Sulphur / 8 Mile Stone's Sheep Project Northern British Columbia

A multi-stakeholder research and planning initiative
in the Muskwa-Kechika Management Area

Stone's sheep population dynamics and habitat use in the Sulphur / 8 Mile oil and gas pre-tenure plan area, northern British Columbia, 2005 – 2010

December 2011

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THANK YOU TO ALL OF THE INDIVIDUALS AND ORGANIZATIONS THAT COMMITTED THEIR SUPPORT TO THIS PROJECT

Stone's sheep population dynamics and habitat use in the Sulphur / 8 Mile oil and gas pre-tenure plan area, northern British Columbia, 2005 - 2010

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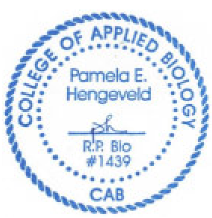
LETTER OF TRANSMITTAL

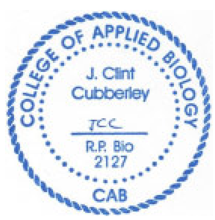
This report is presented to the Sulphur / 8 Mile Stone's Sheep Project Science Advisory Committee on behalf of the North Peace Stone's Sheep Sustainability Steering Committee. It represents the culmination of a 5 year Stone's sheep research program designed and developed by the committees in response to concerns identified in 2004 by the Sulphur / 8 Mile Oil and Gas Pre-Tenure Plan Public Advisory Group.

Since December 2005, the research was managed and implemented by Synergy Applied Ecology (SAE), an independent firm working on behalf of the committees under multiple agreements with project funding partners. Additional work completed for project committees independently of SAE are included in this report to provide a comprehensive summary of project results.

Synergy Applied Ecology
December 2011

Pamela Hengeveld, R.P.Bio. Clint Cubberley, R.P.Bio.





EXECUTIVE SUMMARY

Background

The Sulphur / 8 Mile (S8M) Stone's Sheep Project (S8MP) was a multi-stakeholder collaborative research program addressing Stone's sheep ecology and management concerns in the Muskwa-Kechika Management Area (M-KMA) of northeast British Columbia. The ultimate objective was to support development of science-based management guidelines for Stone's sheep to be incorporated into the Sulphur / 8 Mile oil and gas pre-tenure plan (S8M PTP) and regional Stone's sheep management plans. This report documents the results of field studies initiated in March 2005 and completed in July 2010.

Research objectives and general methods

Primary research objectives were to: 1) determine Stone's sheep population size, structure, and demographic trend; 2) identify limiting factors affecting population dynamics; 3) quantify range use and habitat selection to inform site-specific management plans; 4) integrate local and traditional knowledge of Stone's sheep populations with research results; and 5) establish baseline herd health parameters.

We evaluated population demographics by aerial censuses in December 2006, March 2007, and February 2009, using collared sheep for mark-resight analyses to calculate population estimates (Chapters 4 and 5). Census also provided information on population age and sex structure, lamb recruitment, distribution, and density of sheep, as well as the number of other ungulate species on sheep winter ranges. We determined survival rates and mortality patterns by monitoring 124 radiocollared females over 5 years (2005 - 2010) and 17 radiocollared males over 2 years (2008 - 2010; Chapter 6). We determined seasonal habitat use patterns using GPS collars to collect daily location data for 26 females (2005 - 2009) and 17 males (2008 - 2010; Chapter 7). These data were applied to habitat models and resource selection functions to identify seasonal variation in habitat preferences measured across three spatial scales: movements between consecutive GPS locations; home ranges; and study area (Chapter 9). Health parameters were assessed by laboratory analyses of biological samples collected during capture for collaring (Chapter 3) and during necropsies conducted as part of mortality investigations (Chapter 6). Local knowledge of Stone's sheep ecology was compiled from historical data and interviews with 26 long-time residents (Chapter 1). Kaska Dena traditional knowledge was compiled from interviews with local members of the MacDonald family (Chapter 2).

Study area and sheep populations

The S8MP study area (4,237 km^2) was centered roughly 150 km west-northwest of Fort Nelson BC, within the northeast corner of the M-KMA. It included the communities of Toad River Post and Muncho Lake along the Alaska Highway, and most of BC Wildlife Management (WMU) Unit 7-54. The project area included portions of 5 provincial parks and protected areas: Muncho Lake Park; Liard River Corridor Park; Toad River Hot Springs Protected Area; Stone Mountain Park; and Northern Rocky Mountains Park (including Wokkpash Recreation Area). Known internationally for its exceptional wildlife and wilderness values, much of the area is undeveloped with motorized vehicle access limited to routes designated by the M-KMA Act. The study area included the complete S8M PTP area, with particular management focus on the S8M PTP High Elevation Zone where tenures are expected to be available for disposition in 2012.

Stone's sheep were distributed across two distinct mountain ranges separated by the Toad River. The Sentinel Mountain Range northwest of the Toad River, including adjacent Mount McLearn, Ewe Mountain, and Toad Mountain, is dominated by steep and rugged bedrock at upper elevations. The less imposing Stone Mountain Range southeast of the Toad River is characterized by rounded peaks and increased vegetation at upper elevations. We refer to sheep in these areas as the Sentinel and Stone populations.

Population estimates

We counted a minimum of 939 sheep and estimated about 1,200 sheep (95% confidence interval of 1,007 – 1,429); roughly 650 sheep in the Sentinel population and 550 in the Stone population (Chapter 4). Total counts and population estimates were consistent with limited historic data (Chapter 4). The minimum count observed during this study was nearly 18% of northeast BC's Peace Region Stone's sheep.

Survey timing has implications for sheep sighting probabilities and population estimation (Chapter 4). Detection of collared females varied between populations and censuses but overall was better in December 2006 (84%) than in March (72%) or February (74%). Detection of collared males 4 - 10 yrs old (88%) was higher than for collared females >2 yrs old (74%; Chapter 5). Results from all 3 censuses revealed that detection of young males in the Stone population was lower than for females and older males because younger males were more likely to use subalpine areas in deep snow winters. We did not find the same result in the Sentinel population, likely because population density was lower and winter ranges less limited. Overall, census detects 70 - 90% of sheep (Chapters 4 and 5). Population census during the end of the rut is more effective than late winter census (Chapter 4).

Population dynamics

Annual survival rate of adult females was 80% (95% confidence interval of 76% - 83%), with no difference between populations (Chapter 6). Our limited data on adult males suggested 83% (69% - 95%) annual survival rate (Chapter 6). These estimates are of natural survival rates, excluding sheep that died due to vehicle collisions or were hunted. Annual mortality rates due to vehicle collisions with sheep on the Alaska Highway may exceed 3% of the adult female population annually (Chapter 6). BC Government harvest records were compared to census results, and indicated that legal harvest of mature male Stone's sheep during the study exceeded suggested limits for conservative management (Chapter 6).

Pregnancy rates were estimated at 88% in both Sentinel and Stone populations (Chapter 3). Census results indicated lamb survival to 6 months was lower in the Sentinel population (75%) than the Stone (83%), but overwinter (December - March) lamb survival was lower in the Stone population (96% vs 70%; Chapter 4). With annual survival rate >70% for adult females, late winter ratios of at least 35 lambs to 100 adult females will support a stable or growing population. In late winter 2006/2007, >50% of adult females in both areas had lambs. In February 2009, 37% of Stone area females had lambs (Chapter 5). Demographic structure indicated stable populations during the study.

Differences in Sentinel and Stone population dynamics reflected differences in population densities on alpine winter ranges. Density-dependent effects on Stone population dynamics, where sheep density on alpine areas was nearly double that of Sentinel sheep, included lower over-winter lamb survival, a greater proportion of health-related mortalities, and more use of subalpine habitats by younger males (Chapters 4 - 6). One isolated 3.5 km^2 subalpine ridge supports 20% of the Stone population in winter, suggesting site-specific density of 25 sheep/km^2. We did not find the same level of concentration on distinct winter ranges or isolated ridges anywhere else in the study area. The highest site-specific alpine winter range densities in the Sentinel population were <2 sheep/km^2.

Sheep health and adult mortality patterns

Our observations did not indicate any widespread herd health concerns. Fecal parasitology analyses were consistent with results reported for Stone's sheep populations regionally. Winter ticks (*Dermacentor albipictus*) were observed on a few sheep in the Stone population, and horn abnormalities were noted for a few Sentinel males. *Mandibular osteomyelitis*, an infection commonly known as 'lumpy jaw', has been reported in most subspecies of wild sheep in western North America, particularly in thinhorn sheep, and was common in S8MP sheep.

We confirmed wolf predation (11), bear predation (5), wolverine predation (2), unknown predation (1), avalanche and snow conditions (10), falls (4), and poor body condition (8) as natural causes of mortality for 41 collared adult females (Chapter 6). Natural mortalities of 4 males were attributed to avalanche (2), poor body condition in late winter (1), and fall/injury (1). Two collared males and 3 collared females died in avalanches in winter 2008/2009, when avalanche risk was unusually high across BC. Levels of predation were similar between populations, but avalanches accounted for a greater proportion of Sentinel female deaths and poor body condition was more significant in Stone females. More than 40% of adult female deaths occurred in late winter (March 1 - May 14), particularly April and May. We found a strong negative correlation between annual survival of adult females and May precipitation.

Home ranges and seasonal movements

Annual home range sizes (100% minimum convex polygons on all locations) of males were on average 1.75 times larger than female home ranges (237 km^2 vs 135 km^2), but the size of core areas (95% fixed kernel estimates) was statistically equivalent for males and females. We found no difference in home range sizes between Sentinel and Stone females. Sixty-three percent of annual home ranges included >1 core area. These included distinct migrations between 2 or more core areas used within the same year and repeated seasonal use of mineral licks at the periphery of home ranges.

The maximum distance across annual home ranges was 34.1 km for females and 37.0 km for males. Movement distances from winter ranges to mineral licks and between distinct seasonal ranges averaged 10 - 14 km (range 3.6 km – 25.7 km). Maximum movement rates ranged 512 – 1,641 m/h for females and 881 – 1,550 m/hr for males, and were associated with travel between core areas, including travel to mineral licks. In most cases, individuals showed high fidelity to travel routes. Both sexes initiated movements between core areas used seasonally in mid-April through late June, returning to winter ranges by December. Both sexes also showed strong directionality of movements across the Sentinel Range and along the main axis of the Stone Range, following the orientation of major ridges and drainages which likely facilitate travel.

Seasonal movement to sheep ranges outside the study area occurred regularly at the Alaska Highway 'Rock Cut' west of Summit Lake and the Alaska Highway at Petersen Canyon south of Muncho Lake (Chapter 7). Both the Rock Cut and Petersen Canyon are heavily used as mineral lick complexes and appear to be links for migration and dispersal between adjacent populations.

Mineral licks used by sheep were identified incidentally during field work in 2005 - 2010 and from local interviews. Lick sites included naturally-occurring mineral sources with evidence of sheep use, highway locations where road salts were exploited by sheep, and salt blocks observed or reported in sheep ranges. Most mineral licks were at the periphery of sheep home ranges, including heavily-used licks along the Alaska Highway (Chapter 7).

Most (57%) GPS collared sheep visited the Alaska Highway at least once, exposing them to risk of being involved in a vehicle collision (Chapter 8). Highway use occurred primarily during daylight hours between 0900 and 1600 hrs. Road use was highest in June and July, with no crossing or use events in January through March. Highway use between October and December occurred exclusively at Petersen Canyon, where female sheep alternated use of ranges on the east and west side of the highway. Highway crossing locations are strongly influenced by the presence of topographical features such as incised draws, canyons, and stream fans on both sides of the highway. Highway use data from multiple sources are well correlated and indicate spatial and temporal use patterns exist, offering promise for mitigation.

For both sexes, seasonal ranges were smallest in early winter (<10 km^2, January 1 - February 28), at roughly 10% the size of lambing (May 15 - June 14), summer (June 15 - August 14), and fall (August 15 - October 31) seasonal ranges. Males had larger seasonal ranges than females only during the rut (November 1 - December 31).

Seasonal habitat selection

Broad-scale spatial segregation between sexes was not apparent, although group composition during winter census indicated typical separation into male and female groups interspersed on the same ranges (Chapter 4). Generally, sheep used steep (mean 29° - 37°), rugged, convex sites with high solar radiation, at mean elevations ranging 1,400 m during lambing to 1,700 m in summer (Chapter 9). Late winter ranges were steeper, more south-west facing, and at lower mean elevations than early winter ranges. West aspects were favoured over east aspects in all seasons except summer. Use of vegetated alpine areas was predominant year-round. In summer, >84% of sheep locations were in alpine areas and rocky (talus - scree - bedrock) sites. Use of conifer and shrub was common (up to 35% of sheep locations per season). Use of conifer at treeline and grassy sites was also recorded, but less common (<11% of locations per season). Fluvial sites (gravel debris fans and riparian areas) were rare in the study area but used consistently year-round. We speculate that these were important as travel corridors. Selection for upper slope positions may also offer good visibility, and we speculate these were favoured feeding sites and travel routes. Deciduous tree cover was generally avoided, while use of burned areas varied seasonally.

We observed the typical pattern of change in elevation seasonally by both sexes, following plant phenology, with use of lowest elevations in late winter/spring and highest elevations in summer.

Management Considerations

Sheep in the Sentinel and Stone Ranges should be managed as separate populations, maintaining integrity of links to adjacent populations south and west of the study area. Both populations appear to be healthy, with no evidence of declining populations during the study period. Density on winter ranges is a key factor driving ecological differences between populations. Evidence of density-dependent responses in Stone Range population dynamics suggests potential for rapid changes in population size or age-sex structure even in the absence of any industrial development. Relevance of project results to the S8M PTP High Elevation Zone is presented in the summary chapter. The S8M PTP High Elevation Zone north of the Toad River has low risk for potential impacts of industrial development on sheep populations. Moderate to high risk is identified for the S8M PTP High Elevation Zone south of the Toad River.

Management priorities to support long-term sustainability of S8M sheep populations should address the most practical, management-relevant components of Stone's sheep ecology, with a focus on core ranges and high density areas where disturbance impacts are likely to be most acute. We suggest protection and monitoring of high density winter ranges, natural mineral licks and lick access corridors; reducing highway-related mortality; management of harvest pressure commensurate with future changes to backcountry access; and conservative approaches to management actions or development that may influence distribution and density of other ungulates and predators on sheep ranges.

PREFACE

Sustaining a future for Stone's sheep
Ovis dalli stonei

Stone's sheep are an icon of rugged northern landscapes. They are native only to northern British Columbia and southern Yukon, and have social, cultural and commercial value. Despite their tolerance of extreme montane and climatic conditions, many aspects of their ecology render them vulnerable to disturbance impacts. Strongly driven by nutrition and security considerations, their distribution is associated with patchy habitats that offer adequate forage opportunity in proximity to escape terrain. In winter, deep snow further restricts their range by reducing access to grass, sedge, moss, lichen, and the leaves of shrubs on which they feed. Range expansion throughout the remainder of the year includes habitual use of mineral licks and seasonal movement corridors between isolated alpine ranges. Wild sheep show high levels of range fidelity annually and have highly structured social organization. These behaviours make populations susceptible to density-dependent and human influences on survival. Landscape changes can affect forage quantity and quality, disrupt movement corridors, restrict seasonal ranges, change inter-species relationships, and influence pathogen or disease profiles. On the other hand, sheep occupy niche habitats, have predictable range use, and can be reliably monitored with repeated census. This offers real and practical opportunities to define integrated management plans that support Stone's sheep and human interests to coexist in a sustainable way.

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PROJECT DEVELOPMENT

The Muskwa-Kechika Management Area (M-KMA) Act was designated by the British Columbia (BC) Government as a model for integrated resource management. It was established to maintain the wilderness quality, diversity, and abundance of wildlife and ecosystems while allowing resource use and development in areas designated for those purposes (Province of British Columbia 1998). Under the M-KMA Act, pre-tenure plans (PTPs) are required for areas with high oil and gas resource development potential (MSRM 2004). These plans define management direction and results-based requirements that become legally-binding upon oil and gas tenure proponents.

Stone's sheep (*Ovis dalli stonei*) were identified as a species of significance in the M-KMA. They are a subspecies of thinhorn sheep that is native only to northern BC and south-central Yukon. Most of the world's population occurs in BC; they have social, cultural and commercial value; and many aspects of their ecology render them vulnerable to disturbance impacts (AXYS 2005; Demarchi and Hartwig 2004; Paquet and Demarchi 1999; Shackleton 1999). Concern about Stone's sheep population status was based primarily on anecdotal information and the evaluation of potential effects of oil and gas activities on local herds was hindered by the scarcity of baseline information. This posed risk to both local sheep populations and the resource development industry in the M-KMA's Besa-Prophet, Muskwa West, and Sulphur / 8 Mile (S8M) PTP areas (MSRM 2004).

In May 2004, the BC Government and the PTP Public Advisory Group proceeded with a cautious, independent scientific approach to objectively evaluate the potential for resource development impacts on Stone's sheep. PTP approval for the mountainous portion of the S8M plan area was deferred until completion of Stone's sheep research to support development of science-based management direction. In addition, the Public Advisory Group stipulated that management direction developed and approved in the S8M PTP would also be applied to the northwest portion of the approved Muskwa-West PTP, which joins the southern boundary of the S8M PTP area along Stone Mountain Provincial Park. Anticipated amendments to the approved Besa-Prophet PTP would reflect Stone's sheep research completed in 2005 by a University of Northern BC graduate student (MSRM 2004; Walker 2005).

The North Peace Stone's Sheep Sustainability Steering Committee was established as an independent coalition of industry, government, resource, and conservation sector groups to address commitments made in the PTP process. With support from a Science Advisory Committee, the Steering Committee was charged with implementing the S8M Stone's sheep research program and providing management recommendations to the M-KMA Advisory Board and the BC Government.

The S8M Stone's Sheep Project (S8MP) was designed as a 5-yr research plan with primary emphasis on Stone's sheep population dynamics and habitat use in the S8M PTP area (Churchill 2004, 2005; Hengeveld 2005, 2006). This report documents the results of field studies initiated in March 2005 and completed in July 2010.

RESEARCH OBJECTIVES

We prioritized research to address prior knowledge gaps and provide data relevant to site-specific S8M PTP management plans (AXYS 2005; Churchill 2004, 2005; Demarchi and Hartwig 2004). Primary research objectives were to: 1) determine Stone's sheep population size, structure, and demographic trend; 2) identify limiting factors affecting population dynamics; 3) quantify range use and habitat selection; 4) integrate local and traditional knowledge of Stone's sheep populations with research results; and 5) establish baseline herd health parameters.

STUDY AREA

Project boundary and pre-tenure plan area

The S8MP study area is centered roughly 150 km west-northwest of Fort Nelson, BC (Figure 1.1). It spans 59°25' to 58°30'N and 126°00' to 125°30'W, within the northeast corner of the M-KMA, and includes the communities of Toad River Post and Muncho Lake. The land base is approximately 4,237 km^2 and encompasses the Sulphur / 8 Mile, Toad River Corridor, Toad River Hot Springs and Stone Mountain Resource Management Zones (RMZ) defined by the Fort Nelson Land and Resource Management Plan (MSRM 1997), and most of BC Wildlife Management Unit (WMU) 7-54. The study area is bounded by the Alaska Highway to the south and west, the Liard River Corridor to the north, and the S8M PTP boundary to the east. The study area extends roughly 80 km north to south, between the Liard River corridor and Summit Lake (Historic Mile 363 Alaska Highway), and 80 km west to east from Muncho Lake (Historic Mile 392 Alaska Highway) to the S8M oil and gas pre-tenure plan (PTP) boundary (MSRM 2004).

The complete S8M PTP area includes all but the Muncho Lake and Stone Mountain Provincial Parks portions of the study area. The PTP area was defined in a phased approach, distinguished by the boundary between moderate (S8M PTP West) and high (S8M PTP East) oil and gas potential. Planning processes and opportunities for oil and gas tenure in the S8M PTP West will be addressed when a business case is made for development of the moderate mineral potential (MSRM 2004). The portion considered in the May 2004 PTP approvals included only the S8M PTP East, and was further divided along topographic boundaries to identify a mountainous High Elevation Zone and the foothills Low Elevation Zone (Figure 1.1). The Low Elevation Zone, not considered high value habitat for Stone's sheep, was approved for oil and gas tenure dispositions. Tenure sales were deferred in the High Elevation Zone until completion of Stone's sheep research and development of management direction to mitigate the impacts of industrial activity on sheep. While the S8M PTP High Elevation Zone was a focal point for the project, the actual study area was defined by the movements of Stone's sheep within and adjacent to the complete S8M PTP area (Figure 1.1).

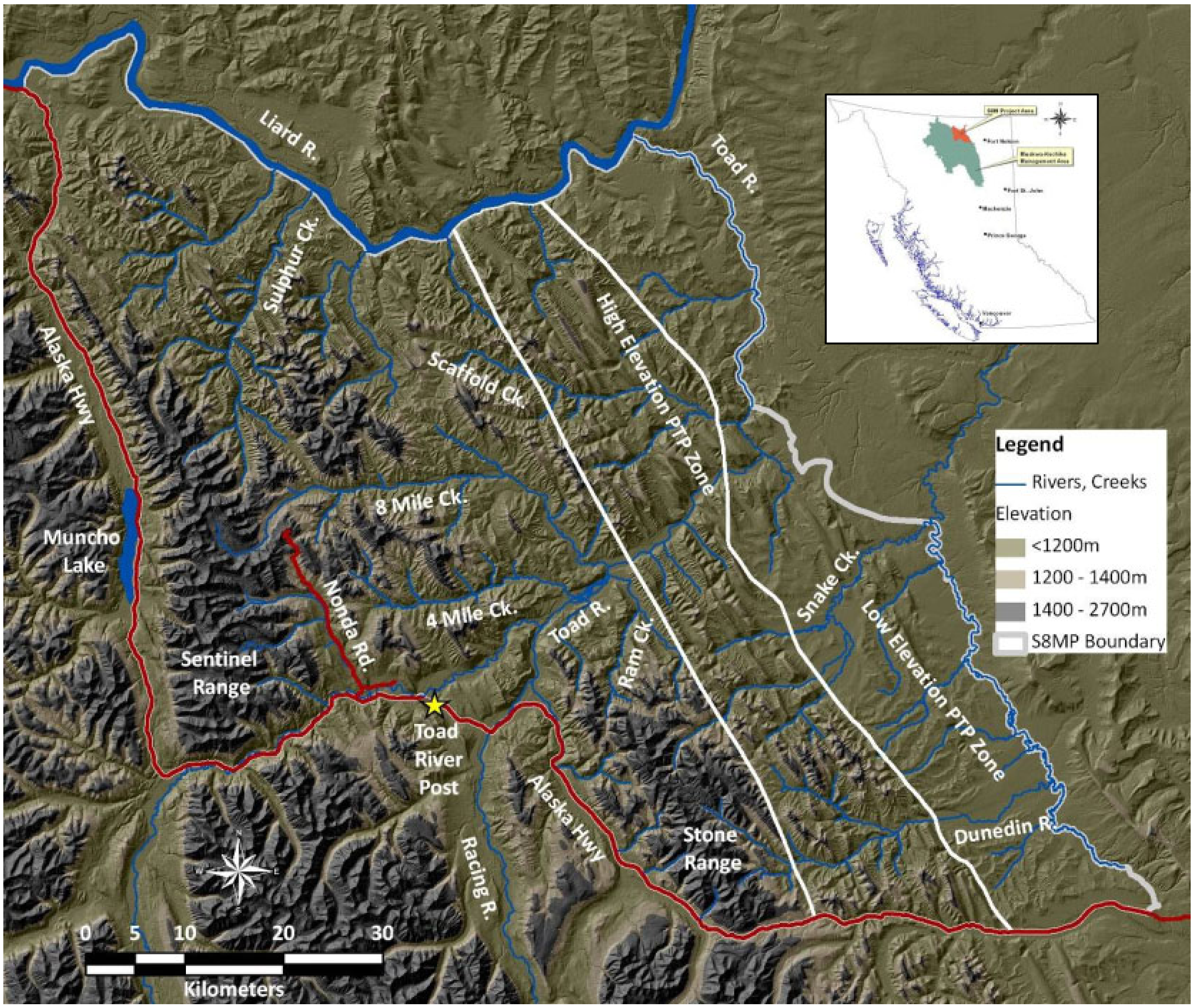

Figure 1.1 Sulphur / 8 Mile Stone's Sheep Project study area, indicating the Sulphur / 8 Mile High and Low Elevation oil and gas pre-tenure plan (PTP) Zones. Inset figure shows the project area within the Muskwa-Kechika Management Area and the province of British Columbia.

Topography and climate

Within the study area, the northern extent of the Rocky Mountain Range meets the Liard River Corridor and transitions east across the foothills to the boreal plateau. This combination of biogeoclimatic conditions creates a diverse range of landforms and habitats. Much of the area was covered by the

Laurentide ice sheet during the Wisconsinan ice age, giving the area its unique landform morphology (Millot et al. 2003).

Predominant biogeoclimatic zones below treeline (approximately 1,400 m) included Spruce-Willow-Birch (SWB and SWBmk) and Boreal White and Black Spruce (BWBSmw1 and BWBSmw2) subzones (Meidinger and Pojar 1991). Coniferous and deciduous forest comprises the majority of vegetation cover. There were no permanent snow fields or glaciers in the study area, and only 4 small lakes.

The Toad River divides the study area into two subunits, which we reference according to dominant mountain ranges as the Sentinel Range and Stone Range areas. North of the Toad River, the Sentinel Mountain Range, including adjacent Mount McLearn, Ewe Mountain, and Toad Mountain, is dominated by steep and rugged bedrock at upper elevations. This portion of the study area covered 2,460 km^2, with 23.5% of the area ≥1,400 m elevation (approximate treeline) and a maximum elevation of 2,350 m. South of the Toad River, the less-imposing Stone Mountain Range, including the adjacent Ram Mountain complex in the S8M PTP High Elevation Zone, is characterized by rounded peaks and increased vegetation cover at upper elevations. This portion of the study area covered 1,777 km^2, 14.5% ≥1,400 m and maximum elevation 2,100 m.

Climatic normals at Muncho Lake from 1971 - 2000 obtained from Environment Canada indicate that the area has a dry climate with an average annual precipitation of 496 mm and 106 frost free days[1]. From November through February, the average temperature is -18 °C; June through August the average temperature is 15 °C. The temperature in summer can exceed 30 °C and in winter can fall to -40 °C for extended periods (Figure 1.2). Snow depth is variable annually and temporally due in part to high winds which transport snow locally (Figure 1.3).

[1] http://www.climate.weatheroffice.ec.gc.ca

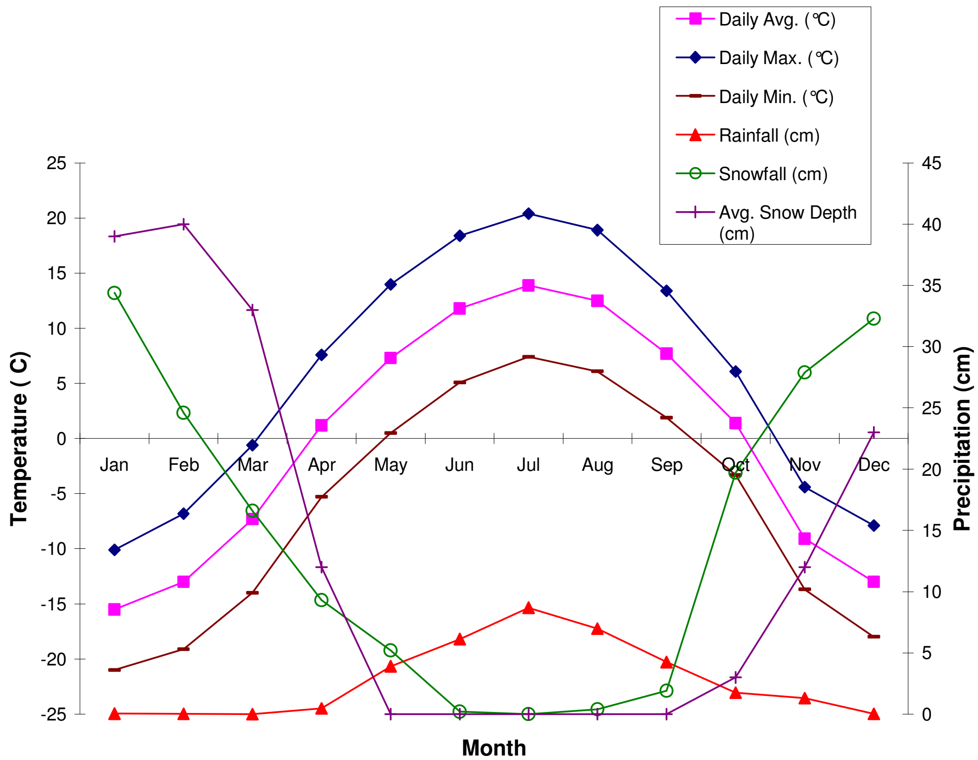

Figure 1.2 Climate normals for Muncho Lake, 1971 - 2000.

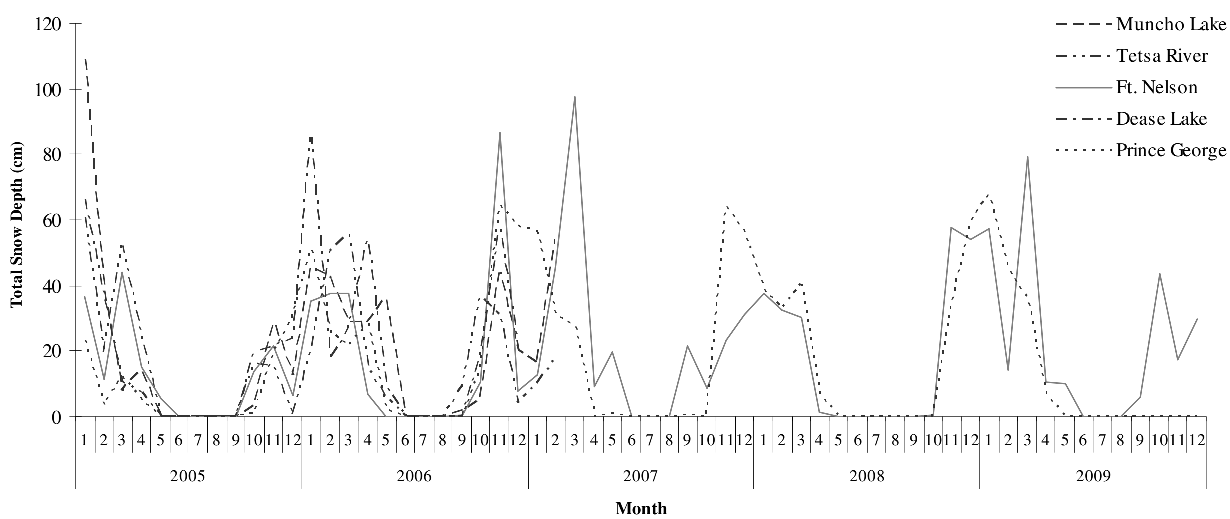

Figure 1.3 Monthly snow depth recorded at Environment Canada weather stations in regional proximity to the study area, 2005 - 2009. Data were not available for every year for some stations.

Commercial, recreational and cultural values

There is moderate and high oil and gas potential, as well as some geothermal potential, low to moderate metallic mineral potential, and moderate industrial mineral potential in the project area (MSRM 2004). Oil exploration surveys have occurred in the Toad River area since at least 1968 (Kjos 2010:198). An exploration program for iron-oxide-copper-gold on the Churchill Copper and Davis Keays properties about 30 km south of the project area was active in the mid-2000s. A preliminary seismic exploration program was conducted across the Sentinel Range in 2007 by Explor Geophysical Ltd.. Unmapped seismic lines were observed in the S8M PTP High Elevation Zone, both north and south of the Toad River. Forest harvesting has been limited to seismic lines and trails, despite the presence of 135 km^2 of commercially-valuable timber (MSRM 2004). The Alaska Pipeline Project has two proposed routes relevant to the study area. One proposed route follows the highway from the Liard River crossing south[2]; the other route follows the Liard River east before turning south and passing through the northern portion of the S8M PTP High Elevation Zone[3].

There are a diversity of commercial and non-commercial recreation opportunities, including guide-outfitter tenures, trapping tenures, transporters, hunting, fishing, hiking, camping, river boating, horseback riding, and wildlife viewing. At least 3 user-maintained trails originating at the Alaska Highway facilitate non-motorized access to the Stone Range backcountry. Access to backcountry reaches of the Sentinel Range is facilitated by the Nonda Microwave Tower Rd and the Toad River.

The S8MP area overlaps most of Wildlife Management Unit (WMU) 7-54. WMUs are management jurisdictions for which wildlife harvest regulations are established. Mature male sheep (Class IV "Full Curl" or ≥8 yrs old) may be hunted between August 1 and October 15 annually by licensed hunters that purchase a sheep permit. The number of permits issued to resident hunters is not limited; non-residents must be accompanied by a licensed guide, with permits managed under a quota system. Local heritage includes historic and current Stone's sheep harvest by the Fort Nelson (Treaty 8 signatory) and Kaska Dena First Nations (Haber 1988; Shackleton 1999), as well as Kaska Dena cultural sites in the study area (Chapter 2).

Wilderness and wildlife values

Known internationally for its exceptional wilderness and wildlife values, much of the area is undeveloped, with motorized vehicle access limited to routes designated by the M-KMA Act. The only backcountry road access in the study area is the Nonda Microwave Tower Rd approximately 10 km west of Toad River Post, which meets the upper 8 Mile Creek corridor. The project area includes portions of 5 provincial parks and protected areas: Muncho Lake Park; Liard River Corridor Park; Toad River Hot Springs Protected Area; Stone Mountain Park; and Northern Rocky Mountains Park (including Wokkpash Recreation Area). Some of the region's protected areas have international significance due in part to the diversity of wildlife that includes wolf (*Canis lupus*), grizzly bear (*Ursus arctos*), wolverine (*Gulo gulo*),

[2] http://www.emr.gov.yk.ca/oilandgas/ahpp.html
[3] http://www.thealaskapipelineproject.com

moose (*Alces alces*), Rocky Mountain elk (*Cervus elaphus*), deer (*Odocoileus spp*.), caribou (*Rangifer tarandus*), mountain goats (*Oreamnos americanus*), and Stone's sheep.

Stone's sheep populations and management history

In BC's Peace-Liard management region 7B, the highest densities of Stone's sheep coincide with suitable winter ranges in the eastern foothills of the Rocky Mountains (Demarchi and Hartwig 2004:22). Development of the Alaska Highway in 1942 facilitated access to these Stone's sheep populations, increasing both harvest pressure and management interest (Heimer 1988, 1999; Hoefs 1976:293; Kjos 2010).

> "Sheep were abundant in the Kechika-Muskwa regions in the 1930s and 1940s …. and long before that the Indian people knew these mountains as good sheep country" (Haber 1988:43).

Despite their iconic status as a premier trophy-hunted species in BC, there "is little historic information about Thinhorn Sheep abundance" (Demarchi and Hartwig 2004:22) and potential evaluation of population trends since the 1940s is limited to review of harvest statistics and sparse survey data (AXYS 2005; Haber 1988). The BC Government reported accelerating declines in Peace region Stone's sheep populations, suggesting 50% decline in the densest areas between 1977 and 1984 and further declines since "peak" numbers in the mid 1990s (Demarchi and Hartwig 2004; Elliott 1985 in Haber 1988; MWLAP 2004).

Concern about Stone's sheep population declines regionally was a major driver of the S8MP research program (AXYS 2005). "Based on the March 2004 survey the S8M Stone's sheep population experienced an overall 11% decline (both sexes all age classes) compared to the 1977 census, less than the believed regional decline of 50%" (MWLAP 2004). However, census areas, methods, and conditions have been poorly documented or are not directly comparable, prompting Haber (1988:47) to caution that "counts are suspect in determining overall Kechika-Muskwa population trends".

The BC Government promoted "intensive management of wilderness areas" to support arbitrary population and harvest targets for ungulates, particularly Stone's sheep, elk, moose, and caribou (Elliott 1983 and 1984, in Haber 1988:109-110). Elk population enhancement was cited as a management priority for decades regionally and one of the primary motivations for regional range burning and wolf control programs (Haber 1988:51; Kjos 2010; Webster 2003). Range burning by the BC Government and by guide-outfitters has been widespread since the 1940s (Haber 1988; Kjos 2010:220; Lousier *et al.* 2009; Parker and Thiessen 2009) with some burns targeting Stone's sheep winter range enhancement and trophy production (Elliott 1978; Seip 1983). Prior to and during this study, ranges were regularly burned during spring along the lower Toad River, with burned areas along the Toad River Post – Toad River Hot Springs corridor serving as winter pasture for privately owned horses (Kjos 2010).

Co-operative wolf control by the BC government, guide-outfitters and trappers has been extensive, with "periodic, heavy legal and illegal wolf control since the 1940s (Demarchi and Hartwig 2004:21-22; Haber

1988:12-13,43; Kjos 2010:217; Wilkerson 2002). Legal wolf harvest through active trapping tenures was on-going during this study. The BC Government also had active radiocollars on wolves in the project area during the study period.

Other on-going enhancement activities by government and non-government groups included placement of mineral salt blocks in undisclosed locations throughout the study area. Salt blocks were deployed prior to and during this study by BC Parks and the Northeast BC Wildlife Fund along the Alaska Highway corridor in an attempt to discourage sheep from congregating on the highway to lick road salts. The BC Government, local guide-outfitters, and hunters have deployed salt blocks and excess hide-tanning salts at remote sites in backcountry ranges as well.

Two sheep translocations have occurred. In 1996, BC Government staff moved 8 sheep from the Toad River Post area to the south end of the Stone Mountain Range (Hatter and Blower 1996). In 2005, during the initial sheep capture sessions for the S8MP, BC Government staff moved 9 sheep (6 females ≤3 yrs old; 1 female lamb; 2 males ≤3 yrs old) from upper 8 Mile Creek and the Stone Mountain Range to a recently burned site in the S8M PTP High Elevation Zone north of the Toad River (Robert Woods, Ministry of Environment, Fort St John, pers. comm., January 10 2008). Two of the transplanted females were fitted with VHF radiocollars prior to release. S8MP advisory committees were not made aware of this second initiative until 2008; no rationale for the action was provided.

GENERAL METHODS

Study animals

Initially, the project focused on adult females only. The Science Advisory Committee recommended in 2004 that research should include marked males, particularly with respect to habitat use analyses. Local hunter communities objected to fitting collars on a trophy-hunted species and expressed concerns about disclosing the males' ranges to the public. In October 2007 the S8MP Science Advisory and Steering Committees approved expanding the research program to include male sheep.

Priority areas for all captures targeted the S8M PTP High Elevation Zone, but included all of the Sentinel and Stone Ranges, within the boundary of the S8MP area. Females were collared throughout the study area and males were preferentially collared in eastern portions of the study area to address specific habitat use questions for PTP management direction. To address multiple project objectives, sheep were marked with either a motion-sensitive Very High Frequency (VHF) collar or a Global Positioning System (GPS) collar with VHF transmitter. Coloured eartags were applied to females to enable visual identification and monitoring of individuals.

We refer to sheep north of the Toad River as the Sentinel population, and south of the Toad River as the Stone population. Results are reported for the Sentinel and Stone populations separately to assess potential differences in ecology.

Mountain goats were also given special consideration in the PTP process. Mountain goat distribution and habitat data were collected opportunistically. Stone's sheep, mountain goats, moose, elk, and bison occur on sympatric ranges and we considered potential species interactions in our analyses whenever feasible. Carnivore observations were also noted and are reported in relevant chapters.

Population demographics

We evaluated population demographics by multiple aerial censuses using mark-resight analyses for population estimation. Census also provided information on population age and sex structure, lamb recruitment, distribution, and density of sheep, as well as the number of other ungulate species on sheep winter ranges. Existing census data, harvest data, and local historical information were integrated with research data to provide a reference for evaluating long-term population trends. Local knowledge of Stone's sheep ecology was compiled from historical data and interviews with long-time residents.

Survival and mortality factors

We determined survival rates, spatio-temporal mortality patterns, and causes of mortality by monitoring 124 radiocollared adult female sheep over 5 yrs (2005 - 2010). We also determined an index of mortality levels for 17 radiocollared adult males monitored over 2 yrs (2008 - 2010) and investigated incidental observations of unmarked sheep mortalities. Health parameters were assessed by laboratory analyses of biological samples collected during capture for collaring and during necropsies conducted as part of mortality investigations.

Habitat use and resource selection

We determined home range sizes and seasonal habitat use patterns using Global Positioning System (GPS) collars to collect daily location data for 26 adult females (2005 - 2009) and 17 adult males (2008 - 2010). These data were applied to habitat models and resource selection functions (RSF) to explain patterns in habitat selection by sheep. Analyses generally followed those used to determine habitat selection by female Stone's sheep in the M-KMA Besa-Prophet PTP area to extend methods and compare results regionally (Walker 2005).

