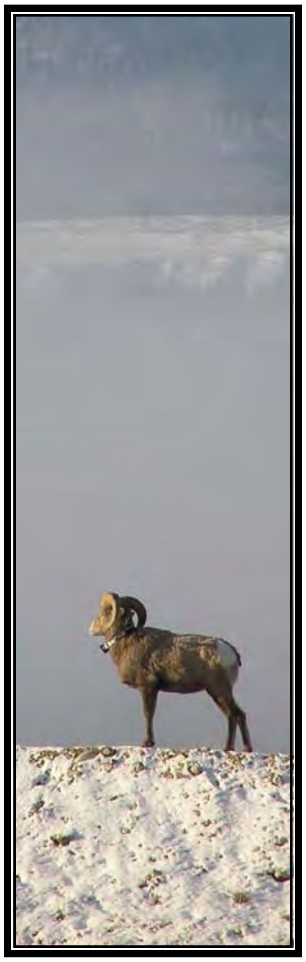

Seasonal Habitat Use and Movement Corridor Selection of Rocky Mountain Bighorn Sheep (*Ovis canadensis*), near Radium Hot Springs, British Columbia. 2002-04 Progress Report.

Alan Dibb
Parks Canada Agency
October 2006

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Introduction

The Radium-Stoddart bighorn sheep (*Ovis canadensis*) herd currently consists of approximately 200 animals (Parks Canada, unpublished data) and historically has fluctuated between approximately 20 and 170 individuals (Stelfox 1990; Parks Canada, unpublished data). Population lows over that period have resulted from disease-induced die-offs (Stelfox 1990). In the last 2 decades this herd has decreased its use of traditional winter ranges on the lower slopes of the Rockies between Sinclair and Stoddart Creeks in favour of human-dominated areas in the valley bottom along the Columbia including the village of Radium Hot Springs, the Springs golf course, and the road allowances of highway 93/95 just south of Radium Hot Springs (Stelfox et al. 1985; Tremblay and Dibb 2004). These changes in winter range use are believed to be due to the loss and degradation of native winter and transitional ranges, degradation of migration routes, human encroachment, the availability of artificial sources of high quality forage and, perhaps, as a means of predator avoidance (Kinley 2003). Associated problems include increased rates of sheep collisions with vehicles (Swan 2005), increased sedentariness, greater potential for disease spread from overcrowding on winter range (Demarchi et al. 2000), and increased habituation to humans (Tremblay and Dibb 2004).

Bighorn sheep in the East Kootenay Trench in south eastern British Columbia depend on open forest and grassland habitats that were historically maintained by frequent, low-intensity ground fires (Demarchi et al. 2000; Kinley 2003). Low elevation, low snowfall open habitats function as critical winter range for bighorns but these habitats are threatened by forest encroachment due to fire suppression over the last century (Davidson 1994). These open habitats are also characteristic of bighorn transitional ranges between winter and summer ranges, and sheep strongly prefer seasonal migration routes with good visibility for predator evasion (Demarchi et al. 2000). However, fire suppression has also been implicated in the growth of dense coniferous forests at these intermediate elevations (Gray 2001; Kinley 2003). This loss or degradation of intermediate ranges is believed to cause sheep to spend more time concentrated on limited winter ranges (Davidson 1994; Kinley 2003), potentially exacerbating problems of disease spread, parasites, vehicle collisions, and overgrazing.

In order to better understand and address the suite of problems associated with bighorn sheep conservation in the Radium Hot Springs area, we began a radio telemetry study in 2002. This study is intended not only to provide insight into the magnitude and spatial characteristics of these problems, but also to measure the response of bighorn sheep to management actions intended to improve the situation. In particular, the 4 main objectives for this study are:

- to determine both specific routes and general habitat types used by sheep moving through transitional ranges between low-elevation winter range and alpine summer range. This will guide the locations of future ecosystem restoration projects in mid-elevation transitional ranges,
- to determine to what extent sheep use ecosystem restoration sites before and following restoration work,
- to document sites of concentrated sheep activity that can be correlated to lambing locations, mineral licks and other point-source habitat features, so that these sites can be considered in land-use planning decisions relating to recreation, forestry road construction, and municipal expansion, and
- to gain preliminary indications of whether there is any population exchange with nearby herds.

This report covers a 3 year period (2002-2004) of what is expected to be at least a 5 year study. Preliminary results are presented on all major objectives, based on results of GPS radio telemetry monitoring of 10 adult animals of both sexes in each year of the study.

This study is an outcome of the Bighorn in Our Backyard (BIOB) project, a cooperative public education, research and management initiative intended to raise public awareness and support for bighorn conservation. For more information on BIOB the reader is referred to Osprey Communications (2003, 2004, 2005) and Dubois et al. (2004). Several other reports and papers are linked to this research or to the Radium-Stoddart bighorn sheep, including summary reports on the first 2 years of the study (Kinley 2002, 2003), a report discussing the wild sheep – domestic sheep issue in the East Kootenay region (Zehnder and Adams 2002), a report on the “Mile Hill” sheep highway mortality problem (Swan 2005), a paper on modeling and restoration of Radium sheep habitat (Tremblay and Dibb 2004), a paper providing a description of ecosystem restoration activities at Radium Hot Springs (Dibb 2004), and 2 reports summarizing vegetation monitoring at the Radium Hot Springs Redstreak restoration site (Page 2004, 2005).

Study Area

The study area encompasses approximately 700 square kilometres in the Stanford and Brisco Ranges of the Rocky Mountains near Radium Hot Springs in south-eastern British Columbia, and is centred on 50^{o} 38' N, 116^{o} 0' W. This area extends from the community of Windermere in the south to the community of Spillimacheen in the north, and is bounded to the west by the Columbia River and to the east by the Kootenay River (Figure 1). We defined the study area as the collective year-round home ranges of study animals, all of which were initially captured on sheep winter ranges at or near the village of Radium Hot Springs. Elevations range from just below 800 metres at the Columbia River to nearly 2,800 metres at the highest summits of the mountain ridges. Approximately one-third of the study area is within Kootenay National Park, with most of the rest occurring on B.C. provincial crown lands. Important areas of winter range also occur on private, municipal, and First Nations lands in the Columbia Valley.

Climate is characterized by a transition from low precipitation and relatively warm conditions in valley bottoms to higher precipitation and cool temperatures at higher elevations (Achuff et al. 1984). Mean annual temperatures range from approximately 5.0^{o}C near the valley bottom at Radium Hot Springs to 1.6^{o}C at Sinclair Pass at 1370 m elevation (Janz and Storr 1977). Mean annual precipitation is 366 mm at the Kootenay West Gate near Radium Hot Springs, and is 608 mm at Sinclair Pass. No climate data is available from alpine regions within the study area, but mean annual temperatures are expected to be lower than at lower elevations and mean annual precipitation amounts are expected to be higher (Achuff et al. 1984).

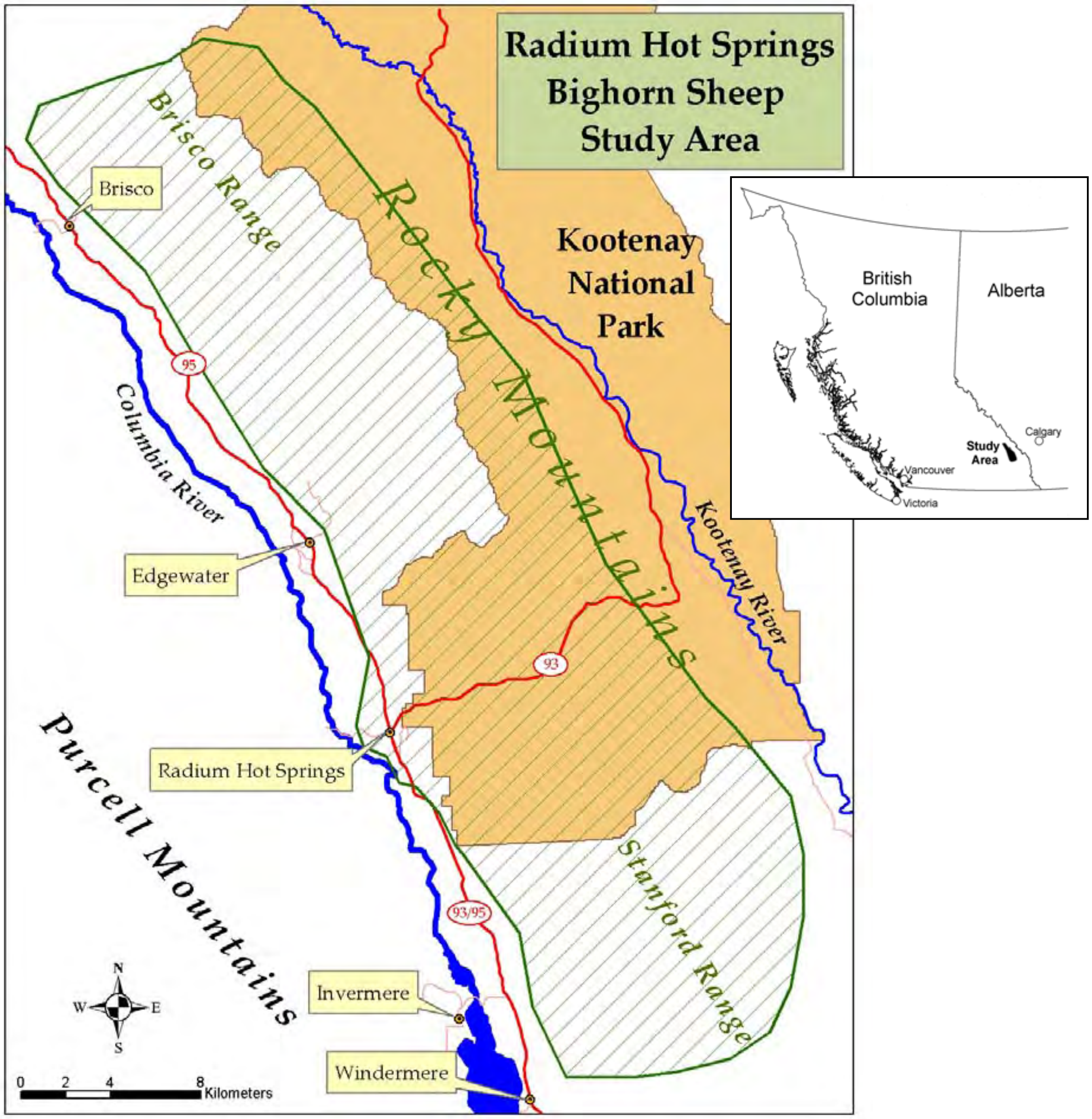

Figure 1. Radium Hot Springs bighorn sheep study area.

Four biogeoclimatic zones occur within the study area including Interior Douglas Fir (IDF) and Montane Spruce (MS) in the valley bottoms, Engelmann Spruce – Subalpine Fir (ESSF) at mid-elevations, and alpine tundra (AT) at higher elevations (Meidinger and Pojar 1991). Lower elevation forests are dominated by Douglas fir (*Pseudotsuga menziesii*), white spruce (*Picea glauca*), and aspen (*Populus tremuloides*) and are interspersed with patches of grassland (Achuff et al. 1984). Upper-elevation forests are dominated by white spruce, Engelmann spruce (*Picea engelmannii*), hybrids of these 2 species, and by subalpine fir (*Abies lasiocarpa*). Stands of alpine larch (*Larix lyallii*) and whitebark pine (*Pinus albicaulis*) also occur at some high elevation sites. Seral forests of lodgepole pine (*Pinus contorta*) occur after fire, except near tree line. Tree line occurs at approximately 2300 metres. Plant communities in the alpine tundra zone form a fine scale mosaic in which microclimate variations produce marked changes in dominant species (Achuff et al. 1984). However, much of the alpine zone consists of unvegetated rock outcroppings, cliffs, talus and scree.

Wildlife mortality records from Kootenay National Park (Parks Canada, unpublished data) suggest that cougars (*Puma concolor*) and coyotes (*Canis latrans*) are the main predators of bighorn sheep in the study area. Other predators present include wolves (*Canis lupus*), grizzly bears (*Ursus arctos*), black bears (*U. americanus*), wolverines (*Gulo gulo*), lynx (*Lynx canadensis*), bobcat (*Lynx rufus*), and golden eagle (*Aquila chrysaetos*). Approximately 6,000 permanent human residents occupy the Columbia Valley along the western edge of the study area, including about 700 permanent residents of the village of Radium Hot Springs. However, there is additionally a large population of seasonal residents and a growing tourism industry. Provincial highways 93 and 95 cross the study area both north-south and east-west. While human settlement is centred on the Columbia Valley, recreational activities occur broadly throughout the study area, in part using access created by a network of logging roads. Some high elevation watersheds and ridge crests remain relatively difficult to access. Trophy hunting of bighorn rams under a limited entry quota system occurs in the fall (outside of the national park), and harvest levels in the provincial wildlife management unit that includes the study area average around 3% annually (B.C. Ministry of Environment, unpublished data).

Methods

Capture and Collar Deployment

We captured sheep and fitted them with GPS radio collars each year from 2002 through 2004 while the sheep occupied their winter range at Radium Hot Springs, B.C. We captured study animals by darting with immobilization drugs after searching for groups of sheep located in gentle terrain and away from hazards such as highways, rivers, and cliffs. We generally selected adult sheep that appeared to be in good physical condition and we aimed for a ratio of approximately two-thirds ewes to one-third rams. We selected rams with horn curl of between one-half to three-quarters curl, and estimated at 4.5 to 7.5 years of age. Where practical we avoided capturing more than 1 animal from the same group. We immobilized free-ranging sheep most frequently using a combination of Xylazine-Ketamine, but occasionally using Xylazine-Telazol, Ketamine-Medetomidine, or Telazol-Xylazine.

We collected several samples and measurements from all study animals at the time of capture, except where high or increasing levels of animal alertness precluded it. We collected faecal pellets for parasite load testing, and blood samples for disease testing and archival purposes for future DNA studies. We estimated animal age by counting horn annuli and assessing tooth wear and eruption, and we carried out a variety of anatomical measurements. Processing of animals, including time required for immobilization to take effect, usually required from 25 to 55 minutes, after which we administered reversal agents. The Parks Canada Wildlife Veterinarian (Dr. Todd Shury) or a biologist with vast experience capturing and handling bighorn sheep (Ian Ross, ARC Wildlife) attended captures. Capture and handling methods are described in more detail by Kinley (2002).

Telemetry

All study animals were fitted with GPS radio collars (Advanced Telemetry Systems, Isanti, Minnesota, USA) which weighed approximately 950 g and included a very high frequency (VHF) transmitter as well as a 12-channel Garmin (Olathe, Kansas, USA) GPS engine. We programmed these collars to log GPS location data on a schedule intended to allow their deployment for up to 12 months, at least covering the period from just prior to study animals leaving their winter range in spring to just after the animals return to their winter range in the fall. In the first year of the study (2002) we programmed the collars to attempt to collect points every 8 hours and 30 minutes from December through March, and at 4 hour and 15 minute intervals during the rest of year. This schedule was based on the assumption that sheep would travel more during spring, summer and fall, and therefore a more frequent sampling frequency would be beneficial during those periods in order to detect movement routes. Based on the first year's results we altered the schedule in years 2 through 3 (2003-04) to collect points at intervals of 12 hours and 48 minutes from November through April, and at intervals of 2 hours and 8 minutes in other months. Once animals had returned to their winter range we released the collars using a remote release mechanism, and downloaded data from the collar's GPS memory to a computer using a serial port cable. We then returned the collars to the manufacturer for refurbishment in preparation for the next field year. Thus, there was a period of approximately 2 months each winter during which no animals wore radio collars, except for occasional animals whose collar release mechanisms malfunctioned, delaying collar removal.

The radio collar VHF function was active from 0800 hours to 1700 hours local standard time each day. We attempted to receive VHF signals from each study animal at least once per week to check for mortality signals and GPS function status through a coded pulse pattern. We attempted to visually locate each animal periodically in order to verify that the collars were not causing injury to the sheep, to collect group composition data, and to verify reproductive status of collared ewes. VHF telemetry was also used to triangulate animal locations periodically as a source of backup data in case of GPS collar failure. In practice, the lack of access and the complexity of terrain in the study area made it difficult to obtain accurate VHF fixes on study animals except when the animals were close to highways, mainly while on their winter range.

All GPS location data was collected subsequent to the removal of the Selective Availability feature of the US military global positioning system (GPS); consequently, horizontal positional accuracy is generally expected to be within 10 metres of the true location 95% of the time under clear tracking conditions (Geographic Data B.C. 2001), although there may be decreases in accuracy in areas where the sky view is obstructed by terrain features or forest cover. D'Eon et al. (2002) investigated GPS radiotelemetry error in mountainous terrain in south eastern British Columbia and found mean location errors of 28.2 m (n = 487) for 2-D fixes and 9.1 m (n = 5712) for 3-D fixes; we expected similar location errors in our study. The potential for habitat bias in our location data was explored by measuring the fix rates of a sample of collars in a variety of habitat types with varying canopy closure, tree size, and other forest structural attributes.

Mortality

Radio collars were equipped with a mortality function in which a coded VHF signal is emitted if the animal has not moved within a 4 hour time period. We monitored VHF signals several times per week to detect mortality events soon after their occurrence. For animal mortalities that were not promptly confirmed in the field, we estimated date of death by examining GPS location data and determining the date after which no movements occurred greater than the expected positional accuracy of GPS locations.

We estimated survival rates using the Kaplan-Meier estimate, modified for staggered-entry of new animals (Pollock et al. 1989). The survivorship function and 95% confidence intervals were calculated and plotted using weekly intervals to tabulate entry of new animals, mortality, and censoring of animals. Due to relatively small sample sizes no attempt was made to calculate male and female survivorship separately. We calculated annual survivorship as the n^{th} root of the cumulative weekly survivorship, where n is the number of years.

Lamb Production and Lambing Areas

We determined lamb production by using VHF telemetry to visually locate radio collared females with lambs in all seasons. A ewe-lamb relationship was considered to be maternal if suckling behaviour was observed, or if the ewe-lamb pair maintained spatial proximity over a period of at least 30 minutes while foraging or travelling. Observations during lambing season were made using spotting scopes from distances of up to 2.5 kms. During summer we hiked into sheep alpine range and observed sheep at various distances, but typically less than 500 metres. During fall, after the sheep had descended to their winter range, we easily observed sheep at close range, although ewe-lamb bonds were expected to be somewhat weaker as weaning progressed (Geist 1971).

Home Ranges, Seasonal Ranges, and Migratory/Dispersal Movements

We estimated individual study animal home range sizes using both 100% minimum convex polygons and a 90% fixed kernel density function using the Animal Movement extension (Hooge and Eichenlaub 1997) within ArcView GIS software (ESRI Version 3.3, 2002). Only animals whose collars collected points at least from late winter (late April) through summer to early winter (late October) were included in home range size estimation.

The spatial extent and timing of use of seasonal ranges were determined by plotting telemetry points, colour-coded by month, on study area maps and looking for clusters. We made a particular effort to determine whether the sheep used distinct rutting (November – December) and mid-winter ranges (January – February). We subdivided a map of the rut-winter range into 5 sub-areas, tallied the points in each season in each sub-area, and then conducted chi-square tests to assess the level of significance of any differences in the numbers of telemetry points recorded in each area in each of the 2 seasons.

We determined bighorn sheep movement routes by considering sequences of telemetry points for each study animal. Qualitative evidence of the use of migration routes was obtained by locating well-used game trails, and by using remote cameras to record photographs of sheep on these trails. Using these information sources we identified a network of 27 location node, mainly at mountain peaks, ridge crests, mineral licks and valley bottom sites well used by sheep, with an average of about 5 kms separating nodes. We used a Geographic Information System (GIS) to graphically depict lines connecting consecutive telemetry points. The extent to which a route (edge) between nodes functioned for sheep movement was estimated by tallying the number of telemetry point sequences which traversed at least half the edge between 2 consecutive points. Thus, some areas used very intensively as habitat by sheep did not emerge as movement routes because sheep rarely traveled rapidly through such areas. We also identified such habitat areas using 90% (females) and 95% (males) kernel density functions. We categorized movement events as “summer”, extending roughly from mid-May through October, and “winter”, extending from November through mid-May. A simplified schematic diagram of the study area was produced, with line thickness between nodes being proportional to the frequency of use, and categorized by sex and season.

Domestic Sheep Issues

We considered the potential for close contact between bighorns and domestic sheep using bighorn telemetry points and the locations of known domestic sheep ranches. Ranch locations were available as a product of a domestic sheep landowner contact program intended to identify and mitigate potential domestic-wild sheep conflict situations (D. Zehnder, personal communication; Zehnder and Adams 2002). We mapped domestic sheep ranch locations using a GIS, then tallied the number of wild sheep telemetry points within 2 and 5 kilometre buffers.

Use of Kootenay National Park Versus Out of Park Areas

The extent to which bighorns use KNP may have important implications for bighorn sheep management, including the setting of hunting regulations and quotas. Using a GIS we tallied the number of sheep telemetry locations within a vectorized representation of the KNP boundary, using a maximum of one point per animal per day. We conducted separate analyses for males and females and considered time frames ranging from all year to individual months.

Use of Terrain

We considered 3 different measures of bighorn sheep use of terrain: elevation, slope steepness, and aspect. Since sheep are sexually segregated most of the year, we conducted separate analyses for males and females. We used one GPS location per day per animal in these analyses. We computed average elevation over the whole year, by season, and by month, and conducted statistical significance testing on male versus female differences using Chi-square tests. We plotted elevation versus date charts for individual sheep to examine the abruptness of altitudinal migrations and use of "intermediate" ranges. We also determined the dates at which individual male and female sheep began their biannual altitudinal migrations.

We derived the slope (in degrees) at each daily telemetry point from a 30 metre resolution digital elevation model (DEM) using the Spatial Analyst extension of ArcGIS (ESRI Version 9.0, 2005) software. We compared average slope selected by males and females over various time periods. We also investigated whether sheep preferred to be within or close to certain slope classes at certain times of the year. We used a GIS to create polygons enclosing all slopes greater than 18^o, 27^o, and 35^o, and then created a second set of polygons that included 150 metre buffers around these same slope classes. We used Chi-square tests to compare the occurrence of telemetry points inside and outside each slope polygon with the proportions of randomly placed points inside and outside. For these analyses we considered summer or winter points within a core range defined by the 90% fixed kernel density function of telemetry points for that season and for that sex. We also examined slope preferences of males and females at a much larger spatial scale encompassing the 100% Minimum Convex Polygon around all animals' daily locations.

The aspect at each daily telemetry point also was derived from a 30 metre resolution DEM using Spatial Analyst. For each sex we calculated the percentage of daily locations in each of 8 45^o aspect classes for 5 different seasons:

- Winter Jan – Apr
- Spring May – Jun
- Summer Jul – Sep

- Fall Oct
- Rut Nov - Dec

We tested for selection of certain aspects by comparing use (# telemetry points in each aspect class) to availability (# of randomly located points in each aspect class).

Use of Mineral Licks

The locations of mineral sites for sheep were known or suspected from historical records and direct observations, and were previously reported by Stelfox et al. (1985). We attempted to verify these sites and search for previously unrecorded sites by examining mapped telemetry point sequences and identifying concentrated areas of sheep use.

For verified mineral sites we tallied the number of sheep travel episodes leading to those sites for each sheep. However, sheep visits to mineral licks can be very brief (Geist 1971) so even GPS collars programmed to collect points every 2 hours may not record points right at the mineral site. Consequently, we also considered seemingly purposeful excursions from usual seasonal range to within about 500 metres or less of a lick site to be a site visit, particularly if part of a return trip. We then summarized mineral site visits by sex and by week of the year. We used t-tests to test for differences in the use of mineral sites by females and males.

Response to Restoration of Winter Range

Prior to the late 1980s, the most heavily used winter range for the Radium herd was along the low, southwest facing slopes between Dry Gulch Creek and Stoddart Creek (Stelfox et al. 1985). By 1990 this range had largely been abandoned in favour of artificial grasslands on the new Radium Springs golf course, within residential areas in the village of Radium Hot Springs, and along the road allowance of highway 93/95 just south of the village of Radium Hot Springs (the “Mile Hill”). This range shift is reflected in survey and random observation data collected by park wardens and volunteers between 1962 and 2000 (Figure 2). The reasons for the range shift are not entirely understood, but likely include a response of sheep to deterioration of range quality on the historic winter range (Stelfox et al. 1985) combined with the availability of high quality forage in the new winter range.

