FISH AND WILDLIFE COMPENSATION PROGRAM

PEACE REGION

EXPERIMENTAL EVALUATION OF LOGGING IMPACTS ON MINERAL-LICK USE BY MOUNTAIN GOATS, NORTH-CENTRAL BRITISH COLUMBIA

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November 2010

PWFWCP Report No. 343

The Fish and Wildlife Compensation Program is a partnership of:

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The Fish & Wildlife Compensation Program – Peace Region, is a cooperative venture of BC Hydro and the provincial fish and wildlife management agencies, supported by funding from BC Hydro. The Program was established to enhance and protect fish and wildlife resources affected by the construction of the W.A.C. Bennett and Peace Canyon dams on the Peace River, and the subsequent creation of the Williston and Dinosaur Reservoirs.

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This report has been approved by the Fish and Wildlife Compensation Program – Peace Region Wildlife Technical Committee.

Citation: Corbould, F.B., J.B. Ayotte, M.D. Wood, and G.W. Blackburn. 2010. Experimental evaluation of logging impacts on mineral-lick use by mountain goats, north-central British Columbia. Peace/Williston Fish and Wildlife Compensation Program Report No. 343. 65pp plus appendices.

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EXECUTIVE SUMMARY

Mineral licks are a fundamental component of ungulate foraging strategies and are thought to have a profound impact on the distributions and movements of individuals within populations. Mountain goats (*Oreamnos americanus*) have a particularly strong appetite for lick soils. Mineral licks not only provide mountain goats with inorganic mineral supplements (e.g., sodium) but they also provide clays and carbonates important to stabilizing rumen pH and reducing digestive ailments during the transition to spring and summer forage. Well-used licks for goats are often on steep, exposed banks near valley bottoms.

Flooding of the Rocky Mountain Trench by the Williston Reservoir may have forced abandonment of low-elevation licks historically used by mountain goats. In addition, forest harvesting practices around the reservoir may have negative effects on the use of remaining low-elevation licks. Given the perceived importance of low-elevation mineral licks to mountain goats, management concerns were raised regarding the potential impacts of forest harvesting activities on mountain goat populations.

As part of a broader initiative to address mountain goat management concerns in the Mackenzie Timber Supply Area, the Fish and Wildlife Compensation Program – Peace Region conducted a field experiment to determine the level of impact of 2 forest-harvesting treatments on the use of a low-elevation mineral-lick complex (an area encompassing several mineral licks) and its main access trail by mountain goats. The first treatment was the "forested buffer treatment" where conventional clearcut logging removed the forested area adjacent to ~680 m of the main lick-access trail but retained a 150-m wide forested buffer on each side of the trail. The second treatment ("clearcut treatment") occurred in the same area as the buffer treatment and involved the removal of 14.5 ha of forest along 670 m of the trail.

The study area encompassed the lower portion of the Ospika River drainage in north-central British Columbia. Mountain goats primarily inhabit the steep high-elevation alpine and subalpine terrain flanking the Ospika River, but they descend periodically in the April-November (non-winter) period to use mineral licks in the valley bottoms of the Ospika River and its tributaries. The 4 mineral-lick complexes (Licks 17, 28, 30 and 40) chosen for our study were identified as having high use by mountain goats. The Lick 17 complex was along the western bank of the Ospika River whereas the other 3 lick complexes were along tributaries on the eastern side of the Ospika River valley. Each lick complex had a well-worn, main access trail that went through the coniferous forests between the mineral-lick complex and an area of rocky escape terrain.

We used a Before-After Control-Impact experimental approach to assess the impacts of the forest-removal treatments on mountain goat use of the mineral-lick complex ("lick") and its main access trail. The study design involved a treatment lick and trail (Lick 28), a primary control lick and trail (Lick 17), and 2 secondary control licks and trails (Licks 30 and 40). The 6-year study involved 1 year of monitoring prior to any treatments (2002; pre-treatment period), 3 years of monitoring following the forested buffer treatment (2003 to 2005; buffer period), and 2 years of monitoring following the clearcut treatment (2006 and 2007; clearcut period).

We monitored behavioural responses of mountain goats to examine the impact of the forest-removal treatments on their use of the treatment lick and trail. Several variables were investigated but we considered the main measure of a treatment effect to be the frequency of lick visits. Trail use by mountain goats was driven by their need to access a lick, so we considered down-trail use to be the most important trail movement and used these data for all analyses of goat behaviour, except when describing trail use specifically. Other response variables evaluated less-overt goat behaviours: duration of lick visits (per visit and per year), timing of lick visits (annual, seasonal and diel use), and trail-use patterns (group size and travel rate).

We used 2 sampling methods (trail-monitoring cameras and radio telemetry) to provide different perspectives on lick visits by mountain goats during the study: lick centred and individual goat. Trail-monitoring camera stations were used to collect data on the frequency, timing, and travel behaviour of mountain goat movements along the main access trail to each of the study licks. Fixed-telemetry stations were used to collect data on the frequency and duration of lick visits, as well as trail fidelity, displacement lick use and frequency of failed lick visits, of 29 radio-collared goats (18 females, 11 males). Aerial-telemetry flights were conducted to ensure radio-collared goats were alive during the study period (i.e., capable of visiting the study licks) and to monitor whether radio-collared goats changed their seasonal range use after the treatments were conducted.

To assess whether the risk of predation for mountain goats changed over the study term, we recorded the number of predators and alternate prey (other ungulates) photo-captured at trail-monitoring camera stations at all licks and across all camera-monitoring years, and at 2 road-monitoring camera stations near the treatment lick. We pooled down-trail and up-trail movement data because we considered these movements to be independent events for these species.

For lick-visit data collected from radio-collared goats, we used a Generalized Linear Mixed Model approach to conduct our analyses. Upon preliminary examination of the data, 4 “types” of goats were identified based on their lick use during the study period: individuals that used the primary control lick exclusively (L17 goats), individuals that used Lick 28 exclusively (L28-only goats), individuals that used Licks 30 and 40 (L30-40 goats), and individuals that used all 3 eastern study licks (L28-30-40 goats). Our analyses focused on radio-collared goats that used the treatment lick (L28-only and L28-30-40 goats) and primary control lick. Power analyses were conducted to assess our likelihood of detecting treatment effects given our datasets for the number of lick visits and trail fidelity.

We estimated the range use (100% minimum convex polygon; MCP) of mountain goats for the non-winter (Apr to Nov) and winter (Dec to Mar) periods. We also determined range use for the period when goats conducted the majority of their lick visits (Jun to Sep; core-lick period). All aerial-telemetry and capture locations were plotted for each goat individually to determine if any changes (size, shape, and distance between range and study licks) occurred in their range use over the study years.

Between 2002 and 2006, we monitored the study trails for 361,399 camera hours, resulting in >20,000 photographs and 3,496 animal-related records. These records identified 8,180 photo-captures of mountain goats; large predators had the next highest trail use with photo-captures totalling 8% of the records observed for mountain goats. Each year between 79 and 345 photo-captured goats were recorded travelling down the trails to the 4 study licks.

There was no treatment effect on the annual number of photo-captured goats travelling to the treatment lick. The number of photo-captured goats using the trail to access the treatment lick did decline following the treatments (starting in 2004, 2nd year after the buffer treatment), but a similar decline occurred at the primary control lick (also starting in 2004). No decline was observed at either of the secondary control licks. The declines in down-trail movements at the treatment ($\bar{x}$ = 94% decline by 2006) and primary control ($\bar{x}$ = 63% decline by 2006) licks were results of fewer goats being photo-captured at essentially all camera stations each year.

Across all study licks and camera-monitoring years, mountain goats used the study trails from 11 April to 24 November, with the majority of mountain goat use occurring between 13 June and 8 September; the earliest date a kid was photo-captured on a study trail was 9 June. There were no obvious treatment-related effects on the dates (calendar date and days since snow free or leaf flush) of down-trail use by goats accessing the treatment lick as the annual distributions of travel dates for goat lick visits varied widely and had considerable overlap among years. There were no treatment effects on seasonal or diel use of lick trails. Goat down-trail use was lowest during the late season at all licks across all years. Goat trail use (down and up trail) was greatest during daylight hours for all licks across all years except for secondary control lick 40, where crepuscular movements were most common.

The largest goat groups photo-captured using the study trails ranged between 28 and 39 goats for the 4 licks. For all licks across all years, the typical group size for goat trail movements was larger when they travelled to the lick than when they travelled away; in general, typical groups sizes ranged between 5 and 15 goats. There were no notable treatment effects on the typical group size or trail travel rate for goat trail movements; though, trail travel rates were consistently >3 times slower at the primary control lick than at the other licks.

Radio-collared goats visited the study licks 703 times (116 to 270 visits per study lick) from 2002 to 2007; 2 of the 29 radio-collared goats (1 female, 1 male) did not use a study lick. The highest visitation rate for goats exclusively using the treatment and primary control licks was 7 visits/year and 8 visits/year, respectively; the highest annual visitation rate for an individual goat was 30 visits by a L30-40 goat. Radio-collared goats typically visited a study lick at least 2 times each year.

There was no treatment effect on the mean number of lick visits per radio-collared goat at the treatment lick, but period and goat type did have individual effects. There was a period effect because goats using the treatment and primary control licks both had, on average, 47% fewer lick visits per goat during the clearcut period than during the pre-treatment period. Based on radio-collared goats, the decline in goat visits to the treatment lick by L28-only goats started in 2005 (3^{rd} year after buffer treatment) whereas the decline in goat visits to the primary control lick started in 2006 (1^{st} year after clearcut treatment at treatment lick). Goat type had an effect because radio-collared goats that exclusively used the treatment and primary control licks had approximately 6 times more lick visits than L28-30-40 goats had at the treatment lick; this was not unforeseen as one would expect a goat that used only 1 lick to have more visits at that lick than a goat that visited 2 additional licks.

The duration of a lick visit by radio-collared goats at the 4 study licks varied from an average of 6.8 hrs/visit at the primary control lick to 43.3 hrs/visit at the treatment lick, with >98% of lick visits lasting less than 4 days. There was no treatment effect on the mean time that goats spent per visit at the treatment lick but goat type had an individual effect. Goats that used the treatment lick spent, on average, about 2.5 times more time at the lick than goats that used the primary control lick.

There was no treatment effect on the average time interval between lick visits by L28-only goats at the treatment lick before and after the treatments. On average, intervals between lick visits were about 4 days shorter for goats exclusively using the treatment lick than goats using the primary control lick.

For the 6-year study, the total time spent by radio-collared goats at the study licks ranged from 1,801 hrs at secondary control lick 40 to 4,984 hrs at the treatment lick. Individually, radio-collared goats that exclusively used the treatment lick spent between 16 and 276 hrs annually at the treatment lick, whereas radio-collared goats spent between 7 and 140 hrs annually at the primary control lick. There was no treatment effect on the total time spent by radio-collared goats that used the treatment licks, but L28-only goats spent more than twice as much time annually at the treatment lick than goats did at the primary control lick. .

L28-only goats, which were all captured south of Aley Creek, did not shift any use to the secondary control licks. The 4 L28-30-40 goats, which were all captured north of Aley Creek, had no significant change in the proportion of lick visits at the treatment lick but, when their visit data were pooled, lick use after 2004 (2 years after the buffer treatment) appeared to decline at the treatment lick and increase at the secondary control licks. The increase in use at the secondary control licks was primarily due to increased use of Lick 30, the closest alternative lick to the treatment lick.

Radio-collared goats used the study trail (i.e., ≤150 m from the trail) >80% of the time when they travelled to the treatment and primary control licks, except 2006 (1^{st} year after clearcut treatment) at the treatment lick when goats used the treatment trail 53% of the time. Although no treatment effect was detected, goats travelling to the treatment lick in 2006 were possibly searching for a better route since conditions along the trail had changed from a mature forest to an early-seral setting. The goats returned to having >80% of their down-trail movements on or near the trail in 2007.

Although our inferential analyses indicated no treatment effect on radio-collared goats using the treatment lick (i.e., decline in lick visits also occurred at the primary control lick), these goats exhibited several behaviours indicating they were impacted to some extent by the treatments: all failed lick visits by radio-collared goats at the treatment lick occurred after the first treatment, goats using the treatment lick had ~3 times more failed visits than goats using the control licks, 8 of the 9 failed visits at the treatment lick occurred at or adjacent to key features resulting from the treatments (including a mortality which occurred adjacent the clearcut treatment), and the time elapsed between an aborted visit and the goat's next lick visit increased with each subsequent year.

Power analyses on lick use (number of lick visits per goat) and trail use (proportion of down-trail movements on or near trail) by radio-collared mountain goats indicated that by the end of the study we would need a treatment-effect decline of >60% and ≥80%, respectively, to be 95% confident we could detect a treatment effect with our data.

Over 1,800 aerial-telemetry locations were collected on the 29 radio-collared mountain goats monitored from March 2002 to November 2007. All L28-only goats primarily used the same small (~37 km^2) alpine area between Frank Creek and Aley Creek for the term of the study. Because these goats remained in this one area, there were no notable changes in the size, shape, or location of their seasonal ranges. Similarly, no treatment effect on seasonal range use was observed for the 4 L28-30-40 goats. Each spring, the majority of radio-collared goats travelled a minimum of 3.6 to 10.6 km from their winter range to access their mineral licks; a male that used the primary control lick travelled up to 60 km. Goats travelled shorter distances (minimum of 1.6 to 6.4 km) when visiting the study licks during the core-lick period.

Predators were photo-captured 650 times on the study trails, with grizzly bears, black bears, and wolves representing 98% of these records. Other ungulates were photo-captured 420 times on the study trails; moose, elk, and deer represented 98% of these records. The number of large predators (grizzly bears, black bears, and wolves) and other ungulates (moose, elk, and deer) photo-captured using the treatment trail increased dramatically after 2004. Large predators and other ungulates also increased at the road camera stations near the treatment lick after 2004. At the primary control lick, the number of wolves photo-captured on the trail doubled in 2005 and again in 2006. There was no trend for these non-goat species at the 2 secondary control licks. Large predators and other ungulates used the study trails in the same months as mountain goats but, unlike goats, used the trails greatest during the crepuscular and night periods throughout the study.

In the first 5 years following the 2 forest-removal treatments, we detected no treatment effects on the behaviour of mountain goats using and accessing their low-elevation mineral lick. By the end of the study however, annual lick and trail use by goats had declined notably at both the treatment and primary control licks. The decline in goat lick use at the treatment lick coincided with a marked increase in photo-captures of large predators and other ungulates on the study trail and logging road near the treatment lick 3 years after the first treatment. Although the decline in lick use at the primary control lick only coincided with an increase in wolf photo-captures, due to the location of the lick and trail, goats using the primary control lick could have been exposed to greater predation risk without an increased incidence of predators being observed on the goat trail.

The corresponding declines in lick visits by mountain goats at the treatment and primary control licks, and no decline at the 2 secondary control licks, suggested that goats were influenced by effects that extended to both the east and west sides of the Ospika River drainage, but in the lower (southern) portion of the drainage. The only obvious change that had occurred was forest disturbances caused by logging. The study treatments, and other logging that occurred in the area during the study, appeared to provide conditions that were advantageous for important predators for mountain goats.

In 2004 (2^{nd} year of forested buffer), there was a rise in up-trail use and a rise in travel rate at the treatment lick. We do not believe this was due to a treatment effect. Instead, we believe it was due to disturbances resulting from silviculture activities (e.g., tree planting, road deactivation). Even with an apparent increase in predator risk in the later years of the study, we did not see any obvious changes in goat movement patterns (group size and travel rate) on the study trails. Other factors than predation risk may dictate patterns in these trail-use behaviours.

Given that goats exhibit high fidelity to mineral licks and predator densities will likely increase further over the next 25-30 years in response to current and future logging, predation on goats that use licks which have been affected by logging will also likely increase.

In general, lick-use patterns by mountain goats in our study were consistent with other studies. Differences in goat-use patterns that did occur across the 4 study licks were likely attributable to site-specific factors (e.g., proximity of lick to escape terrain, lick soil properties).

This study is the only comprehensive study that has investigated the effects of a forest disturbance on mountain goats. Although the direct effects of forest removal (i.e., creation of early seral openings) do not appear to reduce the use of low-elevation mineral licks by mountain goats in the short term, mitigation options for forest planning near low-elevation mineral licks were suggested because of the potential longer term indirect effects of increased predation risk. Research is needed to evaluate the longer term impacts of forest disturbances on mountain goats that use low-elevation mineral licks.

ACKNOWLEDGEMENTS

The Ospika Goat Experimental Trial of the Mackenzie Mountain Goat Initiative was funded by the Fish and Wildlife Compensation Program – Peace Region, which is a partnership between BC Hydro, the BC Ministry of Environment, Fisheries and Oceans Canada, First Nations, and public stakeholders.

Our deepest gratitude goes to Slocan Forest Products – Mackenzie Operations (now Canadian Forest Products), in particular Larry Clark, Ross Lennox and Erik Olsen, for making alterations to their forest harvesting plans to accommodate this project, conducting the treatment harvesting and burning, re-scheduling silviculture activities as best they could, and providing logistical assistance for our planting of the clearcut treatment area. Slocan also provided living and office accommodations for our field crews at Ospika Camp. Thank you to Harold Patenaude and the other camp managers for all your help, and for making our crew visits possible and enjoyable.

Mountain goats were captured and radio-collared by pilot Clay Wilson and handler Tony Vanderbrink of Bighorn Helicopters, and contract handler Steve Myers. Remote camera and telemetry stations were established by Fraser Corbould, Steve Myers, Jacques Perreault and Jim Renn. Over the 4 field seasons, data collection and station maintenance activities were led by Greg Blackburn (FWCP-P and DWB Forestry Services Ltd.), Clint Cubberley (Synergy Applied Ecology) and Debbie Wellwood (SKR Consultants). Field assistance for these activities was provided by Niel Foord, Pam Hengeveld, Mandy Kellner, Chris Pharness, Lothar Schaefer, Adam Schwartz, and Robert Tomah. Field sites were accessed via helicopter using pilots Greg Altoft and Brian Dougherty (Altoft Helicopters), Chris Hutman and Wally Zec (Pacific Western Helicopters), and Kevin McCormick and Sean Rickards (Yellowhead Helicopters). Bryn Kilb and the crew from Dynamic Reforestation Ltd. conducted tree planting activities in the clearcut-treatment area.

Raw camera and telemetry data were interpreted by Greg Blackburn, Fraser Corbould, and Mari Wood. As a special note of gratitude, Fraser and Mari wish to thank Greg for his perseverance in wading through the myriad of photographs and telemetry data to help sequester the necessary data. As part of the greater Mackenzie Mountain Goat Initiative, aerial radio-telemetry locations for “our” collared Ospika goats were collected in partnership with Wildlife Infometrics, Mackenzie BC, who was conducting the Resource Inventory component of the initiative. Lana Ciarniello (Aklak Environmental Consulting Inc.) assisted us with creating seasonal ranges (minimum convex polygons) and range-use maps.

We would like to express our sincere thanks to Dr. Carl Schwarz, Department of Statistics and Actuarial Science, Simon Fraser University, Burnaby, BC, for conducting all the statistical analyses related to the remote telemetry data, and for reviewing and providing insightful feedback on our analytical approach for the camera data.

We wish to thank Doug Heard (Ministry of Environment, Prince George), Scott McNay (Wildlife Infometrics, Mackenzie) and Dale Seip (Ministry of Forests and Range, Prince George) for assisting with the original project study design.

Editorial comments provided by Doug Heard (Ministry of Environment, Prince George), Scott McNay (Wildlife Infometrics, Mackenzie), and Kim Poole (Aurora Wildlife Research, Nelson) greatly improved the quality of the report.

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1.0 INTRODUCTION

Plants and young soils often contain concentrations of essential minerals below the mammalian requirements for maintenance, growth and reproduction (Hebert and McTaggart Cowan 1971a, Robbins et al. 1985, Staaland et al. 1980, Ohlson and Staaland 2001). Ungulates respond to these mineral deficiencies by ingesting soil from mineral licks where short periods of high mineral intake from sites relatively rich in minerals can replace depleted metabolic mineral pools in a short amount of time (Staaland et al. 1980).

Results of several studies indicate mineral licks are a fundamental component of ungulate foraging strategies (Kreulen 1985, Klaus and Schmid 1998, Ayotte et al. 2006). Mineral licks are thought to have a profound impact on the distributions and movements of individuals within populations (Heimer 1973, Jones and Hanson 1985, Watts and Schemnitz 1985). Mountain goats (*Oreamnos americanus*) in particular have been documented travelling up to 24 km, along intricate well-worn trails, between their alpine summer ranges and low-elevation mineral licks, suggesting fidelity by multiple generations (Hebert and McTaggart Cowan 1971b, Fox and Smith 1988).

Mountain goats mainly use sites characterized as dry mineral licks (Hebert and McTaggart Cowan 1971b, Heimer 1973, Singer 1978, Ayotte et al. 2006). Dry licks usually occur along banks bordering streams or river beds where deposits of soluble elements are concentrated above less-impervious and have become exposed by erosion (Jones and Hanson 1985). Well-used licks are often on steep banks near valley bottoms, thus providing topographical attributes similar to alpine areas and escape terrain, which are also important to goats (Hebert and McTaggart Cowan 1971b, Heimer 1973, Singer 1978, Watts and Schemnitz 1985), whereas others are .

Mineral licks not only provide mountain goats with inorganic mineral supplements (e.g., sodium) but they also provide clays and carbonates important to stabilizing rumen pH and reducing digestive ailments during the transition to spring and summer forage (Kreulen 1985, Klaus and Schmid 1998, Ayotte et al. 2008). Mountain goats have a particularly strong appetite for lick soils as they often displace Stone's sheep (*Ovis dalli stonei*) from high-use sites within lick areas (Ayotte et al. 2006). Mountain goats forage on a wider variety of plants than wild sheep (Shackleton 1999) and have been observed with scouring (diarrhoea) during the spring and summer period (Hebert and McTaggart Cowan 1971b). These observations imply that the digestive adaptability that enables mountain goats to forage on a wide variety of plants may increase their demand for inorganic buffering compounds, such as clays and carbonates, that have been found concentrated in lick soils (Klaus and Schmid 1998, Ayotte et al. 2006). Digestive ailments associated with the transition to spring forage become more acute when animals are in poor condition, such as after a severe winter (Kreulen 1985). Consequently, even though the effects of reduced lick access may not have obvious physical symptoms that permit diagnosis (Robbins 1993), chronic elemental deficiencies and rumen dysfunction suffered by some individuals increases an susceptibility to opportunistic factors that can cause mortality and affect recruitment (e.g., bacteria, viruses and predation; O'Hara et al. 2001).

Flooding of the Rocky Mountain Trench by the Williston Reservoir in 1968 may have forced abandonment of low-elevation licks historically used by mountain goats. In addition, forest harvesting practices around the reservoir may have negative effects on the use of remaining low-elevation licks. There is increasing management concern regarding the cumulative effects of human disturbances on mountain goats (Côté 1996, Ayotte 2005), a species that typically has low recruitment rates (Festa-Bianchet et al. 1994). Regionally, the Mackenzie Land and Resource Management Plan identified mountain goats as an important species of special management interest (BCMSRM 2000).

Given the perceived importance of low-elevation mineral licks to mountain goats, management concerns were raised regarding the potential impacts of forest harvesting activities on mountain goat populations. Prior to 2002, there were few provincial guidelines that considered the importance of isolated habitat features such as low-elevation mineral licks in forest stewardship and land-use plans (Hengeveld et al. 2003). At the time, the forest industry and management biologists recognized the need to develop mountain goat management guidelines to consider the full range of habitats used by mountain goats, incorporate an evaluation of industrial disturbance and cumulative effects over time, and facilitate operational planning for the sustainability of forest values. In 2001, the Mackenzie Mountain Goat Initiative (MMGI) was initiated to meet this need (Hengeveld et al. 2003). The MMGI is a multiphase, collaborative study focused on the development and implementation of effective policy to support the integrated management of mountain goat habitat in the Mackenzie Timber Supply Area. The MMGI proposed to address current management concerns through simultaneous implementation and evaluation of:

1. Experimental Trial – test the impacts of alternate forest harvesting strategies on the use of low-elevation mineral licks by mountain goats;
2. Resource Inventory – characterize mountain goat habitats and assess seasonal movements and mortality of radio-collared goats in the Mackenzie Timber Supply Area;
3. Habitat Supply Modeling – provide operational and strategic planning tools that facilitate sustainable management of mountain goats and timber supply; and

4. Policy Development – provide a knowledge-based, adaptive policy that is enabled and implemented by the Mountain Goat Management Team, a regional, multi-agency team with representatives from private industry, government ministries and First Nations.

From 2002 to 2007, we conducted a before-after-control-impact (BACI) field experiment in the lower Ospika River drainage to determine the level of impact of 2 forest-harvesting treatments on the use of a low-elevation mineral lick and its access trail by mountain goats. The first treatment was the "forested buffer treatment" where conventional clearcut logging removed the forested area adjacent to the main lick-access trail except for a 150-m wide forested buffer on each side of the trail. The second treatment was the "clearcut treatment", which involved the removal of the forested buffer.

We investigated the behavioural response of mountain goats to the treatments using several variables, but we considered the main measure of a treatment effect to be the number of lick visits. Therefore, if the forested buffer was effective in preventing a negative impact on goats, we would not expect to see a decline in lick use at the treatment lick relative to the control. If the clearcut treatment had a negative impact, we expected to see a decline in the number of lick visits at the treatment lick relative to the controls.

Other response variables evaluated less-overt goat behaviours: duration of lick visits (per visit and per year), timing of lick visits (annual, seasonal and diel use), and trail-use patterns (group size and travel rate). We predicted that if mountain goats continued to use the trail but perceived an increased threat, lick visits would be longer (but less frequent); use would shift later in the year (when young are larger and less vulnerable), group sizes would increase (lower individual risk), and travel times would decrease (move faster along the trail). We also measured potential changes in predation risk more directly by monitoring the use of lick access trails by predators. We assumed that if any of these variables changed significantly at the treatment lick, with no comparable change at the control licks, the changes would be attributable to the forest-removal treatments.

2.0 STUDY AREA

The study area encompassed the lower portion of the Ospika River drainage in north-central British Columbia (Figure 1). The study area rises from 720 m along the Ospika River to over 2,200 m in the Muskwa Ranges (mountains of the Rocky Mountains north of Peace Arm, Williston Reservoir) that flank the east and west sides of the drainage. Lower elevations (approximately <1,100 m) of the study area lie within subzones of the Sub-Boreal Spruce biogeoclimatic zone (SBSmk2 and wk2) whereas higher elevations transition through Engelmann Spruce-Subalpine Fir subzones (east side: ESSFmv4 and mvp; west side: ESSFwk2, wc3 and mcp) to the Boreal Altai Fescue Alpine zone at elevations above ~1,700 m (BCMFR 2008). Forests in the SBS subzones are dominated by white spruce (*Picea glauca*), hybrid white spruce (*Picea glauca x engelmannii)*, lodgepole pine (*Pinus contorta*), and subalpine fir (*Abies lasiocarpa*) (MacKinnon et al. 1990). ESSF subzones are dominated by Engelmann spruce and subalpine fir (DeLong et al. 1994). Vegetated areas of the Boreal Altai Fescue Alpine zone are primarily dwarf willows, grasses, sedges and lichens (BCMFR 2006). The Ospika River drainage is located within the Mackenzie Forest District, and the Central Canadian Rocky Mountains Ecoregion and the Misinchinka Ranges Ecosection (Demarchi 1996).

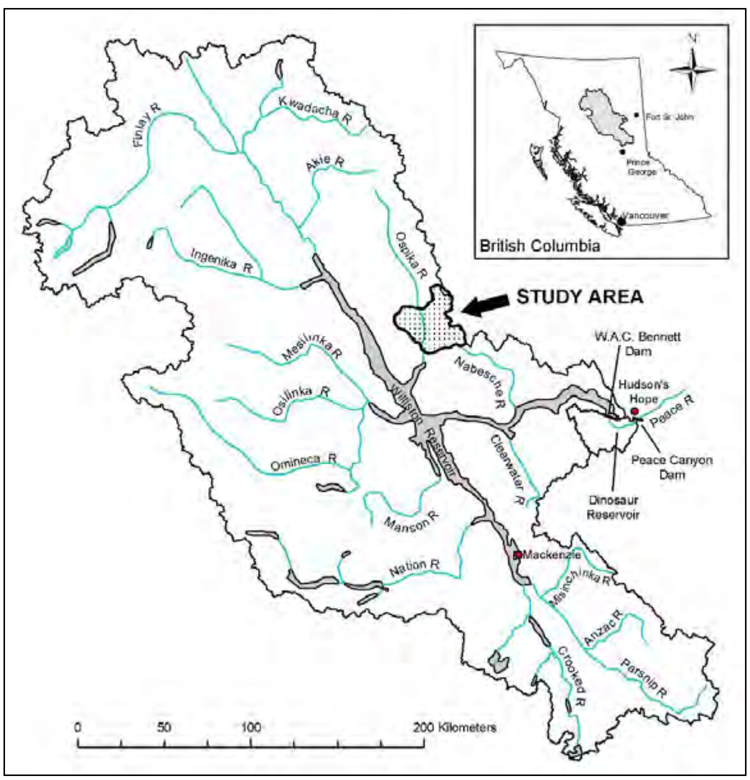

Figure 1. Location of study area for the Ospika Goat experimental trial in the lower Ospika River drainage, Williston Reservoir watershed, north-central British Columbia.

Mountain goats primarily inhabit the steep high-elevation alpine and subalpine terrain flanking the Ospika River, but they descend periodically in the non-winter period to use mineral licks located in the valley bottoms of the Ospika River and its tributaries. The 4 sites (mineral-lick complexes) chosen for our study were identified as having high use by mountain goats in 1999-2000 (FWCP-P, unpublished data); where high use was determined by abundant soil-filled fecal pellets, shed goat hair, and well-worn trails between the lick and adjacent escape terrain or alpine habitat.

The 4 mineral-lick complexes (Licks 17, 28, 30 and 40) were within an 18-km section of the lower Ospika River drainage (Figure 2). Mineral-lick complexes were subjectively defined based the presence of a cluster of "mineral-lick sites" (exposed areas of fine-textured soils [e.g., clay] on moderate to steep slopes). All 4 complexes encompassed ≥5 mineral-lick

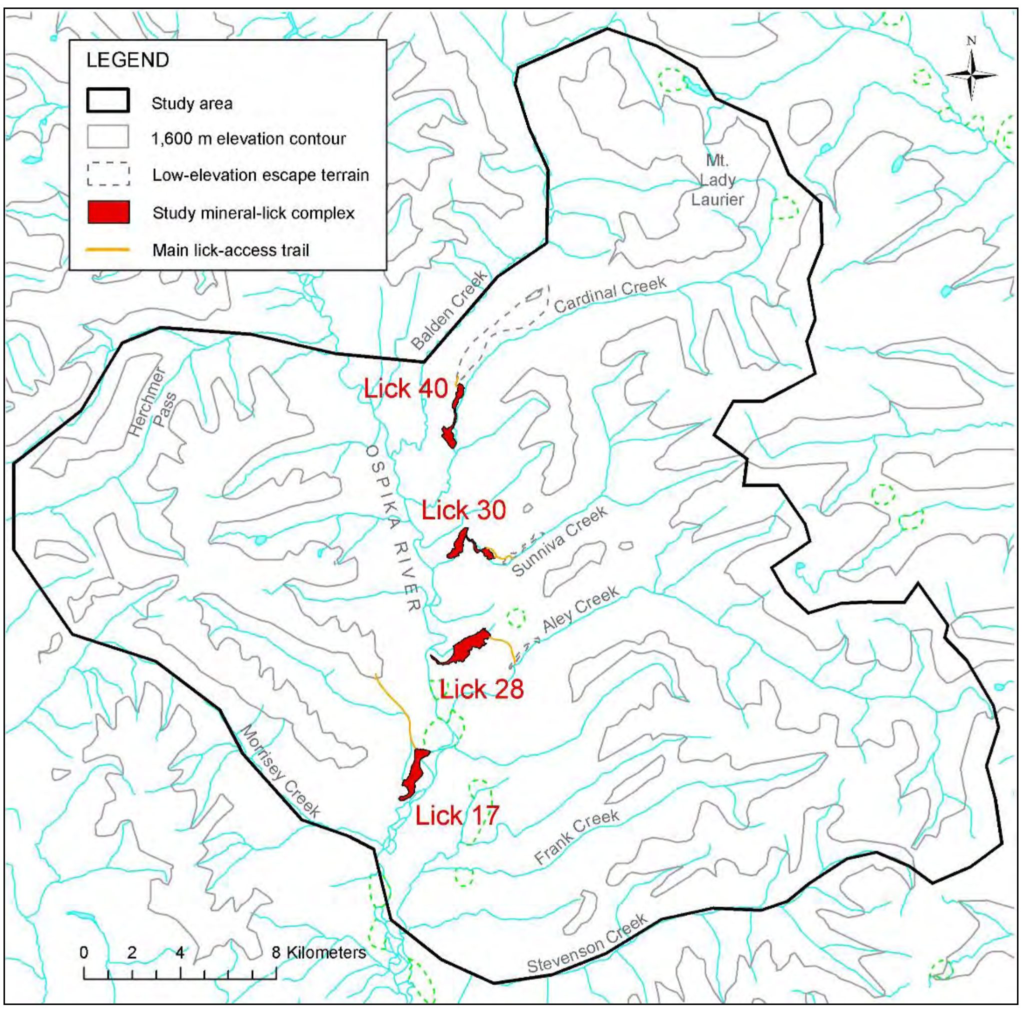

Figure 2. Location of the 4 study mineral-lick complexes, associated low-elevation escape terrain, and high-elevation (1,600 m) habitat used by mountain goats in the experimental trial within the lower Ospika River drainage, north-central British Columbia.

sites, forest matrix between the lick sites and, for Licks 30 and 40, a section of bedrock canyon along the adjacent watercourse. The Lick 17 complex (85 ha) was along the western bank of the Ospika River whereas the other 3 lick complexes were along tributaries of the Ospika River on the eastern side of the valley. Lick 28 encompassed approximately 106 ha, whereas the lick complexes for Licks 30 and 40 were about 64 ha and 58 ha, respectively. Individual mineral-lick sites within these complexes were primarily ≥0.2 ha. The largest definable lick site within each complex was 9.9 ha at Lick 17, 14.2 ha at Lick 28, 2.1 ha at Lick 30, and 2.0 ha at Lick 40.