Applicable permits and animal care guidelines

All field work was conducted under BC Government Wildlife Act research permits authorizing work in the S8MP study area, and in accordance with applicable BC Resource Inventory Standards Committee guidelines[4]. All capture-related activities and animal handling were conducted in accordance with the Canadian Council on Animal Care guidelines for the care and use of wildlife (Canadian Council on Animal Care 2003). Protocols were reviewed and approved by the BC Ministry of Environment Animal Care Committee.

[4] http://srmwww.gov.bc.ca/risc/pubs/tebiodiv/index.htm

REPORT STRUCTURE

This report is structured as a series of stand-alone chapters. Chapter 1 provides historical context, highlighting local knowledge of Stone's sheep distribution and abundance. Chapter 2 reports First Nations traditional ecological knowledge, followed by a preliminary assessment of selected Stone's sheep health parameters in Chapter 3.

The results of population inventories conducted to assess demographic trends and mark-resight estimation are discussed in Chapters 4 and 5, with detection of collared females and the influence of survey timing highlighted in Chapter 4 and detection of collared males and ungulate densities on sheep winter ranges the focus of Chapter 5. Survival and mortality patterns are presented in Chapter 6. Application of GPS collars on adult males and females provided detailed data on spatio-temporal movement patterns, including home range use, fidelity and seasonal movements (Chapter 7), and use of the Alaska Highway corridor (Chapter 8). Natural and artificial mineral lick use by Stone's sheep is addressed in both the seasonal movements and highway corridors chapters (Chapters 7 and 8). Habitat preferences of adult male and female sheep are presented in Chapter 9. Biological relevance of the results is highlighted in the discussion sections of each chapter. In the final summary chapter, we integrate knowledge gained during this research and link primary results to current resource management priorities and opportunities.

PART I LOCAL AND TRADITIONAL KNOWLEDGE

CHAPTER 1 Local community knowledge

Peck, R. 2011. Local community knowledge: executive summary. Pages 11-13 *in* Stone's sheep population dynamics and habitat use in the Sulphur / 8 Mile oil and gas pre-tenure plan area, northern British Columbia, 2005 - 2010. Synergy Applied Ecology, Mackenzie, BC. 167 pp plus appendices.

This is the executive summary of a report prepared by Ross Peck for the S8MP Steering Committee and the Northeast Wildlife Fund (Fort Nelson BC), completed May 2009.

To complement ongoing research on the population dynamics, habitat use, mortality, and herd health of Stone's sheep in the Sulphur/8 Mile (S8M) area near Toad River, B.C., an investigation of local community knowledge relevant to Stone's sheep was conducted from December 2007 to June 2008. Historical, archival, and literature sources were examined and information specific to the S8M area was collated and summarized. Thirty 'local' individuals were contacted, resulting in face to face interviews with twenty, and phone interviews with an additional six.

Stone's sheep have long inhabited the mountains and foothills of the Toad River area and have been important to local First Nations for centuries. Some of the first 'exploratory' expeditions came into the area in the 1930s, when Stone's sheep began to be hunted for trophies as well as meat. The construction of the Alaska Highway in 1942 brought vehicular access to the area, and from a few hunters initially, by the late 1960s the area was attracting Stone's sheep hunters from throughout B.C. and around the world. A number of guide outfitters offering Stone's sheep hunts became established in the Toad and Racing river areas through the 1950s and 1960s. At the time, BC Fish & Wildlife Branch information on the wildlife resources of the area was limited, although sporadic aerial surveys from 1968-78 had documented some of the key Stone's sheep ranges in the S8M area. A foraging ecology and nutrition study was conducted on Stone's sheep in the S8M area north of the Toad River in the early 1980s. Analysis by BC Fish & Wildlife biologists in the early 1980s suggested declining trends in Stone's sheep and other ungulates, and predator management and habitat enhancement programs were conducted in various areas throughout the northeast through the 1980s and 90s including the S8M area.

Respondents' experience within the S8M area ranged from 1 - 55 years (average 17.5 years), and included guides, outfitters, hunters, trappers, packers, pilots and biologists who had lived, worked and recreated in the Toad River area. Knowledge was often specific to north of the Toad River (Sentinel Range) or south of the Toad River (Stone Range). Stone's sheep was a valued species, and their welfare has a high priority for local residents who have a history of supporting Stone's sheep management initiatives.

The 1940s saw the construction and improvements of the Alaska Highway which facilitated access into the area. It also appears that a number of major forest fires burnt portions of the S8M area during the

1940s. Localized harvest of Stone's sheep increased from traditional native harvest, and there were no doubt fire related alterations in habitat for sheep and other species. The 1950s saw an increased number of guide outfitters established in the area offering Stone's sheep hunts, and by the end of the decade there appeared to be competition for the prime sheep hunting areas. However, respondents felt that sheep numbers were in pretty good shape in relation to the hunting activity that was occurring. Adequate sheep numbers appeared to support the increasing hunting activity by both resident and non residents through the 1960s, and a guide outfitter observed in excess of 500 sheep on a fixed wing survey of the Stone Range portion of the S8M area under ideal conditions in January of 1968. Sheep numbers were thought to be relatively stable through the 1970s, with possible declines toward the end of the decade. There was a general consensus that sheep populations were on a downward trend in the early 1980s, but responded positively to management activities, and populations were thought to peak in the early to mid 1990s. By the mid 2000s, Stone's sheep populations were felt to be stable at best in the S8M area, and overall legal ram numbers appeared to be declining in the face of fairly consistent high hunter numbers and sheep harvests.

Some 166 locations were identified where Stone's sheep had been observed within the S8M area, and there was considerable consistency between respondents. These areas included critical habitats such as mineral licks and seasonal ranges. Although there appeared to be core central ewe-lamb areas within both the southern and northern S8M area, there were a number of accounts of considerable movement by rams within and beyond the S8M area. Rams were also observed to frequent 'fringe ranges', whose locations are a closely guarded secret within the hunting community, but were characterized by being adjacent to traditional sheep ranges, often in timbered lower mountain or foothills habitats. It was noted that effective use of these ranges was enhanced when predator numbers were low.

From occasional sightings in the early 1970s, elk have shown dramatic increases within the past 10-15 years. Opinions varied on the impact of increasing elk numbers on Stone's sheep, but all informants felt it was a crucial factor. Other species dynamics have changed as well. Goat populations appear to have increased in recent years. Although caribou were never abundant in the S8M area, they have rebuilt somewhat from lows in the 1970s. It was felt that moose numbers have remained relatively stable over the past 20 years.

There has been a lot of interest and activity in relation to predator species in the S8M area. Over the past 50 - 60 years, wolves have been subject to a variety of management programs within and adjacent to the S8M area that have included hunting, trapping, baiting, and direct aerial control. Moderate wolf numbers were characteristic of the 1960s, and increases observed in the 1980s led to an extensive government control program. In recent years, local trappers have maintained an active wolf trapping program. Other predators that were thought to have potential influence on Stone's sheep included increasing Grizzly bear populations, and coyote and wolverine on specific sheep ranges.

The management of access on and adjacent to Stone's sheep ranges was a key theme raised by all respondents. The long history of predator control in the S8M area has left an expectation amongst many that it should be part of future management scenarios. A diversity of opinion over the role and utility of prescribed fire in relation to Stone's sheep varied from conducting smarter prescriptions to no intentional burning on Stone's sheep range. Harvest allocations issues were timely topics that exhibited wide ranging discussion. Respondents expressed a variety of opinions on the goals and objectives of the overall S8M Stone's sheep research project. A number felt that the Stone's sheep steering committee was proving to be an ineffective venue to bring forward their specific issues and were looking for improved opportunities to be engaged in the dialogue around overall Stone's sheep management in the S8M area.

L O C A L   A N D   T R A D I T I O N A L   K N O W L E D G E

CHAPTER 2 Kaska Dena traditional knowledge

Kisoun, V. 2011. Kaska Dena traditional knowledge. Page 14 *in* Stone's sheep population dynamics and habitat use in the Sulphur / 8 Mile oil and gas pre-tenure plan area, northern British Columbia, 2005 – 2010. Synergy Applied Ecology, Mackenzie, BC. 167 pp plus appendices.

This report was prepared by Viktor Kisoun for the S8MP Steering Committee and the Dena Kayeh Institute (Lower Post BC), with funding provided by the BC Ministry of Energy, Mines, and Petroleum Resources, completed July 2011. Additional documentation available from the Dena Kayeh Institute includes transcriptions of video-taped interviews with members of the Macdonald family.

The report is about the Stone Sheep in the Sulphur / 8 Mile creek area of Muncho Lake. The purpose of the report is to determine the stone sheep population and their ranging habits throughout the area. As well we were instructed to identify the location of an old Kaska Dena gravesite. The study I was contracted to do on behalf of Dena Kayeh Institute was video interviews pertaining specifically to the Stone sheep population and ranging habits in the Sulphur / 8 Mile creek area east of Muncho Lake. We identified the Macdonald family living in the area as the most relevant sources to be contacted and consulted. The nature of the study was conducted to determine if there would be any adverse affects to the stone sheep population due to resource exploration. Two trips were made to the area to meet with members of the family. The first trip we were unable to make it Moose Lake to interview Angus Macdonald due to weather conditions. However we did meet with Louise Macdonald who was able to provide some information on the designated area of interest. The second trip we able to fly out to the Sulphur/8 Mile location with two members of the family, and physically record the area and gravesite.

We were able to determine through our findings that the proposed affected area is a critical stone sheep wintering grounds. Because of the geographical nature of the land, the bare hillsides and low to moderate annual winter precipitation with favorable winds it becomes an ideal location for sheep to travel through during the winter and forage for food. Also directly adjacent to this location on the west side of the Racing River where it meets the 8 Mile creek is an old Kaska Dena gravesite still identifiable from the air where many people related to the Stone/Mcdonald family are buried. Also through the course of the study we found that in separate interviews with individual family members that in the past 10-15 years the stone sheep population has decreased substantively. Factors ranged from, overhunting, to a wide range of adverse disturbances and predation.

It would be recommended that a more in depth study be done in the area to get a better determination of the sheep population and ranging habits, also that a monitoring program be put in place to better mitigate adverse affects to the stone sheep in the area. Also a buffer zone needs to be put in place around the gravesite so that no development can be allowed to occur.

PART II MORPHOLOGY AND HEALTH PARAMETERS

CHAPTER 3 Radiocollaring, body measurements and health parameters

Hengeveld, P.E., J.C. Cubberley, and M.K. Cardinal. 2011. Radiocollaring, body measurements and health parameters. Pages 15-25 *in* Stone's sheep population dynamics and habitat use in the Sulphur / 8 Mile oil and gas pre-tenure plan area, northern British Columbia, 2005 - 2010. Synergy Applied Ecology, Mackenzie, BC. 167 pp plus appendices.

INTRODUCTION

The S8MP offered an opportunity to collect biological samples from 124 female sheep and 20 male sheep. We present capture results and radiocollar specifications, as well as body measurements, pregnancy rates, and parasite levels from samples collected during capture and handling. Additional data were obtained from post-mortem examination of intact carcasses, including bacteriology, histology, and toxicology. We present and discuss the findings of *mandibular osteomyelitis*, an infection commonly known as 'lumpy jaw', in mandible samples collected during sheep mortality investigations, and note horn abnormalities observed during population census.

METHODS

Capture and collaring

All captures were done by professional biologists who net-gunned sheep from a Bell 206 helicopter, a standard technique for efficient capture of widely distributed sheep in remote areas (Barrett *et al.* 1982; Krausman *et al.* 1985). No chemical immobilization was used. The risk of capture myopathy or injury to animals and crew was mitigated by limiting helicopter pursuit time, minimizing handling time, and conducting capture work only when weather and terrain conditions were suitable (i.e., snow was present to minimize risk of injury and sheep were using habitat where efficient capture was possible). In the event of injuries to sheep due to capture, crews were directed by the BC Government wildlife veterinarian to euthanize seriously injured sheep. The entire carcass was to be taken from the capture site, and submitted for laboratory analyses of sheep health parameters. Captures were conducted in short field sessions lasting 2-3 days each, to maximize capture efficiency and minimize disturbance to the sheep. After capture, animals were removed from nets, blindfolded and examined.

Females ≥1 yr old were fitted with either a Very High Frequency (VHF) radiotelemetry collar or a Global Positioning System (GPS) satellite telemetry collar. VHF collars were white Lotek LMRT-3 collars (Lotek Engineering Ltd., Newmarket, ON). Three models of GPS collar were fitted on females: Televilt

GPS-Simplex (TVP Positioning, Lindesberg, Sweden) in 2005; ATS GPS 2110 timed-release (Advanced Telemetry Systems, Isanti, MN) in 2006; and ATS G2000 remote command-release collars in 2007. Because the Televilt and ATS G2110 models only had a 1 yr battery life and each individual was to be monitored for 2 consecutive years, recapture of some individuals was required for collar replacement at the beginning of year 2. Televilt collars had blue or green butyl belts, ATS G2110 collars had brown neoprene belts, and ATS G2000 collar belts were white butyl with neoprene lining. In 2006 and 2007, females were also marked with a unique colour combination of 2 standard small-size ALLFLEX plastic eartags to enable visual identification of individuals.

Males ≥3 yr old were fitted with ATS G2000 remote command-release collars with a 2 yr battery life. Males ranging in age from 3 - 6 yr were prioritized for the application of radiocollars. Belt material was white butyl with neoprene lining and a custom 4-ply cross-stitched elastic portion to allow up to 3" expansion for body growth and seasonal changes in neck diameter.

In 2005/2006, all GPS collars were Televilt and programmed to store GPS location fixes at 6 hr intervals (4 am, 10 am, 4 pm, 10 pm). After 2005/2006, we used ATS collars programmed to take fixes at 7 hr intervals so that locations would be spread across the daily 24 hr cycle. We switched to ATS G2110 collars in 2006 because Televilt collars were no longer available. The Televilt and ATS G2110 models had a 1 yr battery life therefore some individuals required recapture for collar replacement to obtain 2 consecutive years of location data. We switched to ATS G2000 collars when they became available in 2007 because their 2 yr battery life was expected to reduce the need for sheep recaptures for battery replacement. All collars required retrieval for GPS data recovery.

Biological sampling during sheep captures

Data and biological samples collected during capture included:

- Age estimated by number of horn annuli (Geist 1966; Hemming 1969; Hoefs and König 1984);
- Body measurements: total length, shoulder height, chest girth, neck girth, horn length (Shackleton 1999:77);
- Reproductive status of females based on evidence of nursing;
- Body condition score estimated by muscling and fat cover;
- Blood for serum progesterone levels to determine pregnancy and serum antibody levels for estimating infectious disease exposure;
- Ear punch tissue samples (from eartagged individuals) and hair samples for genetic analyses;
- Fecal samples for parasite loads;
- Presence of external parasites (e.g., ticks);
- Record of any injuries and visible signs of disease (abnormal horns, discharges etc.).

Biological samples taken from each sheep during capture were processed, stored and transported according to standard protocols, and transferred to the BC Government wildlife veterinarian for future analyses.

Captures occurred in multiple years. We determined the approximate age distribution of all sampled females using estimated age in 2006 as a reference. We used estimated age in 2008 as a reference for age distribution of males. We used standard regressions to look for linear and curvilinear relationships between body measurements and estimated age. We included estimated age in analyses of body size variance between Stone and Sentinel areas to account for age effects on body measurements. *P*-values < 0.05 were accepted as significant. Female age estimates determined from horn annuli counts can be imprecise (Hoefs and König 1984). Teeth collected during post-mortem investigations were submitted for ageing to test correlations between estimated and actual ages and provide an index for future age-estimate corrections.

Serum progesterone levels were analyzed by the University of Saskatchewan Prairie Diagnostic Services wildlife health laboratory. Levels >2 ng/ml indicated pregnancy, <1 ng/ml indicated not pregnant, and 1 - 2 ng/ml were inconclusive.

Fecal samples collected from females captured in March 2006 were analyzed for parasite loads by the University of Saskatchewan wildlife health laboratory, using the Baermann Exam (Forrester and Lankester 1997) and the Quantitative Wisconsin Floatation techniques. Parasite species found in other wild sheep populations include:

- Roundworms (phylum Nematoda) - *Trichostrongylus* spp., *Nematodirus* spp., *Marshallagia* spp., *Trichuris* spp., and *Skrjabinema* spp. gastro-intestinal worms; *Protostrongylus* spp. lungworms.
- Tapeworms (phylum Platyhelminthes) - *Moniezia* spp. intestinal worms.
- Protozoa (phylum Apicomplexa) - *Eimeria* spp. intestinal parasites.

Parasites are generally identified by their genus or family name upon reaching the adult stage, as the eggs and larvae of many parasite species are indistinguishable (Jenkins and Schwantje 2004). Some early stage larvae are recognized and grouped as dorsal-spined larvae (DSL) (Kutz et al. 2001). We estimated the percentage of females in the population infected with parasites (prevalence) and the average number of parasite eggs or larvae shed in the feces of individuals (intensity).

Samples collected from male sheep were archived for future analyses.

Post-mortem sampling

Post-mortem examinations were performed by Dr. Helen Schwantje and project biologists on intact carcasses recovered during field work (Chapter 6). Overall body condition was assessed by the amount of body fat and signs of injury or disease. Tissues were examined for wounds or parasites. Samples collected from all sheep were submitted to the Ministry of Agriculture and Lands Animal Health Centre in Abbotsford for routine bacteriology and histology.

All mandibles collected during sheep post-mortem investigations (Chapter 6) were assessed for bone deformities, bone recession, fistulas, and abnormal tooth wear typical of lumpy jaw (Hoefs and Bunch

2001). Bone deformities included enlarged, lumpy and asymmetrical mandibles. Bone recession was visible along the gum line, exposing the lower portions of the molars. Abnormal tooth wear included uneven wearing and missing or enlarged teeth.

Field observations

During population census in December 2006 and March 2007 (Chapter 4) we observed unusual horn growth for several male sheep.

RESULTS

Capture results

Females were captured between March 4 and April 11 in 2005, 2006, and 2007 (Table 3.1). Males were captured in 2008 and 2009, the first on January 21 2008 and the remainder between March 6 and April 27 annually. Of 124 collared females, 58 (47%) were from the Sentinel Range and 66 (53%) were from the Stone Range (Figure 3.1). Fifteen males (75%) were captured in the Stone Range, and 5 (25%) in the Sentinel Range.

Table 3.1 Number of Stone's sheep captures for radiocollaring, 2005 - 2010.

Sex	Capture type	Collar type[1]	2005	2006	2007	2008	2009	2010	Total
Female	New captures	VHF	23	56	11				90
	New captures	GPS	15	11	8				34
	Recaptures[2]	GPS	0	9	7		1	1	
	Total females		39	66	19				124
Male	New captures	GPS				19	1		20
	Recaptures[2]	GPS						6	
	Total males					19	1		20

[1]VHF: Very High Frequency radio telemetry collars. GPS: Global Positioning System satellite telemetry collars.
[2]GPS collars had to be replaced in 2006 and 2007 for multi-year monitoring due to limited collar battery life. Re-captures in 2009 and 2010 were for removal of collars with failed release mechanisms.

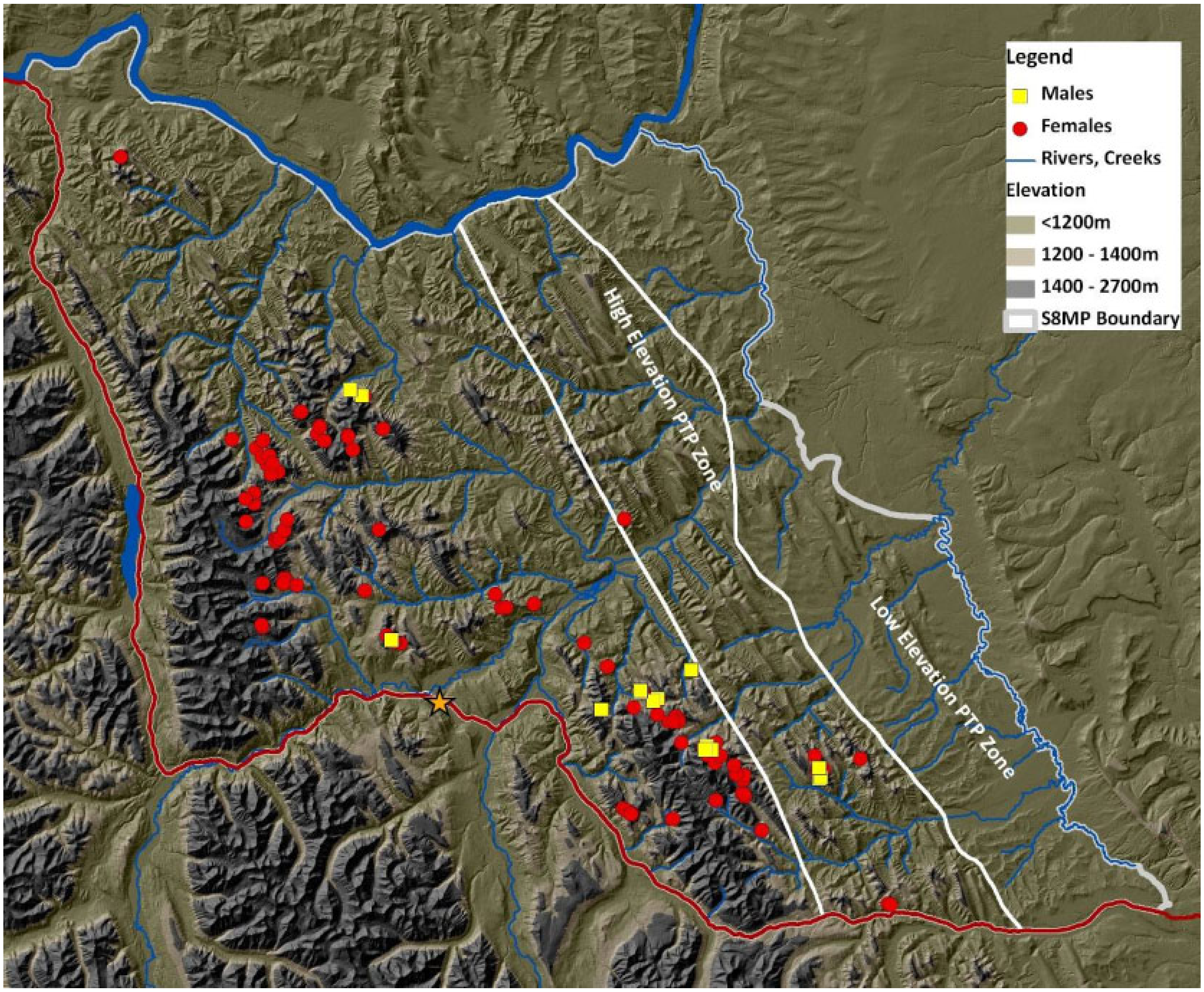

Figure 3.1 Distribution of capture locations for 124 female and 20 male Stone's sheep.

Characteristics of the sample population

Estimated age and body condition

Mean age of collared females was 5.4 ± 2.4 (SD) yrs, ranging 1 - 10 yrs (Figure 3.2). Females assessed during 2006 and 2007 captures generally appeared to be in good body condition, with 6 of 76 females reported as visibly thin; no data were available for 2005 captures. Three female sheep with heavy tooth wear had only a minimal amount of incisors above the gum line, 7 female sheep had broken or absent incisors and 2 had very long incisors that protruded when their mouths were closed. Several females had vertical cracks running lengthwise along the side of the horn and 6 females had broken or broomed horn tips. One female had both horns broken off near the skull base. The left hind leg of one female appeared to have been broken and healed previously. No external parasites or visible signs of disease were observed on sheep at the time of capture. An engorged adult winter tick (*Dermacentor albipictus*) was observed on 1 female in the Stone population during post-mortem investigation 2 years after capture.

Mean age of collared males was 6.3 ± 2.0 (SD) yrs, ranging 3 - 11 yrs (Figure 3.2). Males were generally in good condition, but the youngest male was thin. Four males had broken incisors and one had very long incisors. Among males captured in the Stone area, 2 had severe hair breakage; 6 males had minimal to moderate hair breakage. A few adult winter ticks were found on 4 male sheep in the Stone population. No other signs of disease or prior injuries were noted.

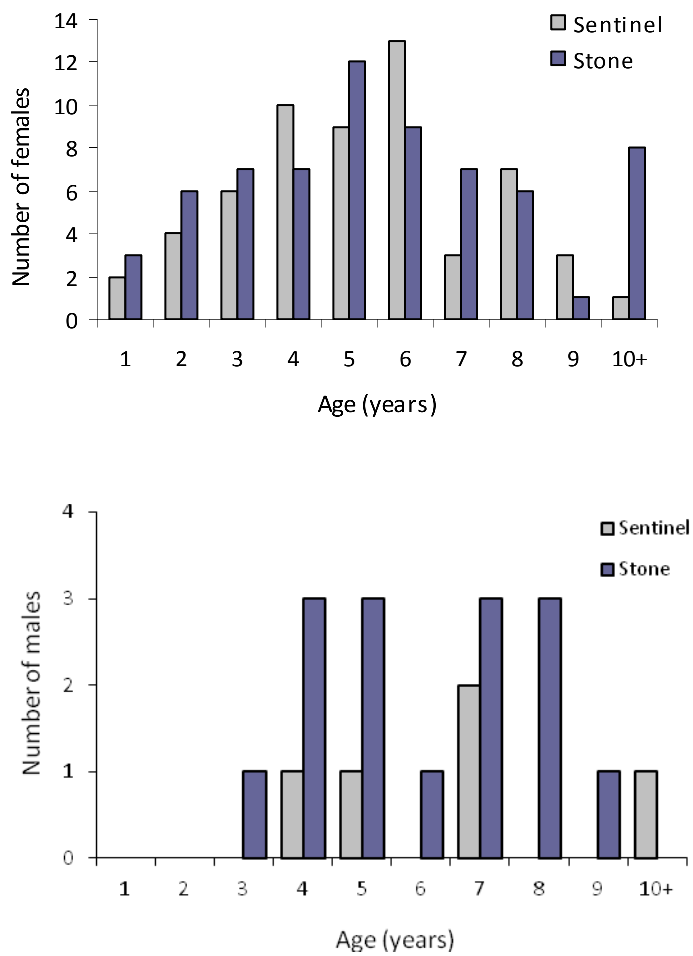

Figure 3.2 Estimated age distribution for 124 collared female Stone's sheep (58 in the Sentinel population, 66 in the Stone population) adjusted to year 2006, and 20 collared male Stone's sheep (5 Sentinel, 15 Stone) adjusted to year 2008.

Pregnancy rates

Mean overall pregnancy rate was 88.2 ± 0.7% for 76 females tested in March 2006. Pregnancy rates in the Sentinel and Stone populations were 88.9% (n = 36) and 87.5% (n = 40) respectively (Figures 3.3 and 3.4). Limited sampling in 2007 found 53% of 19 Sentinel females and 80% of 10 Stone females were pregnant. Of 7 females tested in both 2006 and 2007, 3 were pregnant both years (estimated ages 3-4, 3-4, and 6-7 yrs), 3 were pregnant in one year only (estimated ages 2-3, 5-6, 9-10 yrs), and one female estimated to be ≥10 yrs was not pregnant in either year. We observed primiparity at 2 yrs and 12 yr olds still producing lambs.

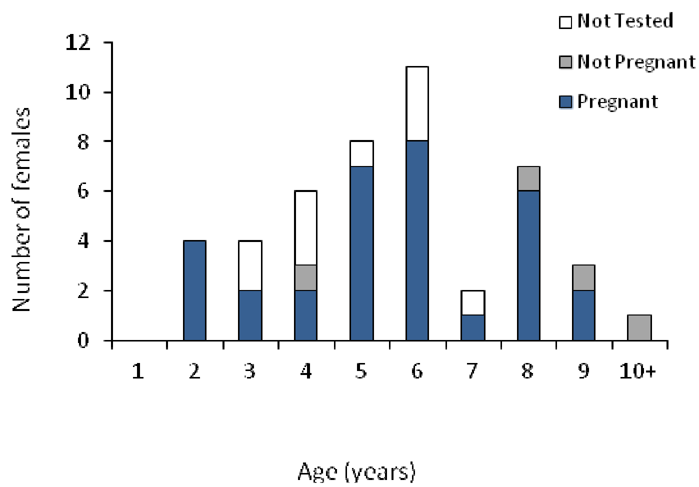

Figure 3.3 Age-specific pregnancy results for 36 female Stone's sheep in the Sentinel population, March 2006.

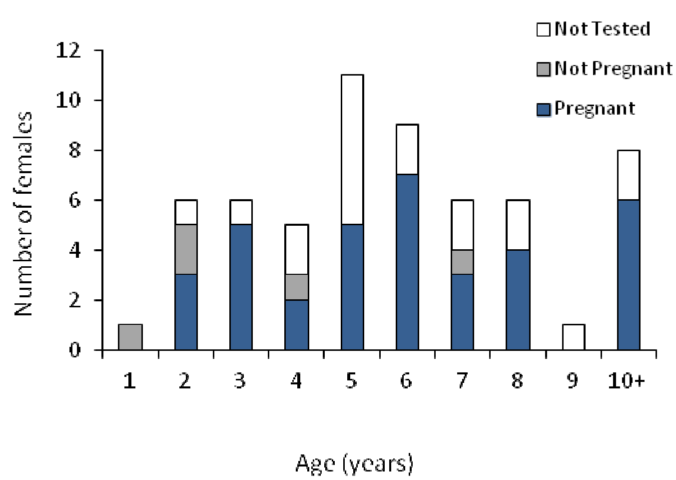

Figure 3.4 Age-specific pregnancy results for 40 female Stone's sheep in the Stone population, March 2006.

Body measurements

We recorded body measurements for 100 females and 20 males (Table 3.2). Growth was linear with age for all body measures except female shoulder height and chest girth, which reached an asymptote at 9 yrs. There was no difference in body measurements between populations when estimated age of collared sheep was taken into account ($P > 0.05$).

Table 3.2 Body measurements determined during late winter captures of male and female Stone's sheep.

Sex[1]	Parameters	Age	Shoulder height (cm)	Neck girth (cm)	Chest girth (cm)	Total Length (cm)
Female	Mean ± SD	6.4 ± 2.5	91.0 ± 3.4	41.4 ± 3.1	100.1 ± 4.3	157.3 ± 8.6
	Range	2 - 13	76 - 101	34 - 59	88 - 114.5	132 - 181
	n	124	100	100	100	100
Male	Mean ± SD	6.2 ± 2.0	98.5 ± 11.5 *	46.5 ± 3.0 *	107.3 ± 7.9 *	168.5 ± 11.9 *
	Range	3 - 11	68 - 114	41 - 52	86 - 120	142 - 185
	n	20	20	20	20	19

[1] We measured body weights during post-mortem exam of 3 sheep: 48.7 kg 8 yr old female with a 2.7 kg male fetus near full term (May 8); 65.5 kg 10 yr old male (March); 90 kg 11 yr old male (January 12).
* significant differences between sexes ($P < 0.05$).

Parasite identification, prevalence and intensity

Parasites were present in both female populations. All but one of the 70 fecal samples were positive for at least one parasite species. Only a pregnant 2 yr old female from the Stone population had negative findings, likely because only a very small fecal sample was collected (0.2g). *Protostrongylus* spp. and DSL had the highest average intensities (Table 3.3).

Twenty-six (37%) of 70 females had *Protostrongylus* larvae in feces; 13 Sentinel females and 13 Stone females. In each population, all but 2 sheep infected with *Protostrongylus* were pregnant in 2006. The intensity of *Protostrongylus* in feces samples for both populations ranged from 13 larvae/g feces to 9,020 larvae/g feces. Using the characterization framework set by (Stelfox 1990), 2 Sentinel females had very high fecal lungworm loads (>1,050 larvae/g feces), 1 had moderate levels (351 - 700 larvae/g feces), and the rest were light (<350 larvae/g feces). One Stone female had very high fecal lungworm loads and the rest were light.

Sixty-one (87%) of 70 females had DSL in fecal samples; 31 were Sentinel females and 30 were Stone females. In the Sentinel population, all but 4 of the DSL-infected sheep were pregnant in 2006. In the Stone population, all but 3 of the DSL-infected sheep were pregnant in 2006. The intensity of DSL for both ranges ranged from 9 - 6,464 larvae/g feces.

Table 3.3 Prevalence (% of sample population) and average intensity (number of eggs or larvae per gram of feces) of parasites in Stone's sheep fecal samples from 34 Sentinel females and 36 Stone females, March 2006.

	Sentinel population		Stone population		Both populations	
Parasite Name	Prevalence	Intensity	Prevalence	Intensity	Prevalence	Intensity
Trichostrongylus spp.	0	0	2.5	0.2	1.4	0.2
Nematodirus spp.	69.4	3.2	55.0	1.8	65.7	2.6
Marshallagia spp.	83.3	10.2	77.5	4.8	87.2	7.5
Trichuris spp.	86.1	17.6	65.0	10.3	81.4	14.3
Skrjabinema spp.	2.8	17.2	5.0	18.0	4.3	17.7
Eimeria spp.	88.9	77.7	87.5	65.9	95.7	71.5
Moniezia spp.	5.6	3.3	5.0	9.1	5.7	6.2
Protostrongylus spp.	36.1	1271.4[1]	32.5	350.4[2]	37.1	810.9
Dorsal-spined larvae	86.1	514.7	75.0	344.0	87.1	430.7

[1] Average intensity is reduced to 172.0 larvae/g feces if the 2 Sentinel females with very high lungworm levels are excluded.
[2] Average intensity is reduced to 74.3 larvae/g feces if the Stone female with very high lungworm levels is excluded.

Post-mortem results

An 8 yr old Sentinel female died in an avalanche in January 2007. She was in very poor body condition but still lactating at time of death. Cause of death was a broken neck, with severe trauma to the neck muscles and a fracture to the C6 vertebra. Histology indicated severe changes to lung tissue from lungworm, and the lower left lung was adhered to the parietal pleura with significant abscesses along the sternum and rib. Bacteriology of the lung and surrounding tissue cultured *Arcanobacterium pyogenes* and mixed bacteria.

A 6 yr old Stone female was euthanized after her capture in March 2006 due to inability to rise. Post-mortem exam determined a pelvic fracture, but she was otherwise in good body condition and pregnant at time of death. Histology revealed chronic lungworm lesions.

A 10 yr old Sentinel male was found dead in emaciated body condition in March 2007. Post-mortem exam revealed no visible fat in fat depots associated with the heart and kidneys, and no femur bone marrow fat. Histology revealed mild lungworm lesions. Severe abnormalities of the tooth arcade were evident and lumpy jaw was diagnosed. Cause of death was emaciation. The male's skull plate and horns were provided to the BC Conservation Officer Service for display purposes at the Fort Nelson airport.

A male lamb died of evisceration and blood loss after being gored in the abdomen by an adult mountain goat. The lamb was in good body condition. Histology identified lungworm lesions in the lung.

Prevalence of lumpy jaw

We examined 21 mandibles from females aged 3 - 11 yr old and diagnosed lumpy jaw in 6 females ≥6 yr old. One (14%) of 7 samples from the Sentinel population and 5 (42%) of 12 from the Stone population were positive for lumpy jaw. Lumpy jaw could not be confirmed in 2 samples from 2 yr old females. The most severe case of lumpy jaw was observed in a 10 yr old female found dead in March 2007. The extent of the deformity suggests that she survived with this disadvantage for several years. Post-mortem exam indicated very poor body condition.

Horn abnormalities

Five males with unusual horn growth were sighted in the Sentinel population during the aerial censuses in December 2006 and March 2007 (Chapter 4). An adult male with right horn growing into its right eye and stunted left horn growth was observed December 12 2006 and March 18 2007. A young adult male with left horn growing from its forehead / left eye was observed December 14 2006. A mature adult male had a 'stub' left horn and uneven growth at the horn bases, March 18 2007. Two other males were observed with broken horns.

DISCUSSION

Preliminary analyses of body condition during capture sessions and observations during post-mortem investigations did not indicate any widespread herd health concerns. Our results from the 2006 fecal parasitology analysis were consistent with fecal parasitology results reported for Stone's sheep populations regionally (Jenkins and Schwantje 2004; Wood *et al.* 2010). Gastro-intestinal nematodes and protostrongylids are common in wild sheep and other ungulate species (Garde et al. 2005), and lungworm does cause chronic damage to the lungs (Kutz et al. 2001). However, lungworm lesions were incidental to, not the cause, of death in sheep that we examined.

Winter ticks (*Dermacentor albipictus*) were observed on sheep in the Stone Range. As potential hosts for large numbers of ticks, moose and elk that share ranges with Stone's sheep can perpetuate tick parasitism in sheep (Wood et al. 2010). A study on the effects of winter ticks on Stone's sheep in northern BC reported that "significant tick-associated hair loss appeared to be a lesser factor than severe weather, winter forage availability, and predation, and did not appear to have a detrimental impact on the population" (Wood et al. 2010).

Lumpy jaw has been reported in most subspecies of wild sheep in western North America, particularly in thinhorn sheep, and is common in S8MP sheep. Mineral deficiencies, such as calcium and phosphorous, may contribute to tooth and jaw anomalies (Glaze et al. 1982). Dental root abscess, trauma to the jaw (Fagan et al. 2005), abnormal wearing of teeth and poor alignment of the tooth arcade (Bunch et al. 1984), and abrasive, coarse, or dust-covered vegetation can also be contributing factors (Hoefs and Bunch 2001). There appears to be minimal evidence of severe, negative impacts of lumpy jaw on wild sheep although Glaze *et al.* (1982) suggest that there may be a correlation between lumpy jaw and malnutrition and, as a result, a shorter life span. The most severe case of lumpy jaw observed in the S8MP was in a mature female (>10 yrs old), suggesting limited influence on survival of affected individuals.

Horn abnormalities were rare observations. We speculate that they may be caused by accidental breakage of the horns, infection in the horn core or sheath, or possible deficiencies in nutrients required for proper horn growth. As with lumpy jaw, the most severe abnormality was observed in a sheep of mature age, suggesting little effect on survival of affected individuals.

While S8M sheep populations appear to be healthy, we caution that managing disease risk is a vital part of wild sheep management (Heimer 1999; Jenkins and Schwantje 2004). Disease outbreaks are common in wild sheep populations, particularly those that come into contact with domestic animals or other wildlife that can carry pathogens infectious to sheep (Garde *et al.* 2005; WAFWA and WSWG 2007).

PART III POPULATION DYNAMICS

CHAPTER 4 Stone's sheep demographics and distribution determined from two censuses in winter 2006/2007 and implications for population estimation

Cubberley, J.C. 2011. Stone's sheep demographics and distribution determined from two censuses in winter 2006/2007 and implications for population estimation. Pages 26-47 *in* Stone's sheep population dynamics and habitat use in the Sulphur / 8 Mile oil and gas pre-tenure plan area, northern British Columbia, 2005 – 2010. Synergy Applied Ecology, Mackenzie, BC. 167 pp plus appendices.

A condensed version of this chapter was presented at the 16th Biennial Northern Wild Sheep and Goat Council Symposium and published in the conference proceedings: Cubberley, J.C. 2008. Stone's sheep demographics in the Sulphur / 8 Mile Project area, northern British Columbia, winter 2006/2007. Bienn. Symp. North. Wild Sheep and Goat Counc. 16: 106-121.

INTRODUCTION

One of the primary objectives of the Sulphur / 8 Mile Stone's Sheep Project (S8MP) was to assess Stone's sheep population size, demographics, and stability. The BC Government conducted aerial sheep census in the project area in 1977 and 2004, without the benefit of marked sheep to assess detection rates and calculate confidence intervals around population estimates (MWLAP 2004). In 2005 and 2006, females were collared in the project area to obtain habitat use data and assess levels and causes of sheep mortality.

Population census was conducted in winter 2006/2007 to assess Stone's sheep distribution, demographic structure and trends. The presence of collars on female sheep enabled mark-resight analyses for population estimation. Initially, a single census was planned. We timed it for the latter stages of the rut, in late November - early December (Nichols 1978), to maximize the potential to enumerate males. Males may not be in the census area at other times of the year (Bleich *et al.* 1997; Corti and Shackleton 2002; Festa-Bianchet 1988a; Ruckstuhl and Neuhaus 2002), but congregate with female groups during this time. Maximizing the potential to observe males was a priority because males were not represented in the collared sample population. Our objectives were to:

- Design and implement a census methodology that is repeatable in the S8M project area and can be applied in other regions that support Stone's sheep;
- Obtain a total count of Stone's sheep in the census area, recording number of sheep, group sizes, age/sex classification, distribution, and habitat characteristics;
- Determine a population estimate with confidence intervals using detection probabilities from mark-resight of collared sheep;
- Map the distribution of all sheep sighted;

- Estimate lamb survival to early winter and compare this estimate to pregnancy rate of females sampled in March 2006;
- Record number and distribution of other ungulate species and predators observed in the census area.