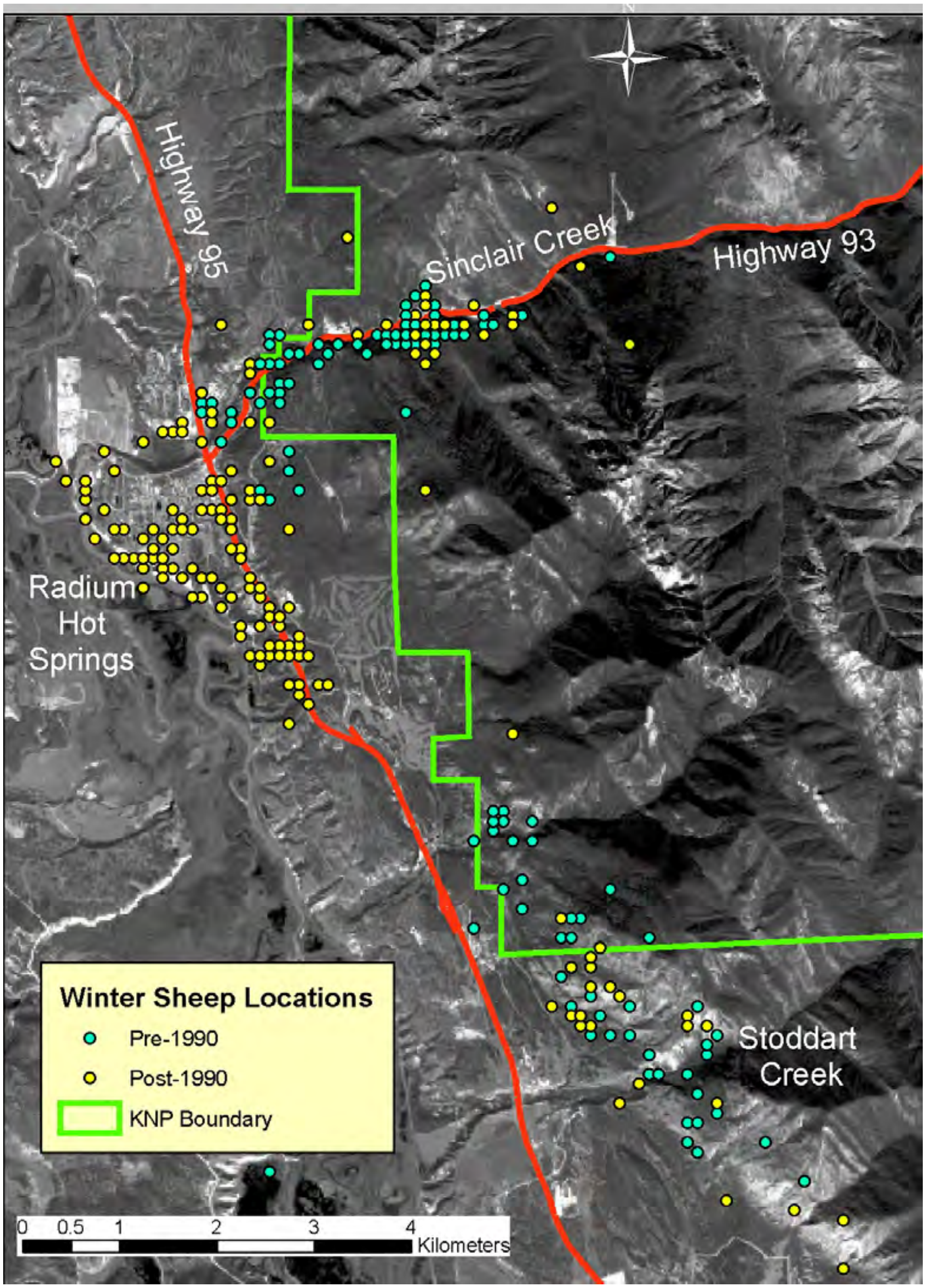

Figure 2. Winter sheep locations pre- and post-1990.

We carried out ecological restoration work, intended to address forest encroachment into open forest and grassland ecosystems, on the Redstreak benches in the winters of 2002 and 2003. This work consisted of thinning and brushing to an average of 8 metre spacing and retention of veteran trees over an area of approximately 200 ha. The work also included non-native plant control and a limited amount of planting of native grasses. A prescribed burn took place on the restoration site in April of 2005, but this was subsequent to the collection of the radio telemetry data reported here.

The B.C. Forest Service carried out the first phase of restoration in the winter of 2002 on provincial crown land ("Provincial Block" in Figure 3). In the winter of 2003 Parks Canada carried out similar treatments on a block of federal crown land belonging to Kootenay National Park. Parks Canada completed additional treatments within KNP in and adjacent to Redstreak campground ("Redstreak Campground Block" and "Prescribed Burn Guard Block" in Figure 3). This latter work was motivated by a need to ensure facility protection and to safeguard against future wildfire or prescribed fire, but was expected to provide similar ecological benefits to the other treatment blocks.

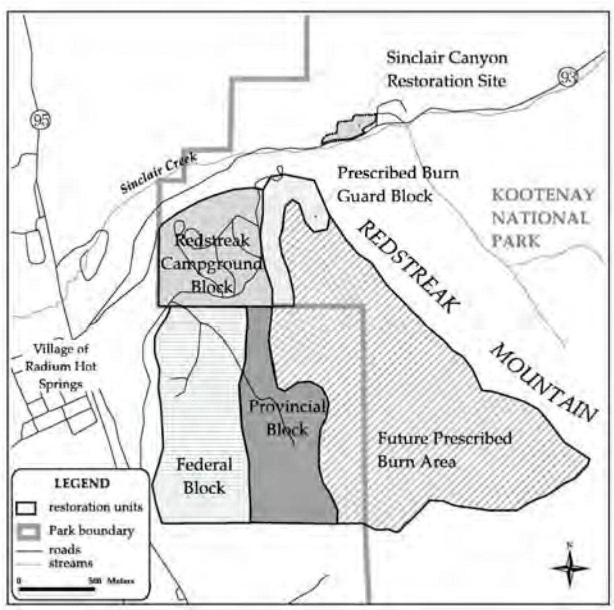

Figure 3. Overview of Restoration Area.

The 2003 treatment areas were closer to pre-treatment sheep winter range than was the 2002 restoration area. Bighorns tend to be slow to colonize new habitats (Geist 1971) but may respond more quickly to new habitat immediately adjacent to occupied habitat (Smith et al. 1999), thus we expected bighorn sheep to respond more quickly to the 2003 restoration treatments. The 2002 telemetry data therefore provides pre-treatment data for assessing bighorn sheep response to the 2003 restoration work. The restoration area comprises 9.0% by area of sheep winter range (173.0 ha out of 1913.3 total ha) as defined by the 95% fixed kernel density function for all sheep winter (October through April) telemetry points.

We assessed bighorn response by using a GIS to determine the number of telemetry points inside and outside the restoration area in each period during each year from 2002 to 2004. The telemetry data set used for the comparison was limited to a maximum of 1 point per day from daylight hours to reduce the potential for temporal autocorrelation of successive data points, and was restricted to 3D GPS points with position dilution of precision (PDOP) values of less than 6.0, according to B.C. Resource Inventory Committee standards (Geographic Data B.C. 2001). We made various comparisons based on particular months and sex classes. Pre-treatment and post-treatment telemetry results among years were compared using chi-square analyses and Fisher's Exact Test (O'Rourke et al. 2005).

Data Storage and Analysis Software

We downloaded GPS telemetry data was downloaded from radio collars using ATS WinCollar software (ATS Version 1.2.2, 2004). We merged the data from all collars into a single file, and performed basic data manipulation tasks using Microsoft Excel 2000 (Microsoft Version 9.0.6926, 1999). We performed spatial analyses using ArcGIS (ESRI Version 9.0, 2005) and ArcView software (ESRI Version 3.3, 2002). We also used the Animal Movements extension of ArcView 3.3 (Hooge and Eichenlaub 1997) and Hawth's Analysis Tools (Beyer 2004) extension of ArcGIS. We conducted statistical tests using SAS software (SAS Version 9.1, 2005).

Results

Capture and Collar Deployment

We captured and radio collared 31 sheep (18 females and 13 males) in 3 sessions. One ram (id M003) in 2002 died within 2 weeks of capture, likely due to pneumonia caused by aspirating rumen contents during immobilization (Kinley 2002). In 2004 another apparently healthy ram was darted while lying down but when he stood up he was recognized as an individual with a lame back leg; we removed his collar several days later. Data from both these animals has not been included in any data summaries or analyses.

Estimated age of sheep at time of capture ranged from 2.5 to 10.5 years for females ($\overline{X}$ = 5.0 ± 0.54 yr) and 4.5 to 7.5 for males ($\overline{X}$ = 6.2 ± 0.26 yr). In 2002 collars were initially deployed on 8-13 January and removed from study animals on 24 October 2002. However, we deployed 1 collar on 4 March 2002 to replace a study animal that had died shortly after capture. Additionally, the collar release mechanism did not function on 2 collars; these collars had to be removed by free-range darting at a later date, and one of these collars continued to collect data until its removal. The GPS function of 4 collars in 2002 malfunctioned prior to the animals' return to rutting/winter range in the fall. In 2003, collars were deployed on 16-18 December 2002, and removed on 1-3 December 2003, except for 3 collars that were deployed on 3 March 2003. In 2004, collars were deployed on 4 non-consecutive days in March 2004 and were removed on non-consecutive days in either late October or late November 2004. We removed collars from 2 rams earlier than planned in the fall of 2004 because the collars appeared to be getting tight, although no decline in animal condition or changes in behaviour were observed. The GPS function of all collars in 2003 and 2004 appeared to work properly. One ram and 1 ewe from year 1, M002 and F007 respectively, had to be immobilized to remove their collars because the collar release mechanisms failed. While immobilized, both these animals were fitted with new radio collars and so participated in year 2 of the study as well. However, the GPS function had failed on F007's collar in April 2002, so 2003 is the only year for which we have a complete data set for this animal. M002, who was easily recognizable because of distinctive horn damage, was also selected for capture and radio-marking in 2004 and we have acquired 3 years of data from him. No other attempts were made to recapture individuals for a second year although, because we did not permanently mark study animals, it is possible that this was done inadvertently. Future DNA testing from archived blood samples may ultimately provide evidence of whether or not any additional animals were part of the marked sample in more than 1 year.

GPS Collar Fix Success Rates

We calculated collar GPS fix rates after excluding data from 3 of the 4 2002 collars whose GPS function malfunctioned. We retained the data for 1 malfunctioning collar because this collar performed normally for most of the field season, whereas other collars either malfunctioned after only a short time period or only collected points at far less frequency than the programmed schedule. Overall, we obtained GPS locations on 87% of scheduled attempts and, of those, 84.8% were 3-dimensional locations (3D) and 15.2% were two-dimensional (2D). 74.2% of scheduled fix attempts resulted in 3D locations. In total, we obtained 35,838 3D locations over a combined 7,333 collar-days of operation (Table 1).

We tested GPS habitat bias (differing fix rates under different habitat conditions) by deploying a sample of GPS radio collars under various forest cover conditions and then measuring the collar fix rates under each set of conditions. Preliminary analysis of these collar GPS bias trials showed that only a weak bias occurred between forested and unforested sites (M. Hebblewhite, University of Alberta, personal communication).

Table 1. GPS collar fix success rate, 2002-2004.

Year	Sheep ID	Date collared	Date collar removed	Period of data collection (days)	Total fixes attempted	Total successful fixes	3D Fixes	2D Fixes	Fix success rate	3D Fix % of fixes	3D Fix % of fix attempts	Notes
2001-02	F001	8 Jan 2002	21 Aug 2002	225	1036	941	816	125	91%	86.7%	78.7%	Collar Malfunction 21 Aug 2002
2001-02	M002	8 Jan 2002	11 Mar 2003	426	1891	1547	1165	382	82%	75.3%	61.6%	Collar release mechanism failed
2001-02	F004	10 Jan 2002	24 Oct 2002	256	1222	451	418	33	37%	92.7%	34.2%	Collar Malfunction 5 May 2002
2001-02	M005	10 Jan 2002	1 Aug 2002	204	923	804	683	121	87%	85.0%	74.0%	Highway Mortality 1 Aug 2002
2001-02	F006	10 Jan 2002	24 Oct 2002	287	1392	1264	1103	161	91%	87.3%	79.3%	Normal operation
2001-02	F007	11 Jan 2002	16 Dec 2002	90	324	170	142	28	52%	83.5%	43.8%	Collar Malfunction 11 Apr 2002
2001-02	M008	11 Jan 2002	29 Nov 2002	311	1592	1213	891	322	76%	73.5%	56.0%	Normal operation
2001-02	F009	12 Jan 2002	24 Oct 2002	285	1386	1231	1036	195	89%	84.2%	74.8%	Normal operation
2001-02	F010	13 Jan 2002	24 Oct 2002	284	1382	1188	960	228	86%	80.8%	69.4%	Normal operation
2001-02	F011	4 Mar 2002	24 Oct 2002	96	461	232	222	10	50%	95.7%	48.2%	Collar Malfunction 28 Apr 2002
		2002 Totals		2464	11609	9041	7436	1605	78%	82.2%	64.1%	
		2002 Totals		1797	9602	8188	6654	1534	85%	81.3%	69.3%	
2002-03	F007	16 Dec 2002	2 Dec 2003	352	2166	2051	1857	194	95%	90.5%	85.8%	Normal operation
2002-03	M002	11 Mar 2003	2 Dec 2003	264	1992	1821	1567	254	91%	86.1%	78.6%	Normal operation
2002-03	M101	16 Dec 2002	2 Dec 2003	352	2153	1734	1340	394	81%	77.3%	62.2%	Normal operation
2002-03	F102	16 Dec 2002	24 Mar 2003	99	183	182	166	16	99%	91.2%	90.7%	Highway Mortality 24 Mar 2003
2002-03	F103	17 Dec 2002	2 Dec 2003	351	2147	2024	1817	207	94%	89.8%	84.6%	Normal operation
2002-03	F104	17 Dec 2002	2 Dec 2003	351	2147	1977	1782	195	92%	90.1%	83.0%	Normal operation
2002-03	M105	18 Dec 2002	2 Dec 2003	350	2147	1777	1415	362	83%	79.6%	65.9%	Normal operation
2002-03	M106	18 Dec 2002	2 Dec 2003	349	2153	1431	907	524	66%	63.4%	42.1%	Normal operation
2002-03	F107	11 Mar 2003	1 Dec 2003	265	1994	1743	1488	255	87%	85.4%	74.6%	Normal operation
2002-03	F108	11 Mar 2003	2 Dec 2003	265	1993	1946	1849	97	98%	95.0%	92.8%	Normal operation
		2003 Totals		2998	19075	16686	14188	2498	87%	85.0%	74.4%	
2003-04	M002	8 Mar 2004	22 Oct 2004	227	2357	1964	1549	415	83%	78.9%	65.7%	Collar removed early - irritation
2003-04	F202	9 Mar 2004	30 Nov 2004	266	2798	2521	2210	311	90%	87.7%	79.0%	Normal operation
2003-04	F203	9 Mar 2004	8 Nov 2004	244	2547	2121	1785	336	83%	84.2%	70.1%	Highway Mortality 8 Nov 2004
2003-04	F204	9 Mar 2004	13 Jul 2004	125	1217	1171	1091	80	96%	93.2%	89.6%	Mortality (fall?) 13 Jul 2004
2003-04	F205	18 Mar 2004	30 Nov 2004	257	2777	2489	2145	344	90%	86.2%	77.2%	Normal operation
2003-04	M206	18 Mar 2004	20 Oct 2004	216	2335	1856	1466	390	79%	79.0%	62.8%	Normal operation
2003-04	M207	18 Mar 2004	30 Nov 2004	256	2776	2683	2494	189	97%	93.0%	89.8%	Normal operation
2003-04	M208	30 Mar 2004	17 Nov 2004	232	2609	2375	2066	309	91%	87.0%	79.2%	Normal operation
2003-04	F209	30 Mar 2004	17 May 2004	48	226	210	190	20	93%	90.5%	84.1%	Mortality (disease?) May 17 2004
		2004 Totals		1871	19642	17390	14996	2394	89%	86.2%	76.3%	
		Grand Totals		7333	48318	42264	35838	6426	87%	84.8%	74.2%	

[a] *Totals do not include data from collars that malfunctioned.*

Mortality

A total of 5 study animals died during the first 3 years of the study (Table 2), 3 from highway strikes and 2 from natural causes. All 3 highway strikes were on the “Mile Hill”, a 2-kilometre stretch of highway 93/95 just south of the Village of Radium Hot Springs. The Mile Hill is a concentration area of sheep highway mortality. From 2002 to 2004, out of a total bighorn sheep population estimated at approximately 200 animals, we recorded 32 vehicle-sheep collisions of which 27 were confirmed kills and 5 were reported strikes (animal carcass not found); 23 of these highway strikes occurred on the Mile Hill. In addition to highway strikes, we recorded 3 railway kills on the CPR line just west of the Village of Radium Hot Springs.

The actual number of road and rail kills is likely higher than the number that we recorded. Elsewhere in North America, Romin and Bissonette (1996) have reported that animal-vehicle collisions are generally under-reported. In the Radium study area we believe that other highway kills of unmarked sheep go unreported due to the numbers of large transport trucks which may sustain no or minimal damage in a wildlife collision, the abundance of large scavengers to quickly remove carcasses, and the presence of terrain and forest cover immediately adjacent to the Mile Hill in which carcasses would be difficult to detect.

Table 2. Study animal mortality, Aug 2002-Nov 2004.

Date	Sheep ID	Cause	Location
1 –Aug 2002	M005	Highway	Mile Hill
24 –Mar 2003	F102	Highway	Mile Hill
17 –May 2004	F209	Natural Causes - infection	Redstreak Bench
13 –Jul 2004	F204	Natural Causes - possibly fall	Brisco Range
8 –Nov 2004	F203	Highway	Mile Hill

The overall estimate of annual survival among our population of adult bighorns was 79.1%, using the Kaplan-Meier estimate (Figure 4).

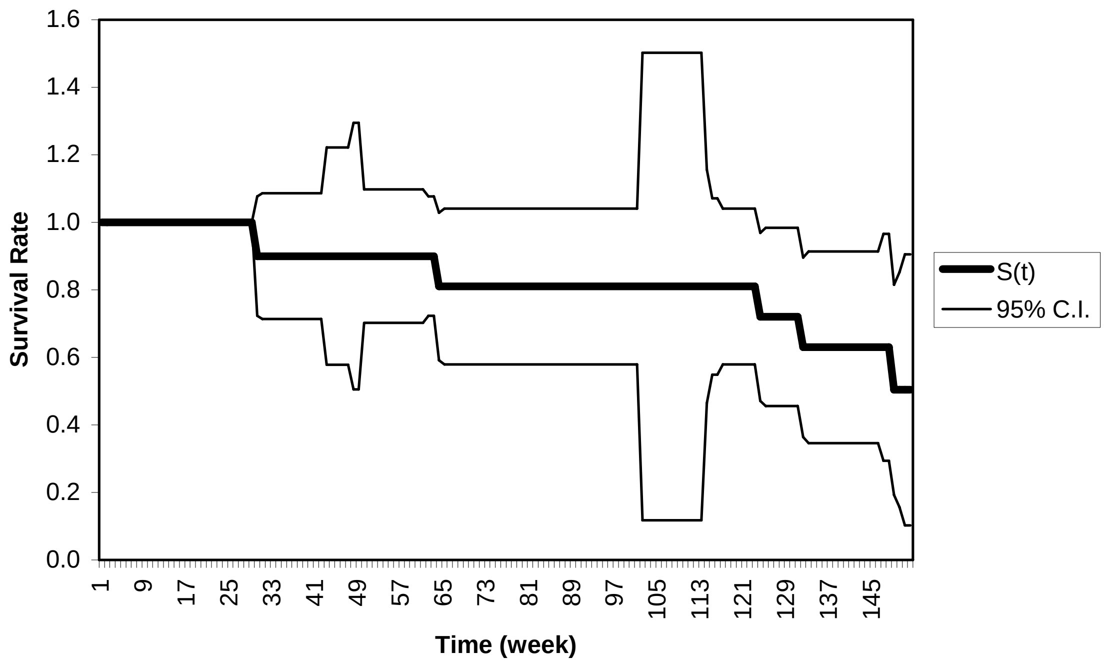

Figure 4. Survival rate (S[t]) of Radium bighorn sheep 2002 to 2004.

Lamb Production and Lambing Areas

Bighorn sheep lamb production, as confirmed by direct observation of marked animals while on summer range, is summarized in Table 3 below. The lamb status of 1 female in 2004, despite hours of observation by field staff, was ambiguous. The ewe:lamb ratios observed each year in the marked animals appeared to broadly reflect the ratios observed among unmarked animals.

Table 3. Bighorn Sheep Lamb Production, 2001-2004

Year	Marked Females Surviving to Summer	Surviving Marked Females with lamb
2001-02	7	6
2002-03	5	4
2003-04	4	1 or 2

Although we could infer the location of some lambing sites from GPS data, and we made direct visual observations of several females immediately post-lambing, we were unable to determine general lambing site characteristics due to sample size limitations. However, such analyses should be feasible with 1 or 2 years of additional data.

Home Ranges, Seasonal Ranges, and Migratory/Dispersal Movements

Bighorn sheep used low elevation valley bottoms in winter and high elevation alpine ranges in summer, and used established migration routes between these ranges. Average minimum convex polygon (MCP) home ranges for adult female sheep averaged 130.9 km^2 (± 14.9; *n* = 11) and average 90% fixed kernel home range size was 39.4 km^2 (± 4.9; *n* = 11). For males, MCP home ranges averaged 146.9 km^2 (± 28.9; *n* = 10) and 90% kernel home ranges averaged 32.67 km^2 (± 3.6; *n* = 10). However, this analysis included all 3 years of male M002's telemetry points as separate home ranges. By excluding from the analysis M002's location data in years 2 and 3, the MCP and 90% fixed kernel home range averages for male sheep are 119.8 km^2 (± 21.9; *n* = 8) and 29.2 km^2 (± 2.9; *n* = 8) respectively. Maps of sheep MCP and kernel home ranges are provided in Appendix 1.

In most cases, larger MCP home ranges corresponded to animals that had migrated farther to summer range, or made other unusual movements. The largest female home range belonged to ewe F010 from year 1, who migrated approximately 30 km north of Radium Hot Springs to her lambing range near Spillimacheen, then returned to the same summer range used by most of the Radium ewes. Other than the one long distance movement to lambing range, F010's range selection was very similar to that of other females. The largest male home range in any year was that of ram M002 who, in year 2, undertook some long distance exploratory movements to the north.

All study animals exhibited migratory behaviour, moving between winter range near the village of Radium Hot Springs and summer range in alpine areas of the Brisco or Stanford ranges. The area within and immediately adjacent to the village of Radium Hot Springs comprised most of the winter range, including the village itself, the Radium Springs Golf Course, the "Mile Hill" on highway 93/95, the road to Redstreak Campground, a small area just north of the Radium 4-way stop, and Sinclair Canyon as far as the Radium Hot Springs pools. Five of 7 rams in years 1 and 2 made winter excursions as far south as Stoddart or Windermere Creeks; in year 3 most ram radio collars were removed in October and so early to mid-winter movements of these animals were not recorded. No marked females were recorded using areas south of the Mile Hill in winter, although we observed several unmarked ewe-lamb groups at Stoddart Creek. We occasionally observed unmarked ewe-lamb groups on Mt. Swansea near Windermere Creek at the extreme south end of the study area, although it is not known if these animals are part of the Radium herd.

In spring, the average date of female sheep migration (*n* =14; determined as the date on which the animal climbed above 1200 m elevation without subsequently returning to lower elevations, except for brief excursions to mineral licks) was 22 May (SD = 6.6 days). The earliest date recorded was 7 May and the latest date recorded was 30 May. No significant difference was found between average dates in the different years of the study (2002: 23 May; 2003: 22 May; 2004: 22 May; 2002-2003: $t_7 = 0.23$, $P = 0.82$; 2002-2004: $t_6 = 0.26$, $P = 0.80$; 2003-2004: $t_6 = 0.09$, $P = 0.93$). For males, the average date of the spring migration to high elevations was June 7th (*n* =10; SD = 10.9 days). The earliest recorded date was 24 May and the latest was 4 July, although animal M005 never did migrate to high elevation before he was killed on the Mile Hill on 1 August 2002. Small sample sizes with males prevent meaningful comparisons of average migration dates in each year of the study. However, over the 3 years of the study, we found that male spring migration dates differed significantly from those of females (16.0 days, $t_{22} = 4.47$, $P < 0.001$).

Summer ranges for both sexes were areas above 2000 m elevation along John McKay Ridge, ridges at the head of Sinclair Creek north to Mt. Crook, Mt. Sinclair, and Kimpton Ridge.

The average date of females returning to their late fall/winter range was September 28th (*n* = 11; determined as the date an individual began travel to below 1200 m for the last time in that year), but there was considerably more variation than for spring migrations (SD = 15.0 days). Average dates by year were 29 September (2002), 23 September (2003), and 5 October (2004), but these differences were not statistically significant (2002-2004: $t = 1.03$, $P = 0.36$; 2003-2004: $t = 0.96$, $P = 0.37$; 2002-2003: $t = 0.42$, $P = 0.69$). For males, the average date of fall migration was 11 October (*n* = 10; SD = 13.8 days), and we found a difference of 13.7 days between male and female average migration dates ($t_{19} = 2.27$; $P = 0.035$).

Seasonal migrations occurred abruptly for individual animals. Most females moved from winter range below 1000 m to lambing or pre-lambing range at or above 2000 m in less than 24 hours. Female migrations from summer to rutting/winter ranges in the fall were nearly as abrupt and may have been triggered, at least in some cases, by the occurrence of snowy conditions in the high country. Figure 5 shows elevation versus date for a typical female sheep (F009, 2002). Ram spring migrations, on average, occurred slightly less abruptly than did female migrations. In some cases this was because their summer ranges were more distant than female ranges were, and it took longer to travel there from the winter range. In other cases, the slower migration appears to have resulted simply from a slower rate of travel. Ram fall migrations took place rapidly, in some cases in apparent response to bad weather, but some rams returned to the high country after briefly retreating to lower elevations. An example chart of ram elevation versus date is shown in Figure 6.