All 4 lick complexes were between 720 m and 950 m in elevation. Forests around the licks and their main access trails were dominated by coniferous stands >100 years old. Main access trails were the primary or only well-worn trails between the mineral-lick complexes and areas of rocky escape terrain (Figure 2). Areas delineating escape terrain were subjectively determined based on rock outcroppings and steep slopes; due to the juxtaposition of outcroppings, portions of the identified area included steep, forested slopes. For Lick 17, the escape terrain extended from the subalpine up into the contiguous alpine. The escape terrain for the other 3 licks was at a lower elevation. For Licks 28 and 30, the escape terrain was immediately adjacent Aley (22 ha) or Sunniva (28 ha) creeks. For Lick 40, its substantive area of escape terrain (324 ha) extended along the northern ridge that paralleled Cardinal Creek. The southern perimeter of this escape terrain was ~215 m (straight-line distance) north of the mineral-lick complex. Due to differences in the juxtaposition of mineral-lick complexes and escape terrain, the main trails connecting these 2 features had varying lengths (approximate trail distance): 2,300 m at Lick 17, 1,700 m at Lick 28, 500 m at Lick 30, and 350 m at Lick 40. Trails likely existed between the low-elevation escape terrain and nearby alpine areas but we did not identify or monitor these trails.

Logging in the drainage started in the early 1990s and was limited to the southern portion of the drainage (south of Aley Creek). During the course of our study, logging extended northward to Sunniva Creek. Due to the area's remoteness, logging roads were used almost exclusively by forestry workers; hunters used the roads to a limited extent.

Other ungulates in the study area were moose (*Alces alces*), Rocky Mountain elk (*Cervus elaphus nelsonii*) and, to a lesser extent, white-tailed deer (*Odocoileus virginianus*), mule deer (*O. hemionus hemionus*) and woodland caribou (*Rangifer tarundus*). Potential predators of mountain goats were wolves (*Canis lupus*), grizzly bears (*Ursus arctos*), black bears (*U. americanus*), wolverines (*Gulo gulo*), coyotes (*C. latrans*), golden eagles (*Aquila chrysaetos*) and, although rare, cougars (*Puma concolor*).

3.0 METHODS

3.1 STUDY DESIGN AND MONITORING SCHEDULE

We used a Before-After Control-Impact (BACI) experimental approach to assess the impacts of 2 forest-removal treatments on the use of a mineral lick (i.e., mineral-lick complex) and its access trail by mountain goats. The study design involved 1 treatment lick and trail (Lick 28), 1 primary control lick and trail (Lick 17), and 2 secondary control licks and trails (Licks 30 and 40).

Lick 28 was designated as the *treatment lick* because proposed logging had been approved for the area and the licensee (Slocan Group [now Canadian Forest Products], Mackenzie, BC) was amenable to altering their cutting plans to conform to our study design. Treatments were to occur in 2 stages: a *forested buffer treatment* followed by a *clearcut treatment*. The prescription for the buffer treatment was to remove (commercially log) the forested area adjacent to ~750 m of the trail that was used to access Lick 28 but still maintain a 150-m wide forested buffer on each side of the trail. The prescription for the clearcut treatment was to remove the forested buffer. Both treatments were to occur in the winter to negate any chance that direct logging activities would affect goat use of Lick 28.

Lick 17 was designated as the primary control lick as there had been prior conservation efforts related to the lick and, from all known data, goats using this lick were a different subpopulation than those that used the treatment lick (Lick 28) on the east side of the Ospika River. Prior conservation efforts involved deferment of proposed logging activities and hunting closures (Hatler 1988; BC Ministry of Environment, unpublished data). Licks 30 and 40 were monitored as secondary control licks to help assess treatment effects related to lick-use displacements from the treatment lick.

The 6-year study involved 1 year of monitoring prior to any treatments (2002; pre-treatment period), 3 years of monitoring following the forested buffer treatment (2003 to 2005; buffer period), and 2 years of monitoring following the clearcut treatment (2006 and 2007; clearcut period). We used 2 different sampling methods to monitor lick visits by mountain goats during our study: photo-captured goats from trail-monitoring camera stations and telemetry data from radio-collared goats from fixed-telemetry stations. These methods provided different perspectives on lick visits at the study licks: trail cameras provided a lick-centered perspective as they recorded all goats that used the study trails to access their respective lick (i.e., down-trail use = lick visit), whereas radio telemetry provided lick-visit data from the perspective of an individual radio-collared goat that visited the study licks. We collected camera data for 5 years (2002 to 2006) and telemetry data for 6 years (2002 to

2007). Except for 2002, monitoring data from camera and telemetry stations were collected from early to mid-April until late November each year; some stations were operational until early December but no goats visited the licks during December so this monitoring effort was excluded from the datasets. In 2002, data collection started in late May for camera stations and mid-May for telemetry stations. Time intervals between data-download visits depended on the level of suspected goat use along the trails (i.e., before a 36-frame film roll was spent); visit intervals varied from once every ~10 days during high-use periods to once per month during low-use periods.

We used behavioural responses of mountain goats to determine the impact of the forest-removal treatments on their use of the study licks and trails, and the greater study area. Trail-monitoring camera stations were used to collect data on the frequency, timing, and travel behaviour of mountain goat movements along the main access trail to each of the study licks. The use of close-range photographs, and their associated event time records, allowed us to determine the number of individuals (by age-sex class), timing of use (annual, seasonal, and diel), and travelling behaviour (group size and travel speed) for each goat group moving along a trail. All records (camera and telemetry data) of mountain goat lick use occurred in the April to November period. Three seasonal periods were identified based on physiological drivers (e.g., changes in forage, reproductive demands) we thought would influence lick-use patterns by mountain goats: early (1 Apr to 29 Jun), mid (30 Jun to 28 Aug), and late (29 Aug to 30 Nov). However, we excluded April and almost the entire month of May from the early season period (i.e., revised early season = 31 May to 29 Jun) because monitoring data for these dates were not available for 2002 and there was low goat use prior to 31 May from 2003 to 2006 (<3% of all goat visits). The diel period was separated into crepuscular (±1 hr from sunrise/sunset), day, and night periods to examine logging-related effects on diel patterns of trail use.

Fixed-telemetry stations were used to collect data on the frequency and duration of lick visits for each radio-collared goat using the study licks, as well as determine if radio-collared goats using the treatment lick displaced their lick visits to the secondary control licks or exhibited changes in their trail fidelity or frequency of failed lick visits after the treatments were conducted. Displaced lick visits, trail fidelity, and failed lick visits were monitored as an index of whether the treatment lick and trail were still suitable for use by goats after the treatments were conducted. A failed lick visit involved a goat that started travelling towards the lick (i.e., moving along the monitored portion of the study trail) but turned around before reaching the mineral-lick complex and returned to its escape terrain or alpine area.

Aerial-telemetry flights were conducted to ensure radio-collared goats were alive during the study period (i.e., capable of visiting the study licks), and to monitor whether radio-collared goats changed their seasonal range use after the treatments were conducted.

To assess whether the risk of predation for mountain goats changed along the main access trail following the treatments, we recorded the number of potential predators and alternate prey (other ungulates) photo-captured at trail-monitoring camera stations at all licks and across all camera-monitoring years.

We attempted to reduce potential confounding factors from affecting goat use of the study licks and trails, and the greater study area, as much as possible. We used fixed helicopter flight paths (using terrain features and flying altitudes to reduce sound levels on the ground) to minimize potential disturbances on goats when our field crews accessed the study sites. Landing sites were located ≥400 m away from mineral-lick sites and main access trails, and our field crew avoided walking on or near the licks and access trails as much as possible when accessing the monitoring stations. We informed personnel from the local forest licensee, helicopter companies, and mining company about of the study and provided access recommendations so they could limit their potential impacts. Time periods for summer replanting and road-deactivation activities near the treatment lick were adjusted and shortened as much as possible. The majority of post-logging activities occurred in 2004 (late May to mid-August). For the duration of the study, hunting of mountain goats was closed within the valley bottom (<1,200 m) of the lower Ospika River drainage.

3.2 LOGGING TREATMENTS

Logging for the first treatment (forested buffer treatment) was conducted November 2002 to March 2003 and included a 111.8-ha area south of the trail and a 95.1-ha area north of the trail (sections A and B of Block 6602, respectively; Figure 3). These areas extended 1.3 km south and 1.8 km north of the forested buffer and they primarily had openings >200 m wide; a couple of locations were as narrow as 60 m but they were >530 m from the buffer.

The forested buffer was 20.5 ha and 265-375 m wide. The majority of the trail within the buffer was ≥150 m from the logged area but a ~230-m section of the trail was as close as 105 m to the northern logged area. Based on the juxtaposition of the trail and logged areas, we considered ~680 m of the trail to be impacted by forest removal. The buffer itself was impacted by a minimum-width (~15-m wide) cleared roadway that was needed to access logging north of the access trail.

Logging for the second treatment (clearcut treatment) was conducted in November 2005 but it did not completely remove the forested buffer as originally prescribed. The treatment area could not be commercially harvested as planned. Instead, trees were felled and piled in low-lying areas away from the trail to minimize sight-line effects on animals using the trail. These piles were then burned in November 2006 after goats had begun moving to their winter range. As a result of these operational changes, the area affected by the clearcut treatment was shifted eastward along the trail (Figure 3). The resulting treatment opening was 14.5 ha and 160-300 m wide, and had a 0.4-ha rocky escarpment along its eastern boundary. The clearcut treatment impacted 670 m of the lick-access trail.

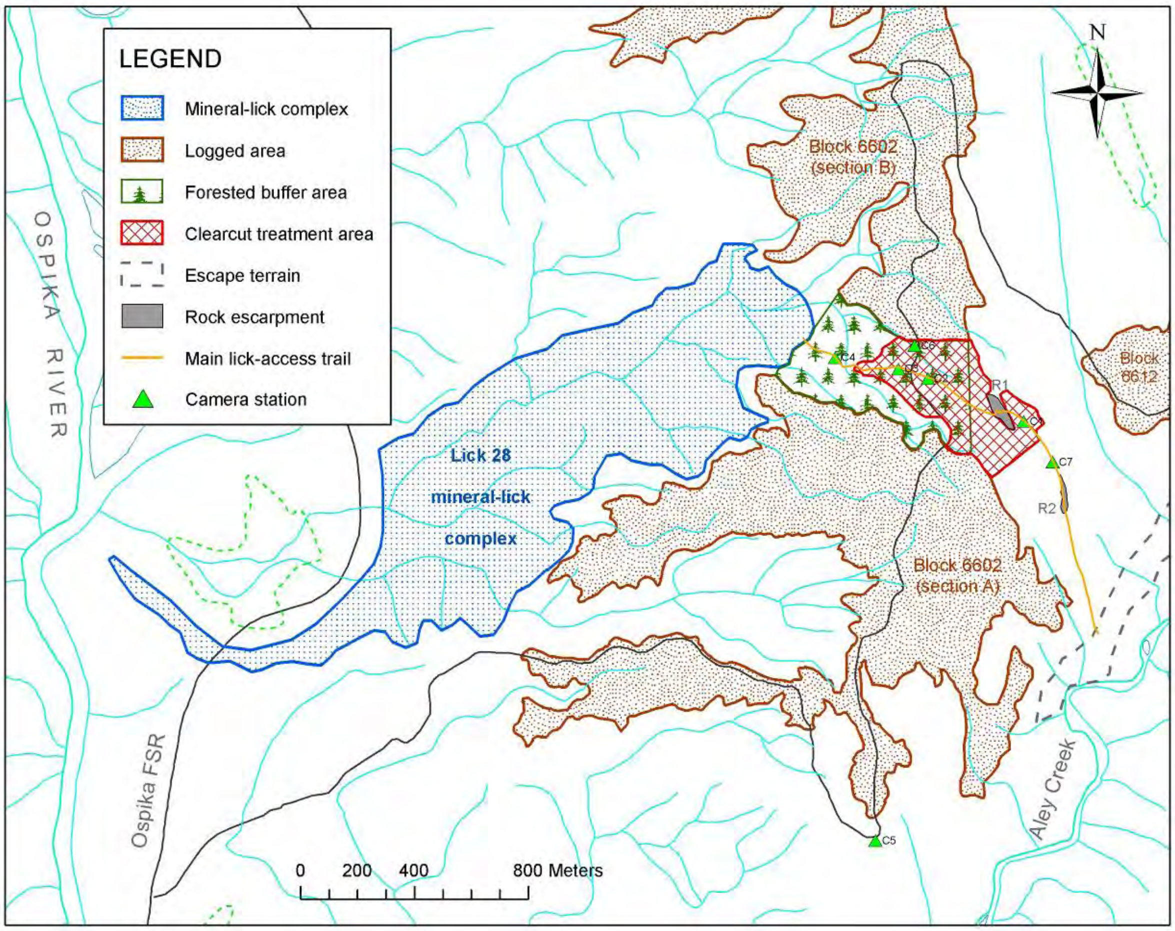

Figure 3. Map illustrating the juxtaposition of the mineral-lick complex, main access trail, and logging treatments at the treatment lick (Lick 28) in the lower Ospika River drainage.

3.3 TRAIL-MONITORING CAMERAS

3.3.1 Monitoring of Trail Use

We used trail-monitoring cameras to monitor the frequency, timing, and travel behaviour of mountain goats moving along the main access trail at each study lick. Multiple camera stations (transmitter, receiver with event logger, and 35-mm film cameras; TrailMaster TM 1550 Active Infrared Trail Monitor and TM35 Camera Kit, Goodsen Associates Inc., Lenexa, KS, USA) were set up along the main access trails to each of the study licks. Sixteen camera stations were established to monitor trail use: 3 stations[1] at Lick 17, 5 stations at Lick 28, 5 stations at Lick 30 and 3 stations at Lick 40. Cameras were primarily set to capture animal movements in series along a single main trail but 2 cameras were established on secondary trails. In addition to the trail cameras, 2 camera stations were established on the logging road near Lick 28 in May 2004. The cameras were used to determine the road's importance to animal movements, and to measure its level of use by humans (i.e., a potential disturbance factor). One camera was established at a road site within the forested buffer (~100 m north of the trail), which was later logged by the clearcut treatment, and the second camera was located about 1.5 km south of the buffer (Figure 3).

All trail camera stations were within 1,075 m (trail distance) of the mineral-lick complex except for camera #4 at Lick 17 which was 1,650 m away. At the treatment lick (Lick 28), cameras were positioned along the trail in the following order: #7 (closest to the Aley Creek escape terrain), #1, #2, #3, and #4 (closest to the lick) (Figure 3). Camera #7 was not established until 2005, when it was realized that the clearcut treatment was going to be shifted along the trail. Cameras #2, #3, and #4 were within the forested buffer. Cameras #1, #2, and #3 were within the clearcut treatment; cameras #4 and #7 were 155 m and 100 m (trail distance) from the edge of the clearcut treatment, respectively.

For a given trail, all cameras were positioned on the same side of the trail so the same side of the animal could be viewed in all photographs, thus facilitating identification of individuals from the multiple camera stations. A 7.5-m camera-activation cable from the receiver/event logger enabled us to place the camera such that an ~8-m wide field of view was centered on where the infrared beam (between the transmitter and receiver) crossed the trail. Transmitters and receivers were mounted on trees so the projected beam crossed the trail at ~60-80 cm above the ground. We believed this height range gave us the greatest likelihood of a goat triggering an event, whether it was walking or running along the trail; it

[1] Excludes 1 camera station located on a trail near Lick 17 that was monitored in 2003 and 2004. Only 1 goat was photo-captured during 2 years of monitoring so the trail was not considered an important goat trail and the station was pulled.

was recognized that kids <6 months old may not always trigger an event, but it was assumed the nanny (which typically has its kid close by) would trigger an event and result in both animals being photo-captured. When the infrared beam was broken for ≥0.25 seconds, a trail event was recorded (to the nearest minute) and the camera was triggered; we believe this setting reduced the number of unwanted photographs (e.g., falling leaves). To avoid exhausting a roll of film on animals and situations that may trigger multiple events within a short period of time (e.g., animal loitering around a camera station, an extreme rain event), the camera system was set so subsequent photographs only occurred after a 6-second delay; the event logger, however, still recorded the time of all beam-breaking events (up to 4,000 events).

During each field visit, the camera film was replaced, the station's operating status was checked, and maintenance activities were conducted (e.g., vegetation cleared along beam path, batteries changed). The film was developed immediately after each trip to ensure any problematic issues were corrected on the next field visit.

Photographs from all camera-monitoring stations were interpreted at the end of each field season. Interpretation involved cross-referencing the time stamps on photographs with data recorded from event loggers to account for known causes of beam-breaking events, and to cluster photographs into distinct groups (e.g., multiple animals in a group). Photographs from all cameras on a trail were interpreted together to aid in the age-sex classification of individuals and to estimate group sizes. To maintain consistency in our estimates of group size, we considered groups distinct if individuals maintained ≥5 min separation from other goats through the entire camera series. The photo-interpretation process documented the species, number of individuals (by age-sex class), direction of travel (down or up trail), and timing of movement (seasonal and diel periods). Age-sex classes of goats were adult (≥22 months old) male, adult female, unknown adult, juvenile (10 to 18 months old), kid (≤6 months old), and unclassified. Other ungulates (e.g., elk, deer) were similarly classified, whereas predators and other wildlife were classified as adult (≥10 months) and young (≤6 months); if young were observed, the adult was assumed to be a female. Event times from the first and last camera stations on a trail provided a measure of travel time. The presence of radio-collared goats, behaviour of the animal group on the trail (walking, running, alert), weather status (good, raining, snowing, windy), and other notable data were also documented for each animal group.

The number of photo-captured animals was a minimum estimate of the number of animals using the trail because differentiation between individuals photographed at different camera stations could not always be positively made. For mountain goats, our ability to differentiate among individuals became more difficult when goats were in larger groups and when their winter coats became fully shed later in the monitoring year. Our ability to detect trail use by animals with a different stature (taller [e.g., moose] or shorter [e.g., wolverine, coyotes) than mountain goats may have been affected by the beam height used at the camera stations.

3.3.2 Photo-interpretation Error

A single observer interpreted the photographic data from all licks and across all years. To quantify the error related to group size estimates (thus, number of goat visits) and age-sex classifications within the data, the same observer re-interpreted a sample of photographs of both large (≥10 goats per group) and small (<10 goats per group) goat groups. For this re-interpretation effort, we randomly selected approximately 5 small and 5 large groups from each lick for 2002 to 2004. Even though small groups had greater frequency in the database, we divided our effort evenly between large and small groups because we expected greater differences in group size and age-sex composition for large groups.

3.3.3 Camera Data Analyses

We could not distinguish repeat visits of individual non-marked goats by using the photographic data so our camera data presents a lick-centered perspective (i.e., a goat visit is the sample unit rather than an individual goat). For that reason, we use the term "photo-capture", instead of "individual", to acknowledge that our records include multiple users and, outside a specific group, represent an unknown number of individuals.

Prior to our analyses, we removed a few mountain goat records collected from 2 camera stations (1 at each of the 2 secondary control licks) that were situated within the boundary of their lick complexes (Appendix A). We believed these records were the result of "in-lick" movements (i.e., movements within the mineral-lick complex itself and not a movement between the complex and escape terrain), therefore they inaccurately inflated the number of goats travelling to or from the lick.

Trail use by mountain goats was driven by their need to access a lick, so we considered down-trail use to be the most important trail movement, especially for determining the annual and seasonal timing of lick use; up-trail use was considered a reflection, albeit a slightly delayed occurrence, of their down-trail movement as goats needed to return to their escape terrain or alpine area. Goats were also photographed more often travelling down the trail than travelling up the trail at all study licks; up-trail movements had 3-41% fewer photo-captured goats across all licks each year (Appendix B). For these reasons, we used the down-trail dataset for all analyses of goat behaviour unless otherwise noted (e.g., when describing trail use specifically rather than using it as a surrogate for lick use).

Our analytical approach for assessing whether there were treatment effects on lick use by mountain goats involved investigating 3 sets of response variables. We examined i) annual trail use, ii) timing of goat visits, and iii) trail-use behaviours. Before analyzing the annual trail-use data, we standardized it to control for variable sampling effort across years; cameras failed during the monitoring period because the film was spent (e.g., excessive animal movements, adverse weather conditions), animal damage (e.g., bears, squirrels), and human error. For each camera, the number of photo-captured goats in a given year was divided by the number of hours the camera was operational for that year. The standardization process required camera-specific analyses of the data but our photo-interpretation process considered all cameras together when determining the group demographics (i.e., no age-sex composition for individual cameras), consequently these factors negated the inclusion of age-sex classes in our analyses of annual trail use. The start date for all analyses was 31 May each year, except for box-and-whisker plots which utilized data from the entire lick-use season (Apr to Nov).

We did not examine treatment-related changes in annual lick use with inferential statistics due to the constraints of the study design (no replication of treatments) and data (repeat visits of individuals could not identified). Instead, we graphically compared the number of goats per hour of camera monitoring across treatment and control licks for each annual period. We kept years separate so year-to-year variation and delays in treatment effects could be considered, but we also pooled the data into the 3 treatment periods (pre-treatment, buffer and clearcut) to investigate overall treatment effects. For graphing and presentation purposes only, multiple camera stations at each lick were considered replicates (although not statistically valid) to provide estimates of the mean and variability for the number of goats using a lick during each year and treatment period. The sampling unit of photo-captured goats per year allowed us to standardize our sampling effort across years (camera-specific hours of monitoring); it also reduced the effects that uneven sampling or non-treatment related events would have had on our analysis if we conducted it at a finer time scale. The use of individual camera stations as statistical replicates was problematic as the assumption that each camera is an unbiased sample of the treatment effect is likely not accurate as the cameras farther into the treatment area would likely record fewer goats than cameras near the beginning of where the trail entered the treatment area. Graphical comparisons and estimates in the text are presented as $\overline{x} \pm$ SE.

The second set of response variables involved the timing of lick visits. Visit times were described as per the calendar date, relative to 2 dates (snow free and leaf flush) that we thought had potential biological importance to mountain goats (Bechtold 1996, Ayotte et al. 2006), and per 3 seasonal (early, mid, and late) and diel (crepuscular, day, and night) periods. The snow-free date was used as an index of increased mobility and, whereas the leaf-flush date provided an index to the emergence of spring vegetation. The annual snow-free date was the date when <0.05 m of snow was remaining at a weather station (Ospika Upper) located in the alpine (1,830 m elevation) on the west side of the drainage; see Sagar and Corbould (2004) for detailed site and monitoring details. The annual leaf-flush date was determined by the presence of the first leaf growth on deciduous shrubs in photographs from any of our 16 trail-monitoring cameras. We graphically evaluated the effects of year on these variables using box-and-whisker plots. Similarly, we used bar graphs to evaluate the effects of year on the seasonal down-trail use and the diel timing of all trail use (down and up combined) by all goats and goat groups with kids. The response variables "goats per day" and "goats per hour" were chosen to control for differences in the number of days among seasons and the number of hours among diel periods, respectively. Neither of these response variables should be confused with "goats per camera-monitoring hour" which we used to examine annual trail use, as the later indicates its data were standardized for monitoring effort. We believed that diel trail use by goats was mainly governed by risk of predation. Therefore, since we did not believe the travel directions placed different levels of risk on a goat, we pooled the data for both travel directions to investigate diel travel patterns. The diel period for each goat group was determined using sunrise and sunset time tables for the study area obtained from the National Research Council website (http://www.nrc-cnrc.gc.ca/eng/services/hia/ sunrise-sunset/angle-calculator.html) using the reference location of 56^{o} 29' N latitude and 123^{o} 55' W longitude.

The third set of response variables we used to evaluate treatment effects on mountain goats involved goat behaviours while they travelled along the trails: group size and travel rate. We used Jarman's (1974) "typical" group size to describe an animal-centered estimate of the group size travelling along the trail. The typical group size is equal to the average group size that a randomly chosen individual would be found; this is in contrast to the more traditional estimate of mean group size that is a measure of group frequency. Typical group size is less affected by animals travelling alone (Heard 1992). We derived the annual variability in the typical group size using Tukey's (1958) jackknifed estimate of variance and then graphically compared trends ($\overline{X} \pm$ SE) in annual use for typical group size across licks. We plotted direction of travel (down and up trail) separately to more accurately examine the treatment effects on group size because we expected (from preliminary examination of our data and another study [Ayotte et al. 2008]) mountain goats to move in larger groups when travelling from their alpine range (or escape terrain) to the lick than when travelling away from the lick.

To calculate travel rates, the time elapsed between the first logged event at the first and last camera station was divided by the distance between these 2 camera stations. A travel rate was calculated for each record where all camera stations were triggered along the main access trail. To test for treatment effects, we used one-way ANOVAs and Tukey's post-hoc multiple comparisons (Statistica, StatSoft, Tulsa OK). All tests met assumptions of normality and homogeneity of variance (Levene's test; Zar 1999). We chose to only use groups with kids (≤6 months old) for our analyses because we expected these groups to be the most sensitive to disturbance. All records with travel times >1 hr were removed from our analysis dataset because these records likely involved behaviours other than travelling. All tests were 2-tailed with significance set at ≤0.05.

Our analysis of camera data for other ungulates (moose, elk, deer, and caribou combined) and the 3 large predators (grizzly bear, black bear, and wolf) was conducted similar to the goat analyses for annual trail use and timing (calendar date, seasonal, and diel) of trail use. Annual trail-use data were standardized for sampling effort (hours of camera monitoring time). Down-trail and up-trail movement data were combined for the analysis because we considered these movements to be independent events for non-goat species. We did not believe non-goat species had the same strong trail-movement relationship as mountain goats because they seldom triggered multiple cameras along a trail and the difference in their down-trail and up-trail movements were quite variable across years and licks. Also, we did not believe their movements were tied to the use of the licks (at least not to the same degree as goats), nor to the location (alpine or escape terrain) where the trails originated.

3.4 GOAT CAPTURE AND HANDLING

Most of the radio-collared mountain goats used for our study were initially captured in March 2002. Additional captures to supplement, supplant, and re-collar goats were conducted in March 2004, March-June and October 2005, and March and July 2006. All captures occurred on alpine sites using a helicopter and a handheld net-gun. All capture and handling protocols met or exceeded provincial capture and handling guidelines (Resources Information Standards Committee 1998; Wildlife Act permit D012230), and capture, handling and tagging protocols were reviewed and approved by the provincial government's wildlife veterinarian.

Goats were fitted with LMRT-3 VHF radio-collars (Lotek Engineering, Newmarket, ON) with motion sensors (6-hour delay) to indicate mortality or a discarded collar. Goats were tagged with coloured ear tags and, for captures after 2002, coloured radio-collars for use in identifying individual radio-collared goats in trail-camera photographs. Goat ages were determined by counting horn annuli at time of capture.

3.5 FIXED-TELEMETRY STATIONS

3.5.1 Monitoring of Lick and Trail Use

Fixed-telemetry stations were erected at 2 vantage points at each of the study sites to monitor the frequency and duration of lick visits, as well as trail fidelity, displacement lick use and frequency of failed lick visits, of individual radio-collared goats. These stations were established in early May 2002, except for the second station at Lick 40 which was erected in early May 2003. In early June 2005, an additional station was established near the access trail to the treatment lick (Lick 28) when it was realized that the clearcut treatment was going to occur southwest of its original location. "Lick" stations were established at or near the first mineral lick that was accessed along the trail. All "trail" stations were ≤100 m from their respective main access trail, and were ≤900 m (trail distance) from the first mineral lick.

Telemetry stations were comprised of a SRX_400A datalogging radio-telemetry receiver with Event_Log W21AST firmware, a Solar-powered Environmental Enclosure Kit, an ASP-8 switch box, and 4-element Yagi antennae (Lotek Engineering Inc., Newmarket, ON). The enclosure and antennae were affixed to trees at the site. Stations had 3 or 4 antennae depending upon site characteristics (e.g., terrain features) and the juxtaposition of the station to the lick and trail; antennae directions were ~120^{o} or ~90^{o} apart depending on the number of antennae present. All antennae at the same station were programmed with the same gain, thus having equal influence on determining the animal's position. Receivers at lick stations were programmed to scan for each radio-collared goat frequency every 2 minutes. Whereas, frequencies were scanned every minute at trail stations due to the limited time spent on the monitored portion of the trail and the number of transmitter frequencies needing to be scanned. During each field visit, crews downloaded the banked data from the receivers and conducted system checks and maintenance activities.

Interpretation of the telemetry data (i.e., goat movement data) were based on signal strength, antennae configuration, and knowledge of signal-influencing features (terrain and vegetation) at the site and in the area. If available, data from >1 station were used to identify the goat's position. Field testing was conducted to identify signal configurations and strengths of transmitters along the trails and at other possible locations in the area (e.g., alpine ridge). Data interpretation was complicated by the variability in signal strengths from the different radio-collared goats and irregular readings caused by signal bounce, signal obstructions and antennae back-readings. Consequently, movement data were interpreted manually rather than by computer algorithms. Transmitter signals could be heard up to 10-20 km away when goats were in some alpine sites (e.g., goats in the alpine on the west side of the Ospika River were recorded at eastern stations, and vice versa). But, when goats were at lower elevations, goats usually needed to be within 1 km of a station to be recorded.

Individual start and end times were identified for each occasion that a radio-collared goat was determined to be coming to a lick (down), in a lick, and leaving a lick (up). For a goat to be considered in a lick, telemetry signals indicated the goat was somewhere in the lick complex area (i.e., not necessarily in a mineral lick site). For each "up" and "down" movement, we identified if the goat appeared to be travelling along (or near; i.e., within ~150 m) the monitored portion of the main access trail or if it took a different route; all up and down movements of radio-collared goats were cross-referenced with camera station data. Although there was some subjectivity in determining a goat's travel route, the same criteria and people were used for all trail-use interpretations at each lick.

3.5.2 Fixed-telemetry Data Analyses

We used a Generalized Linear Mixed Model (GLMM; McDonald et al. 2000) approach to conduct our analyses on data from radio-collared goats. A mixed model was used to account for repeated measurements on the same goats. Year effects were treated as random effects (i.e., study years were representative of past and future years). The most appropriate distribution for each of our analyses was determined by examining the log-log plots of the variance and mean for the response variable being examined. P-values for each analysis are provided in the report text but, for readability, all other model statistics are provided in the appendix.

Upon preliminary examination of the data, 4 "types" of goats were identified based on their lick use during the study period: individuals that used the primary control lick exclusively (L17 goats), individuals that used Lick 28 exclusively (L28-only goats), individuals that used Licks 30 and 40 (L30-40 goats), and individuals that used all 3 eastern study licks (L28-30-40 goats). Our analyses focused on goats that used the treatment and primary control licks, so goat-use data from the secondary control licks were excluded from most analyses. Data for the treatment lick were derived from both L28-only and L28-30-40 goats. If a goat's capture, re-capture, or death occurred within the lick-use period (Apr to Nov), data for the goat were omitted from the analysis for that year.

We investigated changes in mountain goat use at the treatment and primary control licks by assessing 3 different response variables: mean number of lick visits, mean duration of lick visits, and mean total time spent at licks by each individual goat. Analysis of these variables used a binary distribution. A treatment effect was indicated when an interaction effect between lick type (treatment lick or primary control lick) and monitoring period (pre-treatment [2002], buffer [2003-2005], clearcut [2006-2007]) occurred. Effects were indicated when there was evidence of non-parallelism in trend lines.

We used a GLMM analysis for data with a binary distribution to investigate whether goats exhibited a shift in their distribution of lick visits between the treatment lick and the secondary control licks. Only L28-30-40 goats were used for this analysis because no additional information could be garnered from including data from L28-only goats as they showed no change in lick use. The proportion of goat visits at the treatment lick and at the secondary control licks (Licks 30 and 40 combined) were compared.

We also used a GLMM analysis for data with a binary distribution to investigate whether goats exhibited the same fidelity to their trails when they travelled to and from the treatment and primary control licks before and after the treatments. For this analysis, the data were separated into 2 datasets to reflect the down-trail and up-trail movements. Trail-use patterns were categorized as either using the study trail or using a different route. We considered goats to be using the study trail if telemetry and/or camera data indicated their trail movement followed or approximated the study trail (i.e., likely ≤150 m away), all other movements were categorized as a different route.

