long-term effects. It is uncertain, however, whether short-term behavioural responses are translated into long-term changes in habitat use or fitness, for example, or how those changes may influence reproduction, survival or population size (e.g., Gill et al. 2001, Beale and Monaghan 2004, Bejder et al. 2006).

My research was designed to examine the effects of helicopter activity on a daily to seasonal scale to better define the disturbance response of female mountain goats, in terms of both movement behaviour and habitat use. This work on medium-term responses provides additional information that is more likely to extrapolate to longer-term demographic effects than short-term responses; thereby providing valuable information to help guide species conservation efforts. In relating how and why animals respond to heliskiing at a medium-term scale, this work also provides information valuable in refining management guidelines to minimize the effects of heliskiing and helicopter disturbance on mountain goats.

OBJECTIVES

My thesis had three objectives aimed to better understand the movements and habitat use of female mountain goats in relation to heliskiing activity. The first objective was to describe various measures of medium-term movement behaviour exhibited by animals exposed to a gradient of heliskiing activity. The second objective was to examine resource-selection patterns by individual animals during the early winter season and heliskiing season, and how selection strategies differed in relation to heliskiing activity. The final objective was to offer recommendations relative to the current management of heliskiing activity within mountain goat range.

ORGANIZATION OF THESIS

This thesis is presented as 2 'stand-alone' chapters (Chapters 2 and 3) to be submitted for peer-reviewed publications. These chapters are preceded by this introduction (Chapter 1), and summarized by a chapter on the implications of my research to management of helicopter activity within mountain goat range (Chapter 4).

In Chapter 2 (*Effect of Heliskiing Activity on Movement Behaviours of Mountain Goats)*, I examined the movement behaviour of animals relative to helicopter interactions. On a seasonal scale, I assessed whether differences in movement metrics among animals depended on the frequency of interactions. I then described the movement behaviour of individual mountain goats in the days directly following helicopter interactions; determining whether animals made anomalous movements or showed evidence of displacement during the days following helicopter approaches, and what helicopter- or environment-related factors may have influenced these movement behaviours.

In Chapter 3 *(Effect of Heliskiing on Resource Selection by Mountain Goats),* I examined the habitat-use patterns and resource-selection strategies of female mountain goats that inhabited areas with different heliskiing frequency. I examined the resource-selection patterns of individual animals during the early winter and heliskiing seasons, and assessed patterns within and among animals that may have been attributed to heliskiing activity, such as increased use of escape terrain. More directly, I examined the importance of the frequency of helicopter activity as a covariate within resource-selection models, allowing me to determine whether animals avoided areas of frequent heliskiing use.

In the final chapter *(Management Recommendations),* I present a synthesis of the study results in light of present management strategies. Because the tenure operator within our study area followed the management actions suggested in the B.C. Wildlife Guidelines (Government of British Columbia 2006), I assessed the efficacy of those guidelines in terms of: 1) minimizing disruption of the movement patterns of mountain goats; and 2) preventing displacement of animals by heliskiing activity. I also proposed additional restrictions that should be considered in future guidelines managing for helicopter activity, and future research priorities regarding the effects of helicopters on mountain goats.

Throughout Chapters 2 and 3, I use the 1st person plural to both acknowledge the contributions of others to this work, and to be consistent with the format in which the 2 chapters will be submitted for publication.

Chapter 2- Effect of Heliskiing Activity on Movement Behaviours of Mountain Goats

ABSTRACT

Helicopter-related disturbance may result in heightened energetic expenditures and displacement of mountain goats (*Oreamnos americanus*), impacts that could have adverse demographic implications. In 2007–2010, we related proximity and visibility of global positioning system (GPS)-monitored helicopter flights, obtained in cooperation with Last Frontier Heliskiing (LFH), to locations of 11 GPS-collared female mountain goats, inhabiting a gradient of heliskiing activity, both spatially and temporally. We identified the presence or absence of longer-distance, anomalous movements occurring in the 48 h following helicopter interactions that were within 2 km. Using logistic regression and an information-theoretic approach, we determined that the probability of anomalous movements increased: 1) the closer the helicopter was to the animal; and 2) with increasing distance to escape terrain. Paired comparisons of the 3 days pre- and post-helicopter approaches indicated that the size of use-areas increased in 3 of 11 animals, but that animals were not generally displaced relative to pre-disturbance use-areas. Seasonal-movement metrics and seasonal-range sizes of individuals did not increase with increasing helicopter exposure. Our study suggests that helicopter activity within 2 km of mountain goats can result in increases in movements and size of use-areas in the days following interactions. Displacement and seasonal effects (i.e., increased movement rates and range size), however, can be avoided if pre-planning measures ensure heliskiing activity is restricted within 1,500 m of areas identified as mountain goat winter range and frequency of heliskiing exposure is low (i.e., <1 h/month). At higher exposures to heliskiing, separation distances should be extended to 2 km to ensure seasonal effects on movement are avoided.

INTRODUCTION

Increasing access to wilderness areas through helicopter-supported recreation has led to concerns regarding the adverse effects of increased disturbance on wildlife. As a species, mountain goats (*Oreamnos americanus*) may be particularly affected by helicopter disturbance as they appear to respond to disturbance at a farther distance than other ungulates studied (Miller and Gunn 1979, Stockwell et al. 1991) and because helicopter activity is increasing rapidly over much of their range, especially in British Columbia (B.C.), where the majority of the species exists (Wilson and Shackleton 2001). As a form of disturbance, helicopters are of specific concern because they are able to cover large areas and encounter more animals per unit time (Knight and Gutzwiller 1995), move in unpredictable spatial patterns (Taylor and Knight 2003*b*), and can create high-decibel, startling noise (Larkin 1996).

Recognizing the potential consequences of increasing helicopter activity on wildlife, helicopter-based industries such as helicopter-supported recreation are often regulated by guidelines that limit their activity within critical wildlife areas. In B.C., the B.C. Wildlife Guidelines (Government of British Columbia 2006) attempt to minimize the disruption and displacement of mountain goats by recreation- and tourism-based helicopter activity by recommending a 1,500-m line-of-sight avoidance of occupied mountain goat habitat, along with a suite of other recommendations (Appendix A). Within the guidelines it has been recognized, however, that more research focused on mountain goat response to helicopter disturbance is needed to ensure that management strategies are effective.

The issue of disturbance is complex, and quantifying an animal's response to disturbance poses several challenges. First, how an animal responds to a disturbance depends on numerous factors including: 1) the biology of the animal (Walther 1969, Runyan and

Blumstein 2004, Loehr et al. 2005); 2) the characteristics of the disturbance stimuli (Frid 1999, Blumstein et al. 2003, Taylor and Knight 2003*b*); and 3) the environmental surroundings of the animal (Bonenfant and Kramer 1996, Frid 1999, Festa-Bianchet and Côté 2008). Second, responses of animals to disturbance occur at a range of spatial and temporal scales (i.e., short-term, medium-term, and long-term; Wilson and Shackleton 2001), and the inferences made regarding the effects of disturbance are likely to vary according to the scale of examination. As detailed in Chapter 1, short-term refers to the response immediately following the approach; medium-term refers to the behavioural or physiological effects occurring in the days following the disturbance, or the season wherein the disturbance took place; and long-term refers to demographic changes or permanent displacement of populations exposed to disturbance.

Inferences regarding the effects of disturbance typically rely on measurement of short-term effects: the obvious, direct responses of the animal to a disturbance stimulus that can be behavioural (e.g., flight, vigilance) or physiological (e.g., altered heart rate; Gill et al. 2001, Beale 2007). Although these short-term effects are most often documented, it is whether or not these short-term responses translate to detrimental longer-term and cumulative effects that is of primary concern in regards to species conservation (Knight and Gutzwiller 1995, Wilson and Shackleton 2001). Relating demographic change to disturbance effects, however, is challenging because of the multitude of potential confounding factors that affect demographics, and the time required to rigorously study such effects (Wilson and Shackleton 2001, Beale 2007).

Despite concerns regarding the sensitivity of mountain goats to helicopter-related disturbance, relatively few studies have examined the issue in terms of short-term responses, (Foster and Rahs 1983, Côté 1996, Gordon and Reynolds 2000, Gordon and Wilson 2004, Goldstein et al. 2005) and only one study addresses medium-term responses (Poole and Heard 1998). No rigorous studies have examined the effects of helicopter disturbance on a longer-term scale. It is, therefore, uncertain whether the observed short-term responses of animals to disturbance translate to longer-term effects, or whether there are more subtle effects that occur beyond the short-term temporal and spatial scale. The primary goal of our research was to examine the effects of helicopter-supported recreation on medium-term daily and seasonal movement behaviour. To do this, we examined the daily and seasonal movement behaviour of radio-collared female mountain goats inhabiting an active heliskiing tenure area within northern B.C.

By relating animal locations to helicopter locations, we identified the times when helicopters were within 2 km of animals, then monitored individual movement behaviour during the days following these interactions to identify displacement effects or adverse changes to movement behaviour. We also determined individual cumulative helicopter exposure over the heliskiing season, and examined whether exposure to heliskiing affected seasonal movement behaviour. Because the heliskiing tenure holder operating in the study area followed best practices of the B.C. Wildlife Guidelines (Government of British Columbia 2006), our results also provided an assessment of the efficacy of the guidelines to minimize the frequency of helicopter activity within the vicinity of mountain goats and prevent seasonal displacement.

At the scale of seasonal movements, we examined: 1) whether animals in areas of higher heliskiing intensity showed higher rates of movement or increased range sizes relative to those animals in areas of lower heliskiing intensity; and 2) if within-animal movement rates or range size increased during the heliskiing season using the early winter season as a control. The short-term flight responses observed directly after helicopter approaches have been suggested to translate to higher average seasonal movement rates, and therefore higher energetic expenditures (Festa-Bianchet and Côté 2008), but such effects have never been quantified. As the collared animals in our study inhabited a gradient of heliskiing activity, we were able to assess seasonal movement and range metrics in relation to individual levels of heliskiing exposure.

At the scale of medium-term areas used (3-day use-areas), we examined the potential increased movement and displacement of animals in the 72 h following helicopter interactions. Poole and Heard (1998) documented that mountain goats moved up to 70% more in the 24 h following disturbance compared to the 24 h prior to telemetry flights, but whether these movements resulted in animals temporarily abandoning the area where the disturbance occurred is not known. By comparing the size and overlap of the 3-day use-areas pre- and post-helicopter exposure, we were able to examine whether animals: 1) had an increased use-area size; and 2) had been temporarily displaced. We chose to compare 3-day rather than 2-day use-areas to ensure the pre-helicopter control periods were representative of average use-areas, and to detect displacement that persisted longer than 1 day.

Finally, we looked for the presence or absence of anomalous movements by collared mountain goats in the 48 h following helicopter activity. We defined anomalous movements as longer than average movements that involved movement outside of the individuals typical winter range. In short-term observations, these anomalous movements would likely be regarded as flight movements. In examining movements at a medium-term scale, however, we were able to also detect anomalous responses that may be lagged (i.e., occurring up to 48 h following helicopter activity). We chose a threshold of 48 h to ensure that we had accounted for any lagged effects without associating the anomalous movement with other helicopter activity that may have occurred 48 h following the mountain goat-helicopter interaction tested for. Our data also allowed us to examine factors such as helicopter visibility, proximity, landing activity, past disturbance history, and a range of terrain attributes that may influence whether an animal's exhibits an anomalous movement in response to helicopter activity.

We predicted that if heliskiing activity was disruptive to medium-term movement patterns of mountain goats, we would observe: 1) anomalous movement behaviour in the 48 h following heliskiing activity; 2) increased size of use-areas in the 72 h following helicopter approaches compared to the 72 h prior, and displacement from the use-area where the disturbance occurred; and 3) increased seasonal movement rates and range sizes during the heliskiing season in animals that were exposed to higher levels of heliskiing activity. Conversely, if we saw a lack of anomalous movement behaviour, no change in the extent of the use-areas, and no detectable change in seasonal movement rates, we would infer that heliskiing activity, within the range we observed, did not affect the medium-term movements of collared animals.

STUDY AREA

We studied mountain goat-heliskiing interactions within the Last Frontier Heliskiing (LFH) tenure area located in the Coastal Mountains of northwest B.C., Canada (56°18'57°02' N, 129°14'130°32' W) approximately 70 km east of the Pacific Ocean and 250 km south of Dease Lake on Highway 37 (Figure 2.1). The Northern Skeena Mountains study area, based on the distribution of study animals buffered by 5 km, encompassed approximately 800 km^2 of the 9000 km^2 LFH tenure area (F. Fux, LFH manager, personal communication, May 2012).

The topography of the study area is characterized by rugged mountains, steep valleys, glaciers and permanent snowfields. Elevation ranges from 483 m to 2,311 m. Plant

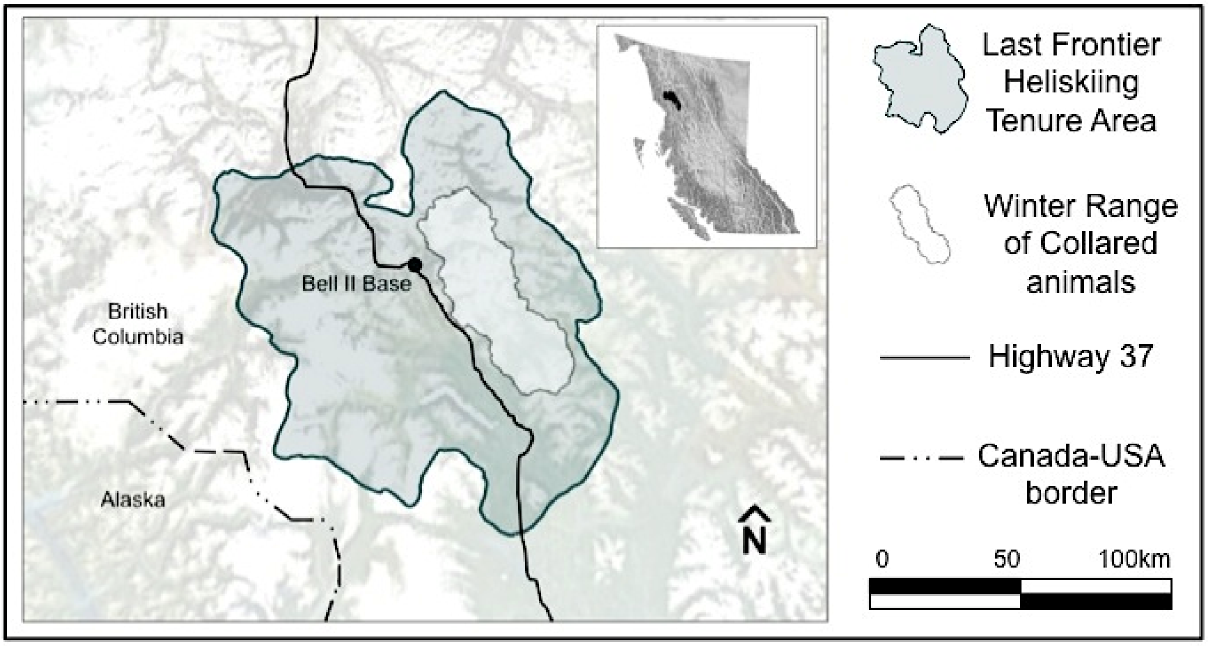

Figure 2.1. Northern Skeena Mountains study area, with map of British Columbia in upper corner. The study area was defined by the winter range of collared female mountain goats, buffered by 5 km, within the larger Last Frontier Heliskiing tenure area in 2007-2010.

communities within the study area were characterized by Interior Cedar – Hemlock forests on the lower slopes and valley bottoms; Engelmann Spruce – Subalpine Fir forests at middle elevations; and alpine vegetation or bare rock on the upper slopes and ridges (Demarchi 2011). Environmental conditions were transitional between the warmer, humid coastal climate of southeastern Alaska and the drier, colder climate characteristic of interior northern B.C., resulting in typical winters that extended from mid-October to early May with snow depths often exceeding 5 m and minimum temperatures dropping to -40° C (Keim 2003, Demarchi 2011).

The study area was selected based on several factors related to population density of mountain goats and helicopter activity. Specifically, the study area supported a sufficient mountain goat population to enable us to collar a representative sample of animals; the sources of potential helicopter and human disturbance within the study area were almost exclusively related to heliskiing, which minimized confounding sources of disturbance (aerial and ground); and the heliskiing operator was interested in partaking in the research. In 2007, the heliskiing operator (LFH) implemented the results of a pre-planning process in cooperation with the B.C. Ministry of Environment aimed to prevent heliskiing activity within 1,500 m of identified mountain goat winter range (best management practices of B.C. Wildlife Guidelines [Government of British Columbia 2006]).

METHODS

Locations of Mountain Goats

We captured mountain goats using clover traps (Rideout 1974), as modified by Cadsand et al. (2010), at pre-determined capture sites within the Last Frontier Heliskiing (LFH) tenure area. We selected capture sites to encompass a continuum of heliskiing exposure, with mountain goats captured at sites closer to the heliskiing base in the north exposed to a higher frequency of helicopter activity compared to animals captured at the southern sites (Figure 2.2). We used ground-trapping procedures to prevent possible sensitization of collared animals to helicopters during the capture process, a priority given the project objectives. We captured and handled all animals in accordance with the University of Northern British Columbia Animal Care and Use Committee (ACUC A2009.0420.017) and B.C. Ministry of Environment protocols.

Between June and July of 2007, 2008 and 2009, we fitted global positioning system (GPS) collars (GPS2000; Applied Telemetry Systems, Insanta, MN) on 19 adult female mountain goats (Appendix B). We collared only adult female mountain goats to prevent confounding differences in movement or resource use due to sex, and because females are the most influential cohort in mountain goat population dynamics (Festa-Bianchet and Côté 2008). We used horn annuli for aging animals, with mountain goats ≥2.5 years considered adults. We programmed collars to acquire locations during the heliskiing season at either 6-h intervals for 2-yr collars or 2-h or 1-h intervals for 1-yr collars. We deployed collars with higher fix rates in the final study year to maximize data acquisition. During the non-heliskiing seasons, we reduced fix rates of all collars to 12-h intervals.

We completed telemetry flights on a bi-monthly basis to monitor collar functioning and confirm general animal locations. We obtained animal locations from retrievable collars at the end of the collar-specific sampling period. We filtered animal-location data to remove fixes obtained within 2 days following capture events. We also excluded erroneous fixes indicated by unrealistic movement distances and high PDOP values (>25) (D'Eon et al. 2002). We then used remaining viable collar GPS location points to calculate movement behaviour of animals.

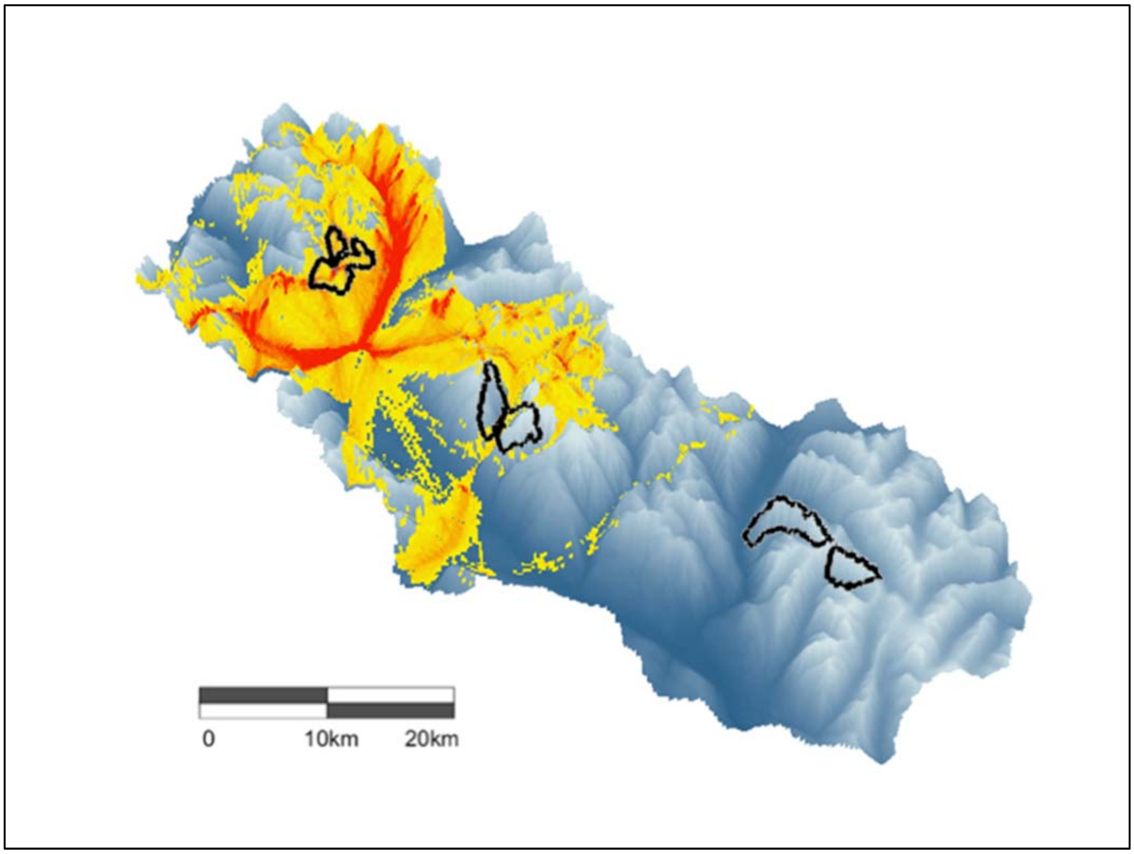

Figure 2.2. Gradient of helicopter activity within the Northern Skeena Mountains study area; red to yellow pixels represent high to low heliskiing activity within a 5-km area surrounding winter ranges of female mountain goats (outlined in black) in 2007-2010. Blue shaded areas were exposed to no heliskiing activity.

Locations of Heliskiing Activity

We recorded heliskiing activity within the LFH tenure area across 3 heliskiing seasons (15 Dec – 30 April; 2007 – 2008, 2008 – 2009, and 2009 – 2010; hereafter referred to as heliskiing years 2008, 2009 and 2010, respectively). We recorded tracks of all heliskiing activity at 100-m intervals, using GPS receivers (Garmin GPSMAP 76CSx, Olathe, KS) on board all LFH-operated helicopters (A-Star B2 and Bell 407). Each track point included the location and elevation of the machine, exact date and time, and leg-length time (the time it took the machine to travel the 100-m distance between fixes). LFH guides and helicopter pilots collected all GPS data. To help ensure data quality, we trained guides at the start of each season regarding study objectives and the procedures necessary to record and download data. At the conclusion of the heliskiing seasons, we reviewed all helicopter tracks to verify track completeness and validity.

Because helicopter points were acquired every 100-m, we examined the times separating consecutive helicopter points to differentiate between over-flight and landing activity. We isolated points with leg-length times exceeding 2 minutes as potential landing sites. We then examined these potential landing sites using a geographic information system (GIS) to confirm locations that corresponded to known heliskiing runs on the landscape. Because of the highly correlated nature of helicopter landings and ski activity, we did not pursue further isolation of ski runs, and the two events (helicopter landing and skiing) were considered as a single disturbance factor in our analyses.

Relating Heliskiing to Locations of Mountain Goats

We compared data sets for animal and helicopter locations both spatially and temporally to identify potential mountain goat-helicopter interactions. We defined interactions as instances when a helicopter was within 2 km of a collared mountain goat. We selected this threshold of 2 km based on previous work on the disturbance responses of mountain goats to aerial disturbance (Foster and Rahs 1983, Côté 1996, Goldstein et al. 2005), and to conservatively assess the current 1,500-m distance suggested in the B.C. Wildlife Guidelines (Government of British Columbia 2006).

We created a Visual Basic program that processed animal-location points sequentially, and for each animal point, identified all helicopter points within a 2-km distance and ≤6-h time threshold (occurred in the 6 h prior to the animal point). We used a ≤6-h time threshold to account for the longest fix-rate interval for the collars. For each animal point, we then used tools in GIS software (ArcMap 10; ESRI 2011) to create line features linking the animal point to each corresponding helicopter point, analyzing each line feature using the Line-of-Sight tool (ArcMap 10; ESRI 2011) to determine whether the mountain goat had a clear view of the helicopter point (visible), or whether the line-of-sight between the goat and the helicopter was obstructed by a topographic feature (non-visible) (Figure 2.3). We then calculated the 3D spatial distance and the exact temporal difference between the animal point and each helicopter point. Each mountain goat-helicopter interaction commonly involved a single animal point being associated with multiple helicopter points of varying visibility and proximities. Therefore, for each animal point we stratified the helicopter points into categories defined by: 1) visibility to the animal (visible or nonvisible); 2) spatial distance from the animal (≤500 m, ≤1 km, or ≤2 km); and 3) temporal scales according to when they occurred relative to the animal fix (≤1 h, ≤2 h, or ≤6 h previous). This partitioning allowed us to summarize helicopter points while minimizing information loss.

For each goat location, from the helicopter points accumulated within each category of combined visibility, distance and temporal scale (i.e., visible, ≤500 m and ≤1 h), we determined: 1) the closest helicopter point; 2) elevation of the closest helicopter point; 3)

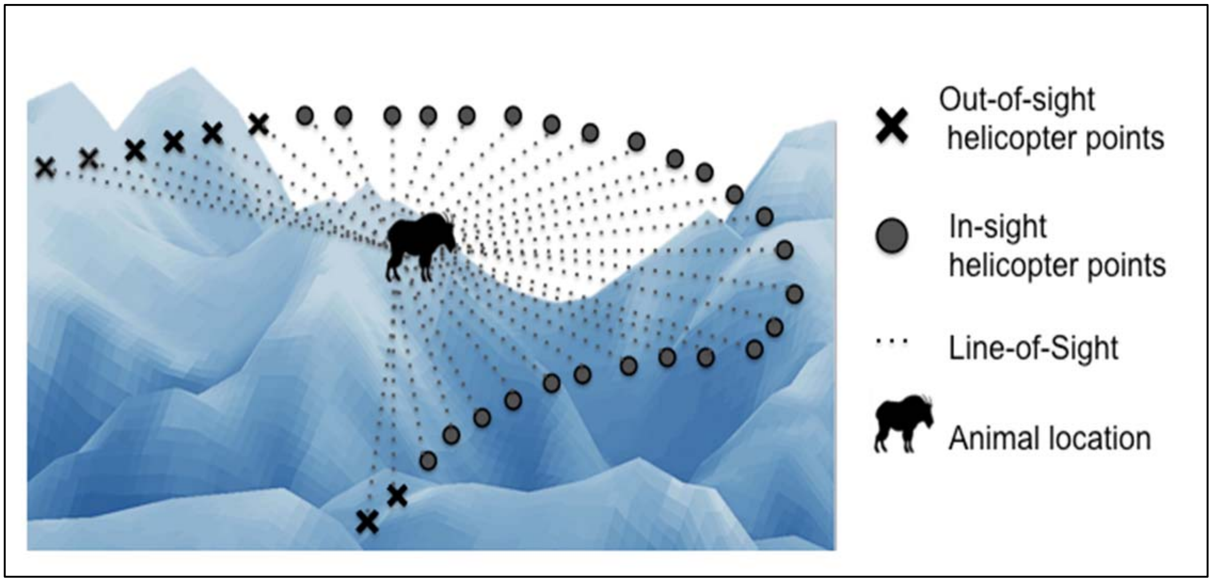

Figure 2.3. Illustration of how line-of-sight analyses were used to determine visibility of surrounding helicopter location points by an individual mountain goat when topography was considered.

whether or not a landing occurred; 4) total number of helicopter points; 5) duration of helicopter activity in seconds (the total number of helicopter points multiplied by average leg-time of 2 sec/100-m interval); and 6) helicopter disturbance history (the cumulative duration of helicopter activity over that season and year to the point in time of the goat location). When calculating cumulative helicopter history, we excluded all helicopter data occurring outside the fix interval for each GPS collar (i.e., for a 1-h collar, we kept only the helicopter points that occurred ≤1 h previous) to avoid double counting or overestimating the number of helicopter points associated with each animal point. We used the final cumulative measure of seasonal helicopter activity to represent the seasonal helicopter exposure for each animal.

Seasonal Movements and Ranges

We defined 4 mountain goat seasons (early winter, heliskiing, early summer and late summer) according to movement rates of mountain goats (m/hr), breeding biology, snow depth (derived from avalanche station data), and heliskiing activity (Table 2.1). Because collars were programmed to obtain fixes at different intervals, we created 2 location-data subsets, rarifying the original data to provide 1 consistent 12-h interval dataset for all seasons, and 1 consistent 6-h interval dataset encompassing only the heliskiing season.

For the 6-h and 12-h datasets we calculated the time between acquired fixes, and for only the consecutive GPS locations, the Euclidian distance between points (step-length) and movement rate (m/h; step-length/time between consecutive fixes). We examined average monthly and seasonal movement rates across individual animals and years to identify variations in movement attributable to animal or year effects or both. As animal movements tended to be composed of predominately short-distance movements with occasional longer-distance movements, we categorized step-lengths as short- or long-distance during winter

Table 2.1. Seasons, dates and rationale for the 4 defined seasons used to analyze movement and selection data for female mountain goats in the Northern Skeena Mountains study area, 2007-2010.

Season	Date	Rationale
Early winter	15 Oct – 14 Dec	Low movement rates, snow present in goat range, no heliskiing activity
Heliskiing	15 Dec – 30 Apr	Low movement rates, snow present in goat range, heliskiing activity
Early summer	1 May – 30 Jun	Movement to kidding areas, Medium movement rates, onset of plant green-up
Late summer	1 Jul – 14 Oct	High movement rates, plant green-up at high elevations, no snow at low elevations

(early winter and heliskiing seasons) and analyzed them as separate rate variables. Long-distance movements were those that were equal to or exceeded the 80th percentile longest movement for that year and season, with all other movements categorized as short-distance. To define this threshold for long-distance movements, we used preliminary broken-stick analyses of movement distances (Johnson et al. 2002) for each season on an individual basis, and visually examined movements using Spatial Viewer (M. P. Gillingham, unpublished program). Using these two methods, we determined that the 80th percentile distance metric provided the best separation threshold for movement distance.