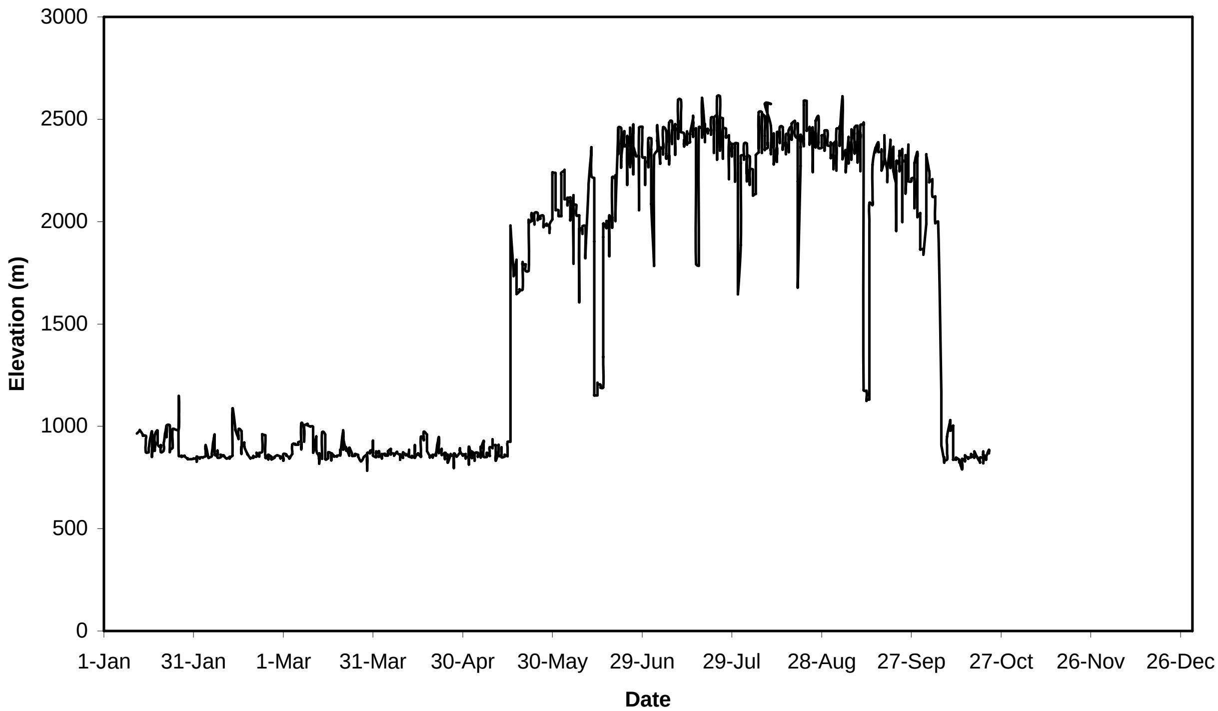

Figure 5. Elevation vs. Day in 2002, Sheep F009.

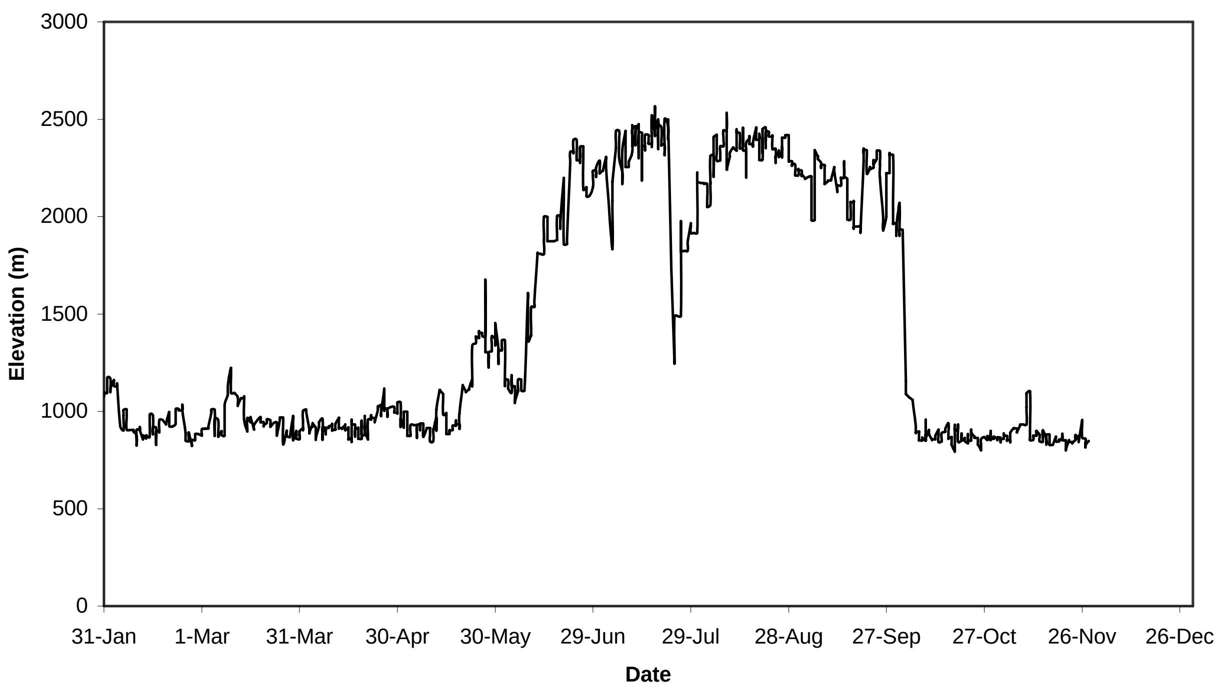

Figure 6. Elevation vs. Day of Year - Sheep M008.

Most late fall and winter (November through February) activity for both sexes was confined to an approximately 10 km^2 area at and near the Village of Radium Hot Springs (Figure 7). During the rut in November and December, nearly 50% of male daily telemetry points were recorded within the area designated as "Radium Village" in Figure 7, while less than 9% of daily points were recorded on the "Mile Hill" (Figure 7). By contrast, in January and February nearly 60% of male points were recorded on the Mile Hill and only 6% were within Radium Village. For males, the relatively high use of the Mile Hill during January and February versus during November and December was highly significant (Chi-square = 105.8, $P < 0.001$). High use of Radium Village in November and December was also highly significant (Chi-square = 85.9, $P < 0.001$). For females, 70% of daily points were in the village in November and December and about 50% in January and February (Figure 8), while use of the Mile Hill remained relatively constant between the 2 periods at 11% and 13% respectively. The higher proportion of female daily points in Radium Village in November and December versus January and February was highly significant (Chi-square = 16.4, $P < 0.001$), but relative use levels of the Mile Hill were not significantly different in the 2 periods (Chi-square = 0.73, $P = 0.39$). Figure 9 shows sheep winter and rutting ranges.

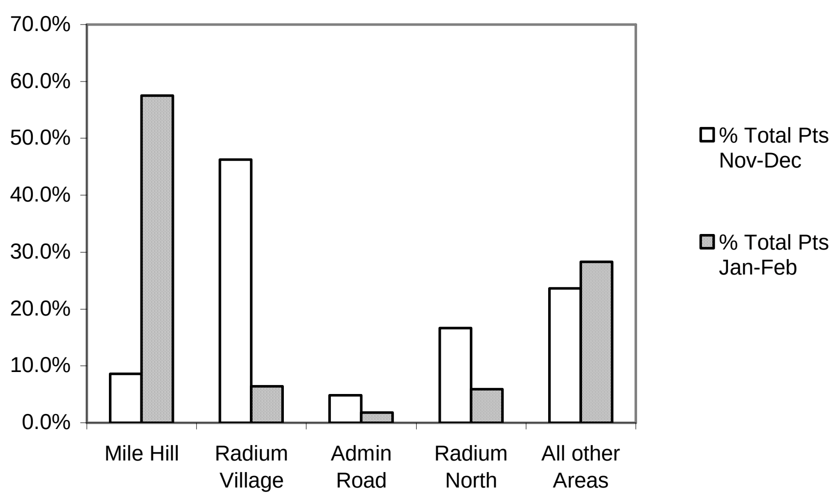

Figure 7. Male daily telemetry locations, Nov-Feb 2002-2004.

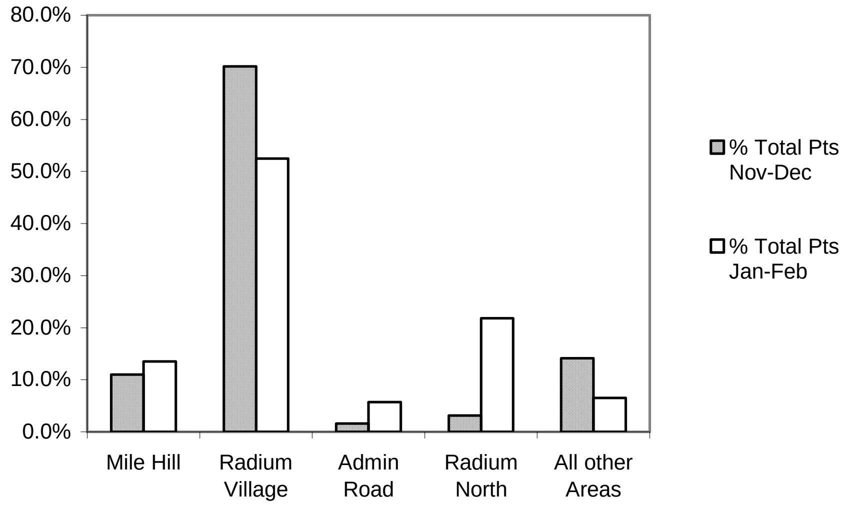

Figure 8. Female daily telemetry locations, Nov-Feb 2002-2004.

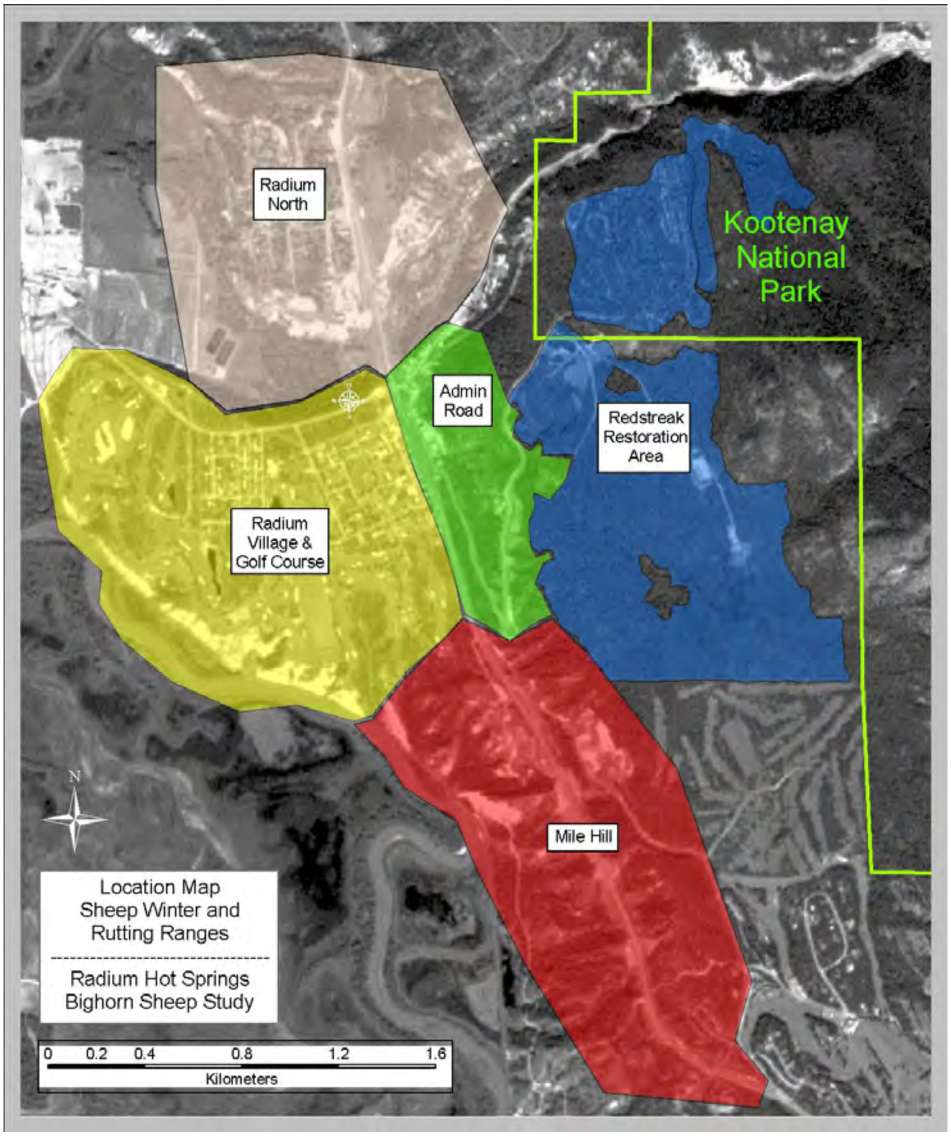

Figure 9. Location map of sheep winter and rutting ranges.

We found that sheep used a set of well-defined corridors for migration and other movements, typically using ridge crests to connect seasonal habitats and important point features such as mineral licks and lambing sites. Diagrammatic representation of these movement routes, along with core habitat areas, is presented separately for males and females in Appendix 2. These diagrams clearly show substantial sexual segregation of sheep, especially during summer, and this is the likely cause of differences in the levels of use of various movement routes. Other factors include the need of females to move to secure lambing sites, and differences between the sexes in the timing and need for minerals.

14 of 15 female sheep selected their primary summer ranges to the north of Sinclair Creek, with heavily used areas including East Sinclair Ridge, Nixon Summit, Sheep Mountain, John McKay Ridge, Mt. Kindersley, and Berland Ridge. Only 1 female sheep, F202, spent the entire summer south of Sinclair Creek on Mt. Sinclair, and few others spent any time whatsoever south of Sinclair Creek in summer.

By contrast, only 2 of 8 male sheep selected their primary summer ranges north of Sinclair Creek. These 2 sheep used summer ranges near Mt. Crook and on the ridge connecting Berland Ridge and John McKay Ridge. The other males used summer habitats on Kimpton Ridge and the ridge south of Mt. Sinclair, but rarely on Mt. Sinclair itself. Thus, there was almost perfect mutual exclusivity of summer habitat selection by male and female sheep.

Domestic Sheep Issues

Domestic sheep, implicated in the spread of disease causing die-offs in wild sheep herds (e.g., Krausman and Shackleton 2000; Demarchi et al. 2000), are currently being kept on several parcels of private land or crown land grazing tenures within the current range of Radium bighorns (D. Zehnder, personal communication). Four locations of active or suspected domestic sheep presence were identified (D. Zehnder, personal communication) and are shown in Table 4, along with the number of telemetry points occurring within the 2 km and 5 km buffers. Approximate locations of domestic sheep ranches are shown in Figure 10, along with 2 km and 5 km buffers around these ranches and bighorn telemetry points.

Table 4. Bighorn locations in proximity to domestic sheep

Domestic Sheep Location	5 km Buffer	2 km Buffer
Spillimacheen	67	0
Edgewater	30	0
Firlands	14,417	1
Shuswap Ck	196	19

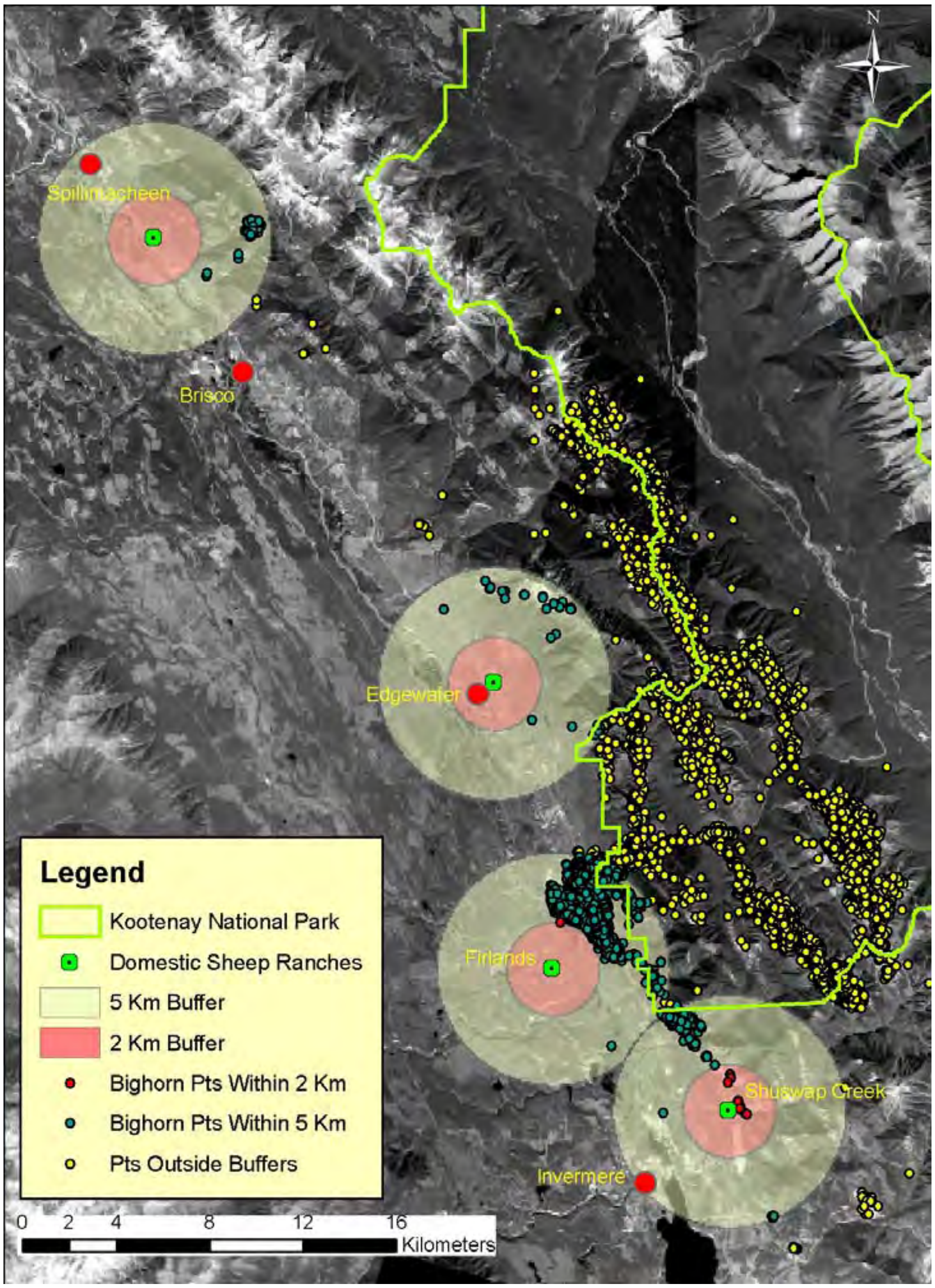

Figure 10. Domestic sheep sites in relation to telemetry points.

Most bighorn locations near the Spillimacheen site were from lambing activity of sheep F010 in 2002 and from November wanderings of sheep M002 in 2003. Bighorn locations near the Edgewater site belong to several females, including F010 and F004, who used this area in May or June. The Firlands ranch is within 5 kms of parts of the village of Radium Hot Springs, so many sheep winter points fall within the 5 kms buffer. Several radio collared rams have closely approached the Shuswap domestic sheep ranch in at least 2 years of this study.

Use of Kootenay National Park Versus Out of Park Areas

Over all months we found that 44.5% of sheep daily telemetry locations occurred within Kootenay National Park. In winter (October through April), only 9.1% of locations were within KNP and in summer 63.9% of locations were within KNP. However, all year and winter figures may be biased towards locations within the park because on average fewer sheep were radio collared during winter when sheep were more likely to be outside the park. This bias can be substantially reduced or eliminated by considering location data on a monthly basis, presented in Figure 11. Use of the park drops to below 10% both for males and females in December through March, but climbs to near 90% for females in June and July and for males in August and September (Figure 11).

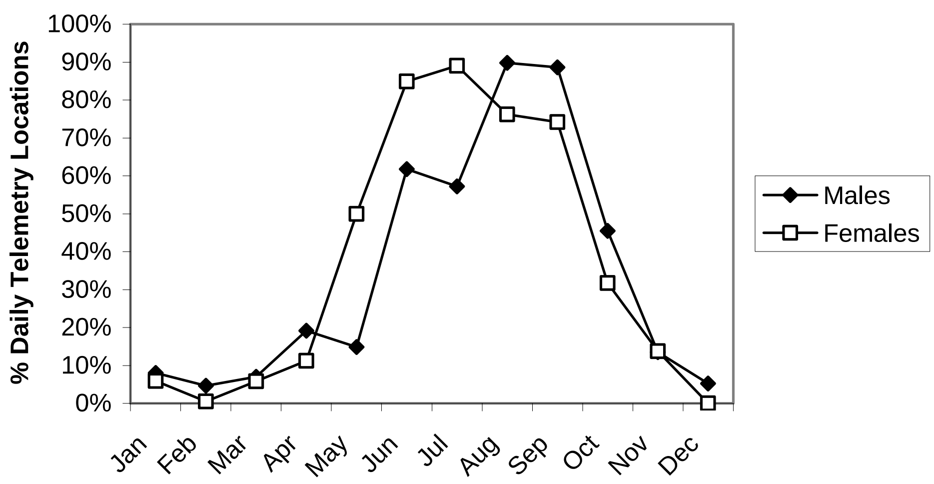

Figure 11. Sheep locations inside the park by month.

Use of Terrain

Elevations used by bighorn sheep spanned nearly the entire range available to them within their collective home ranges (Figure 12). For males, we found that average annual elevation was 1521.5 metres (± 12.9; n=2501) but average monthly elevation varied from a low of 897.4 metres (± 14.99; n=38) in December to a high of 2214.4 metres (± 11.0; n=274).

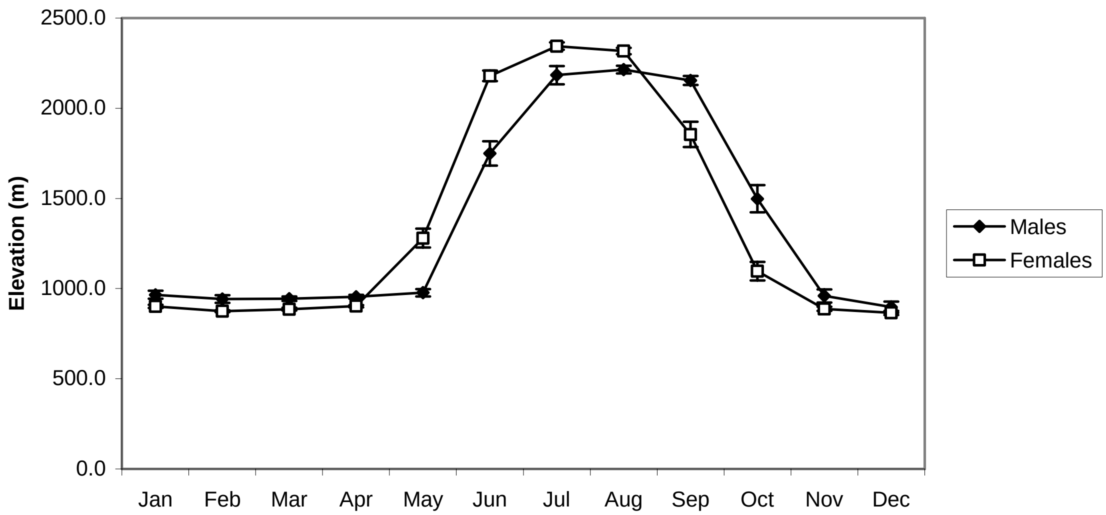

Figure 12. Male and female sheep elevation by month with 95% confidence intervals.

For females, average annual elevation was 1488.5 m (± 11.9 m; n = 3335) and average monthly elevation varied from a low of 865.1 m (± 5.4 m; n = 38) in December to a high of 2344.3 m (± 10.2 m; n = 365). Female sheep moved to higher elevations on average 2-3 weeks earlier than rams did, and returned to lower elevations 2-3 weeks earlier. We found no significant difference in mean annual elevation of males and females (P = 0.061). During summer (1 May – 31 October) females averaged 68.1 metres (± 20.6 m, P < 0.001) higher than males, and in winter (1 November – 30 April) females averaged 59.8 metres (± 4.25 m, P < 0.001) lower than males.

Sheep selected steeper slopes in summer (25.26^o ± 0.20^o; n = 3776) than in winter (11.63^o ± 0.19^o, n = 2060, t = 44.72, P < 0.001; Figure 13). Over the year, males occupied slopes that averaged 2.9^o (± 0.34^o, t = 8.70, P < 0.001) steeper than females. Males selected steeper terrain than females from August through April, while females selected steeper terrain May through July, including the lambing period. Males selected significantly steeper slopes than females (15.4^o ± 0.33^o, n = 793 vs. 9.2^o ± 0.21^o, n =

1267, t = 16.46, P < 0.001) during the 6 month “winter” period of November through April. However, in summer (May through October) there was no detectable difference between slopes used by the 2 sexes (males 25.2° ± 0.28 °, n = 1708 vs. females 25.3° ± 0.28 °, n = 2068; t = 0.10, P = 0.92), likely because the female peak in June would have cancelled out the male peak in September (Figure 13).