Power analyses were conducted to assess our likelihood of detecting treatment effects given our datasets for 2 response variables: number of lick visits and trail fidelity. We also investigated the impact of increased sample sizes on our ability to detect various levels of treatment effect. We used a power of 80% at alpha = 0.05 to determine significant effect levels and required sample sizes; these parameters are a standard used by many researchers (e.g., Cohen 1992, Kraemer and Thiemann 1987).

All modelling and power analyses were conducted using SAS 9.1.3 (SAS Institute Inc., Cary, North Carolina). Significance was set at alpha = 0.05.

Each year, we determined the frequency of failed lick visits for radio-collared goats. Failed visits were only identified for the treatment lick and 2 of the control licks (Licks 17 and 30) because they could not be confidently determined for Lick 40 due to the close proximity of its escape terrain and mineral-lick complex. Three types of failed visits were identified: interrupted (goat returned to the same lick within 24 hrs), aborted (goat did not return to the same lick, or another lick, for ≥2 days), and mortality (goat was killed during the attempted visit).

3.6 AERIAL-TELEMETRY MONITORING

3.6.1 Monitoring of Goat Status and Seasonal Range Use

Radio-collared goats were monitored throughout the year to check that they were alive, thus capable of visiting the study licks during each lick-use season, and also to determine their seasonal range use before and after the treatments were conducted.

Aerial-telemetry flights were conducted[2] using fixed-wing aircraft approximately every 2 weeks when goats were using the study licks (April to November; non-winter period) and monthly when goats did not use the licks (December to March; winter period). An attempt was made to locate all radio-collared goats each flight. The geo-coordinates for each location were collected using an on-board Global Positioning System unit. If a goat's transmitter indicated a mortality, a field investigation was conducted to confirm the goat's status.

3.6.2 Aerial-telemetry Data Analyses

Radio-collared goats were often not located in the licks during telemetry flights each year, yet we had data from our fixed-telemetry stations when they had used a lick. Therefore, for those years when goats had no lick visit recorded for a goat based on its aerial telemetry, but had been recorded in the lick by our fixed stations, 1 location for each used lick was added to each goat's location dataset for calculating their non-winter range. A generic date of 1 June was given to these locations so they would be included in both the non-winter and core-lick MCP ranges. Generic UTM coordinates (middle of first mineral lick accessed via the trail) were given for these locations so MCPs that included a lick location based on these data do not reflect the portions of the lick that were used by the goats. Capture locations were included as data points.

We estimated the range use (100% minimum convex polygon; MCP) of mountain goats for the non-winter and winter periods. We also determined range use for the period when goats conducted a majority of their lick visits (Jun to Sep; core-lick period) because the date when goats moved between their non-winter and winter ranges varied considerably each year and among individual goats, which overtly affected the range size estimate for many of the non-winter MCPs.

All aerial-telemetry and capture locations were plotted for each goat individually to determine if any changes (size, shape, and distance between range and study licks) occurred in their range use over the study years. In particular, we assessed whether any range changes for treatment-lick goats were different than changes observed for goats using the primary control lick (i.e., Was there a treatment effect?). If no obvious trends were observed, locations were pooled across each individual goat's monitoring period to calculate a single multi-annual home range for each of the seasons. These values were then averaged to calculate a mean multi-annual seasonal home range for each goat type. All aerial-telemetry and capture locations were also pooled for each goat type to create a multi-year composite home range for each season for the different goat types. A few locations were excluded from these datasets as the locations overtly skewed the seasonal ranges and were not the result of a treatment effect. Ranges were calculated and created using the HawthTools (Beyer 2004) extension in ArcMap™ 9.2 (ESRI® Environmental Systems Research Institute, Redlands, California, USA).

In addition to the multi-annual seasonal home ranges, a *core-lick high-elevation range* was created for each goat type based on all locations from the core-lick period, except for those locations that were related to a lick visit (i.e., excluded locations when goats were at the lick and travelling between the lick and their high-elevation range). The boundary of the core-lick high-elevation range that did not align with the multi-year composite core-lick MCP was subjectively delineated using core-lick locations and the alpine areas present (i.e., as identified by the orthographic image layer [s515_bc_2004_2006_bcalb_ 15m_panb321_enh] in ArcMap™).

ArcMap™ was also used to calculate the closest and farthest distances between the mineral-lick complexes and the core-lick high-elevation range and multi-year composite winter range for each goat type. These distances were calculated to determine the minimum and maximum distances each type of goat moved from their high-elevation and winter ranges to access their respective mineral licks. No distances were calculated for L30-40 goats.

4.0 RESULTS

4.1 TRAIL USE BY CAMERA-MONITORED GOATS

Between 2002 and 2006, we monitored the main access trails of the 4 study licks for 361,399 camera hours. Over 20,000 photographs were taken and interpreted, resulting in 3,496 animal-related records. These records identified 8,180 photo-captures of mountain goats; large predators had the next highest trail use with photo-captures totalling 8% of the records observed for mountain goats (Appendix C).

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[2] Flights were conducted in conjunction with aerial-telemetry monitoring being conducted by Wildlife Infometrics that was conducting the Resource Inventory component of the Mackenzie Mountain Goat Initiative.

4.1.1 Photo Interpretation Error

We reinterpreted a sample of 117 goat groups (61 large groups and 56 small groups) from 2002 to 2004 to determine the error in our estimates of group size and age-sex composition (Appendix D). Although the 2 photo interpretations often produced different results, the differences were not large and there was no bias in either direction, consequently these results did not influence our overall interpretation of camera monitoring data. Discrepancies in group size estimates among large groups were more common (46%) than small groups (9%), but mean differences were small (means ranged from 0 to 2). Differences in age-sex classifications between the 2 photo-interpretations were more frequent within large groups (90%) than small groups (46%), again with small mean differences (means ranged from -0.8 to 1.5).

4.1.2 Number of Goats Using Trails

Each year between 79 and 345 photo-captured goats were recorded travelling down the main access trails to the 4 study licks (Appendix B). Over the 5 camera-monitoring years, annual down-trail use averaged 177 photo-captured goats (SE =29) at the primary control lick, 238 photo-captured goats (SE = 31) at the treatment lick, 259 photo-captured goats (SE = 27) at secondary control lick 30, and 230 photo-captured goats (SE = 35) at secondary control lick 40. For all licks and years combined, adult goats represented the largest component using the trails (73%), followed by kids (19%) and juveniles (8%).

There was no treatment effect on the annual number of photo-captured goats travelling to the treatment lick (Figure 4). The number of photo-captured goats using the trail to access the treatment lick did decline following the treatments (starting in 2005, 3rd year after the buffer treatment), but a similar decline occurred at the primary control lick (starting in 2004). The declining trend at the primary control lick was less apparent because the number of photo-captured goats using the trail in 2002 was underestimated compared to

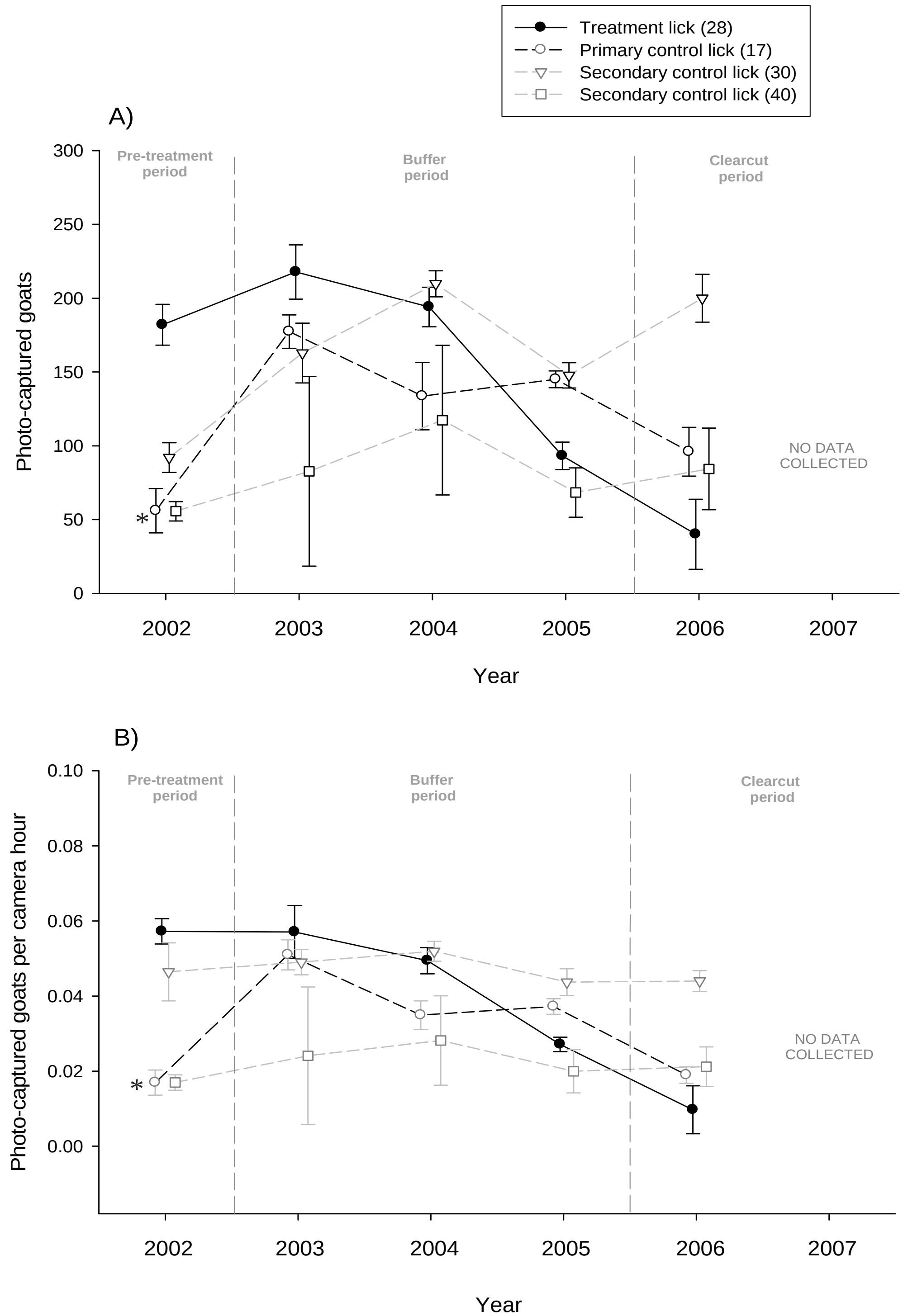

Figure 4. Number of photo-captured mountain goats, a) non-standardized data and b) standardized data, travelling down the main access trails to the 4 study licks in the lower Ospika River drainage, April to November, 2002-2006. Data from each camera station were standardized using their respective total camera-monitoring hours to account for differences in sampling effort between cameras and years. Multiple cameras at each lick were considered replicates to estimate the number ($\overline{X} \pm$ SE) of mountain goats using the trail each year. Asterisks indicate negatively biased data for primary control lick in 2002 (see text for explanation).

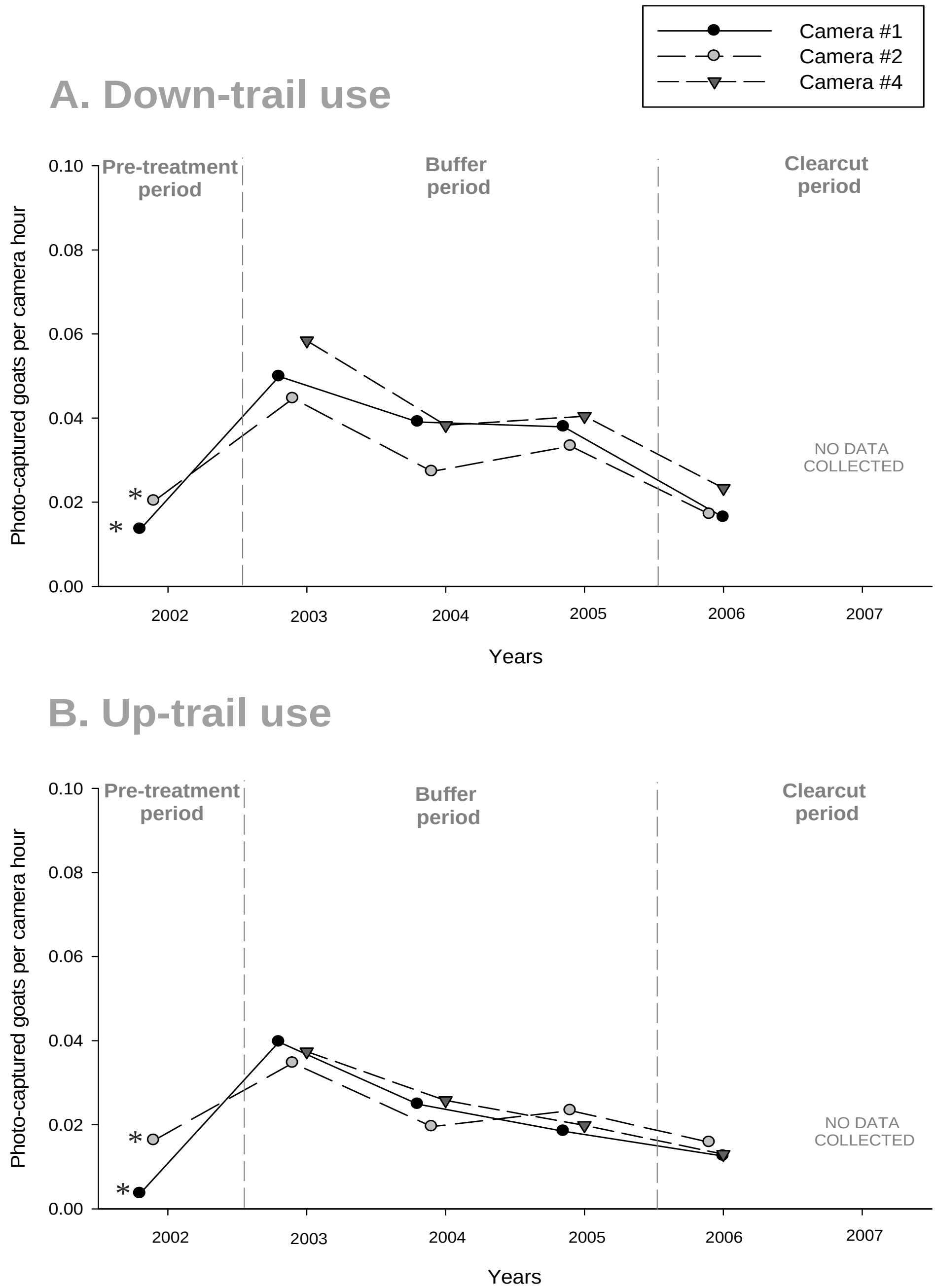

Figure 5. Number of photo-captured mountain goats, by camera station and standardized for camera-monitoring hours, using the main access trail, (A) down-trail use and (B) up-trail use, at the primary control lick (Lick 17) in the lower Ospika River drainage, April to November, 2002-2006. Camera #4 was furthest from the lick, followed by cameras #1 and #2. Camera #4 was not established until 2003. Asterisks indicate negatively biased data for 2002 (see text for explanation).

subsequent monitoring years. The low estimate in 2002 was the result of fewer camera stations being deployed on the trail (2 cameras in 2002 compared to 3 cameras in 2003 to 2006) and 1 of the 2 cameras that was present had less camera monitoring time. By having 1 less station operating in 2002, we had fewer photographs to help identify individual goats within the group as they moved along the trail for that year. The camera station with less monitoring time in 2002 involved camera #1 that did not operate properly from mid-June to late July, the period that had the highest rate of trail use by goats that year. Camera #1 also consistently recorded more goats travelling down the trail than camera #2 in the other monitoring years (Figure 5a). So, all these factors acted to negatively bias the 2002 trail-use estimate compared to the other monitoring years. No decline was observed at either of the secondary control licks (Figure 4).

There was also no treatment effect on the annual number of photo-captured goats travelling to the treatment lick when the yearly data were pooled into treatment-related periods as declines occurred at both the treatment lick and, considering the influence of the negatively biased 2002 data, the primary control lick (Figure 6).

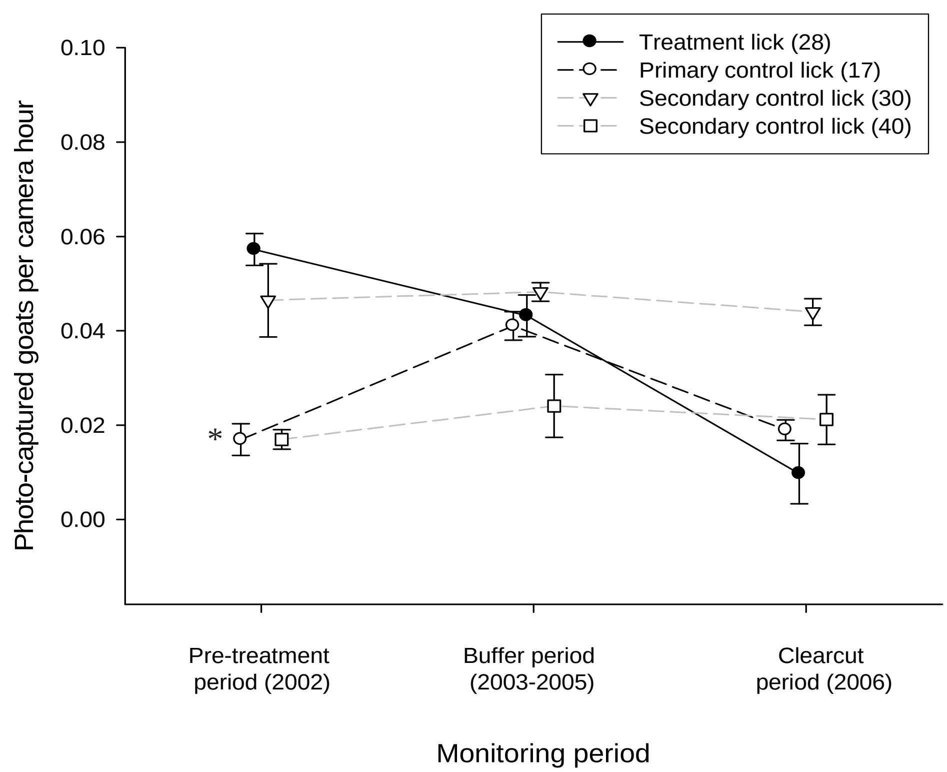

Figure 6. Number of mountain goats photo-captured per hour of camera monitoring, by treatment period, travelling down the access trails to the 4 study licks in the lower Ospika River drainage, April to November, 2002-2006. Multiple cameras at each lick were considered replicates to estimate the number ($\overline{X} \pm$ SE) of mountain goats per time period. Asterisk indicates negatively biased datum for primary control lick in 2002 (see text for explanation).

The declines in down-trail movements to the treatment and primary control licks were results of fewer goats being photo-captured at essentially all camera stations each year from 2004 to 2006 (Figure 5a and 7a). At the treatment lick, this included cameras both inside and outside the areas impacted by the treatments. Down-trail goat use at the treatment lick had declined by about 50% by 2005 and, by 2006, the decline in down-trail use averaged 94% (SE = 3%) for the 4 camera stations operational for the entire study (cameras #1 to #4) (Figure 7a). For the primary control lick, the decline in down-trail goat use from 2003 to 2005 was about 30% and, by 2006, the decline averaged 63% (SE = 2%) at the 3 camera stations (Figure 5a).

Up-trail goat use also declined notably at both the treatment lick ($\bar{x}$ = 86% decline, SE = 11%, n = 4) and primary control lick ($\bar{x}$ = 63% decline, SE = 4%, n = 3) by 2006, though there was a temporary rise in up-trail use at the treatment lick for all camera stations in 2004 (Figures 5b and 7b); camera data were negatively biased at the primary control lick for 2002 (see explanation above) so no valid comparisons could be made between 2002 and the other years.

Camera #7 at the treatment lick was not established until 2005 so data were only collected from this site for 2 years (i.e., 1 year before and 1 year after the clearcut treatment). The data indicated this trail location (located in the forest ~100 m up-trail from the clearcut treatment) was probably not impacted by the clearcut treatment (Figure 7). In fact, both down-trail and up-trail use appeared to be increasing at camera #7 after the clearcut treatment was conducted. Goat movements at camera #4, situated within the buffer area and then 155 m outside (lick side) of the clearcut treatment, appeared less impacted after the clearcut treatment (particularly for up-trail movements) than at the 3 cameras that were inside the clearcut treatment (cameras #1, #2, and #3).

The 2 camera stations on the logging road near the treatment lick photographed 3 goats using the road over 3 years of monitoring (2004-2006); the goats were photo-captured at the road station within the forested buffer (camera #6) while the buffer was still present (2 photo-captures in 2004 and 1 in 2005).

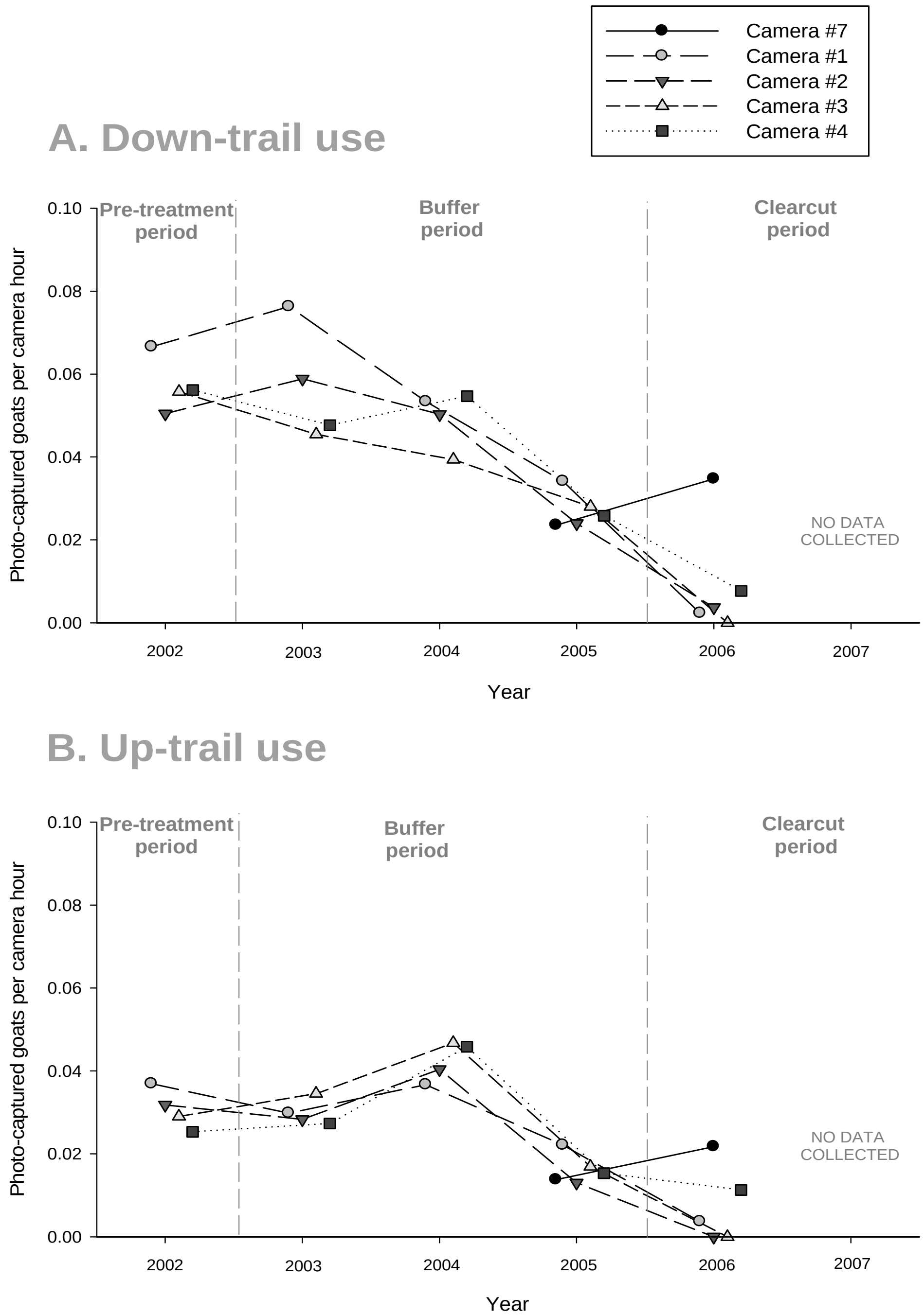

Figure 7. Number of photo-captured mountain goats, by camera station and standardized for camera-monitoring hours, using the main access trail, (A) down-trail use and (B) up-trail use, at the treatment lick (Lick 28) in the lower Ospika River drainage, April to November, 2002-2006. Camera #7 was furthest from the lick, cameras #1 to #4 were sequentially closer to the lick. Cameras #2 to #4 were impacted by the buffer treatment, whereas cameras #1 to #3 were impacted by the clearcut treatment. Camera #7 was not established until 2005.

4.1.3 Timing of Trail Use by Goats

Across all study licks and camera-monitoring years (2002-2006), mountain goats used the study trails from 11 April to 24 November (Appendix E). The majority of mountain goat use occurred between 13 June and 8 September (average of 10^{th}- and 90^{th}-percentile dates across all licks and years). The earliest date a kid was photo-captured on a study trail was 9 June, with the average earliest date being 23 June for all licks and years combined.

There were no obvious treatment-related effects on the calendar dates of down-trail use by goats accessing the treatment lick because the annual distributions of travel dates for goats visiting the treatment lick varied widely and had considerable overlap among years (Figure 8). Depending on the year, average measures (means and medians) of down-trail use to the study licks occurred primarily between mid-July and mid-August for 3 of the licks (treatment, primary control, and secondary control lick 30). The average measures for down-trail use at secondary control lick 40 were generally 1-2 weeks earlier than for the other licks.

When trail-use data for adult males, adult females, and kids were plotted by calendar date, no treatment-related effects were observed because mean dates fluctuated widely across years (Appendix F). With data combined for all licks and all years, down-trail use occurred earlier for adult males than for adult females or kids (Figure 9); core down-trail use (25^{th} to 75^{th} percentiles) occurred between 9 June and 11 July for males, 5 July to 21 August for females, and 12 July to 28 August for kids.

For all licks combined, goat down-trail use occurred on average 43 days after the annual snow-free date and 58 days after the annual leaf-flush date (Appendix G). There was no unique pattern at the treatment lick compared to the control licks for these 2 response variables. Trail-use patterns for the treatment lick appeared more similar to the secondary control licks (i.e., other goats on the east side of the drainage) than the primary control lick (west side of drainage). Days since snow free or leaf flush did not appear to predict the timing of lick use better than the calendar-date unit as the variability in the year-to-year means were similar among these variables.

There were no treatment effects on seasonal or diel use of lick trails by all goats beyond the decline in goat visits observed after 2004 (Appendix H), which was described in section 4.1.1; although we analysed data for both all goats and groups with kids, they had similar trends for both seasonal and diel periods so data were presented for the larger dataset (all goats). From a lick perspective, goat use was lowest during the late season at all licks

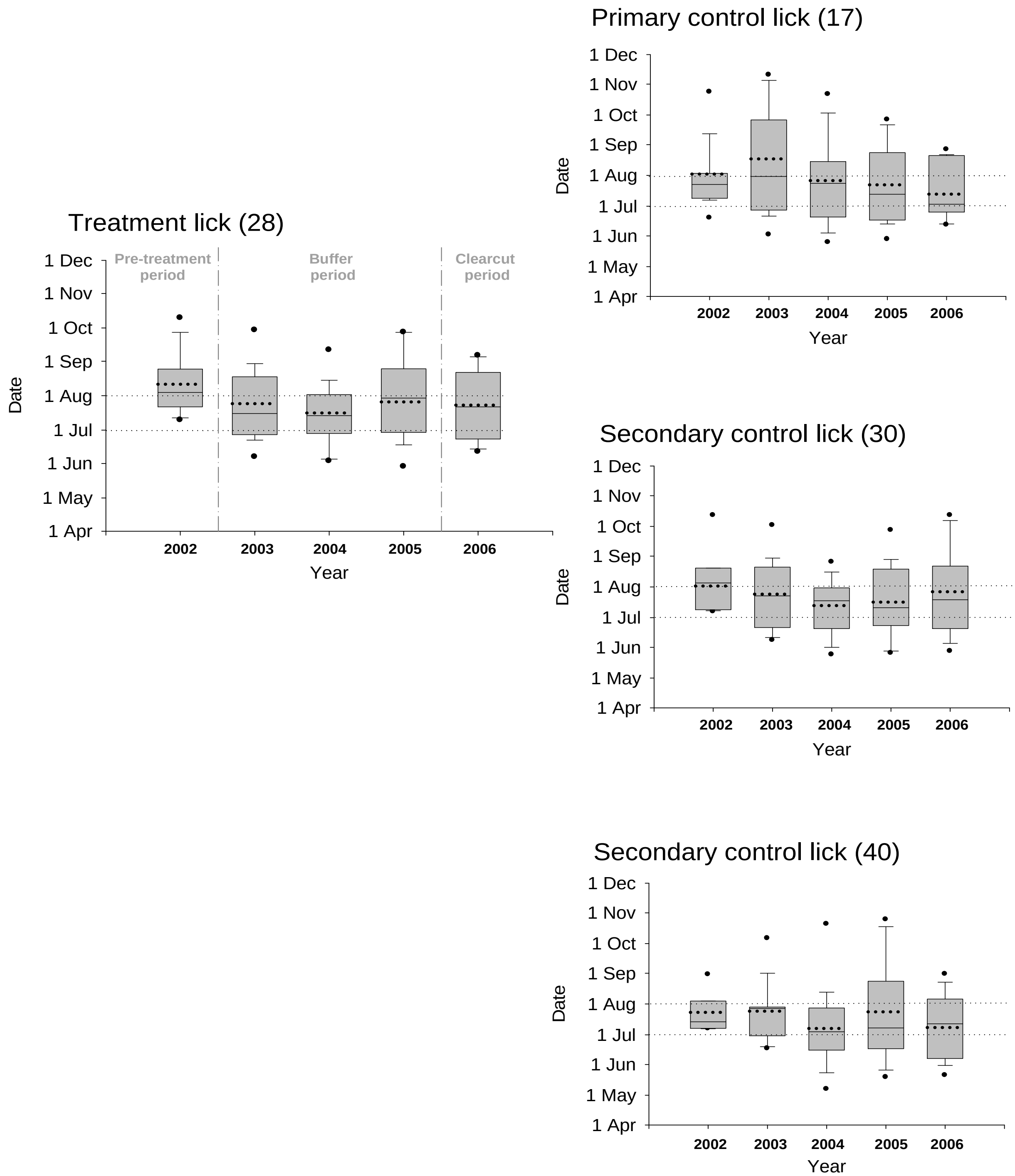

Figure 8. Annual distributions of travel dates for mountain goats photo-captured travelling down the access trails to the 4 study licks in the lower Ospika River drainage, April to November, 2002-2006. Sample unit is an individual goat (e.g., a group of 5 goats represents 5 individual records). Distributions are marked with mean (dotted) and median (solid) lines inside the box, and the 25th and 75th percentiles (box), 10th and 90th percentiles (whiskers), and 5th and 95th percentiles (points) are also identified.

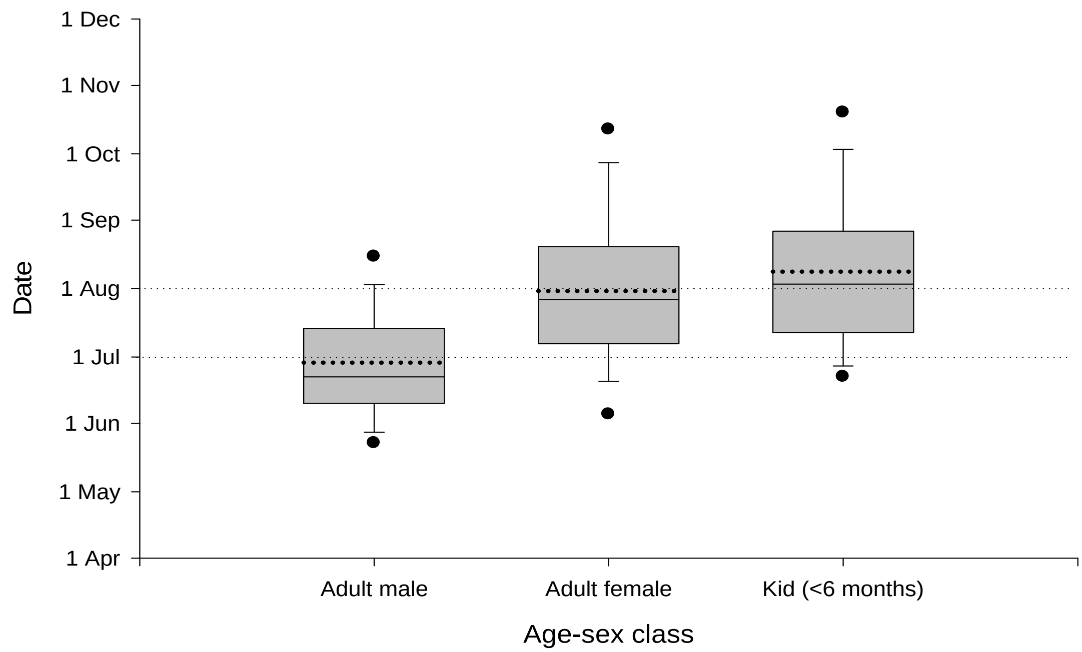

Figure 9. Distributions of dates for adult male, adult female and kid (<6 months) mountain goats photo-captured travelling down access trails to the 4 study licks in the lower Ospika River drainage, 2002-2006. Distributions are marked with mean (dotted) and median (solid) lines inside the box, and the 25th and 75th percentiles (box), 10th and 90th percentiles (whiskers), and 5th and 95th percentiles (points) are also identified.

across all years. And, although it was most pronounced at the treatment lick, goat trail use was greatest during daylight hours for all licks across all years except for secondary control lick 40, where crepuscular movements were usually most common.