For each animal and year during the early-winter and heliskiing seasons, we calculated individual seasonal home range size based on the animal's seasonal movement potential (Walker et al. 2007). Using the GIS program ArcMap 9.2 (ESRI 2009), we buffered animal GPS locations for each season by a circle with a radius equal to the animal's 95th percentile longest distance movement during that season. As such, the buffered region surrounding the animal point represented the distance the animal could have moved in the time between fixes. We then converted the overlapping buffered points to a polygon that was used as an estimate for the animal's seasonal home range. Although this method of home-range calculation was more labour intensive than traditional home-range indices, it prevented overestimation and inflation associated with minimum convex polygon (Mohr 1947) and kernelling methods (Worton 1989).

Movement Analyses: Quantifying Animal Response

We quantified the medium-term movement responses of female mountain goats to helicopter and heliskiing activity at 3 scales of increasing resolution: 1) an individual's seasonal movement rate and range size in relation to the cumulative amount of helicopter activity it was exposed to that year; 2) range size and displacement 0 h – 72 h following mountain goat-helicopter interactions; and at the smallest scale, 3) anomalous movement behaviour 0 h – 48 h following mountain goat-helicopter interactions.

Changes in seasonal movement rates

To assess whether potential variation in individual movement behaviour was related to heliskiing exposure, we tested for correlation between a range of movement metrics and the total helicopter activity the animal was exposed to that year. We tested for relatedness of the short- and long-distance movement rates and range size of individual animals during the heliskiing season to each individual's heliskiing exposure using a Spearman's rank correlation test for non-normally distributed data. Using the same methodology, we also tested for relatedness of the frequency of anomalous movements of individuals during the heliskiing season to heliskiing exposure. To test for differences in movement rates following the onset of heliskiing during the winter, we compared short- and long-distance movement rates between early winter and the heliskiing seasons for each year using a mixed model ANOVA with animal as a random effect (xt mixed; STATA 11, Statacorp 2009). We also present a comparison of individual range sizes during early winter and subsequent heliskiing seasons.

Changes in use areas pre- and post-helicopter activity

We tested for changes in size and extent of area overlap (i.e., displacement) of 3-day use-areas of individual animals following mountain goat-helicopter interactions. First, we grouped individual's locations over a 3-day period prior to and following each mountain goat-helicopter interaction, (the "pre-helicopter" and "post-helicopter" periods). We then grouped an individual's location data over a 3-day period prior to the pre-helicopter period ("control period") (Figure 2.4). The control period was compared to the pre-helicopter period

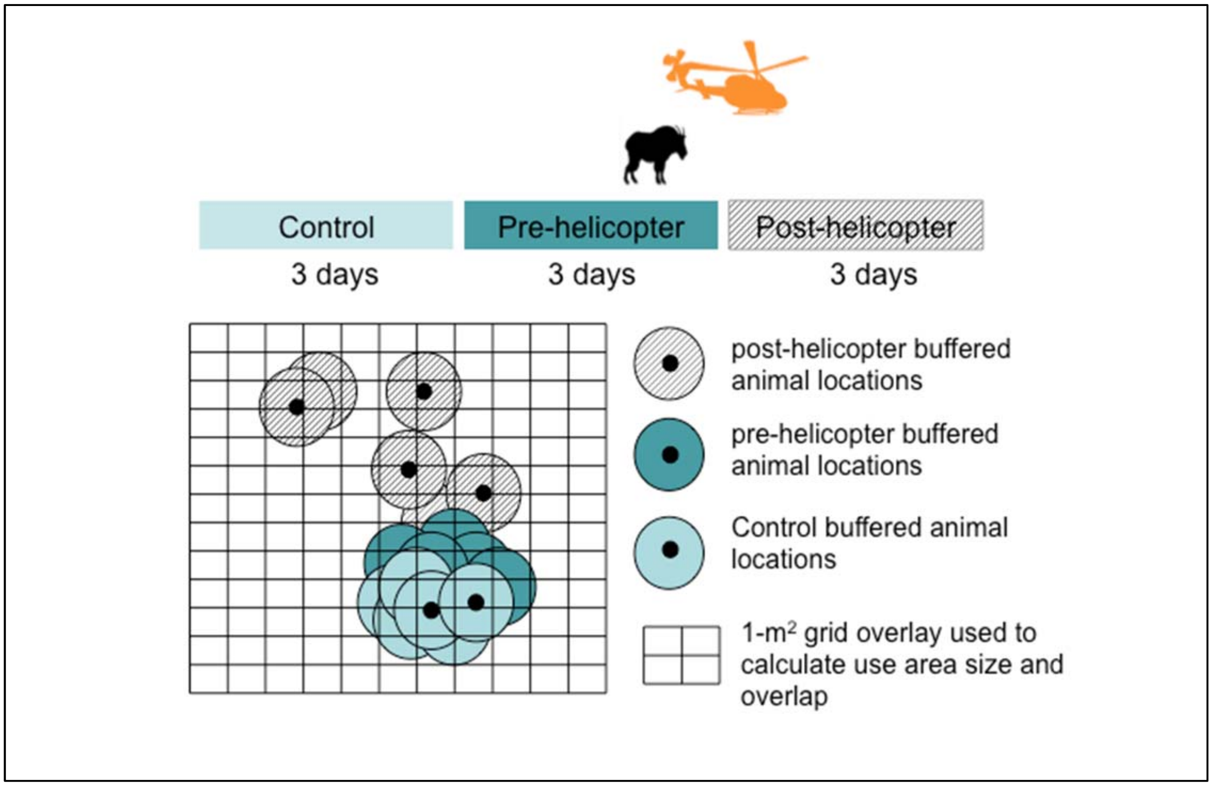

Figure 2.4. Illustration of the methodology used for determining changes in 3-day use areas of mountain goats following helicopter approaches. Animal location points, buffered by individual movement potential distances and plotted on a 1-m^2 grid overlay, illustrate how the area and overlap of the use areas were calculated.

to measure naturally occurring variation in use-area size and location. If a mountain goat-helicopter interaction occurred in the 3 days prior to the control period, we did not use a control comparison, but still compared the pre- and post-helicopter use-areas. If an animal-helicopter interaction occurred during the control period or pre-helicopter period, we excluded all periods from the analyses.

We created use-areas for mountain goats based on animal locations for each period (control, pre-helicopter and post-helicopter). To calculate size and displacement of use-areas during consecutive periods, we created a Visual Basic program that, using an animal's location data and 95^{th} movement potential buffer distance (95^{th} percentile longest movement made by that animal in that season and year), created a UTM spatially relevant distribution of the buffered location points overlaid by a 1-m^2 grid (Figure 2.4). The number of 1-m^2 cells occupied by the area of the buffered points provided an estimate of use area size. To compare control to pre-helicopter or pre-helicopter to post-helicopter periods, the program plotted the 2 use-areas simultaneously, provided a measure of the difference in size of the use-areas, and calculated the number of pixels shared between the two use-areas (calculating overlap as an analog to displacement; 100% shared equated to no displacement).

For each animal, we used paired one-tailed *t*-tests ($\alpha = 0.05$) to assess significant increases in size of post-helicopter use-areas compared to pre-helicopter use-areas and to test for differences in size of use-areas in corresponding control periods to account for naturally occurring variation. To test for temporary displacement following helicopter interactions, we compared the percent overlap of pre-helicopter and post-helicopter ranges to the overlap of control and pre-helicopter ranges for each animal, using a similar paired one-tailed *t*-test approach. We examined what factors might influence the probability of displacement occurring using a GLLAMM analysis (generalized linear latent and mixed-model approach;

STATA 11, Statacorp 2009) with animal as a nested term. Other covariates included in the regression model were terrain ruggedness, distance to escape terrain, helicopter proximity, and cumulative helicopter exposure.

Anomalous movements following helicopter activity

We defined anomalous movements as movements that were both longer and outside the winter areas most frequently used by individuals. For each animal during the heliskiing season we identified anomalous movements using two approaches: 1) plotting the distribution of movement lengths between consecutive 6-h points and identifying those points that exceeded the 80th percentile longest movement (long-distance movements); and 2) viewing the data spatially using the Spatial Viewer program (M.P. Gillingham, unpublished program) and identifying movements that appeared atypical (i.e., long-range movements outside the home range, or movements where a new range was established for only a short period). Because collar fix schedules varied among animals (1 h, 2 h, or 6 h), we used a rarified 6-h animal point dataset to identify and classify anomalous movements. Helicopter metrics were calculated relative to the rarefied points (i.e., the closest proximity helicopter points, and duration of helicopter activity within the 6-h period following the point), thereby preventing any bias among animals associated with fix schedule.

To assess whether anomalous movements were associated with heliskiing events, for every mountain goat-heliskiing interaction we examined whether the animal involved in the interaction made an anomalous movement during the next 48 h. We then classified anomalous movements on the basis of when they had occurred relative to the helicopter activity. If the anomalous movement occurred in the first 6-h following the helicopter approach, it was termed an immediate response; if the movement occurred in the period 6 h – 48 h period following the helicopter activity, it was termed a lagged response.

To examine if animal response was dependent on helicopter visibility, we compared the proportions of anomalous responses (indicated by presence or absence of an anomalous movement in the 48 h period) to visible and non-visible approaches, assessing the significance of differences using a contingency table and *G*-test of independence (Sokal and Rolhf 1981). To determine whether anomalous movements were dependent on helicopter proximity, we stratified observations by helicopter mutually exclusive proximity classes (≤500 m, >500 m − ≤1 km, and >1 km − ≤2 km), and as above, used a contingency table and *G*-test to assess independence of classes.

Factors Influencing the Animal Responses of Mountain Goats to Helicopters

To better understand factors influencing why mountain goats move, or don't move in response to helicopter and heliskiing activity in the medium-term, we focused on anomalous movements in the 48 h following helicopter activity. We reasoned that changes in range size and seasonal movement behaviour would likely be a cumulative result of the changes in movement that occur in the 48 h following helicopters activity. Understanding these anomalous movements therefore may allow for better management of seasonal and longer-term effects.

We used an information-theoretic approach of model selection (Burnham and Anderson 2002) to evaluate terrain- and helicopter-related factors that potentially influence the anomalous movements of mountain goats in response to helicopter interactions. Using explanatory variables related to security terrain and helicopter activity (Table 2.2), we created 19 a priori candidate models (Table 2.3). Model terms were selected based on literature that detailed factors influencing flight responses of mountain goats (Foster and Rahs 1983, Côté 1996, Goldstein et al. 2005), as well as attributes that we considered biologically relevant in influencing an animal's perceived risk and movement response. All

Table 2.2. Security- and heliskiing-related covariates in candidate models used to evaluate factors that influenced anomalous movements of female mountain goats in response to heliskiing-related helicopter approaches in the Northern Skeena Mountains (2007-2010).

Covariate	Description
Distance to escape terrain	Distance (m) to a pixel of slope ≥45° (Keim 2003)
Ruggedness	Vector Ruggedness Measure (VRM), the measure of variation of slope and aspect (Sappington et al. 2007)
Helicopter proximity	Distance (m) to closest helicopter point
Helicopter exposure duration	Total time (sec) a helicopter was within 2 km of mountain goat location
Landings within 2 km	Whether or not a landing occurred within 2 km of mountain goat location
Disturbance history	Total elapsed time (sec) a helicopter was within 2 km of the animal during that season up to that animal point

Table 2.3. Candidate models used in an information-theoretic approach to describe the factors that influenced anomalous movements by female mountain goats in response to heliskiing-related helicopter approaches in the Northern Skeena Mountains (2007-2010). Model covariates are described in Table 2.2.

Model #	Models
1	Distance to escape terrain + ruggedness
2	Distance to escape terrain + ruggedness+ disturbance history
3	Distance to escape terrain + ruggedness + helicopter proximity
4	Distance to escape terrain + ruggedness + helicopter exposure duration
5	Distance to escape terrain + ruggedness+ landing within 2 km
6	Distance to escape terrain
7	Distance to escape terrain + disturbance history
8	Distance to escape terrain + helicopter proximity
9	Distance to escape terrain + helicopter exposure duration
10	Distance to escape terrain + landing within 2 km
11	Ruggedness
12	Ruggedness + disturbance history
13	Ruggedness + helicopter proximity
14	Ruggedness + helicopter exposure duration
15	Ruggedness + landing within 2 km
16	Helicopter proximity + helicopter exposure duration + disturbance history
17	Helicopter exposure duration + disturbance history
18	Helicopter proximity
19	Landings within 2 km

potential variables were tested for collinearity, with variables below the threshold tolerance score of 0.2 dropped from the models (Menard 2002). Other potential terms, including vertical position of the helicopter and landings within 1 km were not included because of issues of near-complete separation (Menard 2002). Topographic variables were derived using a Terrain Resource Information Management (TRIM) 1:20,000 scale digital elevation model (LRDW, B.C. Government Forests, Lands, and Natural Resource Operations GeoBC; 25 m resolution; generated 04 April 2009). Heliskiing metrics were derived using the procedures detailed above.

From those covariates, we used the logistic model and assessed the fit of each candidate model to the data using maximum likelihood estimation (STATA 11; Statacorp 2009). We then used Akaike's Information Criterion (AIC_c) corrected for small sample sizes ($n/K < 40$; Burnham and Anderson 2002) to rank models in order of decreasing parsimony considering both model log likelihood (LL) and number of parameters (K) (Burnham and Anderson 2002). The Akaike's weights (w_i) indicated the relative support for models compared to other models tested (Burnham and Anderson 2002). When the w_i of the top model was <0.95, the next highest ranked model was included in the top model set until the sum of w_i exceeded 0.95. We used the same set of candidate models to assess both immediate and lagged anomalous responses. We examined the predictive accuracy of top models by calculating the area under the receiver-operator curve (AUC), used when true presence and absence data are known (Fielding and Bell 1997). The value of the AUC score provides an index of how well the model discriminates. AUC scores that are: 1) less than 0.5 indicate the model does not improve discrimination beyond random assignment; 2) between 0.5 and 0.7 indicate low discrimination ability; 3) between 0.7-0.9 indicate good discrimination ability; and 4) above 0.9 indicate excellent discrimination ability (Manel et al. 2001).

RESULTS

Locations of Mountain Goats and Heliskiing Activity

We retrieved 23,397 GPS locations from 11 of the 19 mountain goats collared in the study; 16,836 of those locations occurred during the early winter and heliskiing seasons, providing data representative of 15 animal-heliskiing-seasons. Data from the remaining 8 collars could not be recovered because of animal mortalities prior to heliskiing seasons (n = 3), collar failure (n = 3), and logistic recovery issues (n = 2) (Appendix B). Of the 11 collars used in the analyses, 84% of fixes were 3D, with average collar fix precision of 4.28 m (SD = 3.16) determined from location variability of a stationary collar in the field during the winter season. Fix-success rates of collars used in the study ranged from 81.3% to 97.4% during the combined early winter and heliskiing season with an average fix success rate of 91.1% ± 6.9% ($\bar{x}$ ± SD).

Across the 3 years of heliskiing activity, 26,073 helicopter points from flight-track data occurred within 2 km and 6 h of a collared mountain goat. Among these close-proximity helicopter locations, 100 points were identified as landing sites, likely indicative of skiing activity. Although error of the GPS receivers aboard the helicopters was not evaluated statistically, fixes acquired by the receivers used in the study are generally accepted to have a 3 m – 15 m precision of locations 95% of the time (Garmin 2009).

Mountain Goat-Helicopter Interactions

We identified 214 mountain goat-helicopter interactions, as defined by a helicopter approaching within 2 km of a collared mountain goat (regardless of whether the helicopter was in-sight or out-of-sight). The number of heliskiing interactions per animal varied from 0 interactions to 61 interactions over the study period (Table 2.4). The closest mountain goat-

Table 2.4. Summary of mountain goat-heliskiing interactions for collared female mountain goats within the Northern Skeena Mountains study area (2007-2010).

Animal	Total number of approaches	Minimum approach distance (visible)	Minimum approach distance (non-visible)	Total landings within 2 km (visible and non-visible)
160	61	140	220	54
500	45	386	555	10
600	20	461	728	0
220	18	434	551	10
180	14	292	746	0
900	14	252	349	0
120	13	208	395	0
170	12	724	912	0
700	12	172	539	0
300	5	357	1025	26
150	0	–	–	0

helicopter interaction, wherein the helicopter was in-sight, was 140 m; the closest out-of-sight mountain goat-helicopter interaction was 220 m. For 200 of the 214 mountain goat-helicopter interactions, the helicopter was at a lower elevation than the animal. Only 4 of 11 animals were exposed to landings/skiing activity within 2 km.

From the distribution of helicopter proximities during mountain goat-helicopter interactions, the most frequent minimum approach distance of helicopters was 500 m − 1000 m distant from animals (Figure 2.5). Predictably, a higher proportion of close-proximity interactions were in-sight and a higher proportion of farther distance interactions were out-of-sight. Cumulative seasonal heliskiing exposure (i.e., minutes that a helicopter was within 2 km of an animal per heliskiing season), varied among individuals from 0 minutes to 255 minutes (Figure 2.6).

Seasonal Movements and Range Sizes

Average movement rates of female mountain goats during the early winter and heliskiing seasons were similar among years (Appendix C). Movement rates were lowest during the early winter and heliskiing seasons, increased during the early summer, and peaked during the late summer (Figure 2.7). Hourly movement rates were typically <100 m movements >500 m were infrequent (Appendix D). Seasonal range size varied from 1.06 km^2 to 11.53 km^2 during the early winter to 0.79 km^2 to 15.92 km^2 during the heliskiing season. Average seasonal range size was 5.51 ± 3.32 km^2 ($\bar{x}$ ± SD) in the early winter season and 6.46 ± 5.07 km^2 ($\bar{x}$ ± SD) in the heliskiing season.

Movement Responses of Mountain Goats to Heliskiing Activity

Changes in movement rates and ranges

There was no correlation between heliskiing exposure and seasonal movement rate, range size, or frequency of anomalous movements per year of individuals during the

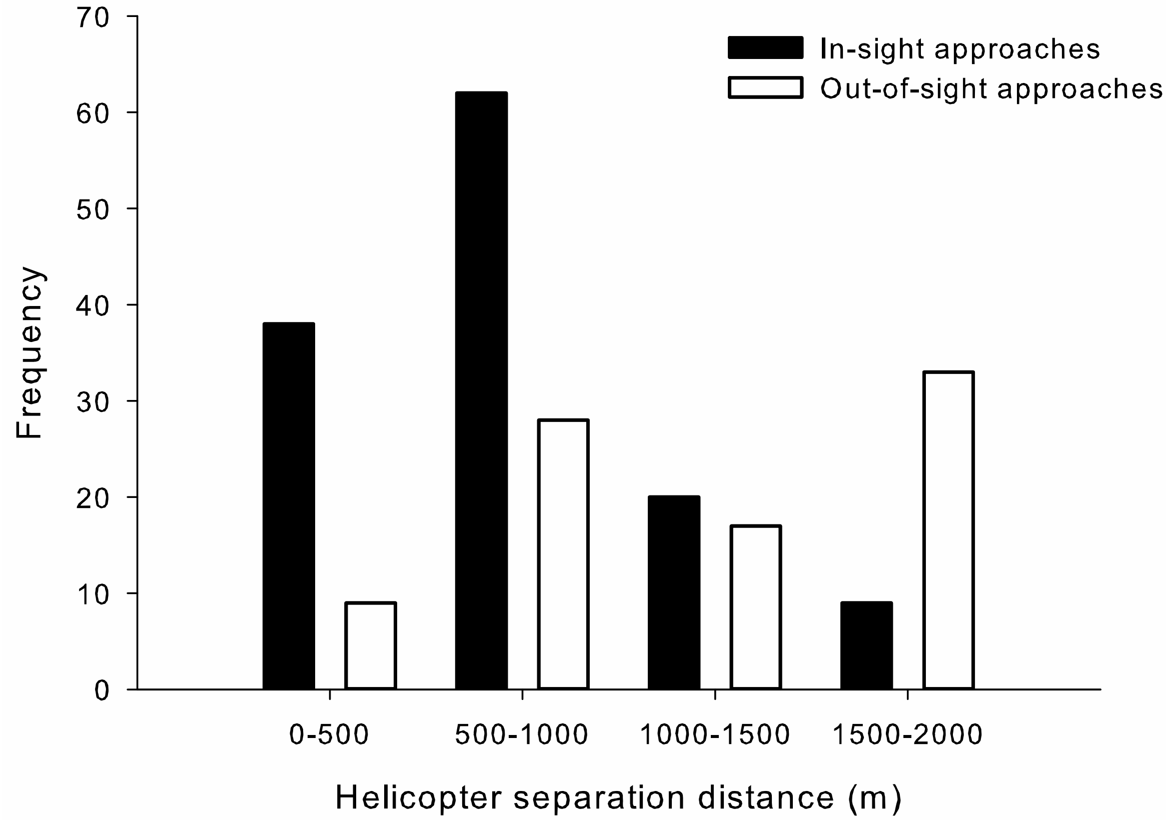

Figure 2.5. Number of helicopter approaches that occurred within 2 km of collared female mountain goats in the Northern Skeena Mountains study area in 2007-2010, stratified by the minimum separation distance between the helicopter and the animal. Approaches that were out-of-sight of the animal resulted because of topography obscuring the line of sight.

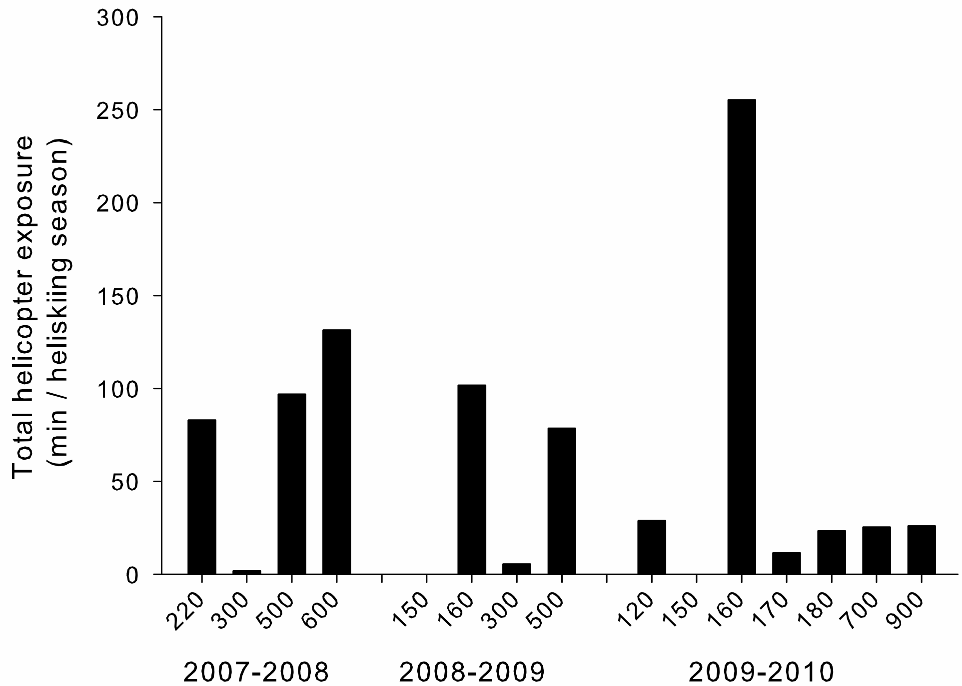

Figure 2.6. Total heliskiing activity (min/yr) that individual collared female mountain goats were exposed to during the heliskiing seasons (2007-2008, 2008-2009, and 2009-2010). Numbers along the x-axis represent individual animals, some of which were collared during multiple heliskiing seasons.

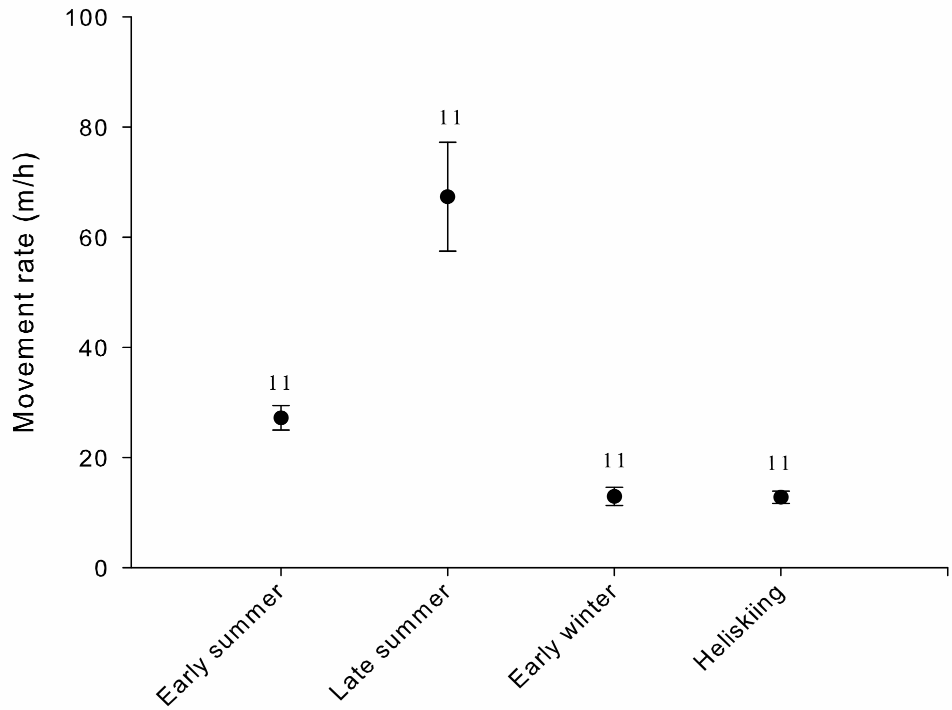

Figure 2.7. Movement rates (m/h, $\bar{x} \pm$ SE) of collared female mountain goats inhabiting the Northern Skeena Mountains across seasons in 2007-2010 (pooled across years): Early summer (1 May - 30 Jun), Late summer (1 Jul - 14 Oct), Early winter (15 Oct - 14 Dec), and Heliskiing season (15 Dec - 30 Apr).

heliskiing season (Table 2.5). Across seasons, individual animals short-distance movements rates were higher in the early winter compared to heliskiing seasons during 2008 and 2010 ($P < 0.01$ in both years; Appendix E). There was no difference in short-distance movement rates between early winter and heliskiing seasons in 2009 ($P = 0.86$). Less than 6% of the observed variation in short-distance movement rates between seasons was explained by differences among animals in any of the 3 study years. Long-distance movement rates differed significantly in 2009 and 2010, but not 2008 ($P < 0.01$ in both 2009 and 2010, $P = 0.84$ in 2008) with animal's long-distance movement rates higher in the heliskiing season compared to early winter (Appendix E). A significant portion of the observed variation in long-distance movements each year was attributed to differences among animals (31.7%, 34.9% and 23.8% in 2008, 2009, and 2010, respectively). When home ranges of individuals within season were compared on a yearly basis, 8 of 15 animals had a larger range size during the heliskiing season compared to the early winter season (Figure 2.8).

Changes in use areas pre- and post-helicopter approaches

The mean size of use-areas increased after helicopter approaches in 3 of 11 animals (all $t > 2.23$, all $P \leq 0.05$), with the balance of the animals showing no significant difference post-helicopter approaches (all $t < 1.08$, all $P \geq 0.16$). As predicted, there was no significant difference in the mean size of control and pre-helicopter use-areas (all $t < 1.03$, all $P \geq 0.15$). The overlap of mean pre- and post-helicopter use-areas were not different compared to the overlap of control and pre-helicopter use-areas, indicating no evidence of medium-term displacement (all $t < 1.32$, all $P \geq 0.10$).

Displacement was not explained by any of the covariates tested for in the GLLAMM analyses, with the exception of the animal term in 2008 ($z = -2.62$, $P \leq 0.01$). The animal

Table 2.5. Relationship between the amount of heliskiing exposure (in minutes) that collared female mountain goats in the Northern Skeena Mountains were exposed to and 5 movement-related metrics. *n* is the number of animal-heliskiing seasons tested, $\bar{r}_s$ is the Spearman's rank correlation test statistic, and *P* is the associated probability value that these relationships could have occurred by chance.

Variable	*n*	$\bar{r}_s$	*P*
$\bar{x}$ movement rate	15	0.03	0.92
$\bar{x}$ rate of anomalous movements	15	0.06	0.82
$\bar{x}$ rate of non-anomalous movements	15	-0.13	0.65
Range size (heliskiing season)	15	-0.08	0.77
Frequency of anomalous movements	15	0.34	0.22

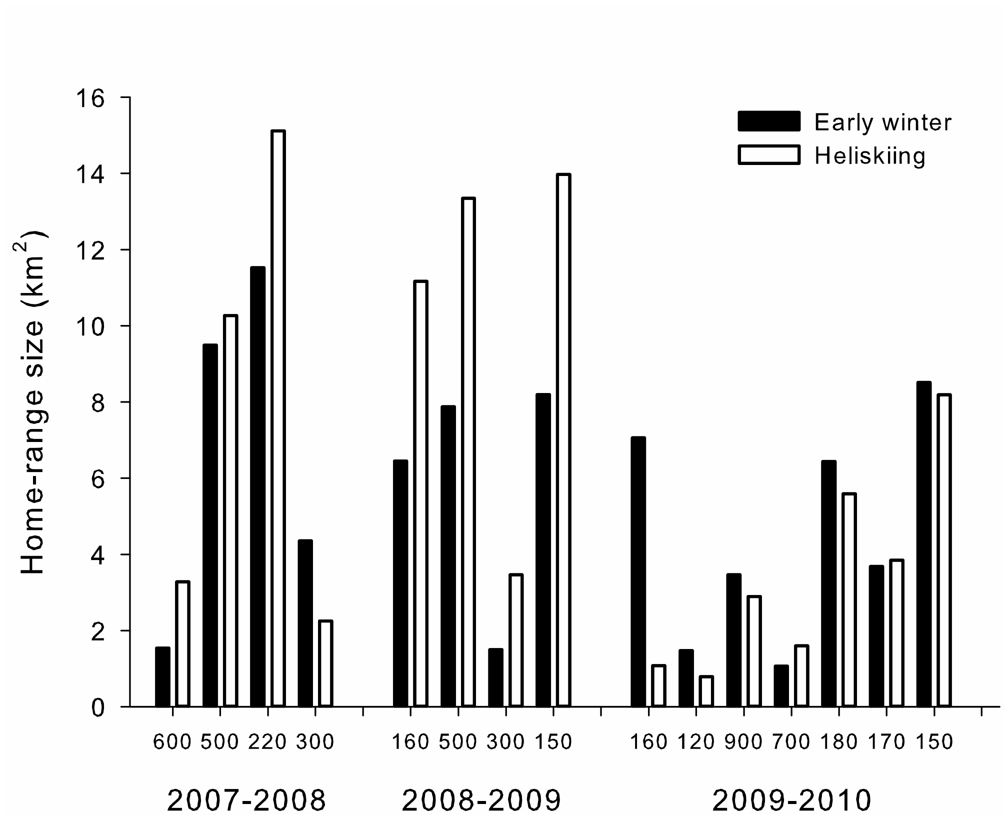

Figure 2.8. Range size (km^2) of collared female mountain goats inhabiting the Northern Skeena Mountains study area during the early winter and heliskiing seasons in 2007-2010. Numbers along the x-axis represent individual animals, some of which were collared in multiple years.

term, however, was not significant in 2009 or 2010 (all $z < -1.82$, all $P \geq 0.07$). All other covariates used in the GLLAMM models (terrain ruggedness, distance to escape terrain, helicopter proximity, cumulative helicopter exposure) were not significant in explaining variation in displacement effects following helicopter interactions (all $z < -1.65$, all $P \geq 0.07$).