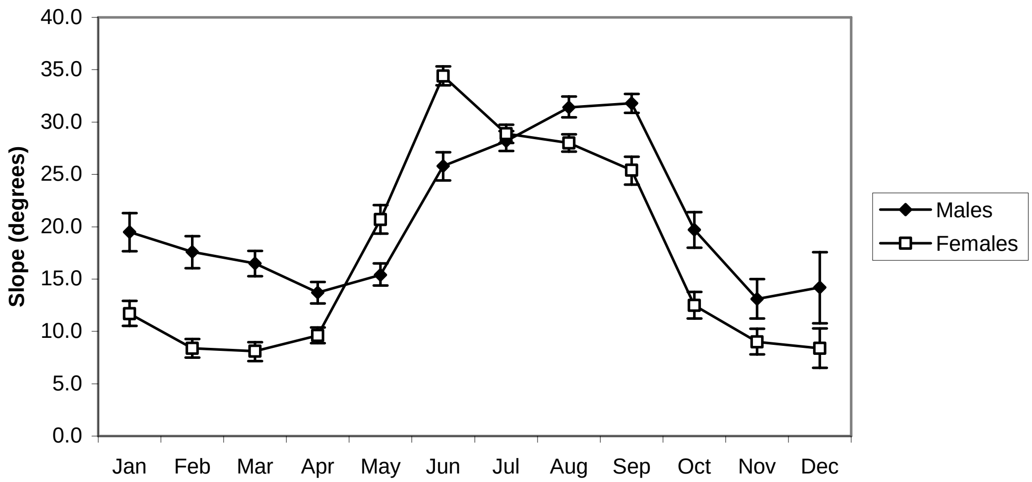

Figure 13. Male and female sheep slope by month with 95% confidence intervals.

Males in winter, when considered within an 11.4 km^2 core range enclosing most of their winter telemetry points (90% kernel density function), preferred habitats within a 150 m buffer of 18° or steeper slopes (Chi-square = 89.5, P < 0.001). However, no such association was found with steeper slopes of 27° (Chi-square = 1.48, P = 0.23) or 35° (Chi-square = 3.29, P = 0.70), although such slopes only comprised approximately 10% and 3% respectively of the core winter range. Females in winter, within their core habitat area of about 4.6 km^2, were not found to prefer habitats within the 150 m buffer of 18° or steeper slopes (Chi-square = 0.88, P = 0.35), and their core winter range did not include terrain steeper than 27°. In summer, male core habitat was defined by the 90% kernel density function to a series of disjunct areas totalling 62.8 km^2. Males showed a slight preference for habitats within a 150 m buffer of 18° or steeper slopes (Chi-square = 11.0; P = 0.009), no preference of >27° buffered slopes (Chi-square = 3.08, P = 0.08), and strong preference of >35° buffered slopes (Chi-square = 28.059, P < 0.001). This result is likely due in part to the occasional use of low angle winter range areas, particularly during May and October. Females in summer, within a series of disjunct core habitat areas totalling 73.1 km^2, showed avoidance of buffered 18° slopes (Chi-square = 15.4, P

< 0.001) and 27^o slopes (Chi-square = 44.0, P < 0.001), but selected buffered 35^o slopes in proportion to their availability (Chi-square = 0.051, P = 0.82).

For males, we obtained similar results when slope preference was considered at a larger spatial scale; in particular, a 542.7 km^2 area corresponding roughly to a minimum convex polygon around all animals' daily locations. At this larger spatial scale, females strongly selected slopes greater than 35^o (Chi-square = 86.01, P < 0.001).

Throughout the year bighorn sheep used slopes facing southwest (29.2%), west (24.6%) and south (14.1%) more often than other aspects (chi-square = 2260, P < 0.001; Appendix 3). During July through September, however, both sexes were located on east-facing slopes 88.1% more often than expected based on availability (Chi-square = 252.8, P < 0.001; Appendix 3).

Use of Mineral Licks

Sheep exploited 3 known areas with natural or artificial mineral concentrations, in addition to frequent consumption of road salt on highways during winter. The most commonly visited mineral site for females was the upper Kindersley-Sinclair trailhead ("KST"), at which we recorded 31 visits between 1 May and 31 October, although males were recorded here only once. The most heavily used site for males was the salt shed at the highways compound ("CMPD"), at which we recorded 13 visits; females made 18 visits to this site. The third site, a known mountain goat mineral lick along Kindersley Creek, was visited twice by female F010 on her way to and from her lambing site near Brisco.

Female sheep visited known mineral sites more frequently than males did (t = 9.14, P < 0.001). Among 11 female sheep for which GPS data was collected continuously from 1 May to 31 October we recorded an average of 4.3 visits (± 0.16) per animal to mineral sites. Among 10 males, on the other hand, only an average of 1.4 visits (± 0.31) was detected. The importance and uniqueness of these mineral sites to sheep are demonstrated by the willingness of sheep to make sudden movements of up to 10s of kilometres to reach them, only to reverse their travels after spending a few hours at the lick. No other sites appear to hold such attraction to the sheep.

We summarized female use of mineral licks in Figure 14. Females appear to have strong urges to seek out minerals throughout the summer, beginning a few weeks after the lambing period. There is a somewhat weak trend towards increasing use of the

CMPD site relative to use of the KST site in late summer and fall. Some females stopped at the CMPD site as part of their spring or fall migration.

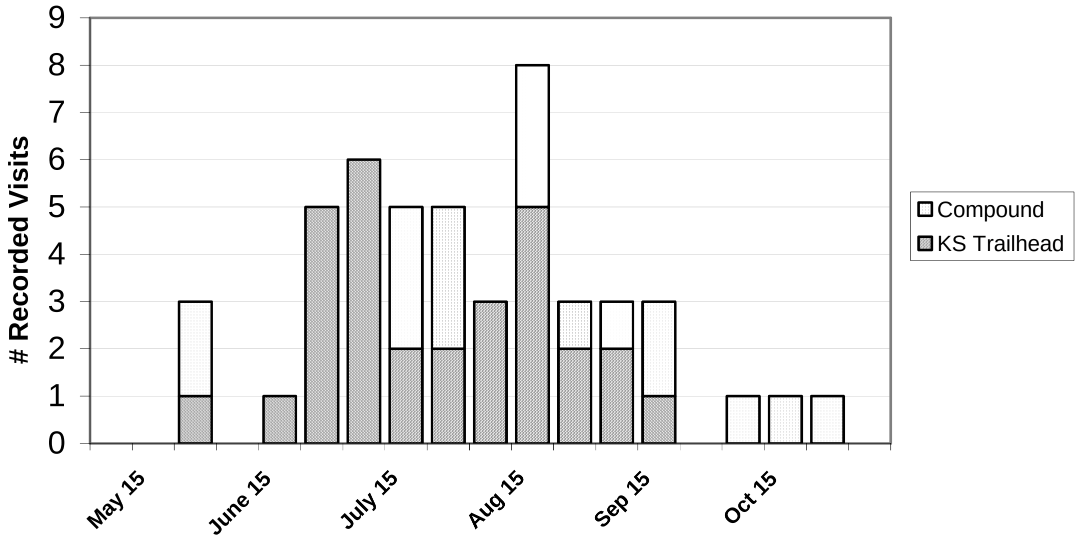

Figure 14. Female use of mineral sites, 2002-2004 (*n* = 11).

Male use of mineral licks is summarized in Figure 15. Of the 10 males considered, 2 did not closely approach either the KST or CMPD sites. Some of the recorded use of the CMPD site appeared to be incidental to seasonal migrations, but brief return trips from the high country in summer were also recorded.

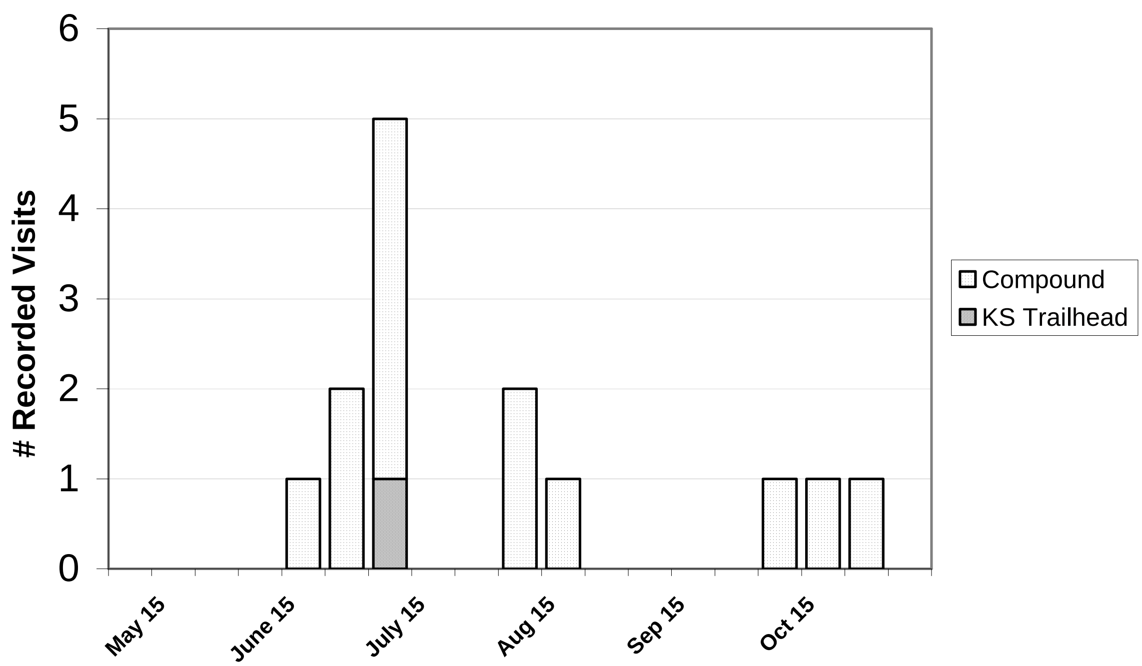

Figure 15. Male use of mineral sites, 2002-2004 (n = 10).

Response to Restoration of Winter Range

Analysis of radio telemetry data shows that sheep made increasing use of the restoration area over the period of 2002 to 2004. With location data pooled for all animals, including both sexes, in all months in each year, use increased from 1.0% (percentage of total points in restoration area) in 2002 to 3.2% in 2003 to 8.9% in 2004 (Table 5). We found the change between 2002 and 2004 to be statistically significant using the Pearson chi-square test (Schlotzhauer and Littell 1997) to $P < 0.001$. However, the restoration area is embedded within the sheep winter range, which is rarely used in summer. The restoration area comprises 9.0% by area of sheep winter range (173.0 ha out of 1913.3 total ha) as defined by the 95% fixed kernel density function for all sheep winter (October through April) telemetry points. In March and April 2002 1.1% of location points were within the restoration area. By 2004 this had increased to 20.4% ($P < 0.0001$). The effect is even stronger if only males are considered in March and April; their use of the restoration area increased from 0% in

2002 to 32.2% in 2004 (*P* < 0.0001). For female sheep the effect appears to be strongest in May, with use increasing from 0.9% in 2002 to 19.0% in 2004 (*P* < 0.0001).

Table 5. Use of the restoration area for all study animals, 2002-2004.

Animals	Years	Months	# Points Outside Restoration Area	# Points Inside Restoration Area	Total # Points	% of Total Inside Restoration Area	% Change Annually	Chi-Square Comparison	Chi-Square Value	Probability
All	2002	All	1812	18	1830	1.0%		2002 to 2003	23.0	<0.0001
All	2003	All	2212	73	2285	3.2%	2.2%	2003 to 2004	59.8	<0.0001
All	2004	All	1568	153	1721	8.9%	5.7%	2002 to 2004	121.0	<0.0001
All	2002	Mar-Apr	461	5	466	1.1%		2002 to 2003	9.3	0.0024
All	2003	Mar-Apr	271	13	284	4.6%	3.5%	2003 to 2004	33.5	<0.0001
All	2004	Mar-Apr	262	67	329	20.4%	15.8%	2002 to 2004	87.1	<0.0001
Males	2002	Mar-Apr	132	5	137	3.6%		2002 to 2003	0.1	0.7325
Males	2003	Mar-Apr	102	3	105	2.9%	-0.8%	2003 to 2004	32.9	<0.0001
Males	2004	Mar-Apr	99	47	146	32.2%	29.3%	2002 to 2004	38.4	<0.0001
Females	2002	Mar-Apr	329	0	329	0.0%		2002 to 2003	18.7	<0.0001
Females	2003	Mar-Apr	169	10	179	5.6%	5.6%	2003 to 2004	3.4	0.0653
Females	2004	Mar-Apr	163	20	183	10.9%	5.3%	2002 to 2004	37.4	<0.0001
Males	2002	May	77	1	78	1.3%		2002 to 2003	3.4	0.0648
Males	2003	May	106	8	114	7.0%	5.7%	2003 to 2004	2.2	0.1408
Males	2004	May	102	15	117	12.8%	5.8%	2002 to 2004	8.3	0.004
Females	2002	May	112	1	113	0.9%		2002 to 2003	6.7	0.0096
Females	2003	May	142	12	154	7.8%	6.9%	2003 to 2004	8.0	0.0047
Females	2004	May	111	26	137	19.0%	11.2%	2002 to 2004	21.0	<0.0001

The increased use of the restoration area was distributed among most or all study animals (Table 6). In 2002, 6 of 10 animals were recorded on at least 1 day within the future restoration area (range: 0 to 5 days), although this use totalled only 18 animal-days, or an average of 1.8 days per animal (SD = 2.0). In 2003, all 10 study animals were recorded using the restoration area (range: 1 to 25 days) for a total of 73 animal-days or 7.3 days per animal on average (SD = 7.4). In 2004, 9 study animals all used the restoration area (range: 1 to 43 days) for a total of 153 days and an average of 17.0 days per animal (SD = 15.6).

Table 6. Use of the restoration area by individual collared sheep, 2002-2004.

2002			2003			2004		
Animal #	**Total daily locations***	**Total in Restoration Areas**	**Animal #**	**Total daily locations***	**Total in Restoration Areas**	**Animal #**	**Total daily locations***	**Total in Restoration Areas**
F001	202	4	M002	258	1	M002	208	20
M002	251	5	F007	267	12	F202	248	7
F004	119	1	M101	251	25	F203	202	1
M005	177	4	F102	63	2	F204	115	25
F006	250	3	F103	275	9	F205	236	7
F007	52	0	F104	293	9	M206	194	43
M008	215	0	M105	256	1	M207	254	39
F009	237	0	M106	210	2	M208	227	5
F010	232	1	F107	226	9	F209	37	6
F011	48	0	F108	233	3			
Total	**1783**	**18**	**Total**	**2332**	**73**	**Total**	**1721**	**153**
Average	**178.3**	**1.8**	**Average**	**233.2**	**7.3**	**Average**	**191.2**	**17.0**

Use of the restoration area by rams in March and April of 2002 and 2004 is shown in Figure 16.

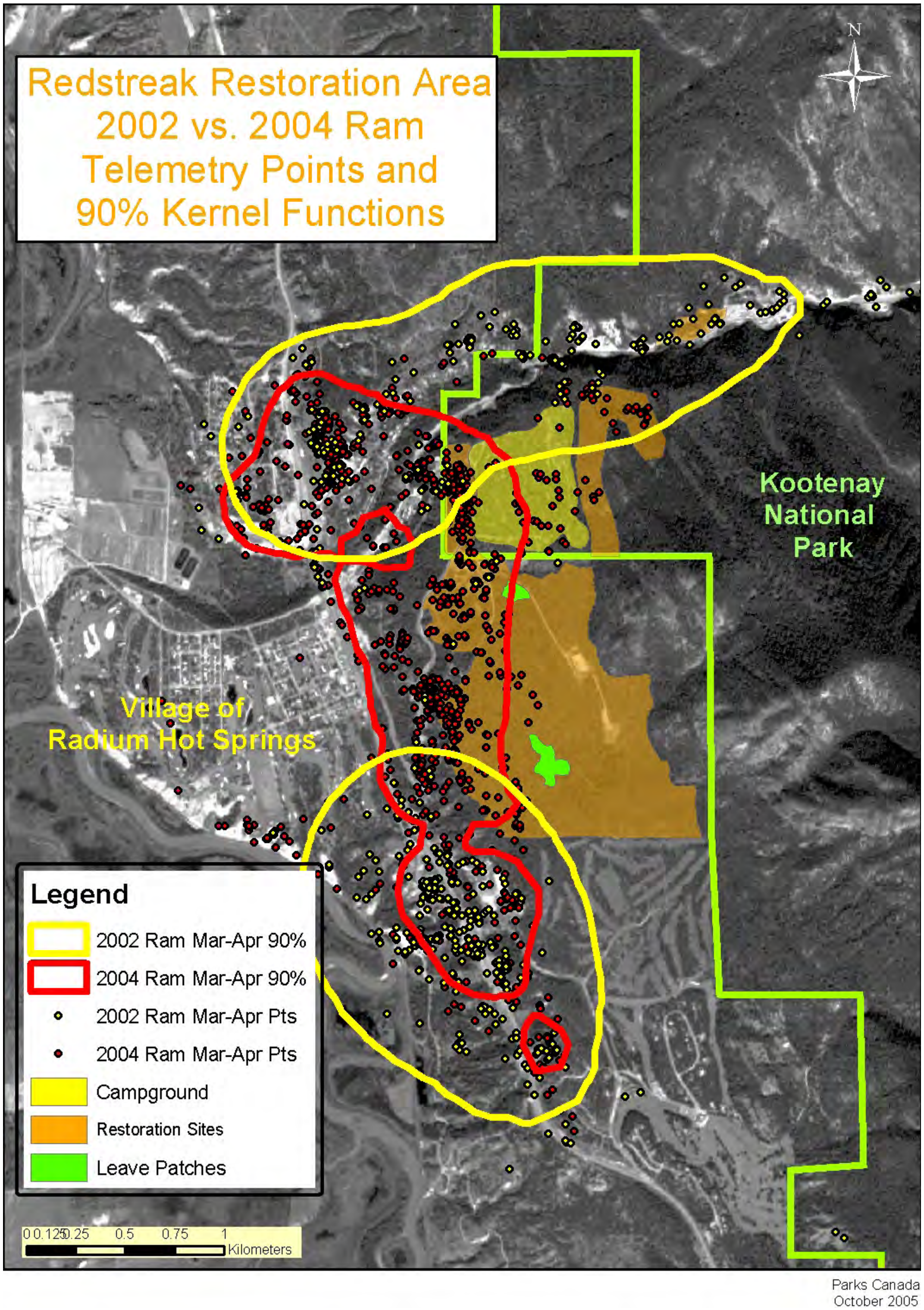

Figure 16. Use of Redstreak Restoration Area by rams: 2002 vs. 2004.

Discussion

Mortality

Estimated annual survival rates (79%) among collared animals, although based on a relatively small sample size and only 5 total mortalities, are cause for concern. Further evidence for high mortality rates comes from records of highway and railway mortality among the population-at-large, with approximately 5 – 10 % of the estimated total population confirmed dead from this cause each year. Since we disproportionately selected healthy, prime-aged animals for our study, it is possible that mortality rates in the general adult population are even higher due to natural causes such as disease and old age. In addition, we avoided selecting full curl rams that could be legally hunted.

60% of the mortalities recorded among study animals occurred as highway strikes on the Mile Hill, and 72% of highway/railway strikes among the entire population over the same period occurred on the Mile Hill. Factors influencing the lethality of the Mile Hill include the presence of high quality habitat on either side of the highway, traffic volumes and speeds, and the attraction of sheep to sodium chloride de-icing compounds applied to the highway surface.

Management options for reducing sheep-vehicle collisions need to be explored, including reduced speed limits with signage and enforcement, alternative de-icing salts, and fencing and animal crossing structures. In addition, habitat manipulation in an adaptive management context should be used to investigate whether sheep will return to their historic winter range and reduce their need to cross highway 93/95. Further discussion of the Mile Hill problem and recommendations for mitigation are provided in Swan (2005).

Lamb Production and Lambing Areas

Generally high lamb productivity, particularly in 2002 and 2003, appear to have been sufficient to maintain herd population levels despite high overall mortality rates. Herd census figures in each year of the study have consistently been in the range of 160 to 240 animals, near or above historic population highs (Stelfox 1978; Parks Canada, unpublished data). Continued monitoring of the Radium sheep population and lamb recruitment is needed to potentially detect possible population changes in response to changing levels of lamb production.

Lambing areas we identified were generally located in relatively inaccessible areas within Kootenay National Park. Human use management objectives for these areas should aim to maintain no human use during lambing season. Prescribed fire plans for these areas need to avoid activity during lambing.

Home Ranges, Seasonal Ranges, and Migratory/Dispersal Movements

Bighorn sheep in our study area typically use distinct winter and summer ranges separated by about 5 to 20 kms. Little use of intervening areas occurs, except for occasional travel to and from mineral licks or on twice-yearly seasonal migrations. Minimum convex polygons seem poorly suited for characterizing space use by bighorns because they include so much unused habitat between seasonal ranges. Kernel estimators of home range, although they may entirely omit migration routes, invariably delineate core seasonal ranges. The best characterization of bighorn sheep space use may be a combination of kernel home range estimation and simple delineation of migration corridors using consecutive telemetry points collected while study animals were travelling.

The Radium herd of 200+ animals currently spends nearly 8 months each year on approximately 10 square kilometres of core winter range. Radium females averaged 236 days in wintering areas while males averaged 239 days. Geist (1971) in his study of Stone's sheep in northern B.C. and bighorn sheep in Banff National Park found that females spent between 240 and 268 days on winter ranges, while males spent 271 to 303 days. Geist (1971) also found that females arrived later on winter ranges and departed earlier than males, whereas we found that females arrived earlier on winter ranges. In addition to the potential for overgrazing of limited natural habitats within this area, such a lengthy period with animals grouped closely together creates an environment in which infectious diseases could propagate more easily through the herd. Few or no "intermediate" ranges between winter and summer ranges are available to these sheep, because closed forest vegetation types dominate between the valley floor and tree-line. Closed forests present little forage opportunity for sheep and may also be avoided by sheep due to predation risk. Restoration programs directed at improving sheep winter habitat in the valley bottoms should continue, but potential habitat at intermediate elevations also requires management attention. Intermediate habitat contiguous with winter range should be a high priority, such as the south slopes and ridges of Mt. Berland and west slopes of Redstreak Mountain. Such a program could be designed as a long-term experiment in which hypotheses are formulated around vegetation and sheep response to particular management treatments, the results monitored, and future management actions adjusted accordingly. The current study provides a solid baseline of sheep location data, and it would be straightforward to monitor the use of particular habitats by sheep, and the dates at which they arrive at and depart from the winter range.

The Brisco Ranges from Radium Hot Springs north to Mt. Crook are highly important as summer range to the Radium bighorn sheep, particularly females. Based on the numbers of sheep using them, these ranges currently could be considered the most important lambing and summering ranges in south eastern B.C. north of the Elk Valley. Nearly all known lambing sites and post-lambing habitat for the Radium herd are within these ranges. Although lambing sites are largely protected from human disturbance by the remoteness and ruggedness of the sites ewes typically choose, much of the most heavily used summer range is easily accessible to humans via the popular Kindersley-Sinclair trail. The sheep here are susceptible to disturbance from humans with dogs, and from hikers venturing off-trail to do ridge walks or to photograph sheep; anecdotally both of these activities appear to be increasing on this trail. Park communications, including brochures and trailhead signage, should emphasize compliance with voluntary restrictions on such activities, and hiking guidebook authors should be encouraged to include such messaging in their accounts of the Kindersley-Sinclair trail. Human use monitoring of this trail should include estimates of the numbers of parties venturing off-trail or travelling with dogs; if trends in these activities are upwards then enforceable restrictions may be needed.

No dispersal movements were detected in this study, but this may be because we did not mark animals in the age-sex category most likely to disperse (3 year old males [Geist 1971]). Several long distance exploratory movements of rams did occur, although these do not appear likely to have resulted in contact with other sheep populations. Unlike Geist (1971) in a Banff National Park study, we did not find that rams in our study area travelled to the ranges of other herds during the rut. Increasing sedentariness and isolation of bighorn sheep herds in North America is a serious conservation concern for this species (Risenhoover et al. 1988). An important future product of our study will be a model of bighorn movement routes based on terrain and forest cover attributes. This model will be developed using the Radium sheep telemetry database but should have applicability throughout at least the western Rockies in B.C. based on similarities of terrain and vegetation types. We anticipate that such a model will be useful in predicting where linkages are likely to occur within and between major sheep ranges, and in predicting the possible consequences of various forest management or human activity scenarios.

Domestic Sheep Issues

In efforts to prevent the spread of disease from domestic livestock to wild sheep, some land management agencies in North America have recommended that no domestic sheep and goat grazing should occur within 13.5 kilometres of bighorn habitat (e.g., Bureau of Land Management 1998). However, no such guidelines currently exist regarding wild sheep in south eastern British Columbia, and in our study we have recorded bighorns occurring within several hundred metres of domestic sheep herds. This is an urgent problem with potentially serious consequences for the persistence of the Radium bighorn sheep population. Zehnder and Adams (2002) have examined this problem in considerable detail for the whole East Kootenay region. We are currently collaborating with those authors in updating the domestic-wild sheep situation in the Radium study area.

Use of Kootenay National Park Versus Out of Park Areas

The peak use of national park lands by female sheep coincides with the immediate post-lambing period, underscoring the importance that KNP manage these lands to minimize disturbance of sheep. Peak use of KNP by rams occurs during hunting season, which means that only a small portion of adjacent out-of-park habitat provides hunting opportunity. Provincial wildlife managers responsible for regulating hunting activity should consider this when allocating sheep tags. Concentrated hunting activity in a small area outside the park could conceivably lead the rams to further concentrate their range use within KNP. See King and Workman (1986) for discussion of possible disturbance effects of hunting on bighorn sheep.