We also investigated the effects of season on the diel timing of trail use (years and up-trail and down-trail movements combined) by all goats, and by goat groups with kids, at all sites (Appendix I). For all goats, there were similar patterns across seasons in the diel timing of trail use at the treatment and control licks, except for night-time use. Night-time trail use was greatest during the mid season at the treatment trail, but it declined as seasons advanced at all 3 control trails. Night-time trail use at the treatment lick was a much smaller proportion of the overall trail use compared to the control licks. Upon further investigation, other than trends observed earlier (i.e., declining trail use at the treatment lick after 2004 and down-trail use greater than up-trail use), there was no trend in night-time use unique to the treatment lick based on year, treatment period, or trail-use direction. For goat groups with kids, no disparate trends in trail use occurred between the treatment lick and the control licks as trail use was greatest in the mid season for all diel periods and at all trails, and daytime use was greater than or equal to use during the crepuscular and night-time periods across all seasons and trails.

When we examined the relationship between trail travel direction and diel periods, the data indicated goats travelled most often during the daytime for both travel directions across all licks, except for up-trail use at secondary control lick 40 where use was greatest during the crepuscular period (Appendix J). These same relationships were also observed for goat groups with kids.

4.1.4 Trail-use Behaviour by Goats

The largest groups recorded travelling to the licks on the study trails were 32 goats at the treatment lick, 28 goats at the primary control lick, 33 goats at secondary control lick 30, and 37 goats at secondary control lick 40. The largest groups travelling away from the licks on the study trails were 17 goats at the treatment lick, 17 goats at the primary control lick, 39 goats at secondary control lick 30, and 23 goats at secondary control lick 40.

For all licks across all years, the typical group size for goats travelling to the licks was consistently larger than for goats travelling away and, in general, typical groups sizes ranged between 5 and 15 goats (Appendix K). For down-trail movements, typical group size declined at the treatment lick after the buffer treatment occurred, but the decline was not unique when compared to the control licks. The typical group size for goats travelling to the primary control lick increased by about 60% from 2004 to 2006. The typical group size of goats travelling away from the treatment and primary control licks remained fairly constant across all years. Both secondary control licks had no trend across the study years.

There was no effect of year on trail travel rate by all goats ($F = 1.57$, $df = 4$, $P = 0.183$) or by goat groups with kids ($F = 1.52$, $df = 4$, $P = 0.202$,) at the treatment lick. When travel rates were plotted across years, the travel rate at the treatment lick was slightly higher in 2004 (Appendix L). Whereas the travel rate, for both directions, appeared to decline at the treatment lick after the clearcut treatment (2006), however sample sizes were small.

4.1.5 Failed Lick Visits by Goats

On a few occasions goats were photo-captured walking through 1 or more camera stations and, soon after, photo-captured either walking or running back up the trail. Due to difficulties in identifying individual non-tagged goats (e.g., observing individuals from the other side of their body) and only having data when they passed through the camera stations, we could not determine the frequency of these events or whether the same goats returned shortly thereafter.

On 2 occasions, though, we had camera data and field observations that indicated failed lick visits. In April 2003 (i.e., beginning of the first lick-use season after the buffer treatment), 3 adult goats travelled down the trail to the treatment lick but, when they reached the 15-m road right-of-way that bisected the forested buffer, they stopped. The goats moved back and forth along ~30 m of the forested edge before they walked back up the trail ~15 minutes later. For the second failed visit, at least 6 goats travelled down the trail to the lick at secondary control lick 30 but, when they met (i.e., came within 10 m) our field crew at the “in-lick” camera station, the goats turned around and travelled back to their escape terrain. They went back through all 3 camera stations, at a walking pace, and their travel time was the same as a normal movement. Goats came down the trail again within a few hours but it was unknown whether they were the same goats.

4.2 Lick and Trail Use by Radio-collared Goats

We captured, radio-collared, and monitored 29 mountain goats[3] in the lower Ospika River drainage from March 2002 to November 2007 (Appendix M). Eighteen goats (12 females, 6 males) were captured on the east side of the drainage and 11 goats (6 females, 5 males) were captured on the west side. All but 2 radio-collared goats (1 female, 1 male) used a study lick. Both goats that did not use a study lick were monitored for ≥2 years. No radio-collared goats were known to traverse the Ospika River based on all data sources, therefore east and west sub-populations appeared distinct.

Over the study term, we monitored 11 goats that used the primary control lick, 13 goats that used the treatment lick (L28-only goats: n = 9; L28-30-40 goats: n = 4), and 3 goats that solely used the 2 secondary control licks. All goats that used the primary control lick were captured between Morrisey Creek and Herchmer Pass, except for 1 goat that was captured 15 km northwest of Herchmer Pass. L28-only goats were captured on alpine ridges between Stevenson and Aley creeks. Goats from the 2 other goat types (L28-30-40 and L30-40 goats) were both captured on alpine ridges between Aley Creek and Mt. Lady Laurier.

Radio-collared goats appeared representative of the goat population using the study licks as radio-collared goats exhibited similar trail-use characteristics as goats photo-captured at camera-monitoring stations; based on their similarities in annual, seasonal, and diel timing of trail use, and their greater trail use for down-trail movementsthan for up-trail movements. For all licks and years combined, the average date that radio-collared goats used the licks was 28 July (SE = 1.5, n = 547; median = 26 Jul; range = 23 Apr to 12 Nov); based on the camera data, the average date of down-trail movements for all goats was 28 July (SE = 0.7, n = 3,026 goats; median = 24 Jul; range = 11 Apr to 24 Nov). The sample of radio-collared goats using the treatment and primary control licks were different based on sex as

[3] Four other goats (3 females, 1 male) were captured and radio collared at the beginning of the project (March 2002) but they were not considered a study animal because they died before any radio-collared goats used the study licks.

females on average represented 56% (SE = 6%, n = 6 years) of the radio-collared goats at the primary control lick whereas L28-only goats were 85% female (SE = 5%, n = 6 years) and the 4 L28-30-40 goats were all female. Two of the 3 L30-40 goats were female. There was no obvious differences in female reproductive status (i.e., with or without a kid) or the average monitoring term per goat (Lick 17: $\bar{x}$ = 3.9 yrs/goat, SE = 0.5, n = 6 years; Lick 28: $\bar{x}$ = 3.4 yrs/goat, SE = 0.6, n = 6 years) for radio-collared goats using the treatment and primary control licks.

4.2.1 Number of Lick Visits by Radio-Collared Goats

Radio-collared goats visited the study licks 703 times during the 6 years of monitoring: 169 visits at Lick 17, 116 visits at Lick 28, 148 visits at Lick 30 and 270 visits at Lick 40. For the 27 radio-collared goats that we recorded using study licks, between 5 and 11 goats used each lick each year. Forty six visits by 10 goats were excluded from our analyses because the goats had been captured, recaptured, or died during a lick-use season. The year most impacted by these omitted data was 2005, when 7 goats (4 from the treatment lick and 3 from the primary control lick) and their 25 lick visits were excluded.

For individuals monitored an entire lick-use season, goats visited study licks at least 2 times each year for 98 of the 100 lick-use seasons; for the 2 cases when multiple visits did not occur, goats had 1 visit/year. The highest visitation rate for an individual goat was 30 visits in a year (for a L30-40 goat), with 26 visits occurring at Lick 40. Annual visit rates were typically highest at Lick 40.

The number of lick visits available from goats with complete data was 657 (Table 1). However, since our analyses focused on the treatment and primary control licks, the number of lick visits available for the majority of our analyses was 257. Visits to the treatment and primary control licks were from 3 goat types (i.e., Lick 17, L28-only and L28-30-40 goats), which represented between 5 and 10 radio-collared goats each year and between 12 and 38 visits/year at each of these 2 licks.

Table 1. Number of visits, by lick and year, used to analyse radio-collared mountain goat use of the 4 study mineral-lick complexes in the lower Ospika River drainage, April to November, 2002-2007.

		2002		2003		2004		2005		2006		2007		Total
Lick	Lick type	Visits	Goats	Visits	Goats	Visits	Goats	Visits	Goats	Visits	Goats	Visits	Goats	visits
Lick 17	Primary control	25	6	38	7	37	9	27	6	15	6	14	5	156
Lick 28	Treatment	19	7	21	8	19	7	13	7	17	10	12	10	101
Lick 30	Secondary control	16	7	25	7	23	6	24	6	25	6	26	6	139
Lick 40	Secondary control	30	7	54	7	57	6	61	6	18	6	41	6	261
Total		90	16[a]	138	18[a]	136	18[a]	125	15[a]	75	16[a]	93	17[a]	657

[a] The total number of goats is less than the sum of the individual values because some goats used multiple licks in a given year (i.e., L28-30-40 and L30-40 goats).

For days when radio-collared goats travelled to or from a lick, about one-third of these days had multiple (2 to 7) radio-collared goats travelling (in the same direction) on the same day; most occurrences involved radio-collared goats being in the same movement group, but some goats were many hours apart. The frequency of same-day travel by radio-collared goats was similar among licks from 2002 to 2004 but, from 2005 to 2007, the treatment lick had a greater frequency of radio-collared goats travelling together; this later situation was likely due to the greater number of radio-collared goats being monitored during those years (4-5 more goats per year). Nonetheless, no 2 radio-collared goats travelled together for all their lick visits in a given year.

There was no treatment effect (P = 0.851) on the mean number of lick visits per radio-collared goat at the treatment lick, but period (P = 0.015) and goat type (P<0.001) did have individual effects (Appendix N). There was a period effect because goats using the treatment and primary control licks both had, on average, 47% fewer lick visits per goat during the clearcut period than during the pre-treatment period, and 44% fewer lick visits per goat during the clearcut period than during the buffer period (Appendix O). Based on radio-collared goats, the decline in goat visits to the treatment lick by L28-only goats started in 2005 (3rd year after buffer treatment [1 year prior to clearcut treatment]) whereas the decline in goat visits to the primary control lick started in 2006 (1st year after clearcut treatment at treatment lick) (Figure 10). There was no difference in the mean number of lick visits for radio-collared goats that exclusively used the treatment (i.e., L28-only goats) and primary control licks, but these 2 goat types had approximately 6 times more lick visits than L28-30-40 goats had at the treatment lick (Figure 10, Appendix O). This was not unforeseen as one would expect a goat that used only 1 lick to have more visits at that lick than a goat that visited 2 additional licks.

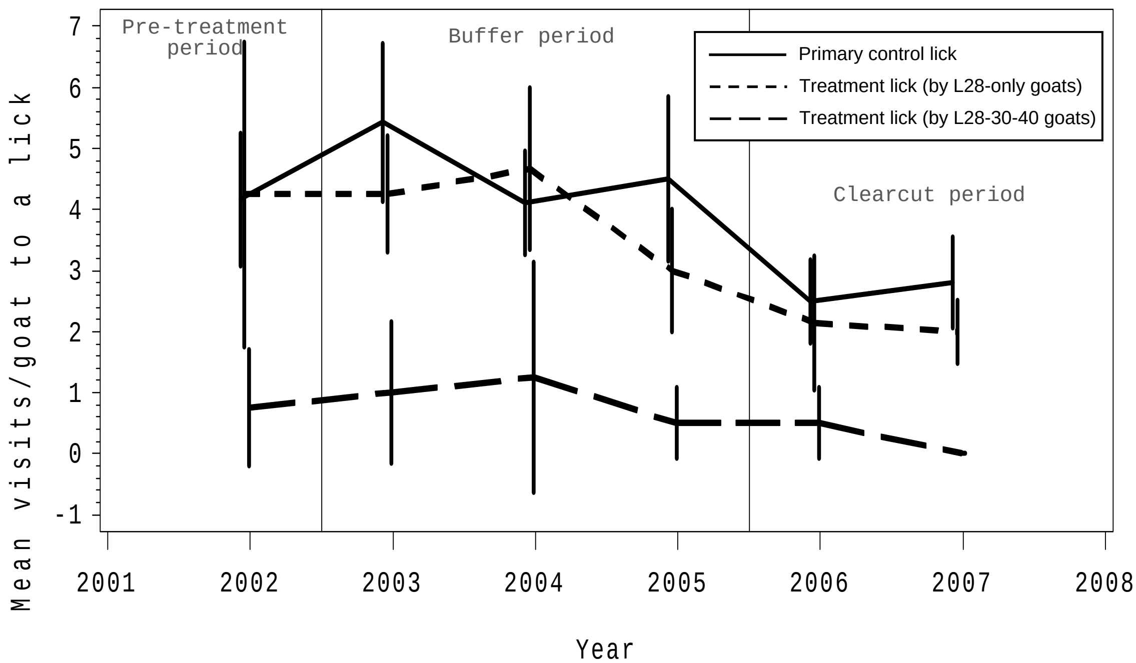

Figure 10. Mean number of lick visits per radio-collared mountain goat, by goat type, at the treatment (Lick 28) and primary control (Lick 17) licks in the lower Ospika River drainage, 2002-2007. Error bars for means are 95% confidence limits.

4.2.2 Duration of Lick Visits by Radio-Collared Goats

The duration of a lick visit by radio-collared goats at the 4 study licks varied from an average of 6.8 hrs/visit at the primary control lick to 43.3 hrs/visit at the treatment lick (Table 2). The longest visit was almost 16 days (376 hrs) but only 1.4% (10 visits) were longer than 4 days: 1 visit at the treatment lick, 6 visits at secondary control lick 30, and 3 visits at secondary control lick 40.

There was no treatment effect (P = 0.204) on the mean time that goats spent per visit at the treatment lick but goat type had an individual effect (P<0.001) (Appendix N). Goats that used the treatment lick spent, on average, about 2.5 times more time at the lick than goats that used the primary control lick (Figure 11, Appendix O). Visits by L28-30-40 goats to the treatment lick in 2006 were based on 2 visits, involving 2 goats travelling to and from the lick together (i.e., no variance), so these 2006 data have low interpretative value. Period had no individual effect on the mean visit time (P = 0.193).

Table 2. Duration of lick visits by radio-collared mountain goats using the 4 study mineral-lick complexes in the lower Ospika River drainage, April to November, 2002-2007.

Lick	Lick type	n[a] (visits)	Duration of lick visits (hrs) Mean	SE	Median	Range	Total time (hrs)
Lick 17	Primary control	169	15.4	1.2	8.4	0.6 - 83.8	2,603
Lick 28	Treatment	115	43.3	18.2	43.4	11.6 - 105.0	4,984
Lick 30	Secondary control	148	31.5	44.9	21.0	0.9 - 376.3	4,664
Lick 40	Secondary control	266	6.8	14.6	3.2	0.2 - 144.7	1,801
	Overall	698	20.1	28.5	9.1	0.2 - 376.3	14,052

[a] Includes all visits that had a defined start and end time to the lick visit.

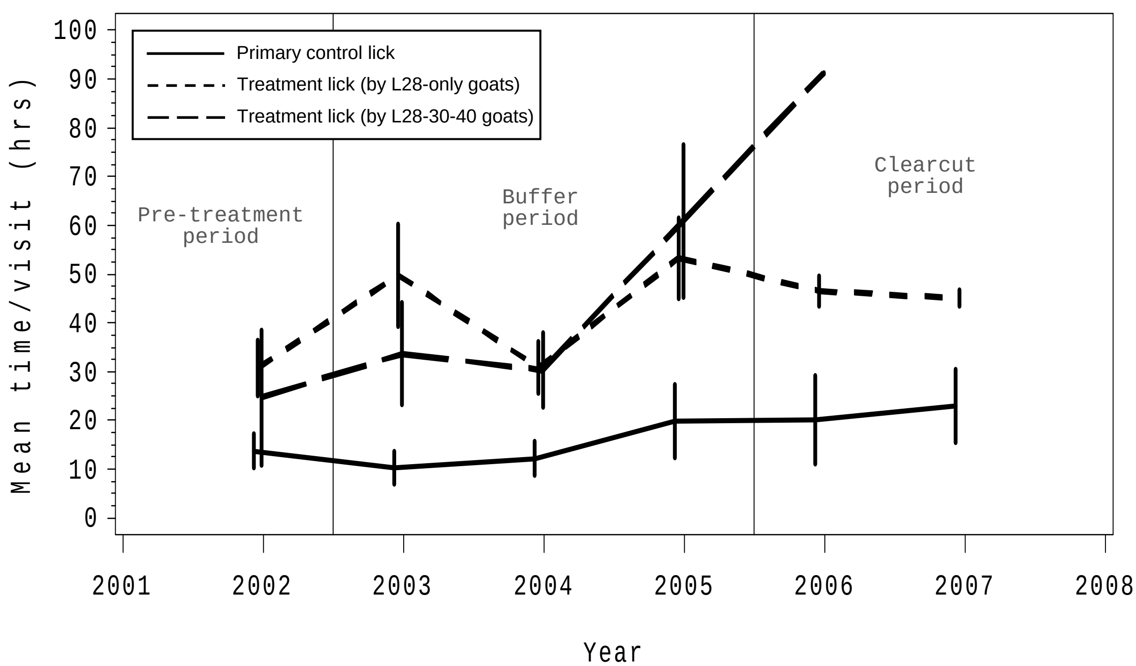

Figure 11. Mean time spent per visit by radio-collared mountain goats, by goat type, at the primary control lick (Lick 17) and the treatment lick (Lick 28) in the lower Ospika River drainage, 2002-2007. Error bars for means are 95% confidence limits.

There was no treatment effect on the average time interval between lick visits by L28-only goats at the treatment lick before and after the treatments (F = 1.73, df = 5, *P* = 0.14) (Table 3). There was also no difference in the average time interval between lick visits during the study by goats using the primary control lick (F = 0.63, df = 5, *P* = 0.68). There was a difference in the average time interval between lick visits for goats that exclusively used these 2 licks (t = 2.08, df = 170, *P* = 0.04). On average, intervals between lick visits were about 4 days shorter for goats using the treatment lick than goats using the primary control lick (Table 3).

For the 6-year study, the total time spent by radio-collared goats (n = 27) at the 4 study licks ranged from 1,801 hrs at secondary control lick 40 to 4,984 hrs at the treatment lick (Table 2). Individually, radio-collared goats that exclusively used the treatment lick (n = 9 L28-only goats) spent between 16 and 276 hrs annually at the treatment lick, whereas radio-collared goats spent between 7 and 140 hrs annually at the primary control lick (n = 11 goats).

Table 3. Time intervals between lick visits, by year, for radio-collared mountain goats exclusively using the treatment and primary control licks in the lower Ospika River drainage, 2002-2007.

Lick and goat type	Treatment period (year)	No. of goats	*n* (intervals)	Interval between lick visits (days) Mean	SE	Range
Primary control lick						
L17 goats	Pre-treatment period (2002)	6	19	14.0	2.9	1.5 - 41.8
	Buffer period (2003)	7	30	18.7	2.8	0.8 - 59.9
	Buffer period (2004)	9	27	16.5	2.5	0.2 - 49.7
	Buffer period (2005)	6	21	18.9	3.1	0.9 - 58.5
	Clearcut period (2006)	6	9	22.8	7.1	5.4 - 62.6
	Clearcut period (2007)	5	9	20.2	2.5	11.7 - 34.3
	Overall		115	17.9	1.3	0.2 - 62.6
Treatment lick						
L28-only goats	Pre-treatment period (2002)	3	13	16.0	3.8	4.0 - 52.4
	Buffer period (2003)	4	12	13.0	2.4	1.0 - 32.2
	Buffer period (2004)	3	11	7.2	0.6	3.1 - 10.0
	Buffer period (2005)	3	8	16.2	2.4	5.0 - 28.9
	Clearcut period (2006)	4	7	12.9	3.7	3.6 - 31.9
	Clearcut period (2007)	5	6	18.2	2.9	5.2 - 23.1
	Overall		57	13.6	1.2	1.0 - 52.4

There was no treatment effect (*P* = 0.125) on the total time spent by radio-collared goats that used the treatment licks (Appendix N). However, there was an individual effect of goat type (*P* = 0.002) (Figure 12; Appendix O). Goats that exclusively used the treatment lick (L28-only goats) consistently spent twice as much time annually at the treatment lick than L28-30-40 goats. This difference was fully attributable to the fact that L28-30-40 goats had fewer visits to the treatment lick (see section 4.2.1). L28-only goats also spent more than twice as much time annually at the treatment lick than goats did at the primary control lick.

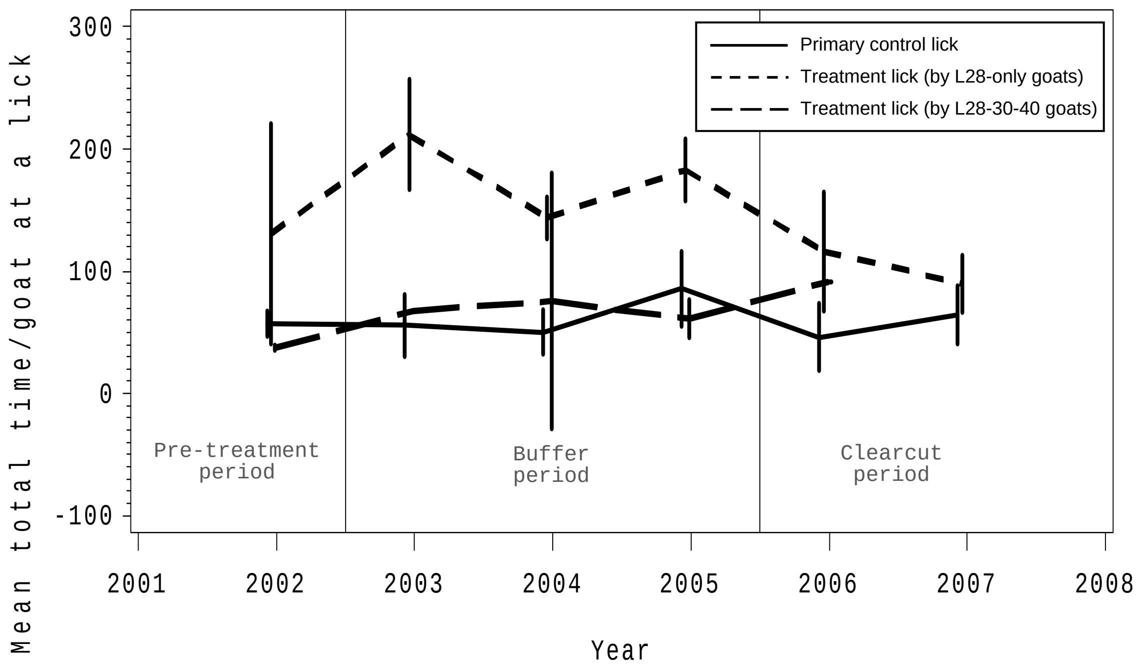

Figure 12. Mean total time spent by radio-collared mountain goats, by goat type, at the treatment (Lick 28) and primary control (Lick 17) licks in the lower Ospika River drainage, 2002-2007. Error bars for means are 95% confidence limits.

4.2.3 Displacement Lick Use by Radio-collared Goats Using Treatment Lick

In addition to investigating changes in the number and duration of lick visits by radio-collared goats at the treatment lick, we also investigated whether treatment-lick goats shifted their lick use to the secondary control licks due to the treatments. L28-only goats, which were all captured south of Aley Creek, did not shift any use to the secondary control licks; 7 of these 9 goats were monitored for ≥3 years (i.e., they were monitored from 1 year before a treatment and ≥2 years after a treatment). As a result, only data from the 4 L28-30-40 goats were used in our analysis of displacement lick use. These goats were all captured north of Aley Creek, all were female, and all were monitored for the entire 6-year study period.

There was no significant change in the proportion of lick visits per goat for the 2 lick groupings (treatment lick and secondary control licks) (P = 0.290; Appendix N). However, when visit data were pooled for the 4 goats, lick use after 2004 (2 years after the buffer treatment) appeared to decline at the treatment lick and increase at the secondary control licks (Figure 13). No visits occurred at the treatment lick for these goats in the final year of the study; for the previous 5 years, 2 of the 4 L28-30-40 goats visited the treatment lick at least once each year. The increase in use at the secondary control licks was primarily due to increased use of Lick 30, the closest alternative lick to the treatment lick.

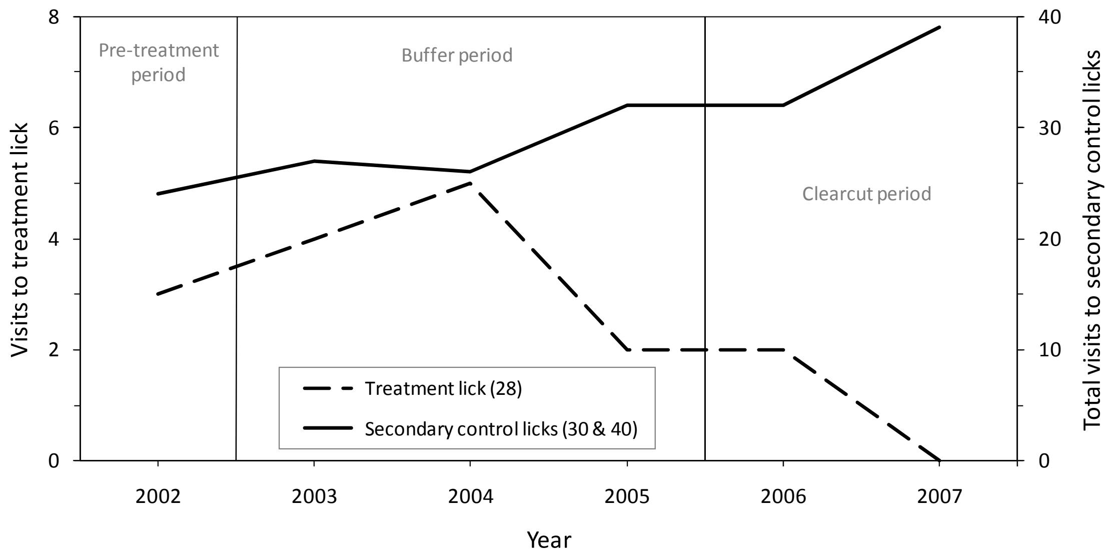

Figure 13. Annual visits to the treatment lick (Lick 28) and secondary control licks (Licks 30 and 40 combined) by 4 radio-collared L28-30-40 mountain goats, lower Ospika River drainage, 2002-2007. These radio-collared goats were all female and all were monitored for all 6 years.

4.2.4 Trail-use Behaviour by Radio-collared Goats

For each monitoring year, except 2006 at the treatment lick, radio-collared goats used the study trail (i.e., on or near the trail) >80% of the time when they travelled to the treatment and primary control licks (Figure 14a); treatment-lick data for L28-30-40 goats were excluded due to small sample sizes. At the treatment lick, goats used the trail 53% of the time when travelling to the lick in 2006 (first year after clearcut treatment). These goats returned to having >80% of their down-trail movements on or near the trail in 2007.

There was no treatment effect on trail fidelity when goats where travelling to the licks (P = 0.998) (Appendix N). Similarly, no individual effects occurred for goat type (P = 1.000), period (P = 1.000), or year within a period (P = 0.100). Data from 2003 were

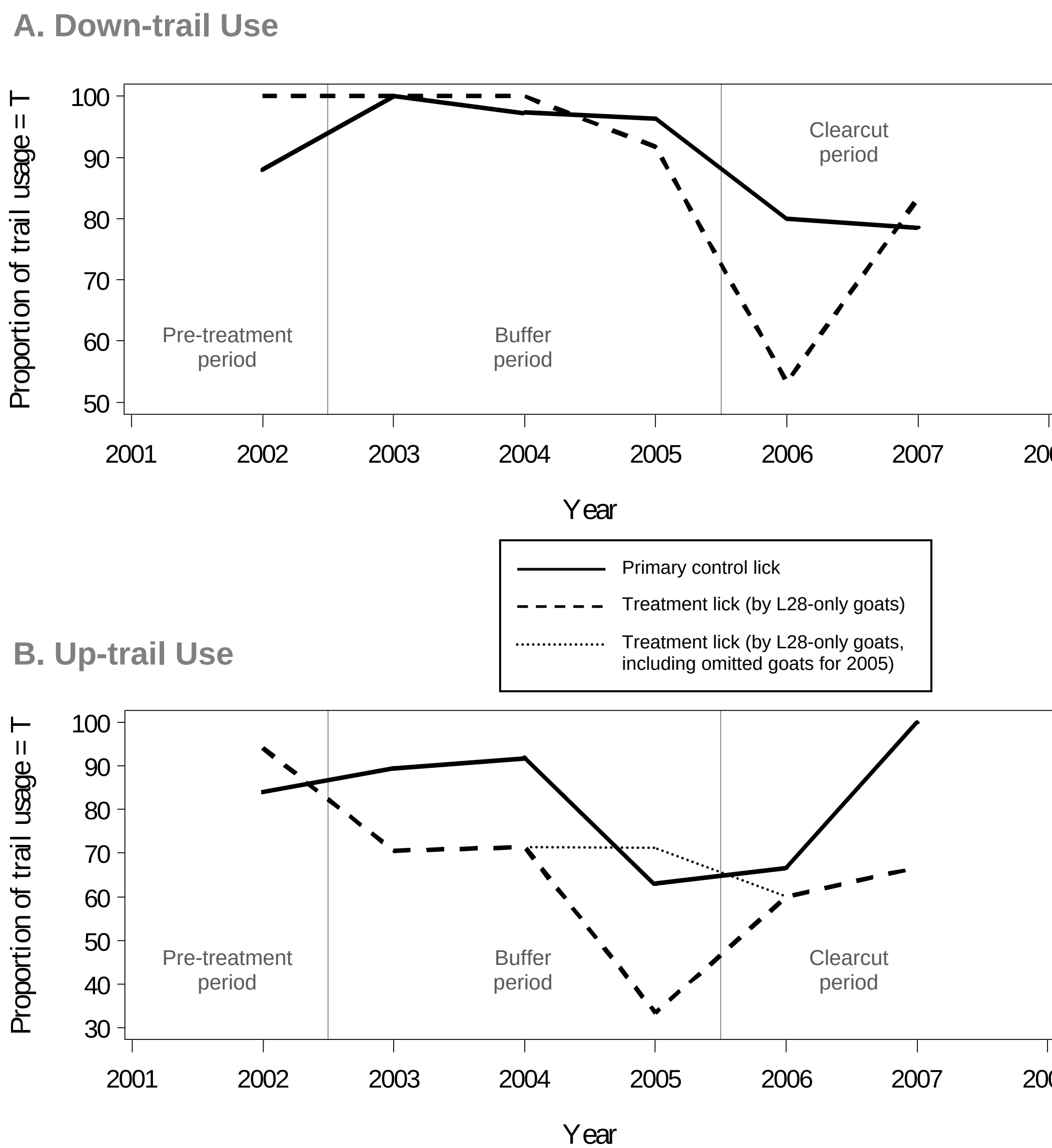

Figure 14. Trail-use patterns (on/near main access trail [T] vs. different route) of radio-collared mountain goats, by goat type, using the study trails, (A) down-trail use and (B) up-trail use, at the treatment (Lick 28) and primary control (Lick 17) licks in the lower Ospika River drainage, 2002-2007.

excluded from these analyses because down-trail movements for all goats were on the study trails (i.e., no variance in use), so there was no information for the analysis.

There were no treatment (*P* = 0.400) or individual goat-type (*P* = 0.672) and period (*P* = 0.169) effects on up-trail movements at the treatment lick, but there was a year effect within the buffer period (*P*<0.001) (Appendix N). In 2005, up-trail movements at both the treatment and primary control licks were significantly lower than the other 2 years in the buffer period. Several goats were omitted from our analysis in 2005 because they were captured or died during the lick-use season. The exclusion of these data had the greatest effect on L28-only goats as their sample size fell from 24 lick visits to 11 visits and, more importantly, the number of goats fell from 7 goats to 3 goats. As such, each goat had a potentially greater impact on the proportion of trail use. When data from the omitted goats were included for both the treatment and primary control licks and for both trail travel directions, the only value that changed by >6% was for up-trail movements by L28-only goats, which changed by 35%. When up-trail movements for L28-only goats included these previously omitted 2005 data, there was no year effect within the buffer period (Figure 14b).

4.2.5 Failed Lick Visits by Radio-collared Goats

There were 17 occasions when 12 different radio-collared goats (7 females, 5 males) did not successfully reach Licks 17, 28 and 30 once they had initiated a movement. Four female goats had 2 to 3 failed visits during the study period, but no goats had >1 failed visit in the same year.