Anomalous movements following helicopter activity

Anomalous responses were observed following 25 of 37 (67.6%) interactions when the helicopter was between 0 and 500 m and 66 of 177 (42.4%) interactions when the helicopter was between 501 m and 2 km. The length of observed anomalous movements ranged from 97 m to 3,413 m (over the 6-h period), with an average movement length of 361 m ± 317 m ($\bar{x}$ ± SD). The proportion of anomalous movements (considering both immediate and lagged movements) made in response to helicopter activity was not dependent on visibility (likelihood-ratio $\chi_1^2 = 1.24$, $P = 0.27$), but was dependent on proximity class (<500 m, 500 m – <1 km, and 1 km – <2 km; likelihood-ratio $\chi_2^2 = 15.44$, $P = <0.01$).

Stratifying anomalous movements in response to helicopters on an individual basis showed that some animals frequently responded o helicopter activity with more anomalous movements than non-anomalous movements (animal 120, 220, and 700) while others appeared less likely to exhibit anomalous movements (animals 160, 500, 600, and 300) (Figure 2.9). The proportion of helicopter approaches that were followed by an anomalous response did not appear to be related to the amount of helicopter activity that the animal had been exposed to that heliskiing season (Figure 2.10).

Factors Influencing Movement Responses

Our examination of movement response strategies indicated that the probability of movement responses was related to topography, helicopter approach characteristics, and an

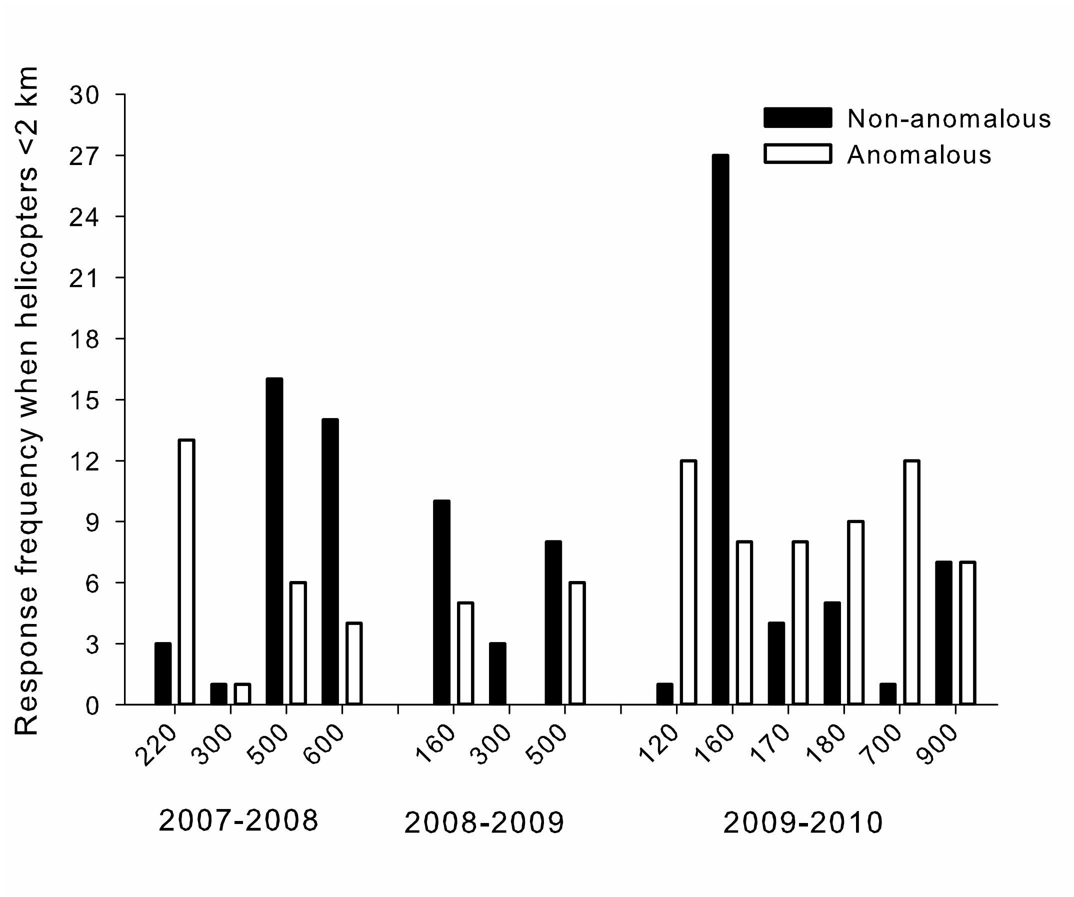

Figure 2.9. Anomalous and non-anomalous movement responses made by collared female mountain goats inhabiting the Northern Skeena Mountains study area (2007-2010) in response to helicopter interactions ≤2 km away. Numbers along the x-axis represent the individual animal involved in the interactions. In some instances animals were collared during multiple heliskiing seasons.

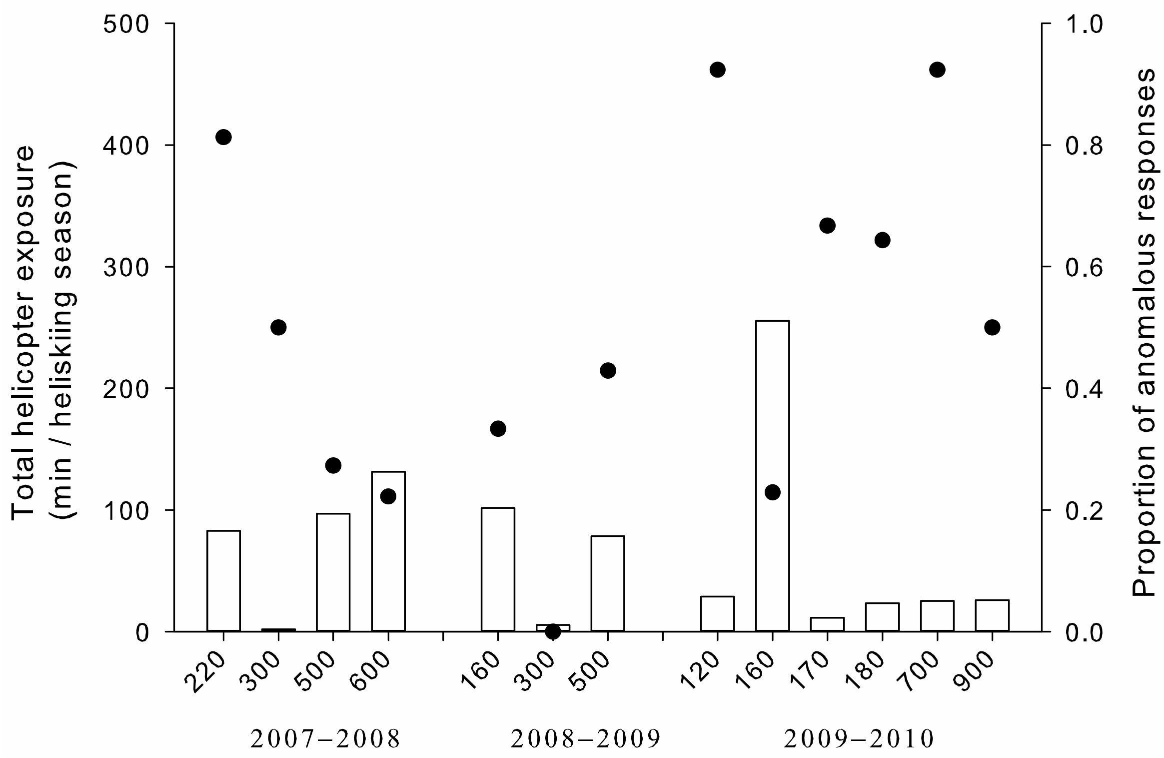

Figure 2.10. The observed proportion of anomalous movements made by female collared mountain goats in response to helicopter approaches within 2 km (●) on the right axis and the cumulative seasonal helicopter activity that mountain goats were exposed to that year (open bar) on the left axis. Values on the x-axis represent individual animals, some of which were collared during multiple heliskiing seasons (2007-2010).

animal's disturbance history. Similar primary explanatory factors influenced both immediate (Table 2.6) and lagged (Table 2.7) responses. Review of AUC values, however, indicated models had low discrimination ability, with AUC scores of immediate models ranging from 0.592 – 0.656, and scores of lagged models ranging from 0.560 – 0.671.

Model results suggested that mountain goats were more likely to make an immediate anomalous movement in response to a helicopter interaction the farther the animal was from escape terrain and the closer the proximity of the helicopter. Other variables within the top models were disturbance history and landings within 2 km; with the probability of anomalous responses decreasing as the disturbance history of the animal increased and when landings occurred. These variables, however, must be viewed with caution as they had large standard errors relative to the coefficients. Distance to escape terrain was also the strongest predictive factor explaining lagged movements, with animals more likely to make a lagged movement when farther from escape terrain. Also similar to the immediate-response models, the probability of lagged movements was inversely related to helicopter proximity and slightly lower when a landing occurred. Unlike the immediate-response model, probability of movement was also found to be dependent on terrain ruggedness with higher probability of movement in less rugged areas.

DISCUSSION

Seasonal Differences in Movement Behaviour

Movement rates during the winter seasons (i.e., early winter and heliskiing season) varied across animals (10.1 m/h – 36.5 m/h), but were similar to other areas in Northern B.C. and Alaska (Keim 2003, White 2006). We found no significant changes in movement rate relative to helicopter activity during the heliskiing season. Likewise, the size of seasonal home ranges during the winter seasons was highly variable (0.78 km^2 – 15.1 km^2) and

Table 2.6. Top models explaining the factors that influenced the probability of immediate, anomalous-movement responses of collared female mountain goats to helicopter approaches in the Northern Skeena Mountains. Statistics include number of parameters in the model (*K*), log likelihood (LL), area under the receiver-operator curve (AUC), Akaike's information criterion for small sample sizes (AIC_c), Akaike's weights (w_i), selection coefficients and probability values of model parameters ($\beta_i \pm$ SE, *P*); $n = 207$.

Models and Variables	*K*	LL	AUC	AIC_C	w_i	$\beta_i \pm$ SE	*P*
Distance to escape terrain + helicopter proximity	3	-110.35	0.652	226.76	0.50		
Distance to escape terrain						0.024 ± 0.009	<0.010
Helicopter Proximity						-0.0007 ± 0.0003	0.046
Distance to escape terrain	2	-112.09	0.592	228.20	0.24		
Distance to escape terrain						0.023 ± 0.0095	0.014
Distance to escape terrain + disturbance history	3	-111.72	0.656	229.50	0.13		
Distance to escape terrain						0.023 ± 0.010	0.021
Disturbance history						-0.0001 ± -0.81	0.418
Distance to escape terrain + landings within 2 km	3	-111.96	0.618	229.98	0.10		
Distance to escape terrain						0.023 ± 0.010	0.017
Landings 2 km						-0.183 ± 0.470	0.697

Table 2.7. Top models explaining the factors that influenced the probability of lagged, anomalous-movement responses of collared female mountain goats to helicopter approaches in the Northern Skeena Mountains. Statistics include number of parameters in the model (K), log likelihood (LL), area under the receiver-operator curve (AUC), Akaike's information criterion for small sample sizes (AIC_c), Akaike's weights (w_i), selection coefficients and probability values of model parameters ($\beta_i \pm$ SE, P); n = 207.

Models and Variables	K	LL	AUC	AIC_C	w_i	$\beta_i \pm$ SE	P
Distance to escape terrain	2	-113.96	0.560	231.94	0.44		
Distance to escape terrain						0.03 ±0.01	0.011
Distance to escape terrain + landings	3	-113.38	0.671	232.83	0.28		
Distance to escape terrain						0.03 ± 0.01	0.010
Landings 2-km						-0.45 ± 0.40	0.259
Distance to escape terrain + proximity	3	-113.85	0.626	233.76	0.18		
Distance to escape terrain						0.03 ±0.01	0.011
Proximity						-0.0002 ±0.0003	0.570
Distance to escape terrain + ruggedness + landings within 2 km	4	-113.37	0.668	234.87	0.10		
Distance to escape terrain						0.034 ±0.0138	0.014
Ruggedness						-1.351 ± 17.087	0.937
Landings 2 km						-0.446 ± 0.378	0.238

although larger than home ranges reported in other studies in some cases (Smith 1977, Schoen and Kirkoff 1982, Keim 2003, White 2006), was not related to exposure to heliskiing. Although we did not expect that movement rates would be equal across the early winter and heliskiing seasons, as animals are transitioning from summer to winter range during the early winter, we found that in 2 of the 3 study years, individuals longer-distance movement rate was higher in the heliskiing season compared to the early winter season. The increased average length of long-distance movements during heliskiing seasons in this study lends support to the theory that short-term flight responses of mountain goats to helicopters may translate to higher overall movement rates (Festa-Bianchet and Côté 2008). The increase in movement, however, was evident regardless of the amount of helicopter activity that animals were exposed to, and may have been related to increased movement during April (the last month of the heliskiing season) due to decreased snow accumulation in some areas of the range. Or, the relatively low movement rates in November (during the early winter), which may be associated with the rut when females have been shown to exhibit reduced movement strategies that maximize chances of discovery by males (White 2006).

Movement behaviour of mountain goats during the winter (early winter and heliskiing seasons) is influenced by many factors including gender, age, body condition, herd size, previous activity, reproductive status, environmental conditions, surrounding topography, and disturbance stimuli, which could be either naturally occurring, as in the case of a nearby avalanche, or anthropogenic, such as helicopter disturbance (Dailey and Hobbs 1989, White 2006, Festa-Bianchet and Côté 2008). Although there was a gradient of heliskiing exposure amongst the collared animals, the scale of the exposure was less than expected at the study's outset. The highest individual helicopter exposure rate (duration of helicopter activity within

2 km during a 4.5 month season) was ~1 h/month, and the next highest rate was 0.5 h/month (approximately 0.13% and 0.07% of the total season, respectively). The low exposure of animals to helicopter activity is indicative of the success of LFH's mitigation strategies to avoid heliskiing activity in areas of mountain goat winter range. LFH and the B.C. Ministry of Environment went through extensive efforts to identify mountain goat winter range within the tenure area and then enact strategies to minimize the use of those areas through alteration and removal of ski-runs, drop off points, and flight paths that were within 1,500 m line-of-sight of those designated winter range areas. The low frequency of helicopter activity, apart from the avoidance of these areas as per the management strategy, was likely also attributed to LFH's large tenure area, which allowed options other than the repeated use of a single ski area.

Considering the low amount of heliskiing exposure among collared animals and the underlying variations in movement rates among animals (that were also evident during early winter periods when heliskiing activity did not occur; Appendix E), it would be difficult to detect any trends in movement resulting from heliskiing exposure, should they exist. Even in a system of frequent disturbance, however, testing for an effect of heliskiing exposure on seasonal metrics such as movement rate or range size would be complicated by individual variation in sensitivity to disturbance, and variable strategies of animals responding to disturbance (i.e., active versus passive response).

How disturbance risks are assessed and the degree of sensitivity to disturbance often varies among individuals in a population (Picton 1999, Ciuti et al. 2008, Stankowich 2008, Neumann et al. 2010), with some animals more tolerant of disturbance than others (Nisbet 2000). When animals do react to disturbance, their response is often analogous to their response to potential predators (Picton 1999, Frid and Dill 2002, Fortin and Andruskiw 2003, Reimers et al. 2003). The anti-predatory responses of mountain goats include: 1) active defense (fighting); 2) active avoidance (flight); and 3) passive avoidance (hiding; Chadwick 1983). Of these strategies, we would expect a response of either active or passive avoidance when considering helicopters as a disturbance stimulus (Kiem and Jerde 2004). Whether an individual's seasonal movement rate and range size increased or decreased due to disturbance would be influenced by the primary avoidance strategy used by the animal. The change in seasonal movement rates and range sizes would also be affected by whether or not an animal's response to disturbance decreased in intensity over time (i.e., habituation). Habituation to even low-impact disturbance such as hiking and mountain biking, however, may take many years to develop or never occur at all (Fairbanks and Tullous 2002).

Medium-term Use Areas Following Heliskiing Exposure

Changes in the size and location of 3-day use-areas following helicopter activity varied among animals, with size increasing for some animals and decreasing for others, but in general, not showing any evidence of overall displacement. This variability, as in the case of seasonal movement rates, could reflect the variable strategies that animals use when responding to predatory or disturbance stimuli, or differing tolerance levels of individuals. An animal already in secure terrain with limited options for alternative escape terrain may respond to disturbance with passive avoidance, resulting in a use-area of equal or smaller size with no displacement. Conversely, animals that are distant from escape terrain, or have access to large tracts of contiguous escape terrain, may respond with active avoidance, moving away from the site of the disturbance and thereby increasing the size of the use-area and resulting in temporary displacement.

Foster and Rahs (1983) noted that during a summer period of active drilling and aerial activity in the Stikine Canyon, B.C., mountain goats moved 1 km – 3 km from the site of disturbance, only returning once activity had ceased. Similarly, mountain goats were found to be displaced by helicopter logging (April through mid-November), separating themselves attitudinally from disturbance, or seeking cover in forested areas (Gordon and Wilson 2004). During the winter, however, disturbance responses may be different from those observed during the snow-free seasons (Calef et al. 1976, Varley 1998). Winter is a critical season for mountain goats, when they depend on suitable wintering areas of low snow and adequate forage (Fox et al. 1989, Taylor and Brunt 2007, Festa-Bianchet and Côté 2008, Poole et al. 2009). When alternative habitats of equal value are not easily accessible, temporarily abandoning these highly specific wintering areas may present a higher cost to animals than remaining despite frequent disturbance, due to loss of the benefits of high-quality habitat (Gill et al. 2001, Beale and Monaghan 2004, Stankowich 2008) as well as higher energetic costs imposed by movements through snow (Parker et al. 1984, Dailey and Hobbs 1989). As such, in winter animals may tolerate greater levels of risk before moving from the area. In a study examining the effects of air traffic (i.e., fixed-wing aircraft, helicopters, and paragliders) on female Alpine Chamois (*Rupicapra rupicapra*) in the winter season, animals were more likely to be displaced on days of increased air traffic (Boldt and Ingold 2005).

Animals that are not displaced by disturbance may still suffer adverse effects. Disturbance can be expressed at many scales affecting animals both behaviourally and physiologically. Animals that fail to disperse away from disturbance may not incur direct costs of locomotion, but if disturbed at high enough frequencies, may experience chronic physiological stress such as increased heart rate (MacArthur et al. 1979) or cortisol levels (Macbeth et al. 2010), which can have cascading effects on individual condition and fecundity (Calef et al. 1976, Joslin 1986, Yarmoloy et al. 1988, Harrington and Veitch 1992). Additionally, animals that are not displaced often remain vigilant in cliff terrain for some time following disturbance, indirectly affecting the ability to forage and partake in other activities beneficial to fitness (Côté 1996).

Anomalous Movement Behaviour Relative to Heliskiing Exposure

Animals often made distinct anomalous movements during the 48 h following helicopter interactions. The anomalous responses observed in the 6 h directly following helicopter approaches in some cases may have been analogous to the short-term flight responses documented in observation-based studies of disturbance. These anomalous flight-type responses, however, occurred with equal frequency in the period that was slightly lagged (6 h − 48 h) following the interaction. This has important implications because short-term disturbance studies would not account for these lagged responses and, therefore, would underestimate the frequency of movement responses that occur following helicopter activity.

Other research has also identified increases in mountain goat movements during the days following aerial disturbance, indicating a potential lagged effect of disturbance on movement behaviour. Poole and Heard (2003) observed up to 70% increase in movements of goats during the 24 h following flight activity when compared to the 24 h previous, and Keim and Jerde (2004) noted an increase in distances moved by some mountain goats for the day following telemetry flights. Interestingly, Keim and Jerde (2004) also noted that some individuals decreased their movement lengths following telemetry flights, potentially indicative of a passive avoidance response. How a mountain goat responds to disturbance (e.g., whether the animal makes an anomalous movement or not) is influenced by many factors related to the biology of the animal, the helicopter stimuli and the environment the animal is in when the disturbance occurs. For example, mountain goat response to helicopter disturbance may be more intense when animals are farther from escape terrain (Foster and Rahs 1983, Côté 1996, Goldstein et al. 2005).

Collared female mountain goats responded equally to visible and non-visible helicopter interactions, highlighting the importance of managing for auditory cues associated with close-proximity helicopter approaches, even when sightlines may be blocked by topography. These findings are supported by Foster and Rahs (1983), who indicated that mountain goat responses to drilling and aerial disturbance were stimulated primarily by auditory and secondarily by visual cues. Similarly, Luz and Smith (1976) observed that the response of Sonoran pronghorns (*Antilocapra americana sonoriensis*) to helicopters varied from mild to strong in relation to decibel levels. Although natural ambient noise such as that from wind or water is capable of reducing the effect of disturbance-produced noise in some environments, including the alpine, ambient noise can also mask the gradual increase in sound of approaching aircraft or vehicles, thereby converting tolerable gradual-onset sound into startling rapid-onset sound capable of eliciting an intense stress response (Penner 1988, Harrington and Veitch 1992).

In general, disturbance stimuli that are closer, approach directly at a rapid rate, or are unpredictable or startling elicit a stronger stress response from wildlife (Frid 1999) – a conclusion supported by previous research observing immediate flight responses of mountain goats to helicopter approaches (Foster and Rahs 1983, Côté 1996, Goldstein et al. 2005). Our findings also support this theory, as we found that the probability of both immediate and lagged anomalous movements increased when the helicopter was closer to the animal. Surprisingly, animals did not respond more strongly to landing events. Although not statistically significant, collared animals were less likely to make a movement when a landing occurred. These findings may be influenced by the distribution of landings among animals that was heavily weighted toward 2 animals (animals 160 and 300), which showed a lower proportion of anomalous movements in comparison with other individuals (Figure 2.9).

Individuals of the same species often vary in their tolerance of disturbance stimuli (Picton 1999, Bejder et al. 2006, Neumann et al. 2010).

A primary factor influencing sensitivity to disturbance is reproductive status, with females with offspring more easily disturbed than males or barren females (Ciuti et al. 2008). This follows a reproductive strategy-predation risk hypothesis (Mooring et al. 2003), wherein the reproductive success of females is dependent on offspring survival, and those behaviours that reduce predation risk (i.e., flight response) are more strongly selected for than in other categories (e.g., males) where fitness is more clearly related to foraging success at the cost of greater predation risk. Although we did not account for the reproductive status of the collared females in our study, we assumed that the presence and absence of offspring varied among individuals and within individuals over time, and may have influenced a mountain goats response to helicopter activity.

The distance an animal was from escape terrain was the strongest factor influencing both immediate and lagged anomalous movements. As expected, the farther an animal was from escape terrain, the higher the probability that an anomalous movement was made. Terrain ruggedness was also a factor influencing lagged movements, with animals inhabiting less rugged areas more likely to make anomalous movements. It follows then, that animals that are already in the most secure terrain available may fail to move when disturbed, even if this means prolonged exposure to disturbance stimuli. In observing the responses of mountain goats to helicopter activity in Alberta, Côté (1996) noted that after animals had reached a cliff following helicopter disturbance events, they remained there for a prolonged period, increasing their exposure to further disturbance and exhibiting panic behaviours.

Also included in our models describing immediate responses was disturbance history, which although not significant, suggested animals were less likely to respond as their history of disturbance increased. Disturbance history was not, however, a factor in models explaining lagged anomalous movements. Considerable controversy remains as to whether the intensity of an animal's response changes over the course of repeated disturbance events (i.e., whether the animal becomes eventually indifferent to the disturbance as in habituation, or conversely, becomes increasingly sensitive as in sensitization; Whittaker and Knight 1998, Gill et al. 2001, Taylor and Knight 2003*a*). Several studies have shown that wildlife appear capable of habituating to forms of routine or predictable disturbance (Cassirer et al. 1992, Colman et al. 2001). For example, both bison (*Bison bison*) and elk (*Cervus elaphus*) showed a decreasing stress response to repeated, predictable on-trail snowmobile tours (Borkowski et al. 2006). Conversely, animals often do not habituate to repeated exposure to unpredictable stimuli such as helicopters, and in some cases appear to become sensitized (Bleich et al. 1994, Frid 1999), as seen in the sensitization of bighorn sheep (*Ovis canadensis*; MacArthur et al. 1979) and Dall sheep (*Ovis dalli dalli*; Frid 1999) to repeated aerial disturbance.

There is no consensus regarding the habituation response of mountain goats to anthropogenic disturbance. Mountain goats on Caw Ridge, Alberta, showed no signs of habituation to helicopter activity over a season of observations (Côté 1996). Further, mountain goats in the Stikine region of B.C. appeared to sensitize to helicopter and drilling-associated disturbance over the study period, suggesting that disturbance effects may have been additive (Foster and Rahs 1983). In Alaska, however, Goldstein and others (2005) found that animals with greater prior exposure to helicopters seemed to have increasing tolerance of disturbance. The discrepancy between perceived habituation in these studies may be linked to the differing topographies of the areas in question and the temporal scale of the observations.

In Côté's (1996) study in Alberta, animals inhabited an open, gently rolling ridge with limited cliff and escape terrain. In our study area, as well as in the Alaska study (Goldstein et al. 2005), terrain was more rugged and steep, with a high proportion of escape terrain. As such, animals were often in close proximity to escape terrain when disturbed, and may have been more likely to respond with a passive, hiding response. If animals that were more frequently disturbed altered their habitat use to remain closer to escape terrain, this would likely translate to a higher proportion of passive responses and apparent increased tolerance of disturbance. In terms of temporal scale, the Alaska study (Goldstein et al. 2005) was based on short-term responses, or non-responses of mountain goats to helicopter activity in the 15 minutes following helicopter activity. The tolerance perceived, therefore, would not have accounted for potential lagged movements that we found occurred regardless of disturbance history; accounting for these lagged effects may have contradicted conclusions regarding habituation.

MANAGEMENT IMPLICATIONS

Mitigating for the effects of helicopter activity is often an objective of conservation management strategies, particularly in areas of increasing helicopter-supported recreation such as B.C. (Wilson and Shackleton 2001, Mountain Goat Management Team 2010). Although several studies have examined the short-term effects of helicopter disturbance on movement and behaviour, the long-term impacts of disturbance on mountain goats populations are not clear, because they have never been rigorously studied (Wilson and Shackleton 2001). Lacking long-term demographic studies, managers extrapolate the documented short-term effects of disturbance on animal movement behaviour to predict potential demographic impacts (Harrington and Veitch 1992, Powell 2004). Whether short-term behavioural reactions are transformed into demographic impacts, however, is dependent on not only the movement response and its estimated energetic costs, but also the frequency of disturbance, and whether the intensity of an animal's response changes over the course of repeated disturbance events (i.e., sensitization or habituation). This study provided insights on not only the changes in movement behaviour in the days following helicopter approaches, but also on how these daily changes influenced seasonal movement rates and range size, information useful in making effective management decisions.

Mountain goats often made long-distance anomalous movements following helicopter activity within 2 km. These longer-distance movements were not limited to the period immediately following approaches (0 h – 6 h); and occurred with equal frequency during the 6 h – 48 h following helicopter interactions. Movements were more likely with decreasing helicopter proximity and increasing distance to escape terrain, and occurred regardless of the visibility of the helicopter (i.e., responses could be provoked by the sound of non-visible helicopters). The degree of sensitivity to disturbance also appeared to vary across our study animals, with some individuals consistently more likely to make anomalous movements than others – a factor that may have been influenced by the strategy of mountain goats in response to disturbance (active versus passive), or variation in individual tolerance levels of disturbance, that may have been affected by the presence or absence of offspring.

Despite these anomalous behaviours resulting from helicopter interactions, helicopter exposure, at the levels we observed (≤1h/month), did not appear to influence seasonal movement rate or range size of individuals during the heliskiing season. This finding indicates that more immediate movement responses to helicopters, though potentially detrimental to the individual should they result in physical injury, separation from the group, or physiological stress (see Côté 1996, Macbeth 2010), do not have a significant seasonal effect on movement if the frequency of disturbance occurs at low frequencies (i.e., ≤1 h/month). We did not find any strong evidence that an animal's response to disturbance changed over the course of the season (i.e., increased as in sensitization, or decreased as in habituation).

Given our results, if the management goal is to completely eliminate disturbance-related movements of mountain goats, we recommend that a 2-km separation distance apply to both in-sight and out-of sight helicopter approaches surrounding areas of mountain goat winter range. Mitigating for out-of-sight disturbance stimuli will require that separation distances apply regardless of surrounding topography, or that soundscape modeling (Andrus and Howlett 2006) be used to determine areas that could be used by helicopter operators with minimal visual or auditory disturbance. Conversely, if the management goal is to prevent changes to seasonal movement rates and range size while accepting that daily movement behaviour will be disrupted (albeit infrequently), our results suggest that designating a separation distance that is less conservative (i.e., 1,500 m) and avoidance of areas of recognized goat range can be effective provided helicopter frequencies are at or below the observed maximum levels of ≤1 h/month. Given the uncertainties regarding the effects of increased disturbance frequency (i.e., whether the animal would habituate or sensitize to the added disturbance), further research is needed before extrapolating our results to management scenarios with higher frequencies of helicopter disturbance.