In March 2007, the BC Government conducted Stone's sheep inventories throughout the North Peace Region, without the benefit of marked animals for population estimation (Thiessen 2009). We conducted a second census in the S8M project area concurrent to the MoE regional Stone's sheep census to:

- Determine detection probabilities for female sheep that can be applied to late winter inventory results;
- Incorporate census results into a repeated count analysis to improve confidence of the S8M population estimate;
- Compare rut (December) and late winter (March) distribution and demographics;
- Compare the efficacy of a rut census in December to those typically conducted in late winter (MSRM 2002).

METHODS

Radiocollars for mark-resight correction

In March 2005 and 2006, female sheep ≥1 yr old were collared in the project area. Sheep were fitted with either a motion-sensitive Very High Frequency (VHF) radiocollar, or a Global Positioning System (GPS) collar with VHF transmitter. Refer to Chapter 3 for a detailed description of sheep captures and radiocollar specifications. In December 2006, 77 collared females were available for mark-resight analyses.

Census area delineation

We stratified the study area according to ecosystem descriptions in Meidinger and Pojar (1991) who suggest that, although variable, alpine typically begins at an elevation of 1,400 m in northeastern BC. We then correlated GPS location data from 9 collared females in our sample population with elevation, to discern if sheep were likely occupying alpine areas during the proposed time of census. The census area was mapped a priori using Geographic Information System (GIS) software to query 25-m resolution Digital Elevation Model (DEM) raster data and produce census polygons for all areas ≥1,400 m (approximate treeline), within the bounds of the formal S8MP area (Table 4.1).

Results are reported for the Sentinel and Stone Range areas separately.

Table 4.1 Total area, census area, and elevation of the Sentinel and Stone Ranges, December 2006 and March 2007.

Study area	Census area (km^2 ≥1,400 m elevation)	Total area ($km^{2)}$	Elevation range (m asl)
Sentinel	579	2,460	450 – 2,350
Stone	257	1,777	360 – 2,100
Total	836	4,237	450 – 2,350

Census protocols

Census methodology conformed to provincial Resource Inventory Standards Committee (RISC) protocols for aerial ungulate inventories (MSRM 2002). Field data forms followed RISC standards as well (MELP 1998). A helicopter equipped with two Yagi-Uda 2-element antennas mounted on opposing sides of the skid assembly was used for both censuses.

The crew consisted of a pilot, sheep habitat and activity recorder, enumerator, and a navigator. The crew sat in the same seating arrangement in the aircraft throughout the census. All crew members actively participated in locating animals. The navigator employed blind telemetry (other members of the crew could not hear the radiocollar VHF beacon), throughout the censuses to calculate detection rates of collared sheep. If collared sheep were not observed, but heard by the navigator, the search for new animals was temporarily suspended at a natural topographic break and the collared sheep were located using radiotelemetry.

Searches for animals began at 1,400 m elevation and, if necessary, subsequent passes increased in elevation until the crew was confident the area was sufficiently searched. Tracks in snow were followed as well. Although the focal species was Stone's sheep, all animals sighted were recorded and geo-referenced during the censuses to provide some insight on inter-specific overlap in habitat use and possible competition on winter ranges within the S8MP area. The total number of each group was recorded first then each crew member was assigned a specific age class or sex to enumerate. Age classifications of male sheep followed Geist (1971), grouped by degree of horn curl in relation to the bridge of the nose as Class I (¼ curl), Class II (½ curl), Class III (¾ curl) and Class IV (full curl). Group tallies were compiled by the enumerator. The potential for classification error was mitigated by using the same observers and taking photos of large sheep groups for post-census review and validation of counts.

We used real-time flight tracking (MNDNR 2000) with a GIS platform (ESRI 1999) to map flight lines during census. An on-board computer displayed the helicopter location relative to the census polygons. Additional GIS maps of local hydrology and roads aided the navigator and pilot during flight by providing a visual reference of landscape features. This enabled us to:

- Provide accurate reference points that allowed the census crew to determine if an area was surveyed previously;
- End the census at natural topographic breaks in contiguous survey areas to find unsighted, collared sheep with telemetry or refuel the aircraft, and then resume with minimal risk of double counting animals;
- Establish a repeatable survey protocol;
- Calculate true survey effort by excluding ferry time between census polygons and re-fueling.

Data analyses

Survey effort

True survey effort for each census was calculated using flight line data to determine only the time spent actively searching for sheep and excluded ferry time to refuel or search for collared sheep with radiotelemetry.

Population estimation

We used NOREMARK software (White 1996) to calculate a population estimate for each population with 95% confidence intervals using the survey data from December 2006 and March 2007. This software incorporates a joint hypergeometric maximum likelihood estimator for repeated counts (Bartmann et al. 1987) with an extension to account for immigration and/or emigration (IEJHE) of sheep to/from the census polygons (Neal et al. 1993). The IEJHE input data is based on observations within the census polygons but incorporates the proportion of collared sheep outside the polygons and the minimum number of sheep sighted to derive an estimate of Sentinel and Stone female populations. We made assumptions that all collared and unmarked individuals within polygons were independently distributed, had an equivalent probability of being observed, and no errors were made differentiating a collared and unmarked individual.

The IEJHE was used to calculate the population estimate for adult females only. We accounted for potential sexual bias of the collared, sample population by multiplying the observed proportion of lambs, yearlings and adult males to females observed in December by our derived population estimate of females for each population. Lamb, yearling and adult male estimates were calculated using the observed proportions to females. We used the December data for all elevations to derive the estimates for lambs, yearlings and adult males because the number of females sighted did not differ between censuses, but fewer males were observed in March. Sheep observed incidentally or by radiotelemetry at elevations below 1,400 m were included in the lower limit population estimates but not included in mark-resight correction.

Group size, composition, and density

A Student's *t*-test was used to determine if there were differences in mean group size among populations and censuses. Groups were classified as being either female only, male only, mixed, or nursery group.

Nursery groups were defined as females with lambs, yearlings and class I males while mixed groups contained at least one class II or older male. Density calculations were derived based on the total area of ≥1,400 m census polygons within each population.

Lamb survival

Lamb survival to 6 and 9 months of age was estimated from March 2006 pregnancy rates (Chapter 3) and observed lamb to adult female ratios for the Sentinel and Stone populations. The proportion of lambs to females was calculated for December and March using observations from all elevations.

Habitat associations

Slope, aspect and elevation of Stone's sheep within census polygons were derived by plotting animal locations on a 25 m resolution DEM grid. Differences in mean slope, aspect and elevation utilized by sheep between populations and censuses were tested for significance using analysis of variance (ANOVA). Mean values are reported ± standard error (SE). All tests of significance were measured against the 95% confidence interval (α=0.05).

RESULTS

Survey conditions

Censuses were conducted on November 22 – 23 and December 9 – 16, 2006 and March 16 – 23, 2007. Very cold ambient air temperatures (< -25 °C) required us to terminate the census temporarily for safety reasons on November 24, 2006 and resume on December 9, 2006. Areas previously searched that were spatially isolated were not resurveyed because the likelihood of animals emigrating or immigrating out of the area was low. Contiguous areas where there was increased likelihood of double counting animals were resurveyed in their entirety. True survey effort was 2.61 min/km^2 in December and 3.03 min/km^2 in March, and covered all census polygons (Figure 4.1).

With the exception of the cold temperatures in November 2006, weather conditions were generally favourable during both censuses (Figure 4.2). Frequent, light snowfall overnight cleared in the morning, providing good visibility. Strong winds made flying difficult at times but wind events were short lived and did not significantly hamper census activities. There were approximately 8 hours of daylight in December, as opposed to approximately 11 hours in March.

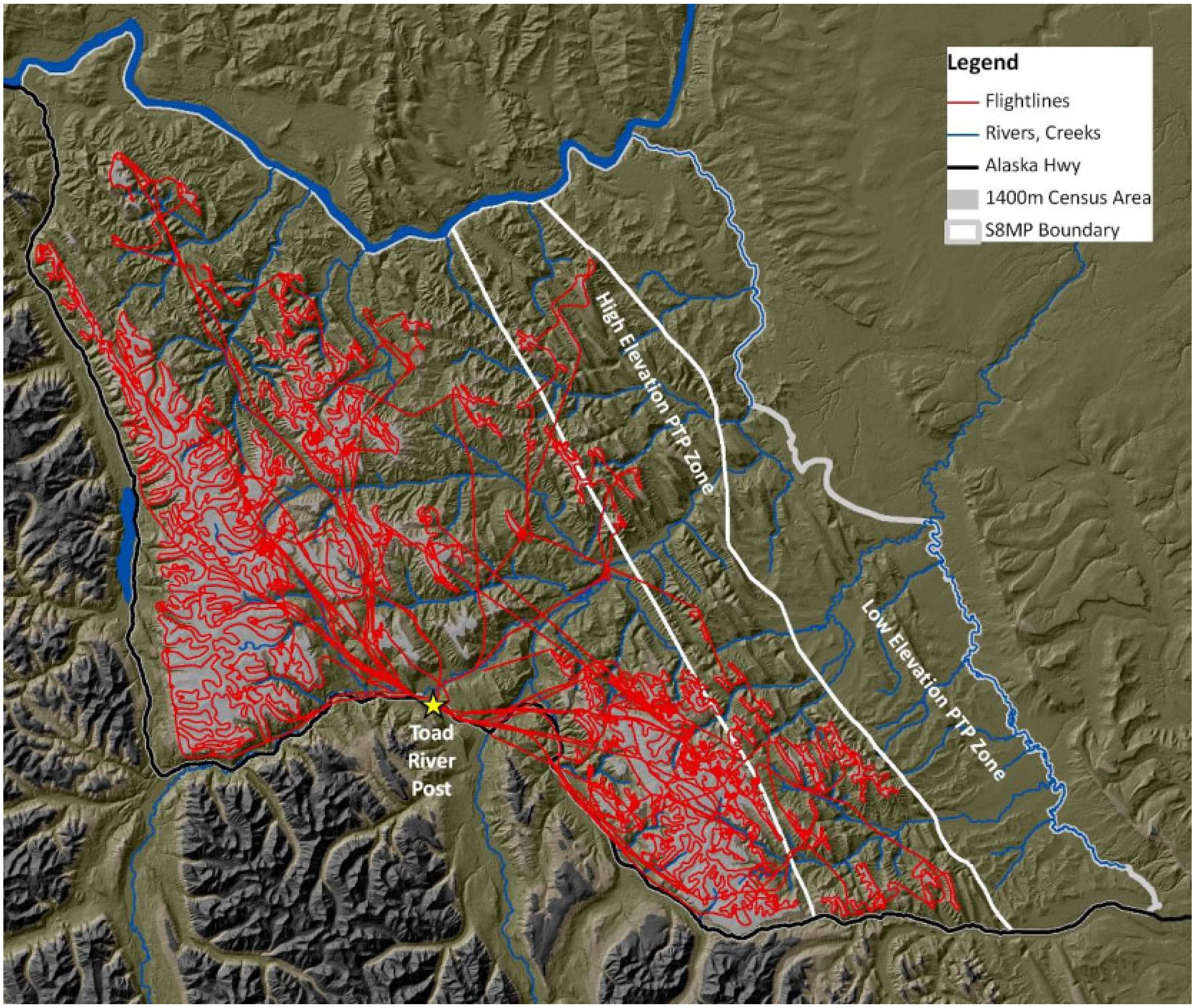

Figure 4.1 Census flight lines for December 2006 and March 2007. The census polygons north of Toad River Post were surveyed but flight lines were not recorded.

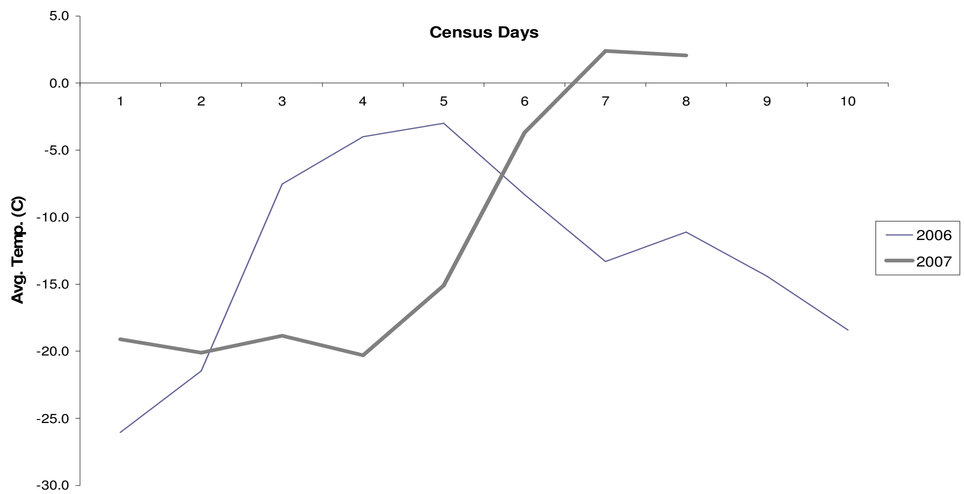

Figure 4.2 Mean daily ambient air temperatures at Muncho Lake during December 2006 and March 2007 censuses.

Stone's sheep demography

Population estimates, age structure, and sex ratios

We counted 939 sheep in December 2006 and 875 sheep in March 2007 (Table 4.2). Detection of collared females varied between populations and censuses (Table 4.3). Overall, detection was better in December (83.5%) than in March (71.9%). The IEJHE population estimates were 224 (95% CI 190-279) Sentinel females and 202 (95% CI 176-240) Stone females (Table 4.3). Based on observed ratios of yearlings, lambs and males to adult females in December (Table 4.4), the estimated Sentinel population included 150 lambs, 43 yearlings, 181 males and 29 unclassified sheep for a total estimate of 627 sheep (95% CI 532-781; Figure 4.3). The Stone population estimate included 147 lambs, 26 yearlings, 156 males and 14 unclassified for a total population estimate of 545 sheep (95% CI 475-648; Figure 4.3).

Table 4.2 Sex and age classification of two Stone's sheep populations enumerated during December 2006 and March 2007. Census was limited to alpine areas (≥1,400 m elevation); sheep sighted at lower elevations (<1,400 m) were located incidentally or found by telemetry of collared sheep.

Census	Total	Male >1 yr Classification						Female >1 yr	Yearling	Lamb	Unclassed
		I	II	III	IV	Unclassed	Total				
SENTINEL											
December											
≥1400 m	370	20	31	47	11	2	111	131	27	87	14
<1400 m	73	1	6	9	1	0	17	27	3	19	7
Subtotal	443	21	37	56	12	2	128	158	30	106	21
March											
≥1400 m	362	18	27	55	9	1	110	134	23	87	8
<1400 m	104	4	9	22	4	2	41	31	10	19	3
Subtotal	466	22	36	77	13	3	151	165	33	106	11
STONE											
December											
≥1400 m	355	14	29	52	6	0	101	133	15	97	9
<1400 m	141	9	15	14	1	0	39	48	9	35	10
Subtotal	496	23	44	66	7	0	140	181	24	132	19
March											
≥1400 m	257	15	19	14	6	4	58	120	16	60	3
<1400 m	152	13	11	14	3	0	41	64	5	34	8
Subtotal	409	28	30	28	9	4	99	184	21	94	11
TOTAL											
December	939	44	81	122	19	2	268	339	54	238	40
March	875	50	66	105	22	7	250	349	54	200	22

Table 4.3 Mark-resight parameters for collared females in two Stone's sheep populations enumerated during December 2006 and March 2007. Census was limited to alpine areas (≥1,400 m elevation); sheep sighted at lower elevations (<1,400 m) were located incidentally or found by telemetry of collared sheep.

Census	Total collared	No. of collars in census area (% of total)	Collars detected (% in census area)	Unmarked females sighted in census area	IEJHE[1] estimate for total number of females (95% CI)
SENTINEL					
December	32	24 (75.0)	21 (87.5)	110	224
March	32	29 (90.6)	17 (58.6)	117	(190 – 279)
STONE					
December	45	39 (86.7)	31 (79.5)	102	202
March	42	27 (64.3)	23 (85.2)	97	(176 – 240)

[1]Joint hypergeometric maximum likelihood estimator with an extension to account for immigration and/or emigration (IEJHE) of sheep to/from the census area.

Table 4.4 Ratios of yearlings, lambs, males, and unclassified sheep to adult females observed in two Stone's sheep populations enumerated during December 2006 and March 2007 censuses.

Census	Male >1 yr Classification						Yearlings	Lambs	Unclassed
	I	II	III	IV	Unclassed	Total			
SENTINEL									
December	0.13	0.23	0.35	0.08	0.01	0.81	0.19	0.67	0.13
March	0.13	0.22	0.47	0.08	0.02	0.92	0.20	0.64	0.10
STONE									
December	0.13	0.24	0.36	0.04	0	0.77	0.13	0.73	0.07
March	0.15	0.16	0.15	0.05	0.02	0.54	0.11	0.51	0.06
TOTAL									
December	0.13	0.24	0.36	0.06	0.01	0.79	0.16	0.70	0.12
March	0.14	0.19	0.30	0.06	0.02	0.72	0.15	0.58	0.06

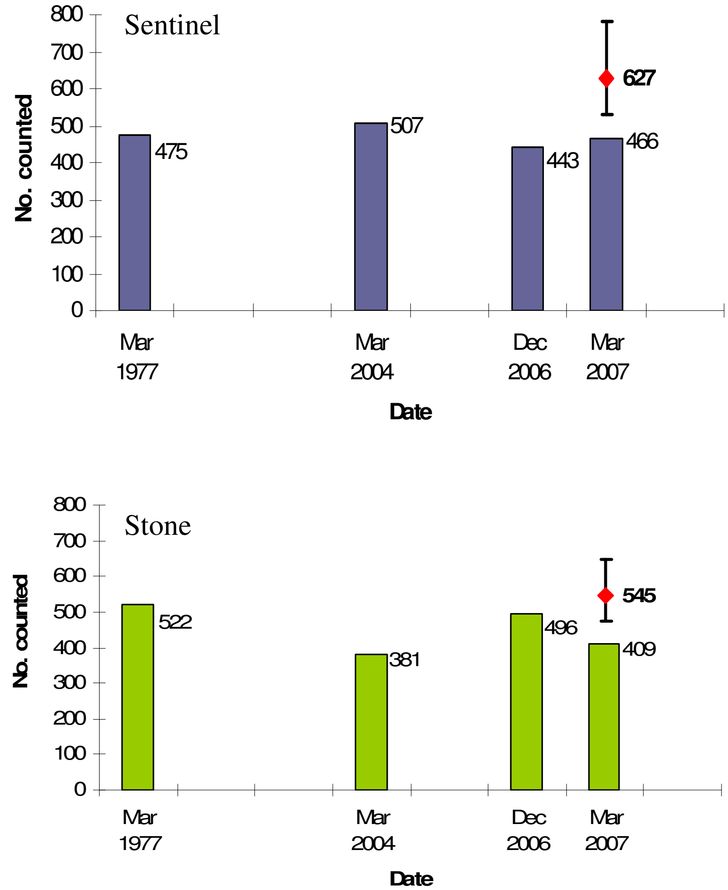

Figure 4.3 Winter 2006/2007 population estimates (red diamonds) with 95% confidence intervals, based on detection of collared females and the total number of Stone's sheep observed in December 2006 and March 2007 censuses. March 1977 and 2004 census counts are from inventories conducted without the benefit of marked sheep for population estimation (MWLAP 2004).

Estimates of lamb survival

Pregnancy rates were estimated at 88% in both Sentinel and Stone populations in March 2006 (Chapter 3). Assuming all pregnant females carried lambs to full term and resulted in successful births, we observed an average 79% survival rate to 6 months (December 2006) and 65% survival to 9 months (March 2007). Lamb survival to 6 months was similar between Sentinel and Stone populations but differed between populations in March (Table 4.5).

Lamb to female ratios were similar between collared and uncollared females. We calculated lamb to collared female ratios of 0.70 in December and 0.60 in March, using observation data from all elevations and both populations. Ratios of lambs to uncollared females were 0.72 in December and 0.61 in March respectively.

Table 4.5 Stone's sheep lamb survival to 6 and 9 months of age estimated from March 2006 pregnancy rates and observed lamb to female ratios for the Sentinel and Stone populations in December 2006 and March 2007.

Date	Recruitment parameters	Sentinel	Stone
March 2006 captures	Pregnancy rate	0.89	0.88
December 2006 census	Lamb to adult female ratio	0.67	0.73
	Lamb survival to 6 mths	0.75	0.83
March 2007 census	Lamb to adult female ratio	0.64	0.51
	Lamb survival to 9 mths	0.72	0.58
December 2006 - Mar 2007	Overwinter lamb survival	0.96	0.70

Group size, composition, and density

Large-scale distribution of groups did not appear to vary notably between censuses; sheep were found within the same general areas from survey to survey. (Figure 4.4) However, we observed a 21% decline (n = 44) in the number of males sighted in census polygons between December and March (Table 4.2). This decrease was most evident with respect to class II and III males (approximately 3 - 6 yrs old) in the Stone population, with 59% (n = 48) fewer observed above treeline in March compared to December (Table 4.2, Figure 4.5).

Mean group size within census polygons varied between censuses, with larger but fewer groups observed in March (Table 4.6). Mean group size was larger in the Stone population than the Sentinel population in March ($F_{1, 113} = 5.27$, $P = 0.024$), but did not differ between populations in December. Group composition was similar with only mixed and nursery groups changing notably from December to March (Table 4.6). In both December and March, 80% of all groups located at <1,400 m elevation were within 200 m of census polygon boundaries.

Stone's sheep density within the census polygons was similar between censuses in the Sentinel population but differed in the Stone population between December and March. The Sentinel population density was 0.64 sheep/km^2 in December and 0.62 sheep/km^2 in March. Stone's sheep density in the Stone population was 1.38 sheep/km^2 and 1.00 sheep/km^2 respectively. Mean sheep density within all census polygons was 1.01 ± 0.37 sheep/km^2 in December and 0.81 ± 0.19 sheep/km^2 in March.

Population density estimates were derived from total counts across the Stone and Sentinel portions of the study area, and therefore do not reflect the patchy distribution of sheep. Specific sites can have much higher densities. One isolated 3.5 km^2 subalpine ridge along upper Ram Cr in the Stone Range supported roughly 20% (83 of 409 sheep counted in March) of the Stone population in winter, suggesting winter range density of 24 sheep/km^2. We did not find the same level of concentration on distinct ranges anywhere else in the study area. Densities on winter ranges at the Ram Mountain complex in the S8M PTP High Elevation Zone and the 115 Cr headwaters were roughly 3.5 - 4 sheep/km^2. In the Sentinel Range, the highest winter densities were 1.5 - 1.7 sheep/ km^2, on the Ewe Mountain - Mount McLearn complex and adjacent Fire Mountain (local name, between upper 8 Mile Cr and upper Sulphur Cr).

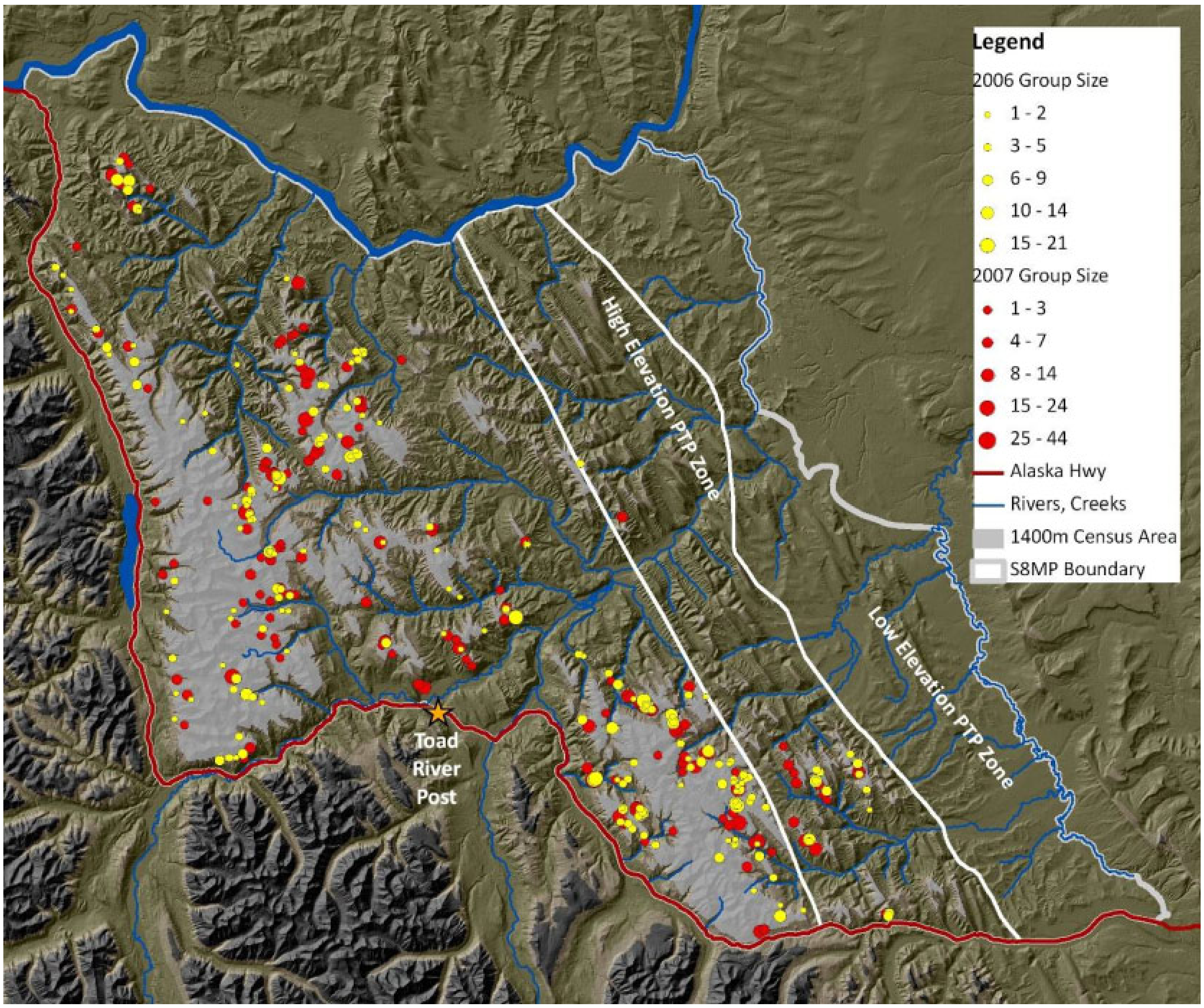

Figure 4.4 Distribution of Stone's sheep observed during December 2006 and March 2007 censuses.

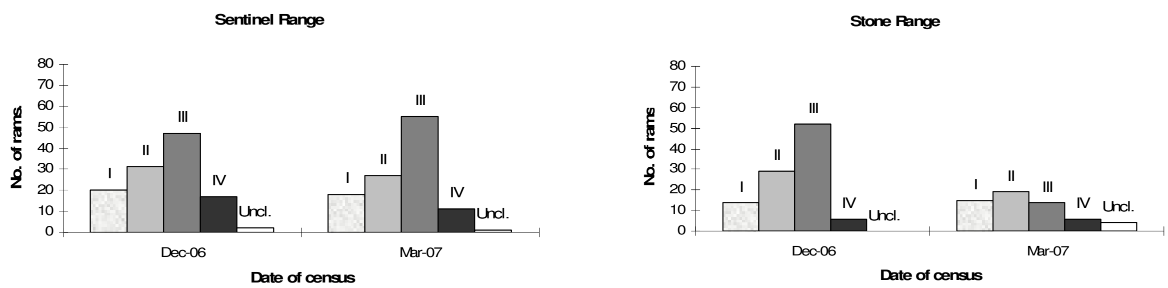

Figure 4.5 Number and age class distribution of male Stone's sheep enumerated within census polygons (≥1,400 m) during December 2006 and March 2007 in the Sentinel and Stone populations.

Table 4.6 Group size and group composition of Stone's sheep enumerated within census polygons (≥1,400 m elevation) during December 2006 and March 2007.

Census	# groups (n)	Mean group size (±SE)	Female only	Mixed[1]	Nursery[2]	Male only	Unclassified
SENTINEL							
December	93	3.98 ± 0.34	0.03	0.41	0.30	0.24	0.02
March	78	4.64 ± 0.53	0.06	0.36	0.29	0.24	0.04
STONE							
December	71	5.00 ± 0.47	0.04	0.54	0.21	0.21	0
March	36	7.14 ± 1.12	0.05	0.28	0.44	0.22	0
TOTAL							
December	164	4.42 ± 0.28	0.04	0.46	0.26	0.23	0.01
March	114	5.43 ± 0.52	0.06	0.33	0.34	0.23	0.03

[1] Mixed groups included females with lambs, yearlings, class I males and at least one male class II or older.
[2] Nursery groups included females with lambs, yearlings and class I males

Habitat associations

Only mean elevation of sheep differed between populations in December ($F_{1, 163} = 7.40$, $P = 0.007$, Table 4.7). Mean slope ($F_{1, 113} = 6.79$, $P = 0.01$) and elevation ($F_{1, 113} = 10.06$, $P = 0.002$) differed between populations in March.

Table 4.7 Mean slope, aspect, and elevation of Stone's sheep groups observed in December 2006 and March 2007.

Census	Slope (degrees)	Aspect (degrees)	Elevation (m asl)
SENTINEL			
December	32 ± 1.0	189 ± 10.9	1617 ± 9.5
March	32 ± 1.0	196 ± 10.8	1620 ± 15.8
STONE			
December	31 ± 1.2	175 ± 13.3	1566 ± 12.3
March	36 ± 1.5	203 ± 9.6	1536 ± 18.1

Other ungulates and predator observations

Several other ungulate species were sighted during both censuses (Tables 4.8 and 4.9, Figures 4.6 - 4.9). Density of other ungulates sighted within census polygons decreased from December to March except for caribou and deer (Table 4.8). Two wolves (*Canis lupus*) were sighted in Sentinel Range census polygons in December. One snowy owl (*Nyctea scandiaca*) and 16 unidentified eagles, likely golden eagles (*Aquila chrysaetos*) due to size and wingspan, were observed in flight in March.

Table 4.8 Number of other ungulates sighted in Stone's sheep census polygons during December 2006 and March 2007. Density values within census polygons (≥1,400 m elevation) are shown in brackets and expressed per km^2.

Census	Moose	Elk	Goat	Caribou	Deer
SENTINEL					
December	20 (0.03)	6 (0.01)	18 (0.03)	39 (0.07)	2 (0)
March	6 (0.01)	7 (0.01)	7 (0.01)	115 (0.20)	8 (0.01)
STONE					
December	45 (0.18)	16 (0.06)	13 (0.05)	28 (0.11)	0
March	14 (0.05)	9 (0.04)	16 (0.06)	20 (0.08)	2 (0)
TOTAL					
December	65 (0.08)	22 (0.03)	31 (0.04)	67 (0.08)	2 (0)
March	20 (0.02)	16 (0.02)	23 (0.03)	135 (0.16)	10 (0.01)

Table 4.9 Number of other ungulates observed incidentally in the study area (all elevations) during the December 2006 and March 2007 Stone's sheep censuses.

Census	Moose	Elk	Goat	Caribou	Deer
SENTINEL					
December	60	53	30	51	8
March	32	16	35	177	16
STONE					
December	93	95	20	28	0
March	33	61	32	20	2
TOTAL					
December	153	148	50	79	8
March	65	77	67	197	18

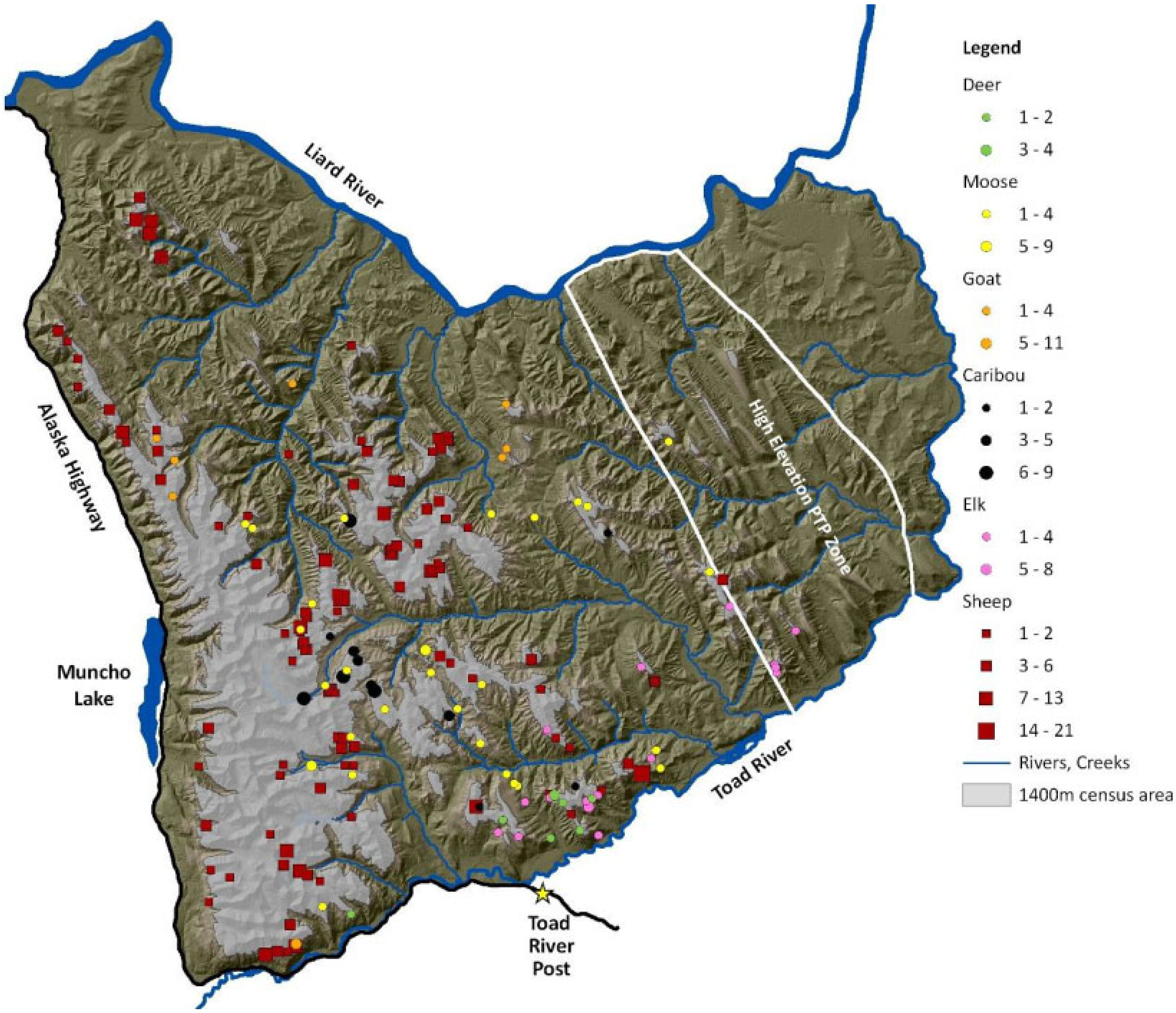

Figure 4.6 Distribution and group size of Stone's sheep and other ungulates observed during December 2006 census of the Sentinel Range.

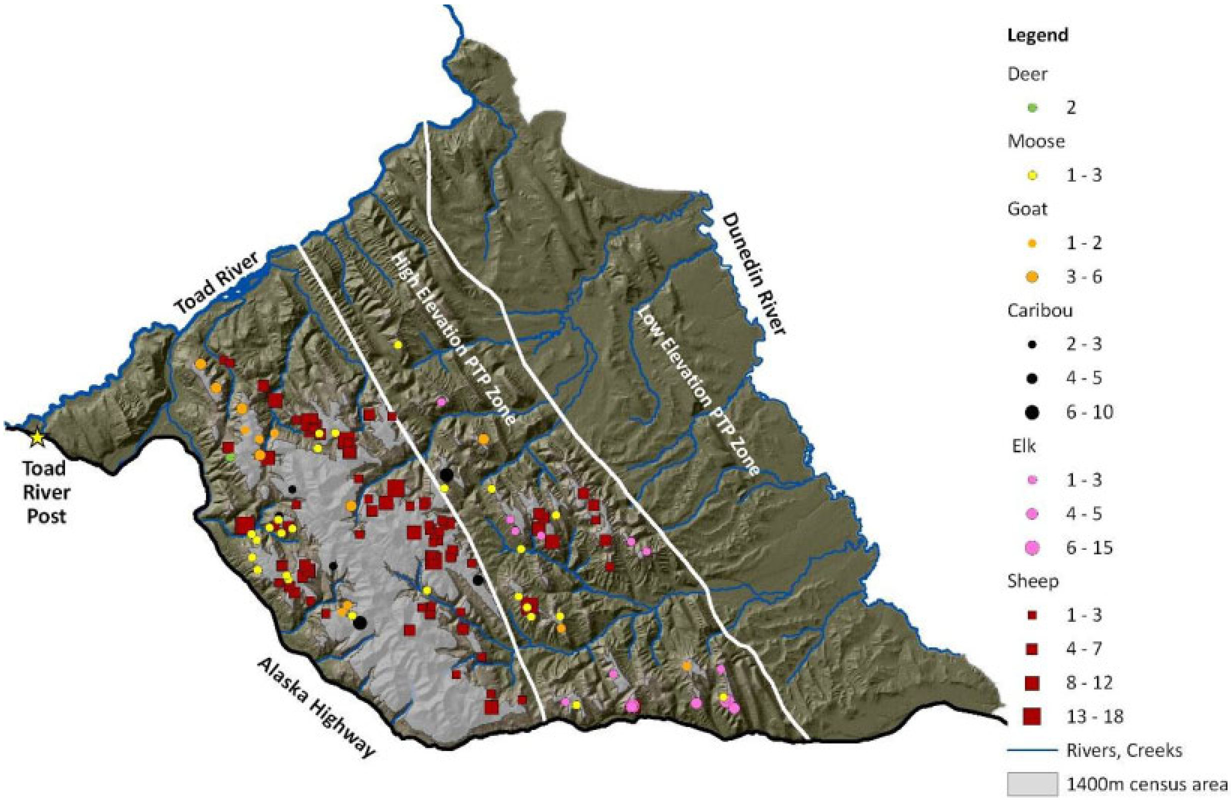

Figure 4.7 Distribution and group size of Stone's sheep and other ungulates observed during December 2006 census of the Stone Range.

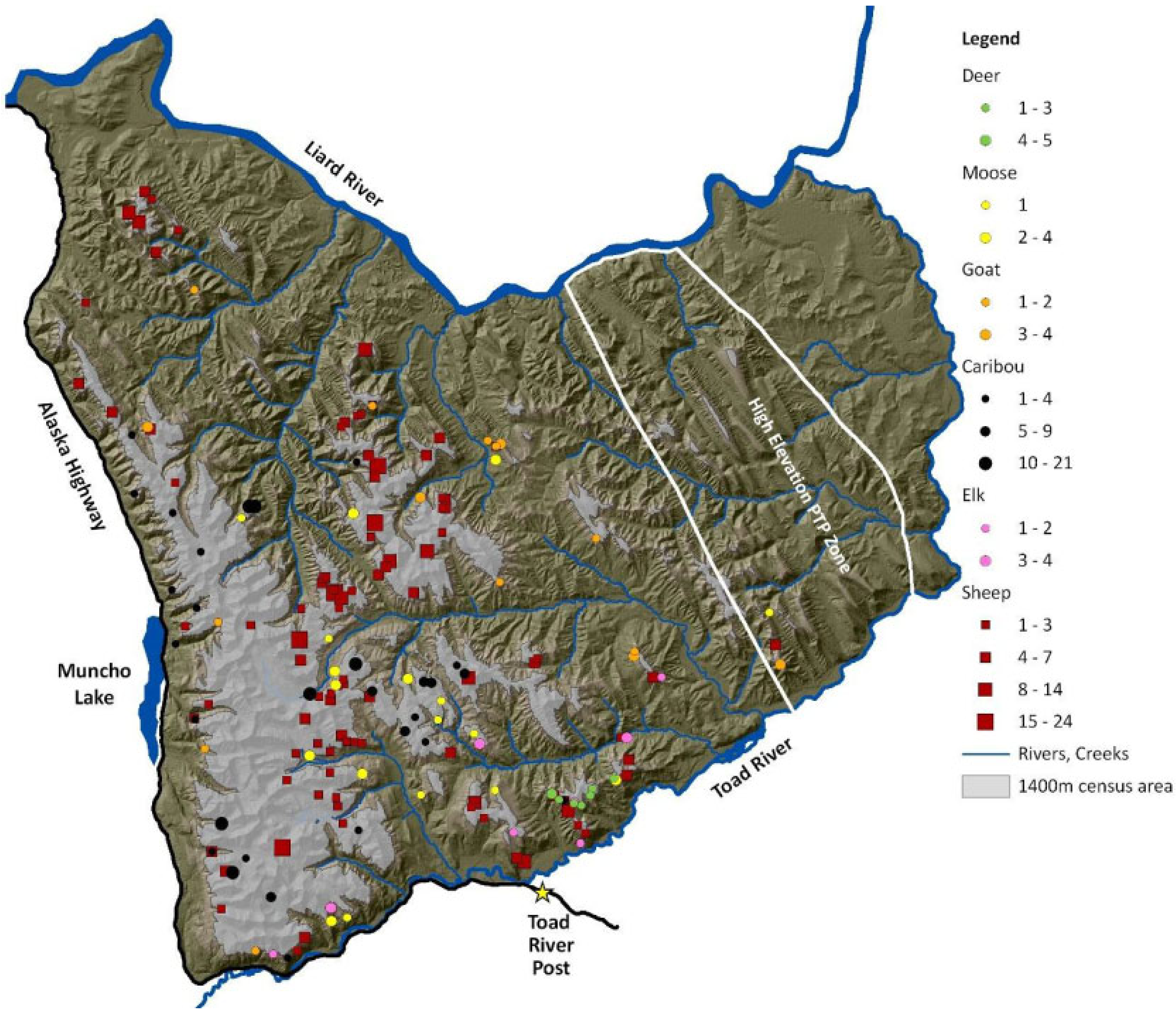

Figure 4.8 Distribution and group size of Stone's sheep and other ungulates observed during March 2007 census of Sentinel ranges.