Four failed visits were classed as interrupted because the radio-collared goat made a successful return visit to the lick within a few hours (3 to 11 hours). Twelve events were classed as aborted because the goat did not make a return visit to the same lick, or another lick, for ≥2 days; in 2 cases, the goat did not return for the rest of the season. The remaining failed visit involved a mortality.

Nine (53%) of the failed lick visits occurred when goats were travelling to the treatment lick and 4 failed visits occurred at both the primary control lick and secondary control lick 30. The 4 visits at the primary control lick were all aborted visits whereas failed visits at secondary control lick 30 included 1 aborted and 3 interrupted visits. Overall, failed lick visits represented 7.8% of the total lick visits by radio-collared goats at the treatment lick and 2.4-2.7% of the total lick visits at the 2 control licks.

All 9 failed visits at the treatment lick (1 interrupted, 7 aborted, 1 mortality) involved L28-only goats (Appendix P). All failed visits occurred after the first treatment had been conducted at the treatment lick, and 8 of these 9 abandoned visits occurred at or adjacent to key features resulting from the treatments: road right-of-way in the forest buffer and start of clearcut-treatment area (i.e., site that was reached first when goats travelled to the lick). The time interval before the goats returned to the treatment lick increased with each year for these aborted visits. The 2 aborted visits in the final year of the study involved 2 radio-collared goats travelling together (and possibly with other goats) but they did not return to the lick that year; this event occurred in mid-August 2007.

For the 4 aborted visits at the primary control lick, 1 occurred each year from 2003 to 2006. The goats all abandoned their visit at the same location on the trail, where the trail entered the creek draw). This area typically had a fair bit of noise present due to the rapids in the creek; the site was <500 m from their subalpine escape terrain and ~1.5 km from the lick. The 3 radio-collared males involved returned to the primary control lick between 2 and 13 days later, whereas the lone radio-collared female returned in 31 days later.

The only aborted visit at secondary control lick 30 occurred in 2002 (pre-treatment period). The radio-collared goat, and at least 12 non-marked goats, started towards the lick but they were disturbed and the radio-collared goat and others quickly ran back to the Sunniva escape terrain. The radio-collared goat's next lick visit was to the treatment lick 2 days later (i.e., she did not return to secondary control lick 30).

Even with excluding the 2 goats that did not return to a lick following their aborted visit at the treatment lick, the elapsed time between a goat's aborted visit and its next lick visit was >1.6 times longer at the treatment lick than at the control licks (Licks 17 and 30): on average, the next visit occurred >23 days later (SE = 6, n = 5) at the treatment lick and 14 days later (SE = 6, n = 4) at the primary control lick.

4.2.6 Power Analyses of Select Response Variables

Using the data for radio-collared goats, we conducted power analyses on the 2 response variables that we believe best described lick use (number of lick visits per goat) and trail use (proportion of down-trail movements on or near trail) by mountain goats during the study. The power analyses were based on parameter estimates exhibited by our study data. Therefore, the baseline scenario included annual monitoring of 6 goats from the primary control lick (L17 goats), 6 goats that exclusively used the treatment lick (L28-only goats), and 4 goats that used the treatment lick as well as the secondary control licks (L28-30-40 goats). Our study data indicated there was an overlying decline (47%) in lick use at both the primary control lick and the treatment lick over the study period (see section 4.2.1) so a 40% decline in lick visits was used in the power study. Consequently, the average number of lick visits per goat by L17 and L28-only goats was 5 visits/year at the start of the study but declined to 3 visits/year by the end of our power study. Similarly, lick visits at the treatment lick by L28-30-40 goats started at 1 visit/year and declined to 0.6 visits/year by the end of the power study. Therefore, if a treatment effect was to occur at the treatment lick, the decline would have to be additional to this overlying decline.

Results of our lick-use (visits/goat) power study indicated we would need a treatment-effect decline of >30% after the buffer treatment, followed by an additional >30% decline (of the original level) after the clearcut treatment, to be 95% confident we could detect a treatment effect with our dataset (Appendix Q). Further analysis indicated we would need a sample size ~5-times larger than what our study possessed to detect an overall decline of 40% after both treatments; a 10-fold increase in sample size indicated a power of <50% to detect an overall decline of 20%.

Results of our trail-use power analysis (i.e., changes in the percentage of down-trail movement on or near trail) indicated that trail use would have to decline by ≥40% after both treatments (i.e., an 80% decline by the end of the study) to be 95% confident that an effect would be detected with the study data (Appendix R). The analysis also estimated that a 5-fold increase in sample size would only be able to detect an overall decline of ≥25%.

4.3 RANGE USE AND MOVEMENT PATTERNS OF RADIO-COLLARED GOATS

Over 1,800 aerial-telemetry locations were collected on the 29 radio-collared mountain goats monitored from March 2002 to November 2007 (Appendix M). All L28-only goats (6 females, 3 males) were monitored for >1 year, and all goats, but 1, exclusively used the same small (~37 km^2) alpine area between Frank Creek and Aley Creek for the term of the study (Figure 15). Because these goats remained in this one area, there were no notable changes in the size, shape, or location of any of their seasonal ranges. Consequently, no treatment effects were detected. The average multi-annual home range size for individual L28-only goats was 24 km^2 for the core-lick season (range 13-35 km^2) and 11 km^2 for the winter season (range: 3-25 km^2) (Table 4). The lone L28-only goat that used high-elevation areas outside the Frank-Aley area involved an adult male that was monitored for the first 2 years of the study. He primarily used the Frank-Aley area but he also used an area between Aley and Sunniva Creeks during the core-lick and non-winter seasons. He used the Aley-Sunniva area during both monitoring years (i.e., 3 locations each for before and after the buffer treatment) so there was no evidence of a treatment effect.

The winter multi-year composite range for L28-only goats was the same size as their core-lick high-elevation range (28 km^2 each; Table 5), both of which were slightly smaller than the Frank-Aley alpine area (Figure 15). The multi-year composite range for winter was smaller than the core-lick and non-winter ranges (25% and 43%, respectively; Table 5), but the only difference was these later ranges included movements to the treatment lick (Figure 15).

No treatment effect on range use was observed for the 4 female L28-30-40 goats as they showed no obvious changes in their seasonal range use during the study. Their multi-annual home ranges for the core-lick season were fairly constant across years (i.e., standard deviation was 17% of mean; Table 4). Winter ranges for L28-30-40 goats were more

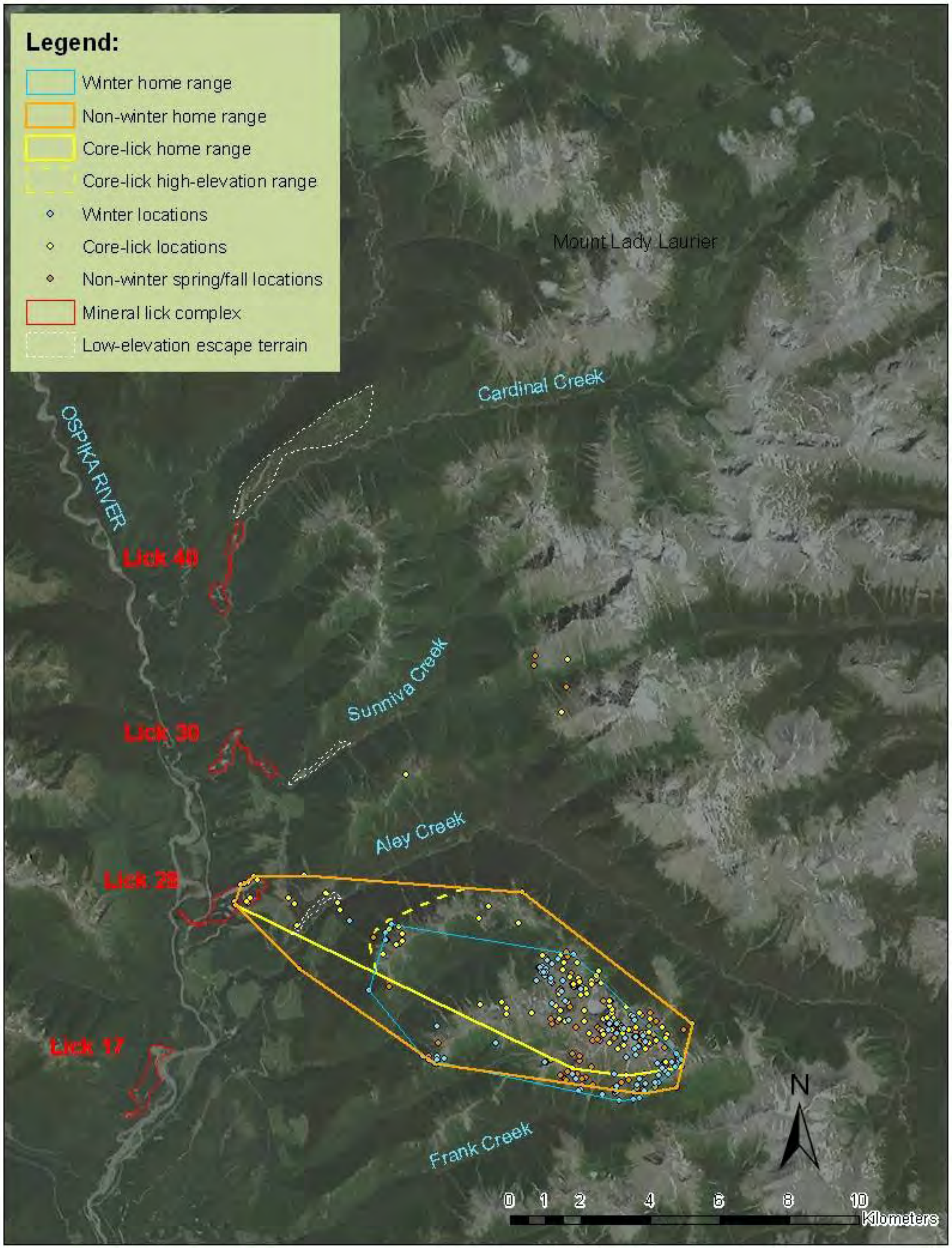

Figure 15. Telemetry locations and multi-year composite seasonal MCP (winter [Dec-Mar], non-winter [Apr-Nov], and core-lick [Jun-Sep]) and core-lick high-elevation home ranges for 9 radio-collared mountain goats (L28-only goats; 6 females, 3 males) that exclusively used the treatment mineral-lick complex (Lick 28) in the lower Ospika River drainage, March 2002 to December 2007. Six locations were excluded from the composite ranges (see text for explanation).

Table 4. Mean core-lick (Jun-Sep) and winter (Dec-Mar) MCP ranges, by goat type, for radio-collared mountain goats that used the primary control and treatment licks in the lower Ospika River drainage, March 2002 to December 2007.

	Core-lick range (km²)					Winter range (km²)				
				Range					Range	
Goat type (sub-type)	Mean	SD	n	Min	Max	Mean	SD	n	Min	Max
L17 goats (all except M11 and M32)	46	26	9	22	110	12	15	9	1	50
L17 goats (only M11 and M32)	127	44	2	96	159	96	117	2	13	179
L28-only goats	24	7	9	13	35	11	9	7	3	25
L28-30-40 goats	124	17	4	99	137	22	17	4	3	44

Table 5. Multi-year composite seasonal (winter [Dec-Mar], non-winter [Apr-Nov], and core-lick [Jun-Sep]) MCP and core-lick high-elevation home ranges, and travel distances, for radio-collared mountain goats that used the primary control and treatment licks in the lower Ospika River drainage, March 2002 to December 2007.

Goat type (sub-type)	Multi-year composite range	Area (km²)
L17 goats (all except M11 and M32)	Winter	88
	Non-winter	153
	Core-lick	101
	Core-lick high-elevation	103
L17 goats (only M11 and M32)	Winter	214
	Non-winter	427
	Core-lick	184
	Core-lick high-elevation	174
L28-only goats	Winter	28
	Non-winter	49
	Core-lick	37
	Core-lick high-elevation	28
L28-30-40 goats	Winter	37
	Non-winter	170
	Core-lick	161
	Core-lick high-elevation	88

variable, ranging from 3 to 44 km^2. Range use for the L28-30-40 goats were sometimes quite different in size and shape from one another, but the alpine areas they used stayed essentially the same. The difference between their range use was mainly due to 1 of the 3 study licks not being used in a particular year. Their multi-year composite home ranges extended from the 3 eastern study licks eastward to the headwaters of Sunniva Creek and the ridge south of Mt. Lady Laurier (Figure 16). The winter range for L28-30-40 goats (37 km^2) was confined to the high-elevation areas in the eastern portion of their range. Their winter range was 42% of their core-lick high-elevation range and only 22% of their core-lick and non-winter multi-year composite ranges (Table 5).

The winter multi-year composite range for L28-30-40 goats was 1.3 times larger than the winter range for L28-only goats, whereas their other 3 ranges (non-winter, core-lick, and core-lick high-elevation) were 3-4 times larger than the same range for L28-only goats (Table 5). L30-40 goats used the same seasonal high-elevation areas between Sunniva Creek and Mt. Lady Laurier as the L28-30-40 goats but no individual or composite MCP ranges were calculated for L30-40 goats due to few data.

For goats using the primary control lick (6 females, 5 males), we identified 2 different groups based on their range use. The main group, which included all goats but 2 males, used the high-elevation range between Morrisey Creek and just north of Herchmer Pass. Multi-annual seasonal home ranges for individuals in this main group averaged 12 km^2 for winter and 46 km^2 for the core-lick period (Table 4). No individuals in this main group showed any notable changes in their range use over the monitoring period (Figure 17). On average, the winter range for these goats was the same as L28-only goats, whereas the average core-lick range was almost twice the size of L28-only goats (Table 5). Both the multi-year composite ranges for this main group at the primary control lick were about 3 times larger than the same ranges for L28-only goats.

The 2 males in the second group of primary control goats also used the area between Morrisey Creek and Herchmer Pass but they only used it during the core-lick period and they stayed along the main north-south ridge. Their ranges also extended up to 49 km north of Herchmer Pass.

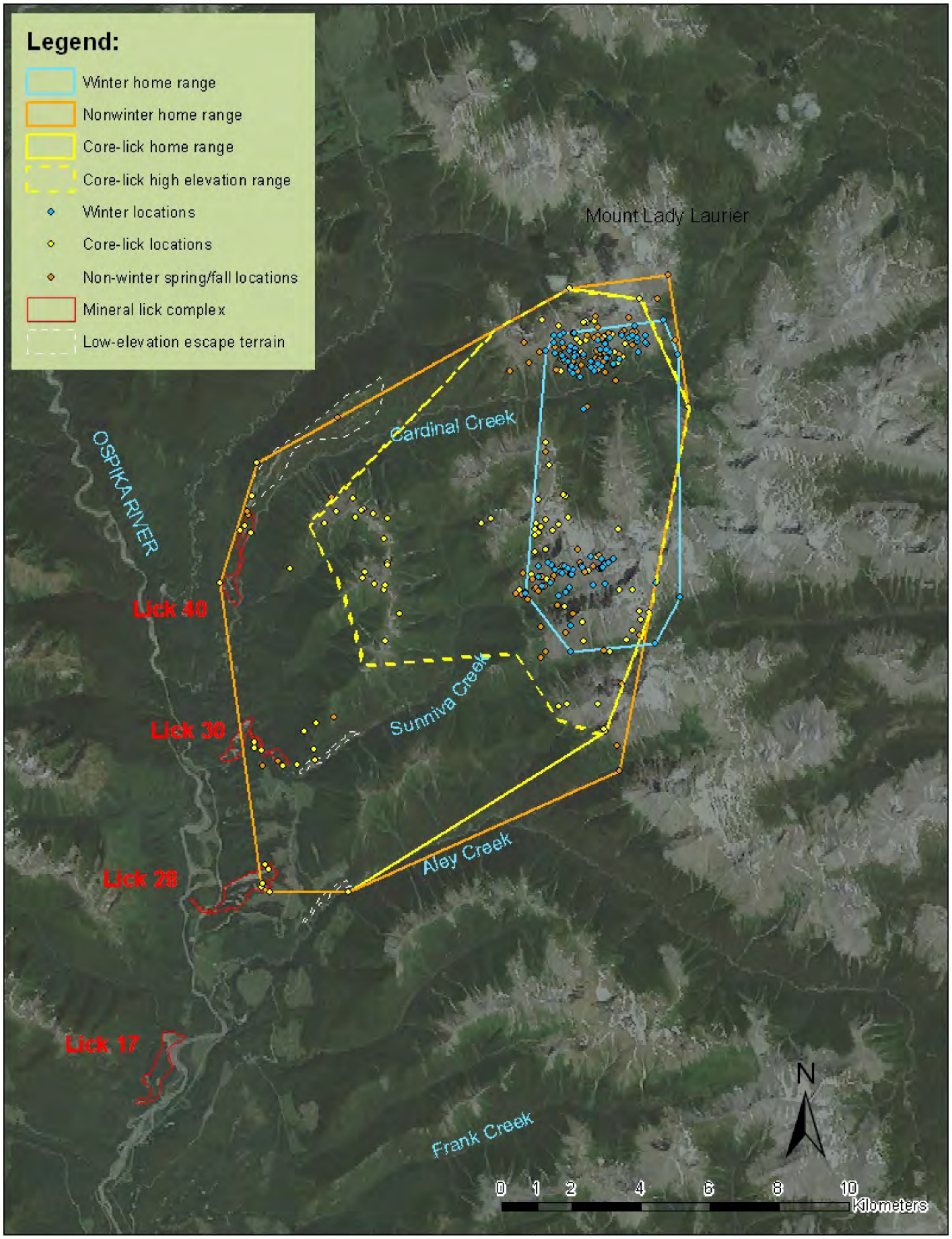

Figure 16. Telemetry locations and multi-year composite seasonal MCP (winter [Dec-Mar], non-winter [Apr-Nov], and core-lick [Jun-Sep]) and core-lick high-elevation home ranges for 4 female radio-collared mountain goats (L28-30-40 goats) that used the 3 eastern mineral-lick complexes (Licks 28, 30 and 40) in the lower Ospika River drainage, March 2002 to December 2007.

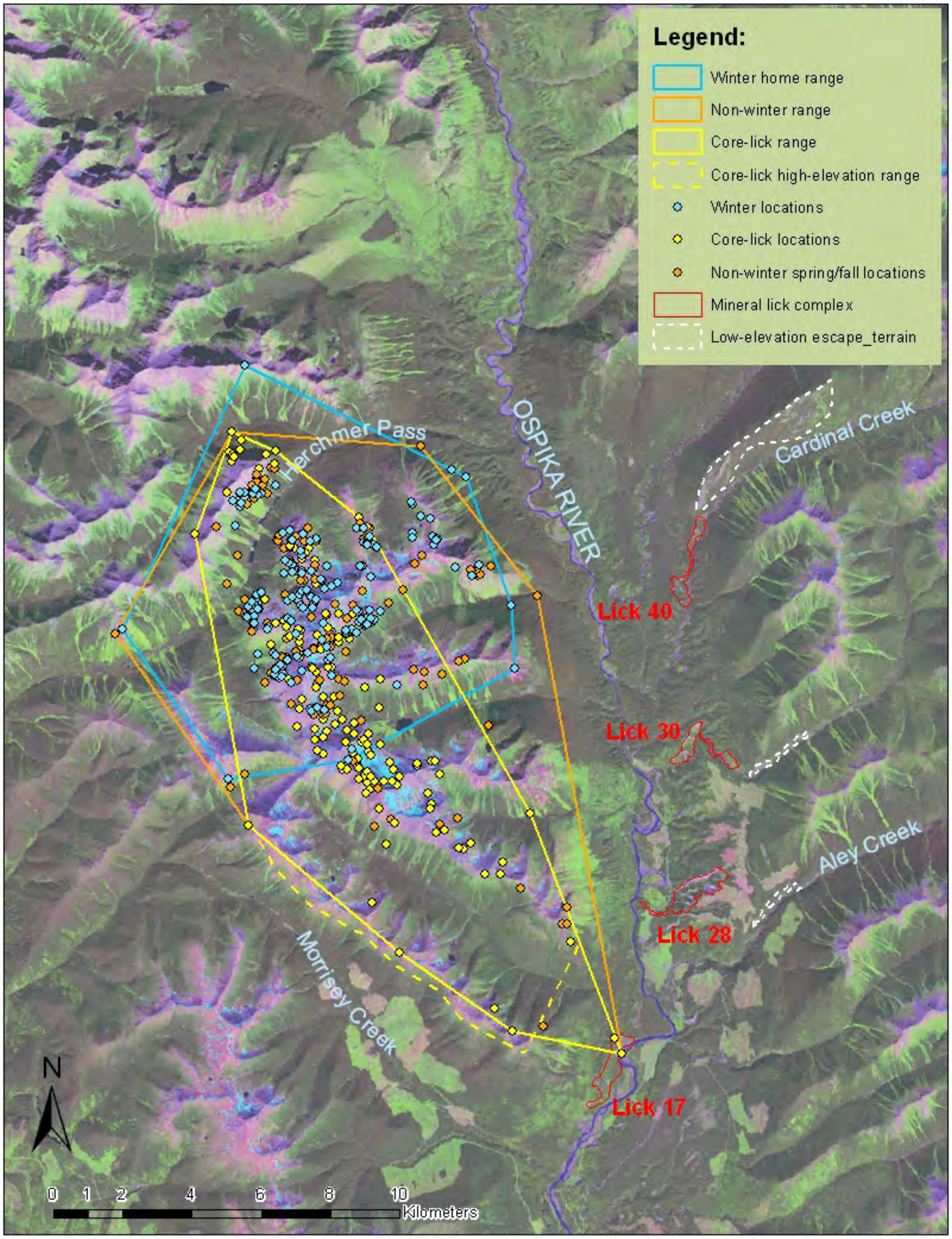

Figure 17. Telemetry locations and multi-year composite seasonal MCP (winter [Dec-Mar], non-winter [Apr-Nov], and core-lick [Jun-Sep]) and core-lick high-elevation home ranges for 9 radio-collared mountain goats (L17 goats: 6 females, 2 males) that exclusively used the primary control mineral-lick complex (Lick 17) in the lower Ospika River drainage, March 2002 to November 2007.

Each spring, the majority of radio-collared goats travelled a minimum of 3.6 to 10.6 km from their winter range to access their mineral licks (Table 6); though, 1 male that used the primary control lick had to travel up to 60 km in some years. L28-only goats had potentially the shortest distance to travel. Goats travelled shorter distances when they were using their core-lick high-elevation range (minimum of 1.6 to 6.4 km). The distance, however, was not reduced as much for L28-only goats compared to the other goat types, and L28-30-40 goats had to travel the farthest when they accessed the treatment lick (i.e., minimum distance travelled was 2 to 4 times farther than when they accessed their other licks or when other goats accessed their lick). Also, for the majority of the radio-collared goats, the maximum distance they travelled to a lick during the core-lick period was the same as the maximum distance from their winter range.

Table 6. Distances between mineral-lick complexes and multi-year composite winter (Dec-Mar) MCP and core-lick (Jun-Sep) high-elevation ranges for radio-collared mountain goats that used the primary control and treatment licks in the lower Ospika River drainage, March 2002 to December 2007.

		Distance (km) between lick and range			
		Multi-year composite winter range		Core-lick high-elevation range	
Goat type (sub-type)	Lick type	Min	Max	Min	Max
L17 goats (all except M11 and M32)	Primary control (17)	10.6	22.1	2.1	20.6
L28-only goats	Treatment (28)	3.6	12.9	3.3	13.0
L28-30-40 goats	Treatment (28)	10.6	19.4	6.4	19.6
	Secondary control (30)	8.4	16.7	3.5	16.6
	Secondary control (40)	7.8	13.0	1.6	12.9

Two goats (1 male, 1 female) never used a study lick, both were captured east side of the Ospika drainage. The female goat was captured in, and used, the same high-elevation area that all the L28-only goats used but she was never recorded leaving this area for the 2 years she was monitored. The male goat was the only goat captured on the northeast side of the Aley Creek drainage. For the 3 years he was monitored (2002-2004), he only used the mountain ranges to the east and north of his capture location; his closest telemetry location to any of the eastern licks was 8 km.

Twelve radio-collared goats died during the study period but only 3 goats died during the lick-use season: 2 L28-only goats and 1 primary control goat. The 2 L28-only goats involved males. One male (3 years old) was killed by a wolf in June 2006 when he was travelling to Lick 28 (for further details see section 4.3 Failed Visits). This goat was 1 of 7 L28-only goats that were monitored in 2006. The other male (6 years old) died in a high-elevation site in mid-May 2004 before accessing any licks that year. Evidence at the site indicated he was possibly killed by a bear. The lone primary control goat that died during the lick-use season involved an ~13-year-old female. The mortality occurred in mid-May on the alpine ridge that leads down to the lick. The female had made 3 visits to the primary control lick in the preceding 17 days, including one that ended 2 days before her death. Necropsy results revealed she died due to starvation.

4.4 TRAIL USE BY PREDATORS AND OTHER UNGULATES

4.4.1 Number of Predators and Other Ungulates Using Trails

Predators, which included grizzly bear, black bear, wolf, cougar and wolverine, were photo-captured 650 times on the study trails (Appendix C). Grizzly bears, black bears, and wolves represented 98% of these records; these 3 species are collectively referred to as “large predators” from here on. The 3 large predators were photo-captured at least once on each of the 4 study trails each year. Cougars and wolverines were photographed infrequently on the trails (10 cougar photo-captures and 3 wolverine photo-captures). All cougar photo-captures occurred in 2004 and 2005, with 8 of the 10 detections occurring in 2005; the 8 photo-captures occurred at 3 of the study licks (5 photo-captures at the primary control lick, 2 at the treatment lick, and 1 at secondary control lick 30).

Other ungulates, which collectively included moose, elk, white-tailed deer, mule deer, and caribou, were photo-captured 420 times on the study trails. Moose, elk, and deer represented 98% of these records (Appendix C).

The number of large predators and other ungulates photo-captured using the treatment trail increased dramatically after 2004 (Figure 18). Except for wolves, these species did not show a notable increase over the study term at the primary control lick. The number of wolves photo-captured at the primary control lick doubled in 2005 and again in 2006. There was no obvious trend for these species at the 2 secondary control licks.

The 3 large predators were photo-captured 62 times (92% were bears) and other ungulates were photo-captured 87 times (46% were elk) at the 2 camera-monitoring stations on the road near the treatment lick from 2004 to 2006, with 90% of the photo-captures occurring in 2005 and 2006; only 3 photo-captured goats were recorded at these sites during the same period.

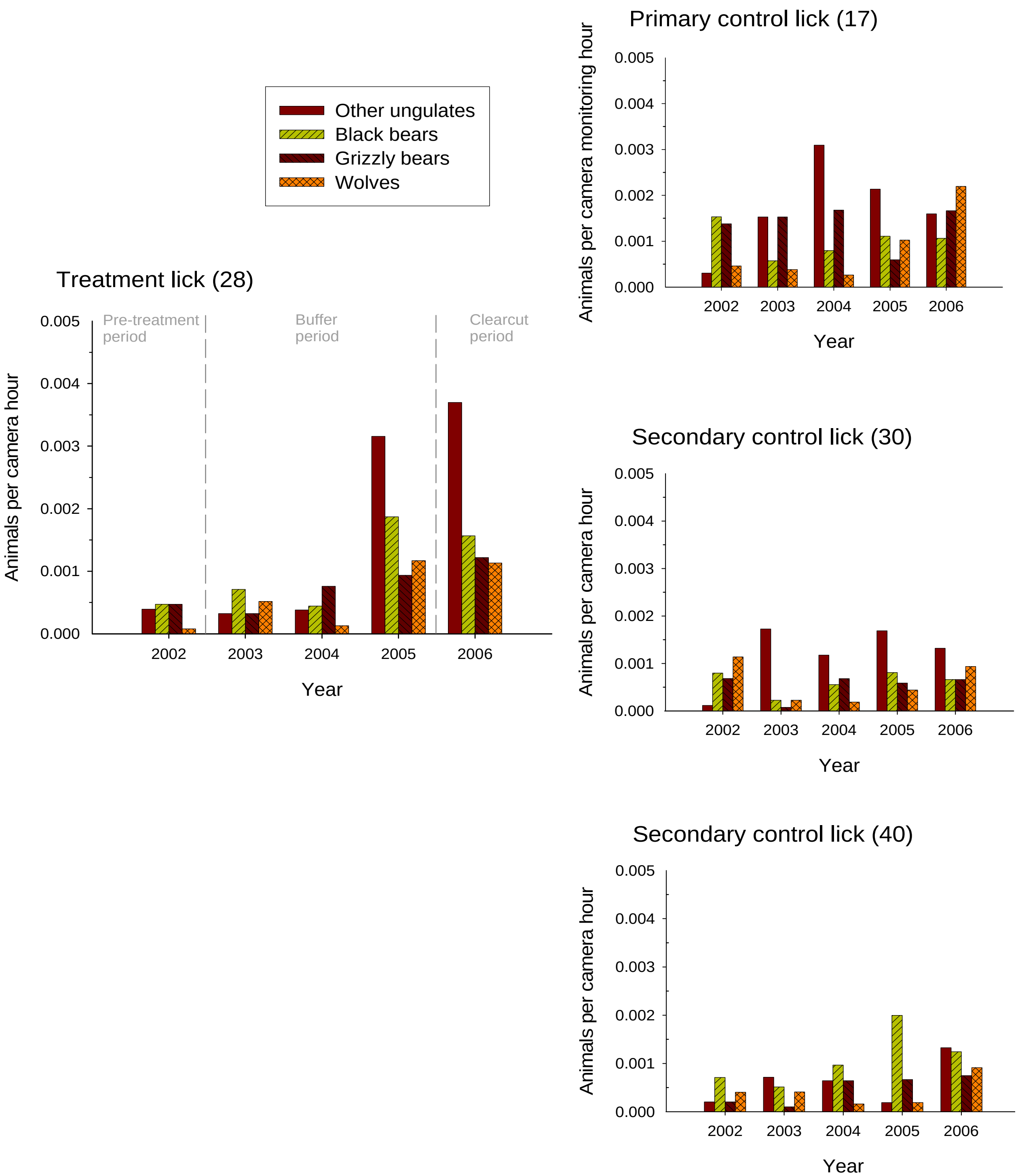

Figure 18. Annual variability of other ungulates (moose, elk, deer and caribou) and 3 large predators (grizzly bear, black bear and wolf) photo-captured using the mountain-goat access trails (up and down trail combined) to the 4 study licks in the lower Ospika River drainage, April to November, 2002-2006.

4.4.2 Timing of Trail Use by Predators and Other Ungulates

The 3 large predators and other ungulates used the study trails in the same months as mountain goats (Figure 19). Trail use overlapped the most from mid-June to mid-September for goats and these other species.

Trail use by the 3 large predators and other ungulates was generally greatest during the crepuscular and night periods; goats used the trails mainly during the daytime (Figure 20).

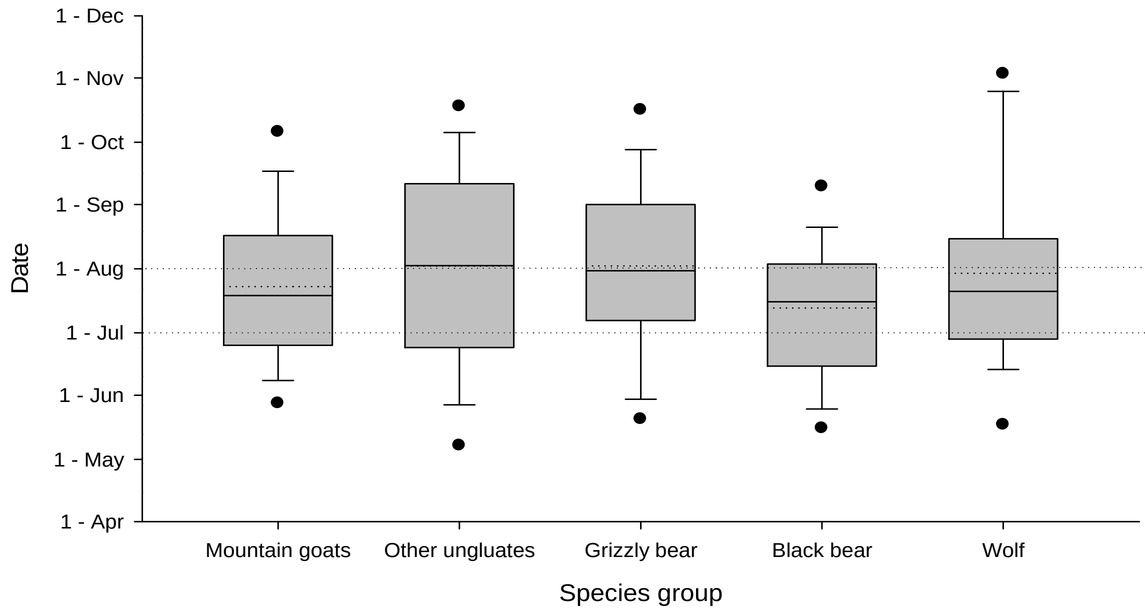

Figure 19. Annual distribution of mountain goats, other ungulates (moose, elk, deer, and caribou combined) and 3 large predators (grizzly bear, black bear and wolf) photo-captured on access trails (up and down movements combined) to the 4 study licks in the lower Ospika River drainage, April to November, 2002-2006. Distributions are marked with mean (dotted) and median (solid) lines inside the box, and the 25th and 75th percentiles (box), 10th and 90th percentiles (whiskers), and 5th and 95th (points) are also identified.