Because it is very unlikely, or impossible, to visually detect an animal at a 2-km or 1,500-m distance, areas of mountain goat winter range should be clearly identified within each tenure area, and pre-planning measures should be taken to alter or remove flight routes, ski runs and drop-off points near these winter ranges. If deemed necessary, compliance to the regulated separation distances from mountain goat range could be monitored through submission of heliskiing flight activity recorded by on-board GPS units, similar to what was used in this study.

Chapter 3- Effect of Heliskiing on Resource Selection by Mountain Goats

ABSTRACT

Disturbance from heliskiing activity within mountain goat (*Oreamnos americanus*) range may result in changes in mountain goat distribution across the landscape, due to either avoidance of disturbed areas or altered selection of resources on the landscape to increase use of escape terrain and other refugia. Changes in resource selection can affect an individual's ability to optimize resource use within its range, which in turn, could reduce fitness. Using an information-theoretic approach, we described resource selection strategies of individual female mountain goats in northwest British Columbia, Canada. We examined whether animals avoided areas of helicopter activity, as well as whether animals in areas with higher heliskiing intensity selected more strongly for security-related attributes than animals in areas of lower heliskiing disturbance. Within the range of helicopter activity observed, we found no evidence that individuals avoided areas of disturbance within their range, but there was some evidence that use and selection of security terrain increased in instances of increased heliskiing activity. Because the overall heliskiing intensity of the study area was low (<1 h/month), these results should not be extrapolated to areas of more frequent heliskiing activity where effects on resource use could be more severe.

INTRODUCTION

As the frequency of human disturbance increases within wildlife habitat, so too does the need to quantify its impact on wildlife populations (Gill et al. 2001, Taylor and Knight 2003*b*). Studies of disturbance effects commonly focus on short-term reactions to disturbance stimuli such as movement behaviour or changes in overt behavioural state (Harrington and Veitch 1992). Few studies, however, examine how disturbance affects the subsequent use of the landscape by animals (Bechet et al. 2004). Although less obvious, changes in resource use due to disturbance (i.e., avoidance of disturbed areas, increased use of security terrain) may be equally detrimental to individual fitness, particularly if animals are dependent on specific range attributes for survival and alternative habitat of equal value is not accessible. The response of animals to disturbance depends on tolerance levels of the species and individual, the type and frequency of disturbance, and the accessibility of both security terrain and alternative range (Madsen 1998, Bechet et al. 2004, Powell 2004).

Avoidance of areas frequently affected by human disturbance has been shown in a wide range of wildlife species: moose (*Alces alces*; Colescott and Gillingham 1998, Neumann et al. 2010), mountain caribou (*Rangifer tarandus*; Seip et al. 2007), desert bighorn sheep (*Ovis canadensis nelson*; Papouchis et al. 2001), white-tailed deer (*Odocoileus virginianus;* Dorrance et al. 1975), elk (*Cervus elaphus*; Ferguson and Keith 1982, Cassirer et al. 1992, Preisler et al. 2006), Alpine chamois (*Rupicapra rupricappa*; Gander and Ingold 1997), and grizzly bears (*Ursus arctos*; McLellan and Shackleton 1989). In other cases, individuals may not move away from the site of human activity, but will move to secure sites (or refugia) within their range (Tolon et al. 2009). This disturbance response is commonly seen in many wildlife species, including mountain sheep (*Ovis spp.)* and mountain goats (*Oreamnos americanus*) that seek out steep, rugged escape terrain (Côté 1996, Papouchis et al. 2001), and marmots (*Marmota spp*.) that seek refuge in underground burrows (Blumstein 1998).

Altering range use in response to disturbance (i.e., avoiding areas of disturbance or increasing the use of escape terrain) can have severe consequences to individuals depending on: 1) the quality of the escape terrain relative to the quality of the habitat that is being avoided (Vistnes and Nellemann 2001, Bechet et al. 2004); and 2) the ability of the individual to compensate for the loss of disturbed habitat and increased use of escape terrain. The ability of the animal to compensate depends on the frequency of disturbance (i.e., there must be time available where disturbance is not occurring), the foraging opportunities available to animals, and the condition of the animal (Gill et al. 2001, Colman et al. 2003, Fortin et al. 2004, Rode et al. 2006). Disturbance-related shifts in habitat use may be particularly critical during the winter season, when costs of movement to new ranges are high, forage is limited, energy stores typically low, and habitat requirements highly specific to provide adequate forage and thermal cover (Varley 1998). With the increasing growth of the winter recreation industry in areas of wildlife habitat, managers must be able to assess the effects of human disturbance on how wildlife use the landscape and offer recommendations for mitigation.

In this study, we examined the effect of heliskiing activity on range use by female mountain goats. Within mountain goat range, heliskiing activity has increased substantially in the past decade, particularly in British Columbia (B.C.), where over half of the species population currently exists (Denton 2000, Wilson and Shackleton 2001, Mountain Goat Management Team 2010). Mountain goats are highly dependent on suitable winter range, where snow depths are less and forage is accessible (Foster 1982, Fox and Smith 1988). In areas of deep snowpack, this winter range is often adjacent to areas of terrain that are suitable for heliskiing (Keim 2004), leading to increased potential for repeated over flights or helicopter landings in close proximity to animals.

Mountain goats respond immediately to helicopter activity up to 2 km distant (Foster and Rahs 1983, Côté 1996, Goldstein et al. 2005), and will alter movement behaviour for up to 48 h following close-proximity approaches (Poole and Heard 1998, Chapter 2). The effects of helicopter activity on habitat use, however, have not been rigorously studied. Mountain goats have been reported to temporarily abandon their range during periods of high-intensity disturbance, such as active drilling (Foster and Rahs 1983), and within their range, animals have been observed to move to secure areas such as cliffs and high elevation when helicopter activity occurs (Côté 1996, Gordon and Wilson 2004). Avoidance of heliskiing-related activity by mountain goats, through either direct avoidance of otherwise high-quality range or increased use of security terrain with limited forage, could have implications to individual fitness through increased risk of nutritional and energetic stress (Foster and Rahs 1983, Denton 2000, Hurley 2004).

As in the case of other disturbance responses, the effects of helicopter activity on resource use by mountain goats are dependent on many factors pertaining to the individual affected, the characteristics of the range they inhabit at the time of disturbance, and the frequency and nature of the disturbance stimuli, including whether efforts are made to prevent helicopter activity from occurring in known mountain goat habitat. Within B.C., the Wildlife Guidelines (Government of British Columbia 2006) aim to prevent changes in habitat use by mountain goats due to human disturbance by defining a minimum 1,500-m, line-of-sight separation distance between helicopters and occupied mountain goat range. The efficacy of the guidelines in practice, however, is not known.

We examined the habitat use and resource selection patterns of female mountain goats exposed to varying levels of helicopter activity from the nearby Last Frontier Heliskiing (LFH) base over a 3-year period. The objective of our work was to determine if animals used escape terrain more often when exposed to higher levels of heliskiing, and whether animals avoided areas of frequent helicopter activity within their range.

To identify potential effects of heliskiing intensity on how animals used their range, we examined patterns of use and resource selection both within and across individuals; assessing whether animals exhibited selection or avoidance of areas frequently used for heliskiing during either the early winter or heliskiing season. We predicted that if the observed levels of heliskiing intensity affected the resource use, we would find that: 1) animals avoided areas of high heliskiing intensity during the heliskiing season; 2) animals avoided areas of traditionally high heliskiing intensity during the early winter, or conversely, selected for heliskiing areas in early winter then avoided the same areas at the onset of heliskiing activity; 3) animals use and selection for security terrain would increase in proportion to the frequency of their exposure to heliskiing activity; and 4) animals use of security features would increase in times of increased heliskiing activity compared to early winter. If neither heliskiing nor security features were important within exhibited selection strategies and animals were consistent in their distribution despite differences in helicopter exposure, we would infer that heliskiing activity, at the level observed, did not affect the resource use of collared animals.

STUDY AREA

The study area was located within the Last Frontier Heliskiing (LFH) tenure area in the Skeena Range of the Coast Mountains in northwest B.C., Canada (56°18’57°02’ N, 129°14’130°32’ W). Developed under glaciation, the topography of the area is steep and rugged with extensive cliff terrain. The elevation of the study area ranges from 483 m to 2,311 m above sea level with small glaciers and perennial snowfields at high elevations.

Transitional between northern interior and coastal climates, the area experienced significant snowfall from mid-October through May with periods of intense cold common in the winter months (Demarchi 2011).

Low-elevation valley bottoms were composed of primarily western red cedar (*Thuja plicata)* and western hemlock *(Tsuga heterophylla*) (Meidinger and Pojar 1991) shifting to stands of hybrid white spruce (*P. engelmannii x glauca*) and sub-alpine fir *(Abies lasiocarpa)* at mid elevations. Boreal-altai-fescue alpine communities occurred at elevations above 1,400 m and were dominant within the study area (Meidinger and Pojar 1991). Cliff terrain, avalanche chutes, and krummholtz communities created a mosaic of habitats at mid to high elevations.

Mountain goat population density within the study area was estimated to be 0.45 animals per km^2 (Keim 2003). Predators of mountain goats within the study area were grizzly bears (*U. a. horribilis)*, wolverines (*Gulo gulo)*, wolves (*Canis lupus)* and golden eagles (*Aquila chrysaetos*). Harvesting of male mountain goats was permitted in the study area. Due to the remote location and rugged terrain of the area, however, hunting mortality was negligible. Highway 37 bisected the study area, but was the only road and because it followed the valley bottom, it likely had negligible impact on mountain goat populations. Bell II Lodge, in the north of the study area on Highway 37, was the site of a helicopter landing pad and the base for helicopter-supported recreation in the region. Helicopter activity during the winter season was primarily for helicopter-based recreation (heliskiing), established in 1997 by Last Frontier Heliskiing (LFH). The tenure area (~9,000 km^2) was typically operational from mid-December through April. Other helicopter activity within the area during this time was negligible.

METHODS

Locations of Mountain Goats

Nineteen adult female mountain goats were outfitted with Global Positioning System (GPS) collars (GPS2000; Applied Telemetry Systems, Insanta, MN) programmed to acquire locations during the heliskiing season at either 6-h intervals (2-yr collars) or 2-h or 1-h intervals (1-yr collars). Fix rates of all collars were reduced to 12-h intervals during the balance of the year (May through mid-December). Mountain goats were captured at 4 capture sites representing a gradient of heliskiing activity within the LFH tenure area. All study animals were ground-captured using clover traps (Rideout 1974) modified to increase trapping efficiency (Cadsand et al. 2010). Handling procedures followed were in accordance with the University of Northern British Columbia Animal Care and Use Committee (ACUC A2009.0420.017) and the B.C. Ministry of Environment protocols.

Captures took place during June – July during 2007, 2008, and 2009 at pre-determined capture sites: Ningunsaw, a site in close proximity to the helicopter base and an area of predicted high helicopter activity; Repeater and Skowill, sites central within the study area and predicted to have medium to low heliskiing exposure; and Cousins Creek, the southernmost capture site, a control area without heliskiing-related helicopter activity for the duration of the study (Figure 3.1). Following recovery and downloading of collars, we screened data, removing fixes that occurred in the 3 days post-capture and pre-recapture, erroneous fixes (>20 km from prior fix) and fixes with high PDOP values (>25; D'Eon et al. 2002). From those screened animal location points, we created individual home ranges for both the early winter (15 October – 14 December) and heliskiing season (15 December – 30 April). Home ranges were estimated as the area encompassed by overlapping animal location points that had been buffered by a radius equivalent to the 95th percentile longest movement

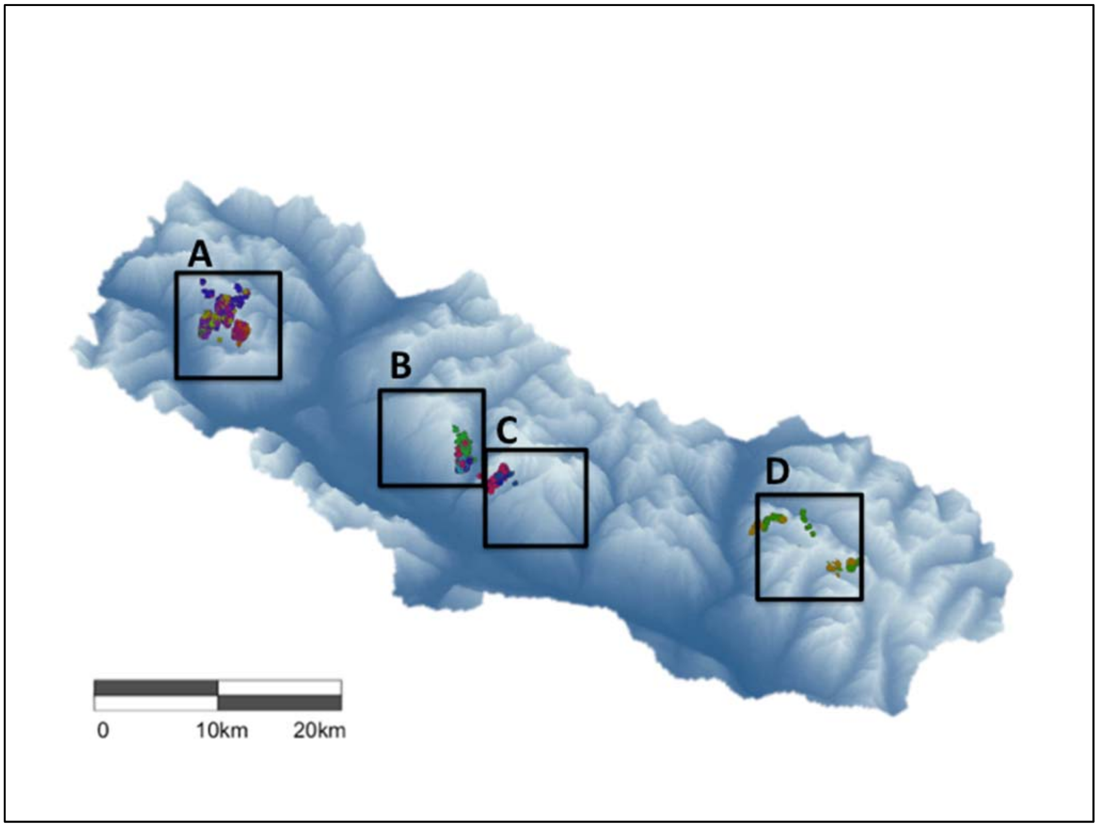

Figure 3.1. Hillshade representation of the 4 sites within the Northern Skeena Mountains study area where female mountain goats were ground-captured and monitored (2007-2010): A) Ningunsaw, B) Skowill, C) Repeater, and D) Cousins Creek. Each capture area represented an area of different heliskiing intensity on the landscape: Ningunsaw was an area of high heliskiing intensity, Repeater and Skowill were medium-low intensity and Cousins was a control area with no heliskiing activity. Dots represent locations of individual collared animals.

made by that individual during that season and year (Walker et al. 2007).

Heliskiing Activity

Flight-track information from helicopters associated with heliskiing was recorded across 3 heliskiing seasons (15 December – 30 April; 2007 – 2008, 2008 – 2009 and 2009 – 2010) within the LFH tenure area. Helicopters used for heliskiing activity were A-Star B2 and Bell 407 machines. During each flight, on-board GPS receivers (Garmin GPSMAP 76CSx, Olathe, KS) recorded the exact time, location and elevation of the helicopter at 100-m intervals. Following each flight day, data from GPS units were downloaded onto an on-site computer and external hard drive. At the end of each season we collated and verified track completeness.

For each season of heliskiing activity (2007–2008, 2009–2009, and 2009–2010), we created a helicopter-intensity layer that quantified the distribution of heliskiing activity across the landscape (e.g., Figure 3.2). We used the point-to-raster function in ArcMap 9.2 (ESRI 2009) to translate the helicopter GPS track-point locations to a raster surface representing helicopter intensity that we could query using Geographic Information Systems (GIS). Because continuous helicopter activity was represented by distinct points acquired at 100-m intervals, we created a 75-m buffer around each point to account for the flight path between consecutive GPS location points. The buffer surrounding each point also accounted for a larger area of influence related to heliskiing activity. The value of each pixel of the helicopter-raster layer represented the total number of helicopter GPS location points that had occurred within the geographic area represented by the pixel area (170 m x 170 m) during that heliskiing year.

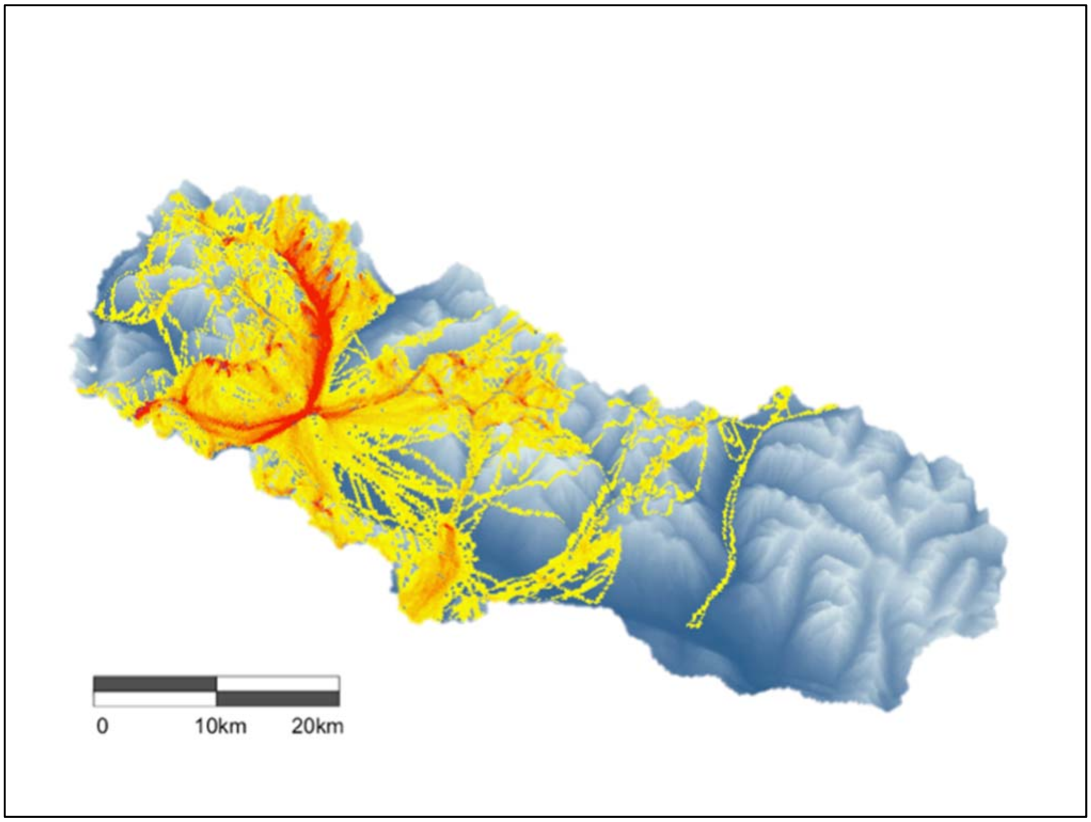

Figure 3.2. Distribution of helicopter activity across the Northern Skeena Mountains study area during the heliskiing season of 2007-2008 represented by a helicopter-intensity raster layer. Colour gradation of pixels (yellow-red) indicates increasing amounts of helicopter activity within the area represented by the pixel. Blue shaded areas were exposed to no heliskiing activity. Study area perimeter determined by locations of collared mountain goats buffered by 5 km.

Relating Heliskiing Activity to Use of Land Cover and Terrain by Mountain Goats

We quantified the amount of helicopter activity that individual female mountain goats had been exposed to and that could therefore affect range-use patterns using two measures: 1) the duration of helicopter activity each animal was exposed to during the heliskiing season within 2 km (the longest distance for which mountain goats are documented to react to disturbance, Côté 1996); and 2) the spatial distribution and frequency of helicopter activity within an animal's seasonal home ranges (early winter and heliskiing seasons) for each year. The measure of seasonal helicopter exposure provided an index of heliskiing disturbance by animal and year, which may affect individual resource selection strategies. The spatial distribution and frequency of activity in relation to animal locations allowed us to examine potential fine-scale selection or avoidance of heliskiing areas.

To quantify seasonal helicopter exposure of collared mountain goats, we isolated all helicopter points that were within 2 km and either 1-h, 2-h, or 6-h previous to each animal location. The time period used corresponded to the fix rate schedules of the individual animal collars, precluding double counting of helicopter points. We then summed all helicopter points that were within these time and distance criteria for each animal during each heliskiing season. For a more detailed description of the methodology associated with GIS and Visual Basic programming, please refer to Chapter 2. We determined the spatial distribution and frequency of heliskiing activity within animal home ranges by tabulating percent overlap and frequency of the heliskiing intensity raster data within each seasonal home range polygon using the Zonal Statistics tool in ArcMap 9.2 (ESRI 2009). The frequency of heliskiing associated with use and availability points was queried from helicopter intensity raster layers using ArcMap 9.2 (ESRI 2009).

To understand broad patterns of habitat use, we examined the primary vegetative land-cover classes, topographical features, and areas of heliskiing activity used by animals (indicated by animal GPS locations) in relation to what was available on the landscape. We defined availability of resources to collared animals at the scale of seasonal movement, within Johnson's (1980) third order of selection. Seasonal movement is an animal's movement potential within a season (Gustine et al. 2006), or a circular buffer around each use point with a radius equivalent to the individual's 95th percentile longest movement distance during that season. To account for variability in movement rates among years, we calculated separate seasonal movement potentials for each year an animal was collared. From the movement-potential area surrounding each use point, we randomly selected 5 points representing availability locations (Gustine et al. 2006). We compared locations of all used and available points within animal, season and year to ensure that no 2 points were used twice and that no overlap occurred between used and available points (Manly et al. 2002). We queried the land-cover class associated with each used and available point using GIS (ArcMap 9.2, ESRI 2009). For both early winter and heliskiing seasons, we then examined the proportions of land-cover classes that were used by, and available to, each individual in each season and year.

We identified 13 land-cover classes (Table 3.1) that occurred across the Northern Skeena Mountains study area (i.e., 5 km from any animal location). Land cover was classified using a combination of B.C. Baseline Thematic Mapping (BTM) 1:250,000 data accessed from Land and Resource Data Warehouse (LRDW, B.C. Government Forests, Lands, and Natural Resource Operations GeoBC; 250-m resolution; acquired 31 March 1992) and land-cover polygons that we classified manually from remotely sensed imagery (Landsat–7 Enhanced Thematic Mapper data; 30-m resolution; acquired 27 July 2004).

Table 3.1. Description of land-cover classes identified in the Northern Skeena Mountains study area during the study period (2007-2010). Source: B.C. Baseline Thematic Mapping 1:250,000 data (B.C. Government Forests, Lands, and Natural Resource Operations GeoBC; 250-m resolution; acquired 31 March 1992).

Land-cover Class	Description
Alpine meadow	Treeless vegetated areas dominated by herbs, graminoids, bryoids, and lichen.
Alpine rock	Treeless, unvegetated areas dominated by steep cliff terrain, exposed ridges and outcrops.
Fresh water	Fresh water bodies (lakes, reservoirs and wide portions of major rivers).
Old forest	Forest ≥140 years old and >6 m in height.
Range lands	Unimproved pasture and grasslands based on cover rather than use. Cover includes drought-tolerant grasses, sedges, scattered shrubs to 6 m in height and <35% forest cover.
Recently burned	Areas virtually devoid of trees due to fire within the past 20 years. Forest with ≤15% cover.
Recently logged	Timber harvesting within the past 20 years, or older if tree cover is <40% and <6 m in height.
Barren surfaces	Rock barrens, badlands, sand and gravel flats, dunes and beaches where un-vegetated surfaces predominate.
Shrubs	Naturally occurring shrub cover with ≥50% coverage. Occurs in northern B.C. on rich mid-slope positions or along valley bottoms, which act as frost pockets.
Avalanche chutes	Areas devoid of forest growth due primarily to snow avalanches. Usually herb or shrub covered.
Wetlands	Wetlands including swamps, marshes, bogs or fens. This class excludes lands with evidence or knowledge of haying or grazing in drier years.
Young forest	Forest <140 years old and >6 m in height.
Glacier and snow	Glaciers and permanent snow.

Although BTM provided an accurate representation of lower elevation vegetation communities, it did not provide adequate classification of land-cover classes in the alpine areas. To account for this inadequacy, we performed a supervised maximum-likelihood classification (PCI Geomatics 2004) to define alpine areas as “alpine meadow”, “alpine rock”, or “glacier and snow”. This classification provided only a coarse delineation of alpine diversity, but it dramatically improved upon the BTM alpine classification. We examined the percent of land-cover classes used in the early winter and heliskiing seasons by each individual, and then reported the average percent and variation of land-cover classes used by animals across each capture site.

Given the importance of terrain characteristics in habitat use by mountain goats, and how these terrain features may be used differently in areas with different heliskiing intensity, we calculated each individual’s use of elevation, slope, aspect, curvature, ruggedness, and distance to escape terrain in both early winter and heliskiing seasons, and then averaged values for each terrain attribute according to animal capture site (i.e., Ningunsaw, Repeater, Skowill and Cousins Creek). This approach allowed us to describe differences in resource use that may be attributed to local site characteristics, including heliskiing intensity and local topography.

We also examined the proportion of each animal’s locations within escape terrain during the heliskiing season relative to the early winter season. We characterized escape terrain as areas ≥45° (Keim 2003). We then examined data for trends in use of escape terrain that could be attributed to the seasonal heliskiing exposure of individuals using a Spearman’s rank correlation test.

Resource Selection

We used resource selection function (RSF) analyses to understand fine-scale selection and avoidance of resource attributes by mountain goats on the landscape. Resource selection for the early winter and heliskiing seasons was quantified for collared animals using Design III (Thomas and Taylor 1990) wherein use and availability were analyzed at the level of the individual, allowing for examination of the variation in resource selection strategies among individuals. Model covariates examined within resource selection analyses included elevation, slope, aspect, terrain ruggedness, distance to escape terrain, curvature, normalized difference vegetation index (NDVI), land cover, and a measure of helicopter intensity. Model covariates were selected based on literature detailing wintering strategies of mountain goats at northern latitudes (Smith 1977, Schoen and Kirkoff 1982, Fox 1983, Gross et al. 2002, Keim 2003), and attributes that we considered biologically relevant. We ensured the independence of all potential variables by dropping variables with a conservative tolerance score of ≤0.2 (Menard 2002). We also examined variables for issues of complete separation, dropping categorical variables or land-cover classes with ≤4 cases in either use or availability points (Menard 2002).

We used the raster layers representing yearly heliskiing intensity, described above, to define the relative heliskiing intensity values within the study area. Accounting for the importance of heliskiing areas in resource selection both in the early winter and heliskiing seasons allowed us to better discern avoidance or selection of these areas. In other words, an effect of heliskiing could be detected through either: 1) changes in the selection of heliskiing areas used in early winter versus the heliskiing season; or 2) selection or avoidance of the areas during heliskiing season.

We used a Terrain Resource Information Management (TRIM) 1:20,000 scale digital elevation model (LRDW, B.C. Government Forests, Lands, and Natural Resource Operations GeoBC; generated 04 April 2009) with a spatial resolution of 25 m to obtain slope, aspect, elevation, curvature, ruggedness and distance to escape terrain attributes. Slope was measured in degrees. We modeled aspect as 2 continuous variables (i.e., northness and eastness; Roberts 1986) to avoid introducing additional categorical variables and to minimize issues of complete separation between used and available datasets. Northness was calculated using the cosine of aspect, with values of 1.00 and -1.00 indicating selection for north and south aspects, respectively. Eastness was calculated as the sine of aspect, with values indicating selection for east (i.e., 1.00) and west (i.e., -1.00) aspects (Palmer 1993).

Elevation (m above sea level) was considered as a quadratic and included both linear and squared terms to allow for selection of intermediate elevations. Curvature was derived using ArcMap 9.2 (ESRI 2009) and provided an indication of the overall convexity or concavity of a pixel (25 m x 25 m) relative to its 3 x 3-pixel neighborhood. Positive values indicated convex sites (i.e., ridges, mountain tops) whereas negative values indicated concave sites (i.e., ravines and valley bottoms). Ruggedness was estimated using the Vector Ruggedness Measure (VRM; Sappington et al. 2007) extension in ArcMap 9.2 (ESRI 2009) that calculated a ruggedness measure for each pixel based on the variations of slope and aspect within its 3 x 3-neighborhood. Ruggedness values ranges from 0 to 1, with areas of ruggedness equivalent to 0 indicating even terrain and areas of ruggedness equivalent to 1 indicating very broken, uneven terrain (Sappington et al. 2007). We defined escape terrain as areas of slope ≥45° (Keim 2003), which we converted into polygons in Idrisi Taiga (Eastman 2009). We then created a raster surface representing the distances (m) from each pixel (25 m x 25 m) to the nearest area (polygon) of escape terrain.

We used the land-cover classification described above to define land-cover classes within the study area. Additionally, we used NDVI as an index for vegetation biomass. NDVI is related to leaf area and plant biomass (Tucker and Sellers 1986, Ruimy et al. 1994). The highest values of NDVI from the imagery used (Landsat–7 Enhanced Thematic Mapper data; 30-m resolution; acquired 27 July 2004) were typically indicative of new growth associated with forbs and grasses in avalanche chutes and meadows, with mid-range values indicative of shrub and krummholtz and coniferous areas, and the lowest values associated with barren and snow-covered areas. Accounting for biomass in winter resource selection models helped determine if animals selected coniferous areas during the winter months for cover and/or forage.

We created 15 ecologically plausible a priori candidate models for resource selection that combined the abovementioned attributes reasoned to influence choice of habitat by mountain goats during the winter seasons, and allowed us to better explore the importance of heliskiing activity relative to other critical habitat components (Table 3.2). We created our model set based on: 1) our knowledge of habitat selection by mountain goats in similar geographic areas; and 2) the premise of our study to better understand the importance of heliskiing activity on resource use. First, we created 5 base models: 2 base models were based on various aspects of security terrain; 1 on selection of specific aspects; 1 on land cover and biomass; and the final model based on a combination of security and land cover. Our candidate model set was then composed of these base models, each base model and topography variant (base model plus elevation and slope), and each base model and a heliskiing variant (base model plus helicopter intensity). Composing our model set in this way helped ensure that the inclusion of heliskiing activity within a top model set inferred that

Table 3.2. Candidate models used to examine the importance of heliskiing activity as a factor influencing habitat use by female mountain goats in the Northern Skeena Mountains from 2007-2010. Models were used to describe resource selection for individual mountain goats exposed to differing levels of heliskiing activity. Base models were sets of ecologically plausible habitat attributes reasoned to influence winter habitat use. Topography variant models were the base models with the addition of elevation and slope. Heliskiing variant models were base models with the addition of heliskiing intensity.