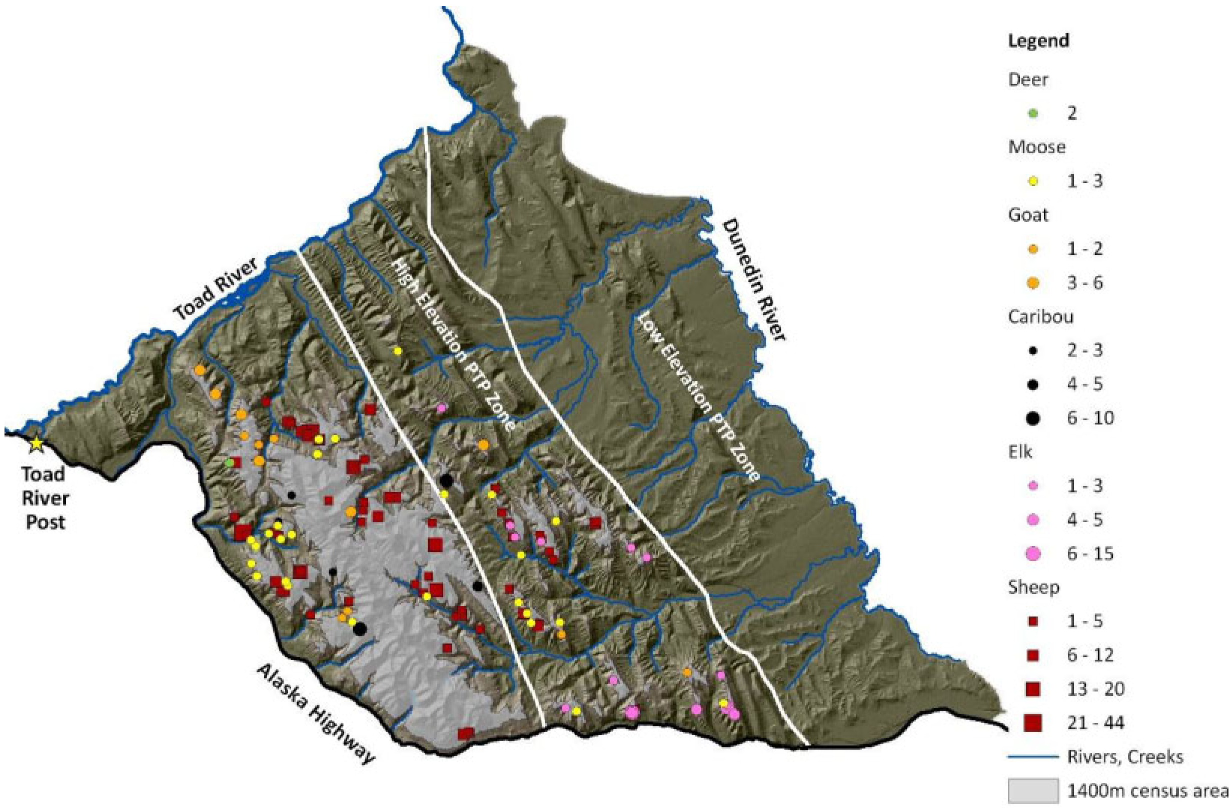

Figure 4.9 Distribution and group size of Stone's sheep and other ungulates observed during March 2007 census of Stone ranges.

DISCUSSION

Conducting two mark-resight population censuses in a single winter provided an opportunity to establish a population estimate with a reasonable level of confidence, and to assess the implications of rut (December) and late winter (March) census timing for population estimation. There were approximately 1200 sheep (minimum 939) in the S8MP area in winter 2006/2007. Our confidence intervals for the winter 2006/2007 population estimate overlap the counts obtained in 1977 and 2004 (MWLAP 2004). The minimum number observed in the S8MP represents 17.9 % of 5,244 total sheep counted in multiple inventories across the Peace region in 2007 - 2009 (Thiessen 2009).

The age-sex structure was also comparable to previous census results. Data summaries presented by AXYS (2005) indicate that MWLAP's March 2004 classification included 419 (47%) females and class I males, 149 (17%) lambs, 80 (9%) yearlings, and 240 (27%) males. They reported 0.36 lambs per female ('females' included yearling and Class I males) and 0.57 males per female. Our March 2007 classification of 875 sheep included 399 (46%) females and class I males, 200 (23%) lambs, 54 (6%) yearlings, and 193 (22%) males observed in the project area (all elevations), for both populations combined.

The general distribution of sheep observed in December 2006 and March 2007 did not change across the study area. With the exception of an expected decline in lamb to female ratios and unexpected decline in the number of young males in the Stone population, our age and sex classifications were also consistent between the December and March censuses. This supports our assumption of geographic closure of wintering herds within the project area (i.e., sheep that rut in the study area also winter in the study area), and indicates good repeatability with respect to our census results.

Typically, aerial surveys of mountain sheep attempt to completely cover an acceptable number of survey units or strata and strive to enumerate every sheep in these strata (Bodie *et al.* 1995; Neal *et al.* 1993; Udevitz *et al.* 2006). Our survey effort is similar to helicopter surveys of mountain sheep in Colorado (2.60 min/km^2) and mountain goats in northern BC, which occupy similar habitats to sheep (3.80 min/km^2; 3.1 min/km^2) (Hengeveld 2004; Neal *et al.* 1993; Poole *et al.* 2001). Survey effort reported from thinhorn sheep inventories in Alaska ranged from 0.30-1.34 min/km^2 using fixed-wing aircraft (Strickland *et al.* 1994; Udevitz *et al.* 2006). However, the detection rates reported were lower in all but one inventory cited than the means of both of our inventories.

It has been suggested that detection of mountain sheep can be influenced by group size and composition, activity, habitat, weather, and the relative location of the animal to the aircraft in complex topography (Bodie *et al.* 1995; Strickland *et al.* 1994). We agree that larger group size increases detection (Eberhardt *et al.* 1998; Udevitz *et al.* 2006) but only to a degree, as large groups (>20 sheep) were more difficult to enumerate and class than smaller groups and marks can easily be missed. Photos helped to get accurate counts. We contend detection was considerably reduced in the Sentinel population in March as sheep appeared to elicit a flight response to the helicopter less often in March than in December. Sentinel sheep were dispersed within expansive, rugged alpine that enabled sheep to retreat for cover against the rocks and remain relatively motionless, lowering their detection to observers.

Our assumption that there was an equivalent probability of sighting all marked and unmarked individuals was likely a source of error. Given the gregarious nature of sheep, their tendency to site fidelity, the presence of more than one marked sheep in some groups, and that group characteristics can affect detection probabilities, it may be argued that mark-resight calculations should be based on the number of marked groups observed, rather than the number of marked individuals. Based on these assertions, we calculated detection of marked females both as an individual and by groups during analyses. Our findings agree with those of Neal *et al.* (1993) that population estimates that use groups for calculations rather than individuals results in an overestimation of the target population, especially if the population is large. As well, a decrease in confidence due to the reduced number of marks available for mark-resight correction emerges when calculating population estimates using marked groups rather than on marked individuals.

Udevitz *et al*. (2006) reported a high mean detection rate (88%) of collars and stated that confidence in annual population estimates increased due to the number of marked sheep sighted and not due to refining estimates of detection probabilities. In some instances, marked females in the S8M area were not sighted in the open alpine during the surveys and were subsequently located outside of census polygons using telemetry, often using tree canopy near the polygon boundaries for refuge. However, due to the relatively large sample size and using proportions of sighted marks over both surveys, the reduction in precision of the estimate is likely small (Neal et al. 1993).

The estimated pregnancy rate of 88% suggests good population productivity as pregnancy rates of 75 to 100% are considered typical for thinhorn sheep (Hoefs and Bayer 1983; Nichols and Bunnell 1999). Lamb to female ratios reported for thinhorn and bighorn mountain sheep range from 0.08-0.82 (Corbould 2001; Douglas and Leslie 1986; Harper 1984; Hass 1989; MoE 1985; Nichols 1978; Walker *et al.* 2006; Wehausen *et al.* 1987; Wood 2002). Our data suggest favourable recruitment in both populations within the S8MP area as our ratios tend toward the upper range of these values. Studies of Stone's sheep in northern BC reported spring-summer lamb to female ratios of 0.82 (Walker et al. 2006) and late winter ratios of 0.27 (Wood 2002) and 0.30 (Corbould 2001). Demarchi and Hartwig (2004) note that summer lamb to female ratios of 0.30 - 0.40 are generally considered sufficient for population stability, assuming normal winter conditions. With annual survival rate >70% for adult females during this study (Chapter 6), late winter ratios of at least 35 lambs to 100 adult females will support a stable or growing population, assuming an equal sex ratio in lamb production.

Over-winter lamb survival was lower in the Stone population than in the Sentinel population. This may suggest that there are density-related limitations of optimal winter habitat at elevations ≥1,400 m. Limited optimal winter range and higher density may cause sheep to utilize habitats that may increase the chance of predation or reduce nutritional resources, increasing winter mortality (Douglas and Leslie 1986; Festa-Bianchet 1988b; Portier *et al.* 1998; Wehausen *et al.* 1987). If limitations of optimal winter range exist, this appeared more evident in the Stone population where late-winter group aggregation was more pronounced, and overall densities were approximately double that of Sentinel sheep. The increase in mean group size and corresponding decrease in the number of groups in late winter also may suggest limitations in optimal winter ranges within the project area (Shackleton et al. 1999).

Broad habitat associations were similar between populations. Differences in mean elevation may be due to the topography and elevation range between mountain ranges or snow depth as Stone's sheep may stop excavating for forage when snow depths exceed 30 cm (Seip and Bunnell 1985) or when snowpack conditions hinder forage efforts (Geist 1971). Habitat data for both December and March agree with that reported from other Stone's sheep studies where winter range typically consists of steep, south-facing cliffs (Corbould 2001; Wood 1995b) and wind-blown alpine ridges (Backmeyer 1991). Use of these areas by other ungulates varied, with moose and elk potentially significant competitors in the eastern Stone area, particularly at elevations at or near treeline, and caribou more prevalent in the Sentinel area.

Results from both censuses indicate little use of the northern half of the S8M High Elevation Zone PTP area by Stone's sheep. Only one group of 4 sheep (including a collared female translocated to the area) was observed during the December 2006 and March 2007 surveys. Both females and males are known to use ranges in the High Elevation Zone PTP area south of the Toad River. Of particular interest with respect to our analyses is that we counted similar numbers of ewes, but less than half the number of 3-6 year old (approx.) rams above treeline in this area in March compared to December. In the Sentinel range, we counted about the same number of rams in December and March. Census results for the same area in February 2009 found similar age-sex class ratios as in December 2006, suggesting significant mortality was not the reason for reduced numbers of sheep observed in March, when group size was larger (Chapter 5). This was further supported by survival rates (Chapter 6) and habitat use data (Chapter 9).

Designing a repeatable census methodology utilizing on-board, real-time flight tracking with GIS and collared females for mark-resight analyses enabled an accurate population estimate. A greater total number of sheep and a greater proportion of marked sheep observed in December indicates that population census during the end of the rut is more effective for population estimation than late winter census, especially if the marked sample population is sex-biased.

PART III POPULATION DYNAMICS

CHAPTER 5 Comparison of population estimators, detection rates of male and female Stone's sheep, and ungulate densities in the Stone Range, February 2009

Cubberley, J.C and P.E. Hengeveld. 2011. Comparison of population estimators, detection rates of male and female Stone's sheep, and ungulate densities in the Stone Range, February 2009. Pages 48-61 *in* Stone's sheep population dynamics and habitat use in the Sulphur / 8 Mile oil and gas pre-tenure plan area, northern British Columbia, 2005 - 2010. Synergy Applied Ecology, Mackenzie, BC. 167 pp plus appendices.

INTRODUCTION

One of the primary objectives of the Sulphur / 8 Mile Stone's Sheep Project (S8MP) was to assess sheep population size, demographics, and stability, to inform S8M pre-tenure plan (PTP) management direction. In winter 2006/2007 censuses, we counted similar numbers of females, but about 30% fewer young males above treeline in the Stone Range in March compared to December. This suggested that males and females have different detection rates that are influenced by males using lower elevation habitats in late winter or moving to different ranges (Chapter 4). These differences in detection influence the choice of population estimators used in mark-resight analyses.

In 2008, the S8MP expanded its research program to include collared males for habitat use analyses. This offered an opportunity to repeat our population census in the Stone Range in February 2009, using mark-resight techniques to estimate population size and evaluate differences in detection rates between sexes. We used an estimator that accepts different detection rates among individuals and discuss results compared to previous estimates that assumed equal detection rates.

In winter 2006/2007 censuses, we found the highest sheep densities in the Stone Range. Ungulate distributions are most restricted in winter months and species interactions can affect density-dependent population dynamics. We examined habitat associations among demographic groups and report observations of other ungulates to evaluate potential for inter-species interactions on sheep winter ranges.

METHODS

Radiocollars for mark-resight correction

Refer to Chapter 3 for a detailed description of sheep captures and radiocollar specifications. In February 2009, 10 collared males and 36 collared females were available for mark-resight analyses in the Stone Range.

Census area delineation

The census area was limited to the S8MP Stone Range, where sufficient numbers of radiocollared males and females were available for mark-resight analyses. In Chapter 4 we reported that 80% of sheep groups located by radiotelemetry outside of alpine census polygons in winter 2006/2007 were between 1,200 m and 1,400 m elevations, and that young male sheep on high density winter ranges may be relegated to alternative habitats in deep snow winters. To test conclusions, we redrew the census area polygons created for the 2006 and 2007 censuses using Geographic Information System (GIS) software to query Digital Elevation Model (DEM) data and produce census polygons ≥1200 m (Table 5.1). The expanded polygons allowed us to include a 200 m band of moderately treed habitat as it transitions from alpine to Spruce-Willow-Birch at lower elevations (Meidinger and Pojar 1991).

Table 5.1 Total area, census area, and elevation in the Stone Range, February 2009. The S8M Pre-Tenure Plan High Elevation Zone is identified separately but included in the Stone Range total.

Study area	Census area (km^2 ≥ 1,200 m elevation)	Total area (km^2)	Elevation range (m asl)
Stone Range	504	1,777	360 - 2128
High Elevation Zone	144	559	478 - 1722

Census protocols

We repeated December 2006 and March 2007 census methods (Chapter 4). Although the focal species was Stone's sheep, all animals sighted were recorded and geo-referenced opportunistically to assess inter-specific competition of winter range with sheep. We mapped flight lines using real-time flight tracking, using a handheld computer with an integrated GPS and GIS software (ESRI 2008) that displayed the aircraft location relative to census polygons.

Data analyses

Population estimation

We used Bowden's estimator in program NOREMARK (White 1996), which incorporates the Minta-Mangel (1989) bootstrap estimator based on a Monte-Carlo simulation sampling without replacement. We made assumptions that the probability of sighting marked individuals did not change after capture, no errors were made differentiating marked and unmarked individuals, the population was geographically and demographically closed, and individuals had different probabilities of being observed. Sheep observed incidentally or by radiotelemetry outside of census polygons (<1,200 m) were included in the minimum count but censored out of analyses for mark-resight correction.

Bowden and Kufeld (1995) improved the Minta-Mangel model by log transforming the variance of resighting frequencies for marked animals to report a 95% confidence interval for the population estimate. This test requires resampling due to the assumption of heterogeneity in detection probabilities. To accommodate this, we resurveyed one polygon that was used by approximately 15% of sheep sighted, typified sheep habitat characteristics, and contained at least 3 marked males and females. This was done after the census was completed, and only detection of marks was recorded during the resighting period.

The estimated number of adult males and females was calculated separately for each sex based on their respective detection rates. The total population estimate was based on observed ratios of age-sex classes to adult males and females.

Group size, composition, and density

Sheep groups were classified as male only, female only, mixed, or nursery groups. Nursery groups were composed of females with lambs, yearlings and class I males while mixed groups contained at least one class II or older male. Population density calculations were derived based on the number of individuals sighted within the total area of ≥1,200 m census polygons. To facilitate future monitoring efforts, we also report density of sheep within the S8M PTP High Elevation Zone.

Habitat associations

We examined habitat associations among groups as potential factors that may influence detection probabilities and inter-specific interactions using freely available GIS models (http://www.geobase.ca/geobase/en/index.html) and utilities (http://arcscripts.esri.com/). A 25 m resolution Digital Elevation Model (DEM) raster coverage of the project area provided the base data for analyses. Slope, aspect and elevation of sheep groups were obtained by querying animal locations plotted on the DEM coverage. Aspect values were categorized into 4 cardinal directions (Table 5.2).

Table 5.2 Aspect values categorized according to the 4 main cardinal directions.

Aspect	Criteria (degrees)
North	> 315 or ≤ 45
East	> 45 and ≤ 135
South	> 135 and ≤ 225
West	> 225 and ≤ 315

We created a Vector Ruggedness Measure (VRM) raster coverage using a 3 by 3 moving window (Sappington et al. 2007) to further explore the effects of landscape complexity on group detection. VRM quantifies the landscape heterogeneity of rugged, mountainous terrain independently of slope. Model values range from 0 (least rugged) to 1 (most rugged). We also categorized the study area into 6 discrete slope positions at a scale relevant to ungulates by employing a circular sample neighborhood with a radius of 80 pixels (Jenness 2006). Slope position categories are independent of elevation but relative to the scale of surrounding landscape, based on neighborhood extent values relevant to mountain sheep. Slope position values were categorized as: Ridge, Upper slope, Middle slope, Flat, Lower slope, and Valley.

We conducted analysis of variance using Tukey's HSD to determine differences in elevation and slope among groups. A non-parametric Kruskal-Wallis Rank Sum Test was used to evaluate VRM among groups. Post-hoc analyses employed a Mann-Whitney Test with Bonferroni correction.

Due to the small size of our contingency tables and because we used unordered nominal categorical variables for our row and column classifications, we selected a 2-sided Fisher's Exact Test (FET) to evaluate proportional differences in slope position and aspect selection between groups (Cox and Plackett 1980; Mehta and Patel 1997). To achieve acceptable accuracy for our *P*-value estimate, we resampled our tables using a Monte Carlo approach with 10,000 repetitions (Agresti 1992). FET was also employed to test for heterogeneity of detection probabilities between marked male and female Stone's sheep (Skalski *et al.* 2005). We used R statistical software for data analyses (http://www.R-project.org). Mean values are reported ± Standard Error (SE). All tests of significance were measured against the 95% confidence interval ($\alpha = 0.05$).

RESULTS

Survey conditions

The population census was conducted February 19 - 23 2009. Weather conditions did not negatively influence the census except for February 21 which brought moderate snowfall that prevented flying due to limited visibility. Flight lines minimized the risk of double-counting when the census was resumed (Figure 5.1). Survey effort was 3.80 min/km^2.

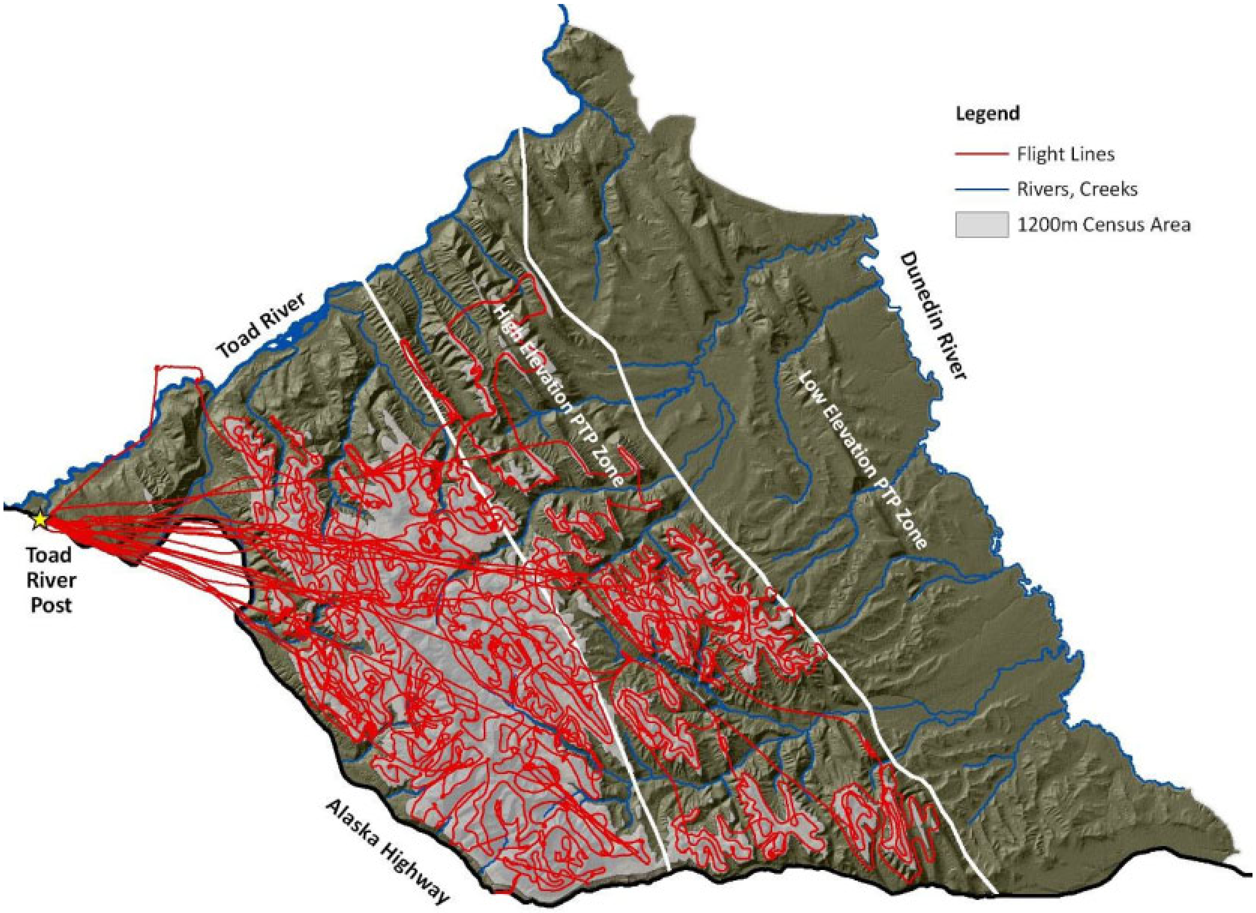

Figure 5.1 Census flight lines in the Stone ranges, February 2009.

Stone's sheep demography

Population estimates, age structure, and sex ratios

We enumerated 430 sheep (Table 5.3). Eighty (94%) of 85 sheep groups were sighted within census polygons. Both male and female sheep were occupying winter ranges in the southern half of the S8M PTP High Elevation Zone, south of the Toad River (Figure 5.2).

Detection rates differed between sexes ($P = 0.002$, two-sided FET). Mark-resight correction was 1.12 for males and 1.26 for females. Marked males were distributed among 5 groups. Mean age of collared male sheep was 7.2 ± 0.6 yr (range 4 - 10 yr) estimated from horn annuli. Collared males not detected ranged in age from 3 - 6 yr.

The population estimate for male sheep was 157 (95% confidence interval 93 - 266; Table 5.4). Based on the proportion of each age class sighted within census polygons to the estimated male population, the age class estimates were 38 Class I, 44 Class II, 68 Class III, and 7 Class IV individuals. The population estimate for females was 231 (95% CI 185 - 288; Table 5.4). Using overall ratios to females ≥2 yr of age, we estimated 85 lambs and 38 yearlings (Table 5.5). The total Stone population estimate was 511 (95% CI 409 - 637) sheep. Figure 5.3 compares male age class structure among 3 population censuses conducted in the Stone Range (Chapter 4).

Table 5.3 Sex and age classification of Stone's sheep sighted during the February 2009 census in the Stone Range. Sheep sighted within the S8M Pre-Tenure Plan High Elevation Zone are identified separately but included in the Stone Range total. The census was limited to areas ≥1,200 m elevation; sheep sighted at lower elevations were located incidentally or found by telemetry of collared sheep.

Area	Total	Male >1 yr Classification						Female >1 yr	Yearling	Lamb
		I	II	III	IV	Uncl.	Total			
STONE										
≥1200 m	411	32	38	59	6	1	136	179	29	67
<1200 m	19	3	7	2	0	0	12	5	1	1
Total	430	35	45	61	6	1	148	184	30	68
High Elevation Zone										
≥1200 m	82	4	8	17	3	0	32	31	2	17
<1200 m	0	0	0	0	0	0	0	0	0	0

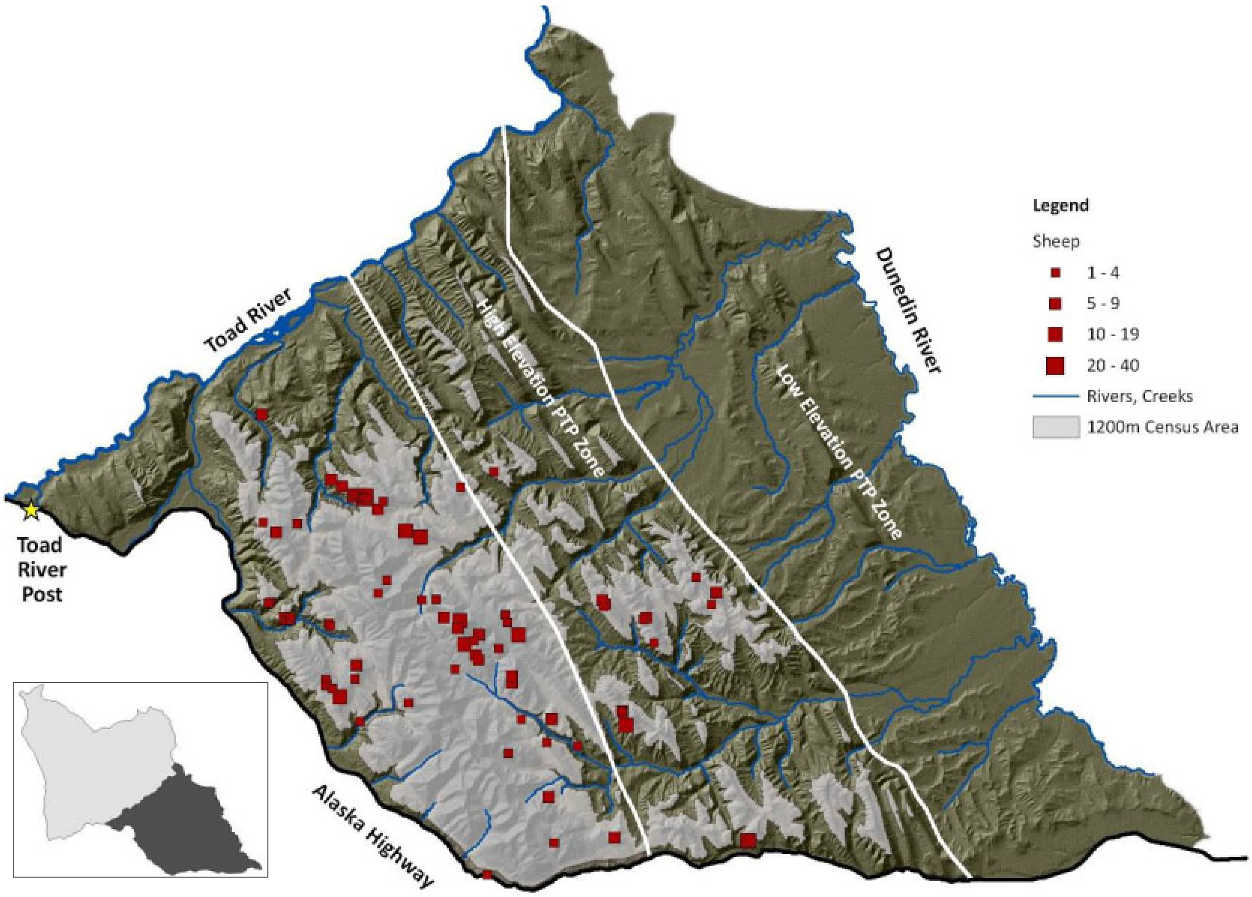

Figure 5.2 Distribution and group size of Stone's sheep observed during the February 2009 census in the Stone Range. Shaded grey areas indicate ≥1,200 m census polygons. The S8M pre-tenure plan high and low elevation zone boundaries are identified.

Table 5.4 Mark-resight parameters for radiocollared Stone's sheep during the February 2009 census in the Stone Range. The census was limited to areas ≥1,200 m elevation; sheep sighted at lower elevations were located incidentally or found by telemetry of collared sheep.

Sex	Total collars	No. of collars in census area (% of total)	Collars detected (% in census area)	Unmarked sheep sighted (all elevations)	Bowden's estimate for total number of males[1] (95% CI)
Male	10	8 (80.0)	7 (87.5)	141	157 (93 – 266)
Female	36	34 (94.4)	25 (73.5)	159	231 (185 – 288)

[1] The total number of males was estimated using Bowden's Estimator in NOREMARK software which incorporates the Minta-Mangel (1989) bootstrap estimator based on a Monte-Carlo simulation.

Table 5.5 Ratios of yearlings, lambs, adult males, and unclassified Stone's sheep to adult females (>1 yr old) enumerated during the February 2009 census in the Stone Range. Sheep sighted within the S8M Pre-Tenure Plan High Elevation Zone are identified separately but included in the Stone Range total.

Study area	Male > 1 yr Classification						Yearling	Lamb
	I	II	III	IV	Unclassed	Total		
Stone	0.19	0.24	0.33	0.03	0.005	0.80	0.16	0.37
High Elevation Zone	0.13	0.26	0.55	0.10	0	1.04	0.06	0.55

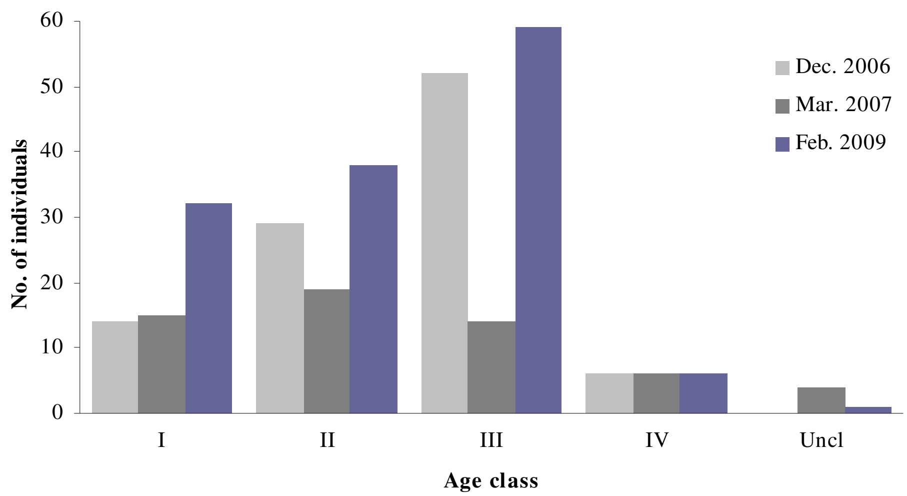

Figure 5.3 Age class distribution of male Stone's sheep enumerated within census polygons in the Stone Range during three population censuses between 2006 and 2009. Census area in 2006 and 2007 was ≥1,400 m elevation; census area in 2009 was ≥1,200 m.

Group size, composition and density

Mixed groups were larger than other groups ($F_{3, 76}$ = 13.73, $P < 0.001$; Table 5.6). The density of sheep sighted in census polygons (≥1,200 m) was 0.82 sheep/km^2 and over the entire Stone Range was 0.24 sheep/km^2. Density of sheep within census polygons in the S8M PTP High Elevation Zone was 0.57 sheep/km^2.

One isolated 3.5 km^2 subalpine ridge along upper Ram Creek in the Stone Range supported roughly 20% (87 of 430 sheep counted) of the Stone population in winter, suggesting maximum site-specific winter range density of 25 sheep/km^2.

Table 5.6 Group size and group composition of Stone's sheep enumerated within census polygons (≥1,200 m) during the February 2009 census in the Stone Range. Nursery groups were defined as females with lambs, yearlings and Class I males while mixed groups contained at least one Class II or older male.

Group	No. of groups (% of total)	Mean group size (±SE)
Female only	11 (14%)	2.36 ± 0.43
Male only	24 (30%)	2.71 ± 0.32
Nursery	27 (34%)	4.70 ± 0.53
Mixed	18 (22%)	10.72 ± 1.97
Total	80	5.14 ± 0.60

Sheep habitat associations

Elevation of all sheep groups (n = 85) ranged from 1,017 – 2,098 m above sea level; 92% of males and 97% of females were above 1,200 m elevation. We found no difference among groups within census polygons (n = 80) for elevation ($F_{3, 76}$ = 1.15, *P* = 0.332, Table 5.7), slope ($F_{3, 76}$ = 0.18, *P* = 0.915, Table 5.7), VRM (χ^2 = 2.45, *P* = 0.485, Table 5.7), slope position (2-sided FET, *P* = 0.269, Table 5.8), or aspect (2-sided FET, *P* = 0.237, Table 5.9). Rock outcrops located mid-slope were utilized by sheep but groups were associated most often with higher slope position. Thirteen percent of male groups were sighted in valleys (Table 5.8). These male groups comprised younger, Class II and III, males exclusively. Generally, groups favored south and west facing slopes, but mixed and male only groups were sighted utilizing all aspects (Table 9). All Class IV males occupied high elevation (>1,500 m), upper slope positions with less rugged, moderate slopes and south and westerly aspects.

Table 5.7 Mean and range of elevation, slope, and vector ruggedness measure (VRM) values for 80 Stone's sheep groups enumerated within census polygons (≥1,200 m) during the February 2009 census in the Stone Range.

Group	Elevation m ± SE	(min -max)	Slope degrees ± SE	(min - max)	VRM ± SE	(min - max)
Female	1532 ± 68.82	(1229 - 2000)	32 ± 3.35	(11 - 50)	0.0070 ± 0.0026	(0.0006 - 0.0304)
Male	1475 ± 31.27	(1217 - 1842)	31 ± 2.29	(4 - 46)	0.0095 ± 0.0019	(0.0001 - 0.0339)
Nursery	1549 ± 33.29	(1248 - 1838)	32 ± 2.37	(5 - 56)	0.0120 ± 0.0030	(0 - 0.0804)
Mixed	1576 ± 50.68	(1261 - 2098)	30 ± 2.76	(8 - 46)	0.0094 ± 0.0033	(0.0002 - 0.0604)

Table 5.8 Slope position of 80 Stone's sheep groups enumerated within census polygons (≥1,200 m) during the February 2009 census in the Stone Range. Relative use (%) of slope position by each group is bound by parentheses.

Group	Ridge	Upper slope	Middle slope	Flat	Lower slope	Valley
Female only	5 (46%)	2 (18%)	3 (27%)	0	1 (9%)	0
Male only	11 (45%)	4 (17%)	6 (25%)	0	0	3 (13%)
Nursery	10 (37%)	6 (22%)	10 (37%)	0	1 (4%)	0
Mixed	12 (67%)	5 (28%)	1 (5%)	0	0	0

Table 5.9 Aspect of 80 Stone's sheep groups enumerated within census polygons (≥1,200 m) during the February 2009 census in the Stone Range. Relative use (%) of aspect by each group is bound by parentheses.

Group	North	South	East	West
Female only	0	8 (73%)	0	3 (27%)
Male only	5 (21%)	8 (33%)	2 (8%)	9 (38%)
Nursery	2 (7%)	18 (67%)	0	7 (26%)
Mixed	2 (11%)	8 (45%)	2 (11%)	6 (33%)

Inter-specific habitat associations

We enumerated 332 other ungulates during the census, including; moose, elk, goat, caribou, and deer (Figure 5.4, Table 5.10). Moose and elk comprised 68% of all other ungulates observed. Moose were the most abundant ungulate within the S8M PTP High Elevation Zone, but elk were more common than moose on ranges ≥ 1,200 m elevation (Table 5.10). No carnivores were observed during the census.

Elevation

- We found differences in elevation among ungulates ($F_{7,\ 200} = 25.56$, $P < 0.0001$, Tables 5.7 and 5.11).
- Moose ($P < 0.0001$) and elk ($P \leq 0.002$) elevation was lower than all 4 sheep group classifications.
- Mountain goat ($P \geq 0.792$) and caribou ($P \geq 0.856$) elevation did not differ from any sheep group.

Slope

- We found differences in slope occupied by some ungulates ($F_{7, 200} = 4.95$, $P < 0.0001$, Tables 5.7 and 5.11).
- Moose used similar slopes as female ($P = 0.188$), male ($P = 0.074$), and mixed ($P = 0.291$) groups, but used less steep slopes than nursery ($P = 0.006$) groups.
- Elk ($P \geq 0.997$), goat ($P \geq 0.873$), and caribou ($P \geq 0.088$) used similar slopes as all 4 sheep groups.

Ruggedness

- We found no difference in VRM among ungulates ($F_{7, 200} = 0.314$, $P = 0.947$, Table 5.11).

Slope position

- Moose were observed at lower slope positions than all sheep ($P \leq 0.033$, two-sided FET, Tables 5.8 and 5.12) groups.
- Elk were associated with higher slope positions used by female ($P = 0.596$, two-sided FET), male ($P = 0.359$, two-sided FET), and nursery ($P = 1$, two-sided FET) groups, but used middle slope positions more than mixed groups ($P = 0.042$, two-sided FET).
- Goats were associated with upper slope positions used by all sheep ($P \geq 0.101$, two-sided FET) groups.
- Caribou occupied most slope positions used by female ($P = 0.773$, two-sided FET), male ($P = 0.5948$, two-sided FET), and nursery ($P = 0.177$, two-sided FET) groups, but used ridges less than mixed ($P = 0.016$, two-sided FET) groups.

Aspect

- Moose were associated with different aspects than all sheep ($P \leq 0.010$, two-sided FET) groups, favouring north and east facing slopes (Tables 5.7 and 5.13).
- Elk were observed on aspects used by mixed ($P = 0.077$, two-sided FET) groups but were less strongly associated with southerly aspects than female ($P = 0.034$, two-sided FET), male ($P < 0.011$, two-sided FET), and nursery ($P = 0.007$, two-sided FET) groups.
- Goats were observed on aspects used by female ($P = 0.138$, two-sided FET), male ($P = 0.682$, two-sided FET), and mixed ($P = 0.872$, two-sided FET) groups, but were less strongly associated with south aspects than nursery ($P = 0.036$, two-sided FET) groups.
- Caribou were associated with westerly aspects also used by male ($P = 0.701$, two-sided FET) and mixed ($P = 0.650$, two-sided FET) groups, but differed with female ($P = 0.030$, two-sided FET) and nursery ($P = 0.017$, two-sided FET) groups.