Use of Terrain

Bighorn sheep preferences for elevation, aspect, and slope during certain seasons have implications for habitat management and restoration, discussed elsewhere in this report. In addition, the ways that bighorn sheep select terrain and forest cover types profoundly influence the options sheep have for moving through the landscape, whether at the scale of daily foraging, seasonal migrations, long distance movements or dispersal. Bighorn sheep in south eastern British Columbia, and elsewhere in North America, are structured as metapopulations (Demarchi et al. 2000; Epps et al. 2005), and inter-herd movements likely are important for long-term conservation of this species (Luikart and Allendorf 1996). Although we have detected no inter-herd movements in the first 3 years of telemetry-based study of this herd, an important tool for managing bighorns in south eastern B.C. will be a model of movement corridors, based on terrain and physiographic features, to identify routes with the potential to provide linkage between sheep subpopulations. A future objective of this study is to use GPS telemetry data to test the theoretical model of bighorn movement corridors developed by Tremblay (2001) for the Radium area, and to develop an independent, empirically-based movement corridor model.

Use of Mineral Licks

The importance of minerals to bighorn sheep is exemplified by the distances sheep will travel to reach sources of these minerals, the well-worn game trails leading to and from sources, and, in the case of the CMPD mineral site, the development of migratory routes in close proximity. Additionally, many sheep are killed on highways while licking road salt.

Stelfox et al. (1985) reported that mineral licks of the Radium herd occurred at Stoddart Creek and along lower Sinclair Creek. These authors did not record mineral lick use at the compound salt shed, or at the upper Kindersley-Sinclair trailhead. It is possible that sheep use of mineral licks has changed in the last 2 decades due to increased availability of road salt at the compound and along sections of highway 93 where large amounts of salt are applied in winter.

The compound salt shed is a concern because, depending on the source of the road salt stored here, the salt may be contaminated with toxic substances with unknown health effects on animals consuming it. Additionally, concentrations of sheep using this site may lead to the spread of saliva-borne diseases. On the other hand, there has been no evidence that sheep have suffered health effects from consuming road salt, and the compound site is a relatively safe place for sheep to consume road salt because of its separation from public highways. It is recommended that supplies of road salt be obtained only from sources with known low toxicity levels. The feasibility of using alternative de-icing salts is still unclear; there may be some benefits to reducing vehicle-wildlife collisions, but significant cost and public safety considerations exist (Knapp 2004). However the Parks Canada Highways Service Centre and the B.C. Government Ministry of Transportation and Highways should continue to explore alternatives to the use of sodium chloride on highways embedded within bighorn sheep range, particularly the 2 kilometres of highway 93/95 south from the village of Radium Hot Springs (the Mile Hill).

Response to Restoration of Winter Range

The Radium bighorns appear to have responded quickly to the 2003 restoration work by making considerable use of this area in March through May of 2004. This success may be partly attributed to the adjacency of the 2003 restoration area to previously occupied winter range along Redstreak Road. Bighorns are notoriously slow colonizers of new habitats (Geist 1971) and this may explain why the sheep have not yet made substantially more use of the 2002 restoration area, which is more distant from current core winter range. Similarly the 2001 restoration area at Stoddart Creek does not appear to have been rediscovered by the radio collared sample of sheep, although groups of unmarked sheep have been observed here each year since 2001. It is possible that a particular group of sheep has an affinity for Stoddart Creek, but was not sampled in our study because we only captured sheep near the village of Radium Hot Springs.

Additional restoration of winter range in the Radium-Stoddart area will be needed to offset possible losses due to the tremendous residential development boom in the village of Radium Hot Springs. Increasing traffic volumes along highway 93/95 at the Mile Hill have the potential to maintain or increase the rate of vehicle-wildlife collisions in this area, so it is recommended to continue the experiment of improving winter range conditions east of the highway so that sheep have less need to cross the highway. In addition to treating more area, treatment prescriptions can be varied according to stand density targets, brushing treatments, weed control, and use of prescribed fire in order to increase our learning about ecosystem response.

Given that sheep tend to be slow colonizers of new habitats, it will be important to continue to monitor the Radium sheep for several more years in order to understand sheep response to our treatments. Our study provides a unique opportunity to investigate the response of a large mammal to restoration treatments, since we already have a rich set of pre-treatment GPS telemetry data. Since sheep winter range coincides with habitat for a large suite of rare and at-risk species in British Columbia, we also recommend that other ecosystem components, including small mammals, birds, and plant communities be monitored.

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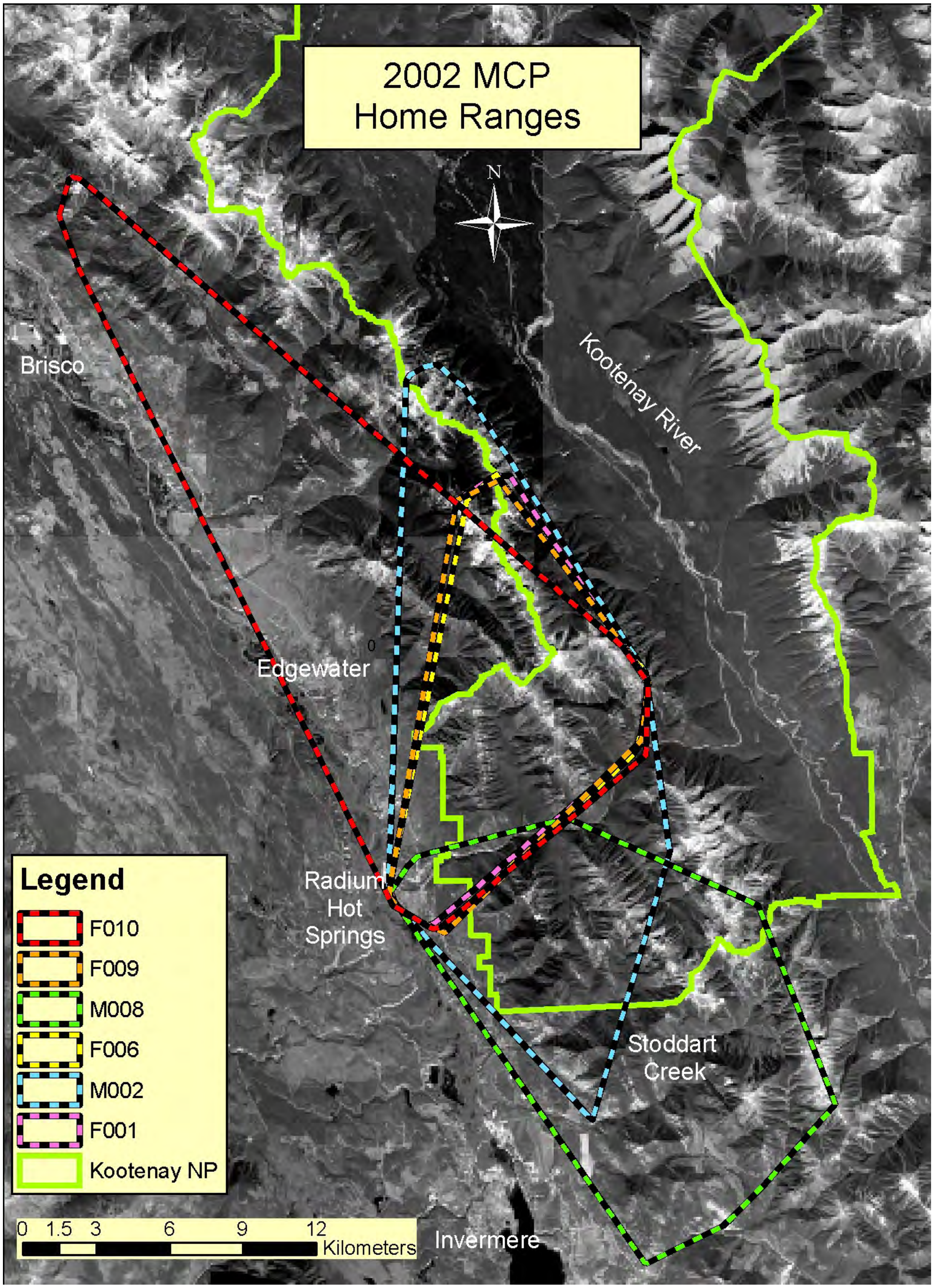
Appendix 1

Appendix 1 - Maps of Minimum Convex Polygon and 90% Fixed Kernel Home Ranges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Edgewater
Radium
Hot
Springs
Stoddart
Creek
Invermere
Legend
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F009
M008
F006
M002
F001
Kootenay NP
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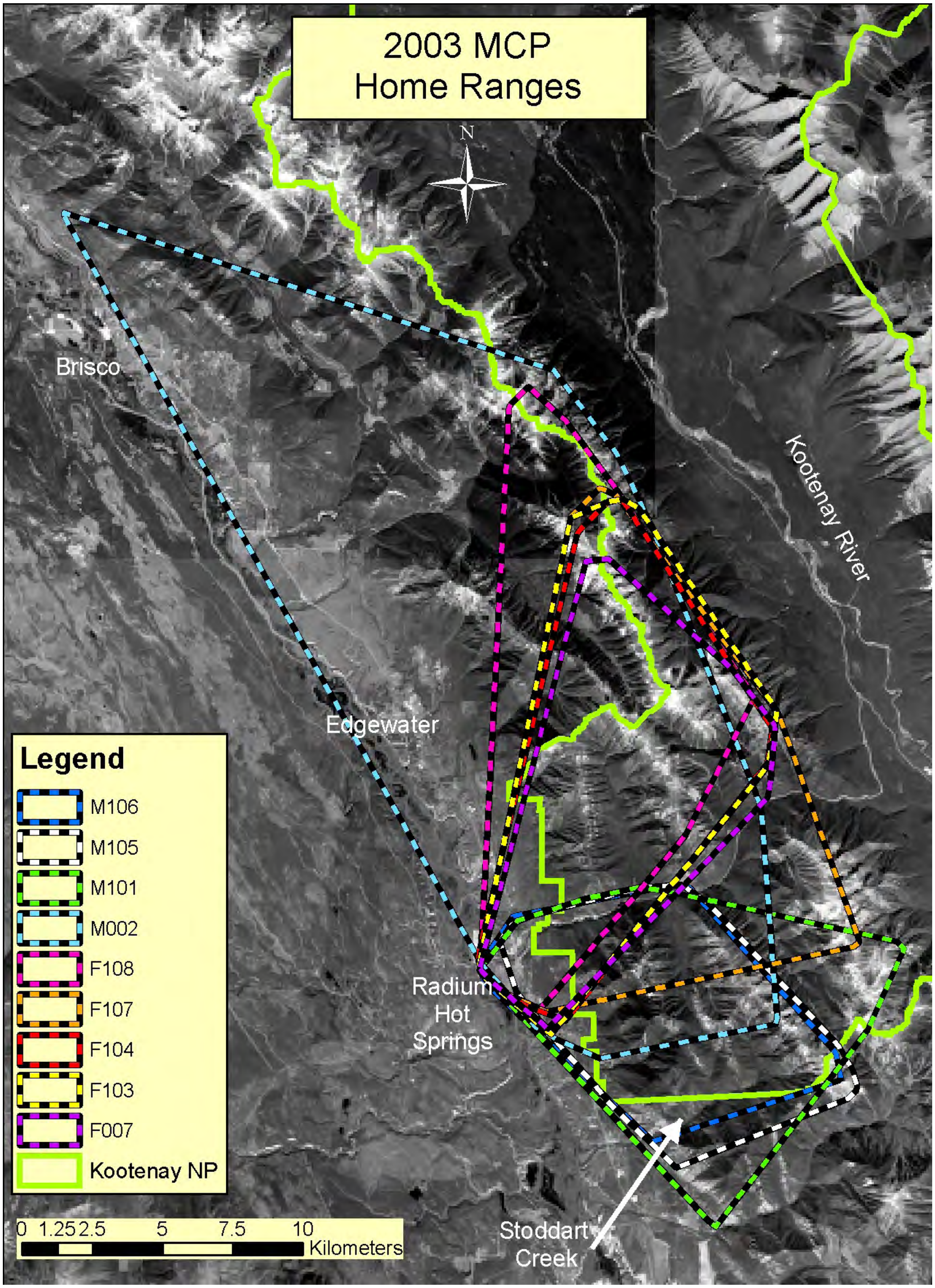
Kilometers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Brisco
Edgewater
Radium Hot Springs
Stoddart Creek
Kootenay River
Legend
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M105
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M002
F108
F107
F104
F103
F007
Kootenay NP
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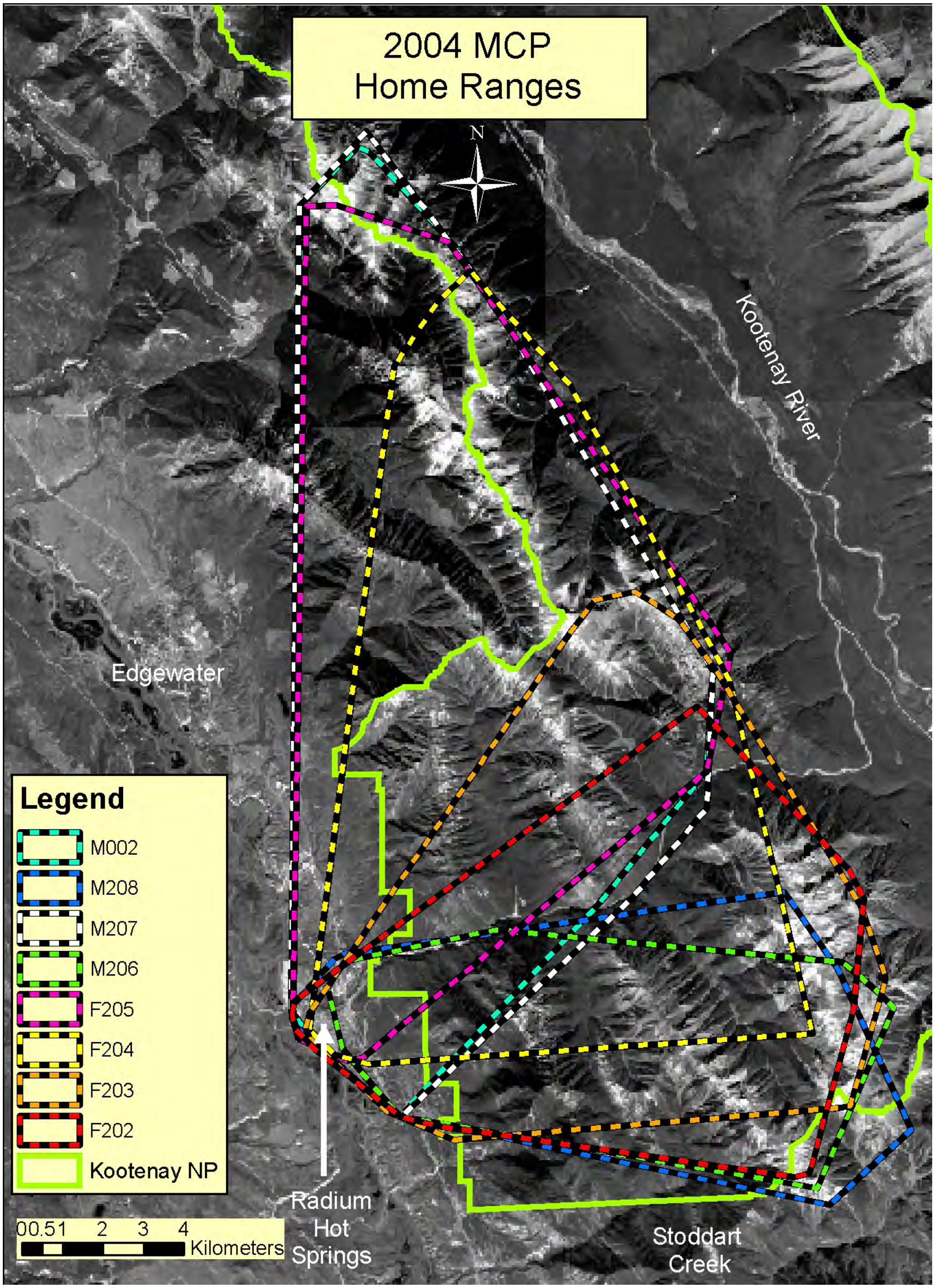
Kilometers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Edgewater
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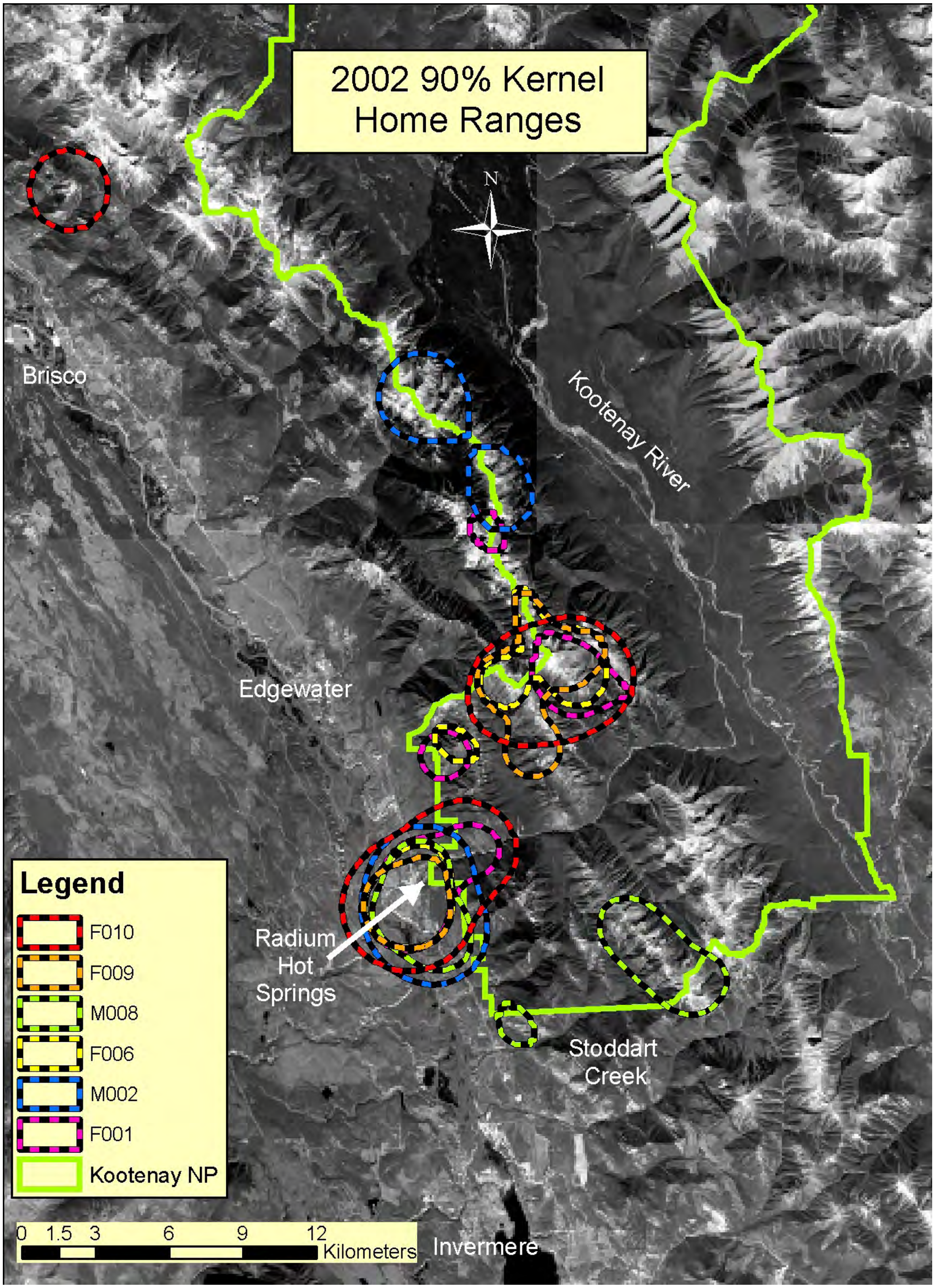
Kilometers
Radium
Hot
Springs
Stoddart
Creek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Brisco
Kootenay River
Edgewater
Radium Hot Springs
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F006
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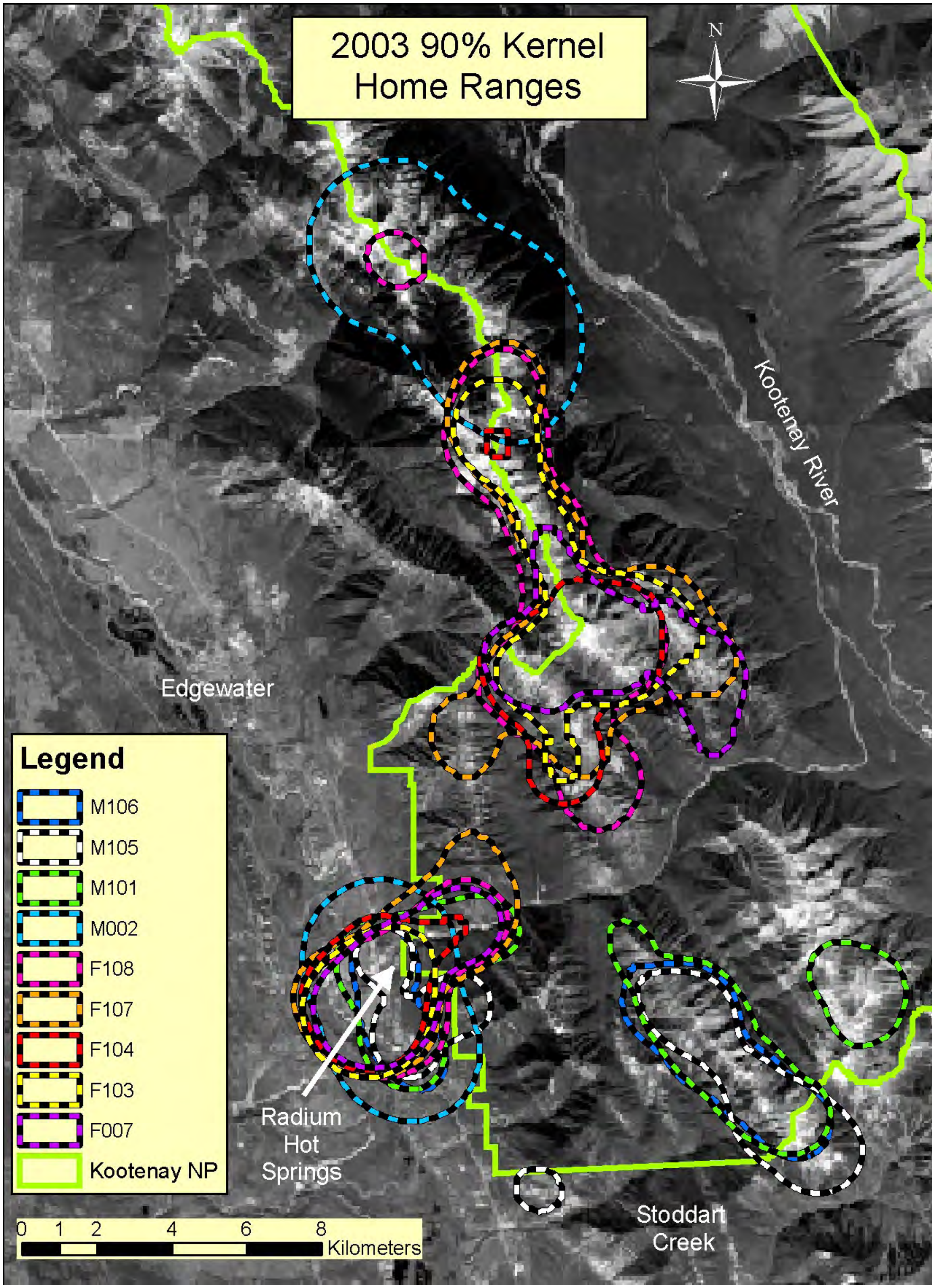
Kootenay NP
0 1.5 3 6 9 12 Kilometers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M101
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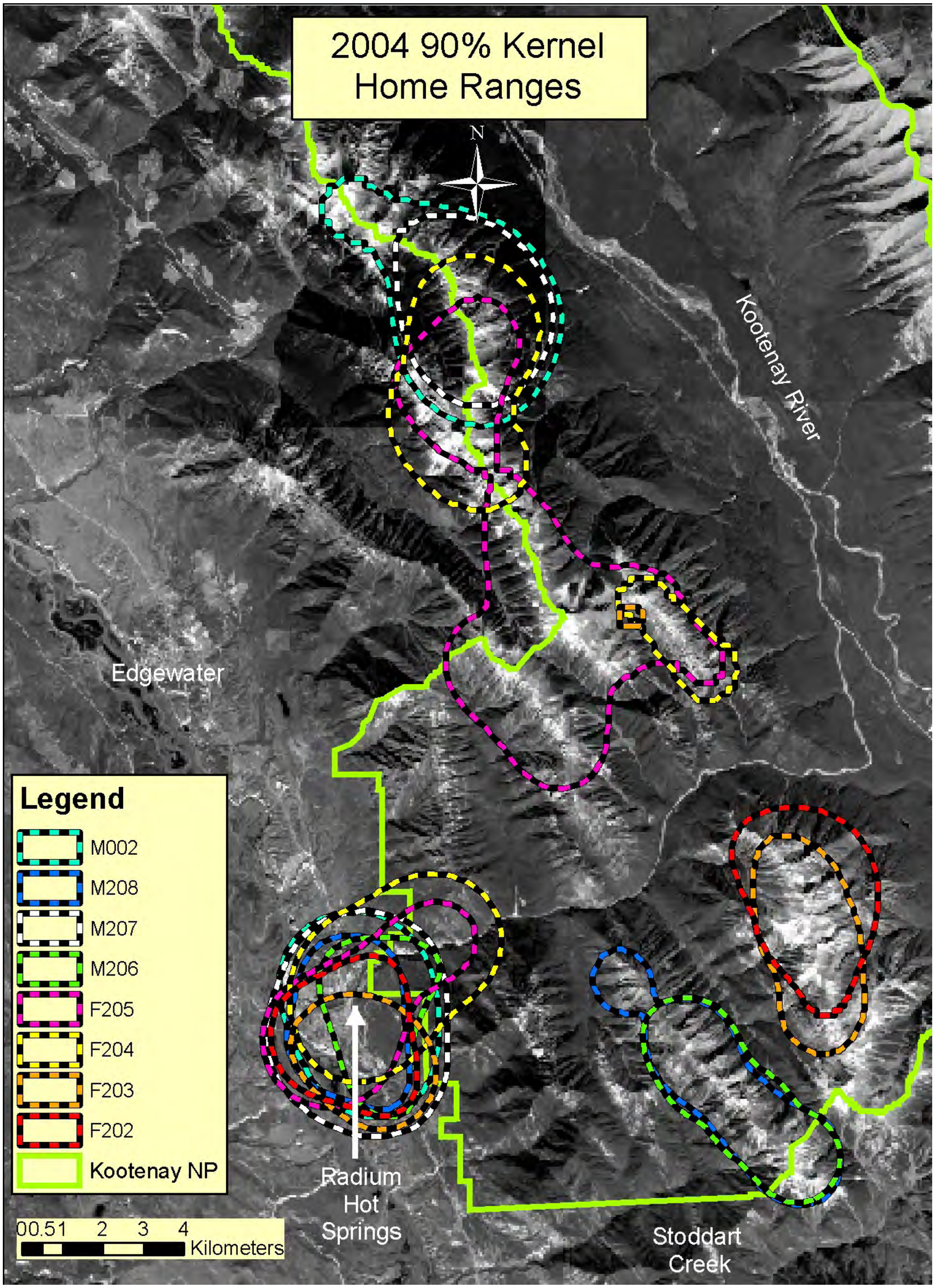
F103
F007
Kootenay NP
Radium
Hot
Springs
Stoddart
Creek
0 1 2 4 6 8
Kilometers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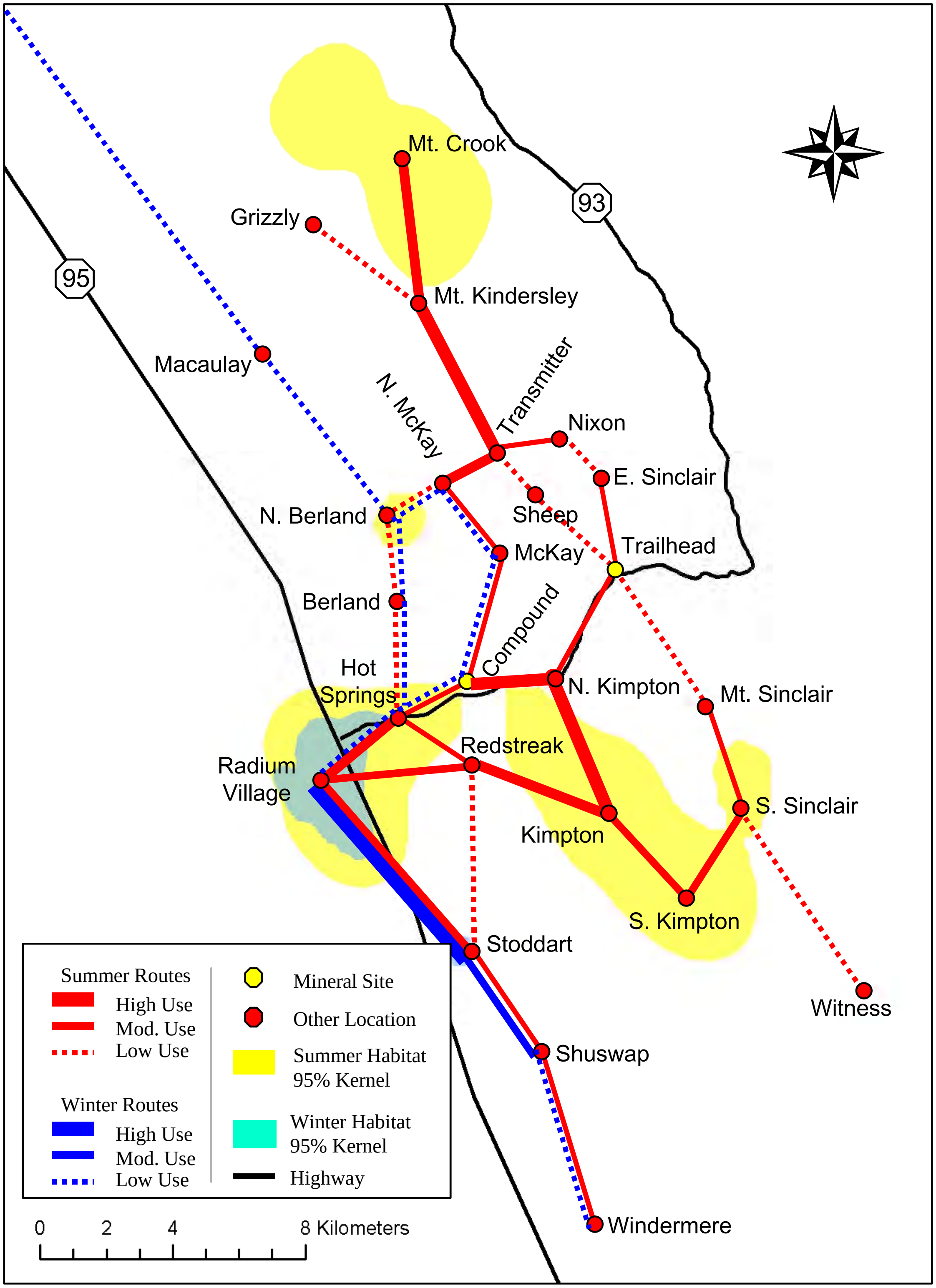
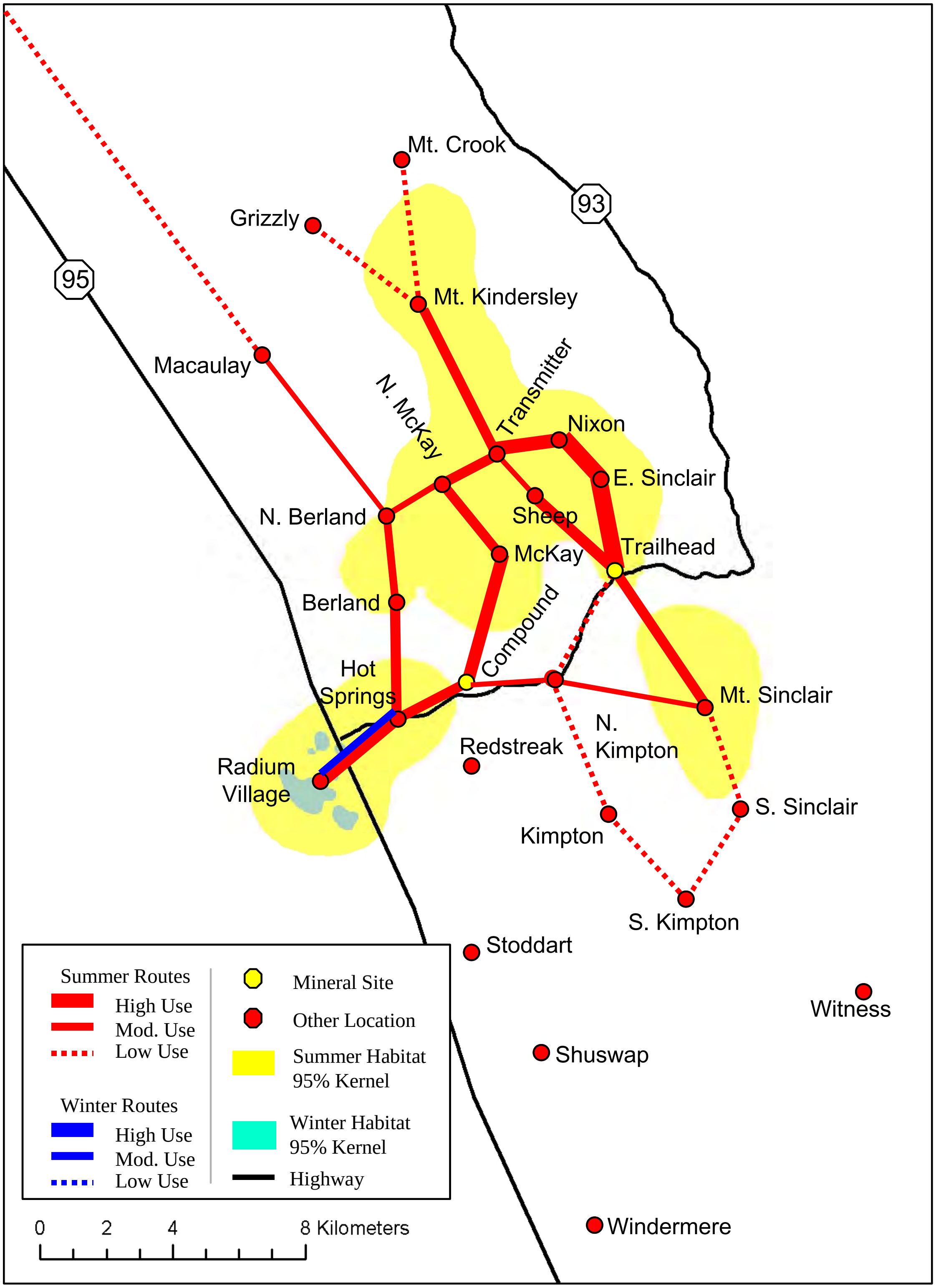
F202
Kootenay NP
00.51 2 3 4
Kilometers
Radium
Hot
Springs
Stoddart
Creek