MODEL	VARIANT	MODEL VARIABLES
Security 1	Security 1	Distance to escape terrain + Ruggedness
	Security 1+ Topography	Distance to escape terrain + Ruggedness + Elevation[a] + Slope
	Security 1 + Heliskiing	Distance to escape terrain + Ruggedness + Helicopter Intensity
Security 2	Security 2	Distance to escape terrain + Curvature + NDVI
	Security 2 + Topography	Distance to escape terrain + Curvature + NDVI + Elevation[a] + Slope
	Security 2 + Heliskiing	Distance to escape terrain + Curvature + NDVI + Helicopter Intensity
Aspect	Aspect	Northness + Eastness
	Aspect + Topography	Northness + Eastness + Elevation[a]+ Slope
	Aspect + Heliskiing	Northness + Eastness + Helicopter Intensity
Land cover	Land cover	Land cover + NDVI
	Land cover + Topography	Land cover + NDVI + Elevation[a] + Slope
	Land cover + Heliskiing	Land cover + NDVI + Helicopter Intensity
Land cover + Security	Land cover and Security	Land cover + Ruggedness
	Land cover and Security + Topography	Land cover + Ruggedness + Elevation[a] + Slope
	Land cover and Security + Heliskiing	Land cover + Ruggedness + Helicopter Intensity

[a] Elevation was considered as a quadratic with both linear and squared terms considered.

heliskiing was an important feature in habitat selection and not simply a spurious covariate in an otherwise strong model.

We fit the parameters in each candidate model using logistic regression (STATA 11; Statacorp 2009), differentiating between used and available points. We used Akaike's Information Criterion (AIC_c) corrected for small sample sizes ($n/K < 40$; Burnham and Anderson 2002) to rank candidate models in order of decreasing parsimony considering both model fit (log likelikood; LL) and number of parameters (K) (Burnham and Anderson 2002). The Akaike's weights (w_i) indicated the relative support for a given model compared to the other models tested (Burnham and Anderson 2002, Johnson and Omland 2004). When the w_i of the top model was <0.95, the next highest ranked model was included in the top model set until the sum of w_i was ≥0.95. Competing top models were then averaged to provide a single final model. We evaluated the predictive ability of all top models using a *k*-fold cross-validation procedure with Spearman's rank correlation ($\bar{r}_s$; Boyce et al. 2002). Inferences were only made only for models in which $\bar{r}_s$ was > 0.648 ($n = 10$, $\alpha = 0.05$; Zar 1972).

In 2 cases, an individual's highly specific use of elevation prevented reliable estimates of selection patterns and resulted in models that could not be validated. For these 2 individuals (i.e., animal 160 during the heliskiing season in 2010 and animal 700 during early winter in 2010), we excluded the elevation terms from the model set, then repeated the model selection analyses detailed above to determine the top model set and evaluate the predictive ability of the models.

Inferences regarding the response of mountain goats to helicopter activity were determined by: 1) changes in the use of escape terrain in the heliskiing seasons compared to early winter that could be reasonably attributed to heliskiing activity; 2) stronger selection of security related covariates in animals exposed to higher seasonal levels of heliskiing activity;

and 3) assessing the relative importance of the helicopter activity covariate within the candidate model sets (i.e., whether there was evidence of animals avoiding areas of helicopter activity). All statistical analyses were completed using STATA 11 (Statacorp 2009).

RESULTS

We retrieved 16, 836 GPS locations acquired during the early winter and heliskiing seasons. These data were from 11 of the 19 collared mountain goats, with 4 animals contributing 2 years of data (amounting to 15 animal-heliskiing seasons of data). The remaining animals (*n* = 8) provided no data due to collar failures (*n* = 3), mortality (*n* = 3), or an inability to recover the collar (*n* = 2). Fix success rates from the collars used in resource selection analyses ranged from 70.1 % to 99.8 % with an average fix rate of 91.1 ± 6.9 % ($\bar{x}$± SD) (Appendix B). Average collar fix accuracy, determined by calculating the average distance between fixes of a stationary collar in the field, was 4.28 m (SD = 3.16) and 84% of fixes were 3D. Size of home ranges during the heliskiing season varied by a factor of 15x both across animals and by year within animals (Table 3.3).

The amount of heliskiing activity within 2 km of animals ranged from 0 minutes to 255 minutes within a heliskiing season (Table 3.3). The duration of heliskiing intensity within home ranges during the heliskiing season ranged from 0 minutes to 89 minutes, and the percent overlap of the heliskiing intensity pixels within animal ranges from 0% to 56% (Table 3.3). The distribution of helicopter activity within animals ranges varied (Figure 3.3A and 3.3B). In some cases helicopter activity was high, but concentrated in a small portion of the entire range of an animal (Figure 3.3A). In other cases, helicopter activity was low, but occupied a larger percent of the overall range of individuals (Figure 3.3B). As expected,

Table 3.3. Home-range characteristics of individual collared female mountain goats in the Northern Skeena Mountains during the heliskiing season (2007-2010; Range statistics: the size of the home range, the percent of the home range where heliskiing occurred, the duration of helicopter activity within the home range, and the total duration of helicopter activity that occurred ≤2 km from animal locations). In instances where animals were collared for multiple heliskiing seasons, each year is presented separately.

Site	Animal	Year	Range size (km^2)	% Home range where heliskiing activity occurred	Seasonal duration of helicopter activity (min) within home range	Seasonal duration of helicopter activity within 2 km (min) of animal locations
Ningunsaw	160	2009	1.1	32.2	3.7	255.2
	160	2008	11.2	37.6	28.2	101.7
	220	2007	15.1	29.6	20.5	82.9
	500	2008	13.4	45.0	88.7	78.6
	500	2007	10.3	32.7	60.0	96.9
	600	2007	3.3	21.1	4.1	131.3
Skowill	180	2009	5.6	25.9	6.4	23.3
	700	2009	1.6	56.2	6.1	25.4
	900	2009	2.9	43.9	8.4	26.0
Repeater	120	2009	0.8	55.1	1.2	28.8
	170	2009	3.8	51.9	4.4	11.6
	300	2008	3.5	28.9	1.4	1.9
	300	2007	2.3	9.0	0.3	1.9
Cousins	150	2009	8.2	0.0	0.0	0.0
	150	2008	14.0	0.0	0.0	0.0

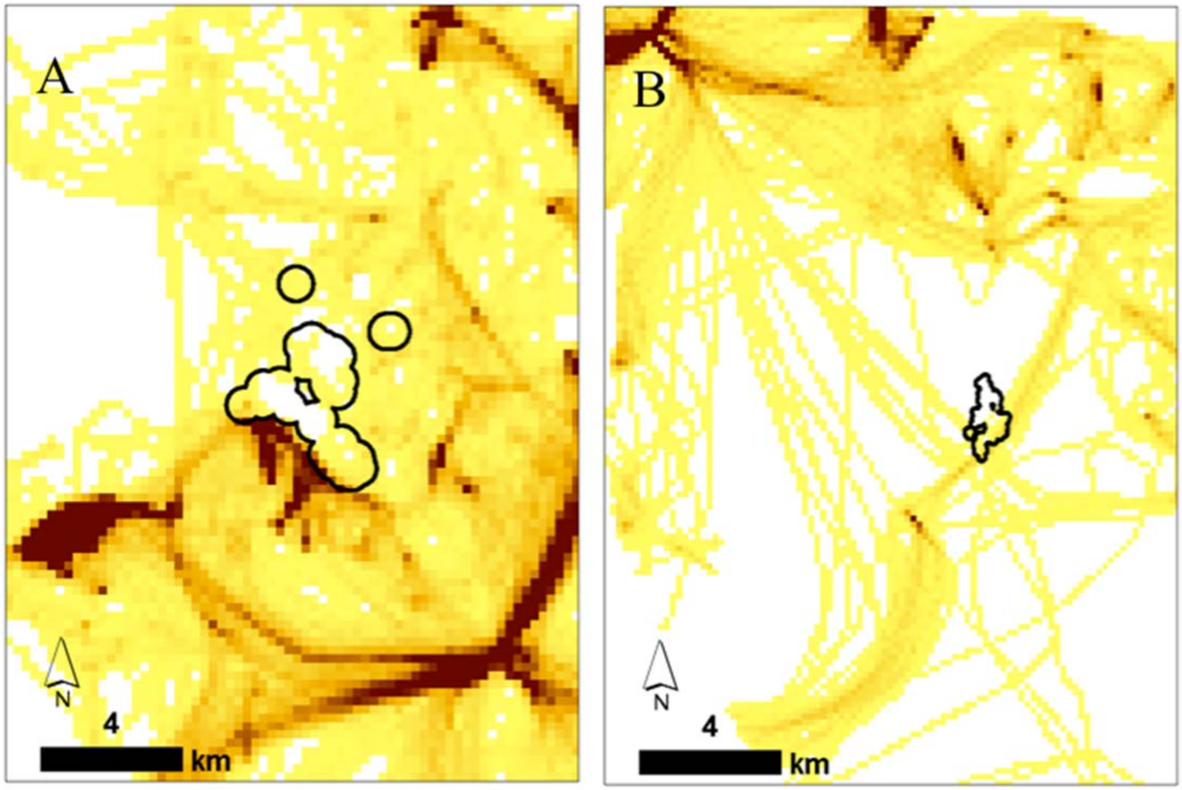

Figure 3.3. Examples of home ranges of individual female mountain goats (black-outlined polygons) in the Northern Skeena Mountains during the heliskiing seasons relative to the helicopter intensity raster layer for A) animal 160 in 2007-2008, and B) animal 700 in 2009-2010. Raster colour gradation (light to dark) indicates increasing frequency of helicopter activity within the area represented by the pixel.

animals in the Ningunsaw areas experienced the highest amount of helicopter exposure, followed by animals in Skowill and Repeater. The animal in the control area (i.e., Cousins) was exposed to no helicopter activity.

Range-Use Patterns of Mountain Goats

Range-use patterns of female mountain goats indicated use of alpine land-cover classes (i.e., alpine meadow, alpine rock, and avalanche chutes) and non-use or general avoidance of lower elevation land-cover classes (Figure 3.4, Appendix F) across all capture sites. There was no recorded use or availability of fresh water, rangeland, recently burned, recently logged, barren surfaces, shrub, young forest or wetlands for any collared animals, and as such, these land-cover classes were excluded from resource selection models due to complete separation issues in logistic regression. There were also 2 cases for old forest and 7 cases for glacier and snow for which the land-cover class was not available or used by animals in either the early winter or heliskiing seasons. In 12 cases, glacier and snow land cover was available but not used, and in 14 cases, old forest land cover was available but not used. These land-cover classes were also removed from corresponding resource selection models due to the same complete separation concern.

In comparison to early winter, collared animals generally increased their use of alpine rock and decreased use of alpine meadow in the heliskiing season; this was especially apparent in the animals in the Repeater and Cousins Creek areas (Figure 3.4). The exception were animals in the Ningunsaw area, that shifted from avalanche chutes to areas dominated by alpine rock area during the heliskiing season with little change in the use of alpine meadow. The use of avalanche chutes varied greatly amongst sites and seasons (Figure 3.4).

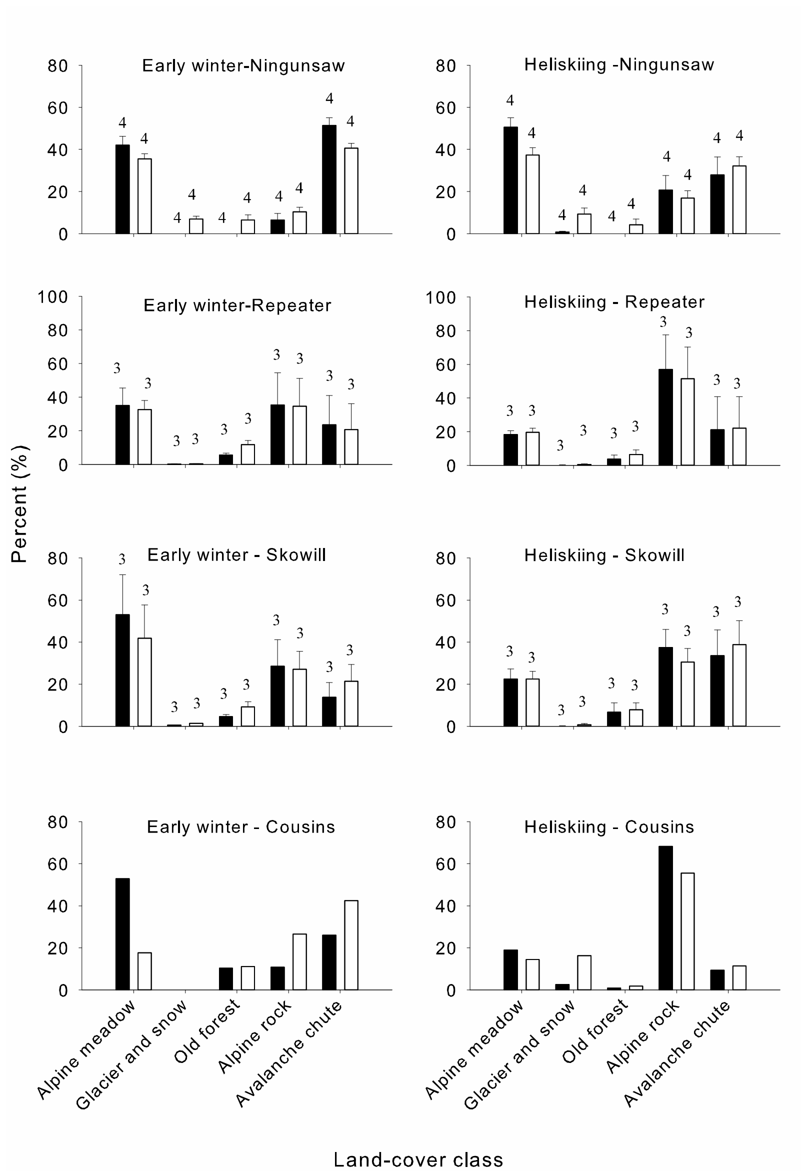

Figure 3.4. The percent ($\bar{x}$ ± SE) of used (closed bar) and available (open bar) land-cover classes used by female mountain goats averaged across capture sites of high, medium-low, and no heliskiing activity (Ningunsaw, Repeater and Skowill, and Cousins, respecively) in the Northern Skeena Mountains during the early winter and heliskiing seasons (2007-2010). Numbers above error bars indicate the number of animals averaged across each capture site. In the control area (Cousins) there was only one animal considered in the analyses.

Average NDVI values calculated across capture sites ranged from 0.27 to 0.44 in the early winter and 0.19 to 0.43 during the heliskiing season and reflected the predominance of alpine rock land-cover classes that mountain goats used. Considering all animals and years, average NDVI values were 0.39 ± 0.05 ($\bar{x}$ ± SD) in early winter season and 0.33 ± 0.10 ($\bar{x}$ ± SD) in the heliskiing season. The slight decrease in average NDVI in the heliskiing season was likely due to the shift of animals from alpine meadow and avalanche chutes to alpine rock, or may have been attributable to sampling error.

Animals inhabited high-elevation sites throughout the early winter and heliskiing seasons with elevations of used sites ranging from 1,009 m to 1,679 m (Figure 3.5). Animals in Ningunsaw and Cousins Creek generally used slightly higher elevations in the heliskiing season in comparison to early winter. The average slopes used by collared animals were ~40° during the early winter and heliskiing seasons, ranging from 38 to 48° across the different capture sites (Figure 3.5). Animals consistently used south-facing slopes during both seasons (Figure 3.5). Use of east- and west-facing slopes was more variable among animals, with a tendency for southwest aspects in animals in Ningunsaw and Cousins, and southeast aspects in Skowill and Repeater.

Animals remained in close proximity (≤25 m) to escape terrain during both seasons, but especially so in the heliskiing season (Figure 3.5). Animals in Ningunsaw were on average approximately ~25 m from escape terrain during the early winter, but appeared to move closer to escape terrain (~5 m distant) during the heliskiing season. The average ruggedness of the terrain used by mountain goats varied across seasons and capture sites from 0.01 to 0.04 (Figure 3.5). Animals in the Repeater area generally used more rugged terrain than animals in other areas. The majority of animals used convex rather than concave

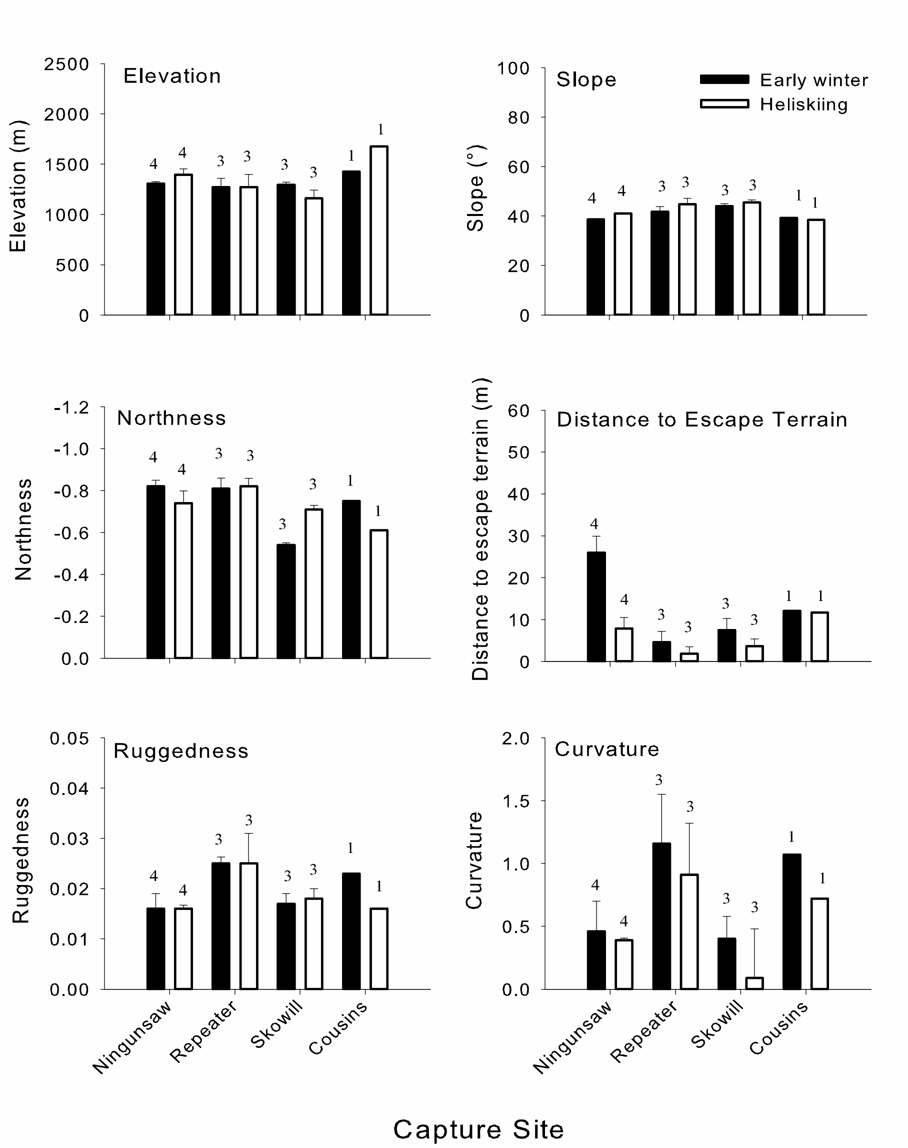

Figure 3.5. The average ($\bar{x} \pm$ SE) values of elevation, slope, northness, distance to escape terrain, ruggedness, and curvature used by female mountain goats in the 4 capture sites of high, medium-low and no helicopter activity (Ningunsaw, Repeater and Skowill, and Cousins, respectively) in the Northern Skeena Mountains study area during the early winter and heliskiing seasons (2007-2010). Numbers above error bars indicate the number of animals averaged within each capture site. In the control area (Cousins), there was only one animal considered in the analyses.

terrain, indicating use of ridges and cliff faces rather than ravines or gullies in both seasons (Figure 3.5). With the exception of the animal in the control area, mountain goats increased their use of escape terrain (% home range with slopes ≥45°) in the heliskiing season compared to the early winter season (Table 3.4). The percent of an individuals home range that was classified as escape terrain, however, was not, related to the seasonal heliskiing exposure of individuals (n = 15, $\bar{r}_s$ = - 0.077, P = 0.79).

Seasonal Selection Patterns

The models that best predicted resource selection strategies of individuals varied among animals and across seasons. The topography variant of the base model (elevation, and slope), however, was included in all top models for all animals in both seasons (Table 3.5 and Table 3.6). During the heliskiing season, the selection patterns of 11 of 15 animals were best characterized by the Aspect + Topography model (northness, eastness, elevation and slope); 3 of 15 animals were characterized by the Security 2 + Topography based strategy (distance to escape terrain, slope, elevation, curvature and NDVI); and 1 animal, the only case wherein helicopter intensity was included in the model set, was characterized by a combination of the suite of Security 2 Base and Base + variant models (distance to escape terrain, elevation, slope, curvature, NDVI and helicopter intensity).

The animal in the control area (i.e., Cousins) exhibited an aspect-based selection strategy similar to the majority of the animals in the active heliskiing area, with the exception of the 4 animals that used a security-based strategy. Three of the 4 animals that selected a more security-based strategy inhabited the Ningunsaw area (area of highest heliskiing use). The relative support for the individual model (w_i) typically approached 1.0 during the heliskiing season, with the exception of one case (animal 160 in 2010), which necessitated the averaging of 3 top models of lesser fit (Table 3.5). The predictive ability of the heliskiing

Table 3.4. Home-range size and percent of the home range classified as escape terrain for each collared female mountain goat during the early winter and heliskiing seasons in the Northern Skeena Mountains, 2007-2010. Animals are grouped by capture sites that represent high, medium-low, and no heliskiing activity (Ningunsaw, Repeater and Skowill and Cousins, respectively).

			Early winter		Heliskiing	
Site	Animal	Year	Range size (km^2)	% Range ≥45° slope	Range size (km^2)	% Range ≥45° slope
Ningunsaw	160	2009	7.1	14.4	1.1	32.7
	160	2008	6.5	19.8	11.2	36.8
	600	2007	1.6	11.8	3.3	31.9
	220	2007	11.5	12.2	15.1	27.2
	500	2008	7.9	14.2	13.4	31.0
	500	2007	9.5	12.5	10.3	20.1
Skowill	180	2009	6.4	54.7	5.6	50.9
	700	2009	1.1	74.3	1.6	76.9
	900	2009	3.5	44.2	2.9	59.0
Repeater	120	2009	1.5	68.7	0.8	75.8
	170	2009	3.7	25.3	3.8	40.1
	300	2008	1.5	54.8	3.5	68.2
	300	2007	4.4	36.8	2.3	71.7
Cousins	150	2009	8.5	24.2	8.2	17.0
	150	2008	8.2	33.7	14.0	18.0

Table 3.5. The top resource selection models for individual female mountain goats in the Northern Skeena Mountains during the heliskiing season (2007–2010). Statistics are number of parameters (*K*), sample size (*n*), log likelihood (LL), Akaike's Information Criterion for small sample sizes (AIC_c), Akaike's weights (w_i), and average Spearman's rank correlation ($\bar{r}_s$) from k-fold cross-validation procedure. Animals grouped by capture site, represent high, medium-low, and no heliskiing activity (Ningunsaw, Repeater and Skowill, and Cousins, respectively).

Site	Year	Animal	Model	*K*	*n*	LL	AICc	w_i	$\bar{r}_s$
Ningunsaw	2007	220	Security 2 + Topography	7	2988	-1007.98	2030.00	1.00	0.95
	2007	500	Security 2 + Topography	7	2589	-995.91	2005.84	1.00	0.96
	2007	600	Aspect + Topography	6	1675	-626.60	1265.24	1.00	0.89
	2008	160	Aspect + Topography	6	2902	-1059.55	2131.12	1.00	0.87
	2008	500	Aspect + Topography	6	2872	-1018.90	2049.83	1.00	0.88
	2009	160	Security 2	4	2820	-1204.23	2416.48	0.48	0.71
	2009	160	Security 2 + Topography	5	2820	-1203.80	2417.61	0.27	0.69
	2009	160	Security 2 + Heliskiing Intensity	5	2820	-1203.88	2417.78	0.25	0.70
Repeater	2007	300	Aspect + Topography	6	2663	-1121.32	2254.66	0.99	0.88
	2008	300	Aspect + Topography	6	2546	-1083.92	2179.87	1.00	0.89
	2009	120	Aspect + Topography	6	17093	-7693.05	15398.10	1.00	0.87
	2009	170	Aspect + Topography	6	8230	-3556.56	7125.12	1.00	0.88
Skowill	2009	180	Aspect + Topography	6	8212	-3319.92	6651.85	1.00	0.96
	2009	700	Security 2 + Topography	7	15694	-7021.88	14057.76	1.00	0.82
	2009	900	Aspect + Topography	6	7616	-3201.36	6414.73	1.00	0.92
Cousins	2008	150	Aspect + Topography	6	2922	-1130.31	2272.64	1.00	0.92
	2009	150	Aspect + Topography	6	2895	-1205.98	2423.98	1.00	0.84

Table 3.6. Top resource selection models for individual female mountain goats in the Northern Skeena Mountains during early winter (2007–2010). Statistics are number of parameters (K), sample size (n), log likelihood (LL), Akaike's Information Criterion for small sample sizes (AIC_c), Akaike's weights (w_i), and Spearman's rank correlation ($\bar{r}_s$) from k-fold cross-validation. Animals grouped by capture site, represent high, medium-low, and no heliskiing activity (Ningunsaw, Repeater and Skowill, and Cousins, respectively).

Site	Year	Animal	Model	K	n	LL	AIC_c	w_i	$\bar{r}_s$
Ningunsaw	2007	220	Aspect + Topography	6	651	-254.60	521.28	1.00	0.80
	2007	500	Security 2 + Topography	7	540	-230.16	474.48	0.09	0.81
	2007	500	Aspect + Topography	6	540	-228.89	469.89	0.91	0.81
	2007	600	Security 1+ Heliskiing Intensity	4	81	-34.24	76.79	0.20	0.19[a]
	2007	600	Security 1 + Topography	6	81	-31.79	76.40	0.25	0.39[a]
	2007	600	Security 2	4	81	-35.66	79.64	0.05	0.38[a]
	2007	600	Security 2 + Topography	7	81	-32.29	79.73	0.05	0.36[a]
	2007	600	Security 1	3	81	-34.63	75.43	0.40	0.27[a]
	2008	160	Aspect + Topography	6	680	-275.46	563.00	1.00	0.69
	2008	500	Security 2 + Topography	7	611	-265.47	545.08	0.72	0.74
	2008	500	Aspect + Topography	6	611	-267.44	546.97	0.28	0.79
	2009	160	Land cover + Topography	7	656	-276.40	566.93	0.28	0.53[a]
	2009	160	Land cover and Security + Topography	7	656	-275.47	565.06	0.72	0.59[a]
Repeater	2007	300	Security 1 + Topography	6	678	-261.38	534.85	0.37	0.78
	2007	300	Security 2 + Topography	7	678	-259.84	533.80	0.63	0.84
	2008	300	Land cover + Topography	8	681	-279.96	576.08	1.00	0.54[a]
	2009	120	Land cover + Topography	8	2387	-1016.74	2049.53	0.38	0.78
	2009	120	Security 2 + Heliskiing Intensity	5	2387	-1020.63	2051.27	0.16	0.70
	2009	120	Security 2 + Topography	7	2387	-1017.59	2049.22	0.45	0.91
	2009	170	Security 2 + Topography	7	1084	-420.53	855.13	1.00	0.83

Table 3.6: continued

Site	Year	Animal	Model	K	n	LL	AIC_c	w_i	$\bar{r}_s$
Skowill	2009	180	Aspect + Topography	6	1054	-415.31	842.67	1.00	0.87
	2009	700	Security 2 + Heliskiing Intensity	5	904	-373.59	757.23	0.13	0.67
	2009	700	Security 2 + Topography	5	904	-371.73	753.51	0.81	0.82
	2009	900	Land cover + Topography	8	1014	-421.61	859.32	0.09	0.77
	2009	900	Land cover and Security + Topography	8	1014	-420.31	856.73	0.33	0.78
	2009	900	Security 1 + Topography	6	1014	-421.86	855.78	0.53	0.87
Cousins	2008	150	Security 2 + Topography	7	526	-193.39	400.94	0.98	0.83
	2009	150	Land cover + Topography	7	677	-228.74	471.60	0.05	0.70
	2009	150	Land cover and Security + Topography	7	677	-225.86	465.84	0.95	0.70

[a] the model $\bar{r}_s$ was below the critical value and dropped from further analyses due to low reliability.

top models, indicated by the mean Spearman's rank correlation coefficient ($\bar{r}_s$), ranged from 0.69 to 0.96. Selection patterns were not as well predicted by the proposed model set in early winter, with the majority of top models a product of several averaged models of lesser fit rather than a single top model of strong predictive ability (Table 3.6). Relative to the early winter season, aspect was more important in the heliskiing season, included in 11 of 15 top models in the heliskiing season, and only 6 of 15 top models in the early winter season. Conversely, land cover was not included in any heliskiing season top models but was in 5 of 15 combined top models for the early winter season. Three of the top models fits were below the threshold $\bar{r}_s$ value of 0.658, (animal 600 in 2008; animal 160 in 2010; and animal 300 in 2009) and as such, were not considered in further selection or avoidance analyses. The predictive ability of the remaining top models in early winter ranged from 0.69 to 0.91.

Helicopter intensity was included only in 1 top model during the heliskiing season and 2 models during the early winter season (Table 3.7, Appendix G, Table G.1 for heliskiing season and Tables G.2 and G.3 for early winter). In the 2 early winter season models where heliskiing intensity was significant, areas of helicopter activity were selected for by one animal and against by the other animal. During the heliskiing season, areas of helicopter activity were selected for by one animal, but not significantly. Elevation was an important parameter in both seasons (Table 3.7, Appendix G, Table G.1 and Table G.2). Animals generally selected for high elevations in both early winter and heliskiing seasons, with the exception of 3 cases in both seasons wherein animals selected for mid elevations.