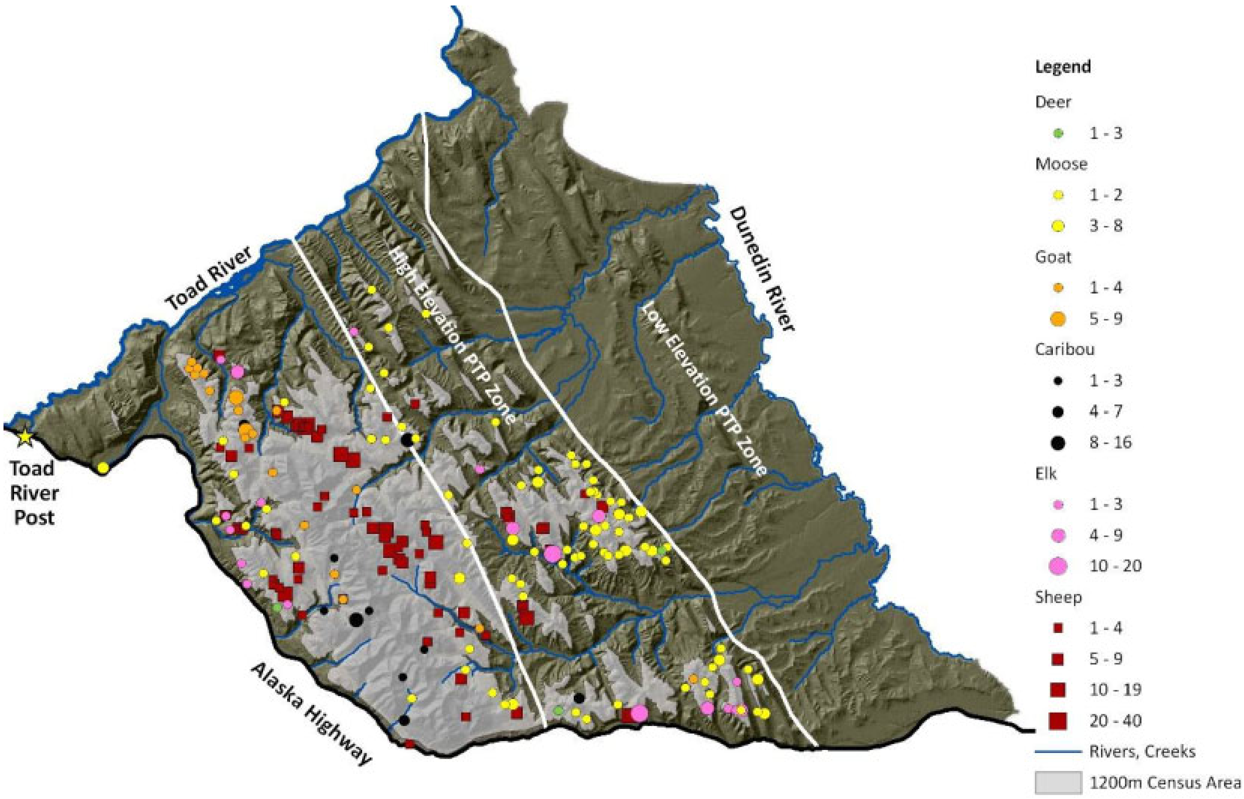

Figure 5.4 The distribution of other ungulates in relation to Stone's sheep groups sighted during the February 2009 census in the Stone Range. Shaded grey areas indicate ≥1,200 m census polygons. The S8M pre-tenure plan high and low elevation zone boundaries are identified.

Table 5.10 Number and density (animal/km^2) of other ungulates sighted incidentally at all elevations, within census polygons (≥1,200 m), and within the High Elevation Pre-Tenure Plan (HEPTP) area during the February 2009 census in the Stone Range.

Species	Total sighted	No. animals (≥1,200 m)	Density (≥1,200 m)	Total sighted HEPTP	No. animals HEPTP (≥1,200 m)	Density HEPTP (≥1,200 m)
Moose	138	54	0.11	105	32	0.22
Elk	88	79	0.16	65	64	0.44
Goat	47	46	0.09	1	1	0.01
Caribou	53	53	0.11	18	18	0.13
Deer	6	3	0.01	4	1	0.01

Table 5.11 Mean and range of elevation, slope, and vector ruggedness measure (VRM) values for 128 other ungulate groups sighted incidentally during the February 2009 census in the Stone Range.

Group	Elevation m ± SE (min -max)		Slope degrees ± SE (min - max)		VRM ± SE (min - max)	
Moose	1217 ± 15.45	(686 - 1649)	24 ± 1.04	(0 - 44)	0.0089 ± 0.0020	(0.0001 - 0.1363)
Elk	1277 ± 28.91	(998 - 1491)	30 ± 1.37	(20 - 41)	0.0089 ± 0.0033	(0.0002 - 0.058)
Goat	1494 ± 36.99	(1196 - 1805)	35 ± 1.86	(14 - 48)	0.0120 ± 0.0029	(0.0011 - 0.0486)
Caribou	1562 ± 75.21	(1243 - 2016)	22 ± 3.42	(2 - 38)	0.0058 ± 0.0016	(0.0007 - 0.0162)

Table 5.12 Slope position of 128 other ungulate groups enumerated within census polygons during the February 2009 census in the Stone Range. Relative use (%) of slope position by each group is bound by parentheses.

Group	Ridge	Upper slope	Middle slope	Flat	Lower slope	Valley
Moose	7 (9%)	13 (16%)	41 (51%)	0	15 (19%)	4 (5%)
Elk	7 (37%)	4 (21%)	8 (42%)	0	0	0
Goat	10 (53%)	2 (11%)	6 (31%)	0	1 (5%)	0
Caribou	3 (30%)	1 (10%)	3 (30%)	0	1 (10%)	2 (20%)

Table 5.13 Aspect of 128 other ungulate groups enumerated within census polygons during the February 2009 census in the Stone Range. Relative use (%) of aspect by each group is bound by parentheses.

Group	North	South	East	West
Moose	22 (28%)	11 (14%)	29 (36%)	18 (22%)
Elk	0	8 (42%)	8 (42%)	3 (16%)
Goat	3 (16%)	7 (37%)	4 (21%)	5 (26%)
Caribou	2 (20%)	2 (20%)	2 (20%)	4 (40%)

DISCUSSION

The relative agreement of Stone Range population estimates over 3 censuses suggests that census protocols are adequately reporting the demographic structure of this sheep population with an acceptable accuracy and precision. We observed a modest difference in female estimates between Bowden's estimator applied in this census and the IEJHE applied to winter 2006/2007 census results. Bowden's female estimate is greater and has a larger 95% confidence interval compared to the IEJHE. Our results found differences in detection probability between male and female sheep, which violates the underlying assumptions of the IEJHE. However, the IEJHE is a better approach for estimating large populations, such as in the S8MP area (Neal *et al.* 1993; Udevitz *et al.* 2006).

Increasing the extent of the census polygons to include the area between 1,200 and 1,400 m appears to have sufficiently captured the extent of winter ranges for most sheep regardless of sex and age class. This area included conifer at treeline that appears to be utilized by both males and females for forage, security and perhaps thermal refuge. Our results agree with those reported by Tilton and Willard (1982) with respect to male bighorn sheep. They found that young males used lower elevations in winter than nursery groups and older males. All Class IV males sighted during our 2009 census occupied alpine ridges above 1,500 m that, presumably, offer high value winter habitat.

The number of Class II and III males sighted during this census compares to December 2006 totals (Chapter 4) and suggests that younger males not sighted in March 2007 were utilizing different winter habitats. Increased snow depth in 2007 (Figure 1.3 in Introduction) likely limited forage opportunities (Seip 1983) and, combined with lower social rank (Festa-Bianchet 1991; Hogg and Forbes 1997), may have moved these individuals into lower-elevation winter habitats. This alternative forage strategy influences sheep detection rates and the objective of a census should consider the influence of snow depth on census results.

In the absence of other limiting factors, sheep populations may increase in density until declining forage availability affects body condition and reproductive rates (Festa-Bianchet *et al.* 2003; Festa-Bianchet *et al.* 1998; Jorgenson *et al.* 1997; Jorgenson *et al.* 1993a; Jorgenson *et al.* 1993b; Jorgenson *et al.* 1998; Leblanc *et al.* 2001). Interactions with other species may contribute to density-dependent responses. High densities of other ungulates on or near Stone's sheep ranges can lead to dietary competition, increased risk of opportunistic predation (Kunkel and Pletscher 2001), disease transmission (Gross *et al.* 2000; Jenkins *et al.* 2007), and increased parasitism (Kutz et al. 2001).

Moose and elk, the primary prey species of wolves and bears (Milakovic 2008), were the most abundant other ungulates observed in the S8M PTP High Elevation Zone south of the Toad River. Both moose and elk respond to human-induced habitat disturbance such as prescribed fire (Schneider and Wasel 2000) and changes in predator density (Hayes *et al.* 2003; Packer *et al.* 2003; Peterson 1999; Weaver *et al.* 1996). Adopting conservative approaches to management or resource development that may influence distribution and density of other ungulates and predators on sheep ranges should be considered.

PART III POPULATION DYNAMICS

CHAPTER 6 Survival and cause-specific mortality of adult Stone's sheep

Cubberley, J.C. and P.E. Hengeveld 2011. Survival and cause-specific mortality of adult Stone's sheep. Pages 62-78 *in* Stone's sheep population dynamics and habitat use in the Sulphur / 8 Mile oil and gas pre-tenure plan area, northern British Columbia, 2005 - 2010. Synergy Applied Ecology, Mackenzie, BC. 167 pp plus appendices.

INTRODUCTION

Mountain sheep populations are dynamic and vary over time in response to environmental and anthropogenic factors (Cassirer *et al.* 2002; Festa-Bianchet *et al.* 2003; Heimer 2002; Jorgenson *et al.* 1997). Survival rates of adult Stone's sheep have not been studied in British Columbia (BC) and potential evaluation of population trends since the 1940s has been limited to review of harvest statistics and sparse survey data (AXYS 2005; Haber 1988). Estimates of survival and cause-specific mortality are fundamental parameters for population monitoring and management. Our objective for this study was to estimate and compare annual survival of adult female Stone's sheep for two populations and for a limited number of males within the Sulphur/ 8 Mile Project (S8MP) area. As well, we examined age-specific survival, spatio-temporal patterns and cause-specific mortality.

METHODS

Survival rates

Between June 15 2005 and June 15 2009, telemetry flights were conducted 1 - 3 times monthly with rotary or fixed-wing aircraft at altitudes 7,000 - 10,000 ft asl to determine status of radiocollared sheep. Refer to Chapter 3 for a detailed description of sheep captures and radiocollar specifications. All collars were programmed to alert field crews if the collar had been motionless for a period of 4 hrs or more, suggesting possible death of the sheep or collar malfunction. Site investigations were conducted as soon as possible after deaths were detected. A final telemetry flight was conducted in June 2010 to determine the fate of all remaining collared individuals. Deaths between June 15 2009 and June 2010 contribute to annual survival estimates but were not included in analyses for cause of death.

Sheep that were shot by hunters or were killed by vehicles were excluded from analyses to calculate natural survival rates (Pollock *et al.* 1989). We grouped sheep by monitoring year, population, age, and sex. Monitoring year was defined as June 15 – June 14 to reflect Stone's sheep birth dates annually. Collared males were pooled regardless of population due to small sample sizes, as were individuals 10 yr or older. Individuals that died before the start of the first monitoring year were excluded from survival rate analyses.

We used a modified Kaplan-Meier staggered-entry method to calculate cumulative survival for each sample population over the duration of the study (Pollock et al. 1989). A non-parametric approach was preferred because sheep survival rates vary seasonally (Coulson *et al.* 2001; Festa-Bianchet 1989). Implicit in the Kaplan-Meier method are assumptions that collared sheep were representative of the total S8M population, that fates of individuals were independent, and that the time of death was accurate. The number of individuals at risk in each sample population at the beginning of each monitoring year was the remainder of the sample population after the previous year's deaths and censors were subtracted. New collars were added at the beginning of the next year. Collars that were removed or malfunctioned were right censored the year after they were last verified alive. Cumulative survival estimates were converted to annual survival by taking the i^{th} root of the cumulative survival value in the final monitoring year (in this case 5 yrs for females and 2 yrs for males), to report mean annual survival for both female populations and all males (Amstrup and Durner 1995).

We used the Mantel-Haenszel log-rank test to detect differences in survival between female populations using R software version 2.13.1. The statistic is computed by comparing the times of death of Sentinel and Stone females over the entire study interval, and allows the same assumptions as the Kaplan-Meier method.

Pearson correlation coefficients were calculated to assess the relationship between annual survival and Environment Canada climate data for average monthly temperature, total precipitation, snowfall and rainfall in winter months (November through May)[5].

Natural mortality factors

During post-mortem site investigations, we considered sheep body condition; evidence of trauma; presence of bite marks, hair, track prints, feces and other wildlife sign (Elbroch 2003); and body condition results from laboratory analyses of biological samples collected during mortality investigations. Site descriptions included signs of pursuit or struggle, habitat type, topographic location, time of year, and prevailing weather conditions at the estimated time of death. Full post-mortem exams were performed on intact carcasses. When sufficient information was available to make a conclusive determination, mortalities were classified into 3 broad categories of primary cause: snow-related; predation; and body condition. Investigations deemed inconclusive due to lack of evidence or delays visiting the mortality site were classed as unknown.

We looked for evidence of predation by wolves, coyotes, bears, wolverine, and cougar (Elbroch 2003). To distinguish predation from scavenging, we looked for evidence of subcutaneous hemorrhage, as animals dying of other causes don't bleed extensively when they are scavenged. Poor body condition

[5] http://www.climate.weatheroffice.ec.gc.ca

describes non-predation deaths due to health or environmental factors other than snow. The presence of an intact carcass, or carcass with minimal scavenging and presence of some or all of the internal organs (tissues which tend to be eaten first by predators), indicated condition-related cause of death. This included chronic health conditions related to the presence of disease, parasites, poor nutrition, emaciation, and senescence, all of which are often exacerbated by poor weather conditions, as well as acute injuries and falls from escape terrain cliffs during non-snow months. Low bone marrow fat content in intact leg bones and smaller amounts of sub-dermal fat and fat reserves surrounding vital organs indicated emaciation (Kistner *et al.* 1980; LaJeunesse and Peterson 1993; Mech and Delgiudice 1985; Neiland 1970; Peterson *et al.* 1982). Snow-related causes include death in avalanches and difficult snowpack conditions.

We analyzed seasonal timing of mortalities based on 6 seasons relevant to Stone's sheep ecology (Chapter 7). We used generalized univariate logistic regression to identify landscape factors that influence survival of adult females. Sample sizes were too small to do this for males. We tested the influence of habitat on mortality risk using 14 topographical and 10 land cover variables (Chapter 9, Appendices A and B). We compared habitat characteristics between GPS locations from collared females and sites where sheep died by predation, poor body condition, or snow-related causes. We pooled all female GPS locations (n = 39,746) and extracted 50 random locations for each female mortality location. Mortality data were not subset by population or season for this analysis because the data sets would be small and unbalanced. The sign and significance of the regression coefficient indicated that the habitat attributes associated with mortality sites were more or less common than expected by random chance. For categorical data, the strength and interpretation of the association was conditional to the relative availability of a given land cover type or slope position.

Highway mortality due to vehicle collisions

We classified vehicle collisions with sheep on the Alaska Highway as human-caused sheep mortality. These were censored out of natural survival estimates. We report the number of radiocollared sheep killed by vehicle collisions, as well as observations of unmarked sheep killed on the highway. Project biologists opportunistically surveyed the highway transect and enlisted local highway maintenance crews and Toad River residents to informally record live and dead sheep observed on the road from 2006 - 2010. The number of confirmed deaths was compared to estimated population size (Chapter 4) to estimate minimum annual mortality rates due to vehicle collisions.

Hunting mortality

Sheep killed by hunters were classed as human-caused deaths and censored out of natural survival estimates. The S8M study area overlaps all but the far northeast corner of BC Wildlife Management Unit (WMU) 7-54. WMUs are management jurisdictions for which wildlife harvest regulations are established. In the study area, mature male Stone's sheep (Class IV "Full Curl" or ≥8 yrs old) may be hunted between August 1 and October 15 annually by licensed hunters that purchase a sheep permit.

Harvest of females is not permitted. The number of permits issued to BC resident hunters is not limited; non-residents must be accompanied by a licensed guide, with permits managed under a quota system.

We compared fall harvest records with the number of full curl males counted during the following winter census to estimate harvest pressure on legal males. Long-term trends in harvest of male sheep was discussed by AXYS (2005), and is not reported here.

RESULTS

Survival rates

We monitored 124 adult females between June 15 2005 and June 15 2010 and 17 adult males from June 15 2008 until June 15 2010. The age of females in the Stone and Sentinel populations followed a normal distribution ranging from 2 - 10 yr (Chapter 3). Males ranged in age from 3 - 11 yr (Chapter 3). A total of 68 deaths (61F; 7M) were observed during the monitoring period, including natural and human-caused mortalities (Figure 6.1).

Annual survival rate for females combined was 80.2% (95% confidence interval 76.4 - 83.4%; Table 6.1). Annual survival was 82.5% for Sentinel females (76.3 - 87.2 %; Table 6.2) and 78.3% for Stone population females (71.7 - 83.3%; Table 6.3). Kaplan-Meier survival models were similar; both Sentinel and Stone female confidence intervals overlapped, with no difference in survival between populations (χ^2 = 0.5, 1 *df*, *P* = 0.479; Figure 6.2). We found a strong negative correlation between annual survival of adult females and May precipitation at the end of each monitoring year (r = 0.92, *P* = 0.027, n = 5; Figure 6.3).

We estimated annual survival of males at 82.9% (68.5 - 95.1%; Table 6.4).

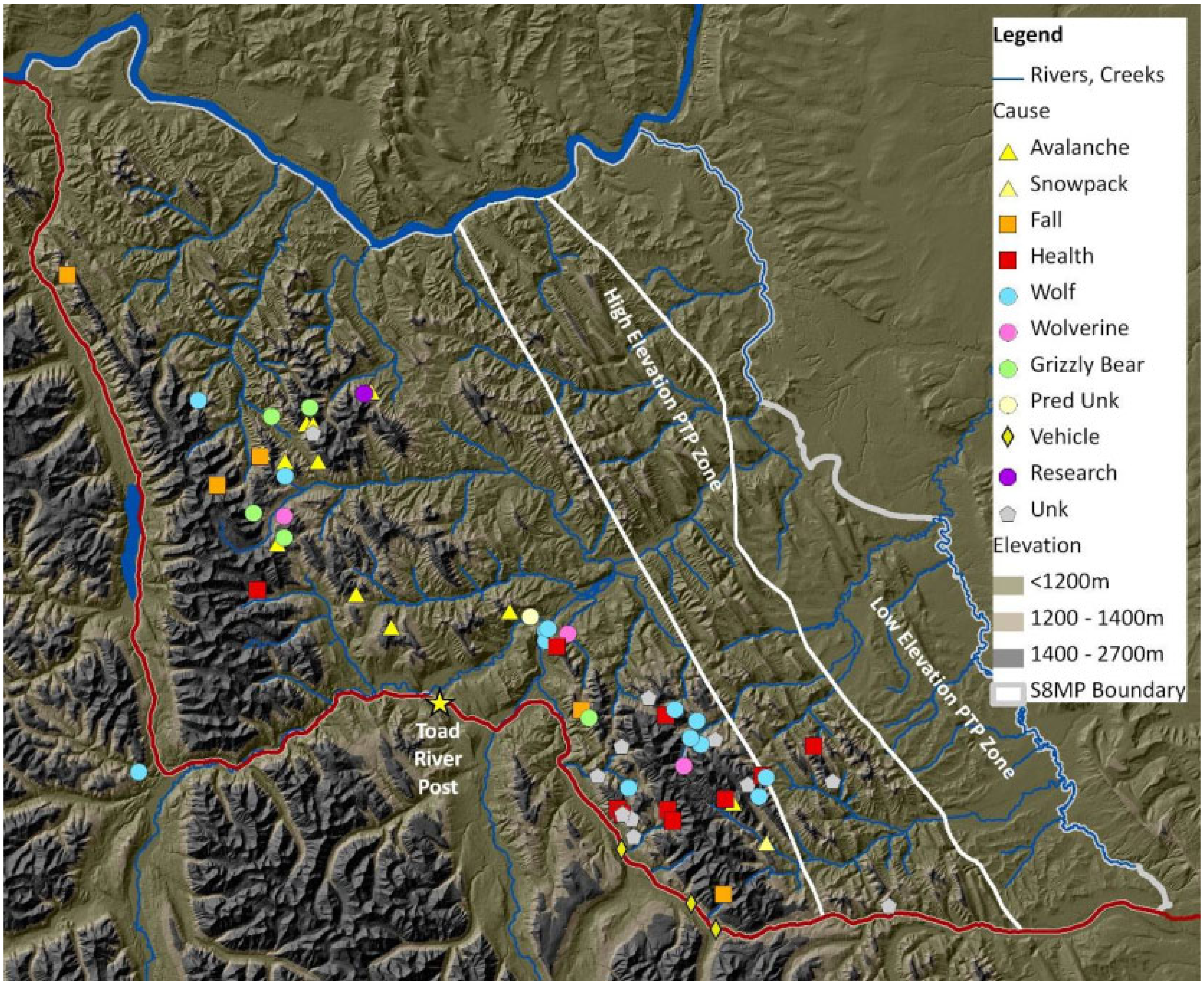

Figure 6.1 Mortality locations and cause of death for 60 female and 7 male Stone's sheep, 2005 - 2010. Location of 1 male sheep legally killed by hunting outside of the project area was excluded from map.

Table 6.1 Cumulative and annual survival of Sentinel and Stone population females combined.

Year	Date	No. at risk (r_i)	No. of deaths (d_i)	No. censored	No. new collars added	No. collars removed	Survival ($\hat{S}[t]$)	Var ($\hat{S}[t]$)	95% CI lower ($\hat{S}[t]$)	95% CI upper ($\hat{S}[t]$)
1	2005/06	37	12	3	67	1	0.676	0.004	0.552	0.800
2	2006/07	88	18	1	19	5	0.538	0.002	0.461	0.614
3	2007/08	83	9	3	0	2	0.479	0.001	0.405	0.554
4	2008/09	69	9	3	0	3	0.417	0.002	0.342	0.492
5	2009/10	54	11	0	0	1	0.332	0.001	0.260	0.404
Annual survival rate							0.802		0.764	0.834

Table 6.2 Cumulative and annual survival of Sentinel population females.

Year	Date	No. at risk (r_i)	No. of deaths (d_i)	No. censored	No. new collars added	No. collars removed	Survival ($\hat{S}[t]$)	Var ($\hat{S}[t]$)	95% CI lower ($\hat{S}[t]$)	95% CI upper ($\hat{S}[t]$)
1	2005/06	15	5	2	31	1	0.667	0.010	0.472	0.862
2	2006/07	38	7	1	12	2	0.544	0.004	0.427	0.661
3	2007/08	40	5	0	0	2	0.476	0.003	0.369	0.583
4	2008/09	33	4	3	0	3	0.418	0.003	0.309	0.527
5	2009/10	23	2	0	0	0	0.382	0.004	0.259	0.505
Annual survival rate							0.825		0.763	0.872

Table 6.3 Cumulative and annual survival of Stone population females.

Year	Date	No. at risk (r_i)	No. of deaths (d_i)	No. censored	No. new collars added	No. collars removed	Survival ($\hat{S}[t]$)	Var ($\hat{S}[t]$)	95% CI lower ($\hat{S}[t]$)	95% CI upper ($\hat{S}[t]$)
1	2005/06	22	7	1	36	0	0.682	0.007	0.521	0.843
2	2006/07	50	11	0	7	3	0.532	0.003	0.431	0.633
3	2007/08	43	4	3	0	0	0.482	0.003	0.379	0.586
4	2008/09	36	5	0	0	0	0.415	0.003	0.312	0.519
5	2009/10	31	9	0	0	1	0.295	0.002	0.208	0.382
Annual survival rate							0.783		0.717	0.833

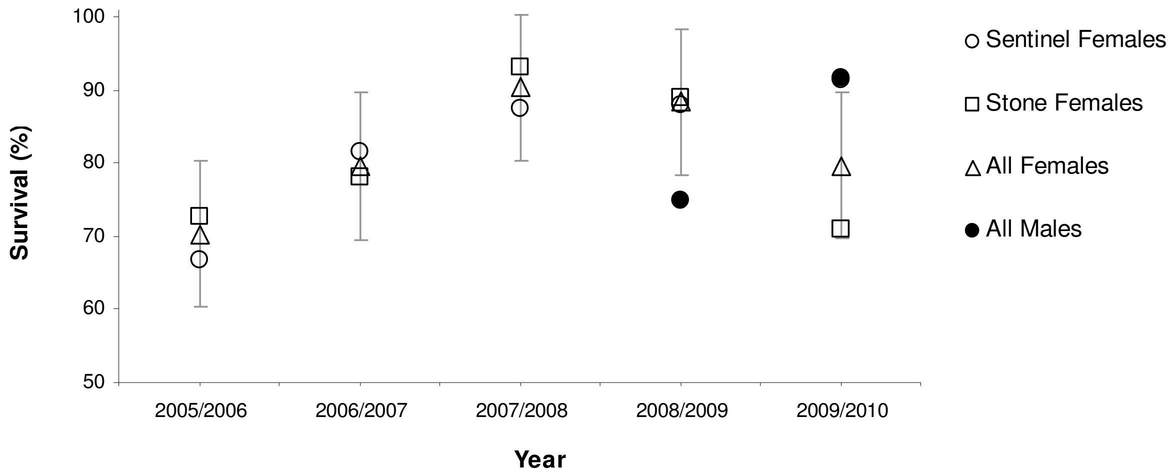

Figure 6.2 Annual survival of 124 female and 17 male Stone's sheep, 2005 - 2010. Confidence intervals are displayed for all females from Sentinel and Stone populations combined.

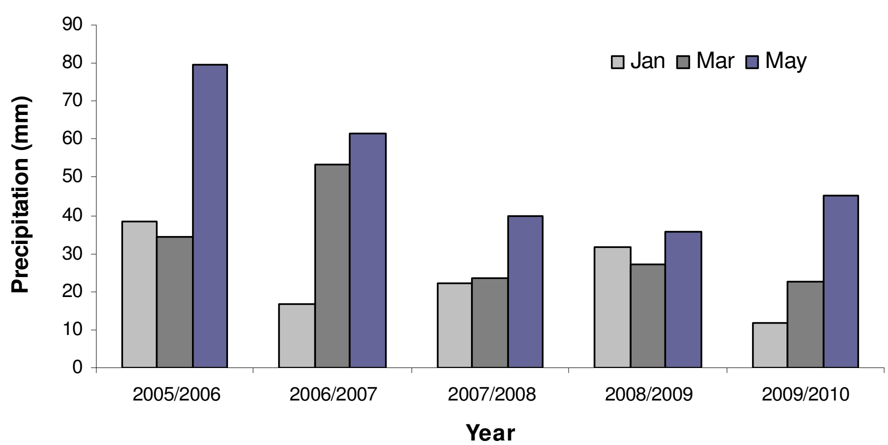

Figure 6.3 Total precipitation in January, March, and May annually, 2006 - 2010.

Table 6.4 Cumulative and annual survival of male Stone's sheep.

Year	Date	No. at risk (r_i)	No. of deaths (d_i)	No. censored	No. new collars added	No. collars removed	Survival ($\hat{S}[t]$)	Mortality (q_i)	Var ($\hat{S}[t]$)	95% CI lower ($\hat{S}[t]$)	95% CI upper ($\hat{S}[t]$)
4	2008/09	16	4	0	1	1	0.750	0.250	0.009	0.566	0.934
5	2009/10	12	1	2	0	8	0.688	0.083	0.012	0.470	0.905
Annual survival rate							0.829			0.685	0.951

Age-specific survival was relatively constant among females aged 3 - 8 yr but decreased in older ages (Figure 6.4). Male survival fluctuated among prime aged individuals (3 - 8 yr). The oldest age reached at the end of the monitoring period by sample females was 15 yr while the oldest male was 11 yr, based on uncorrected estimates from horn annuli counts.

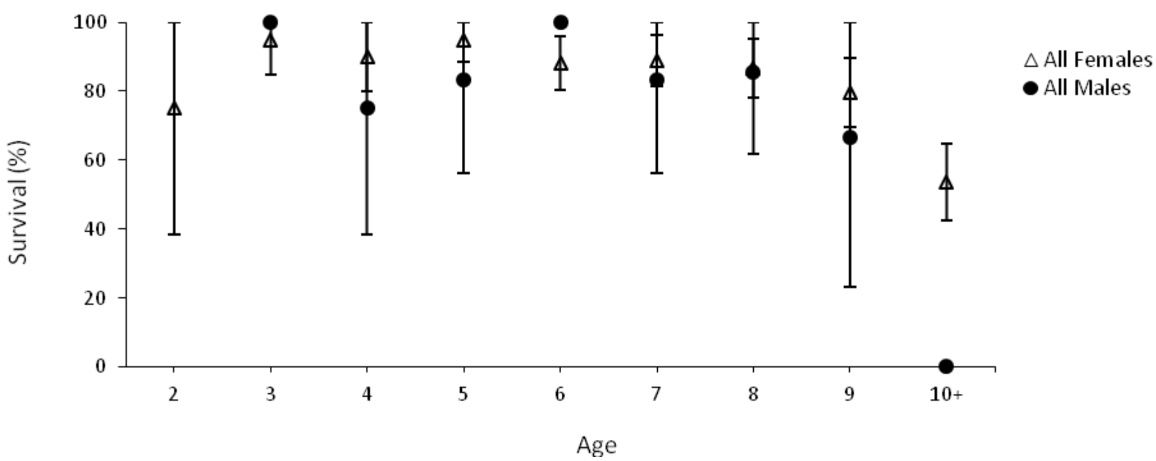

Figure 6.4 Age-specific survival of 124 female and 17 male Stone's sheep, 2005 - 2010. Confidence intervals cannot be calculated for age classes where survival is 0 or 100%.

Causes of mortality

We attributed deaths to 3 natural causes for 48 females (Table 6.5) and 4 males (Table 6.6). Females that died of poor body condition ranged in age from 4 - 12 yrs. Males that died of poor body condition were in the Stone population.

Table 6.5 Causes of natural mortality for 48 female Stone's sheep. Parentheses indicate proportion of totals.

Cause	Sentinel	Stone	Overall
SNOW			
Snowpack	0	1 (3.8%)	1 (2%)
Avalanche	8 (36%)	1 (3.8%)	9 (19%)
PREDATION			
Wolf	3 (14%)	8 (31)%	11 (23%)
Grizzly bear	4 (18%)	1 (3.8%)	5 (10%)
Wolverine	1 (4.5%)	1 (3.8%)	2 (4%)
Unknown	1 (4.5%)	0	1 (2%)
BODY CONDITION			
Health	1 (4.5%)	7 (27%)	8 (17%)
Fall / Injury	3 (14%)	1 (3.8%)	4 (8%)
UNKNOWN	1 (4.5%)	6 (23%)	7 (15%)
TOTAL	22	26	48

Table 6.6 Causes of natural mortality for 4 male Stone's sheep. Parentheses indicate proportion of total.

Cause	Sentinel	Stone	Overall
SNOW			
Avalanche	2 (%)	0	2 (50%)
BODY CONDITION			
Health	0	1 (%)	1 (25%)
Fall / Injury	0	1 (%)	1 (25%)
TOTAL	2	2	4

Seasonal patterns

Deaths occurred most often during Late Winter (March 1 - May 14; Figure 6.5). Stone female deaths were spread throughout the year.

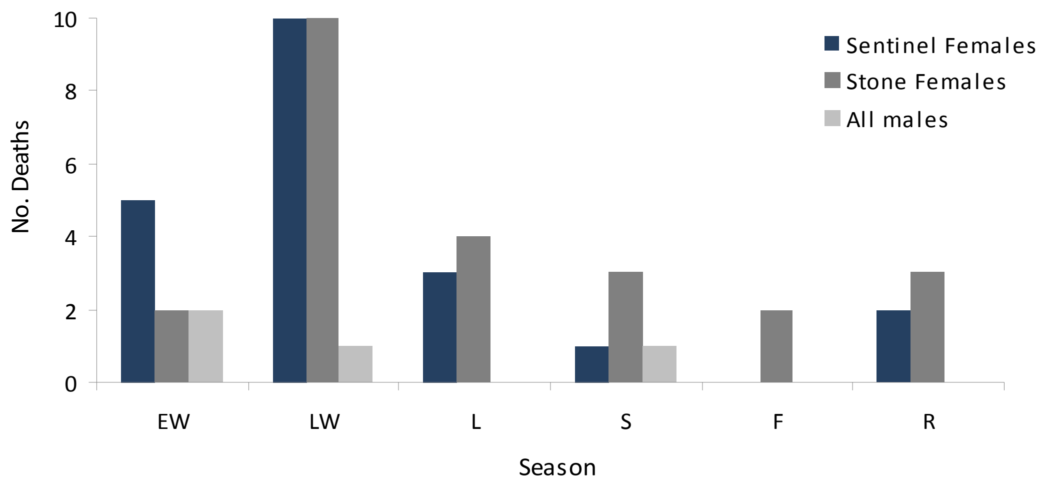

Figure 6.5 Seasonal timing of 48 female and 4 male Stone's sheep deaths from natural mortality causes between June 15 2005 and June 15 2009. Seasons: Early winter (EW) January 1 - February 28; late winter (LW) March 1 - May 14; lambing (L) May 15 - June 14; summer (S) June 15 - July 31; fall (F) August 1 - September 30; rut (R) October 1 - December 31.

Spatial patterns

Predation risk increased for adult females in valley bottoms and low gradient, concave, fragmented habitat at elevations lower than typically occupied (Table 6.7). Upper slope positions were more secure for sheep than other slope positions.

Mortality due to poor body condition increased in fragmented, low elevation habitats. A higher probability of dying in the alpine reflects the higher proportion of this habitat type available to sheep (Table 6.7).

Adult females occupying rugged areas with incised concave draws and less steep, shrub dominated slopes capable of supporting increased snow loads were at greater risk of snow-related death (Table 6.9).

Table 6.7 Univariate logistic regression results of habitat variables sampled from female Stone's sheep mortality sites with confirmed death by predation. Numbered attributes indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

Attribute	β	SE	*P*-value	Significance[1]	AIC
Ruggedness	-0.218	13.315	0.987		187.9
Slope	-0.072	0.021	0.000478	***	175.45
Escape distance	0.000792	0.000324	0.0144	*	182.49
[1] Ridge	0.8617	0.4878	0.0773		178.73
[2] Upper slope	-1.8024	0.8258	0.0291	*	
[3] Mid slope	0.4102	0.5354	0.4436		
[4] Flat	×	×	×		
[5] Lower slope	-0.5163	0.4487	0.2499		
[6] Valley bottom	1.0468	0.316	0.0153	*	
Solar radiation	-0.2918	0.7452	0.695		187.75
East-West	-0.5849	0.3498	0.0945		184.93
Elevation	-0.0014391	0.0006028	0.01696	*	182.43
Elevation^2	-6.413×10^{-7}	2.608×10^{-7}	0.0139	*	181.74
Curvature	-0.3104	0.1108	0.00508	**	180.99
Fragmentation	0.3635	0.1125	0.00123	**	179.06
[4] Rock	-0.43411	0.58238	0.4560		185.33
[6] Conifer at treeline	-1.59036	0.90274	0.0781		
[7] Deciduous tree	2.13935	1.02342	0.0366		
[11] Conifer tree	0.05990	0.91600	0.9479	*	
[44] Alpine	0.01244	0.46776	0.9788		
[46] Fluvial	-1.22795	0.48940	0.0121	*	
[66] Grass	×	×	×		
[88] Shrub	1.04073	0.70132	0.1378		
Burned areas	-0.6138	0.5311	0.248		186.92

[1] Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.
× indicates categories excluded from analyses due to zero counts.

Table 6.8 Univariate logistic regression results of habitat variables sampled from female Stone's sheep mortality sites with confirmed death from poor body condition. Numbered attributes indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

Attribute	β	SE	*P*-value	Significance[1]	AIC
Ruggedness	-5.4159	18.1663	0.766		81.673
Slope	-0.01321	0.03397	0.69735		81.619
Escape distance	0.000804	0.000534	0.132		79.923
[1] Ridge	0.6870	0.8500	0.419		81.928
[2] Upper slope	-0.8614	0.8413	0.306		
[3] Mid slope	-0.5815	0.8421	0.490		
[4] Flat	×	×	×		
[5] Lower slope	0.7560	0.5549	0.173		
[6] Valley bottom	×	×	×		
Solar radiation	2.225	1.542	0.149		79.38
East-West	0.2089	0.5300	0.693		81.62
Elevation	-0.006284	0.003084	0.0416		77.3
Elevation^2	-2.134×10^{-6}	1.058×10^{-6}	0.0438	*	77.228
Curvature	-0.1053	0.1599	0.51		81.341
Fragmentation	0.4737	0.2030	0.0196	*	77.075
[4] Rock	0.5520	0.6465	0.3932		78.8
[6] Conifer at treeline	×	×	×		
[7] Deciduous tree	×	×	×		
[11] Conifer tree	-0.9456	0.8123	0.2444		
[44] Alpine	1.4393	0.6625	0.0298	*	
[46] Fluvial	×	×	×		
[66] Grass	×	×	×		
[88] Shrub	-1.0456	0.5673	0.0653		
Burned areas	-11.7186	1455.3976	0.994		81.729

[1] Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.
× indicates categories excluded from analyses due to zero counts.

Table 6.9 Univariate logistic regression results of habitat variables sampled from female Stone's sheep mortality sites with confirmed death from snow-related causes. Numbered attributes indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

Attribute	β	SE	P-value	Significance[1]	AIC
Ruggedness	36.3652	8.9726	5.06×10^{-5}	***	100.82
Slope	-0.05876	0.02844	0.0388	*	115.36
Escape distance	-0.0001945	0.0006691	0.771		119.29
[1] Ridge	×	×	×		121.19
[2] Upper slope	×	×	×		
[3] Mid slope	0.05966	0.54892	0.913		
[4] Flat	×	×	×		
[5] Lower slope	-0.1787	0.4079	0.661		
[6] Valley bottom	0.1191	0.5493	0.828		
Solar radiation	-1.2422	0.8283	0.134		117.22
East-West	-0.5801	0.4994	0.245		117.9
Elevation	-0.002611	0.001587	0.0999		116.84
Elevation^2	-9.956×10^{-7}	5.928×10^{-7}	0.0931		116.66
Curvature	-0.3323	0.1076	0.00201	**	110.89
Fragmentation	-0.04532	0.12482	0.717		119.24
[4] Rock	-1.28152	0.89000	0.150		115.43
[6] Conifer at treeline	-0.57184	0.58692	.032990		
[7] Deciduous tree	×	×	×		
[11] Conifer tree	0.34445	0.91491	0.70656-		
[44] Alpine	0.06102	0.59111	0.91778		
[46] Fluvial	-1.25942	0.58368	0.03095	*	
[66] Grass	×	×	×		
[88] Shrub	2.82935	0.88403	0.00137	**	
Burned areas	×	×	×		

[1] Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.
× indicates categories excluded from analyses due to zero counts.

Highway mortality

Vehicle collisions accounted for 8% of deaths (3 of 37) for collared females in the Stone population over 5 years. This suggests that 1.6% of adult females are killed annually on the Alaska Highway. One of these deaths occurred in 2007, a year in which 10 vehicle-related deaths of unmarked sheep (7 females, 3 lambs) were observed incidentally (Chapter 8). Annual mortality rates of females from vehicle collisions ranged from <1% to 4% of the female population over the course of the S8M Project (8 of 202 females counted in the Stone population in March 2007; Chapter 4). If unreported vehicle-wildlife collisions are factored into the confirmed mortality rate, annual road mortality could exceed 5% (Chapter 8). Incidental observations of unmarked Sentinel females and one unmarked Stone male killed by vehicles suggest that highway mortality is likely significant for both populations and all age-sex classes.

Hunting mortality

BC Government data for WMU 7-54 indicate an average annual harvest of 17 males from 1976 - 1989, 31 males per year in the 1990s, and 22 per year in 2000 - 2008. Harvest in WMU 7-54 varies annually, with 10 - 37 mature male sheep legally killed each year since compulsory inspection began in 1976.

Most males collared in the S8MP were not of legal harvest age or horn size. One male that became legal by horn size during the study was shot the year he became legal. He traveled 17.5 km away from winter ranges between June 15 - 17, returning August 20 – 21, 2008. The following year he made the same trip on June 11 - 12 and was legally hunted on August 2, 2009.

Harvest limits of 8% of the total number of male sheep ≥1 yr old, or up to 15% of observed minimum ¾ Curl (Class III) males, have been suggested for conservative management (Toweill 1999). Applied to the December 2006 census counts across the study area, this implies a maximum of 21 sheep available for harvest in fall 2007 (8% of 268 males ≥1 yr old or 15% of 141 Class III and IV males; Chapter 4). In fall 2007, 28 males were harvested in WMU 7-54.

The data indicate 50% harvest pressure on mature males that are legal by degree of horn curl, presuming that most hunters select males with minimum full curl horn growth. Twenty-six (26) males were harvested in the fall of 2006, equivalent to the number of full curl males estimated in the population the following winter (2006/2007; Chapter 4).