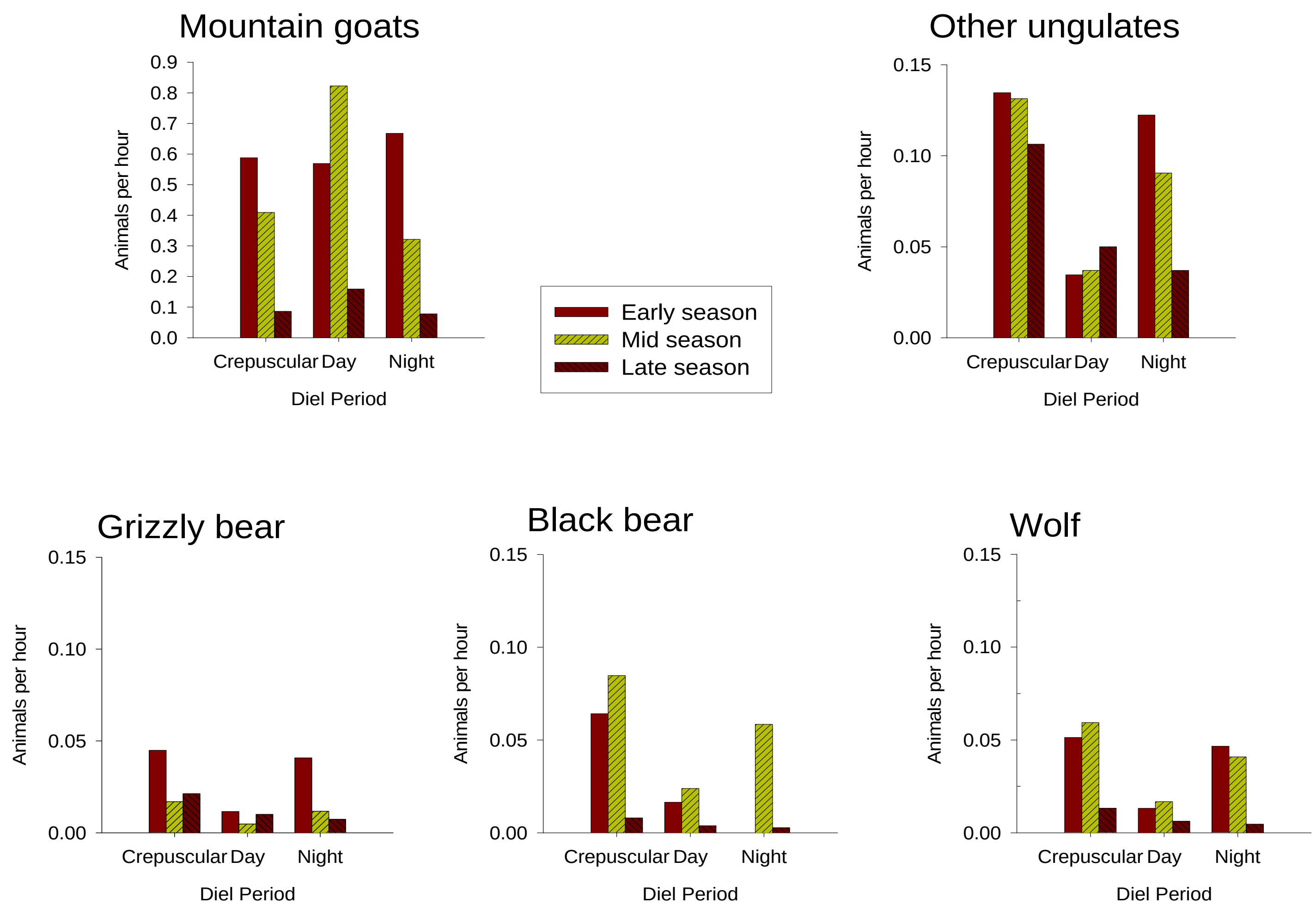

Figure 20. Effect of season on diel patterns of trail use (down and up movements combined) by all mountain goats, other ungulates (moose, elk, deer and caribou) and 3 large predators (grizzly bear, black bear and wolf) near the 4 study licks in the lower Ospika River drainage, 2002-2006. Seasonal periods were: early (31 May – 29 June), mid (30 June – 28 Aug), and late (29 Aug – 30 Nov). Although all camera stations were set up by 31 May each year, many stations malfunctioned in the early season of 2002. Diel periods were crepuscular (±1 hr from sunrise and sunset), day and night.

5.0 DISCUSSION

In the first 5 years following 2 forest-removal treatments, we detected no treatment effects on the behaviour of mountain goats using and accessing their low-elevation mineral lick. By the end of the study however, annual lick use by goats had declined by 47% (Figure 10), and annual trail use had declined by 63-94% (Figure 5 and 7), at both the treatment lick and primary control lick. We also observed a marked increase in photo-captures of 3 large predators (grizzly bear, black bear, and wolf) and 4 other ungulates (moose, elk, mule deer and white-tailed deer) on the trail to the treatment lick, and a marked increase in photo-captures of wolves at the primary control lick (Figure 18).

By using both trail cameras and radio-collared individuals we were able to observe lick-visit patterns from 2 perspectives – all goats that used the study trails to access the study licks and individual goats that visited the study licks. Both data sources indicated goats continued to visit the licks at the treatment and primary control licks following the treatments, and that there was a notable decline in lick visits at both these licks over the study term. However, there was a discrepancy in the extent of the decline in lick visits at the treatment lick based on the 2 data sources. The primary control lick had similar results from both datasets by the end of the study: a 63% decline in down-trail use by goats and a 47% decline in lick visits by radio-collared goats. For the treatment lick, down-trail use at the 4 camera stations monitored for the entire study indicated an average decline of 94% (SE = 3%), whereas there was a 47% decline in lick visits by radio-collared goats. Trail-fidelity data from radio-collared goats indicated that goats continued to primarily use the same approximate route (i.e., within ~150 m of the original trail) in the final year of the study, so the difference between our 2 lick-visit metrics for the treatment lick was likely a result of goats not using the exact route of the original trail (i.e., not using segments of the trail where camera stations were located), particularly once the forested buffer was removed.

Goats that used all 3 eastern licks (L28-30-40 goats) appeared to switch their lick use from the treatment lick to the nearest alternate study lick; the change was not significant but power to detect a difference was low. Goats that exclusively used the treatment lick, however, did not show any compensatory use of another study lick when their lick use declined at the treatment lick. This may be due to their lack of awareness of the other study licks or, alternatively, these goats may have used mineral-lick sites that we did not monitor (e.g., sites along Stevenson Creek to the south); however, there was no evidence of the later based on aerial-telemetry data.

Radio-collared goats that used the treatment lick exhibited other behaviours associated with lick visits that indicated they were impacted to some extent by the treatments: all failed lick visits by radio-collared goats at the treatment lick occurred after the first treatment, goats using the treatment lick had ~3 times more failed visits than goats using the control licks, and 8 of the 9 failed visits at the treatment lick occurred at or adjacent to key features resulting from the treatments, including a mortality which occurred adjacent to the clearcut treatment. Also, the time elapsed between an aborted visit and the goat's next lick visit increased with each subsequent year, with aborted visits in the last year of the study involving goats that did not return to the treatment lick (or any other study lick) that year.

Although the number of lick visits declined at the treatment and primary control licks during the study, the duration of goat visits did not change at either of the licks during this period (Figure 11). On average though, goats that used the treatment lick spent >2 times longer per visit than goats using the primary control lick, and goats that exclusively used the treatment lick spent >2 times longer at the lick each year than goats using the primary control lick. Visit frequencies for these 2 goat types were similar so the difference in their annual lick use appears to be solely due to the difference in their time spent per visit. Factors that can influence the duration of a lick visit include lick soil properties (e.g., mineral composition and concentrations), condition of the goat (e.g., extent of mineral deficiency and digestive ailments), and site characteristics (e.g., predation risk, proximity to escape terrain) (Hebert and McTaggart Cowan 1971, Kreulen 1985, Klaus and Schmid 1998, Poole and Heard 2003, Ayotte et al. 2006).

There were no treatment effects on the 5 metrics we used to determine timing of lick visits by mountain goats: calendar date, days since the snow-free and leaf-flush dates, and seasonal and diel periods. We expected that snow-free and leaf-flush dates would provide a more biologically-relevant measure of when goats used their licks each year than the calendar date since the onset of spring and the resulting drivers that cause goats to seek out mineral licks can occur over a range of dates across years. This was not the case, as all 3 measures had relatively wide distributions for goat lick use and there was variability in the timing of lick use among the 4 study licks. The locations that we used to determine "day 0" for these metrics were perhaps not appropriate for reflecting the location (i.e., conditions) where goats initiated there lick movements. Alternatively, these index dates may be a good measure of when goats first use a lick each year but not define when the average yearly visit or majority of visits occur.

Radio-collared goats used the main access trail (i.e., stayed within ~150 m) for the majority of their lick visits to the treatment lick, except for the first year after the clearcut treatment. During that year, radio-collared goats used alternative routes ~30% more often than the previous years. Goats were possibly searching for a better route to the treatment lick since conditions along the trail had changed from a mature forest to an early-seral setting, which was more similar to their alpine habitat. The original trail location appeared to be the preferred route however, as the percentage of trail use along the original route regained its previous usage the following year. Topography and sight-lines may have been important in determining the original location of this trail as a large section of the logged portion of the trail was situated on or near the highest point of a gently sloping, convex ridge.

Monitoring the response of non-goat species to the forest-removal treatments was not one of our primary objectives in the study design, nonetheless there was a notable increase in the abundance of large predators (black bear, grizzly bear, and wolf) and other ungulates (moose, elk, and deer) using the treatment-lick trail over the study term. For the first year after the clearcut treatment, the increase in these species was likely even higher than what was recorded because these species had much lower fidelity to the trail. Consequently, once the forested buffer was removed, these individuals likely had little need to continue using the trail, so the ratio of photo-captured animals to the number of animals present in the area was likely much less in 2006 than prior years. For the second year after the clearcut treatment (when we did not conduct camera monitoring), the abundance of predators was likely the same or even higher because logged areas were regenerating, thus providing more forage for their primary prey and bears themselves, and more animals were likely aware of the newly altered area.

Grizzly bears and wolves are 2 of the 3 most important predators for mountain goats (review by Peek 2000, review by Côté and Festa-Bianchet 2003, Festa-Bianchet and Côté 2008); cougars, the third important goat predator, were detected infrequently. Some grizzly bears are reported to predate heavily on mountain goats even though they are not typically their primary prey (Festa-Bianchet et al. 1994). The numerical response of bears and wolves in the first 5 years following logging is unknown (e.g., review by Fisher and Wilkinson 2005) but the increases we observed for these species were consistent with other research that indicate their primary prey (moose, elk and deer), and some preferred plant species for bears, increase in abundance 2-5 years after logging disturbances occur in conifer-dominated communities (Reynolds 1962 [in Lyon and Jensen 1980], Potvin et al. 1999, Stelfox et al. 2000, Nielsen et al. 2004a).

The increase in predators may account for the decline in lick and trail use at the treatment lick, but the primary control lick had a similar decline in goat use yet, except for wolves, there was no numerical response in predators and other ungulates. Wolves alone could have had an impact on goat lick use but goats using the primary control lick could have also been exposed to greater predation risk without an increased incidence of predators being observed on the goat trail. The primary control lick was situated immediately adjacent to a large watercourse (the Ospika River), the shores of which are often used as travel corridors by large predators (Apps et al. 2007; authors, personal observations). The sites where we collected our monitoring data from may have also had an effect on the number of predators and other ungulates detected since the trail features at these sites were quite different for the 2 trails. The trail at the treatment lick was on the main valley-bottom bench in the Ospika drainage and was within the forest matrix impacted by the logging. Conversely, the trail monitoring sites at the primary control lick were on a flat micro-site on a steep sidehill and on a small bench next to an incised, narrow valley. Therefore, bears and other ungulates may have been less likely to use the trail where the camera stations were located for the primary control lick.

The corresponding declines in lick visits by mountain goats at the treatment and primary control licks, and no decline at the 2 secondary control licks, suggested that goats were influenced by effects that extended to both the east and west sides of the Ospika River drainage, but in the lower (southern) portion of the drainage. The only obvious change that had occurred was forest disturbances caused by logging, which provide conditions that are beneficial for the primary prey of large predators (Potvin et al. 1999, Stelfox et al. 2000, Nielsen et al. 2004a and b). During the study, 537 ha were logged within 4 km of a study lick. The area near the treatment lick incurred the most logging (485 ha), with logged areas occurring all around the lick complex and main access trail; secondary control lick 30 incurred 389 ha, the primary control lick incurred 96 ha, and secondary control lick 40 incurred no logging (Canfor, Mackenzie, unpublished data; Landsat 5 satellite imagery, Ministry of Environment). Interestingly, secondary control lick 30 did not show a decline in goat lick visits during the study even though a substantial amount of logging had occurred nearby, yet the primary control lick had much less logging occur nearby during the study but incurred a notable decrease in goat lick visits. This discrepancy was perhaps due to secondary control lick 30 having few roads in the area, none of which provided a view of the lick, whereas the primary control lick abutted the Ospika River (a potential predator travel corridor) and the main logging road in the drainage closely paralleled the river and provided several unhindered views of the primary control lick. So, the likelihood of the treatment and primary control licks being the only licks affected by the indirect effects of the recent logging in the area (for the period of the study, at least) was reasonable.

Based on the larger dataset of lick visits (i.e., trail use from camera data), the decline in goat visits at the primary control lick appeared to start in 2004, whereas the decline in use at the treatment lick occurred in 2005 (Figure 4b). This discrepancy was probably due to the timing of when the logging occurred near each of these areas, and the resultant suitability of these areas to the predators' prey, and bears as well. The treatment lick was situated near the leading edge of logging in the valley, so logged areas were not near the treatment lick and trail until the first study treatment occurred, whereas logging had occurred east of the primary control lick prior to this date.

The decline in goat use at the treatment lick began 2 years after the buffer treatment had occurred (Figures 4 and 21), and only after there was an increase in predators. Therefore, retention of the forested buffer along the trail appeared to provide suitable conditions for goat movements after logging had occurred in the area. This is consistent with the only other study that investigated logging effects on low-elevation mineral-lick use by mountain goats. From the pre-treatment period to the first year after logging, there was no change in trail detection rates for trail monitoring sites that were in the forest but near the logged area (L. Turney, Ardea Biological Consulting, personal communication); no further monitoring was conducted for this study. Anecdotal information from a study in southeastern British Columbia suggested that logged areas <100 m from a lick may have imparted increased predation risk (Poole et al. 2010).

With the increase in predators at the treatment and primary control licks in the final years of the Ospika study, we expected that increased predation risk would affect goat behaviours along the trails. There was no change in the typical group size for goats travelling to the treatment lick, or up-trail to the primary control lick, but there was a 60% increase in group size for down-trail movements to the primary control lick from 2004 to 2006. Goats may have been travelling in larger groups to lessen their individual risk to predation. No similar change in group size was observed for the treatment lick or up-trail movements at the primary control lick so different drivers may have been affecting a goat's behaviour for these other movements. Alternatively, the observation of increased group size at the primary control lick may have been an aberration of the sampling data as fewer goats were travelling to the lick and using the trail.

Both our study and Turney et al.'s (2002) study observed goats primarily walking (i.e., 2-4 km/hr) to and from their licks complexes as they travelled along their lick access trails through mature stands in lower elevation areas. Other researchers (Festa-Bianchet et al. 1994, Côté and Festa-Bianchet 2003) have reported that goats often run through forested areas when travelling along their traditional trails, either to access mineral licks or to traverse forested valley bottoms. We did not see this travel behaviour very often, even with an apparent increase in predator risk in the later years of the study. Our observations were based on remote cameras, which appeared to have no affect on goat movement patterns, whereas there was no mention on how the other observations were collected so the goat movements reported by others may have been influenced by the observer or something else. Alternatively, since our rate calculations relied on movements that remained on the trail (i.e., went through all camera stations), these data may not accurately reflect the "average" goat that was travelling to the treatment lick in the final years as such events were much fewer. Goats may not change their trail-use behaviour until the threat of predation is imminent, rather potentially making themselves more susceptible (e.g., faster movements likely increases their chance of being detected, more goats increases the chance that a group will be seen) based on a potential perceived increase in predation risk. So, other factors than predation risk may dictate trail-use behaviour (e.g., human disturbance, social relationships, energetic cost, heat stress).

In 2004 (2nd year of forested buffer), there was a rise in up-trail use (Figure 7b) and a rise in travel rate (Appendix L) at the treatment lick. We do not believe this was due to a treatment effect. Instead, we believe it was due to disturbances resulting from silviculture activities (e.g., tree planting, road deactivation). During 2004, silviculture activities occurred on many days during the core lick-use period (i.e., ~35 days between late May and mid-August); these activities occurred on ≤6 days per year for the other lick-use seasons. Interestingly, the down-trail use appeared to remain the same. Goats may have become aware of these disturbance activities on their way to the lick and then used the trail in the forested buffer (i.e., the safer route) more often, and travelled more quickly along the trail, when they travelled away from the lick.

There was substantial overlap in seasonal use of trails by goats and predators, but there were differences in diel use. Goats primarily used trails at the treatment and primary control licks during the daytime, before and after the treatments were conducted. Predators were recorded primarily using the trails during the crepuscular and night periods, as were the majority of the moose, elk, and deer trail movements. Therefore, predators did not appear to alter their diel trail use to target when goats were most likely on the trail. Predators may have kept to times when they had the best chance of killing prey (i.e., when their primary prey were using the trail and when conditions were most advantageous for hunting).

Given that goats exhibit high fidelity to mineral licks (Fox and Smith 1988, Ayotte et al. 2008) and predator densities will likely increase further over the next 25-30 years in response to current and future logging (e.g., Seip and Cichowski 1996, Smith et al. 2000, Kinley and Apps 2001 Wielgus and Vernier 2003, Nielsen et al. 2004b, Wittmer et al. 2007), predation on goats that use licks which have been affected by logging will also likely increase. Goats that access low-elevation mineral licks are vulnerable to predation as a goat's main defence mechanism is to escape to security terrain (Geist 1971, Festa-Bianchet and Côté 2008), which may be relatively distant when they are travelling to a low-elevation mineral lick; goats usually stay within 500 m of their escape terrain (Poole and Heard 2003). Goat population models suggest that goats are very sensitive to low levels of hunter harvest (>1%; Festa-Bianchet et al. 1994, Peek 2000, Côté and Festa-Bianchet 2003, Hamel et al.

2006), partly when mature females are harvested (Hamel et al. 2006). If increased predation also removes mature females from the population, this predation may increase the risk of extirpating isolated populations. If goats respond to an increased risk of predation by reducing or abandoning their use of mineral licks, chronic elemental deficiencies and rumen dysfunction may increase their susceptibility to opportunistic factors that can also increase mortality and reduce recruitment (e.g., predation, bacteria, and viruses; O'Hara et al. 2001).

In general, lick-use patterns by mountain goats in our study were consistent with other studies in terms of: a) the majority of lick visits occurred between mid-June and early September, b) on average, males accessed licks earlier in the season than females, c) goats used licks multiple times per year, d) lick visits primarily lasted ≤4 days, e) goats travelled outside their normal range to access licks, and f) goats used their main access trail more often when travelling to the lick than when travelling away (Hebert and McTaggart Cowan 1971b, Singer 1978, Singer and Doherty 1985a, Romeo and Lavari 1996, Turney et al. 2002, Poole and Heard 2003, Ayotte et al. 2008, Poole et al. 2010). Within our study however, there were several differences in goat-use patterns across the 4 study licks. For example, there were differences in the number of visits to a lick (e.g., more lick visits per goat at Lick 40), duration of lick visits (e.g., on average, goats visiting Lick 28 spent 2.5 times longer at the lick than goats visiting Lick 17), and timing of lick use (e.g., goat visits to Lick 40 were on average ~10 days earlier than at the other licks). Several of these differences were likely attributable to site factors such as proximity of the lick to the escape terrain (e.g., on average, Lick 40 had the highest visitation rate per goat and it had the shortest distance to its escape terrain) and soil properties at the lick.

6.0 MANAGEMENT IMPLICATIONS

Lyon and Jensen (1980) stated that for as long as "foresters have been prescribing clearcuts, wildlife biologists have been evaluating the effects of these clearcuts on big game". Yet, only 2 studies have investigated the impacts of logging (i.e., the temporary loss of mature forest) on mountain goats that utilize low-elevation mineral licks: our study in north-central British Columbia and a cursory study near Houston, BC (Turney et al. 2002; L. Turney, Ardea Biological Consulting, personal communication). For at least 5 years after logging, the direct effects of forest removal (i.e., creation of an early seral opening) do not appear to reduce the use of low-elevation mineral licks by mountain goats. But, the indirect effects of increased predators as a consequence of forest removal may increase goat risk to mortality from predation, and the impacts may not be confined solely to the area that was logged.

The results of this study suggest that the benefits of leaving a forested buffer along the access trail to a mineral lick are small in the short term but we predict that the importance of a trail through a forested corridor will increase as the density of re-growth in the logged areas restricts movement and visibility. Given that collared goats continued to travel in the vicinity of the original trail after the treatments, even after the forest cover was removed, there may be specific attributes of the trail location that provide security or other benefits to goats.

Although the following conclusions are not a direct result of the experimental design of this study, as a precautionary approach, we feel it is important to emphasize mitigation options for forest disturbances that occur near low-elevation mineral licks because of the potential disturbance to mountain goats from increased industrial activity (review by MGMT 2010) and increased predation (Festa-Bianchet and Côté 2008). During this study, we observed no direct effects of human disturbance as a result of conducting the logging treatments and only a minimal effect of subsequent silviculture activities; this was likely due to these activities being scheduled to avoid the lick-use season (e.g., logging conducted in winter) and to minimize their presence in the peak lick-use period (e.g., planting conducted with more workers on fewer days). Consideration of predator behaviour may help to avoid co-occurrence between predators and goats. For instance, Courbin et al (2009) reported that wolves select mixed and deciduous forests, roads, and cutblocks. Avoiding intersecting roads with mineral-lick access trails and providing forested buffers around trails that minimize the abundance of mixed and deciduous stands may improve the suitability of forest harvesting plans for the long-term persistence of sensitive prey populations such as mountain goats. Research is needed to evaluate the longer term impacts of forest disturbances on mountain goats that use low-elevation mineral licks.

We believe our findings are applicable not only to the Ospika River drainage but to all areas of interior British Columbia where mountain goats travel from their alpine habitats to access low-elevation mineral licks. Mountain goat populations in the interior of British Columbia are likely exposed to similar predator communities and generally have access to similar forages and undergo similar nutritional stresses that influence lick use behaviours (Peek 2000, Turney et al. 2002, Côté and Festa Bianchet 2003, Ayotte et al. 2008, Poole et al. 2010).

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Appendix A: Mountain goat data contributed by "in-lick" cameras[a] at Lick 30 (camera #4) and Lick 40 (camera #3) and the number of goat groups, and the number of associated photo-captured goats, removed from these camera datasets prior to analyses being conducted.

Lick	Year	Goat groups from in-lick cameras			Goat groups removed	Number of photo-captured goats removed
		Total	In-series[b]	Alone[c]		
30	2002	52	29	23	23	50
	2003	80	61	19	18	38
	2004	119	109	10	10	21
	2005	155	114	41	12	33
	2006	187	144	43	26	48
40	2002	27	1	26	0	0
	2003	71	2	69	1	2
	2004	90	0	90	1	1
	2005	110	1	109	0	0
	2006	108	1	107	0	0

[a] "In-lick" cameras were cameras located on trails between mineral licks within the lick complex.
[b] "In series" records are goat groups that were photographed at in-lick cameras and also at other camera stations along the main access trail.
[c] "Alone" records are goat groups that were photographed only at in-lick camera stations (i.e., no associated camera-triggering events occurred at camera stations outside the lick complex).

Appendix B: Number of photo-captured mountain goats, by year, age-sex class and direction of travel (*down* is toward the lick; *up* is away from lick), using the trails that accessed the 4 mineral-lick complexes studied in the lower Ospika River drainage, April to November, 2002-2006.

		Adults										Unclassified goats		All goats			
		Males		Females		Unclassified		Juveniles		Kids							Up vs. Down
Lick	Year	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Total	difference[a]
17	2002	15	8	27	23	25	24	3	2	8	5	1		79	62	141	-22%
	2003	37	26	86	68	44	43	17	14	49	46	1	6	234	203	437	-13%
	2004	24	17	72	52	44	33	28	20	37	28			205	150	355	-27%
	2005	47	13	74	44	64	52	26	20	13	9			224	138	362	-38%
	2006	19	9	63	49	44	52	7	8	12	6			145	124	269	-14%
28	2002	15	10	122	76	41	39	14	11	52	33	15	9	259	178	437	-31%
	2003	27	10	125	75	50	31	31	20	80	49	1	2	314	187	501	-40%
	2004	9	7	111	77	86	89	39	29	43	36			288	238	526	-17%
	2005	15	10	71	42	39	32	12	3	29	16			166	103	269	-38%
	2006	7	7	63	37	44	35	5	3	44	22			163	104	267	-36%
30	2002	13	10	89	74	21	29	11	13	43	33	1	1	178	160	338	-10%
	2003	26	38	83	93	63	39	13	11	54	51			239	232	471	-3%
	2004	46	47	95	74	89	54	19	12	56	50	4		309	237	546	-23%
	2005	29	31	85	76	51	55	24	16	52	47			241	225	466	-7%
	2006	58	48	109	115	72	63	18	12	69	68	3		329	306	635	-7%
40	2002	14	8	60	32	18	16	6	4	24	14	3		125	74	199	-41%
	2003	12	17	85	88	67	55	12	12	60	55			236	227	463	-4%
	2004	28	31	108	94	114	95	31	27	64	57			345	304	649	-12%
	2005	16	20	77	68	52	34	17	26	41	34			203	182	385	-10%
	2006	25	29	65	55	100	91	13	11	36	39			239	225	464	-6%
Overall total		482	396	1,670	1,312	1,128	961	346	274	866	698	29	18	4,521	3,659	8,180	-19%

[a] Difference (up trail minus down trail) as a percentage of the down trail value (i.e., negative value indicates fewer photo-captured goats were observed going up trail).

Appendix C: Number of photo-captured wildlife, by year, using the trails that accessed the 4 mineral-lick complexes studied in the lower Ospika River drainage, April to November, 2002-2006.

Lick	Year	Mountain goat	Rocky Mountain elk	Moose	White-tailed deer	Mule deer	Unknown deer	Caribou	Grizzly bear	Black bear	Unknown bear	Wolf	Cougar	Wolverine	Lynx	Other mammals[a]	Birds[b]
17	2002	141	1	1					9	10		3					
(primary control lick)	2003	437	10	7	4			2	16	6		4			1		
	2004	355		7	30	3			19	9		3	2	1		2	1
	2005	362	2	12	11				7	13		12	5			5	1
	2006	269	2	5	13	4			25	16	1	33					1
28	2002	437		1	3				6	6		1				1	
(treatment lick)	2003	501		3	1			1	5	11		8		1		1	
	2004	526	4	5	3	4	1		12	7		2				1	1
	2005	269	31	10	14	17		1	16	31	1	22	2			3	17
	2006	267	29	13	11	28		4	28	36	1	26				4	43
30	2002	338		1					6	7		10					
(secondary control lick)	2003	471	14	8		1			1	3		3					
	2004	546	3	16					11	9		3					
	2005	466	1	9	8	5			8	11		6	1			1	1
	2006	635	6	5	10	3			12	12		17				4	
40	2002	199		2					2	7		7			1		
(secondary control lick)	2003	463		2		5			1	5		4		1			
	2004	649	1	4	3				8	12		2					2
	2005	385			1				7	20	1	2				1	
	2006	464	1	5	7		1		8	14	2	11					1
Overall		8,180	105	116	119	70	2	8	207	245	6	179	10	3	2	23	68

[a] Other mammals: red fox (*Vulpes vulpes*), marten (*Martes americana*), weasels (*Mustela* spp.), snowshoe hare (*Lepus americanus*), red squirrel (*Tamiasciurus hudsonicus*).

[b] Birds: ruffed grouse (*Bonasa umbellus*), spruce grouse (*Falcipennis canadensis*), raven (*Corvus corax*), and unknown owl.

Appendix D: Results of data reinterpretation on randomly selected samples of large and small mountain-goat groups photographed at camera stations from the 4 study licks in the lower Ospika River drainage, 2002 to 2004. Negative mean values indicate the original estimate was higher than the reinterpreted estimate.

Sample group and metric	Lick 17	Lick 28	Lick 30	Lick 40
Large group samples (>10 goats per group)				
Groups reinterpreted (n)	15	16	15	15
Frequency of difference in group size	40%	38%	53%	53%
Overall difference (mean ± SE) in group size	0 ± 0.5	1.0 ± 0.4	0.5 ± 0.4	2.0 ± 0.8
Frequency of difference in age-sex classification	94%	94%	80%	94%
Difference (mean ± SE) in age-sex classification				
Adult male	-0.6 ± 0.3	0 ± 0.2	-0.2 ± 0.2	1.3 ± 0.6
Adult female	-0.2 ± 0.3	-0.4 ± 0.4	0.2 ± 0.4	0.2 ± 0.6
Adult unclassified	0.1 ± 0.7	-0.1 ± 0.5	0.5 ± 0.4	0.6 ± 0.2
Yearling (10-22 months)	0.7 ± 0.0	0.3 ± 0.3	-0.2 ± 0.3	-0.1 ± 0.2
Kid (<6 months)	-0.2 ± 0.2	0.2 ± 0.1	0.2 ± 0.3	0.3 ± 0.2
Unclassified goat	0	0.4 ± 0.4	0	1.5 ± 0.2
Small group samples (≤10 goats per group)				
Groups reinterpreted (n)	14	15	13	14
Frequency of difference in group size	7%	7%	15%	7%
Overall difference (mean ± SE) in group size	1.0 ± 0.1	-0.1 ± 0.1	0.0 ± 0.2	-0.1 ± 0.2
Frequency of difference in age-sex classification	28%	40%	85%	36%
Difference (mean ± SE) in age-sex classification				
Adult male	-0.7 ± 0.3	-0.5 ± 0.1	-0.8 ± 0.3	0.3 ± 0.3
Adult female	-0.3 ± 1.0	0.1 ± 0.1	-0.4 ± 0.3	-0.4 ± 0.2
Adult unclassified	1.4 ± 0.2	0.0 ± 0.3	0.5 ± 0.5	-0.3 ± 0.1
Yearling (10-22 months)	-0.7 ± 0.2	1.0 ± 0.0	0.6 ± 0.2	0.3 ± 0.1
Kid (<6 months)	0.2 ± 0.1	-0.3 ± 0.1	0.0 ± 0.2	-0.1 ± 0.2
Unclassified goat	0	0	0	0

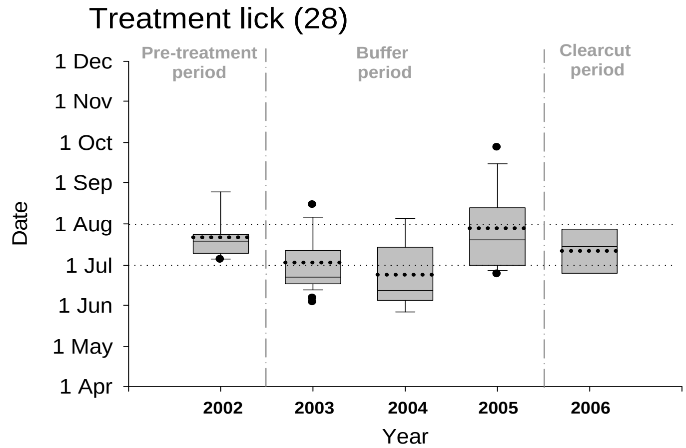
Appendix E: Calendar dates of mountain goat movements, based on photographs by trail camera stations, on access trails (down and up movements combined) to the 4 study licks within the lower Ospika River drainage, April to November, 2002-2006.