All top models for early winter and heliskiing seasons incorporated slope (Table 3.7, Appendix G, Table G.1 and Table G.2). Animals consistently chose steeper slopes during the heliskiing season. In the early winter, selection was not as strong, and in 4 of 15 cases

Table 3.7. The number of female mountain goats in the Northern Skeena Mountains study area that selected (+) or avoided (-) model parameters, based on *P* values of selection coefficients (β_i) included in the top individual resource selection models for the years 2007-2010. Number in parentheses indicates the number of animals for which each attribute was selected for or avoided in the top model, but was not statistically significant.

Parameter	EW		H	
	+	-	+	-
Helicopter intensity	1	1(1)	(1)	
Elevation	7(2)	1(1)	9(2)	1(2)
Elevation^2	1(1)	6(3)	2(1)	8(3)
Slope	8(1)	1(3)	12(3)	
Eastness	3(2)	1	6(2)	2(1)
Northness		6		11
Distance to escape terrain		7(2)		3(1)
Ruggedness	1	1(1)		
Curvature	8		2(1)	1
NDVI	2	7(1)	1	3
Land-cover class				
Alpine meadow	1	2		
Avalanche chute	1(1)	1		
Alpine rock		2		
Old forest	1	2		
Glacier and snow	1	1		

animals selected for less steep slopes than what was available. Animals strongly selected for south aspects and avoided north aspects in both seasons (Table 3.7; Northness, Appendix G, Table G.1 and Table G.2). The selection for east and west aspects was variable, with selection coefficients for several animals tending toward southeast-facing aspects in the early winter, and varying between southeast and southwest aspects during the heliskiing season (Table 3.7; Eastness, Appendix G, Table G.1 and Table G.2).

Ruggedness was not an important parameter during the heliskiing season. It was only significant in 2 models during the early winter season (Table 3.7,), and the direction of selection was variable (Appendix G, Table G.2). Distance to escape terrain was important in 8 top models during early winter and 4 models during the heliskiing season (Table 3.7). Animals consistently selected for locations that minimized their distance from escape terrain (Appendix G, Table G.1 and Table G.2). Curvature was important in both seasons, but was included in more top models in early winter (Table 3.7). Positive selection coefficients indicated predominant selection for convex terrain, with the exception of 1 animal that significantly selected for concave terrain (Appendix G, Table G.1 and Table G.2).

Areas of higher NDVI were generally selected against in top models for both early winter and heliskiing seasons, with the exception of 2 animals: 1 in the heliskiing season and 1 in the early winter (Appendix G, Table G.1 and Table G.2). Land-cover class was not a significant component explaining resource selection patterns in the heliskiing season, and was important in only 3 models during the early winter season (Table 3.7). Across these 3 models, selection for or against the major land-cover classes of alpine meadow, alpine rock, avalanche chutes, glacier and snow, and old forest were variable, with the only consistency being an apparent avoidance of alpine rock (Appendix G, Table G.3).

DISCUSSION

Although mountain goats did not directly avoid areas of heliskiing activity, and the one animal in the control area did not show resource selection strategies that differed from the majority of animals in the active tenure area, there was some evidence that use of security terrain increased during periods of heliskiing activity. The observed changes in resource use were not dramatic, but it is important to note that the overall exposure of collared mountain goats to heliskiing activity within the Northern Skeena Mountain study area was generally very low (i.e., ≤1h/month), due to the successful avoidance of mountain goat habitat by LFH helicopters and differences in the terrain used by mountain goats versus helicopters. As the behavioural response of wildlife to disturbance is often influenced by the frequency of disturbance events (Klein 1993, Powell 2004, Stankowich 2008, Reimers et al. 2012), these results apply only to levels of heliskiing activity that collared goats were subjected to in the observed study period, and can not be extrapolated to effects on mountain goats in areas of more frequent heliskiing activity.

Influence of Helicopter Activity on Use of Escape Terrain

All collared female mountain goats, with the exception of the animal in the control area and one animal in the medium-low heliskiing area, used escape terrain more frequently during the heliskiing season than in early winter. Following helicopter activity, mountain goats often move to escape terrain and remain there presumably until a sense of security is regained (Foster and Rahs 1983, Côté 1996, Goldstein et al. 2005). The increased seasonal use of escape terrain could, therefore, reflect animal's response to more frequent helicopter activity during the heliskiing season, particularly as the increase was not evident in the control area animal. The increased use of escape terrain could result in indirect costs to individual fitness, should the use of these safer areas compromise the animal's ability to forage or carry out other behaviours beneficial to fitness (Murphy and Curatolo 1987, Bradshaw et al. 1998, Geist 2011). Elk, shifting from meadows to less risky forested areas when a risk of predation was imposed, were found to have reduced diet quality (Hernandez and Laundre 2005).

Prior research has identified the importance of escape terrain in the habitat use of mountain goats (Gross et al. 2002, Keim 2003, Festa-Bianchet and Côté 2008). Previous studies in the nearby Nass Valley of northwest B.C. found that presence and sign of mountain goats were typically within 50 m of escape terrain (Demarchi and Johnson 1998). Although primarily used for avoiding predation and perceived threats, steep, rugged escape terrain in the winter season has the added benefit of shedding snow (Fox et al. 1989). Animals inhabiting escape terrain during winter, therefore, benefit from increased mobility, decreased energetic expenditures, and increased access to food sources due to lack of snow cover.

Given the beneficial functions of steep slopes during the winter season and their increased use as the winter progresses, it is not surprising that a seasonal increase in use of escape terrain was observed in the majority of animals and not just those that were most exposed to helicopter activity. The lower use of escape terrain in the heliskiing season by the animal in the control area may be attributed to the animal using areas steep enough to prevent snow accumulation, but not steep enough to be classified as escape terrain. Further, the areas used by mountain goats during the winter must be not only snow free, but contain adequate forage (Fox 1983). If the escape terrain available had little forage or was not interspersed with areas of forage such as meadows, avalanche chutes, or forest, the animal may have had to use areas that were less steep but of higher forage quality to meet nutritional requirements.

Resource Selection Strategies in Relation to Heliskiing Activity

Resource selection analyses consider multiple variables and allow us to quantify the tradeoffs that animals make in selecting locations. In composing our resource selection model set, our objective was to determine whether mountain goats were responding to helicopter activity on the landscape through their resource selection strategies. If heliskiing activity was an important factor influencing distribution patterns of mountain goats, we expected that individuals would: 1) show avoidance of heliskiing areas within their selected locations; and/or 2) make tradeoffs to choose secure locations in areas of highest helicopter exposure. We expected that the relative importance of heliskiing activity and security features within resource selection strategies would be directly related to the total helicopter exposure of the individual, with the animal in the control area showing different resource selection strategies from animals in high use areas.

Influence of helicopter activity on use of seasonal ranges

Heliskiing intensity, at the levels observed, was generally not an important factor influencing resource selection patterns of collared mountain goats during the heliskiing season. In the one instance where it was included within the top predictive model, avoidance was not apparent ($\beta_i = 0.007$, $P = 0.26$). Additionally, there were few data showing that areas of heliskiing activity were important in the early winter, indicating that: 1) animals did not select against areas of traditional heliskiing activity outside of the heliskiing season; and 2) animals did not select for areas of traditional heliskiing activity during the early winter, then avoid the same areas at the onset of heliskiing activity.

Heliskiing and helicopter activity, occurring predominately in the airspace, do not cause any detectable loss or change of habitat quality apart from their associated auditory and visual disturbance stimuli (Hamilton and Wilson 2003). The influence of heliskiing activity on wildlife habitat is thereby dependent on the frequency of activity detectable to animals (i.e., the amount of time that the heliskiing activity is taking place within range of the animals). Avoidance responses are often directly related to the intensity of the disturbance or human activity on the landscape (Klein 1993, Dyer et al. 2001). In cases of rare or sporadic disturbance, the costs of avoidance of disturbance may outweigh the benefits to individual fitness, particularly if undisturbed areas of equivalent habitat value are not easily accessible, or the disturbance occurs within an area of critical habitat, such as wintering areas or areas vital to reproduction (Bejder et al. 2009).

In this study, the maximum helicopter exposure of animals inhabiting the active heliskiing area ranged from 3 minutes to 255 minutes over the course of a season. The low frequency of disturbance observed is likely due to the avoidance of mountain goat habitat by helicopters, as recommended in the B.C. Wildlife Guidelines (Government of British Columbia 2006) that companies are expected to comply with, as well as the differences in the areas used for heliskiing activity versus the areas used by mountain goats. Heliskiing activity occurs in areas of deep, unconsolidated snow (Hamilton and Wilson 2003), whereas mountain goats select for areas with minimal snow accumulation. Although mountain goat habitat may be adjacent to areas of heliskiing, heliskiing activity would likely rarely occur directly within the generally snow-free that areas mountain goats inhabit.

In other species where avoidance of disturbance has been observed, the disturbance was often higher intensity and more predictable than the helicopter disturbance experienced by animals in our study. Many wildlife species have been shown to avoid areas of predictable human disturbance, such as roads and trails, and established infrastructure such as mines and drilling operations (Dorrance et al. 1975, McLellan and Shackleton 1989, Gander and Ingold 1997, Colescott and Gillingham 1998, Papouchis et al. 2001, Johnson et al. 2005). In areas where the source of the disturbance is infrequent and not as predictable, animals respond behaviourally to the disturbance, but may not recognize and associate specific areas with disturbance, evoking an avoidance response. For example, although caribou were found to avoid areas of intensive snowmobile use that overlapped a large percentage of their range (Seip et al. 2007), similar studies examining snowmobile use, when maintained at a lower frequency, had no perceptible effect on distribution (Tyler 1991).

Conversely, the opposite effect has also been shown, wherein animals will eventually acclimatize to disturbance that is predictable (i.e., habituation), remaining in areas of high activity, and in some instances, even attracted to these areas as they can provide protection from predators that may be more wary (Isbell and Young 1993, Kloppers et al. 2005, Stankowich 2008). Confirming habituation, however, requires sequential measurements of the responses of marked individuals to controlled disturbance stimuli, often over a period of years to determine a decline in intensity of response (Nisbet 2000, Bejder et al. 2006). Without confirming that the change in response over time occurred within individuals, observations of increased tolerance to anthropogenic disturbance may instead indicate the displacement of more sensitive animals away from the area of disturbance, resulting in only tolerant animals remaining in the study area (Griffiths and van Schaik 1993, Fowler 1999, Bejder et al. 2006); a management issue if the displacement leads to reductions in population size.

Where mountain goats have been observed to avoid areas of disturbance, the avoidance has often been associated with a focal source disturbance, such as a drilling pad (Foster and Rahs 1983) or specific logging block on the landscape (Gordon and Wilson 2004). Focal-point disturbances may be more easily recognized on the landscape, and therefore avoided, than a more dynamic, unpredictable and dispersed form of disturbance, such as heliskiing. Because helicopter-mountain goat interactions were very infrequent among animals and not focused on a single part of the range, association and avoidance of a specific area of repeated activity would be unlikely. In areas where heliskiing activity is more concentrated, such as smaller heliskiing tenure areas with repeated use of flight routes, landing points, and ski runs, different results regarding resource use and distribution relative to activity might occur.

Avoidance of disturbance is also reliant on an animal's ability to move away from the site of disturbance and find adequate range in a less disturbed area, which may be limited due to either anatomical, behavioural, or energetic restrictions, or to habitat constraints such as a high degree of habitat specificity or a lack of suitable movement corridors (Miller 1994, Gill et al. 2001, Beale and Monaghan 2004, Stankowich 2008). In cases where movement is impeded, animals may persist despite disturbance, regardless of whether or not their survival or reproductive success is reduced (Gill et al. 2001). As an obvious example, avian species exposed to helicopter disturbance, but unable to disperse due to molting, have exhibited decreased body condition due to disturbance effects (Miller 1994). Although more subtle, movement limitations also may be a factor affecting resource use by mountain goats exposed to heliskiing disturbance during the winter season, because of their specificity of winter range and the energetic costs of movement in the winter season. Mountain goats often exhibit a high fidelity to small areas of winter range (Taylor and Brunt 2003, Taylor et al. 2004) and rarely move between widely separated patches of winter range due to the energetic costs of moving long distances through deep snow (Dailey and Hobbs 1989). As such, animals may be less likely to move away from helicopter activity despite potential fitness effects. For example, Joslin (1986) found that although a significant decline in mountain goat productivity occurred during a period of frequent seismic activity, mountain goats did not abandon their range, a fact attributed to the animals' high fidelity to traditional home ranges.

Influence of helicopter activity on resource selection strategies

Although we did not find evidence of mountain goats directly avoiding areas of heliskiing activity, we did observe patterns in resource use that suggest animals in areas with higher heliskiing activity select more strongly for security features. The ranges of mountain ungulates are often a mosaic of steep and rugged cliff terrain interspersed within a matrix of more forage-rich, but relatively dangerous, vegetated habitats of alpine meadows, avalanche chutes, shrub and forested areas (White 2006). Predation risk often forces animals to trade off quality foraging sites for areas of increased safety (Bleich et al. 1994, White 2006, Hamel and Côté 2007, Walker et al. 2007). Although disturbance such as heliskiing activity does not pose a predation threat, animal response to disturbance is often analogous to their response to predators, and it can be reasoned that the same tradeoffs in resource use may therefore occur.

The majority of individuals within the study area (11 of 15, including the control animal) exhibited an aspect + topography-based selection strategy during the heliskiing season, while 4 individuals exhibited a security + topography-based strategy. There was not a clear threshold of helicopter activity above which animals seemed to select more or less strongly for security-type features. Three of the 4 animals that exhibited the security strategy, however, inhabited the area of highest helicopter activity (Ningunsaw), and for 2 of these animals, inter-annual variations in resource use occurred wherein a security-based strategy was used only during the year of relatively higher helicopter exposure. The increased selection for security features in more frequently disturbed areas and years may represent a tradeoff between avoidance of disturbance and selection for other beneficial functions of winter range. For mountain goats inhabiting areas of high helicopter activity, it may be more energetically conservative for these animals to inhabit areas closer to escape terrain, where threats can be more easily detected and avoided, rather than less secure areas that may be optimal in terms of forage or insolation but perceived as more dangerous.

In our study, the use of security features during the heliskiing season was generally consistent among all animals regardless of the apparent selection strategy, indicating that the selection detected in the resource selection analyses may be influenced by variation in availability of resources. Inferences of RSF analyses rely on the variation in used and available points, and in cases where the home range is very small or homogenous, as in many of the winter ranges in our study, detecting selection can be difficult (McLean et al. 1998, Boyce et al. 2002). To corroborate the findings related to resource selection identified through the RSF analyses, we compared individual selection patterns with observed use data.

During the heliskiing season, mountain goats, including those animals that exhibited a security-based selection strategy, generally used areas of steep slopes and southern aspects that were located at upper elevations. Snow accumulation is minimized on steep south-facing slopes due to melt and sublimation with solar radiation, and because of the snow-shedding characteristics of steep terrain (Fox et al. 1989, Wilson 2005). Animals were also typically in close proximity to escape terrain such as cliffs or rock outcrops. This affinity for escape terrain is commonly documented in mountain goats, and attributed to both increased security from potential predatory threats and likely decreased snow accumulation during the winter months (Demarchi and Johnson 1998, Gross et al. 2002, Festa-Bianchet and Côté 2008).

The majority of animals selected for and used convex landscape features, such as ridges, slopes and rock faces rather than concave features such as gullies or ravines. Steep, convex sites have been shown to be important features in mountain ungulates winter range due to their function in decreasing snow deposition, as the convexity of a site influences the deposition of snow and exposure to wind (Pomeroy et al. 1998, Walker et al. 2007). Additionally, it has been proposed that areas of convex terrain may provide security functions as well, allowing animals better visibility for detecting and avoiding perceived threats (Rowland et al. 2000).

Although not as consistent among individuals, NDVI was selected against in both the early winter and heliskiing seasons. We had anticipated NDVI to provide an indication of an individual's selection for types of vegetation that could provide cover as a security attribute (i.e., forested areas). Due to the infrequent use of forest, however, the patterns of NDVI selection in individuals were related only to the vegetated status of the primary land-cover classes that animals inhabited. Predominant selection against areas of high NDVI in collared animals was therefore interpreted as individuals increased use of rock relative to avalanche chutes and alpine meadow during the early winter and heliskiing seasons. Mountain goats have been shown to increase use of rock cliffs, caves and overhang areas during the winter months to gain shelter during severe weather events (Soper 1970, Mountain Goat Management Team 2010). The avoidance of areas of high NDVI was more apparent during the early winter than during the heliskiing season as individual ranges typically encompassed a greater diversity of land-cover classes, and therefore, available NDVI values.

When we compared resource selection patterns between seasons, we found that overall, selection strategies were more variable in the early winter and influenced by a larger number of habitat attributes. Compared to the heliskiing season, animals were not as selective in choosing the steepest available slopes or the most southerly aspects. In early winter when snow depths are shallower (Appendix C), selection for snow-moderating habitats is probably less important for optimizing fitness. In western Montana, the selection by mountain goats for southern exposure and cliff terrain was strongest when winter snow depths were greatest

(Smith 1977). When not as reliant on selecting for locations that minimize snow accumulation, mountain goats may be more plastic in their selection strategies, using a greater diversity of terrain- and vegetation-related features to optimize foraging opportunities, reproductive success or other behaviours beneficial to fitness.

The selection for security attributes including distance to escape terrain, terrain ruggedness and curvature appeared to be more prevalent during the early winter season, counter to what would be expected if heliskiing induced a selection for security terrain. In other areas, mountain goats affinity for security terrain is most influenced by predation pressure, with animals remaining closer to security terrain when predators are more abundant (Singer and Doherty 1985, Fox and Streveler 1986, Varley 1998). In our study, however, selection for security features appeared to be largely influenced by availability, with selection more apparent during the early winter when seasonal ranges encompassed a greater diversity of terrain, including areas that were less steep.

MANAGEMENT IMPLICATIONS

Conserving winter range is often perceived as a critical factor in the management of mountain goats. Activities such as heliskiing, which may compromise the quality or availability of winter range, therefore, require careful consideration. The effect of disturbance on the distribution of wildlife has been identified across many species, but is difficult to predict as it is complicated by many factors related to the species and individual, the nature of the disturbance, the quality of the habitat where the disturbance occurs, the relative quality of alternative habitat that is less disturbed, dispersal limitations, and environmental conditions (Gill et al. 2001, Fernandez-Juricic et al. 2002, Frid and Dill 2002, Rode et al. 2006).

At the levels observed in our study (≤1 h of heliskiing activity per month, attempting to adhere to a 1,500-m separation distance), heliskiing activity did not appear to be a factor influencing the distribution of mountain goats on the landscape, and therefore, was not likely to impact the quality or availability of winter range. The negligible effect of helicopter activity in this study was likely largely a factor of: 1) previous management actions that altered flight routes and ski-runs that occurred in close proximity to identified mountain goat winter range; and 2) mountain goats using high-elevation, snow-free terrain while helicopter activity generally occurred along valley bottoms and low passes, and when at high elevations, occurred within areas of deep, unconsolidated snow desirable for skiing, but rarely used by goats. We do not, however, assume that the same lack of effect would occur in a system with increased frequencies of helicopter activity, or in instances where mountain goats wintered at lower elevations where they helicopter overflight activity may be more frequent.

The female mountain goats in our study exhibited high-elevation wintering strategies typical of many interior ecotype systems (Poole et al. 2009). In coastal ecotype systems, animals exhibit a different wintering strategy, descending to older age forest stands with dense canopy cover capable of intercepting snow, and foraging primarily on conifers, arboreal lichen, and litterfall during the winter months (Gordon and Reynolds 2000, Rochetta 2002, Taylor and Brunt 2007). Mountain goats that winter at high elevations on exposed rock faces, such as we observed, may be easier to detect and be avoided by helicopter pilots than animals inhabiting forested stands (Poole 2007, Rice et al. 2009). Further, in our study, lower elevation slopes often had higher frequencies of helicopter over-flight activity than upper elevation areas; resulting in a potential increased level of disturbance for animals wintering at lower elevations.

Given the importance of frequency of disturbance on habitat-use effects (Klein 1993, Dyer et al. 2001, Powell 2004, Boldt and Ingold 2005) and the possibility of increased effects at higher intensities of helicopter activity, we recommend that to prevent any adverse effects on habitat use, wildlife managers consider maintaining helicopter activity levels at or below those observed during our study period. To effectively achieve this, managers should work co-operatively with helicopter-based industry to identify areas of mountain goat habitat and define areas where helicopter activity is to be avoided. In areas of frequent heliskiing activity (i.e., in small tenure areas or areas of multiple sources of helicopter activity), activity should be managed using a more conservative separation distance (2 km, Chapter 2) or regulated to reduce the frequency of activity surrounding winter mountain goat habitat. Compliance to regulations could be monitored by requiring that heliskiing companies submit flight activity recorded by on-board GPS units, similar to what was used in this study.

Also, a lack of avoidance does not necessarily equate to a lack of impact. Avoidance of disturbance is influenced by a myriad of factors including the quality of the occupied site, the distance to and quality of other alternative sites, the energy expenditure associated with avoidance, dispersal limitations and the individual's nutritional condition (Gill et al. 2001). As such, animals may persist in disturbed areas despite reduced fitness (Bechet et al. 2004). The most effective course of management action in disturbed areas would therefore be to complement assessment of habitat use with monitoring of demographics such as reproductive rates and population numbers, monitoring for any changes associated with increased helicopter activity.

Chapter 4: Management Recommendations

INTRODUCTION

The management goal for mountain goats in British Columbia (B.C.) is to: "maintain viable, healthy and productive populations of mountain goats throughout their native range in British Columbia" (Mountain Goat Management Team 2010: v). Under this broader goal of conservation, 3 management objectives are listed to: 1) maintain suitable, connected mountain goat habitat; 2) mitigate threats to mountain goats; and 3) ensure that opportunities for non-consumptive and consumptive use of mountain goats are sustainable (Mountain Goat Management Team 2010). Increasing levels of human disturbance within mountain goat range in B.C., particularly helicopter-based disturbance, have been identified as a potential threat to mountain goat populations requiring further research and management action (Wilson and Shackleton 2001, Festa-Bianchet and Côté 2008, Mountain Goat Management Team 2010). The purpose of my thesis research was to better understand the response of mountain goats to helicopter disturbance at a medium-term scale, thereby allowing managers to better evaluate the risk it poses to conservation goals and the measures necessary to manage for it.

In assessing the risk of human activities such as heliskiing to wildlife populations, researchers often focus on the short-term responses of individuals (i.e., movement responses or changes in vigilance) to disturbance events, and then attempt to extrapolate their results to potential demographic impacts (Harrington and Veitch 1992, Powell 2004). This approach typically entails determining the distance at which individuals respond behaviourally to the disturbance stimuli, then designating a separation distance for that species and disturbance stimuli based on the most sensitive individuals observed (Blumstein et al. 2003). Implicit in this approach is the assumption that reducing or eliminating short-term behavioural responses will similarly prevent any long-term demographic effects (Blumstein et al. 2003, Beale 2007). It is unknown, however, whether short-term behavioural reactions are transformed into long-term changes in fitness or habitat use, or how those changes may influence demographics (i.e., reproduction, survival or population size; Gill et al. 2001, Beale and Monaghan 2004, Bejder et al. 2006). In some cases, individuals that exhibit short-term flight behaviour suffer no long-term consequences (Richens and Lavigne 1978), while in other cases, short-term flight responses of animals and increased use of escape terrain can lead to reductions in body mass, productivity, and ultimately, population size (Reimers et al. 2012, Miller 1994).

Given the uncertainties associated with making inferences of demographic effects from short-term studies, managers should use an approach that considers: 1) the estimated costs of disturbance to individuals, incorporating not only the direct costs of movement, but also costs attributed to changes in habitat use and physiological stress; 2) how these costs may be affected by the frequency of disturbance (i.e., if an individual's response intensifies with increasing frequency of disturbance); and 3) the potential for individuals to habituate or sensitize to the disturbance stimuli over time. Considering these factors, managers can better predict the demographic risks associated with disturbance and make appropriate management decisions that achieve the desired management outcome, whether it be eliminating all disturbance or reducing the effects to a point that detrimental demographic effects are prevented.

In B.C., management of recreation- and tourism-related activity is defined within the B.C. Wildlife Guidelines (Government of British Columbia 2006). According to the guidelines, heliskiing and other forms of aerial disturbance are to maintain a minimum separation distance of 1,500 m line-of-sight from mountain goats and their identified habitat.

Adherence to this minimum separation distance, in conjunction with other precautionary measures (i.e., a ban on landing in winter range, and seasonal closures in critical areas; see Appendix A), are assumed to achieve the desired management outcomes of preventing disruption to typical mountain goat behaviour and ensuring continued occupancy of mountain goat range. By preventing changes to the observed distributions and behavioural response of mountain goats within the heliskiing tenure areas, it is assumed that demographic impacts on reproduction and survival also will be prevented (Government of British Columbia 2006).

The guidelines, however, have been questioned as being too restrictive (Denton 2000). Goldstein et al. (2005) argued that separation distance recommendations pertaining to mountain goats and helicopters should be more flexible because flight responses vary depending on factors of topography, environment, and, potentially, prior disturbance history (see Chapter 2). Conversely, it also can be reasoned that the recommendations may be insufficient to prevent demographic impacts, in that they: 1) are not based on the most sensitive individuals (i.e., 2-km response distance to helicopters observed by Côté (1996), Chapter 1); 2) do not consider the potential indirect effects of disturbance; 3) do not regulate the frequency of disturbance and possible sensitization effects; 4) are dependent on compliance of helicopter operators in avoiding mountain goat range; and 5) are dependent on the accurate avoidance of animals at a distance of 1,500 m when animals are outside of designated mountain goat range. Further, by designating a line-of-sight separation distance, it is assumed that animals will not respond to the noise associated with a non-visible helicopter. Because of the controversy surrounding guidelines, compliance and enforcement of guidelines is inconsistent throughout the provincial heliskiing tenure areas, leading to concerns that many operators are not in compliance relative to the guidelines (Denton 2000).

The operator of the heliskiing tenure area in my study, Last Frontier Heliskiing (LFH; operating since 1996), has made extensive efforts to minimize their potential impact on mountain goats. The LFH tenure area lies within an area of high mountain goat density in B.C. (0.45 animals/km^2) (Keim 2003). A winter habitat suitability index (HSI) algorithm created for the area by Keim (2003) for the B.C. Ministry of Environment (containing attributes of slope, elevation, distance to escape terrain and aspect) predicted that 9.8% of the LFH tenure area was suitable winter habitat for mountain goats. Aerial surveys, performed by Keim (2003), validated the HSI predictions of range use by mountain goats, indicating that the algorithm correctly identified 93% of the habitat use, and confirmed 3.6% of the tenure area as occupied winter range (Keim 2003). To avoid these identified winter-range areas, in 2007 (the same year this study was initiated), LFH altered or eliminated a large proportion of established ski runs and landing areas (>50%), and redistributed their activity to minimize helicopter flight frequency within the designated 1,500 m surrounding probable winter range.

My thesis work, in documenting the movement and resource use responses of mountain goats within the LFH tenure area to helicopter disturbance over several heliskiing seasons, offered an opportunity to evaluate the efficacy of the recommended avoidance measures. Further, in examining the effects of helicopter disturbance on daily to seasonal movement and resource use patterns, this research provided a more in-depth understanding of the effects of helicopter disturbance on movement and resource use by mountain goats. Here, I recommend measures to help mitigate helicopter-related changes to movement and resource use by mountain goats, and potential refinements to existing management guidelines. I also discuss the uncertainties associated with management of helicopter-related disturbance such as heliskiing, and the future research needed to assess the impacts of helicopter activity on the population viability of mountain goats.

MANAGEMENT CONCLUSIONS

During the 3 years of the study, 214 close-proximity mountain goat-helicopter interactions (≤2 km) occurred among 11 animals, resulting in anomalous movements and at times, changes to range size. This indicates that even concerted attempts to adhere to the avoidance measures defined in the wildlife guidelines did not eliminate all activity potentially disruptive to mountain goats. There are several reasons for this: 1) the recommended separation distance does not account for activity that the most sensitive individuals would respond to (i.e., 1,500 m – 2 km, Côté 1996, Chapter 2); 2) the guidelines permit helicopter activity up to 500 m from animals if it is out-of-sight, however, animals still respond to the audible cues from non-visible helicopters (Chapter 2); and 3) when outside of identified winter range areas, helicopter pilots were not able to detect and avoid mountain goats at distances sufficient to prevent a movement response. This is not surprising as mountain goats are difficult to detect even at close range, and almost impossible at 1,500 m.

The effects of these interactions on mountain goats were evident in changes to daily movement behaviour in the 48 h following interactions (i.e., 91 anomalous movements were recorded across individuals; Chapter 2) and in some cases, the increased use of security terrain by animals inhabiting areas of high heliskiing activity (Chapter 3). Despite these effects, seasonal movement rates and range size did not increase in individuals exposed to higher levels of heliskiing, and there was no evidence that collared animals avoided areas of heliskiing activity within their range, indicating no evidence of functional habitat loss due to heliskiing activity. Through the course of the season, I did not find any strong evidence suggesting either sensitization or habituation to helicopter disturbance, though I could not rigorously test for this in my study design.

From the results of my thesis, I recommend that if the management objective is to eliminate any behavioural response of mountain goats to heliskiing activity, a 2-km minimum separation distance be applied to both in-sight and out-of-sight helicopter activity. Reduction of this separation distance should be considered if both visual and auditory effects can be eliminated by topography. This could be achieved by accounting for both the viewscape, and the soundscape when designating restricted areas surrounding mountain goat habitat (Andrus and Howlett 2006). Further, identification of mountain goat range, and, therefore, areas restricted to heliskiing, should be conservative and incorporate travel routes that mountain goats utilize between adjacent clusters of winter range.

Although the HSI model used to identify winter range within the LFH tenure area proved accurate most of the time according to validation surveys (Keim 2003), it could not predict the locations of all animals at all times because of inherent variations in individual resource-use behaviour, differences in local environments across the range and seasons, and the potential for mountain goats to be outside of identified winter ranges when moving between discrete winter ranges (Taylor et al. 2004). Outside of the identified winter range areas where helicopter activity is restricted, avoidance relies on detection of animals at a distance (>1,500 m), which can be almost impossible, particularly when animals are in forest cover, extremely rugged terrain, or when weather conditions such as blowing snow or cloud cover impede sightability (Poole 2007, Rice et al. 2009). During the close-proximity encounters recorded in this study, helicopters were consistently at lower elevations than the animals. If an animal was in a rugged area or obscured by a cloud ceiling above the helicopter, the helicopter pilot and occupants would likely not have been able to detect the animal and take the appropriate avoidance measures. A larger, more conservative range estimate may compensate for the uncertainty in predicting animal locations, and prevent these interactions outside identified range areas.