Appendix 2

Appendix 2 - Diagrams of Movement Routes and Core Ranges for Males and Females



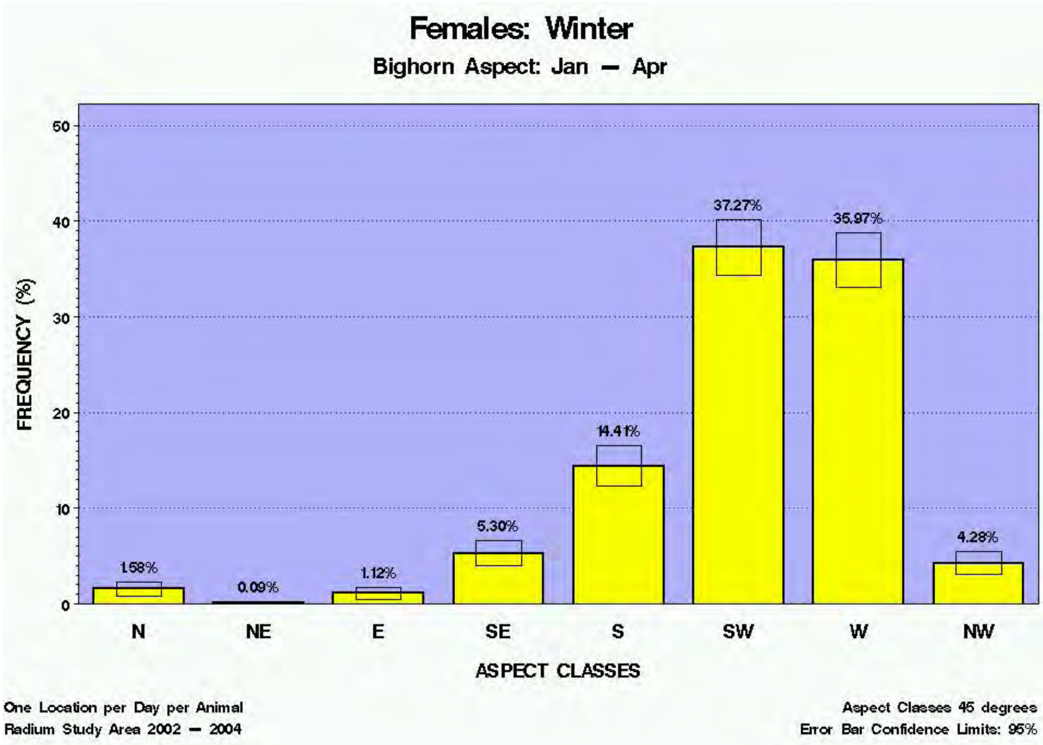
Male Movement Routes and Core Ranges: 2002-2004

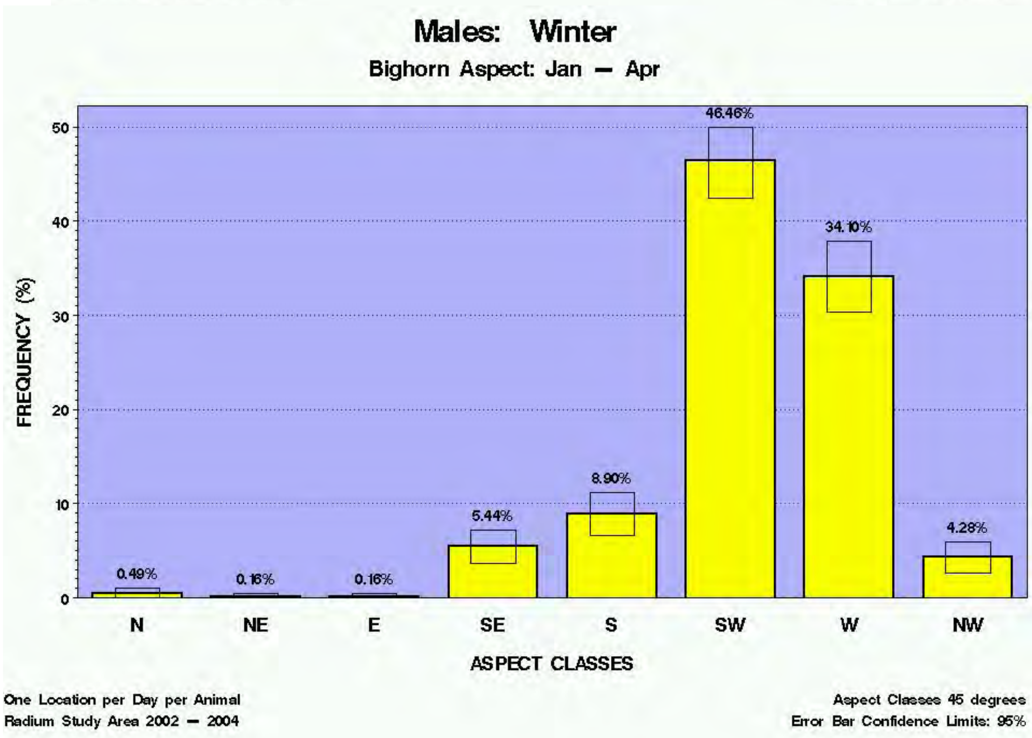


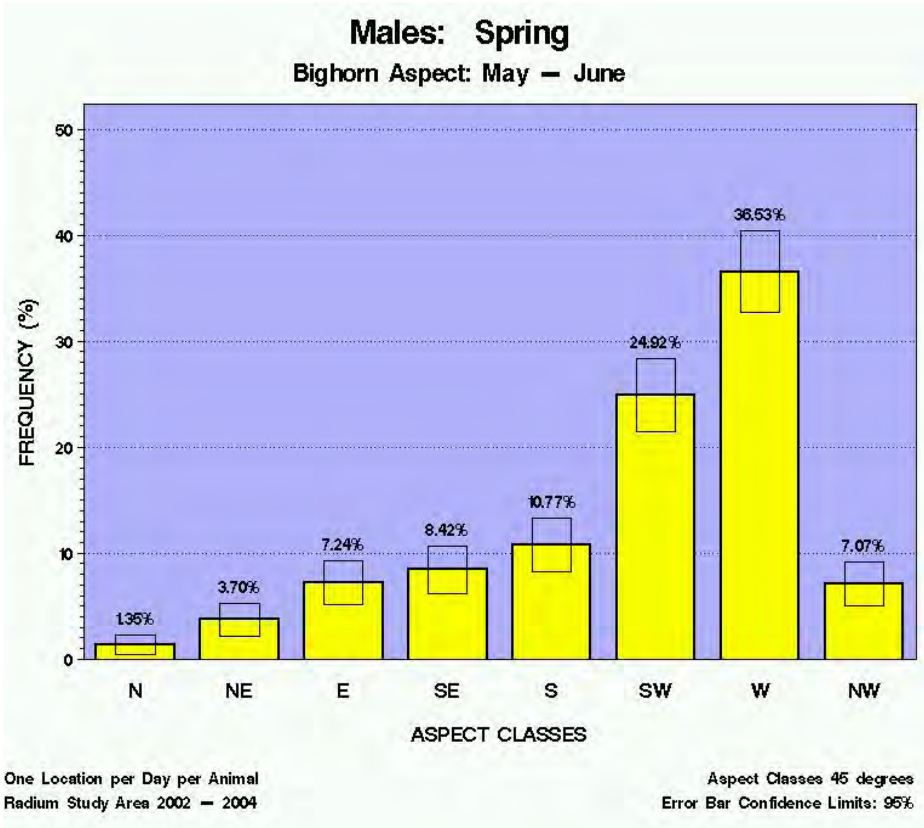
Female Movement Routes and Core Ranges: 2002-2004

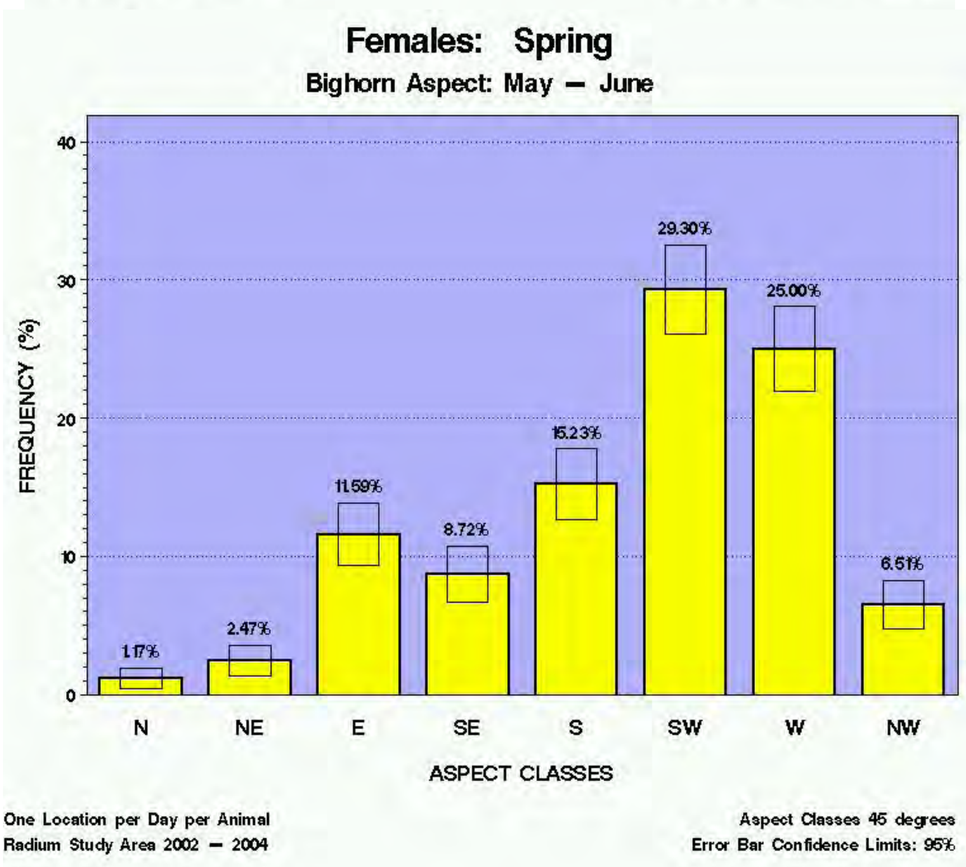
Appendix 3

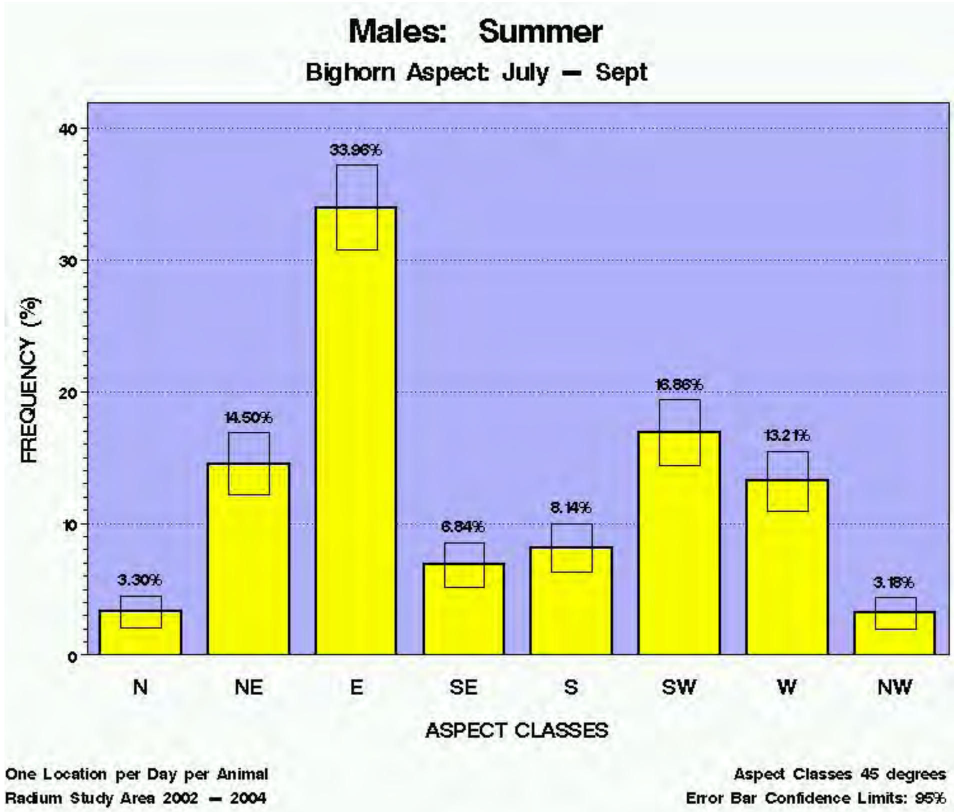
Appendix 3 - Charts of Female and Male Selection of Aspect by Season

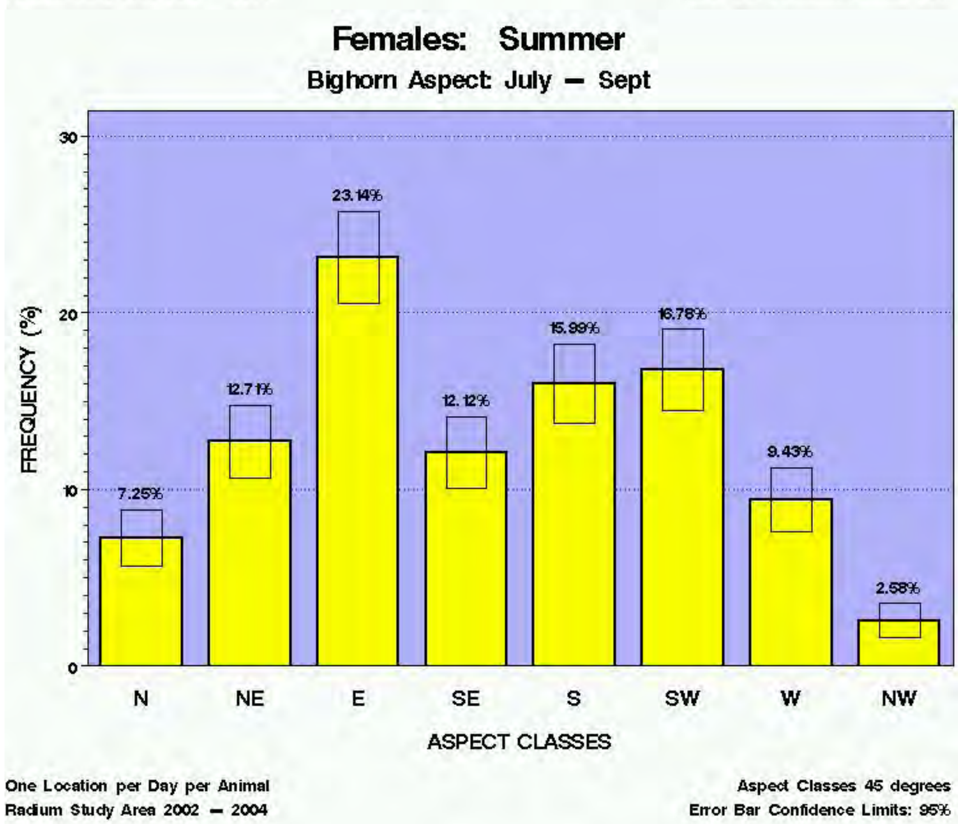

Females: Winter
Bighorn Aspect: Jan — Apr
FREQUENCY (%)
50
40
30
20
10
0
37.27%
35.97%
14.41%
5.30%
4.28%
1.58%
0.09%
1.12%
N
NE
E
SE
S
SW
W
NW
ASPECT CLASSES
One Location per Day per Animal
Radium Study Area 2002 — 2004
Aspect Classes 45 degrees
Error Bar Confidence Limits: 95%