DISCUSSION

Long-term studies of bighorn sheep (*Ovis canadensis*) and other ungulates indicate 92% average annual survival (range 81 – 98%) of adult females, declining after 8 yrs of age (Gaillard *et al.* 1998; Gaillard *et al.* 2000; Jokinen *et al.* 2007; Loison *et al.* 1999). Average annual survival rate of adult females in the S8MP Sentinel and Stone populations was 5 - 10% lower than reported for other ungulates, including bighorn sheep, mountain goat, and roe deer (*Capreolus capreolus*) (Festa-Bianchet *et al.* 2003). Our limited data on adult male mortality suggests survival rates similar to adult females. Annual survival rate of adult males in the S8MP is similar to rates reported for other ungulates (Festa-Bianchet *et al.* 2003).

The age and sex structure of a population influence survival rates. Prime age survival is usually high and relatively constant among ungulates (Loison *et al.* 1999). Because survival is <100% for all ages, the probability of reaching older ages declines even if senescence does not occur (Sacher 1978). In both S8MP female populations survival began to decrease at approximately 9 yrs of age. Age-specific survival rates for S8MP adult females may be lower at most ages than observed in other wild ungulates. This may have been influenced by the horn annuli count method used to estimate age, as some suggest that this method is imprecise for female sheep after about 4 yrs of age (Hoefs and König 1984). Teeth collected during sheep post-mortem investigations were submitted for ageing to test correlations between estimated and actual ages and provide an index for future age-estimate corrections.

Survival and recruitment in the S8MP area appear to be strongly driven by spring weather patterns. More than 40% of adult female mortalities we investigated occurred in late winter, particularly April and May. At this time of year, pregnant females are constrained by several months of limited forage and increasing metabolic demands as pregnancy nears full-term. We found a strong negative correlation between annual survival of adult females and May precipitation. In contrast, other studies have reported that spring precipitation has a positive influence on lamb growth and survival to 1 yr of age (Portier *et al.* 1998). Wet conditions promote earlier green-up of herbaceous forbs and graminoids and provide young of the year with quality forage sooner, leaving them better nourished to endure the following winter.

With annual survival rate >70% for adult females during this study, late winter ratios of at least 35 lambs to 100 adult females will support a stable or growing population, assuming equal sex ratio at birth. We found higher lamb survival (0.64 lambs per female in March 2007; Chapter 4) in the winter following a year of high female mortality (33%), and more moderate lamb survival (0.37 lambs per female in February 2009; Chapter 5) in the winter following a year of low female mortality (10%). In the absence of other limiting factors, both lamb to female ratios are sufficient to compensate for adult female mortality. If this pattern is consistent over the long-term, the demographic effect of high adult female mortality in years with wet spring weather may be offset by positive population recruitment the following spring. This can change the population age structure annually and dampen variation in total population size over time. These apparent relationships require further study, but are consistent with other studies of weather and population density influences on wild sheep survival patterns (Bender and Weisenberger 2005; Coulson *et al.* 2001; Jacobson *et al.* 2004). Our results agree with Murphy and Whitten (1976) who suggested that lamb to female ratios were inversely correlated with the severity of annual climatic fluctuations. Picton (1984) further stated that snow depth best explained the annual variations, and the extent of these variations were highly dependant on the size of the population with respect to winter habitat carrying capacity.

While survival rates did not differ, primary cause of death varied between Sentinel and Stone populations. Stochastic factors such as herd health and weather issues were collectively more responsible for female deaths than predation. Ungulate survival estimates from populations where predators have been artificially reduced experience mortality rates much different than unaltered predator-prey systems (Owen-Smith 1993). Wolf, bear, cougar, and wolverine have been artificially reduced by hunting, trapping and government-led culls for decades within the S8MP area (Bergerud and Elliott 1998; Haber 1988; Kjos 2010).

Snow-related deaths were more common for Sentinel females, while deaths attributed to poor body condition were more pronounced in Stone population females. Survival in the 2008/2009 monitoring year was influenced by several sheep (2 M; 3 F) being killed in avalanches. Hazardous snowpack conditions existed throughout most of BC in the winter of 2008/09; avalanches closed several major highways and human deaths occurred. The survival rate estimate for males is likely lower than average survival over longer monitoring periods because 2 of the 4 deaths by natural causes were in avalanches in winter 2008/09.

There may be a relationship between sheep density, health-related deaths, and the degree of wolf predation in the Stone population. Health-related deaths were more common in the Stone Range and may be related to higher sheep density. Survival of young of the year and females >6 yr old has been found to be negatively associated with population density, while survival of younger sheep >1 yr old is often not affected by density (Coulson *et al.* 2001). Assumptions that population density alone negatively influence survival are erroneous because the average age of females within ungulate populations increases in response to higher densities, resulting in lower survival (Festa-Bianchet *et al.* 2003; Jorgenson *et al.* 1997).

Predation of Sentinel females by wolves and grizzly bears were equal in proportion, while Stone females succumbed to wolves more often. Post-mortem investigations revealed old age and poor body condition were contributing factors in the Stone population. During the course of field activities some females were observed alone and far removed from security habitat, and subsequently found dead from wolf predation. Our predation risk model results agree with Milakovic *et al.* (2011) who reported that wolves favored shrub habitat and riparian areas with variable cover, but not unvegetated areas and west aspects that Stone's sheep typically occupy (Chapter 9). Sheep affinity for fluvial habitat types such as riparian areas and debris fans for movement between core ranges make them susceptible to wolf predation occasionally. Mortality locations from wolf predation were often within these habitats throughout the course of our study.

Road related mortality can be as significant as predation or disease with respect to the long-term viability of sheep (Gunson et al. 2006). Vehicle conflicts are not specific to age or sex and high mortality of adult females can significantly influence population trends (Gaillard *et al.* 2000; Trombulak and Frissell 2000). Between June and September, Stone's sheep females have increased nutritional demands from gestation and lactation and require essential minerals from lick sites (Ayotte *et al.* 2008; Harper 1984). Road salt deposited by road maintenance crews may provide additional mineral salts that create or enhance naturally occurring mineral licks adjacent to road networks (Case 1938; LeBlond *et al.* 2007; Morgantini and Bruns 1988). If post-partum females are replenishing minerals by licking at the roadside, both females and their lambs are at risk of road mortality. Vehicle collisions with mature males are likely underestimated and underreported due to their trophy status. This may explain the observed disproportion of road-killed females compared to male sheep. Because male Stone's sheep are trophy-hunted, road or access development is likely to increase poaching or illegal possession of animal parts (Cole *et al.* 1997; Pynn 2007).

Although there was no difference in survival between Sentinel and Stone females based on natural mortality factors, the Stone population is at increased risk due to consistent use and high vehicle-related mortality at the Rock Cut mineral lick along the Alaska Highway. Use of mineral licks along the Alaska Highway corridor is discussed in Chapter 8.

BC Government harvest records were compared to current S8MP population estimates and age-sex structure (Chapter 4), and indicated that legal harvest of mature male Stone's sheep during the study exceeded suggested limits for conservative management (Toweill 1999). Improved or increased access to backcountry areas is likely to be the most significant factor influencing harvest pressure and the potential need for more restrictive harvest regulations in the future.

PART IV HABITAT USE AND SELECTION

CHAPTER 7 Spatial dynamics of Stone's sheep populations: home ranges, seasonal movements, mineral licks, and site fidelity

Hengeveld, P.E. and J.C. Cubberley. Spatial dynamics of Stone's sheep populations: home ranges, seasonal movements, mineral licks, and site fidelity. Pages 79-101 *in* Stone's sheep population dynamics and habitat use in the Sulphur / 8 Mile oil and gas pre-tenure plan area, northern British Columbia, 2005 – 2010. Synergy Applied Ecology, Mackenzie, BC. 167 pp plus appendices.

INTRODUCTION

Wild sheep typically have spatially-structured populations due to their association with discrete habitat patches (Bleich *et al.* 1990; Festa-Bianchet 1986b, 1986a; Geist 1971, 1999). In all seasons, predator avoidance strategies have a strong influence on the distribution of wild sheep. Forage areas near cliffs and rugged terrain are heavily favoured and in some cases sheep will compromise higher quality forage for lower predation risk (Bleich *et al.* 1997; Festa-Bianchet 1986b). Winter ranges are limited by snow depths >30 cm that restrict access to forage (Hoefs 1976; Seip 1983). During summer both sexes follow plant phenology and elevation gradients to access nutrition as forage quality peaks (Geist 1971; Hebert 1973; Hoefs 1976; Seip 1983). Typically, sheep use mineral licks to satisfy physiological needs associated with changes in forage quality and nutritional needs, improving digestion and nutrient retention (Ayotte et al. 2008). Mineral-rich springs and eroded banks associated with fluvial processes are often isolated habitat features and may therefore be a significant influence on seasonal range use and movement patterns (Durtsche *et al.* 1990; Heimer 1973, 1974; Holl and Bleich 1987; Jones and Hanson 1985; Keller and Bender 2007; Watts and Schemnitz 1985).

Wild sheep populations also have highly structured social dynamics which foster development of traditional movement patterns based on philopatric range familiarity. Festa-Bianchet (1986b) speculated that nursery group (female and juvenile sheep) fidelity to seasonal ranges ensures that traditional knowledge of coarse-scale habitat features (e.g., seasonal ranges, movement corridors) and fine-scale habitat features (e.g., natal areas, escape routes, mineral licks) is passed to offspring before sheep reach 1 yr of age. Young males remain loosely associated with nursery groups until approximately 4 yrs of age, before joining the hierarchical social structure of male-only groups where dominant rams dictate group movements. Male and female sheep may segregate most of the year (Geist 1971), due to physiological and metabolic differences that influence forage requirements (Ruckstuhl 1998; Ruckstuhl and Kokko 2002; Shank 1982), differences in perceived risk of predation (Bleich *et al.* 1997; Corti and Shackleton 2002), or a combination of both (Festa-Bianchet 1988a; Ruckstuhl and Neuhaus 2002).

The spatial relationships among preferred forage, escape terrain, and mineral licks is a primary influence on the distribution and spatial dynamics of wild sheep, and studying movement patterns can provide insight to some of these complex interactions (Schick et al. 2008). We investigated spatial dynamics of Stone's sheep populations in the Sulphur / 8 Mile Project (S8MP) area using Global Positioning System (GPS) satellite telemetry data to determine home range sizes, seasonal movements, and site fidelity of male and female sheep. Our objectives were to:

- Estimate annual home range, core range, and seasonal range sizes;
- Identify seasonal movements between core ranges;
- Quantify fidelity to seasonal ranges using measures of range overlap from season to season and year to year;
- Identify general movement patterns and movement rates;
- Describe mineral lick distribution and frequency of use;
- Compare the distribution of GPS collar data with the results of previous population censuses to assess how well the GPS data represented Stone's sheep across the S8MP area.

METHODS

GPS collar data processing

We studied seasonal distribution and movements of adult females between March 2005 and June 2009. Adult males were studied April 2008 - July 2010. Refer to Chapter 3 for a detailed description of sheep captures and radiocollar specifications. We mapped location data for each GPS collared sheep using ArcGIS 9.3 (Environmental Systems Research Institute, Redlands, CA, USA) and visually scanned the data for obvious outliers beyond the continuous distribution of locations. We removed outliers but we did not filter data by location fix quality (i.e., 2-dimensional [2-D] locations and lower dilution of precision values were not censored) to include sheep locations in habitat where topography or canopy cover may impair GPS line of sight during satellite acquisition. We excluded location data from the day of capture and subsequent day, to reduce potential habitat use bias associated with capture activities. We also excluded locations that did not match the expected fix schedule (Chapter 3).

Annual home ranges and core areas

We computed annual home range size estimates for individuals with at least 12 consecutive months of location data. We estimated home range sizes with 100% minimum convex polygons (MCP) and estimated core areas using 95% kernel density estimation (KDE) probability contours. MCPs connect the outermost locations of an animal's distribution and are standard measures of home range size. However, MCPs can overestimate the size of ranges typically used by sheep because they don't identify the distribution and density of location data. Annual home ranges can include large areas of unused habitat between core ranges that have varying intensity of use seasonally (Festa-Bianchet 1986b, 1986a).

Core (KDE) area estimates reflect concentrated use within an individual's annual (MCP) home range. Because the number of core areas within an MCP home range can vary among individuals, a single area of high density use was interpreted as a single core and multiple, non-overlapping clusters of high density use indicated multiple cores.

We estimated core area from the 3-dimensional utilization distribution (UD) of each individual's locations using the fixed kernel method to define the minimum area in which an animal has 95% probability of occurrence by UD volume (Worton 1995). All UDs were estimated on the same 100 m resolution study area grid. We used adhoc reference (h_{REF}) selection of the smoothing parameter (h, also known as bandwidth value) for bivariate normal kernels because the preferred method using least squares cross-validation (LSCV) failed to converge. Non-convergence may occur with large sample sizes and high density location clusters (Gitzen et al. 2006). MCP and KDE sizes were calculated using the adehabitat package (version. 1.8.3, www.lme4.r-forge.r-project.org, accessed 20 Oct 2010) in R statistical software (version 2.11.1, www.R-project.org, accessed 14 Jul 2010).

We compared home range and core area sizes between sexes using generalized linear models with a log-link gamma distribution because range sizes were not normally distributed (glm function in R package 'stats' version 2.11.1). These produced a better model fit with lower null deviance than log-normal models (Faraway 2006:138). We also compared home range and core area sizes between Sentinel females and Stone females. Small sample size for Sentinel males prevented comparison with Stone males. We used one-way analysis of variance to test for a difference between core sizes that included multiple cores compared to single cores. We considered analyses significant at $\alpha = 0.05$.

Migratory patterns and movement rates

We classified individuals as migratory or resident based on the number of core ranges in their annual home range. We defined migratory movements as directed movement between 2 or more non-overlapping core areas used within the same year. Resident sheep had overlapping seasonal core areas.

Movement rates were calculated from straight-line distances each sheep traveled between consecutive 6 hr Televilt collar and 7 hr ATS collar GPS location fixes (Chapter 3). When a series of location fixes were missed, we excluded the first location after a gap of >10 fixes. We also excluded fixes associated with unrealistic movement distances, determined by comparison with maximum movement distances identified by Walker (2005). We calculated movement rate per hour to account for differences in location fix frequencies. We used the directional distribution tool in ArcGIS 9.3 to visualize general movement patterns across the study area.

For each sheep, we mapped core areas and movement paths associated with 99^{th} percentile movement distances to identify travel dates and distances between core areas. We created movement path maps for each sheep using the Animal Movement extension version 2.04 for ArcView 3.2 (Environmental Systems Research Institute, Redlands, CA, USA). Travel distances were based on multiple straight-line measures between consecutive GPS fixes and may therefore underestimate the actual distance traveled if topography was accounted for. Distance traveled between multiple core areas was estimated from the last fix taken before leaving one core area to the first fix within another core area.

Seasonal ranges

We used fixed calendar dates identified by Walker (2005) for Stone's sheep studies in the M-KMA's Besa-Prophet area, roughly 200 km south of the S8MP, to define 6 seasons relevant to Stone's sheep ecology (Table 7.1). We estimated seasonal range sizes for each individual by year, for all seasons in which an individual's location data spanned the entire season. We used the same 95% KDE method described for annual core area estimates.

We estimated the effects of sex, female population, and male age on seasonal range sizes using Penalized Quasi-Likelihood generalized linear mixed models with a log-link gamma distribution ('glmmPQL' function in R package 'MASS' version 7.3-7). Mixed models accounted for unequal variance in range sizes and repeated measures per individual, and estimated the influence of individual and year as random effects on range size. Because males and females were not monitored in all years, year was included as a random effect term in sex-specific models only. All comparisons were made to the smallest seasonal range.

While the h_{REF} KDE method is most suitable for location distributions with a single area of high density use, it can accommodate clustered data distributions (Gitzen et al. 2006). However, h_{REF}-based kernels can overestimate range sizes if dense location clusters with distinct edges are interspersed with large areas of unused habitat (Downs and Horner 2008; Gitzen *et al.* 2006). We observed inflated range size estimates when the timing of movements between core ranges did not coincide with our season delineations, and clustered locations were spatially dispersed. In these cases, the estimates reflected the sum of 2 non-overlapping ranges and exceeded annual MCP home range sizes. To reduce bias from inflated estimates, comparative analyses excluded all seasonal range sizes that exceeded annual home range sizes.

Table 7.1 Calendar dates for 6 seasons relevant to Stone's sheep ecology.

Season (abbreviation)	Date interval
Early Winter (EW)	Jan 01 – Feb 28
Late Winter (LW)	Mar 01 – May 14
Lambing (L)	May 15 – Jun 14
Summer (S)	Jun 15 – Aug 14
Fall (F)	Aug 15 – Oct 31
Rut (R)	Nov 01 – Dec 31

Seasonal range fidelity

We used range overlap measures for all combinations of individual, year, and season to evaluate range fidelity within and among years using the volume of intersection index for paired UDs ('kerneloverlap' function in R package 'adehabitat' v. 1.8.3 (Fieberg and Kochanny 2005). Calculating overlap as a function of the UDs takes into account the clustering of sheep locations, rather than the distribution of locations alone. For each sheep, we measured range overlap (%) between successive seasons to evaluate seasonal dispersion. We measured range overlap (%) for each season in successive years to evaluate inter-annual fidelity to seasonal ranges (Rettie and Messier 2001). Only one female was available for analysis of Late Winter range overlap between years because timing of capture and collaring limited the number of sheep with more than one full season of Late Winter location data.

Mineral lick use

Mineral licks used by sheep were identified incidentally during field work in 2005 - 2010 and from local interviews (Chapters 1 and 8). Lick sites included naturally-occurring mineral sources with evidence of sheep use, highway locations where road salts were exploited by sheep, and salt blocks observed or reported in sheep ranges. Highway and salt block locations known to be associated with natural mineral licks were defined as 'enhanced licks'; salt block locations not associated with known natural mineral licks were designated 'artificial'.

We defined lick complexes as aggregates of lick sites <1.5 km apart, a distance roughly equivalent to the observed maximum movement rate per hour for S8MP sheep. We determined mineral lick use by extracting GPS location data from a 400 m analysis buffer around mineral licks. We selected a 400 m buffer distance based on average movement rate per hour for male and females combined. Mean movement rate was 64 m/hr (n = 50, 987 locations), resulting in a mean movement potential during 6 hr and 7 hr fix intervals of 416 m. These values are under estimated as we did not account for variations in travel direction and landscape topography.

A histogram of male and female GPS locations was used to evaluate general timing of mineral lick use. Histogram intervals represent 14 day periods between 1 January (beginning of Early Winter) and 31 December (end of Rut). We excluded mineral lick sites that occurred in the middle of an individuals' home range to reduce bias from incidental locations near mineral licks versus defined use of the lick. Use of mineral licks along the Alaska Highway corridor is discussed in Chapter 8.

RESULTS

GPS collar data

We collected 40,006 locations for 26 females and 18,929 locations for 17 males (Figure 7.1). We excluded 260 (0.6%) female locations and 146 (0.8%) male locations interpreted as errors, leaving 58,528 locations with 72.0% 3-dimensional fixes. The subset of consecutive locations used for movement rate analyses included 34,780 female and 16,207 male locations, with 74.1% 3-dimensional fixes.

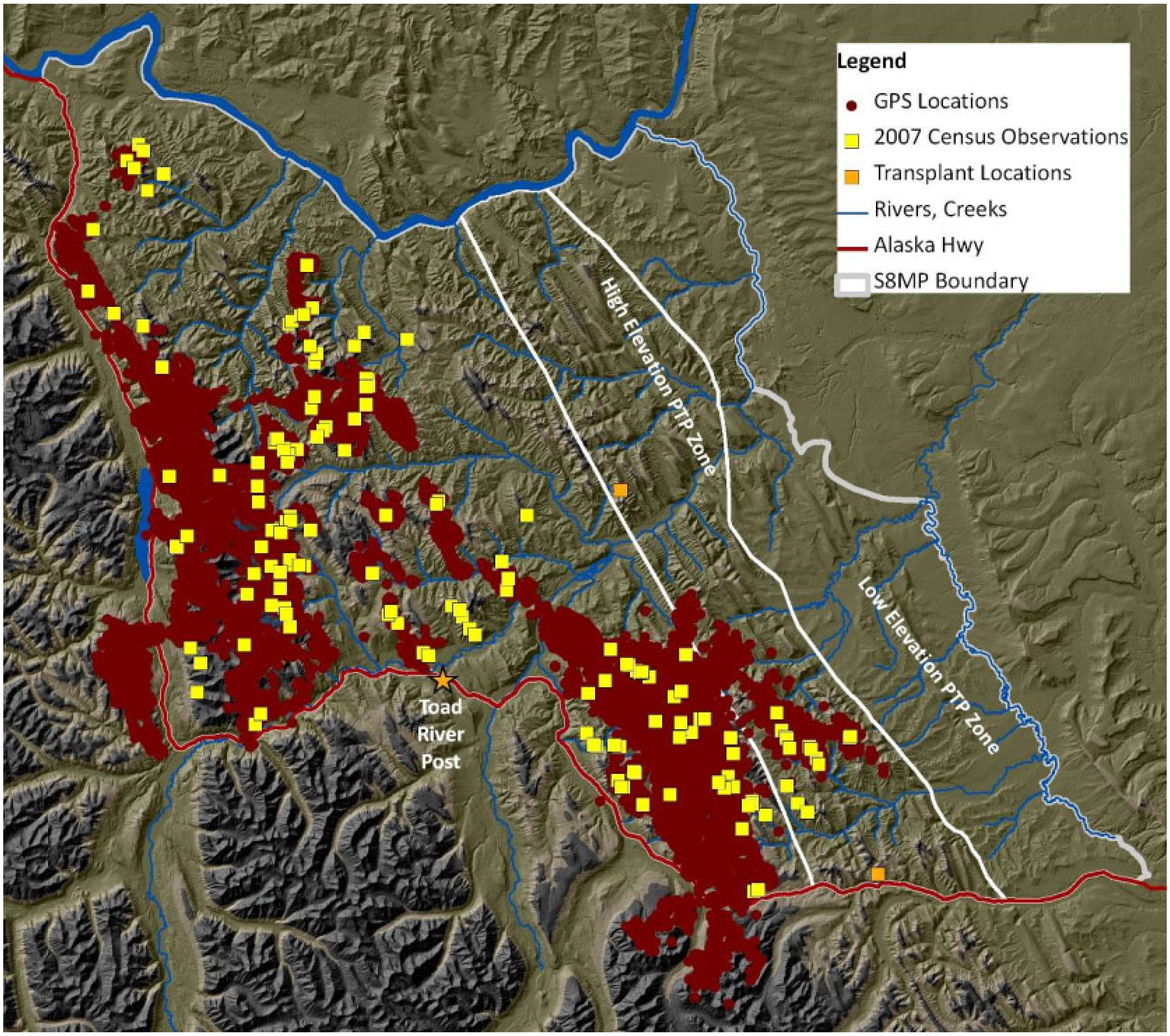

Figure 7.1 Distribution of GPS location data for 26 female and 17 male Stone's sheep (2005 - 2010) relative to late winter census observations (March 2007).

Annual home ranges and core ranges

We calculated home ranges and core areas for 19 females (983 - 3,282 locations per individual over 12 - 35 mths) and 8 males (1,194 - 2,481 locations per individual over 15 - 24 mths; Table 7.2, Figure 7.2). We found no difference in home range ($P = 0.214$) or core area estimates ($P = 0.055$) between Sentinel (n = 13) and Stone (n = 6) females. Male home ranges were 1.75 times greater, on average, than female home ranges ($\beta = 0.56 \pm 0.025$ SE, df = 26, $P = 0.031$), but there was no difference in core area sizes between sexes (*P* = 0.291). The maximum distance across annual home ranges was 34.1 km for females and 37.0 km for males.

Core area sizes were equivalent for resident individuals with a single core and migratory individuals with multiple cores (F: $F_{1,17} = 2.87$, P = 0.108; M: $F_{1,6} = 2.61$, P = 0.157). Core areas were used by individuals in each year that they were monitored.

Table 7.2 Annual home range and core area sizes for 19 female and 8 male Stone's sheep with more than 12 consecutive months of location data.

Annual range	Sex	Mean km^2 ± SE	Minimum - maximum km^2
Home range (100% MCP)[1]	Female	135.0 ± 19.5	25.3 - 344.5
	Male	236.9 ± 37.2	121.1 - 363.1
Core range (95% KDE)[2]	Female	143.9 ± 17.5	16.4 - 340.2
	Male	143.9 ± 17.5	95.6 - 383.3

[1] MCP: minimum convex polygon
[2] KDE: kernel density estimation

Migratory patterns and movement rates

Both sexes showed predominant east - west movement patterns across the Sentinel Range and north - south movements across the Stone Range (Figure 7.3). Elongated directional distributions are typical of migratory sheep that use non-overlapping core areas seasonally. Rounded distributions are more typical of resident sheep that use a single core area year-round.

Sixty-three percent of annual home ranges included >1 core area (12 of 19 F; 5 of 8 M). These included distinct migrations between 2 or more core areas used within the same year (8 F; 2 M) and repeated seasonal use of mineral licks at the periphery of home ranges (4 F; 3 M; Figure 7.4). Both sexes initiated movements between core ranges in mid-April through late June, returning as late as December (Table 7.3).

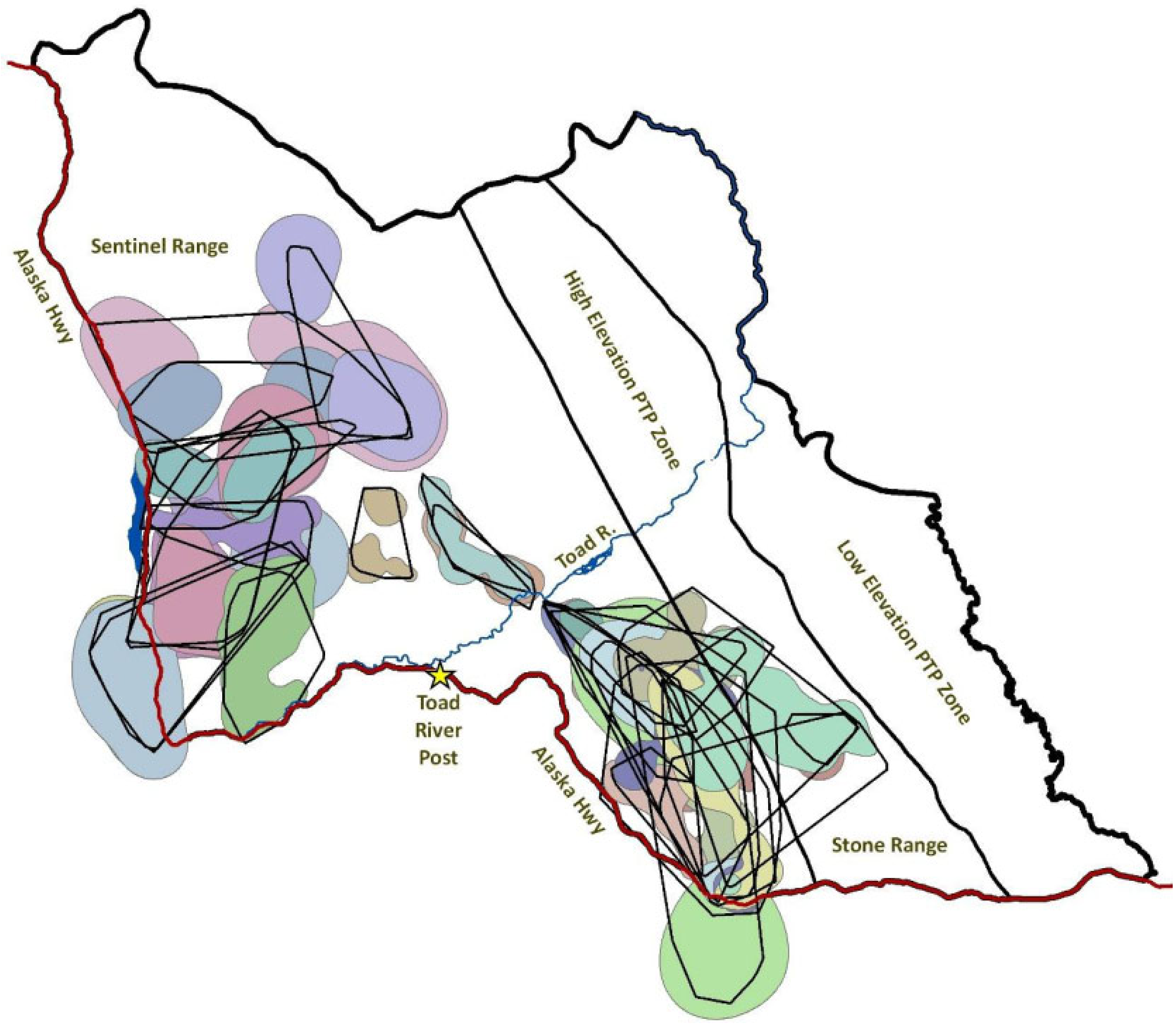

Figure 7.2 Annual home ranges (outlines) and core areas (shaded) for 19 female and 8 male Stone's sheep with >12 consecutive months of GPS location data.

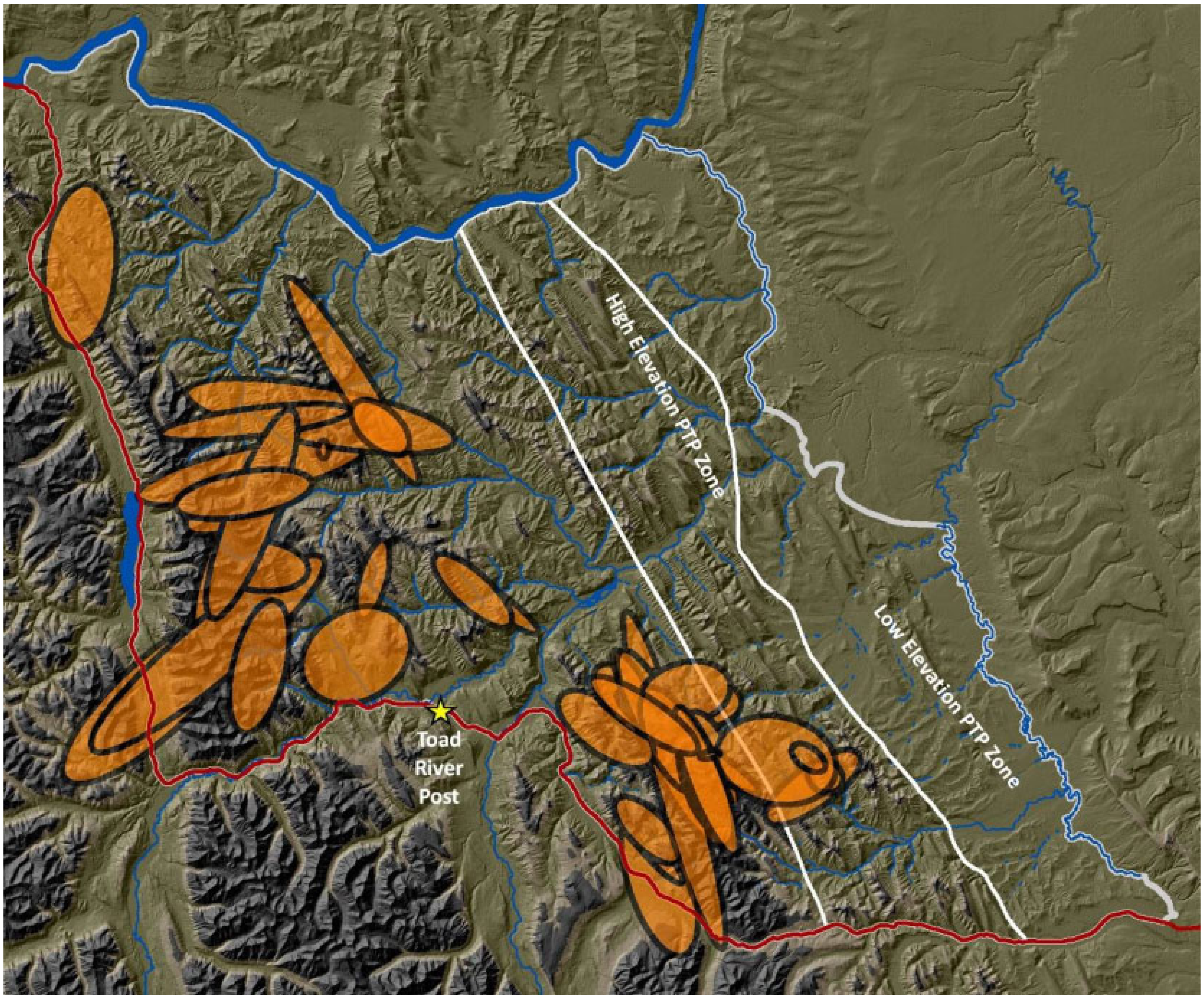

Figure 7.3 Directional distribution of GPS location data for 24 female and 13 male Stone's sheep.

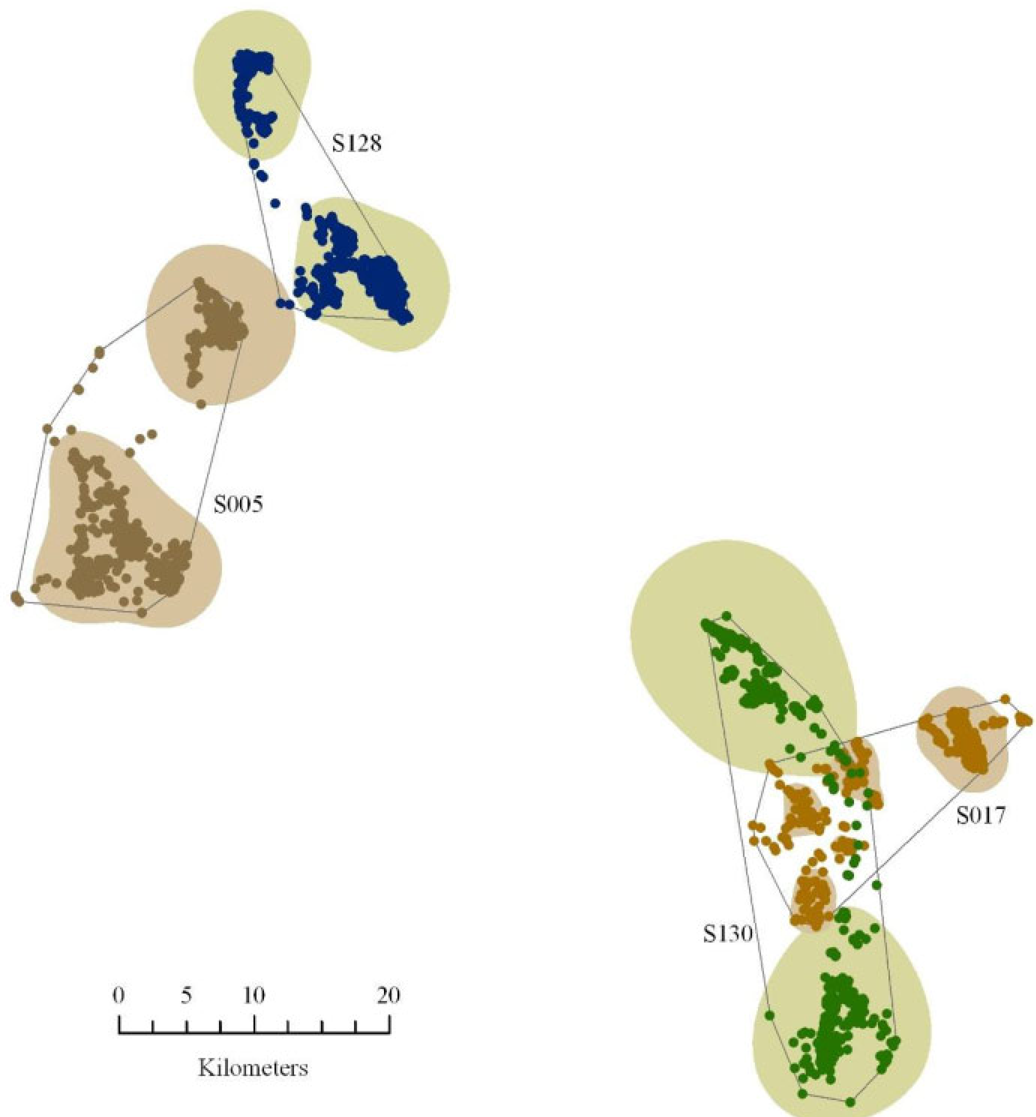

Figure 7.4 Representative sample of 100% minimum convex polygon home ranges (outlines) and 95% fixed kernel core areas (shaded) relative to location point distributions for 2 male (S128 and S130) and 2 female (S005 and S017) Stone's sheep.

Table 7.3 Travel between core areas for 12 female (19 F-Yr) and 5 male (9 M-Yr) Stone's sheep whose annual home ranges included multiple core areas used seasonally. Range of values indicated in parentheses.

Parameter	Females	Males
Median arrival date	Jun 3 (Apr 16 – Jun 28)	Jun 10 (Apr 23 – Jun 26)
Mean duration of travel (days)	1.9 (1 – 4)	1.7 (1 – 6)
Mean distance (km ± SD)	10.5 ± 6.3 (3.6 – 25.7)	13.6 ± 2.3 (9.8 – 16.1)
Mean period of use (days)	122 (38 – 183)	61 (5 – 192)
Median departure date	Sep 22 (Aug 5 - Dec 10)	Aug 6 (Jun 27 – Dec 2)
Duration of travel (days)	1.9 (1 – 3)	2.4 (1 - 4)
Mean distance (km ± SD)	9.7 ± 5.4 (3.9 – 21.6)	11.0 ± 3.1 (8.1 – 16.9)

Movement rates varied during the year and between sexes (Figure 7.5). In July through October females had higher movement rates than males; in November through April the opposite was true. For both sexes, the largest movement rates were most common in summer (Figure 7.6). Maximum movement rates ranged 512 - 1,641 m/h for females and 881 - 1,550 m/hr for males, and were associated with travel between core areas, including mineral licks. On average, 95% of an individual's movements were <300 m/hr, with 99% <550 m/hr (Table 7.4). Valid GPS locations included 159 zero movement distances between consecutive fixes. Most (77%) of these records were for fixes at 4 am indicating sheep were quiescent or returned to the same location since the previous fix.

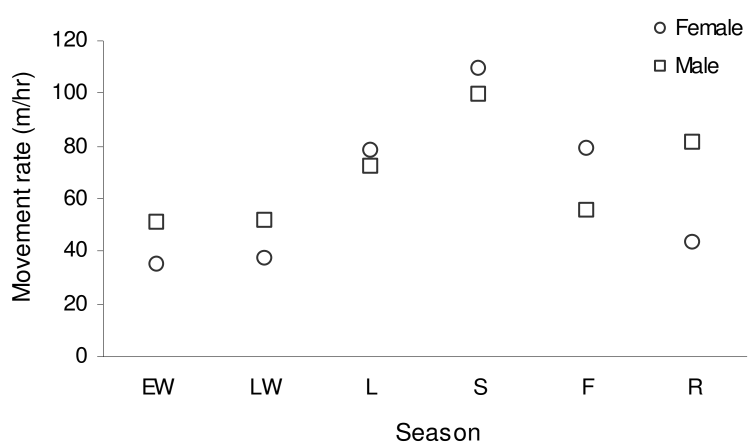

Figure 7.5 Average movement rates by season for 19 female and 8 male Stone's sheep. Seasons: Early winter (EW) January 1 - February 28; late winter (LW) March 1 - May 14; lambing (L) May 15 - June 14; summer (S) June 15 - July 31; fall (F) August 1 - September 30; rut (R) October 1 - December 31.

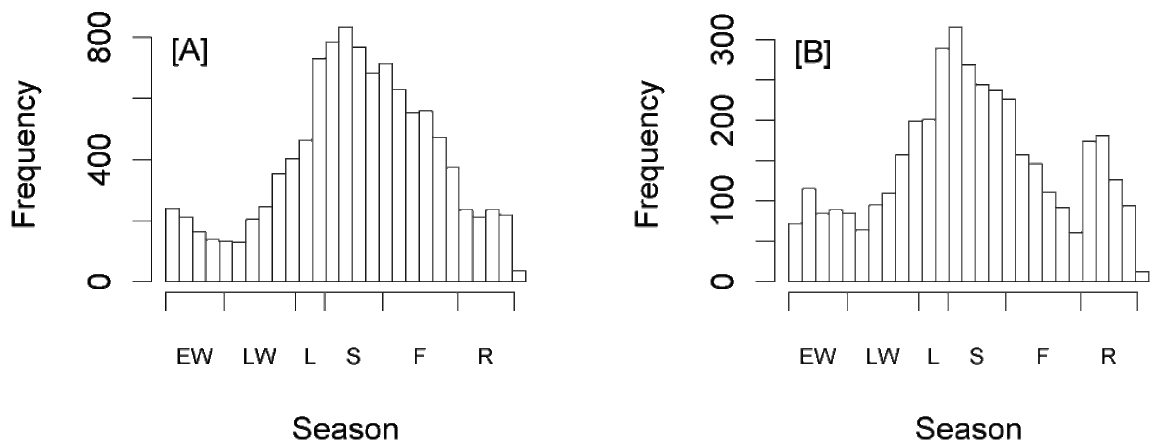

Figure 7.6 Seasonal distribution of the largest 1% of movement distances between consecutive GPS locations for [A] 19 female and [B] 8 male Stone's sheep. Seasons: Early winter (EW) January 1 - February 28; late winter (LW) March 1 - May 14; lambing (L) May 15 - June 14; summer (S) June 15 - July 31; fall (F) August 1 - September 30; rut (R) October 1 - December 31. Histogram intervals represent 14 day periods between 1 January and 31 December.