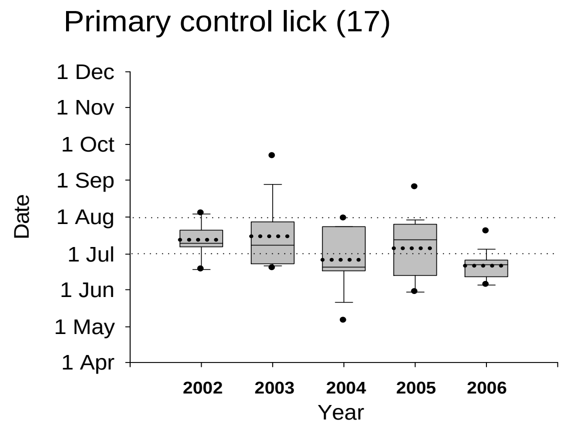
		All goats				Kids (<6 months old)	
Lick	Year	Date of 1st record	Date of 10th percentile	Date of 90th percentile	Date of last record	Date of 1st record	Date of 10th percentile
17	2002[a]	18-Jun	6-Jul	11-Sep	25-Oct	22-Jul	23-Jul
	2003	7-May	21-Jun	5-Nov	16-Nov	22-Jun	10-Jul
	2004	2-May	3-Jun	2-Oct	26-Oct	20-Jun	20-Jun
	2005	23-Apr	12-Jun	20-Sep	30-Sep	16-Jun	16-Jun
	2006	23-Apr	12-Jun	21-Aug	8-Oct	25-Jun	25-Jun
28	2002[a]	5-Jul	12-Jul	29-Sep	27-Oct	10-Jul	11-Jul
	2003	25-Apr	21-Jun	31-Aug	2-Nov	22-Jun	26-Jun
	2004	1-May	4-Jun	16-Aug	6-Oct	27-Jun	29-Jun
	2005	26-Apr	9-Jun	25-Sep	23-Oct	18-Jun	28-Jun
	2006	6-Jun	13-Jun	5-Sep	15-Oct	14-Jun	14-Jun
30	2002[a]	19-Jun	7-Jul	20-Aug	1-Nov	5-Jul	8-Jul
	2003	3-May	11-Jun	29-Aug	4-Nov	26-Jun	15-Jul
	2004	11-Apr	1-Jun	17-Aug	4-Oct	16-Jun	26-Jun
	2005	21-May	29-May	30-Aug	30-Sep	9-Jun	24-Jun
	2006	4-May	5-Jun	7-Oct	24-Nov	23-Jun	3-Jul
40	2002[a]	19-Jun	6-Jul	5-Aug	25-Sep	7-Jul	7-Jul
	2003	25-May	19-Jun	31-Aug	7-Oct	18-Jun	29-Jun
	2004	16-Apr	22-May	13-Aug	11-Nov	17-Jun	22-Jun
	2005	3-May	25-May	18-Oct	1-Nov	17-Jun	17-Jun
	2006	16-Apr	28-May	23-Aug	8-Oct	25-Jun	27-Jun
Earliest or latest date		11-Apr	22-May	5-Nov	24-Nov	9-Jun	14-Jun
Overall average date		12-May	13-Jun	8-Sep	21-Oct	23-Jun	29-Jun

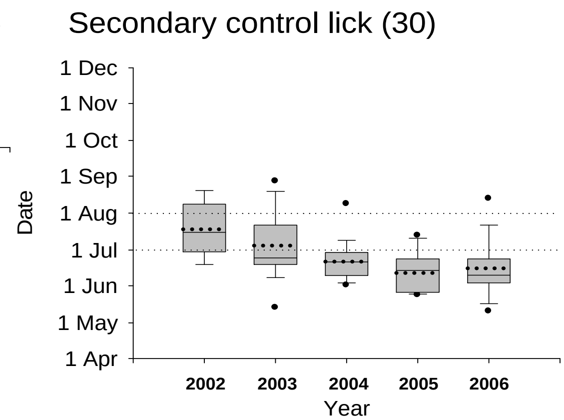
[a] Camera stations were not operational until the 31 May 2002.

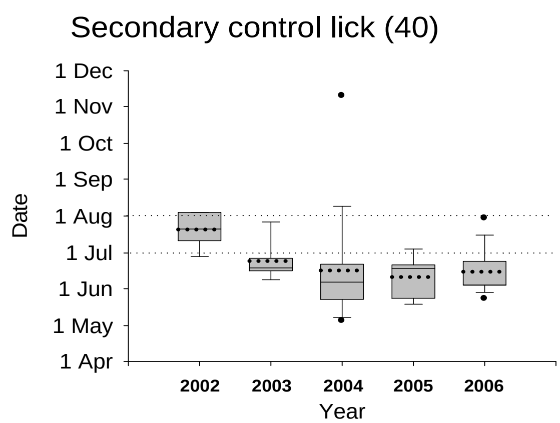
Appendix F: Annual distributions of travel dates for mountain goat age-sex classes (adult male, adult female and kid [<6 months old]) photo-captured travelling down access trails to the 4 study licks in the lower Ospika River drainage, April to November, 2002-2006. Distributions are marked with mean (dotted) and median (solid) lines inside the box, and the 25th and 75th percentiles (box), 10th and 90th percentiles (whiskers), and 5th and 95th (points) are also identified.

Adult males



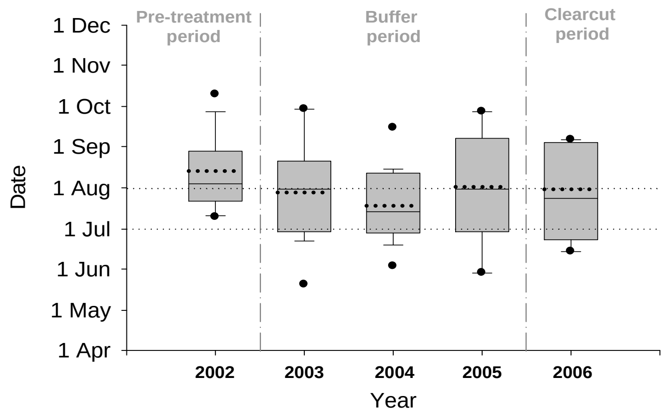




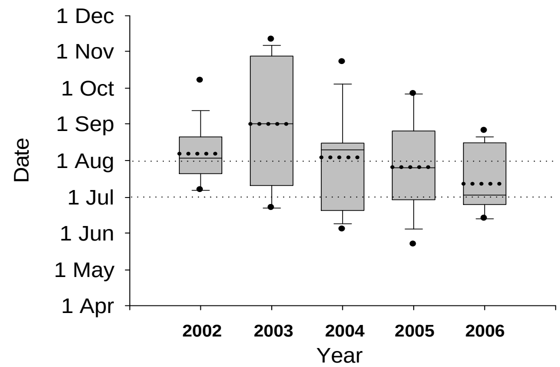


Adult females

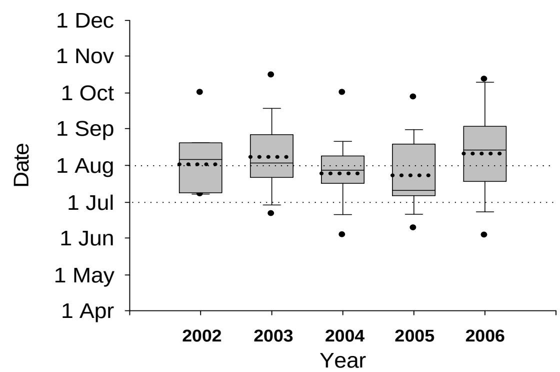
Treatment lick (28)



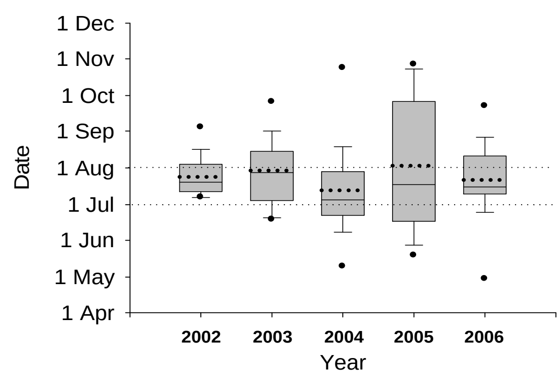
Primary control lick (17)



Secondary control lick (30)

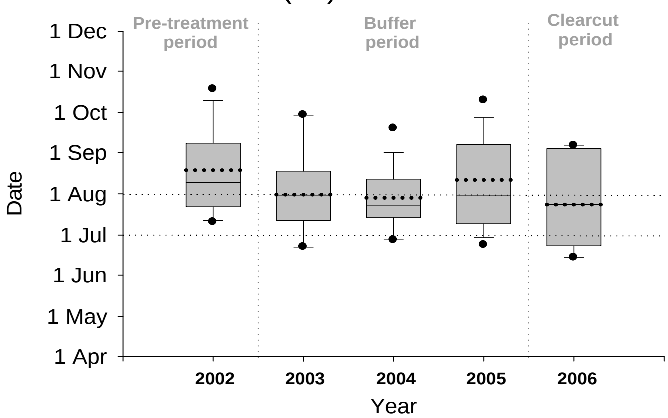


Secondary control lick (40)

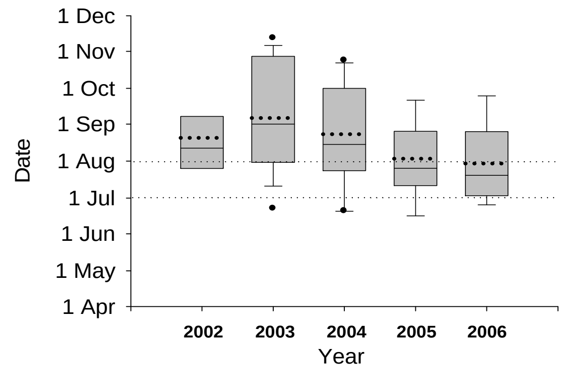


Kids (<6 months old)

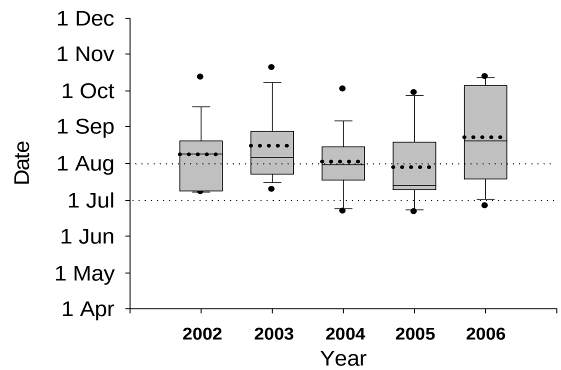
Treatment lick (28)



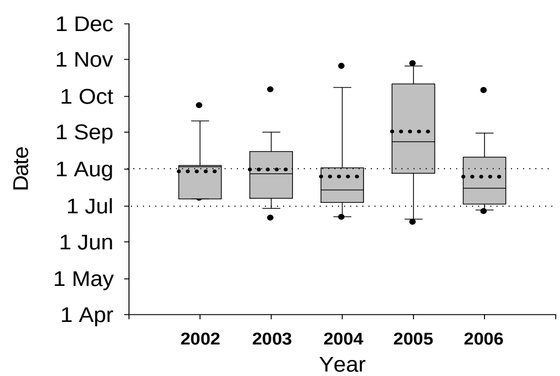
Primary control lick (17)



Secondary control lick (30)



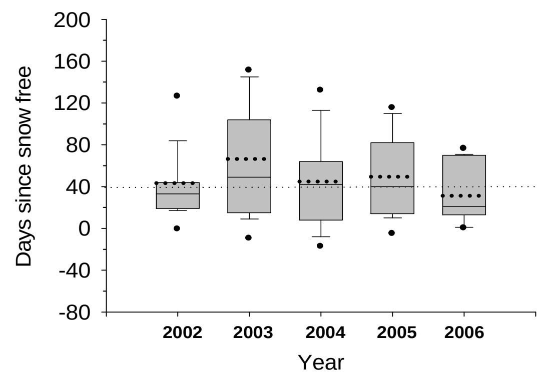
Secondary control lick (40)



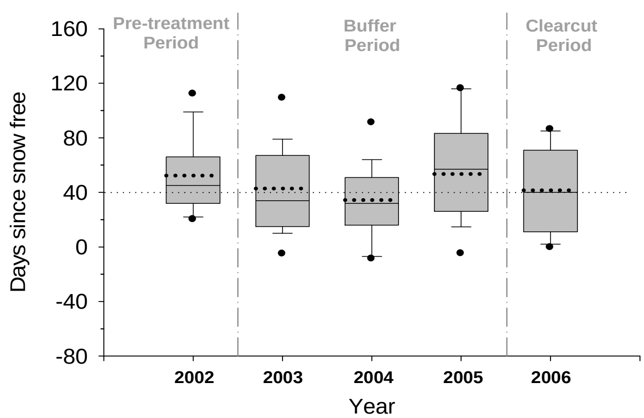
Appendix G: Annual distributions of travel dates, relative to the a) annual snow-free date and b) annual leaf-flush date, for all mountain goats photographed travelling down the main access trail to 4 study licks in the lower Ospika River drainage, April to November, 2002-2006. Sample unit is an individual goat (e.g., a group of 5 goats represents 5 individual records). Distributions are marked with mean (dotted) and median (solid) lines inside the box, and the 25th and 75th percentiles (box), 10th and 90th percentiles (whiskers), and 5th and 95th percentiles (points) are also identified.

A) Annual snow free

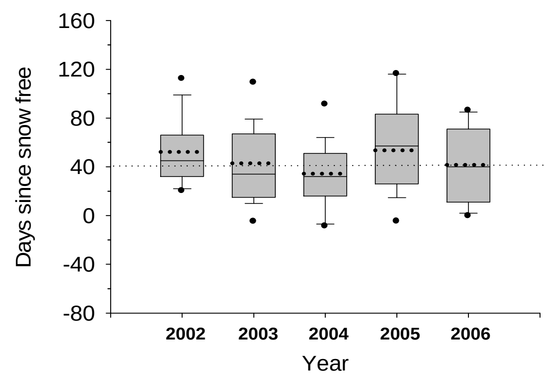
Primary control lick (17)



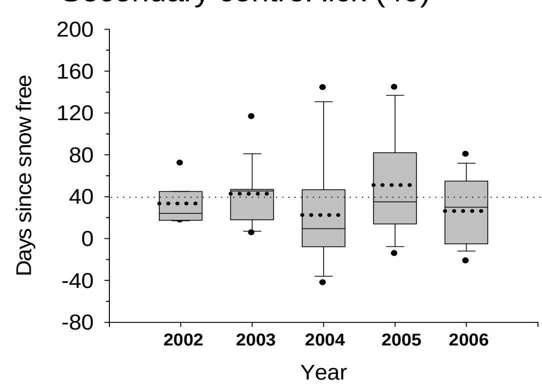
Treatment lick (28)



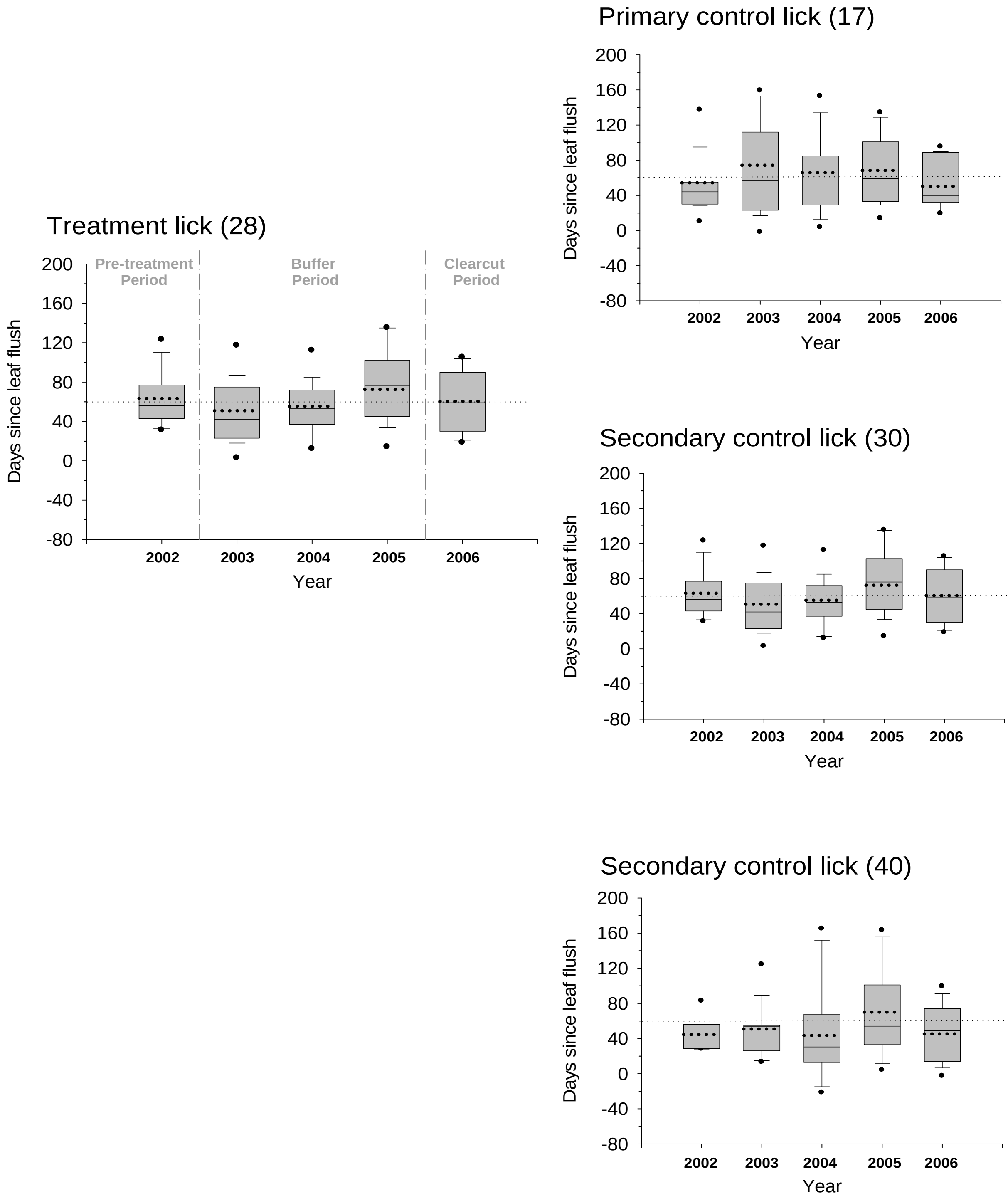
Secondary control lick (30)



Secondary control lick (40)

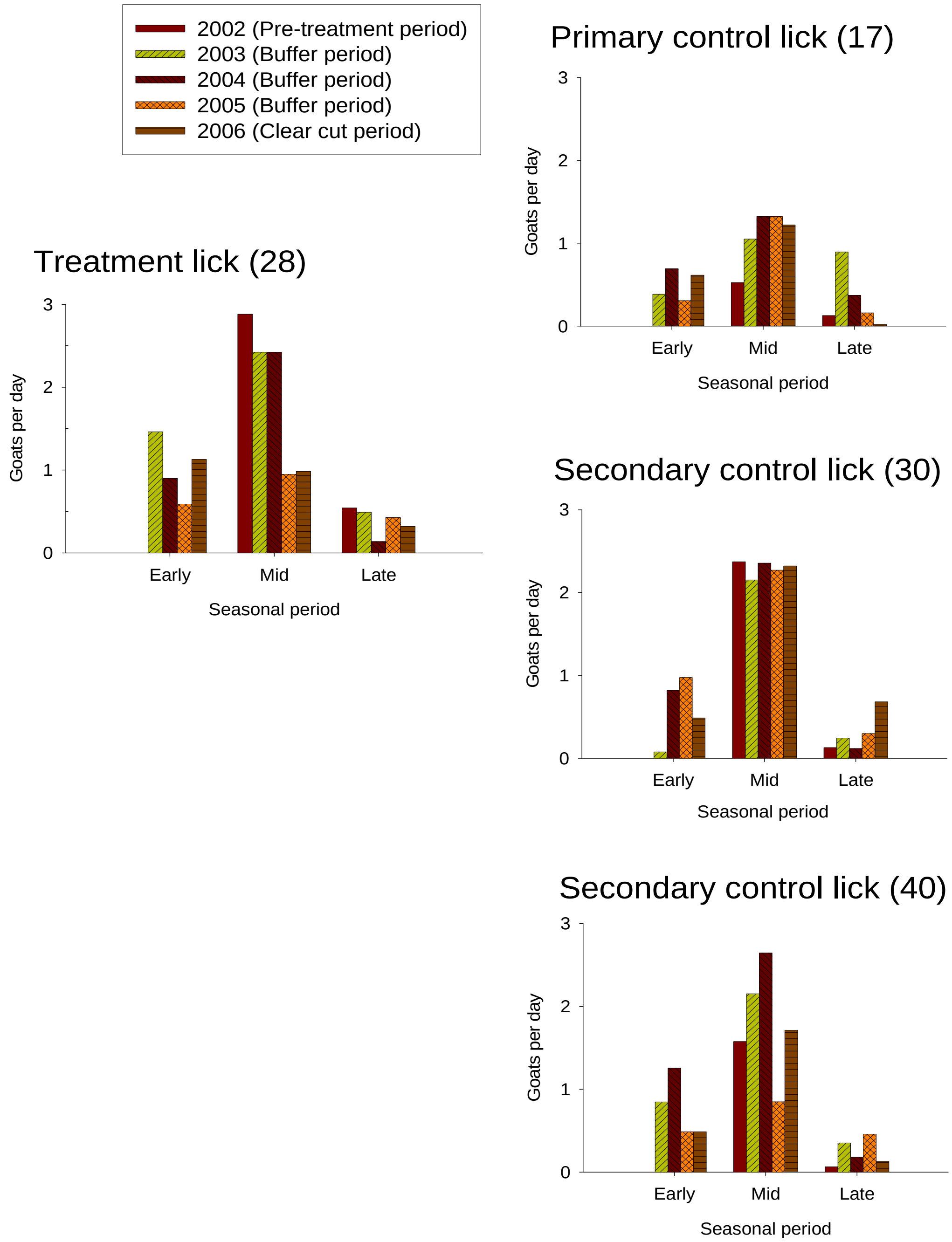


B) Annual leaf flush

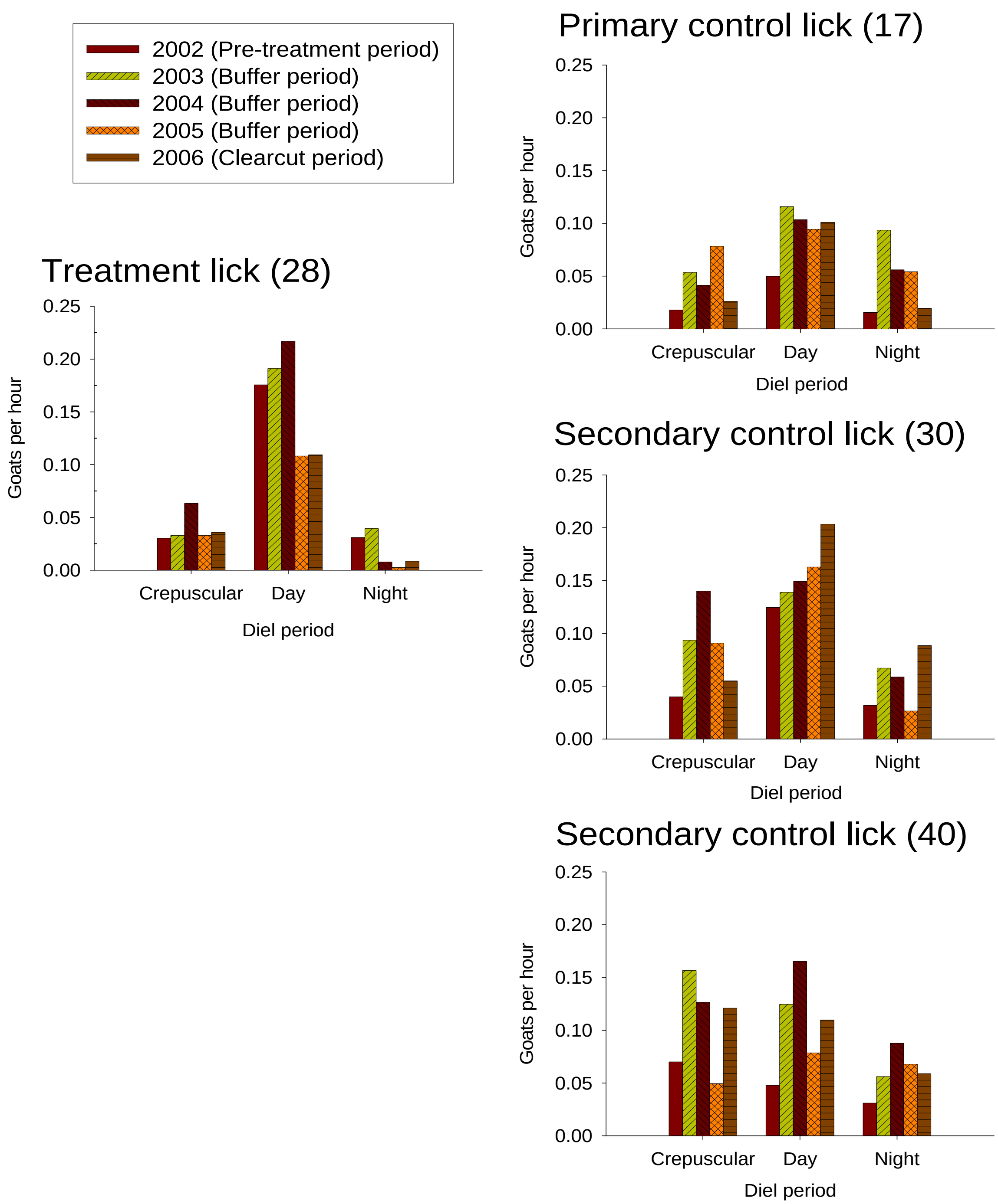


Appendix H: Effect of year (as indicator of treatment period) on a) seasonal trail use and b) diel patterns of trail use by all mountain goats travelling down the access trails to the 4 study licks in the lower Ospika River drainage, 2002-2006. Seasonal periods were early (31 May – 29 June), mid (30 June – 28 Aug), and late (29 Aug – 30 Nov). Diel periods were crepuscular (±1 hr from sunrise and sunset), day, and night.

A) Seasonal trail use

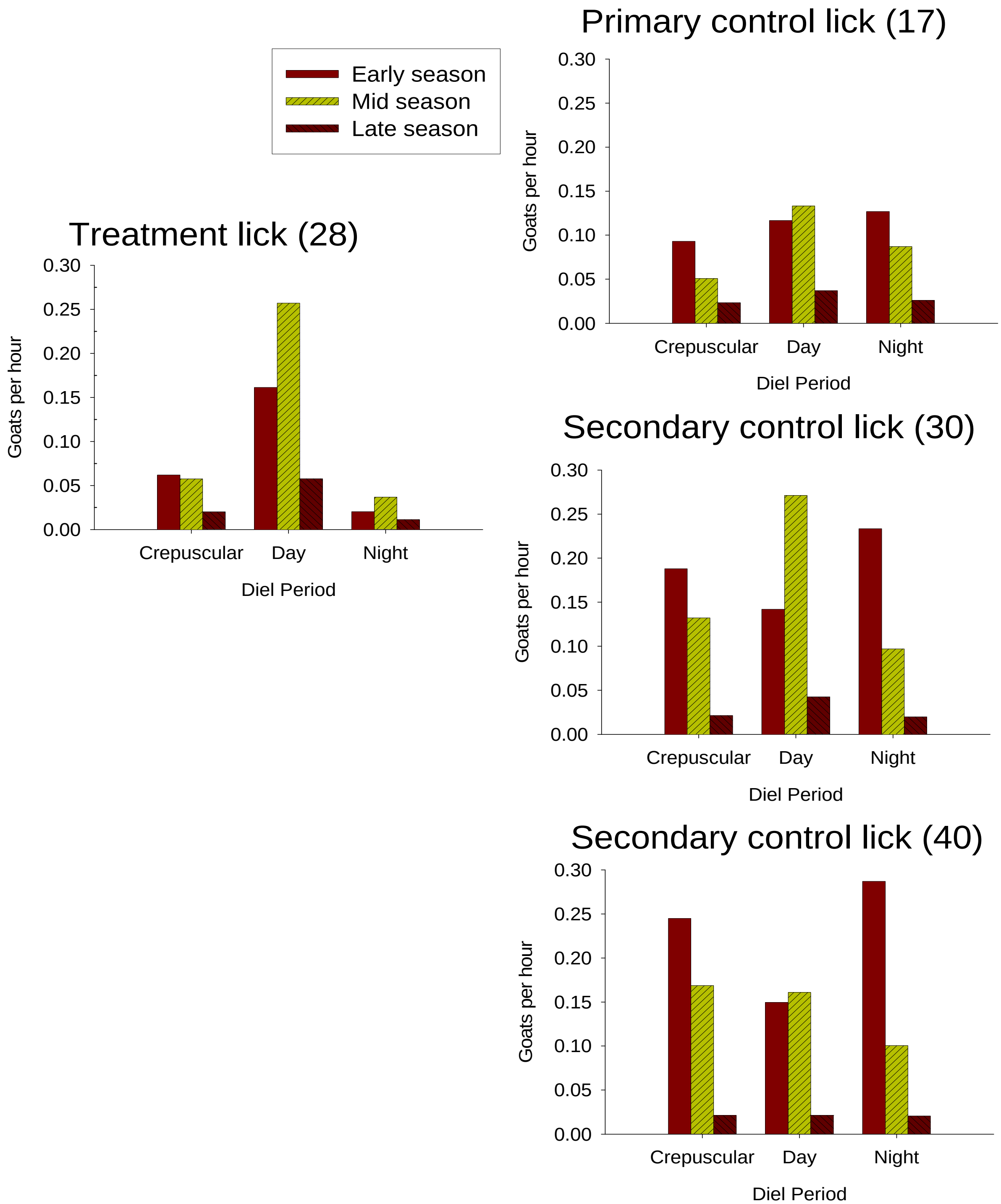


B) Diel patterns of trail use

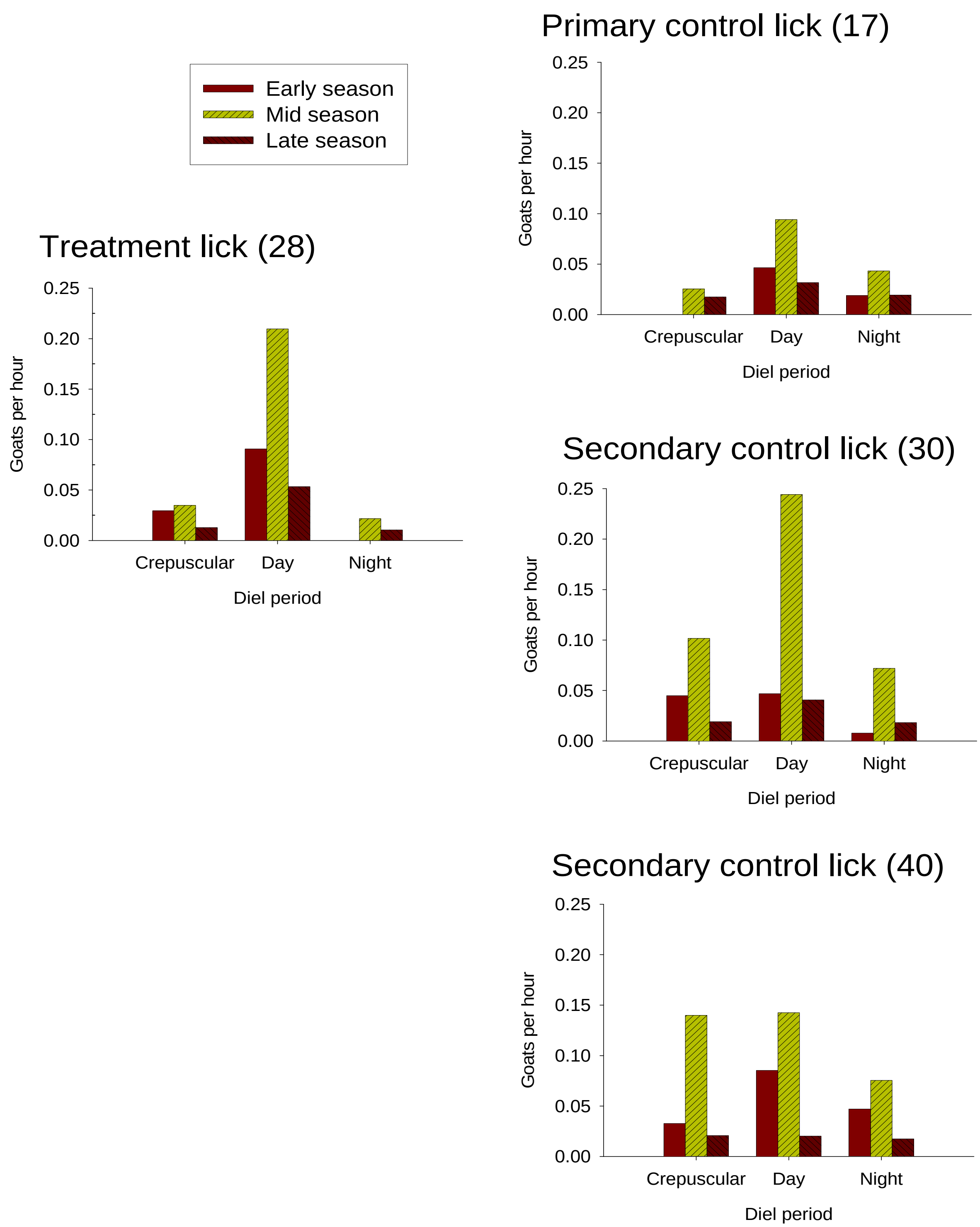


Appendix I: Effect of season on diel patterns of trail use (down and up movements combined) by a) all mountain goats and b) goats with kids accessing the 4 study licks in the lower Ospika River drainage, April to November, 2002-2006. Seasonal periods were early (31 May – 29 June), mid (30 June – 28 Aug), and late (29 Aug – 30 Nov). Diel periods were crepuscular (±1 hr from sunrise and sunset), day and night.