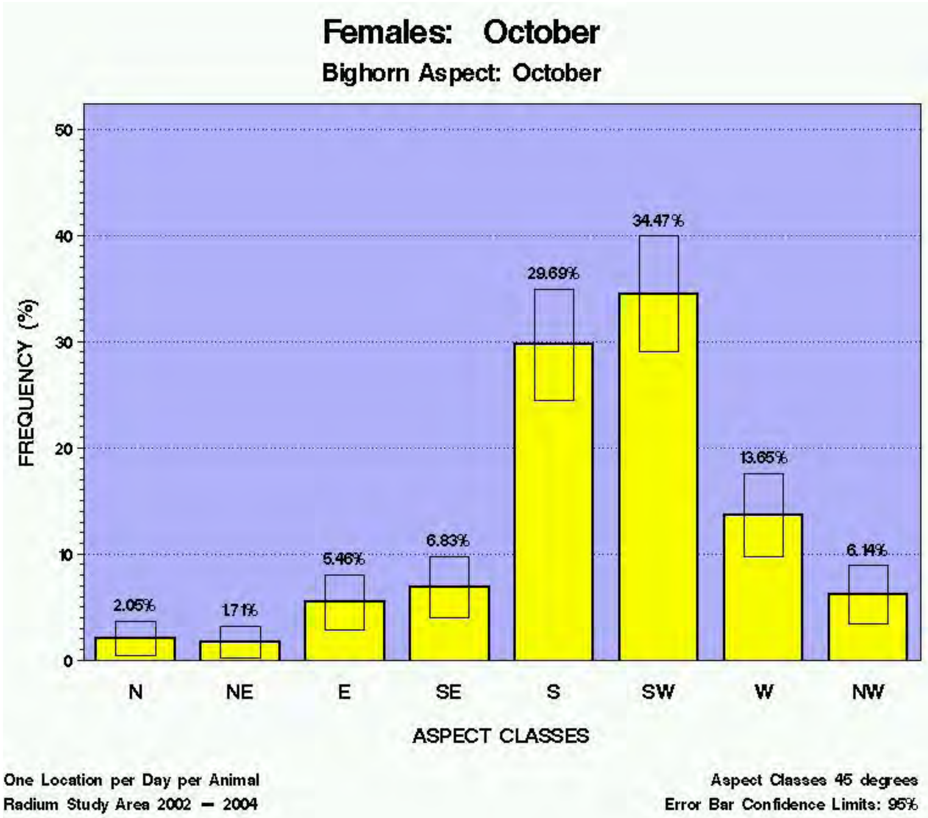

Males: Winter
Bighorn Aspect: Jan — Apr
FREQUENCY (%)
50
40
30
20
10
0
46.46%
34.10%
8.90%
5.44%
4.28%
0.49%
0.16%
0.16%
N
NE
E
SE
S
SW
W
NW
ASPECT CLASSES
One Location per Day per Animal
Radium Study Area 2002 — 2004
Aspect Classes 45 degrees
Error Bar Confidence Limits: 95%

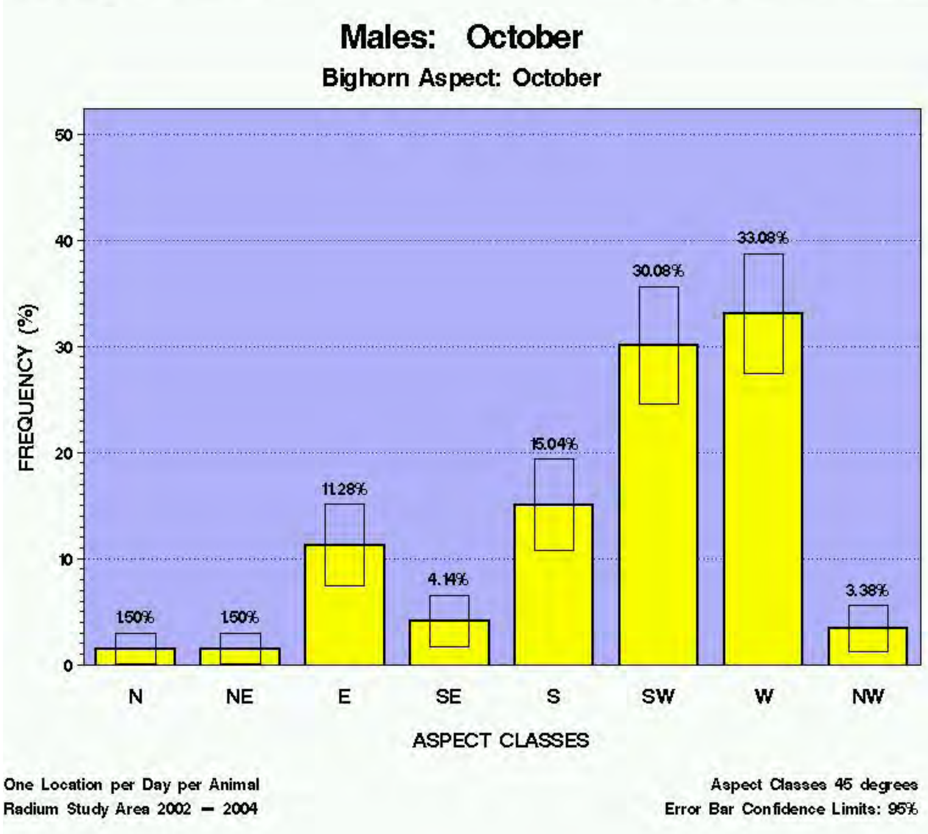

Males: Spring
Bighorn Aspect: May — June
FREQUENCY (%)
0
10
20
30
40
50
1.35%
3.70%
7.24%
8.42%
10.77%
24.92%
36.63%
7.07%
N
NE
E
SE
S
SW
W
NW
ASPECT CLASSES
One Location per Day per Animal
Radium Study Area 2002 — 2004
Aspect Classes 45 degrees
Error Bar Confidence Limits: 95%

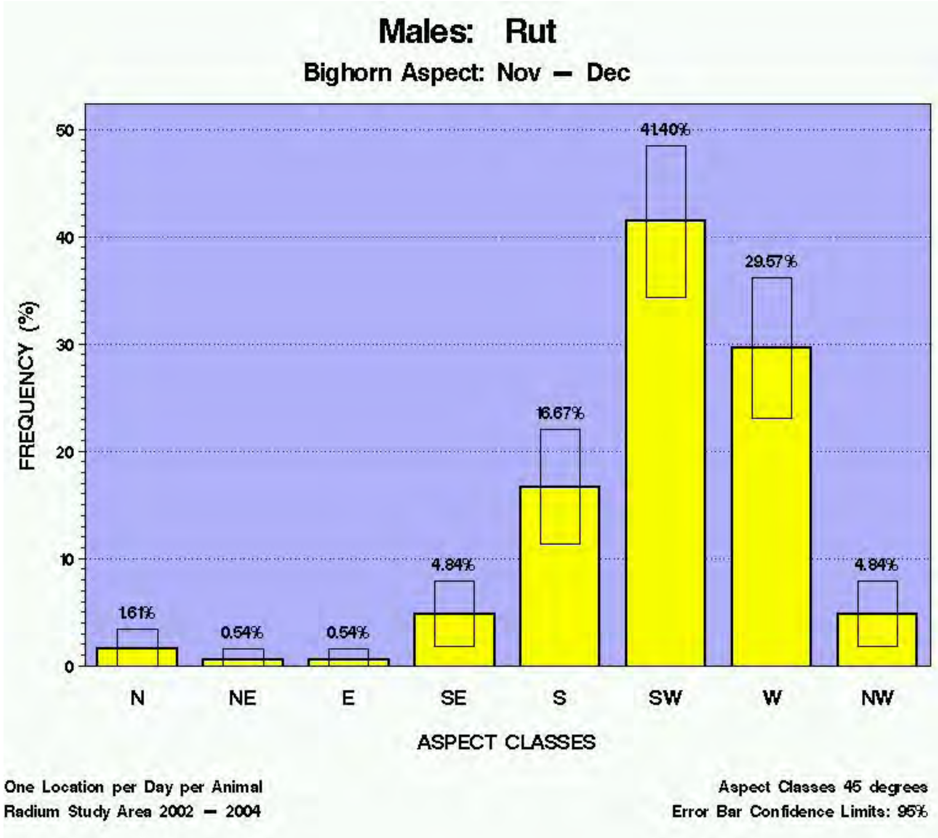

Females: Spring
Bighorn Aspect: May — June
FREQUENCY (%)
0
10
20
30
40
1.17%
2.47%
11.59%
8.72%
15.23%
29.30%
25.00%
6.51%
N
NE
E
SE
S
SW
W
NW
ASPECT CLASSES
One Location per Day per Animal
Radium Study Area 2002 — 2004
Aspect Classes 45 degrees
Error Bar Confidence Limits: 95%

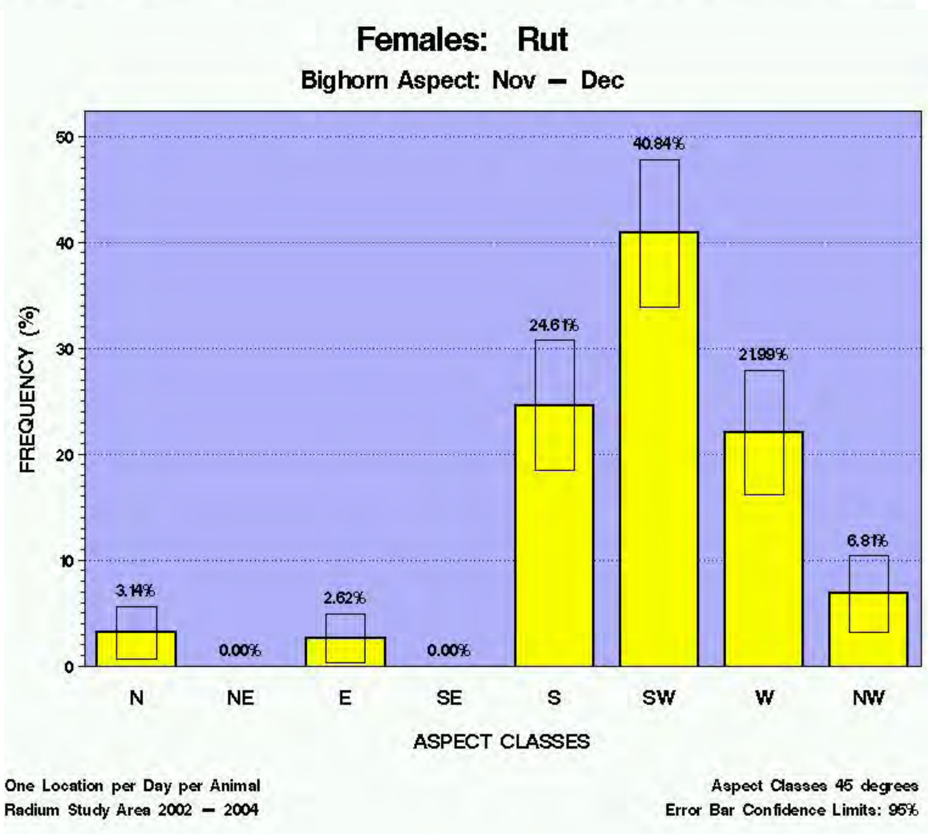

Males: Summer
Bighorn Aspect: July – Sept
FREQUENCY (%)
40
30
20
10
0
33.96%
14.50%
3.30%
6.84%
8.14%
16.86%
13.21%
3.18%
N
NE
E
SE
S
SW
W
NW
ASPECT CLASSES
One Location per Day per Animal
Radium Study Area 2002 – 2004
Aspect Classes 45 degrees
Error Bar Confidence Limits: 95%


Females: Summer
Bighorn Aspect: July – Sept
FREQUENCY (%)
30
20
10
0
7.25%
12.71%
23.14%
12.12%
15.99%
16.78%
9.43%
2.58%
N
NE
E
SE
S
SW
W
NW
ASPECT CLASSES
One Location per Day per Animal
Radium Study Area 2002 – 2004
Aspect Classes 45 degrees
Error Bar Confidence Limits: 95%


Females: October
Bighorn Aspect: October
FREQUENCY (%)
0
10
20
30
40
50
2.05%
1.71%
5.46%
6.83%
29.69%
34.47%
13.65%
6.14%
N
NE
E
SE
S
SW
W
NW
ASPECT CLASSES
One Location per Day per Animal
Radium Study Area 2002 — 2004
Aspect Classes 45 degrees
Error Bar Confidence Limits: 95%


Males: October
Bighorn Aspect: October
FREQUENCY (%)
0
10
20
30
40
50
1.50%
1.50%
11.28%
4.14%
15.04%
30.08%
33.08%
3.38%
N
NE
E
SE
S
SW
W
NW
ASPECT CLASSES
One Location per Day per Animal
Radium Study Area 2002 — 2004
Aspect Classes 45 degrees
Error Bar Confidence Limits: 95%


Males: Rut
Bighorn Aspect: Nov – Dec
FREQUENCY (%)
0
10
20
30
40
50
1.61%
0.54%
0.54%
4.84%
16.67%
41.40%
29.57%
4.84%
N
NE
E
SE
S
SW
W
NW
ASPECT CLASSES
One Location per Day per Animal
Radium Study Area 2002 – 2004
Aspect Classes 45 degrees
Error Bar Confidence Limits: 95%


Females: Rut
Bighorn Aspect: Nov – Dec
FREQUENCY (%)
0
10
20
30
40
50
3.14%
0.00%
2.62%
0.00%
24.61%
40.84%
21.99%
6.81%
N
NE
E
SE
S
SW
W
NW
ASPECT CLASSES
One Location per Day per Animal
Radium Study Area 2002 – 2004
Aspect Classes 45 degrees
Error Bar Confidence Limits: 95%

Appendix 4

Appendix 4 - Summary Accounts of Individual Study Animals

Individual Female Study Animal Summaries

F001. F001 was captured and collared on January 8, 2002 near the Canyon Campground just north of the village of Radium Hot Springs, and was an estimated 6.5 years old. On May 12th she left the Radium Aquacourt area for Mt. Berland, then followed an undetermined route to John McKay Ridge. By the 14th she was back near the Aquacourt. On May 23rd F001 travelled north along the west mid-slope of Mt. Berland to a point at 1900 metres elevation about 6 km due north of the village. The following day she returned to lower Sinclair Creek. On the morning of May 25th F001 again left the Aquacourt area, this time following the south ridge of Mt. Berland. By late on the 26th she had moved west off the Mt. Berland ridge into complex terrain on a subsidiary ridge, where she spent the next 9 days within an area of about 700 by 200 metres; it is likely that she had her lamb within this area. On June 5th F001 moved back to the Aquacourt area, then spent several days in the village of Radium Hot Springs before ascending John McKay Ridge on June 13th. By June 14th she was on the south end of the East Sinclair Ridge, and she spent the rest of June near here or on nearby Sheep Mountain. July and August were mostly spent on the ridges between Transmitter Peak and Mt. Crooks, with the exception of a short trip to the mineral lick at the upper Kindersley-Sinclair trailhead on July 22nd and a circuit of the ridges east and west of John McKay Creek on August 7th and 8th. On August 21st F001's collar stopped collecting GPS points.

F004. F004 was captured on the Springs golf course on January 10, 2002 and was estimated to be 6.5 years old. It appears that her collar began to malfunction by the middle of May, and it only collected 1 GPS point in June, 2 in July and August, and 1 in September. However we do know that she was still near Radium Hot Springs on May 25th, and by May 27th had arrived at a point approximately 11 km north of Radium Hot Springs, on west facing cliffs above Hewitt Road, just northwest of the community of Edgewater. She was observed here with a lamb, and in the company of another ewe and lamb on June 3rd. F004's remaining few telemetry points from July, August and September were all from the Transmitter Peak area.

F006. F006 was captured on the Springs golf course on January 10, 2002 and was estimated at 2.5 years of age. She left the hot springs area on May 25th, followed the south ridge of Mt. Berland to the north, and spent 3 days in a small area (150 x 100 metres) approximately 200 metres east of the ridge. On May 29th she moved over the ridge to the west side and travelled about 1.5 km west onto the south aspect of a subsidiary ridge, only about 250 metres from the suspected lambing site of F001. She remained within about 200 metres of this site, likely having her lamb here, until June 7th when she moved north and followed the ridge at the head of John McKay Creek east to John McKay Ridge. F006 used this ridge system until July 3rd, when she suddenly traveled 7 aerial kms to the lick at the Kindersley-Sinclair trailhead; it is not known which route she followed to get here. She spent the rest of the summer on East Sinclair Ridge, Sheep Mountain, Transmitter Peak and the ridge system north towards Mt. Crook. She made 3 additional trips south along East Sinclair Ridge towards the mineral lick on August 1st, August 12th, and September 13th. No GPS points were recorded right at the lick, but this could be because of the short duration of these visits and the length of time between successful GPS fixes. On September 18th F006 moved west to John McKay Ridge, and between October 1st and 4th she traveled south along Mt. Berland to the hot springs area. She spent much of the rest of October on the Springs golf course, and her collar was removed on October 24th.

F007. F007 was captured near the Kootenay National Park administration building on January 11th, 2002. Her collar began to malfunction in mid-March and did not collect any points after April 11th, and so the GPS location data does not provide any insights into seasonal movements of this animal. Additionally, her collar release mechanism failed to work in October as planned, and we were not able to immobilize her until December 16th, at which time her old collar was removed and a new collar was installed. One event affecting F007 in 2002 was recorded by direct observation: in April of this year she was observed in Sinclair Canyon with a pronounced limp and a large wound on her right flank, consistent with a cougar attack. Inspection of the collar at the time of its removal in December showed evidence that the collar had been scratched and bitten; we speculated that the collar might possibly have played a role in F007 surviving this apparent attack. Nonetheless, F007 was observed with a lamb later in the summer.

In 2003, F007 left the Sinclair Canyon area around 7:00 a.m. (Mountain Daylight Time) on May 27th and was near the north end of Berland Ridge by 11:30 a.m. By 10:00 p.m. she had reached a point at 2150 metres elevation on the south end of John McKay Ridge, likely by having traversed the entire ridge system west, north and east of McKay

Creek. She then followed an undetermined route to reach the vicinity of the upper trailhead for the Kindersley-Sinclair trail by 10:00 p.m. on May 28th. F007 spent the rest of May and the first half of June slowly working her way up the south end of East Sinclair Ridge, with no clear pattern of seclusion consistent with lambing behaviour of other ewes. She did spend 4 days between June 21st and June 25th in a relatively small area near the north end of East Sinclair Ridge, but the timing, duration, and terrain features of this site do not seem consistent with lambing activity of other ewes. In the last 6 days of June F007 moved from the East Sinclair Ridge to Kindersley Peak, then south to Sheep Mountain. Her summer ranges were similar to those of most other female sheep. F007 visited the upper Kindersley-Sinclair trailhead lick on July 4th and may have visited it on at least 2 other occasions later in July. On July 30th she traversed south along John McKay Ridge, then descended to the Parks Canada compound, where she presumably licked the stockpiled road salt before returning to the ridge crest that same evening. On August 12th F007 again descended from John McKay Ridge to the vicinity of the road salt shed at the Parks Canada compound, but this time she continued down Sinclair Creek to the hot springs, before climbing up Mt. Berland and back into her summer range. She descended for good on September 10th via McKay Ridge and the compound again, and spent the next 2 weeks in Sinclair Canyon. On September 24th she moved into the village of Radium Hot Springs, spending considerable time on the Springs golf course even though it remained open for golfing for over another month. Her collar was removed on December 2nd, 2003 near the CPR railway tracks below the north end of the golf course.

F009. F009 was captured on January 12th, 2002 near the Kootenay National Park administration building. In the pre-dawn hours of May 17th she left Canyon Campground and by 6:00 a.m. she was near the hot springs. By 3:00 p.m. she was at 2000 metres on the south end of John McKay Ridge. She then dropped 500 metres down the west side of the ridge and spent 3 days within an area about 100 by 200 metres, then returned to the ridge crest and spent 3 more days in an equally small area there. It is possible that she had her lamb at 1 of these 2 sites. During summer she occupied typical female sheep range north of highway 93. She made 4 trips down to or near the Kindersley-Sinclair trailhead lick, on July 4th, July 18th, August 2nd, and August 18th, with all visits lasting well under 24 hours. On 1 of these occasions (July 4th), she appeared to travel from the south end of John McKay Ridge to near the highway, and may have followed the highway to the lick. On 3 occasions she seemed to approach via Sheep Mountain, but missing data points make it impossible to infer her exact route(s). On 3 of these visits F009 returned to the high country via the south end of East Sinclair Ridge, but on 1 visit she appears to have traveled directly to Sheep Mountain by contouring the lower west slopes of East Sinclair Ridge and then cutting directly across Sinclair Creek. On September 12th F009 moved abruptly down from John McKay Ridge to or near the Park compound salt shed, continued down valley to the Iron Gates tunnel near the hot springs, then moved north up Mt. Berland and back to the high country. She returned to her winter range for good on October 7th by descending from John McKay Ridge. Like F007, F009 spent most of the rest of October at the Springs Golf Course. Her collar was removed on October 24th on the golf course.

F010. F010 was captured on the Springs golf course on January 13th, 2002. In the middle of May she moved from the village up to the hot springs area, and on May 20th began travelling north on Mt. Berland. When F010 reached a point about 4 kms north of the hot springs she turned northwest, following a complex system of subsidiary ridges down to the Columbia Valley benchlands, passing within 1 kilometre east of Baptiste Lake. By May 24th she had climbed back up to the ridge crest of the range just northeast of the community of Edgewater, only to descend back to the benchlands where Kindersley and Luxor Creeks emerge from the Brisco Range. On May 27th her collar recorded 2 data points at a mineral lick known to be used by goats, suggesting that she spent some hours there. She continued following the benchlands north until she began to climb again just northeast of the community of Brisco. Her destination, reached on May 29th, was an open south-facing ridge 6 kms north of Brisco, or 32 kms northwest of her winter range at Radium Hot Springs. She confined herself to an area of about 600 by 300 metres until June 27, with several shorter periods of confinement to even smaller sub-areas. She almost certainly lambed in this area. She returned to Mt. Berland by following the reverse route, arriving on July 1st. F010 summered mainly in upper Sinclair Creek on Transmitter Peak and Sheep Mountain, as well as on John McKay Ridge. She made 2 approaches to the Kindersley-Sinclair trailhead lick; 1 on July 22nd and the other on August 1st; both visits were for a single late afternoon – evening period. The August 1st visit appears to have been approached directly from Sheep Mountain, crossing Sinclair Creek to the south end of the East Sinclair Ridge. She took until August 6th to return to Transmitter Peak, following the whole length of the East Sinclair Ridge. On

August 19th F010 descended from John McKay Ridge to the compound, likely following the traditional route via the salt shed. After 2 days near the hot springs she returned to John McKay Ridge by first traversing Mt. Berland ridge. On September 18th F010 returned to the hot springs area, likely using the same route as for her descent of August 19th. She spent nearly all of October near the hot springs until her collar was removed on October 24th.

F011. F011 was captured on March 4th, 2002 at the Springs golf course. Her collar began to malfunction in late April and did not collect any points between May 10th and June 6th, thus likely missing this animal's lambing range. On June 7-8th points were collected on the northern half of John McKay Ridge, after which the collar failed completely. The collar was removed on October 24th.

F102. F102 was captured on the Springs golf course on December 16th, 2002. She spent the rest of the winter in the Village and area, until she was killed in a highway collision on March 24th, 2003.

F103. F103 was captured on the Springs golf course on December 17th, 2002. She wintered within and near Radium Village, and began her spring migration on May 20th, when she began climbing John McKay Ridge from the south, reaching her probable lambing site on May 21st. This site was an area about 300 by 400 metres on the west side the ridge at near 2000 metres. On June 1st she left this site and spent the next 10 days wandering north and south along the ridge. On June 10th F103 suddenly moved to Sheep Mountain, apparently traveling directly across the forested valley, as it took her only about 2 hours to move from summit to summit. On June 16th she traveled south along East Sinclair Ridge and then returned to the Transmitter Peak area by June 26th. She spent the remainder of the summer in these same areas and north towards Mt. Kindersley. F103 made 3 day trips to the vicinity of the upper Kindersley-Sinclair trailhead on July 2nd, August 16th, and August 20th. On July 17th she descended John McKay Ridge to the compound, where a GPS point was recorded at the salt shed. On the 18th she returned to the high country via Mt. Berland and continued on to Transmitter Peak by the 14th. F103 made her fall migration on September 14th via John McKay Ridge, although it is not clear whether she visited the compound and the salt shed at the same time. She returned to the Springs golf course by September 17th and spent most of the remainder of the fall here. Her collar was removed on December 2nd at the north end of the Springs golf course.

F104. F104 was captured on the Springs golf course on December 17th, 2002. She spent the remainder of the winter on the Springs golf course and nearby areas, but in late April moved just north of RadiumVillage near Canyon Campground. On May 6th F104 began moving east up Sinclair Creek and remained in this area until May 13th. She then entered her lambing range on the west side of John McKay Ridge on May 14th and departed on May 28th. This was the same area used by F103, although F103 did not enter this area until May 21st. She stayed on John McKay Ridge until June 18th, then spent most of the rest of the summer between Sheep Mountain and Mt. Kindersley. She appears to have made 2 excursions down to the highway near the upper Kindersley-Sinclair trailhead, on June 24th and July 1st, although no GPS points were recorded right at the lick site. F104 also made 2 excursions down towards the Parks Canada compound and Sinclair Canyon, on July 16th and August 23rd, in both cases descending south off John McKay Ridge and returning to the high country via Mt. Berland. On September 17th F104 migrated down from her summer range via John McKay Ridge. She spent the remainder of the fall in the Radium Village area, mainly on the Springs golf course. Her collar was removed on December 2nd on the Springs golf course.