Table 7.4 Movement rates for 19 female and 8 male Stone's sheep with more than 12 consecutive months of location data.

Sex	Mean ± SE (m/hr)	95th percentile ± SE (m/hr)	99th percentile ± SE (m/hr)	Maximum (m/hr)
Female	63.8 ± 2.8	224.6 ± 10.0	462.6 ± 24.8	1,640.6
Male	82.1 ± 13.4	297.8 ± 39.2	542.3 ± 61.9	1,549.7

Seasonal range sizes

Seasonal range sizes were calculated for 18 Sentinel sheep (15 F; 3 M) and 19 Stone population sheep (9 F; 10 M). For both sexes seasonal ranges were smallest in Early Winter (Table 7.5, Figure 7.7, Figure 7.8). Compared to Early Winter, female ranges were roughly 10 times larger during Lambing ($\beta = 2.47 \pm 0.25$ SE, df = 242, $P < 0.001$), Summer ($\beta = 2.25 \pm 0.25$, df = 242, $P < 0.001$) and Fall ($\beta = 2.34 \pm 0.26$, df = 242, $P < 0.001$), with no difference between Rut and Early Winter range sizes ($P = 0.073$) and a small increase in Late Winter ($\beta = 0.79$, SE = 0.31, df = 242, $P = 0.011$).

Males had larger seasonal ranges than females only during Rut (β = 1.96 ± 0.44, df = 242, $P < 0.001$) and Late Winter (β = 0.98 ± 0.47, df = 242, $P = 0.039$). Although not a significant random effect, individuals explained 16.1% of model variance. Age of males ranged 3 - 11 yr (mean 6.7 yr, n = 13). There was no effect of age on range size (β = -0.10 ± 0.06, df = 19, $P = 0.084$), and neither individual nor year contributed to explained model variance.

Sentinel and Stone females had equivalent seasonal range sizes except during Summer and Rut. Stone females used Summer ranges 2.6 times larger than Sentinel females (β = 0.94 ± 0.48, df = 132, $P = 0.050$). Rut ranges of Sentinel females were almost 3 times larger than Stone females (β = -1.27 ± 0.48, df = 132, $P = 0.014$). Variation among females within years explained 25.4% of total variance, but year alone had negligible influence.

Table 7.5 Seasonal range size estimates for 24 female and 13 male Stone's sheep. Sample sizes (n) indicate the number of range estimates (sheep-years) per season.[1,2]

Season	Date interval	Female		Male	
		Mean ± SE km^2	n	Mean ± SE km^2	n
Early Winter	Jan 01 – Feb 28	9.7 ± 2.2	28	9.2 ± 2.1	16
Later Winter	Mar 01 – May 14	21.1 ± 7.0	17	54.6 ± 17.2	16
Lambing	May 15 – Jun 14	111.7 ± 15.2	39	100.5 ± 25.7	21
Summer	Jun 15 – Aug 14	88.7 ± 10.9	37	97.2 18.2±	18
Fall	Aug 15 – Oct 31	98.5 ± 16.0	34	63.0 ± 17.5	18
Rut	Nov 01 – Dec 31	15.3 ± 3.5	27	105.4 ± 18.0	18

[1] For sheep with location data from multiple years, seasonal range estimates were calculated independently for each individual, year, and season. We accounted for repeated measures in statistical analyses of range size comparisons by using mixed models with individual as a random effect term.

[2] This table and statistical analyses presented in the text exclude 6 seasonal ranges estimated to be larger than annual home range sizes (>395 km^2). See methods for justification.

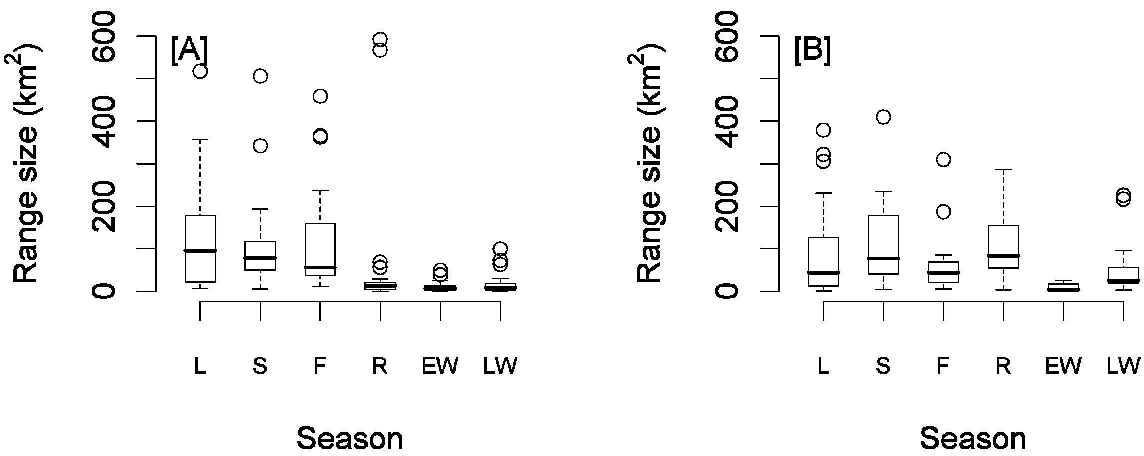

Figure 7.7 Box plots of seasonal range size estimates for [A] 24 female and [B] 13 male Stone's sheep. Seasons: Early winter (EW) January 1 - February 28; late winter (LW) March 1 - May 14; lambing (L) May 15 - June 14; summer (S) June 15 - July 31; fall (F) August 1 - September 30; rut (R) October 1 - December 31.

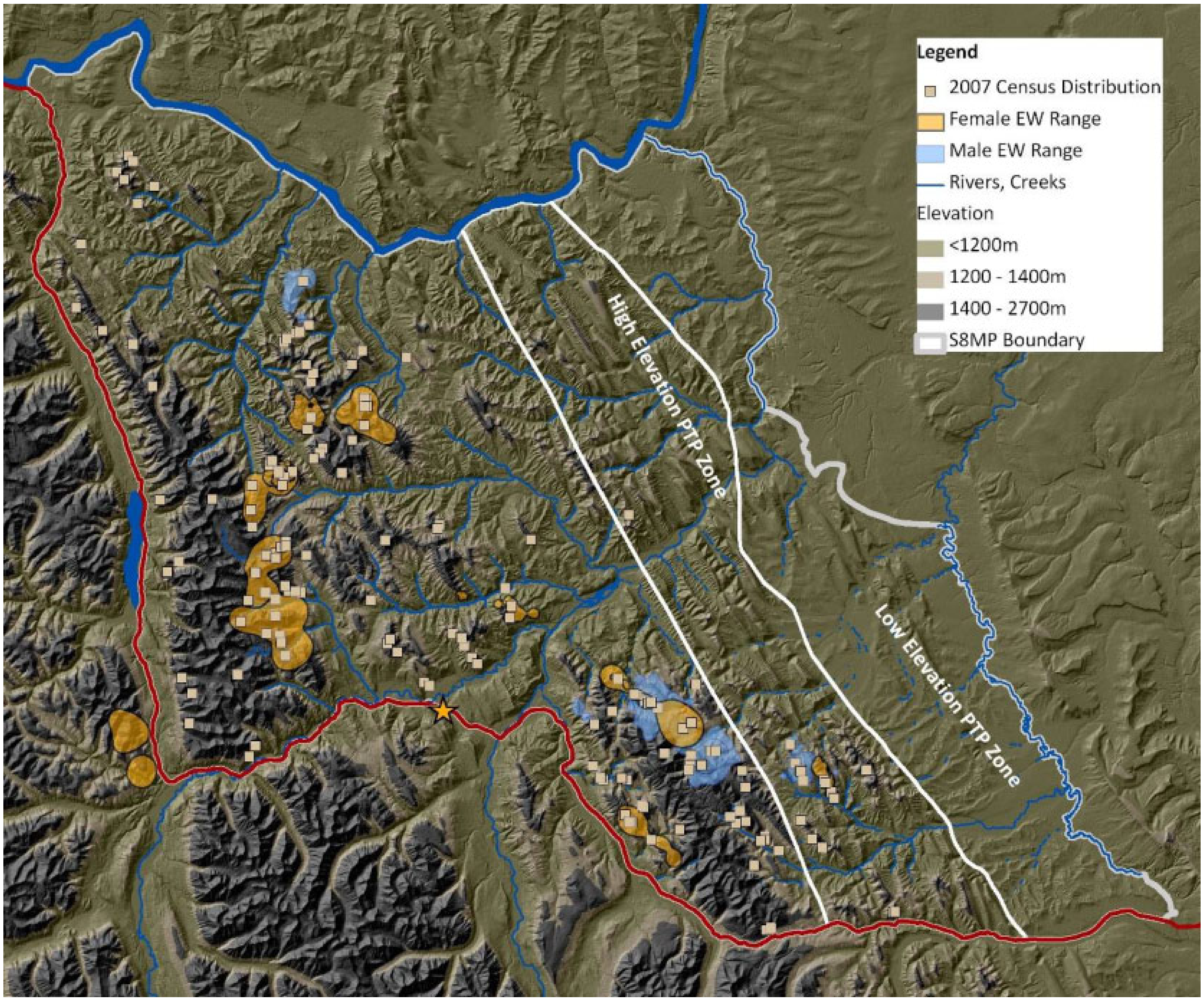

Figure 7.8 Distribution of Early Winter (EW) ranges estimated from location data for 24 females and 13 males. Stone's sheep observations from winter census in March 2007 are provided for comparison.

Seasonal range fidelity

The greatest seasonal range overlap within years was observed among female Rut and Early Winter ranges. Males showed most consistent use of ranges from Summer to Fall (Figure 7.9). Both sexes showed greatest overlap from year to year in Summer and Fall.

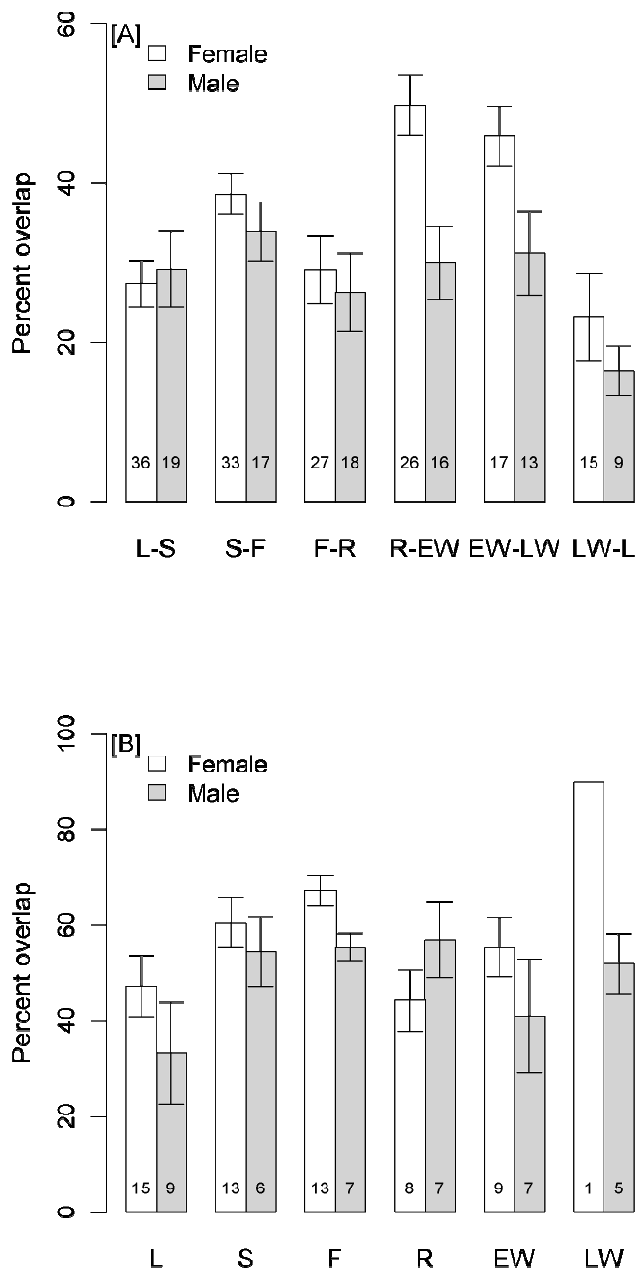

Figure 7.9 Percent overlap of seasonal ranges of male and female Stone's sheep. Numbers within the plots indicate sample size. Overlap among [A] successive seasons within years measures dispersal from one seasonal range to the next, while overlap [B] of seasonal ranges used by individuals in successive years measures inter-annual range fidelity. Seasons: Early winter (EW) January 1 - February 28; late winter (LW) March 1 - May 14; lambing (L) May 15 - June 14; summer (S) June 15 - July 31; fall (F) August 1 - September 30; rut (R) October 1 - December 31.

Mineral lick use

Forty-nine mineral lick sites were confirmed in known sheep ranges (Figure 7.10). These were grouped into 26 lick complexes: 4 natural backcountry licks; 17 enhanced licks (1 backcountry, 16 along the Alaska Highway corridor), and 5 artificial backcountry licks.

All 4 natural backcountry lick complexes were exposed mineral deposits along valley-bottom river and creek corridors, at elevations <1,000 m above sea level. The enhanced backcountry lick consisted of incised rock outcrops on steep mid-upper slopes at 1,500 - 1,600 m supplemented with salt blocks. Well-used licks along the Alaska Highway include the Rock Cut (local name) in Stone Mountain Provincial Park and Petersen Canyon in Muncho Lake Provincial Park (Chapter 8). Highway crossing locations were influenced by the presence of topographical features such as incised draws, canyons, and stream fans on both sides of the highway. Daily and seasonal use of highway licks is discussed in Chapter 8.

All but one GPS collared sheep (24 F; 12 M) used at least one lick complex (Table 7.6). One Sentinel female's range in the north 4 Mile Creek area did not include any known licks. Most sheep (96% F; 83% M) used at least one natural lick. In the Stone Range, one female and two males apparently used artificial licks only. Three-quarters of all GPS collared sheep used licks at the periphery of their home range (Figure 7.10). Females used natural backcountry licks earlier and for a longer period than males did, with peak use for both sexes in May - June (Figure 7.11).

Table 7.6 Estimated use of 25 mineral lick complexes by 24 female and 12 male Stone's sheep.[1]

Population	Sex	No. of individuals	Mean no. of licks used per individual (min – max values in parentheses)
Sentinel	Female	15	1.5 (0 – 5)
	Male	3	1.7 (1 – 3)
Stone	Female	9	1.0 (1 – 2)
	Male[1]	9	1.3 (1 – 2)

[1] This excludes one male whose GPS location data did not span the period of peak mineral lick use.

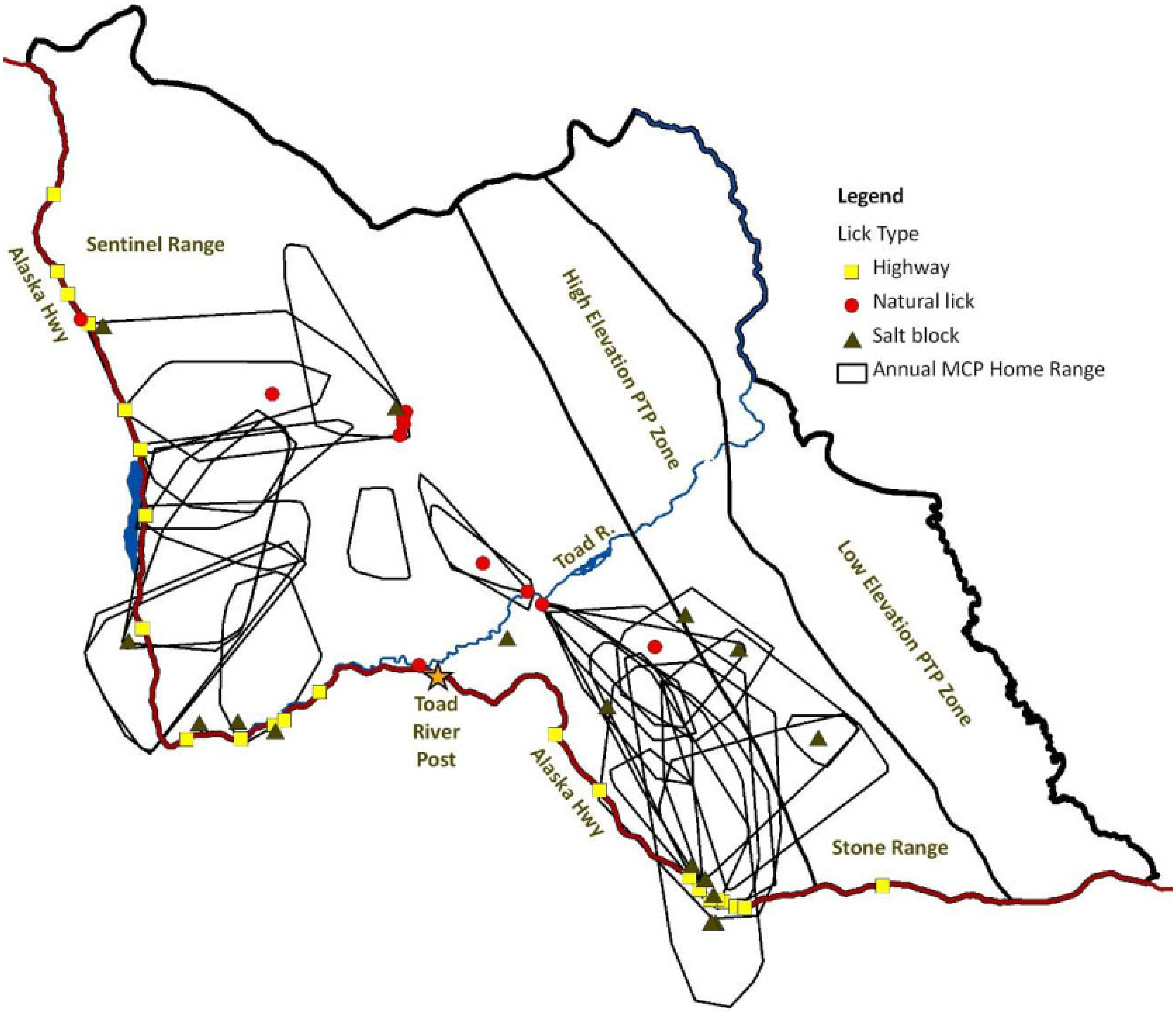

Figure 7.10 Annual minimum convex polygon home ranges for 19 female and 8 male Stone's sheep relative to distribution of known mineral licks.

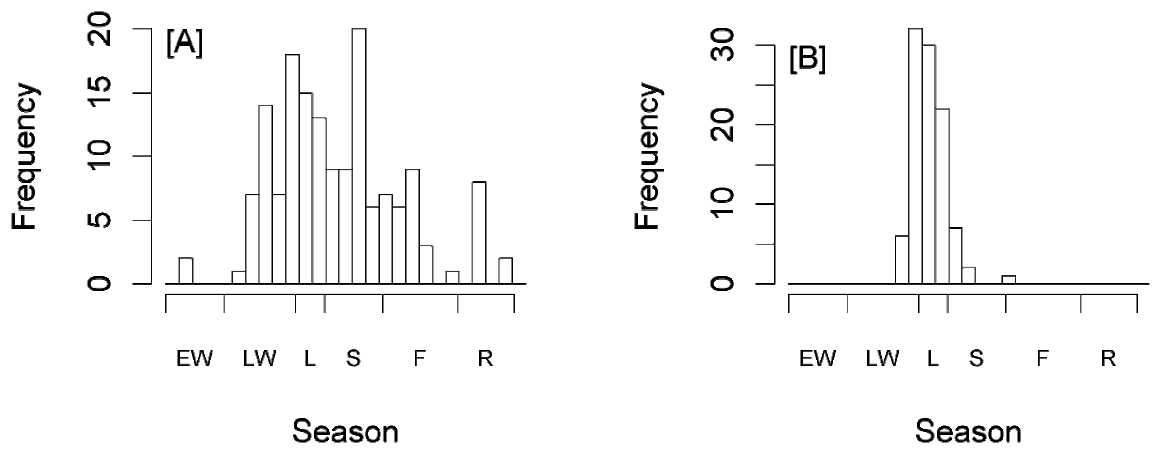

Figure 7.11 Timing of mineral lick use at 4 natural backcountry licks by [A] 7 female and [B] 5 male Stone's sheep. Histogram intervals represent 14 day periods between 1 January and 31 December. Seasons: Early winter (EW) January 1 - February 28; late winter (LW) March 1 - May 14; lambing (L) May 15 - June 14; summer (S) June 15 - July 31; fall (F) August 1 - September 30; rut (R) October 1 - December 31.

Summary of general distribution and movement patterns

Geographical limits

There was no evidence of GPS collared sheep crossing the Toad or Racing Rivers but seasonal movement to ranges outside the study area occurred at the Rock Cut (Alaska Highway west of Summit Lake) and at Petersen Canyon (Alaska Highway south of Muncho Lake).

With the exception of highway crossings at the Rock Cut and Petersen Canyon, GPS collared sheep did not move beyond the distribution of winter census observations in the S8MP area (Chapter 4 and 5, Figure 7.1).

Sentinel Range (north of Toad River)

Core winter ranges for both sexes were concentrated at (Figure 4.4 in Chapter 4, Figure 7.8):

- Mount McLearn - Ewe Mountain complex that extends north along Sulphur Cr;
- Mount Prudence;
- Fire Mountain (local name) at the Sulphur Cr – 8 Mile Cr headwaters;
- Nonda Cr headwaters.

Sheep herds also winter on the mountains between the Toad River, 4 Mile Cr, and 8 Mile Cr. A few small, scattered groups of sheep were observed in winter along the west and north extremities of the Sentinel Mountain Range (Figure 4.4 in Chapter 4).

All 15 GPS collared females moved away from core winter ranges or expanded their ranges seasonally, traveling to distinct summer ranges or to visit distant mineral licks.

- Females that wintered on the Mount McLearn - Ewe Mountain complex moved to the mid-Sentinel Range in summer months, using mineral licks along the Alaska Highway at Muncho Lake and the Trout River.
- Mt Prudence females moved to the northwest end of the Sentinel Mountain Range and used mineral licks along the Alaska Highway at the Trout River, north of Muncho Lake.
- Fire Mountain / 8 Mile Cr females used the 8 Mile Cr headwaters and southwest Sentinel Mountain Range, visiting Alaska Highway mineral licks at Muncho Lake and Petersen Canyon.
- Nonda Cr females used the south end of the Sentinel Mountain Range or crossed the Alaska Highway to Mt Petersen, in summer. One female remained at Petersen the following winter and subsequent summer before returning to Nonda Cr at the end of the second monitoring year.
- 4 Mile Cr females used different portions of their annual home range seasonally, but remained within the 4 Mile Cr drainage year-round. Mineral lick use by one of these females was not confirmed. Females that wintered above the Toad River Hot Springs alternated ranges north and south of 4 Mile Cr in summer.

Data for GPS collared males was limited to 2 males that wintered at Ewe Mountain and 1 male that wintered in the 4 Mile Cr ranges. All three expanded their ranges in summer, but used the same general areas year-round (Figure 7.10). Ewe Mountain males moved north from their winter range but remained on the Ewe Mountain complex, while the 4 Mile Cr male moved west to Nonda Cr ranges seasonally. None of these males made long-distance movements to isolated licks, instead using small natural licks within their core ranges. The GPS collar on one additional male captured at Ewe Mountain malfunctioned at the end of the 2 yr monitoring period, but we confirmed one observation of this male on the Alaska Highway at Muncho Lake in July. This suggests that at least some males have seasonal movement and mineral lick use patterns similar to females.

Movement corridors for both sexes are defined by general east - west travel across the Sentinel Range (Figure 7.3), including:

- East - west pass between Mount McLearn alpine ranges and Fire Mountain, between the upper reaches of 8 Mile Cr and Sulphur Cr.
- East - west lower-elevation passes in the 8 Mile Cr, upper Sulphur Cr, and 4 Mile Cr headwaters, leading from eastern winter ranges to mineral licks and summer range along the west slopes of the Sentinel Mountain Range, Alaska Highway, and Mount Petersen.
- North - south pass in the north Sentinel Mountain Range, leading from Mount Prudence to mineral licks along the Trout River and Alaska Highway.

- Low-elevation rocky bluffs between alpine ranges along the north and south sides of 4 Mile Cr.
- Trails tend to be well-worn and are often easily visible from aircraft.

Stone Range (south of Toad River)

Core winter ranges for both sexes were concentrated at (Figure 4.4 in Chapter 4, Figure 7.8):

- Upper Ram Creek;
- Upper Snake River;
- Ram Mountain (local name) in the S8M PTP High Elevation Zone;
- One Fifteen Creek.

Sheep herds also winter in isolated groups at the northwest extremity of the Stone Mountain Range. A few small, scattered groups of sheep were observed in winter along the east and west slopes of 'Airplane Valley' (local name) south to Stone Mountain Provincial Park, and a small group (possibly the result of a sheep translocation done by Ministry of Environment in 1996) on south-facing slopes above the Alaska Highway and the North Tetsa River (Figure 4.4 in Chapter 4).

All but one of 9 GPS collared females and all 10 males moved away from core winter ranges or expanded their ranges seasonally, traveling to distinct summer ranges or to visit distant mineral licks (Figure 7.10).

- Both male and female sheep captured on winter ranges at the north end of the Stone Range (Ram Cr - Stone Mountain - Snake Cr headwaters) summered throughout the Stone Mountain Range and used the Rock Cut mineral lick along the Alaska Highway. Sheep captured on the same winter range did not travel together year-round.
- One female was resident at Ram Mountain year-round. A second female captured at Ram Mountain moved west to summer ranges along the upper reaches of the Dunedin River, and visited the Rock Cut mineral lick along the Alaska Highway.
- Sheep that winter at the 115 Cr headwaters are predominantly resident there year-round, but use mineral licks along the Alaska Highway at the Rock Cut and adjacent Baba Canyon.
- Primary natural licks for all Stone Range sheep are (1) at the north end of the Stone Range where it meets the Toad River - Racing River confluence, and (2) along the Alaska Highway between the Rock Cut and Baba Canyon (within Stone Mountain Provincial Park) at the south end of the Stone Range. Females that visited the Racing River lick also visited the Rock Cut lick.

Movement corridors are defined by general north-south movements across the Stone Range, and east - west movements between the main Stone Mountain Range and ranges in the S8M PTP High Elevation Zone (Figure 7.3), including:

- North - south movements from winter ranges in the Ram Cr - Stone Mountain - Snake Cr headwaters to southern summer ranges and the Rock Cut mineral lick, traveling along Airplane Valley and lower-elevation passes to Mount St Paul in Stone Mountain Provincial Park.
- Trails tend to be well-worn and are often easily visible from aircraft.

DISCUSSION

S8MP annual home range estimates were larger than those reported for other Stone's sheep populations regionally. Average female home ranges were 4 times larger than in the M-KMA's Besa-Prophet area 200 km south of the S8MP, and 3 times larger than in the Dunlevy area 350 km south of the S8MP (Parker and Walker 2007; Wood *et al.* 2010). Average male home ranges were 1.5 times larger than Dunlevy males (Wood et al. 2010).

Implicit in home range concepts is that less energy is expended traversing smaller home ranges and, as such, smaller home ranges should be favoured when they meet all nutritional, social, reproductive, and security requirements (Mitchell and Powell 2007). In theory, optimal ranges support year-round use. Seasonal resource limitations can lead to distinct use of multiple, spatially-separated core areas annually, as was observed for most GPS collared sheep in the S8MP. Equivalent core area sizes for individuals with a single core versus multiple core areas suggests that individuals generally needed the same amount of space to obtain required resources, but for some individuals the distribution of resources was disjunct. A mix of resident and migratory behaviours has also been observed in other BC Stone's sheep populations (Wood et al. 2010).

It is not known if S8MP sheep that were resident on particular ranges year-round, particularly females in the S8M PTP High Elevation Zone that also had the smallest home ranges, were associated with high-quality ranges or restricted by limiting factors. Heimer (1999) suggests that "better habitats correlate with smaller home ranges that support higher population densities where high range fidelity dominates distribution". Resident behaviours were more common in the Stone population, where sheep density was estimated to be twice the density of the Sentinel sheep (Chapter 4).

Both sexes showed strong directionality of movements across the Sentinel Range and along the main axis of the Stone Range. With few exceptions, east to west movements across the Sentinel Range and north to south movements along the Stone Range in summer follows the orientation of major ridges and drainages, which likely facilitate travel. Average movement distances of 10 - 14 km between distinct core areas in the S8MP were consistent with distances of 8 km for Stone's sheep movements to licks in BC's Besa-Prophet area, and roughly 15 km between seasonal ranges of Dall's sheep (*Ovis dalli dalli*) in Alaska (Luckhurst 1973; Simmons 1982).

The 99th percentiles of individual movement rates clearly represented travel between core areas. Rapid and direct movement between isolated habitats suggests individuals perceive risks associated with movements across areas they don't normally occupy. In most cases, individuals showed high fidelity to travel routes. Fidelity to corridors is likely also a strategy for minimizing risk during these movements because familiarity can facilitate rapid retreat to the closest escape terrain during predator attack or disturbance (Festa-Bianchet 1986b).

We observed temporary shifts in winter range use, suggesting flexibility in range use strategies adopted by individuals. Temporary range shifts have also been observed in Dall's sheep and bighorn sheep populations (Becker *et al.* 1978; Festa-Bianchet 1986b; Simmons 1982). Despite examples of occasional flexibility in range use, most wild sheep show strong fidelity to ranges, even in cases where ranges are of poor quality or are associated with high mortality risk (Watts and Schemnitz 1985).

Metapopulation spatial structuring is apparent because S8MP sheep belong to at least two populations separated by the Toad River. Contiguous populations with no barriers to dispersal may interact, likely primarily through dispersal and seasonal movements of males (Bleich *et al.* 1996; Festa-Bianchet 1986a). Seasonal movement to sheep ranges outside the study area occurred regularly at the Alaska Highway 'Rock Cut' west of Summit Lake (Stone Mountain Provincial Park) and the Alaska Highway at Petersen Canyon south of Muncho Lake (Muncho Lake Provincial Park). Occasional observations of sheep on the highway near the Trout River mineral licks and at the south end of the Sentinel Range (Chapter 8) suggest these locations may also facilitate movements among adjacent populations.

The Alaska Highway corridor, which follows the Tetsa, McDonald, Toad, Muncho, and Trout watercourses, is a heavily-used mineral source for both Sentinel and Stone S8MP sheep populations. Licks are typically associated with glacio-fluvial processes of weathering and sediment deposition, and therefore tend to be in valley-bottoms. Heimer (1974) reported that all marked females and more than 80% of marked males returned annually to a mineral lick in Alaska that was used by multiple populations of Dall's sheep, with home ranges overlapping only at the lick. Mineral lick use at the periphery of home ranges may have social and genetic implications at the metapopulation level, as links for migration and dispersal. Dispersal may be associated with use of peripheral mineral licks, if young males in nursery groups follow other family groups away from the lick (Heimer 1974; Simmons 1982).

The natural licks that we documented were consistent with historic and local knowledge reports, suggesting that we likely documented all of the important natural licks in the study area. For the one female with no confirmed use of mineral licks, it is possible that she used known licks scarcely or at finer time scales than our GPS collar fix schedule would capture, that small unmapped lick sites were used, or that forage provided sufficient minerals (Nichols and Bunnell 1999).

We confirmed use of some mineral lick complexes by both sheep and mountain goats. Differences in forage use among species may be reflected in different lick use patterns (Ayotte *et al.* 2006; Ayotte *et al.* 2008; Hebert and McTaggart-Cowan 1977), but generally, management activities that maintain the integrity of mineral lick use by sheep may also serve local mountain goat populations.

PART IV HABITAT USE AND SELECTION

CHAPTER 8 Use of the Alaska Highway corridor by Stone's sheep

Cubberley, J.C. 2011. Use of the Alaska Highway corridor by Stone's sheep. Pages 102-117 *in* Stone's sheep population dynamics and habitat use in the Sulphur / 8 Mile oil and gas pre-tenure plan area, northern British Columbia, 2005 – 2010. Synergy Applied Ecology, Mackenzie, BC. 167 pp plus appendices.

INTRODUCTION

The Alaska Highway is an important transportation and infrastructure corridor providing the only direct ground route from the contiguous United States to Alaska through British Columbia (BC), Canada since the 1940's. Its construction serves as an engineering and historical monument of World War II and prompts scores of travelers and tourists to experience the highway each year. Many travelers enjoy wildlife viewing opportunities the highway provides.

In the Sulphur / 8 Mile Project (S8MP) area Stone's sheep are regularly seen along the Alaska Highway. Road salt deposited by highway maintenance crews in winter may provide minerals that create or enhance naturally occurring mineral licks along roads (Case 1938; LeBlond *et al.* 2007; Morgantini and Bruns 1988). S8MP sheep also cross the Alaska Highway to reach seasonal ranges south and west of the study area (Chapter 7). Addressing the effects of road and right of way use is relevant because the highway and other linear infrastructure such as seismic lines, transmission lines, and pipelines fragment habitat and have the potential to inhibit movement to mineral licks or seasonal ranges (Cole *et al.* 1997; Laurian *et al.* 2008; LeBlond *et al.* 2007; McCallum and Dobson 2002; McGregor *et al.* 2008; Papouchis *et al.* 2001; Wiegand *et al.* 2005). Proposed routes for the Alaska Pipeline Project may influence S8M Stone's sheep that frequent the Alaska Highway.

Vehicle collisions with sheep on the Alaska Highway are a significant mortality factor for sheep in the S8MP area (Chapter 6). Road use by wildlife is common in Canada and often leads to conflicts with vehicles. On average, 25,000 animals are involved in collisions every year in Canada, resulting in an estimated cost of over $200 million annually (Tardiff 2003; Transport Canada 2003). Between 2001 and 2005, the Insurance Corporation of British Columbia (ICBC) reported over 9,000 vehicle-wildlife collisions in BC per year (Hesse 2006).

The greatest importance to mitigation planning is determining where conflicts occur and focusing efforts on site-specific measures. The primary objective was to characterize temporal and spatial patterns of road use and associated mortality of Stone's sheep along the Alaska Highway on the S8MP boundary.

Specifically, we:

- Identify movement patterns relative to the Alaska Highway corridor using location data from GPS collared sheep;
- Identify common highway use and highway crossing points;
- Identify daily and seasonal use patterns at the Alaska Highway 'Rock Cut' mineral lick using remote camera photo data;
- Identify vehicle traffic and vehicle-wildlife collision patterns using ICBC claims data;
- Discuss mortality risk to sheep that use the highway;
- Assess efficacy of salt blocks to intercept and reduce sheep occurrence on the highway.

METHODS

Study area

We focused on the 180 km stretch of the Alaska Highway between Summit Lake and the Liard River. Ten-year average traffic volume is estimated at 523 vehicles/day, peaking to 853 vehicles/day in July and August (http://www.th.gov.bc.ca/trafficData).

The Alaska Pipeline Project has two proposed routes that may affect Stone's sheep within the S8MP area. One proposed route follows the Alaska Highway from the Liard River crossing south (http://www.emr.gov.yk.ca/oilandgas/ahpp.html) while the other route follows the Liard River east before turning south and passing through the northern portion of the S8M Pre-Tenure Plan High Elevation Zone (http://www.thealaskapipelineproject.com/).

Road use and movements

We compiled and compared data from multiple sources between 2005 and 2010 to characterize temporal and spatial patterns of highway use and mortality of both male and female Stone's sheep. Data were obtained using GPS radiocollars, remote cameras, Insurance Corporation of British Columbia (ICBC) wildlife claims, and observations by highway maintenance crews, project biologists, and local residents. Refer to Chapter 3 for a detailed description of sheep captures and radiocollar specifications.

We mapped the centre line of the segment of Alaska Highway from the Liard River to east of Summit Lake at 50 m resolution and used movement rates of GPS collared sheep to define analysis distances from the highway centerline. Movements were calculated as straight-line distances traveled by individuals between consecutive GPS location fixes every 6 or 7 hrs on a 2-dimensional plane, then standardized by calculating movement distance in m/hr. We selected a 400 m buffer distance based on average movement rate per hour for male and female sheep combined (Chapter 7). Data from 2005 were excluded from analyses of daily timing of highway use to reduce bias caused by an even (6 hr) GPS collar fix interval (Chapter 3).

Location data were analyzed to examine whether sheep use the highway incidentally to cross on their way to seasonal ranges (road crossing event), or if they travel to the highway specifically to lick road salts (road use event). We derived directionality polygons using the directional distribution tool in Geographic Information System software (GIS; ArcGIS 9.3.1, Chapter 7) to indicate general movement of radiocollared sheep between backcountry ranges and the Alaska Highway.

Salt blocks were deployed along the Alaska Highway corridor prior to and during this study by BC Parks and the Northeast BC Wildlife Fund, in an attempt to discourage sheep from congregating on the highway to lick road salts. We conducted a post-hoc analysis to assess the effects of salt blocks on sheep movements in relation to the highway. We assumed that collared individuals located ≤50 m away from a salt block were not random locations and indicated use of the block. Sheep movements before and after salt block visits were examined to determine whether individuals still used or crossed the highway.

To quantify site-specific diurnal road use, we used Moultrie Model 160 remote infrared digital cameras to photograph a 350 m contiguous segment of the Alaska Highway known locally as the 'Rock Cut' between May and October 2009 (Figure 8.1). This segment of road bisects a naturally occurring mineral lick where sheep congregate and mineral characteristics are enhanced due to road salt application during winter months. To include the greatest field of view, we used 2 remote cameras identically programmed (Table 8.1) to take a photo simultaneously at the top of each hour, resulting in a 2 photo mosaic of the sample length of highway. Cameras were mounted mid-slope on the opposite side of the valley approximately 250 m from the highway. We aimed the cameras to photograph the largest segment of highway used by sheep most often. Photos were stored on a removable compact flash card to ensure sufficient storage capacity and increased data security.

Table 8.1 Moultrie model 160 remote infrared digital camera settings used to record diurnal road use by Stone's sheep at the Rock Cut along the Alaska Highway.

Attribute	Setting
Mode	Photo
Image resolution	High (3M; 2048 x 1536)
Multi-shot	1 Photo per event
Delay	Off
Time-lapse frequency	1 hour
Information strip	On

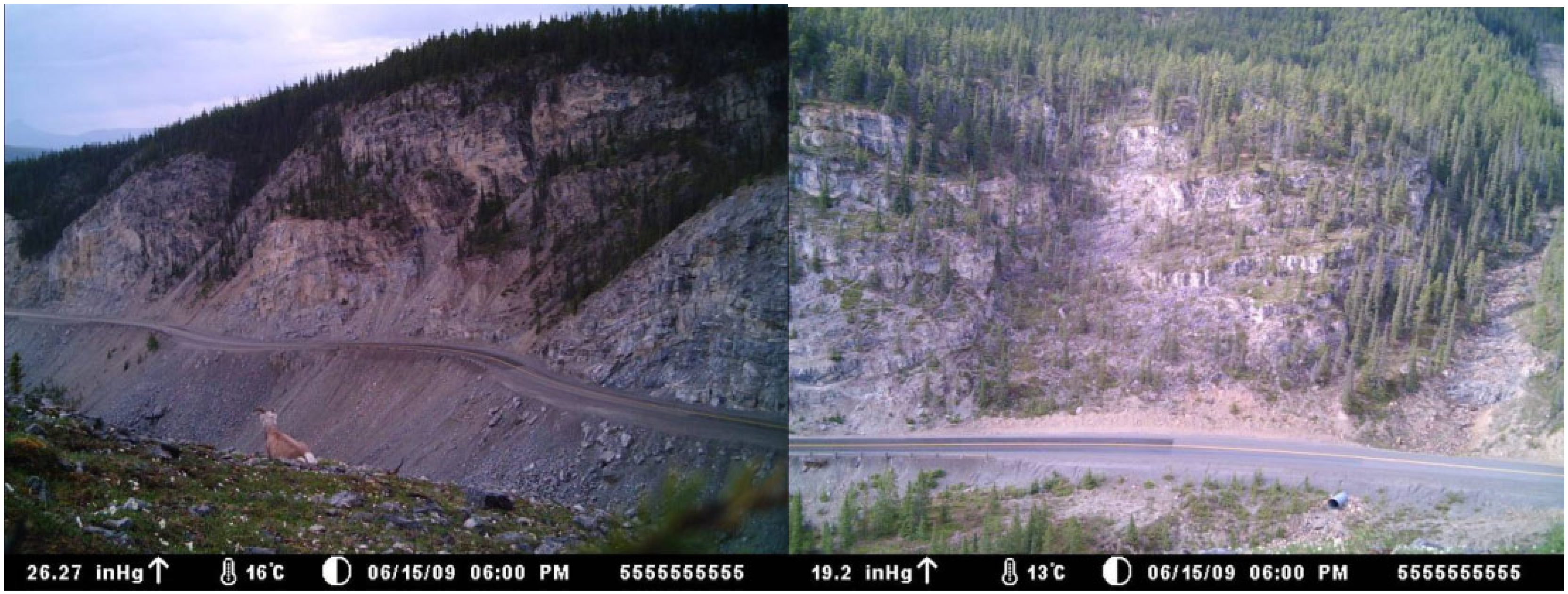

Figure 8.1 View of the Rock Cut along the Alaska Highway at the southern boundary of the Sulphur / 8 Mile Stone's Sheep Project area.