A) All mountain goats

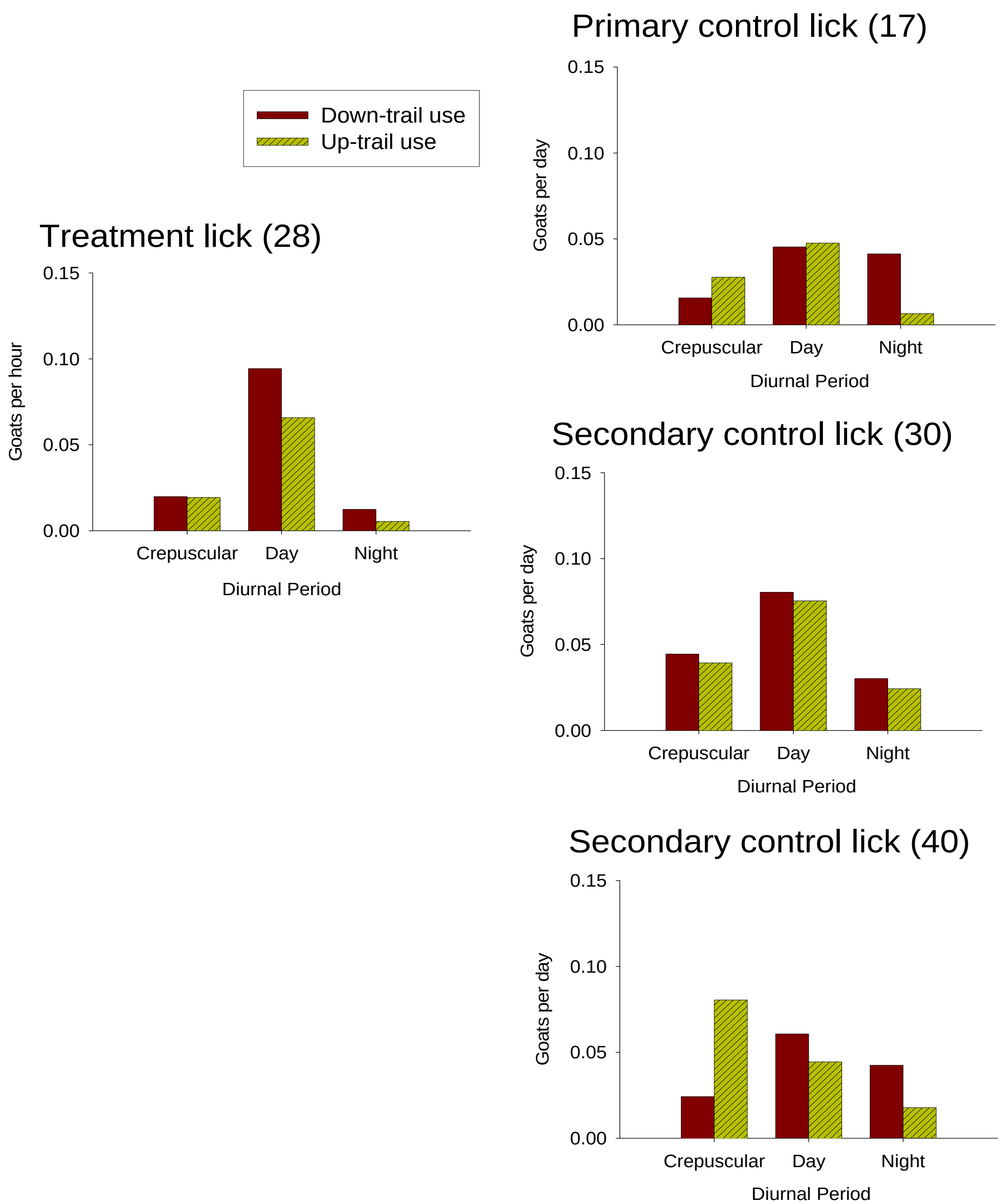


B) Mountain goats with kids

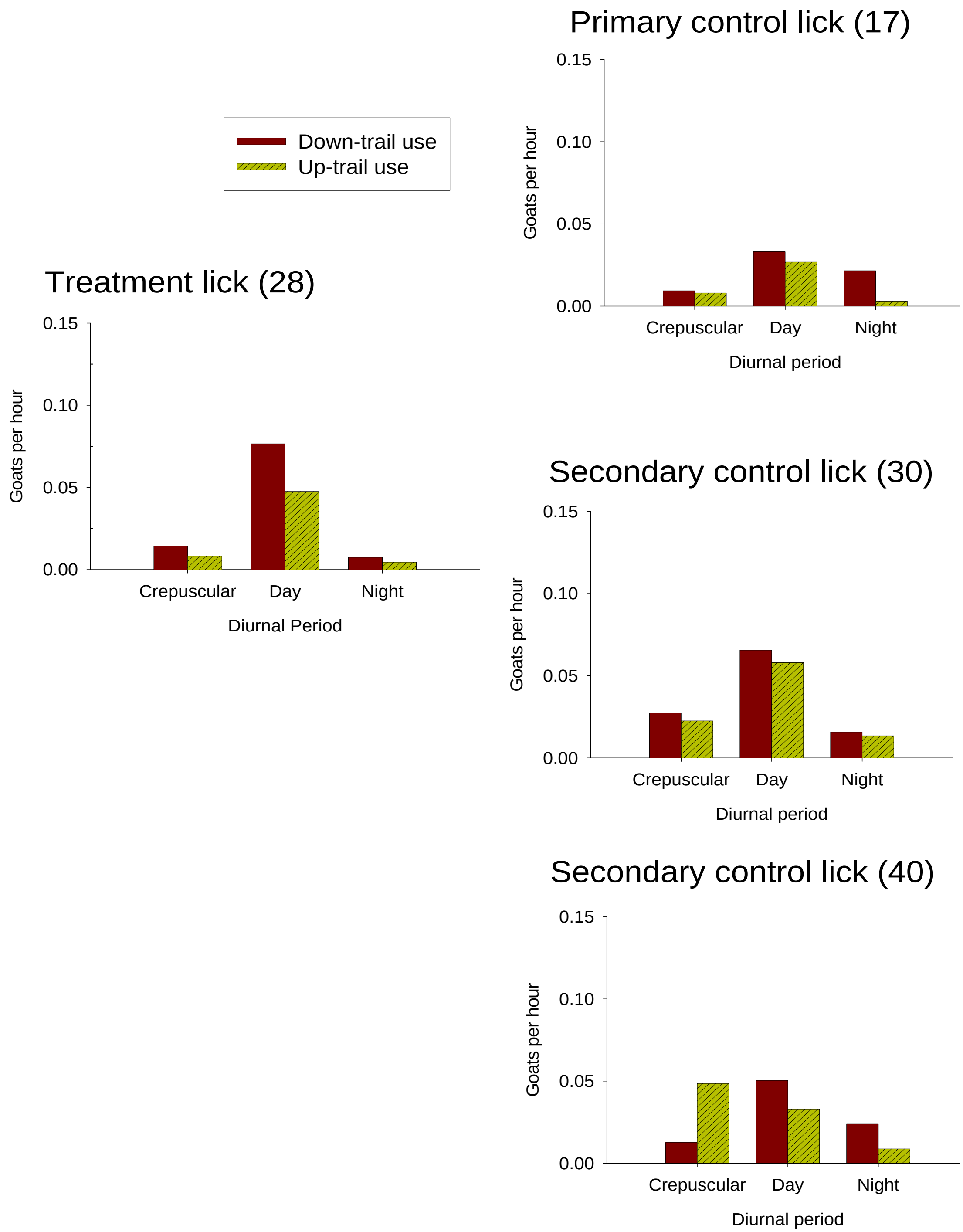


Appendix J: Effect of travel direction (down trail vs. up trail) on diel patterns of trail use by a) all mountain goats and b) goats with kids accessing the 4 study licks in the lower Ospika River drainage, 2002-2006. Diel periods were crepuscular (±1 hr from sunrise and sunset), day and night.

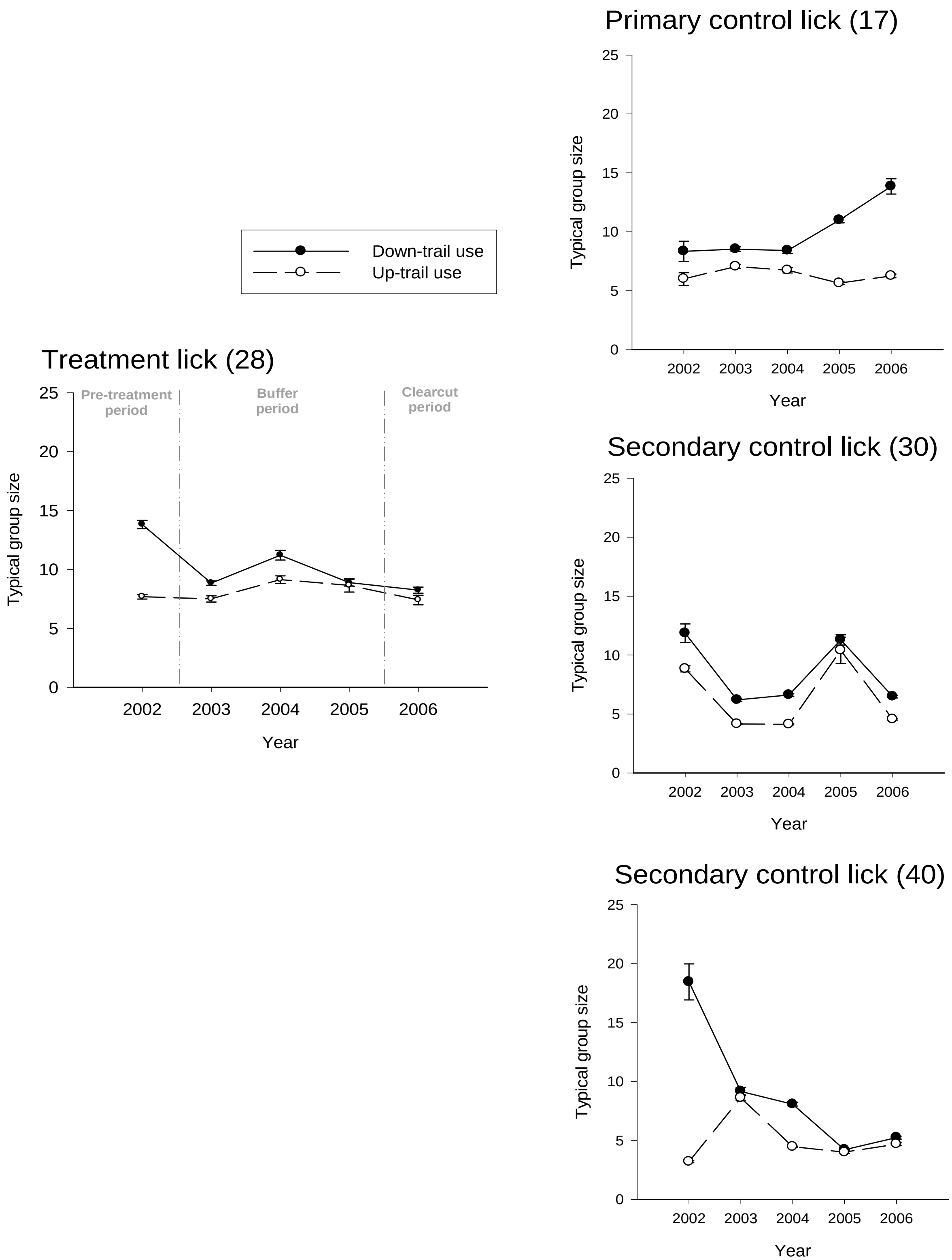
A) All mountain goats



B) Mountain goats with kids

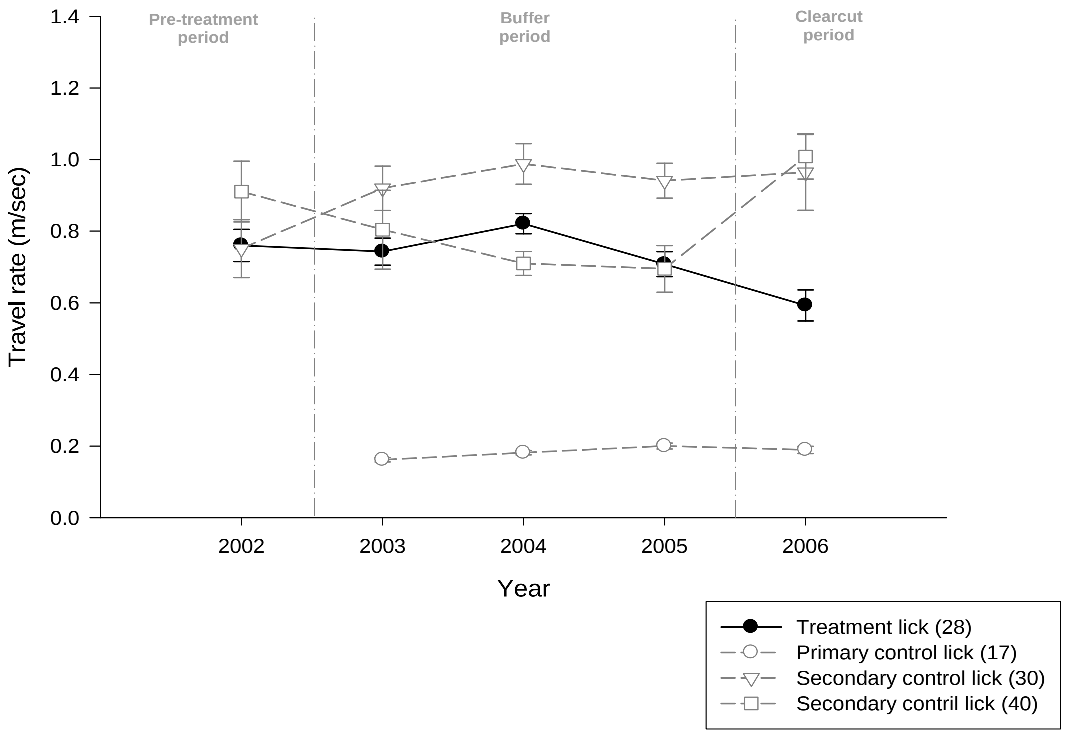


Appendix K: Annual variation in the typical group size (Jarman 1974) of mountain goat groups, by travel direction, photographed using trails to the 4 study licks in the lower Ospika River drainage, 2002-2006. Standard error bars were calculated with a jackknifed estimate of variance (Tukey 1958).

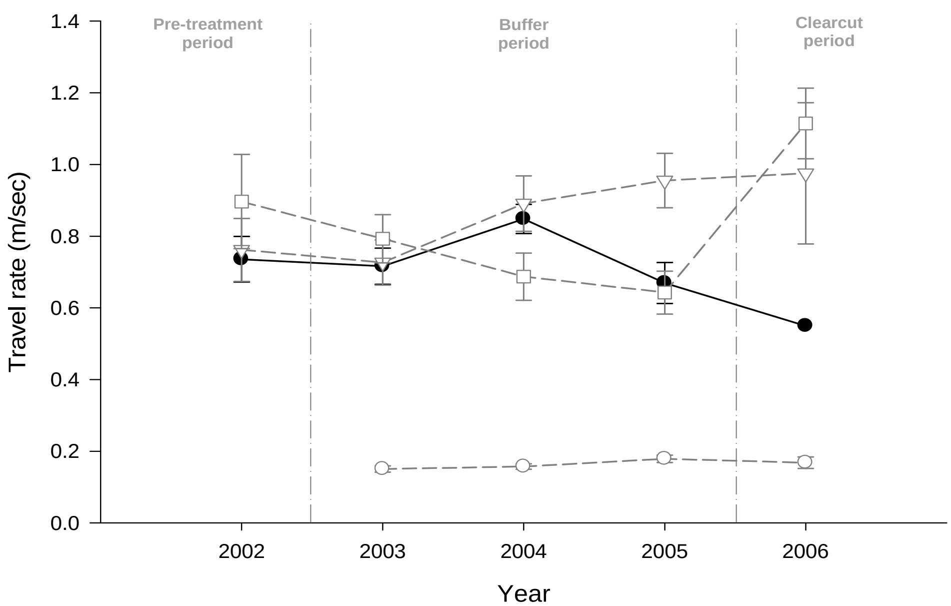


Appendix L: Annual variability in the travel rate, (A) all mountain goat groups and (B) mountain goat groups with kids, along access trails to the 4 study licks in the lower Ospika River drainage, 2002-2006. Trail distances sampled at each lick varied between 310 m at Lick 40 and 1,530 m at Lick 17.

A. All mountain goats



B. Mountain goat groups with kids



Appendix M: Capture and aerial-telemetry monitoring data, by goat type, year and season (non-winter – Apr to Nov; winter: Dec to Mar), for the 29 radio-collared mountain goats studied in the lower Ospika River drainage, March 2002 to November 2007.

		Date of	Date of		Mortality	2001	2002		2003		2004		2005		2006		2007	
Goat type	Goat id[a]	1st capture	2nd capture	Last alive	date	Winter	Non-winter	Winter	Non-winter	Winter	Non-winter	Winter	Non-winter	Winter	Non-winter	Winter	Non-winter	Total
L17	F05	9-Mar-02	21-Jun-05			1	14	5	11	11	11	4	14	2	5	5	11	94
	F12	11-Mar-02	27-Mar-05	11-May-05	12-May-05	1	15	6	11	11	11	5	2					62
	F21	27-Mar-02		29-Jan-04	10-Feb-04	1	16	6	11	6								40
	F59	21-Mar-04								2	11	4	13	2	5	5	11	53
	F60	21-Mar-04								2	11	4	14	2	5	5	11	54
	F61	21-Mar-04								2	11	4	13	2	4	5	11	52
	M10	11-Mar-02	9-Apr-05			1	15	6	10	11	11	4	14	2	5	4	11	94
	M11	11-Mar-02		28-Oct-04	17-Dec-04	1	15	5	11	11	9	1						53
	M22	27-Mar-02	21-Jun-05	17-Sep-05	3-Nov-05	1	15	6	12	11	11	4	10					70
	M32	30-Oct-02		22-Jul-06	22-Jul-06		2	6	12	11	11	4	13	2	1			62
	M62	28-Mar-05		11-Apr-07	29-Apr-07							1	12	2	5	6	1	27
L17 goats total						*6*	*92*	*40*	*78*	*78*	*97*	*35*	*105*	*14*	*30*	*30*	*56*	*661*
L28-30-40	F06	10-Mar-02	3-Jul-06			1	15	5	13	11	11	4	13	2	6	4	11	96
	F07	10-Mar-02				1	14	6	13	11	11	4	13	2	5	5	11	96
	F17	27-Mar-02	1-Mar-06			1	14	6	12	13	10	4	13	2	4	5	11	95
	F19	27-Mar-02				1	15	6	12	11	11	4	13	2	5	5	11	96
L28-30-40 goats total						*4*	*58*	*23*	*50*	*46*	*43*	*16*	*52*	*8*	*20*	*19*	*44*	*383*
L28-only	F03	9-Mar-02	20-Oct-05			1	15	6	13	12	11	4	13	2	5	5	14	101
	F08	10-Mar-02		4-Jan-05	10-Mar-05	1	15	6	14	12	11	3						62
	F09	10-Mar-02		20-Oct-05		1	15	6	14	12	11	4	13	2	5	4	14	101
	F65	21-Jun-05		8-Oct-07	11-Nov-07								11	2	5	4	14	36
	F67	21-Jun-05											11	2	5	4	14	36
	F69	22-Jun-05											11	2	5	5	14	37
	M13	26-Mar-02		15-May-04	31-May-04	1	15	5	14	12	2							49
	M64	15-Apr-05		26-Jun-06	26-Jun-06								13	2	2			17
	M68	22-Jun-05											11	2	5	5	14	37
L28-only goats total						*4*	*60*	*23*	*55*	*48*	*35*	*11*	*83*	*14*	*32*	*27*	*84*	*476*
L30-40	F20	27-Mar-02	22-Jul-06			1	14	6	13	12	11	4	13	2	6	4	11	97
	M16	27-Mar-02	22-Jul-06			1	14	6	13	12	11	4	13	2	6	4	11	97
	M18	27-Mar-02		5-Jan-04	24-Jan-04	1	14	5	13	4								37
L30-40 goats total						*3*	*42*	*17*	*39*	*28*	*22*	*8*	*26*	*4*	*12*	*8*	*22*	*231*
No lick	F63	9-Apr-05		27-Mar-07	29-Apr-07								13	2	5	4	1	25
	M01	9-Mar-02		4-Jan-05	10-Mar-05	1	15	6	12	12	8	3						57
No-lick goats total						*1*	*15*	*6*	*12*	*12*	*8*	*3*	*13*	*2*	*5*	*4*	*1*	*82*
All monitored goats						18	267	109	234	212	205	73	279	42	99	88	207	1,833

[a] F = female, M = male.

Appendix N: Effect results of Before-After Control Impact (BACI) analyses of response variables for mountain goats using the treatment (Lick 28) and primary control (Lick 17) lick complexes, and their associated access trails, in the lower Ospika River drainage, 2002-2007. Bold text indicates significance (alpha = 0.05).

Response variable	Analysis approach and parameters	Effect	Df	*F*	*P*
Mean number of lick visits	GLMM[a], random effects, Poisson distribution	**Goat type**	2	14.92	**<0.0001**
		Period	2	4.44	**0.0146**
		Treatment	4	0.34	0.8510
Mean time (hr) spent per visit	GLMM, random effects, gamma distribution	**Goat type**	2	19.15	**<.0001**
		Period	2	2.07	0.1931
		Treatment	4	1.5	0.2038
Mean total time (hr) at licks	GLMM, random effects, gamma distribution	**Goat type**	2	8.18	**0.0020**
		Period	2	1.15	0.3814
		Treatment	4	1.88	0.1255
Displacement lick use (proportion of visits at treatment lick and secondary control licks) for L28-30-40 goats	GLMM, random effects, binary distribution	Period	2	1.70	0.2903
Trail fidelity - DOWN trail	GLMM, random effects, binary distribution	Goat type	2	0	0.9997
		Period	2	0	0.9998
		Treatment	4	0.03	0.9978
		Year (period)	2	2.33	0.0997
Trail fidelity - UP trail	GLMM, random effects, binary distribution	Goat type	2	0.4	0.6715
		Period	2	1.79	0.1693
		Treatment	4	1.01	0.4002
		Year (period)	3	7.47	**<.0001**

[a] GLMM: Generalized Linear Mixed Model

Appendix O: Differences in least square means for effect categories from Generalized Linear Mixed Model analyses of response variables for mountain goats using mineral licks, and their associated access trails, at the treatment (Lick 28) and primary control (Lick 17) licks in the lower Ospika River drainage, 2002-2007. Bold text indicates test was significant (alpha = 0.05).

Response variable	Effect	Category 1	Category 2	Estimate	SE	*t*	*P*	Lower 95%	Upper 95%
Mean number of lick visits	Goat type	L17	L28	0.16	0.17	0.97	0.3424	-0.18	0.51
		L17	**L28-30-40**	**1.89**	0.34	5.48	**<.0001**	1.20	2.57
		L28	**L28-30-40**	**1.73**	0.35	4.93	**<.0001**	1.03	2.42
	Period	Pre-treatment	Buffer	-0.06	0.25	-0.23	0.8161	-0.55	0.44
		Pre-treatment	**Clearcut**	**0.76**	0.34	2.25	**0.0272**	0.09	1.42
		Buffer	**Clearcut**	**0.81**	0.28	2.93	**0.0044**	0.26	1.37
Mean time (hr) spent per visit	Goat type	**L17**	**L28**	**-0.96**	0.17	-5.74	**<.0001**	-1.30	-0.61
		L17	**L28-30-40**	**-1.07**	0.30	-3.58	**0.0006**	-1.67	-0.48
		L28	L28-30-40	-0.12	0.31	-0.38	0.7047	-0.73	0.50
	Period	Pre-treatment	Buffer	-0.26	0.30	-0.86	0.4276	-1.03	0.51
		Pre-treatment	Clearcut	-0.73	0.37	-1.97	0.0807	-1.57	0.11
		Buffer	Clearcut	-0.47	0.29	-1.60	0.1372	-1.11	0.18
Mean total time (hr) at licks	Goat type	**L17**	**L28**	**-0.88**	0.22	-3.98	**0.0006**	-1.34	-0.42
		L17	L28-30-40	-0.17	0.30	-0.57	0.5737	-0.78	0.44
		L28	**L28-30-40**	**0.71**	0.31	2.32	**0.0289**	0.08	1.35
	Period	Pre-treatment	Buffer	-0.35	0.23	-1.51	0.1996	-0.97	0.27
		Pre-treatment	Clearcut	-0.24	0.28	-0.87	0.4125	-0.91	0.42
		Buffer	Clearcut	0.11	0.21	0.50	0.6337	-0.40	0.61
Displacement lick use (proportion of visits at treatment lick and secondary control licks) for L28-30-40 goats	Period	Pre-treatment	Buffer	-0.05	0.73	-0.07	0.9479	-2.69	2.59
		Pre-treatment	Clearcut	1.44	0.97	1.48	0.1868	-0.92	3.79
		Buffer	Clearcut	1.49	0.81	1.84	0.0967	-0.32	3.30
Trail fidelity - down trail	Goat type	L17	L28	4	194	0.02	0.9826	-378	387
		L17	L28-30-40	8	730	0.01	0.9910	-1431	1448
		L28	L28-30-40	4	755	0.01	0.9958	-1486	1494
	Period	Pre-treatment	Buffer	-8	501	-0.02	0.9868	-996	979
		Pre-treatment	Clearcut	-5	755	-0.01	0.9947	-1495	1485
		Buffer	Clearcut	3	566	0.01	0.9954	-1112	1119
Trail fidelity - up trail	Goat type	L17	L28	-0.4	0.5	-0.89	0.3732	-1.3	0.5
		L17	L28-30-40	-6	126	-0.04	0.9644	-254	243
		L28	L28-30-40	-5	126	-0.04	0.9670	-254	243
	Period	Pre-treatment	Buffer	-1.2	0.6	-1.89	0.0598	-2.4	0.0
		Pre-treatment	Clearcut	-5	126	-0.04	0.9689	-253	244
		Buffer	Clearcut	-4	126	-0.03	0.9763	-252	245

Appendix P: Failed lick visits on the main access trail to the treatment lick by radio-collared mountain goats that exclusively used the treatment lick (i.e., L28-only goats), lower Ospika River drainage, 2002- 2007.

Year	Treatment period	Lick visit attempt (successful visits to L28 that year)	Type of failed visit[a]	Sex of radio-collared goat	Number of goats present[b]	Date	Time	Location reached	Time until return visit	Information
2003	Buffer period (1st year)	3rd (5)	Aborted	Female	1	27-Jul	Evening	R1 rock escarpment	9 days	Goat reached rock escarpment R1, then after ~2.5 hrs went back up trail to Aley escape terrain and beyond.
2005	Buffer period (3rd year)	1st (5)	Aborted	Female	3 (2 radio-collared & 1 unmarked)	29-Jun	Mid-afternoon	Road right-of-way in buffer	12 days	Goats reached the road right-of-way in the buffer but, after milling around the area for ~0.5 hrs, they went back to their high-elevation/alpine habitat.
		Likely 1st (3)	Aborted	Female	3 (2 radio-collared & 1 unmarked)	29-Jun	Mid-afternoon	Road right-of-way in buffer	19 days	Same group as above. Goat had been captured for the first time 8 days prior to the aborted visit.
2006	Clearcut period (1st year)	1st (0)	Mortality	Male	1	25-Jun	Evening	Area between forest edge & R1 rock escarpment (interface of clearcut treatment)	Not applicable (mortality)	Goat travelled down the trail to forest edge/rock escarpment R1 area (i.e., went through camera #7). One or more wolves (1 caught on camera), a few minutes behind and travelling in the same direction, caught up to the goat, chased it for a few minutes, then killed it ~300 m from where the billy had likely left the trail.
		1st (2)	Aborted	Female	≥1 (1 radio-collared & unknown unmarked)	28-Jun	Morning	R2 rock escarpment	42 days	Goat(s) reached rock escarpment R2 but only stayed there for a few minutes before returning to Aley escape terrain and beyond. About 1 hr after she left R2 for the escape terrain, 8 goats (including 3 kids) went to the lick.
		2nd (2)	Aborted	Female	1	22-Jul	Afternoon	Forest edge at clearcut treatment	31 days	Goat made it to the forest edge of the clearcut treatment (i.e., went through camera #7), stayed there for a few minutes, then went back to rock escarpment R2 for ~0.5 hrs before heading back to Aley escape terrain and beyond. At the same time this goat left R2 for the escape terrain, a lone male went to the lick.
		3rd (4)	Interrupted	Female	2 (1 radio-collared & 1 unmarked)	09-Aug	Early morning	Area between forest edge & R1 rock escarpment (interface of clearcut treatment)	11 hours	Goats travelled down the trail to forest edge/rock escarpment R1 area (i.e., went through camera #7) and stayed in area for ~2.5 hrs. She then started towards the lick but, within 5 min, turned back and returned to Aley escape terrain. She returned and successfully reached the lick 11 hrs later, but she took a different route than the study trail; it was unknown if other goats were with her.
2007	Clearcut period (2nd year)	2nd (1)	Aborted	Female	≥2 (2 radio-collared & unknown unmarked)	19-Aug	Late evening	R1 rock escarpment	Not again this season	Goats reached rock escarpment R1, stayed in area for ~6 hrs, then went back to Aley escape terrain and beyond.
		3rd (2)	Aborted	Female	≥2 (2 radio-collared & unknown unmarked)	19-Aug	Late evening	R1 rock escarpment	Not again this season	Same group as above.

[a] Type of failed visits: interrupted (goat returned to lick within 24 hours), aborted (goat did not return to study lick for ≥2 days), and mortality (goat died while attempting to reach lick).
[b] Number of goats present based on camera data.

Appendix Q: Results of the lick-use power analysis based on visit data from mountain goats that used the treatment (Lick 28) and primary control (Lick 17) licks in the lower Ospika River drainage, 2002-2007.

Response variable	Scenario[a] (pre-treatment - buffer - clearcut)	Effort factor[b]	Power to detect treatment effect (lick * period)
Mean number of lick visits per goat	0 - 0.1 - 0.1	1	0.06
		2	0.06
		5	0.09
		10	0.13
	0 - 0.1 - 0.2	1	0.08
		2	0.11
		5	0.22
		10	0.42
	0 - 0.2 - 0.2	1	0.08
		2	0.12
		5	0.25
		10	0.48
	0 - 0.2 - 0.4	1	0.22
		2	0.45
		5	0.88
		10	1.00
	0 - 0.3 - 0.3	1	0.14
		2	0.25
		5	0.60
		10	0.91
	0 - 0.3 - 0.6	1	0.68
		2	0.96
		5	1.00
		10	1.00
	0 - 0.4 - 0.4	1	0.25
		2	0.49
		5	0.91
		10	1.00
	0 - 0.4 - 0.8	1	1.00
		2	1.00
		5	1.00
		10	1.00
	No BACI effects	1	0.05
		2	0.05
		5	0.05
		10	0.05

[a] The decline scenario values indicate the % decline in the original value of the response variable for each goat after each treatment (e.g., 0 - 0.3 - 0.6 indicates a 30% decline after the buffer treatment, followed by another 30% decline [of the original value] after the clearcut treatment, thus resulting in an overall decline of 60% over the 6 years). This decline is additional to the overall decline in the response variable that occurred at both the treatment and primary control licks.

[b] The effort factor is a multiplicative value of the sample size that was used to compute the results of the scenario (e.g., a value of 5 indicates a 5-fold increase in the sample size).

Appendix R: Results of the trail-use power analysis based on down-trail data from mountain goats that used the treatment (Lick 28) and primary control (Lick 17) licks in the lower Ospika River drainage, 2002-2007.

Response variable	Scenario[a] (pre-treatment - buffer - clearcut)	Effort factor[b]	Power to detect treatment effect (lick * period)
Trail fidelity - down trail	0 - 0.1 - 0.1	1	0.12
(proportion of trail use on the trail)		2	0.15
		5	0.39
		10	0.68
	0 - 0.1 - 0.2	1	0.18
		2	0.29
		5	0.65
		10	0.91
	0 - 0.2 - 0.2	1	0.25
		2	0.35
		5	0.72
		10	0.91
	0 - 0.2 - 0.4	1	0.37
		2	0.59
		5	0.92
		10	1.00
	0 - 0.3 - 0.3	1	0.35
		2	0.49
		5	0.87
		10	0.98
	0 - 0.3 - 0.6	1	0.54
		2	0.76
		5	0.97
		10	1.00
	0 - 0.4 - 0.4	1	0.44
		2	0.61
		5	0.92
		10	1.00
	0 - 0.4 - 0.8	1	0.80
		2	0.93
		5	1.00
		10	1.00
	No BACI effects	1	0.05
		2	0.05
		5	0.05
		10	0.05

[a] The decline scenario values indicate the % decline in the original value of the response variable for each goat after each treatment (e.g., 0 - 0.3 - 0.6 indicates a 30% decline after the buffer treatment, followed by another 30% decline [of the original value] after the clearcut treatment, thus resulting in an overall decline of 60% over the 6 years). This decline is additional to the overall decline in the response variable that occurred at both the treatment and primary control licks.

[b] The effort factor is a multiplicative value of the sample size that was used to compute the results of the scenario (e.g., a value of 5 indicates a 5-fold increase in the sample size).