F107. F107 was captured on March 11th, 2003 on the Springs golf course. She spent the rest of the winter on the Springs golf course and adjacent portions of the Village, and then spent most of May along the Mile Hill, Redstreak benches, and Sinclair Canyon. On May 19th she left Sinclair Canyon and climbed north along Mt. Berland. The location and timing of use of her lambing range, if any, is difficult to infer from the GPS telemetry data. However she traversed around the head of McKay Creek onto John McKay Ridge, and it is possible that she lambed on the west side of the ridge about 3 kms north of the lambing sites of F103 and F104. By June 18th F107 moved northeast to Transmitter Peak and spent most of the rest of the summer in the typical female sheep summer range north of highway 93. She made excursions down East Sinclair Ridge to the upper Kindersley-Sinclair trailhead area on June 23rd and August 25th, and on June 29th appears to have traversed Lookout Peak to the same area, then climbed back into the high country via East Sinclair Ridge. On July 4th F107 made an unusual movement, descending East Sinclair Ridge to the highway, then continuing south up onto Mt. Sinclair before returning by the same route on July 9th. On July 17th she made a brief excursion down John McKay Ridge to the compound salt shed. She descended for good on September 15th, apparently making another stop at the salt shed before continuing down into Sinclair Canyon. F107 stayed in or near the canyon the rest of October before dropping to her winter range in the Village and at the golf course. Her collar was removed on December 1st in Sinclair Canyon just below the hot springs.

F108. F108 was captured on March 11th, 2003 on the Springs golf course. She spent the rest of the winter on the Springs golf course but spent much of May on the road to the park administration building. On May 26th she began moving up Sinclair Creek and on May 30th was recorded behind the compound near the salt shed. Between June 1st and 7th F108 was confined to an area of about 100 by 300 metres on the south ridge crest of John McKay Ridge, possibly her lambing site. For the rest of the summer she used the typical female summer ranges north of highway 93, except that she ranged further north of Mt. Kindersley to Mt. Crook, and made little use of the East Sinclair Ridge. On July 29-30th F108 descended John McKay Ridge to the Park compound area, returning by the same route. On August 12th she again descended from John McKay Ridge via the salt shed, then continued down into Sinclair Canyon and, briefly the village of Radium Hot Springs, before returning to the high country on October 3rd by heading north over Mt. Berland. She traversed around to the east and then south again along John McKay Ridge before descending back to Sinclair Canyon and into the village. On October 17th she again went north along Mt. Berland and back to John McKay Ridge. She spent most of the rest of October on the upper west slopes of the ridge, before dropping down to the compound salt shed area on October 30th. F108 spent November in Sinclair Canyon and the Springs golf course, and her collar was removed at the north end of the golf course on December 2nd.

F202. F202 was captured on March 9th, 2004 at the Springs golf course. In the first half of May she made considerable use of the newly restored areas on the Redstreak benches. On May 21st she quickly traveled up Sinclair Creek to beyond the Parks Canada compound, then began to move up the north end of Kimpton Ridge. Five hours later she was high on Mount Sinclair, although it is unclear whether she got there by cutting directly across Kimpton Creek or by dropping back to Sinclair Creek and then climbing from Sinclair Pass to Mount Sinclair. On May 24th F202 entered a relatively small area of about 1000 by 200 metres in which it is possible that she lambed. She emerged from this area on June 2nd, and spent the rest of the summer mainly on north and east facing slopes north of Mt. Sinclair. She did make 2 brief excursions north of highway 93 to the lick area near the Kindersley-Sinclair trailhead and the bluffs just north of the lick, 1 on June 27th and returning on July 5th, and the other on September 4th and returning September 6th. On July 29th F202 traveled from 2200 metres on Mt. Sinclair to Highway 93 just above the Park compound in 2 hours, a straight line distance of nearly 4 kilometres. She was recorded near the compound salt shed later that same day. On July 30th she began ascending the steep, forested north slopes of Kimpton Ridge, then followed the crest of the ridge south to Kimpton Pass and thence north to Mt. Sinclair. She began her fall migration on October 11th, reversing her route of July 30th and following Kimpton Ridge north to near the compound, arriving on October 16th. By October 20th F202 was back in the Village of Radium Hot Springs, and she spent the rest of October and November here, in Sinclair Canyon and on the Mile Hill. Her collar was removed on November 30th on the north end of the Springs golf course.

F203. F203 was captured between highway 93/95 and the Columbia River below the Mile Hill on March 9th, 2004. Her spring range was in the Radium Hot Springs area, but substantially more on the Mile Hill and the Redstreak benches than most other female sheep. She began moving up Sinclair Canyon on May 28th and by 9:00 a.m. on the 29th was 0.5 kms west of the hot springs. AT 1:00 p.m. a GPS point recorded was within 200 metres of the compound salt shed. She continued further up Sinclair and at some point turned east or south towards Mt. Sinclair, although which route she used is unclear from the telemetry data. By 9:00 pm she was at 2400 metres elevation just to the west of Mt. Sinclair. On May 30th she entered an area of about 500 by 300 metres high on a ridge just south of Mt. Sinclair and she remained within this area until June 9th, likely having her lamb here. On June 18th she travelled north from Mt. Sinclair, crossed highway 93 near the upper Kindersley-Sinclair trailhead, and climbed up the East Sinclair Ridge at least to the 2000 metre elevation at a point about 2 kms north of the highway. She returned to Mt. Sinclair by the same route on June 20th. F203 made 3 additional return trips north of highway 93 and at various times used the whole length of East Sinclair Ridge, Transmitter Peak and Sheep Mountain. Those trips occurred between July 8th and July 12th, August 10th and August 22nd, and September 5th and September 16th. On September 30th F203 descended Mt. Sinclair to highway 93 for the last time, and was in Sinclair Canyon by 10:00 am on October 1st. She stayed between the Parks Canada compound and the hot pools until October 12th, then spent the rest of October and early November at the south end of the Springs golf course, near the Mile Hill, and on the Redstreak benches. She was struck and killed by a vehicle on the Mile Hill on November 8th.

F204. F204 was captured on the Redstreak road between highway 93/95 and the park administration building on March 9th, 2004. She spent most of the rest of the spring on or near the Redstreak restoration area, particularly the area just west of Redstreak Campground that was treated in 2003, or in Sinclair Canyon. On May 28th or 29th she appears to have become part of the same group as F203, as the GPS telemetry points for these 2 animals match nearly perfectly on May 29th. By 9:00 p.m. on the 29th she was up at 2400 metres elevation just to the west of Mt. Sinclair, as was F203. However the 2 animals parted company near 10:00 a.m. on May 30th when F203 entered the confined area that could have been her lambing range. Near this point, F204 abruptly turned around and by 7:00 p.m. on the 30th was north of highway 93 on the upper slopes of East Sinclair Ridge, a straight line distance of about 9 kilometres. She spent the first few days of June in a relatively confined area here, although by June 4th she was travelling long distances again, possibly inconsistent with lambing at this site. She traveled north to the Mt. Crook area, then returned to East Sinclair Ridge in late June. On July 1st she moved north again beyond Mt. Kindersley to the Mt. Crook area, but her collar switched into mortality mode in a high alpine basin on July 11th. Due to the difficulty of access to this site, field investigation did not take place until July 30th. At that time F204's carcass was found in relatively intact condition, suggesting that the animal had not been the victim of predation. The probable causes of death include natural causes, such as disease or a fall.

F205. F205 was captured on the Springs golf course on March 18th, 2004. After wintering within the Village and the Springs golf course, she made a 1 day excursion to the summit of Mt. Berland on April 20th. On May 7th F205 ascended the south approach to John McKay Ridge, although it is not clear whether she visited the compound salt shed. On May 13th she entered an area of about 200 by 300 metres on a southwest slope off John McKay Ridge, and emerged on May 22nd. She left John McKay Ridge on June 3rd, and followed an undetermined route to the south slopes of East Sinclair Ridge.

She then traveled north along the ridge system to Mt. Kindersley and further northwest to a connecting ridge that separates Kindersley Creek from the drainage immediately south of Mount Crook. Here she was confined to an area of about 100 by 200 metres with a northeast aspect from June 7th to 10th. F205 then moved north of Mt. Crook for several days but on June 19th began heading south to Transmitter Peak and East Sinclair Ridge, reaching the lick at the upper Kindersley-Sinclair trailhead on June 28th. She traveled widely the remainder of the summer, reaching her northernmost point about 2 kms northwest of Mt. Crook on August 8th. She also made at least 2 other brief excursions to near the trailhead lick on July 12th and August 27th. On September 3rd F205 moved from Sheep Mountain to John McKay Ridge, then on September 22nd traveled all the way from John McKay Ridge to north of Mt. Crook, a distance of at least 16 kilometres. She then worked her way back south more slowly, returning to John McKay Ridge by October 2nd. On October 5th F205 migrated down from John McKay Ridge to near the compound, although again it is unclear whether she passed by salt shed. She spent the rest of October and November in Sinclair Canyon, the Springs golf course and the village, and her collar was removed on November 30th by the Columbia River below the Springs golf course.

F209. F209 was captured on March 30th, 2004 at the old bungalow site just west of the Aquacourt parking lot. She showed signs of systemic infection and was administered intramuscular antibiotics. She remained in this area until April 12th when she moved down to the Springs golf course. On May 10th she moved up to the Redstreak benches, and near the end of the May her carcass was found in Redstreak campground even though the collar had not switched into mortality mode. Downloaded collar data showed that she likely died on May 17th, as no movement was apparent after that date. Her skeleton had been cleaned by scavengers but was otherwise intact suggesting that she had not been the victim of predation. It is likely that her death was related to the infection she had at the time of capture, and that her collar did not switch into mortality mode because of movement of the carcass caused by the action of scavengers.

Individual Male Study Animal Summaries

M002. M002 was collared on January 8th, 2002 at Canyon Campground. He spent the rest of the winter and spring, including all of June, in the Radium village area, mainly on the Mile Hill, the southern portion of the Springs Golf Course, and Canyon Campground. On July 4th he began moving up Sinclair Creek to a point about 1.5 kms east of the Parks Canada compound. By 1:00 a.m. on July 6th M002 was near the crest of John McKay Ridge. By July 9th he was at Mt. Crook, approximately 20 kms due north of his winter range at Radium Hot Springs. He spent most of the rest of the summer on mainly east-facing slopes between Mt. Crook and Mt. Kindersley, with 1 brief excursion at the end of July to East Sinclair Ridge. On October 11th M002 began moving south, reaching John McKay Ridge on October 12th, and was recorded at the compound salt shed in the afternoon of October 14th. He then occupied the south end of the Springs golf course for the remainder of October. The remote release mechanism on M002's collar did not work as planned in late October, and so his collar remained on collecting points until we were finally able to immobilize him on March 11th, 2003. In November M002 began moving extensively. Between November 10th and 13th he traveled south as far as Shuswap Creek, where points were recorded less than 300 metres from a domestic sheep ranch. On the 16th he climbed John McKay Ridge, followed the ridge north and around the head of McKay Creek and then took Berland Ridge south back to the hot springs area by late afternoon on the 17th. On November 21st M002 was on the Springs golf course at 8:20 a.m. and, by 9:00 p.m., using an undetermined route, was at 2000 metres elevation on Mt. Sinclair. By 6:00 p.m. on the 22nd he was back at the hot springs. In December M002 moved frequently within a relatively small area bounded by the southern portion of the Springs golf course, Canyon Campground, and the hot springs.

Between January and May of 2003, M002 alternated between the Mile Hill and the Canyon Campground and Bighorn Meadows area just north of the highway 93/95 junction. On June 6th he began moving up Sinclair Canyon, and appears to have followed the same route up John McKay Ridge as he followed on July 4th, 2002. By June 11th M002 had arrived near the northern end of his summer range near Mt. Crook. However on June 27th M002 began moving south to Transmitter Peak, Sheep Mountain, and the highway 93 corridor, and by June 30th was near the hot springs. That same evening he went up Kimpton Ridge, then returned to near the compound on July 8th. He immediately continued on up John McKay Ridge and followed the crest of the Brisco Range to the Mt. Crook area. He remained in this area until October 20th when he began following the crest of the range south to Sheep Mountain and then across Sinclair Creek to the south end of East Sinclair Ridge. By October 26th M002 was back in the village of Radium Hot Springs. On November 11th he headed north over Mt. Berland, then continued north in the Kindersley Creek drainage and by the 15th had climbed up to over 2000 metres on a ridge just west of Mt. Crook near the northern limit of his summer range. On the 17th M002 emerged in the Columbia Valley 3.5 kms north of Spillimacheen before returning to the Mt. Crook area. He returned to Radium on the 26th by following a lower elevation route on the west slope of the Brisco Range. His collar was removed on December 2nd at the north bank of Sinclair Creek at Bighorn Meadows.

In 2004 during the capture session, M002 was recognized by his damaged right horn, and it was decided to re-capture him for a third year in order to have 1 animal with a nearly continuous record of telemetry locations over the entire study period. He was captured just below the Mile Hill on March 8th. M002 spent much of the rest of the spring of 2004 on the Mile Hill and at the Redstreak restoration area. On June 6th he moved to Sinclair Canyon and then climbed up the south ridge of Mt. Berland. He followed the main ridge systems north from there, and by June 23rd was in his usual summer range in the Mt. Crook area. On July 1st M002 began moving south of Mt. Kindersley, then travelled along the East Sinclair Ridge to the lick at the Kindersley-Sinclair trailhead, arriving there in the morning of July 2nd. M002 then followed the highway corridor down to McKay Creek, where he appeared to have visited the salt shed by late on July 3rd. He moved at least as far west as the Iron Gates tunnel before turning around and following his usual route up John McKay Ridge on July 5th. He was in his preferred summer range by July 9th. M002 began his fall migration in the afternoon of October 16th. He followed the ridge system south from Mt. Crook onto John McKay Ridge and arrived in the village of Radium Hot Springs on October 20th. His collar was removed on October 22nd at the Springs golf course. This was about a month earlier than planned, but was done because the collar appeared to be getting tighter, likely due to neck swelling associated with hormonal changes during the rut.

M005. M005 was captured at the Springs golf course on January 10th, 2002 and was estimated at 6.5 years of age. He made 4 separate trips to the Stoddart Creek area between January 31st and May 24th, apparently following a route just east of the developed highway corridor. He also made considerable use of Sinclair Canyon in April, and in June as far east as the Kimpton Creek trailhead. However, he spent most of July adjacent to the Mile Hill or near the Springs golf course, and he was killed in a collision on the Mile Hill late on August 1st.

M008. M008 was captured at the Springs golf course on January 11th, 2002 and was estimated at 5.5 years of age. In late January he traveled south from the Radium area as far as the south end of Mt. Swansea near Windermere Creek, apparently following the lower slopes of the westernmost ridges, and then returned a few days later. On May 24th he followed a similar route as far as Shuswap Creek, but then took a higher route to the old gypsum mine site in Windermere Creek. On June 3rd he returned as far north as Palmer Creek, but then turned east through complex mountain terrain before moving south near the crest of the Stanford Range to a point about 3 kms east of Pinto Mountain. M008 retraced his route north to Mount Sinclair, then traveled west to Kimpton Ridge, arriving on June 30th. He remained on Kimpton Ridge for the rest of the summer, except for 1 brief excursion in late July to Sinclair Creek via the north end of Kimpton Ridge. On October 4th M008 took the same route to Sinclair Creek, then continued down to the village of Radium Hot Springs where he spent the remainder of the fall until his collar was removed on November 29th. During the rut he was frequently seen with M002 and the 2 rams were observed in combat several times.

M101. M101 was captured was captured in the Village of Radium Hot Springs on December 16, 2002, and was estimated at 7.5 years of age. In addition to using the winter range near the Village, M101 made 3 brief winter excursions to the Dry Gulch and Stoddart Creek areas, on about January 27th, March 10th, and April 16th. He also made a trip to lower Shuswap Creek between November 3rd and 7th. On June 6th, M101 left the hot springs area for an excursion up Redstreak Mountain by following a forested ridge system to the southeast. He then moved from Redstreak Mountain to Kimpton Ridge in 2 to 4 hours, suggesting that he crossed Redstreak valley rather than following ridges around far to the south. By noon on the 9th M101 was back at highway 93, having descended the north ridge system of Kimpton Ridge. On June 10th, M101 repeated his route of June 6th, returning to Kimpton Ridge by the morning of June 13th. At 6:00 a.m. on June 15th he was near the ridge crest about 5 kms south of highway 93, but by 10:30 a.m. he was recorded at the compound salt shed. M101 began his final spring migration on June 22nd, this time climbing up Kimpton Ridge from the north, continuing south along the ridge to Kimpton Pass, then traveling northeast to the Mt. Sinclair area, arriving on June 30th. He spent the summer and early fall in these same alpine ridges, then began slowly descending the north end of Kimpton Ridge on October 9th, arriving back at the hot springs area on the 14th. M101 spent the rest of October in Redstreak Campground, including the prescribed burn guard block, then was recorded mainly in the Village and the south end of the Springs Golf Course in November. His collar was removed on the CPR rail right-of-way below the golf course on December 2nd.

M105. M105 was captured on the Springs golf course on December 18th, 2002 and was estimated to be 5.5 years. In addition to the main winter range near the Village, M105 spent considerable time in the Stoddart Creek area over 3 periods: between December 23rd, 2002 and February 7, 2003, between April 15th and April 23rd, and between November 23rd and December 2nd. He also made use of an area of open bluffs just east of the Redstreak restoration area in April and November, and traveled through these bluffs on several other occasions. At the end of April he made an excursion to near the summit of Redstreak Mountain, then returned to the Redstreak bluffs. On June 10th M105 left the bluffs for Redstreak Mountain and continued across Redstreak Creek to Kimpton Ridge. He descended the north end of Kimpton Ridge on June 25th, briefly visited the Parks Compound area, and then returned to Kimpton Ridge on June 27th. On August 4th he again descended Kimpton Ridge to the compound, where he was recorded at or near the salt shed, before retracing his steps the following day. M105 spent the rest of the summer and early fall on Kimpton Ridge. On October 30th he began traveling slowly north along the ridge, arriving in Sinclair Canyon on November 2nd and at the Redstreak bluffs by November 5th. His collar was removed at the Village on December 2nd.

M106. M106 was captured on the Springs golf course on December 18th, 2002 and was estimated at 6.5 years. He wintered in the usual areas near the Village, but also made 3 excursions to Stoddart Creek in January through March. On May 24th he began winding up the ridge systems leading to Redstreak Mountain, and arrived on Kimpton Ridge on May 27th. M106 passed the rest of the summer on Kimpton Ridge, with the exception of brief excursions to the compound on June 23rd, August 1st and October 23rd. He also made a return trip to Redstreak Mountain and then the Village between October

1st and 13th. On October 31st he left the high country for good, again traveling over Redstreak Mountain and arriving at Radium Village on November 2nd. His collar was removed near the CPR line below the Springs golf course on December 2nd.

M206. M206 was captured on March 18th, 2004 on the slopes between the Mile Hill and the Columbia River, and was estimated to be 7.5 years old. He mainly used the Mile Hill and the Redstreak benches, including the restoration areas, until May 22nd when he moved into Sinclair Canyon. On the 29th M206 began working his way south from near the Parks Canada compound up some forested ridges north of Redstreak Mountain. From near the summit of Redstreak Mountain at noon on May 31st, M206 moved to a point high on the west side of Kimpton Ridge by 6:00 p.m. He remained on Kimpton Ridge until June 26th, when he moved to Mt. Sinclair, returning on July 1st. He spent the remainder of the summer on Kimpton Ridge, except for a brief excursion down from the north end of the ridge to the highway near the compound on July 4th, returning via Redstreak Mountain on July 6th. On September 28th M206 appears to have again descended the forested north ridges to the highway, then travelled down Sinclair Creek to the Redstreak benches. His collar was removed on October 20th at the park administration building. This was about a month earlier than planned, but was done because the collar appeared to be getting tighter, likely due to neck swelling associated with hormonal changes during the rut.

M207. M207 was captured on March 18th near the switchback on the Redstreak road. His age was estimated at 6.5 years. He mainly used the Mile Hill and the Redstreak benches, including the Redstreak restoration areas, until June 12th, when he crossed Sinclair Creek and began climbing up Mt. Berland. M207 continued north then followed the ridge at the head of McKay Creek around to the north end of John McKay Ridge. He continued east to Transmitter Peak and followed the ridge north to Mt. Kindersley and Mt. Crook, arriving at a point about 2 kms northwest of Mt. Crook on June 26th. He made just 1 excursion back to Sinclair Creek, traversing East Sinclair Ridge on July 1st then following the highway corridor down to the compound, where he was recorded at the salt shed on July 3rd. On July 5th M207 ascended John McKay Ridge and spent the rest of the summer in the Brisco Range north of Transmitter Peak. On September 30th he began moving south and on October 2nd was recorded within 200 metres of the compound salt shed. He continued down into the village and was on the

Springs golf course most of the rest of October, then wandered more widely through the village, north of the 4-way stop, and occasionally back to Sinclair Canyon in November. His collar was removed on November 30th.

M208. M208 was captured on the Redstreak benches near the Park administration building on March 30th, 2004. His age was estimated at 4.5 years. He spent most of April, May and early June along the Mile Hill, north of the Radium 4-way stop, and on the Redstreak benches. On June 3rd M208 left the prescribed burn guard block at the end of Redstreak Campground and ascended Redstreak Mountain. However, several GPS fix attempts during this time were unsuccessful, and his route could not be determined. By midnight on the 3rd M208 was above 2200 metres on Kimpton Ridge. On June 23rd he moved further east to Mt. Sinclair via Kimpton Pass, and on July 1st he followed the Mt. Sinclair ridge system north to or near the highway 93S corridor. It appears likely that he then followed the highway corridor west to Kimpton Creek, then climbed up Kimpton Ridge from the north, arriving back on the ridge crest in the morning of July 2nd. M208 spent the rest of the summer on Kimpton Ridge. He began his fall migration on September 28th by moving back north over Kimpton Ridge to the highway, although taking a slightly different route than on his July 2nd ascent. By the morning of the 29th M208 was back on the Redstreak benches and he stayed on or near the south end of the Springs golf course for most of October. In November he wandered more widely within the Village, including the north end of the golf course. His collar was removed on November 17th in the Village.

Appendix 5 - Photo Gallery

All photographs © Parks Canada, A. Dibb, unless otherwise noted

F010 and lamb, July 2002

M105, Stoddart Creek, January 2003

M008 (left) and M002, December 2002

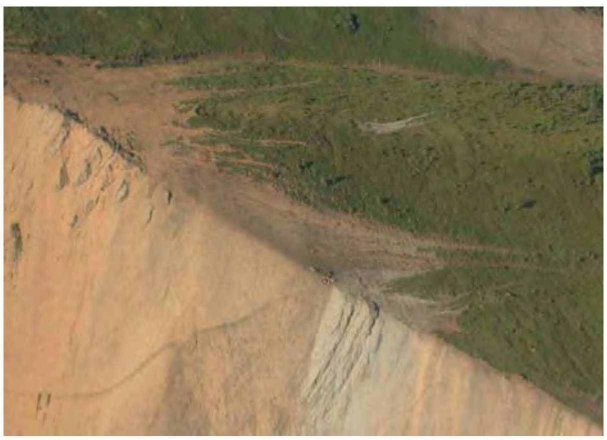
M101 in ram group, Mile Hill, February 2003

M002 showing damage to right horn, May 2004

F007, wounds from cougar attack, Apr. 2002

Ewe band in upper Sinclair Creek, Sept. 2003

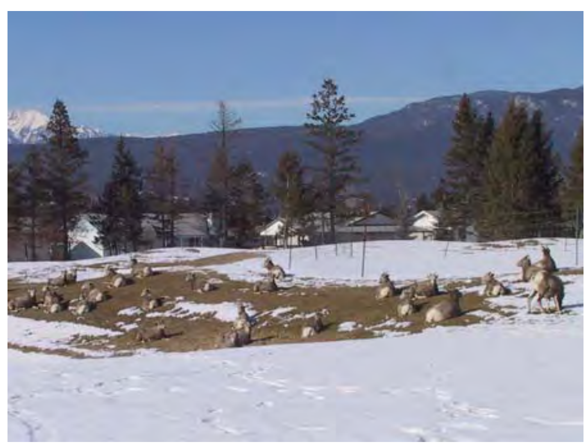
Redstreak restoration site during treatment, February 2002



Sheep on alpine ridge in Brisco Range, July 2003 (T. McAllister)

Ram in Redstreak restoration area, October 2004

Lambing site in Brisco Range, June 2004



Radium Springs golf course, Feb. 2003

Winter range: mile hill, Redstreak benches, village of Radium Hot Springs, May 2003

Steve Canning with ram, March 2004

Highway 93/95 (mile hill) in winter

Dr. Todd Shury during sheep immobilization, March 2003

Ian Ross collaring a ewe, January 2002

Omar McDadi on ridge above Kindersley-Sinclair trail, August 2004 (O. McDadi, Parks Canada)

Ellie Ames and Morgan Anderson, upper Sinclair Creek, September 2004

Sarah Anning, Kindersley-Sinclair summit, July 2002

Ben Geselbracht on McKay Ridge, June 2003

Trevor Kinley using collar release unit, Sinclair Canyon, October 2002