In contrast, if the objective in managing for heliskiing is not to eliminate all disturbance but to accept a low level of disturbance while maintaining seasonal movement rates and range occupancy, the guidelines adhered to by the helicopter activity in this study (i.e., 1,500 m line-of-sight separation distance and avoidance of identified mountain goat habitat) may be adequate given the frequency of heliskiing activity remains at or below the 1 h/month observed in this study. Although I documented anomalous movement behaviour from both close-proximity incidental interactions and interactions that occurred outside the 1,500 m line-of-sight buffer area, these anomalous movements were too infrequent to influence individual seasonal movement rates or range sizes (Chapter 2).

The impact of anomalous movements on seasonal movement rates, and ultimately, an individual's fitness is likely related to the frequency of their occurrence and the ability of animals to either compensate for energetic costs, or habituate to the disturbance stimuli. Even in instances where heliskiing is managed to avoid areas of mountain goat range, the occurrence of incidental interactions, and interactions with sensitive individuals would be expected to increase with increasing heliskiing frequency. Similarly, in terms of range use, the increase in use of security terrain by mountain goats could intensify with increasing frequency of flight activity, and unless animals were able to compensate or habituate, could compromise use of other beneficial resources within their range, potentially reducing fitness. It should also be considered that in designating a minimum separation distance that is not based on the most sensitive animals, the most responsive animals that will be compromised by increased frequency of disturbance may be females with offspring that are known to have a higher perception of risk than barren females or males (Hamel and Côté 2007, Ciuti et al.

2008). In mountain goat populations, where changes in population size are most influenced by reproductive females (Hamel et al. 2006), this should be carefully considered.

The frequency and distribution of helicopter activity within tenure areas will vary according to tenure size, the amount of terrain conducive to skiing, the number of skiers, and the number of helicopters in an area at a time. The size of heliskiing tenure areas varies greatly within B.C., with several tenure areas only a small fraction of the size of LFH (i.e., 9,000 km^2 [F.Fux, LFH manager, personal communication, May 2012] compared to ~237 km^2 [Chatter Creek Heliskiing, http://www.chattercreek.ca, accessed 30 July 2012]). The large tenure size and extensive terrain options of LFH, combined with their practice of using different areas of ski terrain each day, limiting group sizes, and only having one helicopter in an area at a time, mean that the frequency of heliskiing activity within my study area was relatively low. In smaller tenure areas of limited terrain options, or tenures where multiple helicopters were used, the frequency of heliskiing activity per unit area, and therefore, the number of unintended mountain goat-helicopter interactions, would likely increase. The increased frequency of disturbance could lead to sensitization of animals, for which individuals respond to helicopter disturbance at a closer proximity than previously assessed; an effect described in both mountain goats and Dall sheep in response to aerial disturbance (Foster and Rahs 1983, Frid 2003).

Given the uncertainties regarding the effect of increased frequency on animal response to disturbance, and consequently, the costs incurred, I recommend that if the current 1,500 m separation distance is maintained, that frequency of heliskiing exposure be regulated to levels either at or below that observed in my study (i.e., ≤1 h/month) to ensure minimal changes to seasonal movement or habitat use. In instances of increased frequency, separation distances should be extended to 2 km or frequency of flights reduced to a level proven to prevent longer-term changes to movement behaviour or habitat use. To ensure that avoidance is effective, companies should collaborate with regional biologists to clearly identify areas of mountain goat winter range within their tenure area, and undertake pre-planning measures to alter or remove flight routes, ski runs and drop-off points within range of these winter ranges. If deemed necessary, records of heliskiing flight activity (acquired using on-board GPS units), could also be kept to allow review of company compliance in avoiding mountain goat range.

Although the source of helicopter activity analyzed in this thesis was related to heliskiing, I also recommend that the inferences made regarding animal responses, potential effects, and necessary mitigation measures are applicable to all sources of helicopter activity. The increasing frequency of helicopters within the range of mountain goats is not solely attributed to helicopter-supported recreation, and is associated with diverse government, industry, and private sectors. The cumulative effects of this activity may elicit a heightened stress response relative to recreation- or tourism-related helicopter activity, because of the larger helicopters and use of sling-loads (i.e., loads lifted and transported through the air using a long-line attached to the helicopter) often associated with industrial helicopter activity (Gordon and Wilson 2004).

Future research

My research provides a more thorough understanding of the effects of helicopter disturbance on movements and range-use of mountain goats, and provides insights to better predict the long-term effects of disturbance on mountain goat populations. It does not, however, conclusively prove or disprove demographic consequences of disturbance, and leads to further questions regarding the effects of increased frequency of disturbance. In this section, I discuss future research I believe is necessary to effectively manage for helicopter disturbance without compromising the conservation of mountain goats.

To assess demographic effects, I recommend that a long-term study compare the population demographics of a marked mountain goat population for a period of several years both before and after the establishment of heliskiing activity. Lacking a before-and-after approach of the same area, a comparison of adjacent areas with similar environmental influences and population demographics could be conducted, wherein researchers can compare the demographics of the disturbed and undisturbed populations. In both approaches, it is important that the control area is exposed to no helicopter activity, and that the heliskiing area is newly established, so that responses of the most sensitive individuals can be assessed. In some wildlife populations in heavily disturbed areas, it has been found that the more sensitive individuals will be displaced, or be selected against over time, resulting in a population of tolerant individuals (Bejder et al. 2006).

By marking individuals in the long-term study population and determining age, reproductive status, and genealogy of individual mountain goats, researchers would be able to discern the life-history characteristics of the most sensitive individuals, the fate of those most sensitive individuals as disturbance increases, and whether or not sensitivity to disturbance is a heritable trait. With this knowledge, we could better assess: 1) whether the most sensitive individuals are reproductive females critical to population viability; 2) whether the most sensitive animals in the population are selected against, displaced, or whether they eventually habituate; 3) whether sensitivity to disturbance is a hereditary trait or learned by individual experience (which would allow us to make better inferences regarding habituation and sensitization); and most importantly; 4) whether increased disturbance leads to population decline.

Lacking a long-term study, there are several questions that could be addressed in shorter-term studies that would also increase our understanding of the effects of disturbance and how they should be effectively managed. An experimental approach could be used to increase the frequency of helicopter disturbance until a population effect of disturbance was seen (i.e., until population decline). Although powerful, this approach raises serious ethical concerns regarding harassing a population of mountain goats to the point of potential decline, and should be carefully considered. Short-term studies could also be conducted to better understand the characteristics of sensitive versus tolerant individuals. In ungulates, it is generally found that female with offspring have a higher perception of predatory risk (Horejsi 1981, Hamel and Côté 2007, Ciuti et al. 2008), so it follows that they may be more sensitive to disturbance as well. If this was demonstrated, it would suggest that contracted separation distances that allowed for the frequent disturbance of sensitive individuals may compromise the most demographically important subset of the mountain goat population (i.e., reproductive females; Hamel et al. 2006, Festa-Bianchet and Côté 2008).

Finally, this thesis focused on changes in movement and resource use attributed to heliskiing, but was unable to account for physiological stress; an effect of disturbance that can lead to compromised reproduction and survival rates, but is not always associated with changes in behavioural cues such as flight (MacArthur et al. 1979, Macbeth et al. 2010). Cortisol, a glucocorticoid produced in most mammals, is often used to assess the stress response of mammals (Millspaugh et al. 2001). Advances in the development of cortisol concentration in hair as a tool to monitor long-term stress in wildlife (MacBeth et al. 2010, Russell et al. 2012) may provide an indication of stress levels in mountain goats inhabiting areas of increased heliskiing intensity. For example, comparing the hair samples of individuals in a highly disturbed area to historical hair samples from the same region prior to disturbance may provide an effective, non-invasive approach to assessing the physiological effects of disturbance.

Literature Cited

Andrus, K., and T. Howlett. 2006. Development of a heliskiing and mountain goat habitat management model. <http://esri.com/mapmuseum/mapbook_gallery/volume19/environment4.html>. Accessed 20 October 2007.

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

Beale, C. M., and P. Monaghan. 2004. Behavioural responses to human disturbance: a matter of choice? Animal Behaviour 68:1065–1069.

Bechet, A., J. F. Giroux, and G. Gauthier. 2004. The effects of disturbance on behaviour, habitat use and energy of spring staging snow geese. Journal of Applied Ecology 41:689–700.

Bejder, L., A. Samuels, H. Whitehead, and N. Gales. 2006. Interpreting short-term behavioural responses to disturbance within a longitudinal perspective. Animal Behaviour 72:1149–1158.

Bejder L., A. Samuels, H. Whitehead, H. Finn, and S. Allen. 2009. Impact assessment research: use and misuse of habituation, sensitisation and tolerance in describing wildlife responses to anthropogenic stimuli. Marine Ecology Progress Series 395:177–185.

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

Blumstein, D. T. 1998. Quantifying predation risk for refuging animals: a case study with golden marmots. Ethology 104:501–516.

Blumstein, D. T., L. L. Anthony, R. G. Harcourt, and G. Ross. 2003. Testing a key assumption of wildlife buffer zones: is flight initiation distance a species-specific trait? Biological Conservation 110:97–100.

Boldt A. and P. Ingold. 2005. Effects of air traffic, snow cover and weather on altitudinal short-term and medium-term movements of female Alpine chamois *Rupicapra rupicapra* in winter. Wildlife Biology 11: 351–362.

Bonenfant, M., and D. L. Kramer. 1996. The influence of distance to burrow on flight initiation distance on the woodchuck, *Marmota monax.* Behavioural Ecology 7:299–303.

Borkowski, J. J., P. J. White, R. A. Garrott, T. Davis, A. R. Hardy, and D. J. Reinhart. 2006. Behavioral responses of bison and elk in Yellowstone to snowmobiles and snow coaches. Ecological Applications 16:1911–1925.

Boyce, M. S., P. R. Vernier, S. E. Nielsen, and F. K. A. Schmiegelow. 2002. Evaluating resource selection functions. Ecological Modelling 157:281–300.

Bradshaw, C. J. A., S. Boutin, and D. M. Hebert. 1998. Energetic implications of disturbance caused by petroleum exploration to woodland caribou. Canadian Journal of Zoology 76:1319–1324.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Second edition. Springer-Verlag, New York, New York, USA.

Cadsand, B., B. Jex, and M. P. Gillingham. 2010. Modified clover trap for capturing mountain goats in Northwest British Columbia. Proceedings of the Biennial Symposium of the Northern Wild Sheep and Goat Council 17:71–77.

Calef, G. W., E. A. DeBock, and G. M. Lortie. 1976. The reaction of barren-ground caribou to aircraft. Arctic 29:201–212.

Cassirer, E. F., D. J. Freddy, and E. D. Ables. 1992. Elk responses to disturbance by cross-country skiers in Yellowstone National Park. Wildlife Society Bulletin 20:375–381.

Chadwick, D. H. 1983. A beast the color of winter. Sierra Club Books, San Francisco, California, USA.

Ciuti, S., A. Pipia, F. Ghiandai, S. Grignolio, M. Apollonio. 2008. The key role of lamb presence in affecting flight response in Sardinian mouflon (*Ovis orientalis musimon*). Behavioural Processes 77:408–412.

Colescott, J. H., and M. P. Gillingham. 1998. Reaction of moose (*Alces alces*) to snowmobile traffic in the Greys River Valley, Wyoming. Alces 34:120–125.

Colman, J. E., B. W. Jacobsen, E. Reimers. 2001. Summer response distances of Svalbard reindeer *Rangifer tarandus platyrhynchus* to provocation by humans on foot. Wildlife Biology 7:275–283.

Colman J. E., C. Pederson, D. O. Hjermann, O. Holand, S. R. Moe, and E. Reimers. 2003. Do wild reindeer exhibit grazing compensation during insect harassment? Journal of Wildlife Management 67:11–19.

Côté, S. D. 1996. Mountain goat responses to helicopter disturbance. Wildlife Society Bulletin 24:681–685.

Dailey, T., and N. Hobbs. 1989. Travel in alpine terrain: energy expenditures for locomotion by mountain goats and bighorn sheep. Canadian Journal Zoology 67:2368–2375.

Demarchi, D. A. 2011. The British Columbia ecoregion classification. Third edition. Ecosystem Information Section, Ministry of Environment, Victoria, British Columbia, Canada

Demarchi, M. W., and S. R. Johnson. 1998. Mountain goat inventory in the Nass Wildlife Area, Region A: 1997 annual report. Prepared for Forest Renewal B.C., and B.C. Ministry of Environment, Lands and Parks, Smithers, British Columbia, Canada.

Denton, J. 2000. Dealing with unprecedented levels of aircraft-supported commercial activities. Proceedings of the Biennial Symposium of the Northern Wild Sheep and Goat Council 12:138–152.

D'Eon, R. G., R. Serrouya, G. Smith, and C. O. Kochanny. 2002. GPS radiotelemetry error and bias in mountainous terrain. Wildlife Society Bulletin 30:430–439.

Dorrance, M. J., P. J. Savage, and D. E. Huff. 1975. Effects of snowmobiles on white-tailed deer. Journal of Wildlife Management 39:563–569.

Dwyer, C. M., 2004. How has the risk of predation shaped the behavioural responses of sheep to fear and distress? Animal Welfare 13:269–281.

Dyer, S. J., J. P. O'Neill, S. M. Wasel, and S. Boutin. 2001. Avoidance of industrial development by woodland caribou. Journal of Wildlife Management 65:531–542.

Eastman, J.R. 2009. IDRISI Taiga. Clark University, Worcester, Massachusetts.

ESRI (Environmental Systems Resource Institute). 2009. ArcMap 9.2. ESRI, Redlands, California.

ESRI (Environmental Systems Resource Institute). 2011. ArcMap 10. ESRI, Redlands, California.

Fairbanks, W. S., and R. Tullous. 2002. Distribution of pronghorn (*Antilocapra americana* Ord) on Antelope Island State Park, Utah, USA, before and after establishment of recreational trails. Natural Areas Journal 22:277–282.

Ferguson, M. S. D., and L. B. Keith. 1982. Influence of nordic skiing on distribution of moose and elk in Elk Island National Park, Alberta. Canadian Field-Naturalist 96:69–78.

Fernandez-Juricic-Juricic, E., M. D. Jimenez, E. Lucas. 2002. Factors affecting intra- and inter-specific variations in the difference between alert distances and flight distances for birds in forested habitats. Canadian Journal of Zoology 80:1212–1220.

Festa-Bianchet, M., and S. D. Côté. 2008. Mountain goats: ecology, behaviour, and conservation of an alpine ungulate. Island Press, Washington, D.C., USA.

Fielding, A. H. and J. F. Bell. 1997. A review of methods for the assessment of prediction errors in conservation presence-absence models. Environmental Conservation 24:38–49.

Fortin, D. and M. Andruskiw. 2003. Behavioral response of free-ranging bison to human disturbance. Wildlife Society Bulletin 31:804-813.

Fortin, D., M. S. Boyce, and E. H. Merrill. 2004. Multi-tasking by mammalian herbivores: overlapping processes during foraging. Ecology 85:2312–2322.

Foster, B.R. 1982. Observability and habitat characteristics of the mountain goat (*Oreamnos americanus*, Blainville, 1816) in west-central British Columbia. Thesis, University of British Columbia, Vancouver, Canada.

Foster, B. R., and E. Y. Rahs. 1983. Mountain goat response to hydroelectric exploration in Northwestern British Columbia. Environmental Management 7:189–197.

Fowler, G. S. 1999. Behavioural and hormonal response of Magellenic penguin (*Spheniscuc magellanicus)* to tourism and nest site visitation. Biological Conservation 90:143–149

Fox, J. L. 1983. Constraints on winter habitat selection by the mountain goat (*Oreamnos americanus)* in Alaska. Dissertation, University of Washington, Seattle, USA.

Fox, J. L., and C. A. Smith. 1988. Winter mountain goat diets in southeast Alaska. Journal of Wildlife Management 52:362–365.

Fox, J. L., and G. P. Streveler. 1986. Wolf predation on mountain goats in southeastern Alaska. Journal of Mammalogy 67:192–195.

Fox, J. L, C. A. Smith, and J. W. Schoen. 1989. Relation between mountain goats and their habitat in southeastern Alaska. U.S. Forest Service General Technical Report PNW-GTR-246, Portland, Oregon, USA.

Frid, A. 1999. Fleeing decisions by Dall's sheep exposed to helicopter overflights. Report for the Yukon Fish and Wildlife Branch, Department of Renewable Resources, Whitehorse, Yukon, CA.

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

Frid, A., and L. M. Dill. 2002. Human-caused disturbance stimuli as a form of predation risk. Conservation Ecology 6:11.

Gander, H., and P. Ingold. 1997. Reactions of male alpine chamois *Rupicapra r. rupicapra* to hikers, joggers and mountain bikers. Biological Conservation 79:107–109.

Garmin. 2009. GPSMAP 76CSx mapping GPS owner's manual. Garmin Ltd. Olathe, Kansas, USA.

Geist, V. 2011. Wildlife habituation: advances in understanding and management application. Human-Wildlife Interactions 5:9–12.

Gill, J. A., K. Norris, and W. J. Sutherland. 2001. Why behavioural responses may not reflect the population consequences of human disturbance. Biological Conservation 97:265–269.

Goldstein, M. I., A. J. Poe, E. Cooper, D. Youkey, B. A. Brown, and T. L. McDonald. 2005. Mountain goat response to helicopter overflights in Alaska. Wildlife Society Bulletin 33:688–699.

Gonzalez-Voyer, A., K. G. Smith, and M. Festa-Bianchet. 2003. Dynamics of hunted and unhunted mountain goat populations. Wildlife Biology 9:213–218.

Gordon, S. M. and D. M. Reynolds. 2000. The use of video for mountain goat winter range habitat inventory and assessment of overt helicopter disturbance. Proceedings of the Biennial Northern Wild Sheep and Goat Council Symposium 12:26–37.

Gordon, S. M., and S. F. Wilson. 2004. Effect of helicopter logging on mountain goat behaviour in coastal British Columbia. Proceedings of the Biennial Northern Wild Sheep and Goat Council Symposium 14:49–63.

Government of British Columbia. 2006. Wildlife guidelines for backcountry tourism/ commercial recreation. <http://env.gov.B.C.ca/wld/twg/index.html>. Accessed 1 Feb 2009.

Griffiths, M. and C. P. van Schaik. 1993. The impact of human traffic on the abundance and activity periods of Sumatran rain forest wildlife. Conservation Biology 7:623–626.

Gross, J. E., M. C. Kneeland, D. F. Reed, and R. M. Reich. 2002. GIS-based habitat models for mountain goats. Journal of Mammalogy 83:218–228.

Gustine, D. D., K. L. Parker, R. J. Lay, M. P. Gillingham, and D. C. Heard. 2006. Calf survival of woodland caribou in a multi-predator ecosystem. Wildlife Monograph 165: 1-32

Hamel, S., S. D. Côté, K. Smith, and M. Festa-Bianchet. 2006. Population dynamics and harvest potential of mountain goat herds in Alberta. Journal of Wildlife Management 70:1044–1052.

Hamel, S., and S. D. Côté. 2007. Habitat use patterns in relation to escape terrain: are alpine ungulate females trading-off better foraging sites for safety? Canadian Journal of Zoology 85:933–943.

Hamilton, D., and S. Wilson. 2003. Cumulative effects of habitat change and backcountry recreation on mountain caribou in the central Selkirk Mountains. Unpublished report for British Columbia Ministry of Sustainable Resource Management, Nelson, British Columbia, Canada.

Harrington, F. H., and A. M. Veitch. 1992. Calving success of woodland caribou exposed to low-level jet fighter overflights. Arctic 45:213–218.

Hernández , L., and J. W. Laundré JW. 2005. Foraging in the 'landscape of fear' and its implications for habitat use and diet quality of elk *Cervus elaphus* and bison *Bison bison*. Wildlife Biology 11:215–220.

Horejsi, B. L. 1981. Behavioral response of barren ground caribou to a moving vehicle. Arctic 34:180–185.

Hurley, K. 2004. NWSGC Position Statement on Helicopter-Supported Recreation and Mountain goats. Proceedings of the Biennial Symposium of the Northern Wild Sheep and Goat Council 14:131–136.

Isbell, L. A., and T. P. Young. 1993. Human presence reduces predation in a free-ranging vervet monkey population in Kenya. Animal Behaviour 45:1233-1235.

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65–71.

Johnson, C. J., K. L. Parker, D. C. Heard, and M. P. Gillingham. 2002. Movement parameters of ungulates and scale-specific responses to the environment. Journal of Animal Ecology 71:225–235.

Johnson, C. J., M. S. Boyce, R. L. Case, H. D. Cluff, R. J. Gau, A. Gunn, and R. Mulders. 2005. Cumulative effects of human developments on arctic wildlife. Wildlife Monographs 160:1–36.

Johnson, J. B., and K. S. Omland. 2004. Model selection in ecology and evolution. Trends in Ecology and Evolution 19:101–108.

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

Keim, J. 2003. Modeling core winter habitats from habitat selection and spatial movements of collared mountain goats in the Taku River drainage of northwest British Columbia. Ministry of Water, Land and Air Protection, Smithers, British Columbia, Canada.

Keim, J. 2004. Modeling core winter habitat and spatial movements of collared mountain goats. Proceedings of the Biennial Symposium of the Northern Wild Sheep and Goat Council 14:65–86.

Keim, J., and C. L. Jerde. 2004. Measuring movement responses of wintering mountain goats during aerial telemetry occurrences. Ministry of Water, Land and Air Protection, Smithers, British Columbia, Canada.

Klein, M. L. 1993. Waterbird behavioural responses to human disturbances. Wildlife Society Bulletin 21:31–39.

Kloppers, E. L., C. C. St. Clair, T. E. Hurd. 2005. Predator-resembling aversive conditioning for managing habituated wildlife. Ecology and Society 10 (3). <http:// www.ecologyandsociety.org / vol10/iss11/art31/>. Accessed 30 July 2012.

Knight, R. L., and K. J. Gutzwiller, editors. 1995. Wildlife and recreationists: coexistence through management and research. Island Press, Washington, D.C., USA.

Larkin, R. P. 1996. Effects of military noise on wildlife: a literature review. Technical Report 96/21. Centre for Wildlife Ecology, Champaign, Illinois, USA.

Loehr, J., M. Kovanen, J. Carey, H. Hogmander, C. Jurasz, S. Karkkainen, J. Suhonen, and H. Ylonen. 2005. Gender- and age-class specific reactions to human disturbance in a sexually dimorphic ungulate. Canadian Journal of Zoology 83:1602–1607.

Luz, G. A., and J. B. Smith. 1976. Reactions of pronghorn antelope to helicopter overflight. Journal of the Acoustical Society of America 59:1514–1515.

MacArthur, R. A., V. Geist, and R. H. Johnson. 1979. Cardiac and behavioural responses of mountain sheep to human disturbance. Journal of Wildlife Management 46:351–358.

Macbeth, B. J., M. R. L. Cattet, G. B. Stenhouse, M. L. Gibeau, and D. M. Janz. 2010. Hair cortisol concentration as a noninvasive measure of long-term stress in free-ranging grizzly bears (*Ursus arctos*): considerations with implications for other wildlife. Canadian Journal of Zoology 88:935–949.

Madsen, J. 1998. Experimental refuges for migratory waterfowl in Danish wetlands. II. Tests of hunting disturbance effects. Journal of Applied Ecology 35:398–417.

Manel, S., H. C. Williams, and S. J. Omerod. 2001. Evaluating presence-absence models in ecology: the need to account for prevalence. Journal of Applied Ecology 38:921–931.

Manly, B. F. J., L. L. McDonald, D. L. Thomas, T. L. McDonald and W. P. Erickson. 2002. Resource selection by animals: statistical design and analysis for field studies. Kluwer Academic Publishers, Dordrecht, Netherlands.

McLean, S. A., M. A. Rumble, R. M. King, and W. L. Baker. 1998. Evaluation of resource selection methods with different definitions of availability. Journal of Wildlife Management 62:793–801.

McLellan, B. N., and D. M. Shackleton. 1989. Immediate reactions of grizzly bears to human activities. Wildlife Society Bulletin 17:269–274.

Meidinger, D. V., and J. Pojar. 1991. Ecosystems of British Columbia. Ministry of Forests, Research Branch, Victoria, British Columbia, Canada.

Menard, S. 2002. Applied logistic regression analysis. Second edition. Sage, Thousand Oaks, California, USA.

Miller, F. L., and A. Gunn. 1979. Responses of Peary caribou and muskoxen to helicopter harassment. Canadian Wildlife Service Occasional Paper 40:1–90.

Miller M. W. 1994. Route selection to minimize helicopter disturbance of molting pacific black brant: a simulation. Arctic 47:341–349.

Millspaugh, J. J., R. J. Woods, K. E. Hunt, K. J. Raedeke, G. C. Brundige, B. E. Washburn, and S. K. Wasser. 2001. Fecal glucocorticoid assays and the physiological stress response in elk. Wildlife Society Bulletin 29:899–907.

Mohr, C. O. 1947. Table of equivalent populations of North American small mammals. American Midland Naturalist 37:223–249.

Mooring, M. S., T. A. Fitzpatrick, J. E. Benjamin, I. C. Fraser, T. T. Nishihira, D. D. Reisig, E. M. Rominger. 2003. Sexual segregation in desert bighorn sheep (*Ovis canadensis mexicana*). Behaviour 140:183–207.

Mountain Goat Management Team. 2010. Management plan for the mountain goat (*Oreamnos americanus*) in British Columbia. British Columbia Ministry of Environment, Victoria, 87pp.

Murphy, S. M., and J. A. Curatolo. 1987. Activity budgets and movement rates of caribou encountering pipelines, roads, and traffic in northern Alaska. Canadian Journal of Zoology 65:2483–2490.

Neumann W., G. Ericsson, and H. Dettki. 2010. Does off-trail backcountry skiing disturb moose? European Journal of Wildlife Research 56:513–518.

Nisbet, I. C. 2000. Disturbance, habituation, and management of waterbird colonies. Waterbirds 23:312–332.

Palmer, M. W. 1993. Putting things in even better order: the advances of canonical correspondence analysis. Ecology 74:2215–2230.

Papouchis, C. M., F. J. Singer, and W. B. Sloan. 2001. Responses of desert bighorn sheep to increased human recreation. Journal of Wildlife Management 65:573–582.

Parker, K. L., C. T. Robbins, and T. A. Hanley. 1984. Energy expenditure for locomotion by mule deer and elk. Journal of Wildlife Management 48:474–488.

PCI Geomatics Corporation. 2001. PCI Works Version 7.0. Richmond Hill, Onatrio, Canada.

Penner, D. F. 1988. Behavioural response and habituation of mountain goats in relation to petroleum exploration at Pinto Creek, Alberta. Biennial Symposium of the Northern Wild Sheep and Goat Council 6:14–158.

Picton, H. D., 1999. Energetic cost of wildlife displacement by winter recreationists. In: Olliff, T., Legg, K., Kaeding, B. (Eds.), Effects of winter recreation on wildlife of the Greater Yellowstone Area: a literature review and assessment. Report to the Greater Yellowstone Coordinating Committee. Yellowstone National Park, Wyoming, pp. 135–144.

Pomeroy, J. W., D. M. Gray, K. R. Shook, B. Toth, R. L. H. Essery, A. Pietroniro, and N. Hedstrom. 1998. An evaluation of snow accumulation and ablation processes for land surface modeling. Hydrological Processes 12:2339–2367.

Poole, K. G. 2007. Does survey effort influence sightability of mountain goats (*Oreamnos americanus*) during aerial surveys? Wildlife Biology 13:113–119.

Poole, K. G., and I. Adams. 2002. Mountain goat monitoring in Canadian Mountain Holidays' Bugaboo and Bobbie Burns heli-hiking areas, East Kootenay. Unpublished report for Canadian Mountain Holidays, Cranbrook, British Columbia, Canada.

Poole, K. G., and D. C. Heard. 1998. Habitat use and movements of mountain goats as determined by prototype GPS collars, Robson Valley, British Columbia. Proceedings of the Biennial Symposium of the Northern Wild Sheep and Goat Council 11:22–35.

Poole, K. G., and D. C. Heard. 2003. Seasonal habitat use and movements of mountain goats in east-central British Columbia. Canadian Field-Naturalist 117:565–576.

Poole, K. G., K. Stuart-Smith, and I. E. Teske. 2009. Wintering strategies by mountain goats in interior mountains. Canadian Journal of Zoology 87:273–283.

Powell, T. 2004. Réponse comportementale des caribous des bois au harcèlement par les motoneiges. Thesis, Université de Sherbrooke, Quebec, Canada.

Preisler, H. K., A. A. Ager, and M. J. Wisdom. 2006. Statistical methods for analysing responses of wildlife to human disturbance. Journal of Applied Ecology 43:164–172.

Reimers, E., S. Eftestol, and J. E. Colman. 2003. Behavior responses of wild reindeer towards direct provocation by a snowmobile or skier. Journal of Wildlife Management 67:747–754.

Reimers, E., K. H. Røed and J. E. Colman. 2012. Persistence of vigilance and flight response behaviour in wild reindeer with varying domestic ancestry. Journal of Evolutionary Biology 25:1543–1554

Rice, C. G., K. T. Jenkins, and W. Chang. 2009. A sightability model for mountain goats. Journal of Wildlife Management 73:468–478.

Richens, V. B., G. R. Lavigne. 1978. Response of white-tailed deer to snowmobiles and snowmobile trails in Maine. Canadian Field- Naturalist 92:334–344.

Rideout, C. B. 1974. Comparison of techniques for capturing mountain goats. Journal of Wildlife Management 38:573–575.

Roberts, D. W. 1986. Ordination on the basis of fuzzy set theory. Vegetation 66:123–131.

Rochetta, S. 2002. Soo timber supply area mountain goat winter range plan. B.C. Ministry of Water, Land and Air Protection, Surrey, British Columbia, Canada.

Rode K. D., S. D. Farley, C. T. Robbins. 2006. Behavioural responses of brown bears mediate nutritional effects of experimentally introduced tourism. Biological Conservation 133:70–80.

Rowland, M. M., M. J. Wisdom, B. K. Johnson, and J. G. Kie. 2000. Elk distribution and modelling in relation to roads. Journal of Wildlife Management 64:672–684.

Ruimy, A., G. Dedieu, and B. Saugier. 1994. Methodology for the estimation of terrestrial net primary production from remotely sensed data. Journal of Geophysical Research 99:5263–5283.

Runyan, A. M., and D. T. Blumstein. 2004. Do individual differences influence flight initiation distance? Journal of Wildlife Management 68:1124–1129.

Russell, M., G. Koren, M. Rieder, and S. Van Uum. 2012. Hair cortisol as a biological marker of chronic stress: current status, future directions and unanswered questions. Psychoneuroendocrinology 37:589–601.

Sappington, J. M., K. M. Longshore, and D. B. Thomson. 2007. Quantifying landscape ruggedness for animal habitat analysis: a case study using bighorn sheep in the Mojave Desert. Journal of Wildlife Management 71:1419–1426.

Schoen, J. W., and M. D. Kirchoff. 1982. Habitat use by mountain goats in southeast Alaska. Final Report, Federal Aid in Wildlife Restoration Projects W-17-10, W-17-11, W-21-1, and W-21-2, Job 12.4R. Alaska Department of Fish and Game, Juneau, Alaska, USA.

Seip, D. R., C. J. Johnson, and G. Watts. 2007. Displacement of mountain caribou from winter habitat by snowmobiles. Journal of Wildlife Management 71:1539–1544.

Singer, F. J., and J. L. Doherty. 1985. Managing mountain goats at a highway crossing. Wildlife Society Bulletin 13:469–477.

Smith, B. L. 1977. Influence of snow conditions on winter distribution, habitat use, and group size of mountain goats. Pages 174–89 *in* Proceedings of the first international mountain goat symposium. W. Samuel and W. G. Macgregor, editors. Kalispell, Montana, USA.

Sokal, R. R., and F. J. Rohlf. 1981. Biometry. Second edition. W.H. Freeman and Company, New York, New York, USA.

Soper, J. D. 1970. The mammals of Jasper National Park, Alberta. Canadian Wildlife Service No. 10. Department of Indian affairs and Northern Development. Ottawa, Ontario, Canada.

Stankowich, T. 2008. Ungulate flight responses to human disturbance: a review and meta-analysis. Biological Conservation 141:2159–2173.

StataCorp. 2009. Stata Statistical Software: Release 11. StataCorp LP. College Station, Texas, USA.

Stockwell, C. A., G. C. Bateman, and J. Berger. 1991. Conflicts in national parks; a case study of helicopters and bighorn sheep time budgets at the Grand Canyon. Biological Conservation 56:316–328.

Taylor, A. R., and R. L. Knight. 2003*a*. Behavioural responses of wildlife to human activity: terminology and methods. Wildlife Society Bulletin 31:1263–1271.

Taylor A. R., and R. L. Knight. 2003*b*. Wildlife responses to recreation and associated visitor perceptions. Ecological Applications 13:951–963.

Taylor, S. D., and K. Brunt. 2003. Winter habitat use by mountain goats in the Kingcome River drainage of coastal British Columbia. Draft. Prepare for Forest Renewal B.C., Habitat Conservation Trust Fund, Forest Investment Account, B.C. Ministry Water, Land and Air Protection, Nanaimo, and International Forest Products, Vancouver, British Columbia, Canada.

Taylor, S. and K. Brunt. 2007. Winter habitat use by mountain goats in the Kingcome River drainage of coastal British Columbia. BC Journal of Ecosystems and Management 8:32–49.

Taylor, S. D., W. Wall, and Y. Kulis. 2004. A GPS–telemetry study of mountain goat habitat use in south coastal B.C. International Forest Products, Campbell River, and Forest Investment Account, Victoria, British Columbia, Canada.

Thomas, D. L., and E. J. Taylor. 1990. Study designs and test for comparing resource use and availability. Journal of Wildlife Management 54:322–330.

Tolon, V., S. Dray, A. Loison, A. Zeileis, C. Fischer, E. Baubet. 2009. Responding to spatial and temporal variations in predation risk: space use of a game species in a changing landscape of fear. Can Journal of Zoology 87:1129–1137.

Tucker, C. J., and P. J. Sellers. 1986. Satellite remote sensing of primary production. International Journal of Remote Sensing 7:1395–1416.

Tyler, N. J. C. 1991. Short-term behavioural responses of Svalbard reindeer *Rangifer tarandus platyrhynchus* to direct provocation by a snowmobile. Biological Conservation 56:179–194

Varley, N. 1998. Winter recreation and human disturbance on mountain goats: a review. Proceedings of the Eleventh Biennial Symposium. Yellowstone National Park, Wyoming, USA.

Vistnes, I., and C. Nellemann. 2001. Avoidance of cabins, roads, and power lines by reindeer during calving. Journal of Wildlife Management 65:915–925.

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

Walther, F. R. 1969. Flight behaviour and avoidance of predators in Thomson's gazelle (*Gazella thomsoni*; Guenther 1884). Behaviour 34:184–221.

White, K. S. 2006. Seasonal and sex-specific variation in terrain use and movement patterns of mountain goats in southeastern Alaska. Proceedings of the Biennial Symposium of the Northern Wild Sheep and Goat Council 15:183–193.

Whittaker, D., and R. L. Knight. 1998. Understanding wildlife responses to humans. Wildlife Society Bulletin 26:312–317.

Wilson, S. F. 2005. Desired conditions for coastal mountain goat winter range. B.C. Ministry of Water, Land, and Air Protection, Wildlife Working Report No. WR-107. Victoria, British Columbia, Canada.

Wilson, S. F., and D. M. Shackleton. 2001. Backcountry recreation and mountain goats: a proposed research and adaptive management plan. British Columbia Ministry of Environment, Lands and Parks Wildlife Bulletin B-103. Victoria, British Columbia, Canada.

Worton, B. J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. Ecology 70:164–168.

Yarmoloy, C., M. Bayer, and V. Geist. 1988. Behavior responses and reproduction of mule deer, *Odocoileus hemionus,* does following experimental harassment with an all-terrain vehicle. Canadian Field-Naturalist 102:425–429.

Youngman, P. M. 1975. Mammals of the Yukon Territory. National Museums of Canada, Publications in Zoology 10:1–192.

Zar, J. H. 1972. Significance testing of the Spearman rank correlation. Journal of the American Statistical Association 67:578–580.

Appendix A: Recommendations defined in the B.C. Wildlife Guidelines that pertain to management of aerial-based commercial recreation and tourism activity within mountain goat range.

In British Columbia, helicopter-based recreational activities are managed by the Wildlife Guidelines for Backcountry Tourism/Commercial Recreation Guidelines (Government of British Columbia 2006), which were developed to ensure that commercial tourism and recreation do not compromise wildlife or their habitat. The guidelines provide recommendations to achieve desired results. Within the guidelines address 2 areas of management: 1) the direct disturbance of wildlife; and 2) disturbances specific to mountain goats by aerial-based activities. (Table A.1). The only key recommendations germane to this study are those which recommend a >1,500 m separation distance.

Government of British Columbia. 2006. Wildlife guidelines for backcountry tourism commercial recreation. <http://env.gov.B.C.ca/wld/twg/index.html>. Accessed 1 Feb 2009.

Table A.1. Recommendations defined in the B.C. Wildlife Guidelines that pertain to management of aerial-based activity within mountain goat range. Listed are the expected results and recommended desired behaviours to achieve results.

Results	Desired Behaviours
Direct Disturbance of Wildlife (Government of British Columbia 2006)	
Minimize physiological and behavioural changes in animals associated with aircraft activity	Record wildlife encounters, actions taken and responses of animals
	Obey all area closures
	Do not harass wildlife
Minimize changes in habitat use resulting from aircraft activity	Focus activities in areas and times of the year when wildlife are least likely to be disturbed (seasonal closures may be necessary)
	Take immediate action to increase separation distances when animals react to aircraft
	Use consistent flight paths, preferably in the center of valleys, or the valley side opposite key wildlife habitat
	Stay at distances sufficient to prevent changes to the behaviour of animals (>500 m line of sight default)
Special Management Concern: Mountain Goats (Government of British Columbia 2006)	
Minimize physiological or behavioural disruption of mountain goats	Do not land in identified mountain goat winter range
	No intentional "flight-seeing" of mountain goats
	Stay at distances sufficient to prevent changes in the behaviour of animals (default > 1,500 m line-of-sight)
Continued occupation of mountain goat winter ranges	Where aircraft are within 1,500 m due to topography, they should maintain maximum vertical separation from the areas of goat habitat (>500 m)
	Avoid occupied habitats where mountain goats have been seen in the current season and/or animals consistently occupy the area and the area is mapped as occupied
	Minimize use in areas of high probability or potential, where there is documented past use by mountain goats
	No behavioural restrictions apply in areas not considered mountain goat habitat or where potential habitat is mapped with no verification of mountain goat use

Appendix B: Capture summary of mountain goats collared in the Northern Skeena Mountains (2007-2010) including the status of collar data, total GPS fix rate, and fix rate by season.

Table B.1. Female mountain goats collared in the Northern Skeena Mountains (2007-2010) including status of the collar data, total GPS fix rate, and seasonal fix rate. Collar status abbreviations: R=recovered, m pre-heli= Mortality pre-heliskiing season, NR= not recovered, TF= Transmitter failure, PSR= collar prematurely self-released. EW=early winter season, H= Heliskiing season.

Animal	Capture Site	Date Deployed	Status	Fix rate (%)	Seasonal Fix Rates (%)					
					EW 07	H 07/08	EW 08	H 08/09	EW 09	H 09/10
120	R	07/01/09	R	92.4					86.3	92.9
150	C	6/20/08	R	95.6			89.8	99.0	96.9	95.7
160	N	6/24/08	R	93.6			89.5	96.0	93.4	93.4
170	R	6/22/09	R	89.8					89.6	89.6
180	S	6/26/09	R	86.3					82.6	86.9
220	N	6/27/07	TF-R	97.4	99.4	99.8	87.7			
300	R	6/24/07	R	91.4	95.0	91.3	91.5	89.2	91.9	
500	N	6/23/07	R	94.3	92.6	94.7	95.3	97.4	80.1	
600	N	07/02/07	R	84.3	37.6	95.2	100.0			
700	S	6/25/09	R	81.4					55.9	82.4
900	S	6/25/09	R	81.3					80.3	81.0
Collar data below not utilized in analyses										
--	N	07/12/08	M pre-heli	83.7			83.7			
--	N	6/26/09	M pre-heli	96.2					96.2	
--	N	6/24/09	M pre-heli	71.4					71.4	
--	N	07/02/07	M pre-heli	97.3	97.3					
--	R	6/22/09	NR- logistic[a]	–						
--	R	6/22/07	NR- logistic[a]	–						
--	N	6/22/09	PSR pre-heli	88.0					88.0	
--	R	6/30/07	TF-NR	–						

[a] logistic= logistical difficulties in safely retrieving collar due to terrain and weather conditions.

Appendix C: Monthly movement rates (m/h, $\bar{x} \pm$ SE) of female mountain goats in the Northern Skeena Mountains study area and average snowdepth estimates during the same time period.

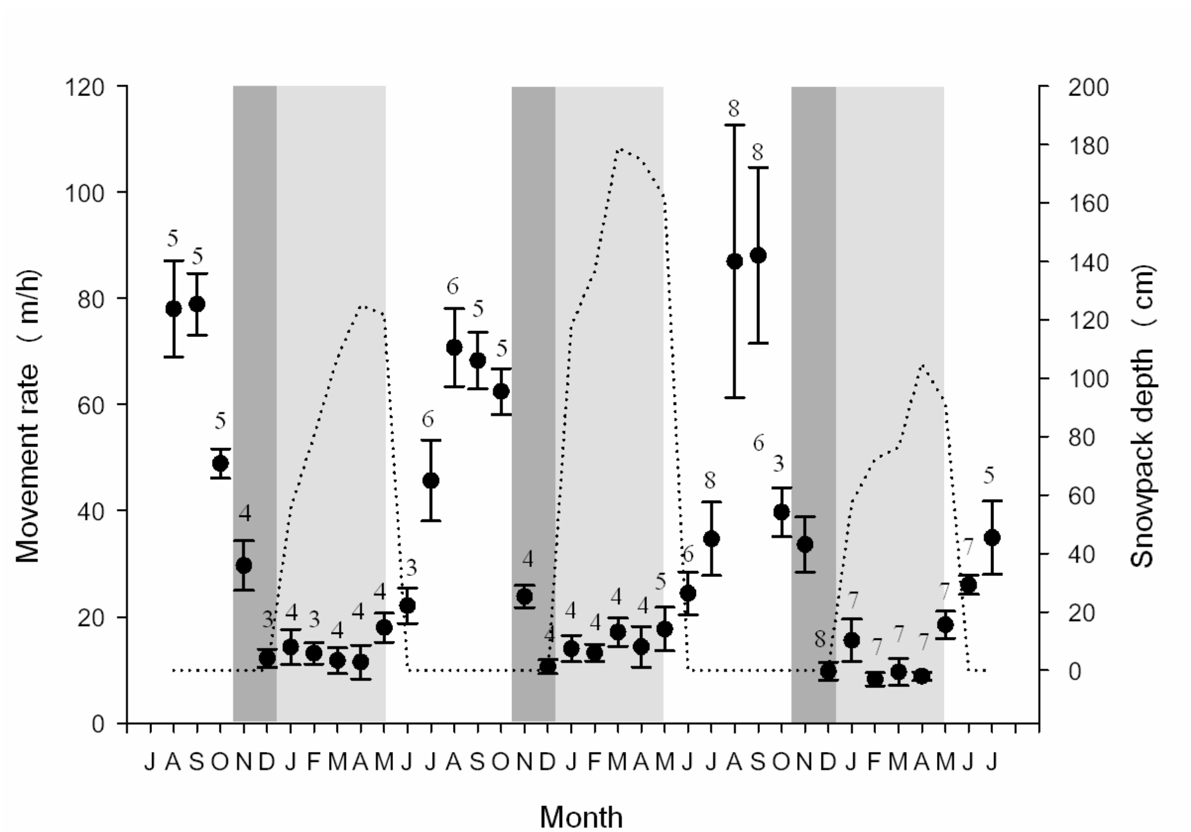

Figure C.1. Monthly movement rates (m/h, $\bar{x} \pm$ SE) of mountain goats in the Northern Skeena Mountains study area (left axis) between July 2007 and June 2010 relative to estimates of average snow depth during the same period (right axis). Dark shaded areas indicate the early winter season, lighter shaded areas indicate the heliskiing season. Values above error bars indicate the number of individuals that were averaged to calculate means and variation. Snow depth data were derived from the Gamma weather station located at 1175 m elevation on Ningunsaw Peak (<https://pub-apps.th.gov.bc.ca/saw-paws/weatherstation> accessed 10 Jan 2012).

Appendix D: Hourly movement rates of female mountain goat number 700 inhabiting the Northern Skeena Mountains study area during the month of January 2010.

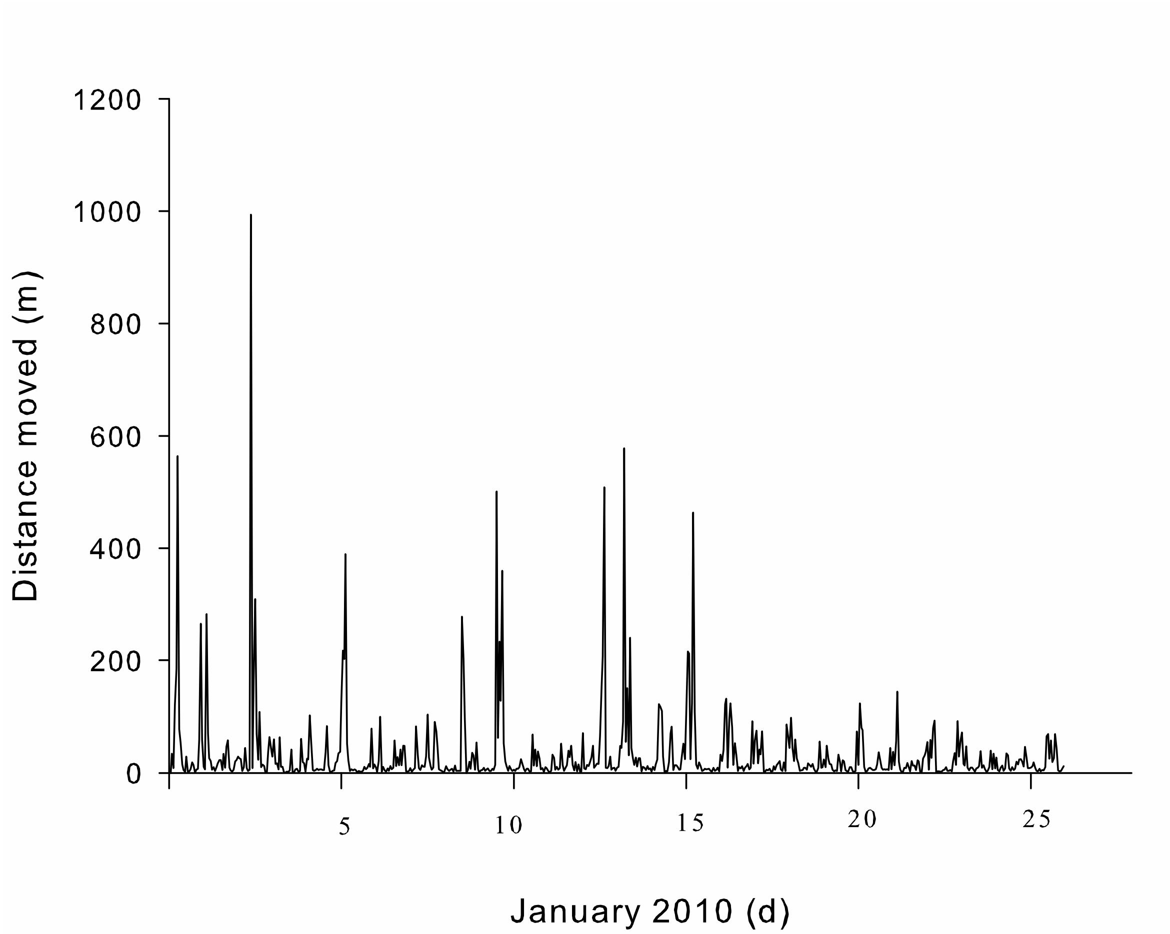

Figure D.1. Typical example of Distance moved by mountain goat number 700 (m/h) during the month of January in 2010. Representative of winter movement patterns of other collared female mountain goats within the Northern Skeena Mountains Study area (2007-2010).

Appendix E: Comparison of seasonal movement rates (m/h, $\bar{x}$ ± SE) of individual female mountain goats during early winter and heliskiing seasons.

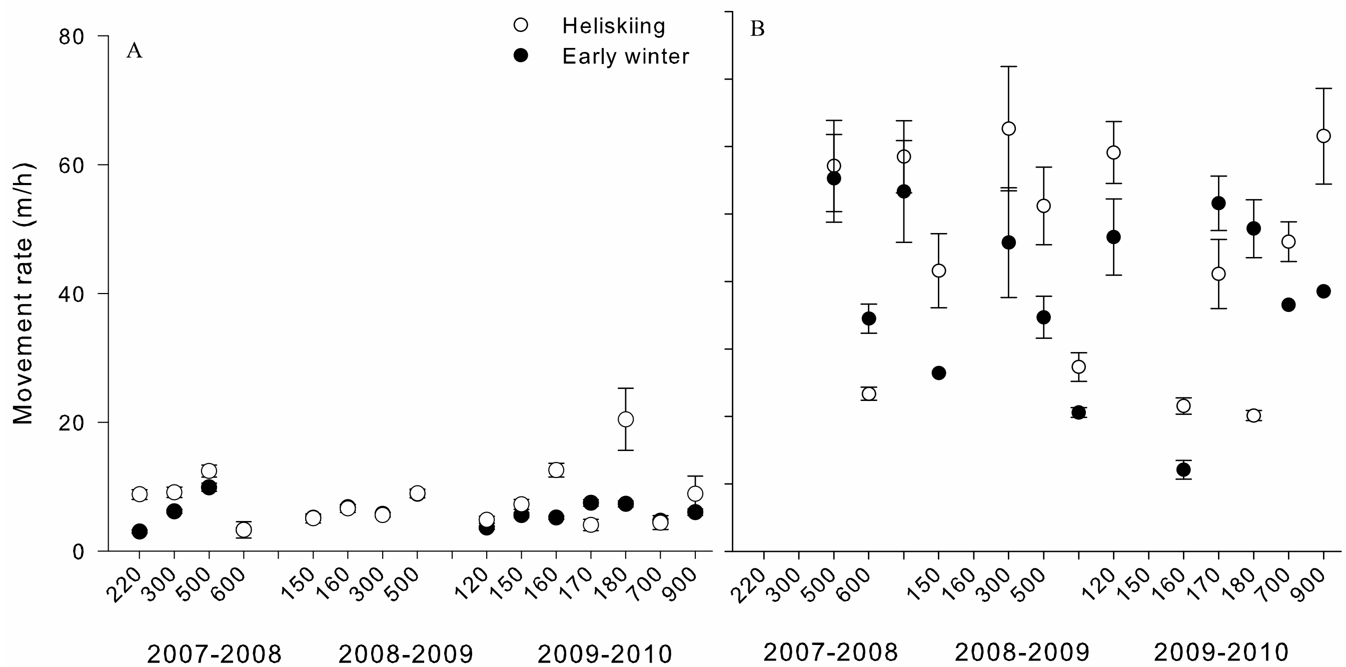

Figure E.1. Seasonal movement rates (m/h, $\bar{x} \pm$ SE) of individual female mountain goats in the Northern Skeena Mountains study area during early winter (●) and heliskiing (○) seasons (2007-2010). Graph A) represents the comparison of seasonal short-distance movements (0-79th percentile longest movements) and B) represents the comparison of seasonal long-distance movements (80-100th percentile longest distance movements).

Appendix F: Cases wherein land-cover classes were missing (zero-cell counts) in either the used or available response variable in seasonal resource selection models for female mountain goats during early winter and heliskiing seasons.

Table F.1. The number of cases wherein land-cover classes were missing (zero-cell counts) in either the used or available response variable in seasonal resource selection models for mountain goats. Numbers are relative to a maximum of 15 cases. EW = early winter and H = heliskiing seasons.

Land-cover Class	Response Variable	Season	
		EW	H
Fresh Water	Used	15	15
	Available	15	15
Range Lands	Used	15	15
	Available	15	15
Recently Burned	Used	15	15
	Available	15	15
Recently Logged	Used	15	15
	Available	15	15
Barren Surfaces	Used	15	15
	Available	15	15
Wetlands	Used	15	15
	Available	15	15
Young Forest	Used	15	15
	Available	14	15
Shrubs	Used	15	15
	Available	14	14
Glacier and snow	Used	13	6
	Available	5	2
Old Forest	Used	7	9
	Available	–	2

Appendix G: Selection coefficients and associated standard errors of habitat parameters within top resource selection models determined for female mountain goats in early winter and heliskiing seasons.

Table G.1. Selection coefficients (top row) and associated standard errors (bottom row) for continuous parameters included in the top resource selection models for female mountain goats during the heliskiing-season in the Northern Skeena Mountains for each year that animals were collared (2007-2010). Bold selection coefficients indicate parameters were statistically significant ($P \leq 0.05$). Year 2007 = heliskiing season 2007-2008; 2008 = heliskiing season 2008-2009; 2009 = heliskiing season 2009-2010. Parameter abbreviations: North. = Northness, East. = Eastness, D2Esc = Distance to Escape Terrain, Curv. = Curvature, Heli-Int = Helicopter Intensity.

Site	Animal	Yr	Elevation[a]	$Elevation^2$	Slope	North.	East.	D2Esc	Curv.	NDVI	Heli-Int.
Ningunsaw	220	2007	**25.469**	**-9.356**	**0.078**			**-0.034**	**0.061**	**-1.719**	
			5.654	2.026	0.012			0.004	0.024	0.327	
	500	2007	**67.249**	**-25.396**	**0.035**			**-0.019**	0.031	**-2.762**	
			9.105	3.354	0.010			0.003	0.022	0.327	
	500	2008	**49.417**	**-16.003**	**0.091**	**-1.783**	0.120				
			8.766	3.021	0.011	0.159	0.118				
	600	2008	**74.641**	**-29.862**	**0.110**	**-3.798**	**0.944**				
			7.462	3.135	0.018	0.852	0.203				
	160	2008	**96.096**	**-32.257**	**0.058**	**-1.820**	-0.188				
			13.377	4.560	0.010	0.231	0.186				
	160	2009			0.002			**-0.056**	**0.068**	**1.782**	0.007
					0.002			0.004	0.011	0.194	0.007
Skowill	180	2009	-1.151	**1.267**	**0.063**	**-2.370**	**0.933**				
			1.469	0.602	0.004	0.190	0.176				
	700	2009	1.046	-0.653	0.015			-0.006	-0.028	-2.280	
			1.112	0.514	**0.003**			0.003	**0.005**	**0.163**	
	900	2009	2.107	-0.099	**0.067**	**-1.982**					
			1.496	0.641	0.004	0.232					

Table G.1. continued

Site	Animal	Yr	Elevation	Elevation^2	Slope	North.	East.	D2Esc	Curv.	NDVI	Heli-Int.
Repeater	300	2007	**75.693**	**-29.545**	**0.018**	**-0.748**	**0.507**				
			8.213	3.274	0.006	0.285	0.118				
	300	2007	**52.580**	**-19.272**	0.012	**-2.156**	**0.971**				
			9.525	3.679	0.006	0.275	0.131				
	120	2009	**4.497**	-1.698	**0.036**	**-1.460**	0.055				
			2.240	1.016	0.004	0.181	0.137				
	170	2009	**15.326**	**-4.824**	0.000	**-2.499**	**0.576**				
			2.513	0.875	0.003	0.201	0.067				
Cousins	150	2008	**-23.095**	**8.454**	**0.059**	**-1.279**	**-1.308**				
			2.490	0.838	0.007	0.129	0.131				
	150	2009	-2.882	1.614	**0.040**	**-1.455**	**-0.949**				
			4.955	1.552	0.007	0.162	0.175				

[a] Elevation and Elevation^2 were in km above sea level for these models.

Table G.2. Selection coefficients (top row) and associated standard errors (bottom row) of continuous parameters included in the top resource selection models for female mountain goats during the early winter in the Northern Skeena Mountains for each year that animals were collared (2007-2010). Bold selection coefficients indicate parameters were statistically significant ($P \leq 0.05$). Parameter abbreviations: North. = Northness, East. = Eastness, D2Esc = Distance to Escape Terrain, Curv. = Curvature, Heli-Int = Helicopter Intensity, VRM = Ruggedness.

Site	Animal	Yr	Elevation[a]	$Elevation^2$	Slope	North.	East.	D2Esc	Curv.	NDVI	Heli-Int.	VRM
Ningunsaw	160	2008	**42.420**	**-15.662**	**0.078**	**-1.377**	0.198					
			17.615	6.459	0.023	0.246	0.189					
	220	2007	**76.911**	**-29.267**	-0.006	**-2.269**	0.242					
			16.581	6.286	0.022	0.358	0.243					
	500	2008	**62.001**	**-24.544**	-0.006	**-0.462**	**0.169**	**-0.004**	**0.090**	**-2.063**		
			5.802	2.285	0.007	0.133	0.053	0.001	0.018	3.909		
	500	2007	**69.831**	**-26.571**	**0.025**	**-1.394**	**0.375**	**0.000**	**0.010**	**-0.233**		
			9.935	3.786	0.010	0.189	0.115	0.000	0.005	0.097		
Skowill	180	2009	6.271	-1.633	**0.070**	**-1.647**	**0.640**					
			3.899	1.642	0.011	0.311	0.281					
	700	2009			**0.050**			**-0.012**	**0.052**	**-2.601**	**-0.031**	
					0.008			0.003	0.012	0.233	0.014	
	900	2009	**-7.322**	**3.752**	**0.062**			**-0.006**		**0.165**		**-2.888**
			1.560	0.682	0.005			0.001		0.077		0.615

Table G.2 cont.

Site	Animal	Yr	Elevation	Elevation^2	Slope	North.	East.	D2Esc	Curv.	NDVI	Heli-Int.	VRM
Repeater	120	2009	**20.460**	**-9.334**	**0.022**			**-0.013**	**0.032**	**-3.459**	**0.014**	
			2.443	1.103	0.004			0.004	0.007	0.142	0.004	
	170	2009	0.566	0.905	-0.017			**-0.037**	**0.146**	**2.461**		
			6.653	2.491	0.010			0.007	0.025	0.693		
	300	2007	**64.690**	**-25.685**	**-0.051**			**-0.016**	**0.021**	**-0.564**		-0.091
			5.454	2.131	0.005			0.001	0.009	0.227		0.179
Cousins	150	2008	-5.933	1.584	**0.076**			-0.012	**0.186**	**-2.131**		
			7.917	3.043	0.023			0.007	0.055	0.662		
	150	2009	56.232	**-18.959**	**0.060**					**-0.164**		**6.992**
			10.528	3.515	0.007					0.054		0.548

[a] Elevation and Elevation^2 were in km above sea level for these models.

Table G.3. Selection coefficients (top row) and associated standard errors (bottom row) of categorical land-cover parameters included in the top resource selection models for female mountain goats during the early winter in the Northern Skeena Mountains for each year that animals were collared (2007-2010). Bold selection coefficients indicate parameters were statistically significant ($P \leq 0.05$).

Capture Site	Animal	Year	Avalanche Chutes	Old Forest	Alpine Rock	Alpine Meadow	Glacier and Snow
Ningunsaw	160	2008					
	220	2007					
	500	2008					
	500	2007					
Skowill	180	2009					
	700	2009					
	900	2009	0.052	0.038		**-0.073**	-0.018
			0.031	0.022		0.031	0.017
Repeater	120	2009	**0.117**	**-0.169**	**-0.123**	**-0.174**	
			0.036	0.058	0.058	0.048	
	170	2009					
	300	2007					
Cousins	150	2008					
	150	2009	**-0.029**	**-0.269**	**-0.040**	**-0.652**	**0.990**
			0.012	0.109	0.016	0.128	0.086