Mortality due to vehicle collisions on the Alaska Highway

We examined ICBC data for all vehicle collisions involving ungulates along the 282 km stretch of highway between Fort Nelson and the Liard Hot Springs from 1996 to 2005. Data on the exact collision locations are rare and as a result ICBC claims data are grouped by the closest population center. Sheep are not known to frequent the Alaska Highway east of the North Tetsa River crossing and collisions likely occurred within the monitored S8MP highway segment. We compared time of day and month when collisions were reported with sheep highway use patterns determined from GPS collar and remote camera data.

Project biologists opportunistically surveyed the highway transect and enlisted local highway maintenance crews and Toad River residents to informally record live and dead sheep observed on the road from 2006 - 2010. The number of confirmed deaths was compared to estimated population size (Chapters 4) to estimate minimum annual mortality rates due to vehicle collisions.

RESULTS

Highway use by GPS collared sheep

Mean movement rates for all GPS collared sheep locations (n = 50,987) was 64 m/hr, resulting in a mean movement potential during 6 and 7 hr fix intervals of 416 m. The mean 95th percentile movement rate was 261 m/hr and mean 95th percentile movement distance between consecutive GPS locations was 1,697 m. These values are under estimated as we did not account for variations in travel direction and landscape topography.

Sixty-five percent of all GPS collared sheep (n = 37) were within the 95th percentile movement distance (1,697 m) from the highway at some time throughout their monitoring period. Thirteen individuals were from the Sentinel population and 11 from the Stone population. Most (57%) GPS collared sheep were within 400 m of the highway at least once. Some individuals traveled several kilometers from backcountry ranges to use or cross the Alaska Highway (Figure 8.2, Chapter 7).

Road use occurred more frequently between June and August (Figure 8.3). Movements to ranges across the Alaska Highway occurred between May - July and October - December with the most crossing events in June. Crossing and use events between October and December were located exclusively at Petersen Canyon where female sheep alternate ranges on the east and west side of the highway. There were no crossing or use events between January - March. Highway use occurred primarily during daylight between 0900 and 1600 hrs (Figure 8.4). Sentinel Range sheep north of Petersen Canyon do not appear to be crossing the highway to visit the Trout River Licks north of Muncho Lake, choosing to remain on the east side of the highway to lick (Figure 8.2).

Eighty percent of GPS collared sheep that used salt blocks along the highway either crossed or licked at the Alaska Highway despite the presence of salt blocks. As well, an aerial survey to verify salt drop locations determined that some salt blocks did not show sign of being utilized by any animal.

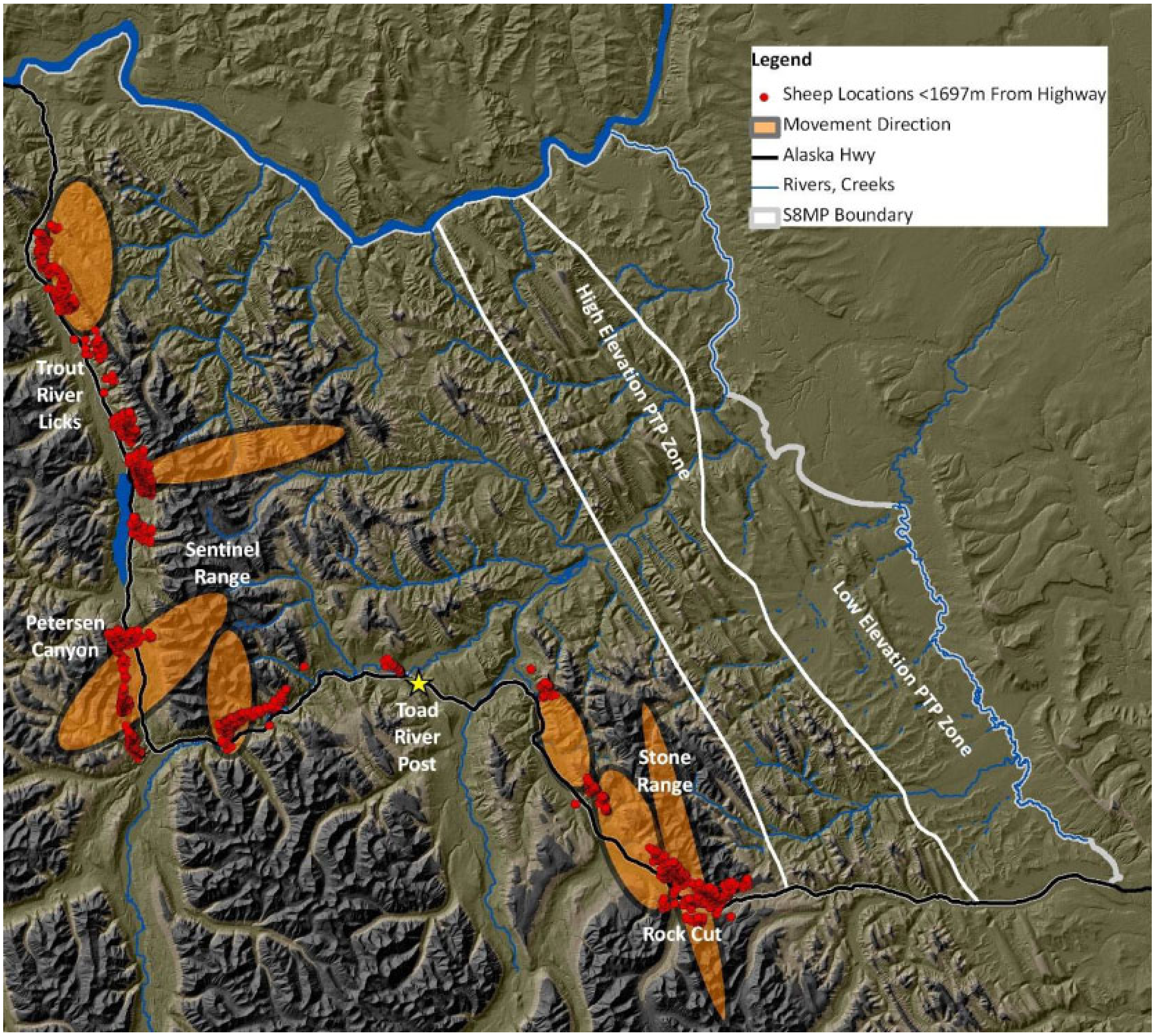

Figure 8.2 GPS locations within the 95th percentile of movement distances between consecutive locations (1,697 m) from the Alaska Highway centre line for 24 Stone's sheep, 2005 - 2010. Polygons indicate generalized movement direction of sheep between backcountry ranges and the highway.

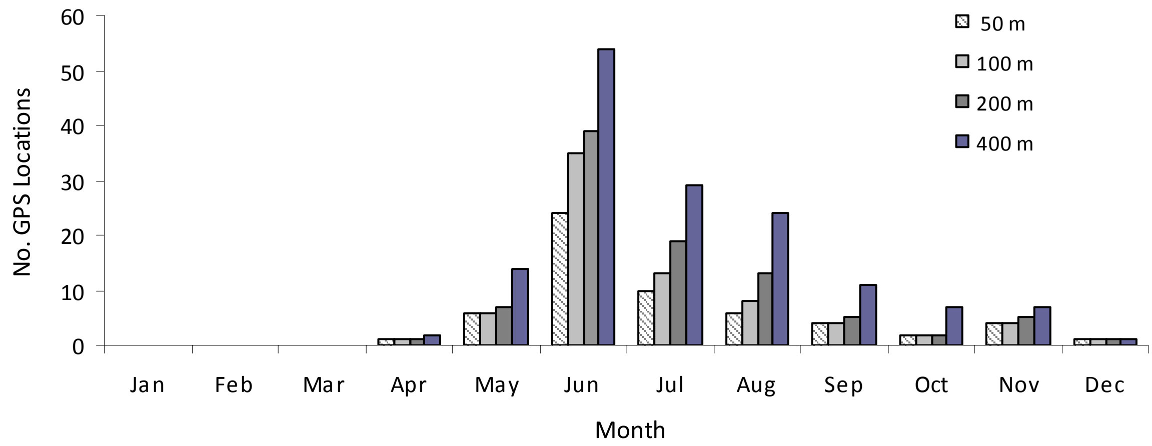

Figure 8.3 Number of GPS locations by month within 400 m of the Alaska Highway centre line for 21 Stone's sheep, 2005 - 2010.

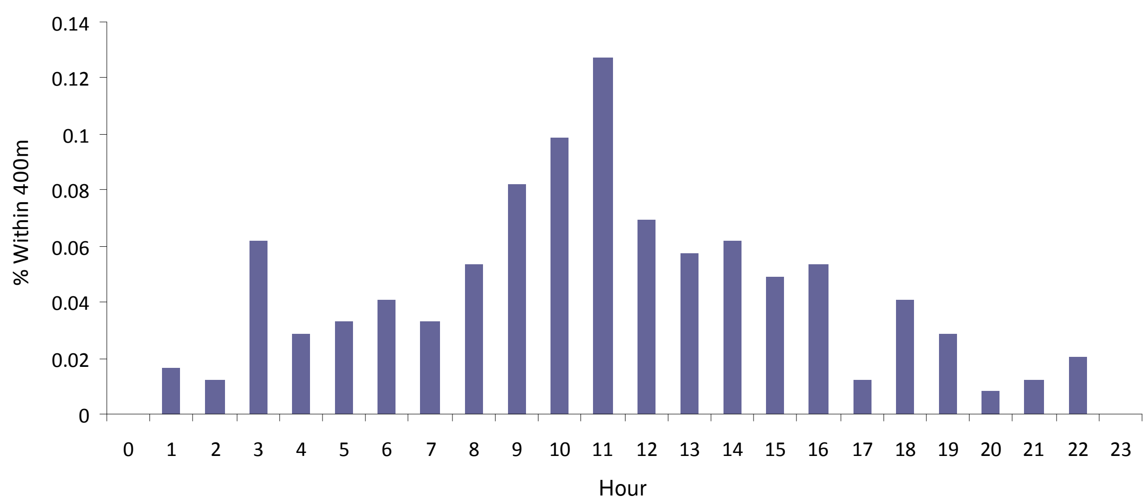

Figure 8.4 Proportion of GPS locations within 400 m of the Alaska Highway centre line each hour for 21 Stone's sheep, 2005 - 2010.

Highway use detected by remote cameras

Remote cameras captured 7,399 photos and operated continuously for 176 days between May 9, 2009 and October 31, 2009. Overall mean photo success was 88% with cameras operating as programmed 99% of the time from May to July, falling to 79% between September 1 and October 31. Remote camera data corresponded well with GPS collar data with respect to month (Figure 8.5) and time of day (Figure 8.6) that sheep were on the road. Camera data suggest both male and female Stone's sheep utilize roads in short but relatively frequent visits normally distributed throughout daylight hours. Time spent on the road typically lasted no longer than an hour.

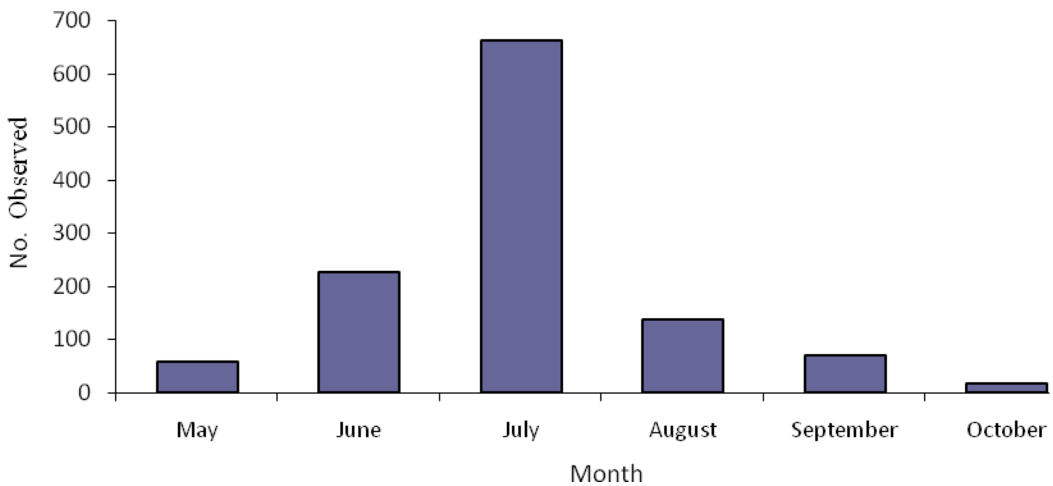

Figure 8.5 Number of road use events per month for male and female Stone's sheep photographed at the Rock Cut along the Alaska Highway, during daylight hours from May - October 2009. Monthly values are the sum of sheep observed during hourly counts and may include double counts of individuals.

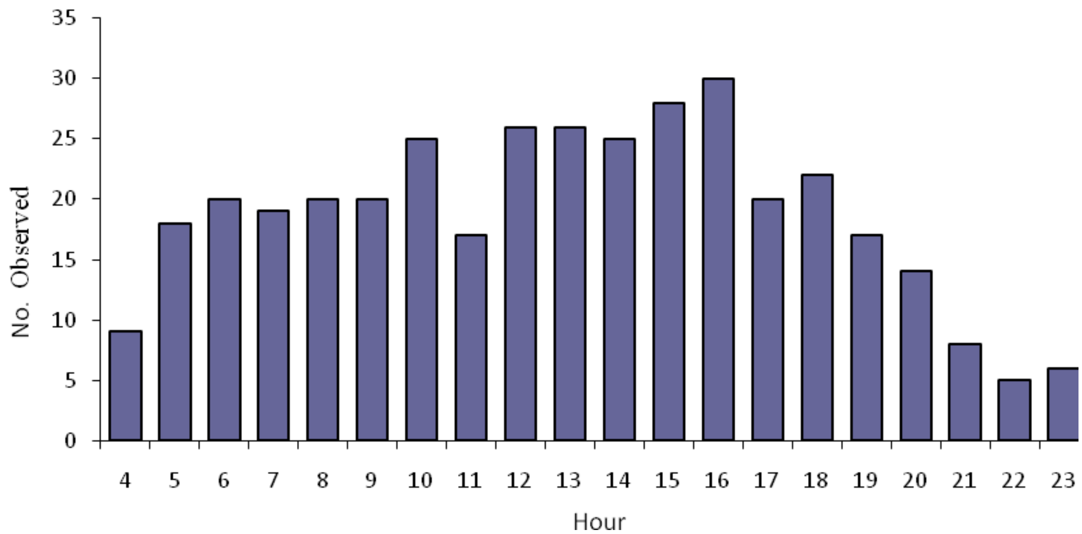

Figure 8.6 Number of road use events per hour for male and female Stone's sheep photographed at the Rock Cut along the Alaska Highway, during daylight hours from May - October 2009. Values are the sum of sheep observed during hourly counts and may include double counts of individuals. Varying hours of daylight bias the extreme left and right portions of the histogram as night photos were inconclusive and excluded from analyses.

Incidental observations

Local resident observations confirmed male and female Stone's sheep were sighted on the highway primarily at locations identified by GPS collar data (Figure 8.7, Table 8.2). Resident observations also corresponded with temporal trends highlighted by GPS collar and camera data.

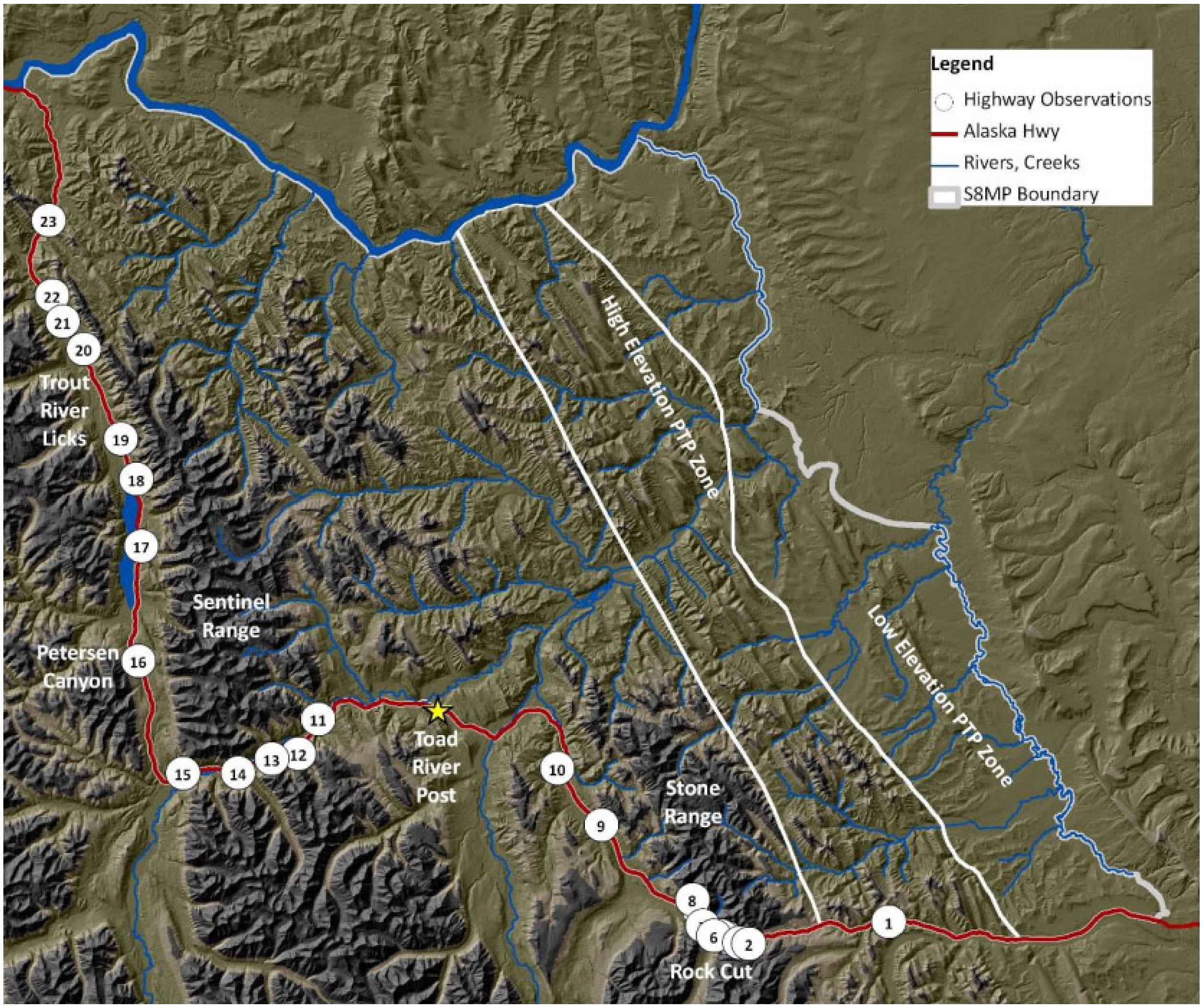

Figure 8.7 Location of Stone's sheep observations on the Alaska Highway, 2005 - 2010. GPS coordinates of numbered points are provided in Table 8.2.

Table 8.2 Coordinates of Stone's sheep observations on the Alaska Highway recorded by local residents, project biologists and highway maintenance crews, 2006 - 2010.

Map number	Location	Easting[1]	Northing[1]
1	Tetsa River Bridge #1	416215	6503765
2	Highway 2 km west of Summit Lake	402167	6501557
3	Highway near Erosion Pillars trailhead	401236	6501687
4	Rock Cut east end	399860	6502171
5	Rock Cut	399339	6502390
6	Rock Cut west end	398634	6502349
7	Baba Canyon and Wokkpash River trailhead	397527	6503400
8	Highway at pullout north of Baba Canyon	396494	6504687
9	Mile 406 hill	387316	6513523
10	MacDonald R Bridge	382875	6519179
11	Highway along Toad River 6 km east of Centennial Falls	358860	6523548
12	Highway along Toad R 1 km east of Centennial Falls	355269	6520675
13	Centennial Falls	354210	6520139
14	Toad River Bridge	350857	6518739
15	Mile 441 hill	345285	6518705
16	Petersen Canyon	340823	6529998
17	Highway at Muncho Lake alluvial fan	341128	6541546
18	Muncho Lake viewpoint corner	340634	6548220
19	Boulder Canyon	339049	6552278
20	Highway near Trout River mineral licks	335318	6561035
21	Mile 474 hill	333218	6564035
22	Highway 6 km north of Trout River mineral lick parking	332164	6566355
23	Mile 480 Trout River	331808	6574239

[1] Coordinates are Universal Transverse Mercator Zone 10, North American Datum 1983.

Mortality due to vehicle collisions on the Alaska Highway

ICBC claims data comprised 448 records of wildlife-vehicle collisions. Of these claims, 371 (83%) were for ungulate-vehicle collisions including moose, deer, caribou, elk, sheep, and bison (Figure 8.8). Moose and deer comprised 311 of the ungulate related claims with only 6 records for Stone's sheep. Five of 6 claims involving sheep were made between 2001 and 2004 and occurred between the months of May and August, with most collision claims occurring in July (Figure 8.9). Collisions occurred between 12:01 and 18:00 hours, with the majority occurring during 12:01 - 15:00 hours (Figure 8.10). These results are consistent with road use recorded by GPS collar and remote camera data.

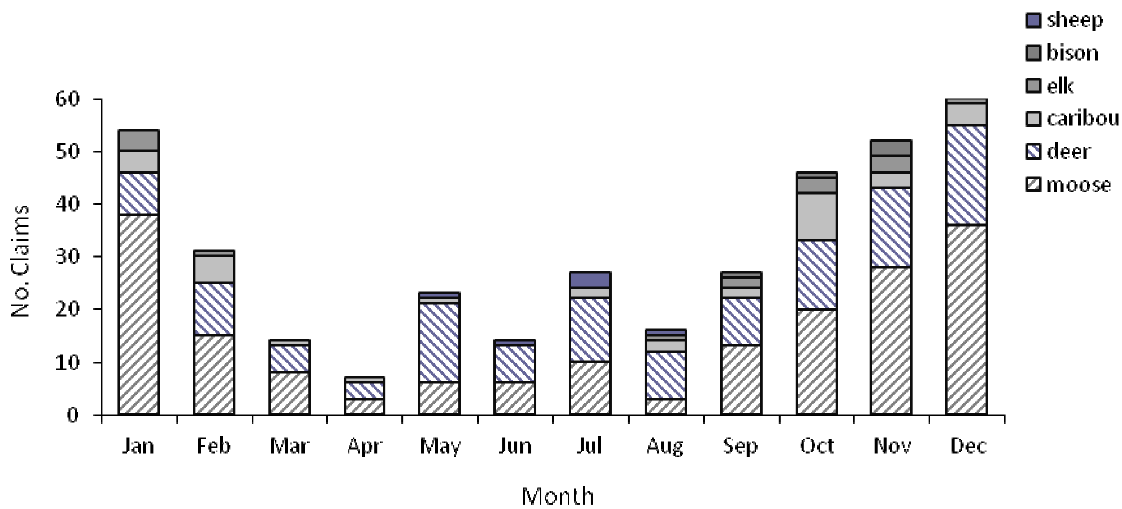

Figure 8.8 Monthly Insurance Corporation of British Columbia collision claims (n = 371) involving large ungulates along the Alaska Highway between Fort Nelson and the Liard River Hot Springs, 1996 - 2005.

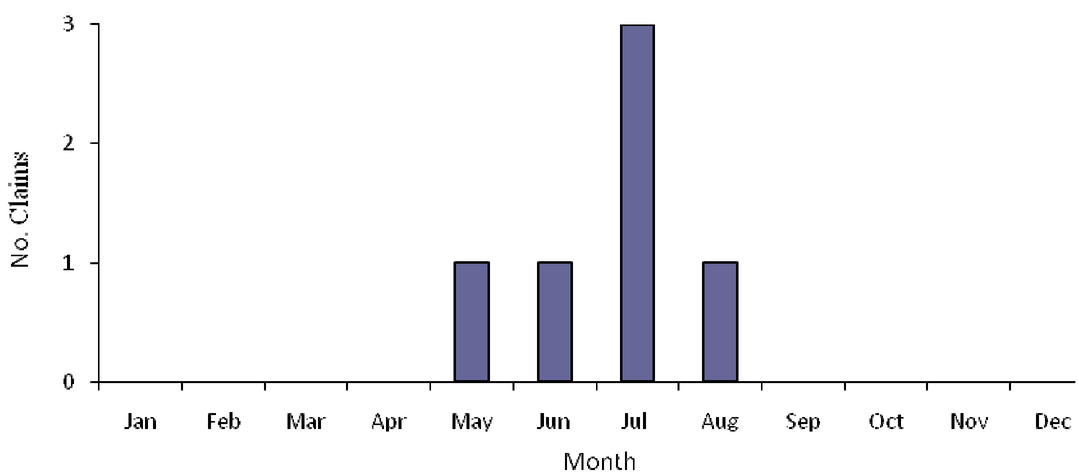

Figure 8.9 Monthly Insurance Corporation of British Columbia collision claims (n = 6) involving Stone's sheep along the Alaska Highway between Fort Nelson and the Liard River Hot Springs, 1996 - 2005.

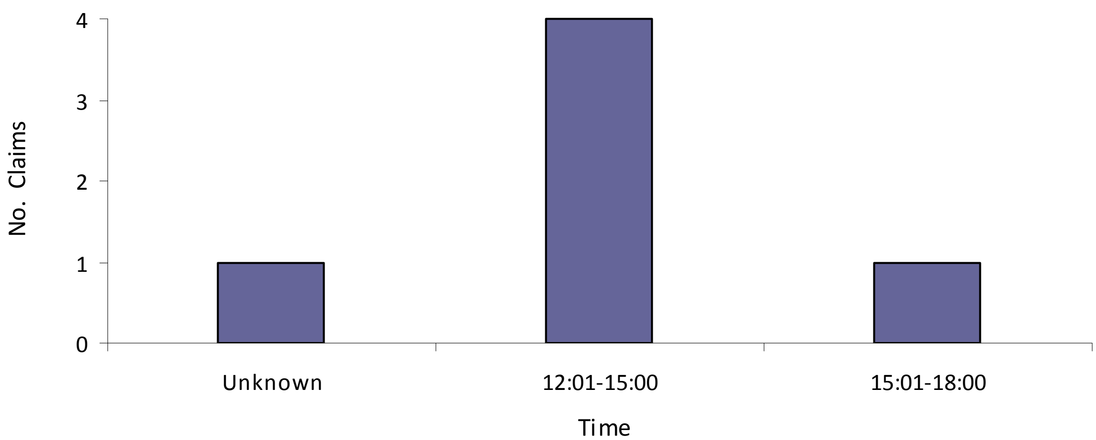

Figure 8.10 Time of day when 6 Insurance Corporation of British Columbia highway claims involving Stone's sheep occurred. Collisions occurred between Fort Nelson and Liard River Hot Springs, 1996 - 2005.

We confirmed 14 Stone's sheep (10 F; 1 M; 3 lambs) mortalities due to vehicle collisions along the monitored segment of the Alaska Highway, from 2005 - 2010 (Figure 8.11). All mortalities occurred between June and September. Vehicle collisions accounted for 8% of deaths (3 of 37) for collared females in the Stone population over 5 years (Chapter 6). One of these deaths occurred in 2007, a year in which 10 vehicle-related deaths of unmarked sheep (7 females, 3 lambs) were observed incidentally. Annual mortality rates of females from vehicle collisions ranged from <1% to 4% of the female population over the course of the S8M Project (8 of 202 females counted in the Stone population in March 2007; Chapter 4). Incidental observations of unmarked Sentinel females and one unmarked Stone male killed by vehicles suggest that highway mortality is likely significant for both populations and all age-sex classes.

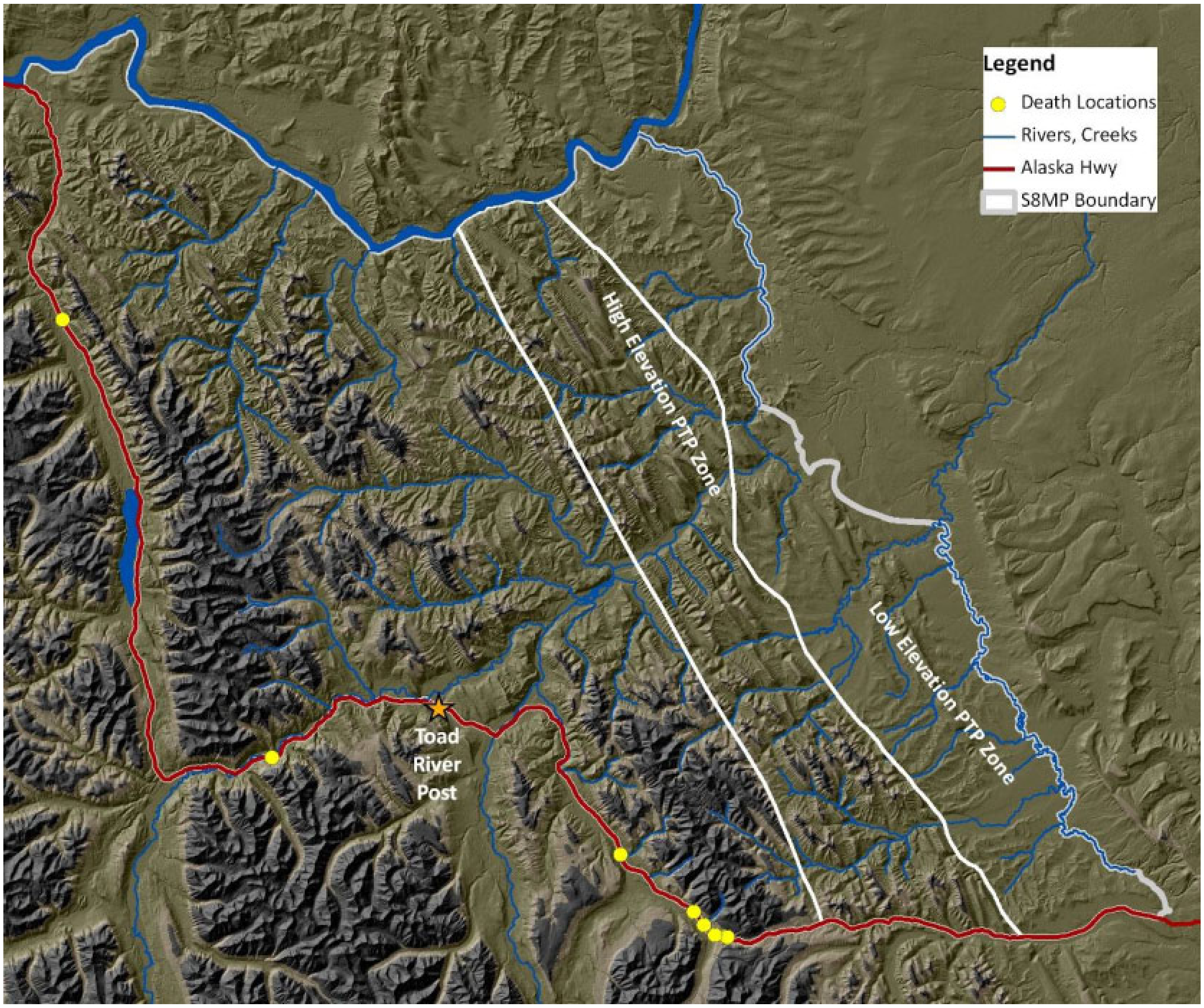

Figure 8.11 Road mortality locations for 14 unmarked male and female Stone's sheep on the Alaska Highway, 2005 - 2010.

DISCUSSION

Highway use data from multiple sources are well correlated and indicate that sheep have defined, predictable spatial and temporal road use patterns. Almost two-thirds of GPS collared sheep licked mineral salts on the Alaska Highway at least once during the study. Highway use occurred primarily in June and July during daylight hours between 0900 and 1600 hrs, coinciding with the heaviest traffic volume. No collared sheep used or crossed the highway in January – March. Highway use and crossings in October through December occurred exclusively at Petersen Canyon, where female sheep use ranges seasonally on the east and west sides of the highway (Chapter 7). These patterns offer promise for mitigation of risks and impacts associated with highway use by sheep.

Recent studies suggest that patterns in the distribution of collisions are dependant on animal density, traffic volume, topography, distribution and extent of habitat, and vehicle speed. Other contributing factors include landscape features such as road width, forest cover, fences, guardrails, roadside embankments, and vegetation near the road along with the amount of time the animal spends on the roadway (Forman and Alexander 1998; Jaeger *et al.* 2005; Malo *et al.* 2004; Seiler 2004; van Langeveld and Jaarsma 2004; Waller *et al.* 2006). Highway crossing locations in the S8MP area are influenced by topographical features such as incised draws, canyons, and stream fans on both sides of the highway.

Our data is unable to infer if Stone's sheep suffer significant sub-lethal impacts related to the Alaska Highway. High levels of human/traffic disturbance can cause physiological reactions such as increased heart rate, depleted energy, adrenal gland enlargement and increased susceptibility to disease (Keller and Bender 2007). Bighorn sheep in Colorado were affected by traffic disturbance and avoided road use but kept trying to access mineral licks, suggesting the want for minerals may lead to unpredictable behavior around traffic (Keller and Bender 2007; Papouchis *et al.* 2001).

Although reporting rates of incidents are increasing and may suggest that human and wildlife injuries are escalating, the few ICBC records for Stone's sheep-vehicle collision claims are due to underreporting. Fatal collisions with transport trucks likely cause no damage to the truck and therefore are not reported. Fear of rising insurance premiums may deter motorists from reporting collisions with wildlife that cause little or no property damage. Less than 5% of all animal-related collisions result in human injury, however, some collisions do cause extensive injuries to humans and death almost always results for the animals involved (Seiler 2004). Typically, observed mortality is less than actual mortality levels as an estimated 35% of wildlife-vehicle collisions are not reported and many deaths go undetected if animals that are hit and injured die a distance away from the roadway (Hesse 2006; Sielecki 2004; Slater 2002; Tardiff 2003). If unreported vehicle-wildlife collisions are factored into the confirmed mortality rate, annual road mortality for Stone's sheep in the S8MP area could exceed 5%.

To improve reporting rates, the BC Ministry of Transportation implemented a Wildlife Accident Reporting System (WARS) for highway maintenance contractors to collect information on wildlife mortalities along several highways in BC. Unfortunately, this system does not collect such information for the BC segment of the Alaska Highway, which is managed and maintained by the Government of Canada (Hesse 2006). Collection of highway observations over multiple years will allow insight into the severity and potential trends of all wildlife-vehicle collisions, and allow for implementation of informed mitigation techniques. Local monitoring could include continued use of remote cameras.

Public awareness needs to be increased. Wildlife conservation efforts are often enhanced by public awareness (Dalman 2004; Gayton 2004; Jacobson *et al.* 2010; Mech 1996; Weber *et al.* 2006) and the opportunity to engage with wildlife on a road is often the only prospect to connect and foster concern for their long-term viability. Complacency is perhaps the main reason for failure of signage to be effective in reducing collisions. Updated signage should be erected at the common crossing points to warn motorists. Posters in gas stations and information kiosks should also be considered. Site-specific physical mitigation measures such as fences or wildlife passages combined with adjustments of speed limits can be costly, but endure for several decades and as such offer potential for long-term benefits and cost savings.

PART V HABITAT USE AND SELECTION

CHAPTER 9 Seasonal habitat preferences of male and female Stone's sheep described by multi-scale resource selection functions

Hengeveld, P.E. and Cubberley, J.C. 2011. Seasonal habitat preferences of male and female Stone's sheep described by multi-scale resource selection functions. Pages 118-144 *in* Stone's sheep population dynamics and habitat use in the Sulphur / 8 Mile oil and gas pre-tenure plan area, northern British Columbia, 2005 – 2010. Synergy Applied Ecology, Mackenzie, BC. 167 pp plus appendices.

INTRODUCTION

Resource selection functions (RSF) define probabilities of habitat use based on comparisons of used and available habitat (Manly et al. 2002). Habitat, as defined here, is the set of resources and conditions necessary for animals to occupy an area. Insights to habitat use decisions made by individuals can be gained by evaluating selective use of resources distributed across the landscape. Selection is defined as use of a resource disproportionately more than it is available and, conversely, avoidance is inferred when a resource is used less in proportion to its availability (Manly et al. 2002).

Our goal was to interpret relative importance of Stone's sheep habitat attributes that best predict sheep distribution, and to identify variation in use of these attributes among seasons, between sexes, and across areas (populations) that vary topographically. We evaluated 3 competing habitat selection models to assess relative influence of predator avoidance, forage type and forage availability on distribution of sheep. We also evaluated how habitat selection varied for an all-inclusive habitat model applied to three expanding spatial scales to provide insight to the scales at which habitat selection decisions are made. We report habitat use to provide a reference for Stone's sheep habitat characteristics, and use RSFs to help explain patterns in habitat selection by sheep. Analyses generally followed those used to determine habitat selection by female Stone's sheep in the M-KMA Besa-Prophet PTP area to extend methods and compare results regionally (Walker 2005).

METHODS

Model development

We developed competing habitat models a priori to test selection preferences for topographic and land cover attributes that influence security and foraging ecology of sheep (Table 9.1). The distribution and behaviour of wild sheep are often explained by trade-offs between avoiding predation risk and maximizing nutrition from limited forage resources (Bleich *et al.* 1997; Corti 2000; Festa-Bianchet 1988a; Ruckstuhl and Neuhaus 2002). Mountain sheep minimize predation risk through close association with habitat features that provide security in the form of steep and rugged escape terrain (Côté and Festa-Bianchet 2003; Festa-Bianchet 1988a; Frid 1994; Hamel and Côté 2007; McKinney *et al.* 2003; Pérez-Barberia and Nores 1994; Risenhoover and Bailey 1985).

Foraging ecology is influenced by distribution of vegetated resources and topographic features which determine availability of forage, particularly grass, sedge, moss, lichen, and the leaves of shrubs. Forage type and quality are also influenced by wildfire and prescribed burns which alter successional stages of vegetated land cover, influencing nutrient quality or abundance and structural qualities in the short-medium term as vegetation regenerates post-burn. Forage availability in winter is heavily influenced by snow depths, with Stone's sheep generally restricted to areas with <30 cm snow (Corbould 1998; Seip 1983; Seip and Bunnell 1985). Warm aspects and windblown areas with convex curvatures are likely to hold less snow, improving forage availability to sheep. In summer, forage availability is linked to site moisture and plant phenology along elevational gradients.

As predation risk and forage availability differ seasonally, we evaluated habitat selection across 6 seasons relevant to Stone' sheep ecology (Berger 1982; Jorgenson *et al.* 1997; Nichols 1978). Season delineations were validated by monthly movement rates of GPS collared sheep in the S8MP area (Chapter 7) and were consistent with Walker (2005).

Table 9.1 Habitat models developed to test selection preferences for topographic and land cover attributes that influence security and foraging ecology of Stone's sheep.

Model	Attributes
Security	Ruggedness + Slope + Escape distance + Slope position
Forage type	Land cover + Burned areas
Forage availability	Solar radiation index + Aspect + Elevation + Elevation^2 + Curvature
All inclusive	All 11 attributes (with 6 slope positions ,8 land cover classes, 2 burn categories = 24 total)

Table 9.2 Calendar dates for 6 seasons relevant to Stone's sheep ecology.

Season (abbreviation)	Date interval
Early Winter (EW)	Jan 01 – Feb 28
Late Winter (LW)	Mar 01 – May 14
Lambing (L)	May 15 – Jun 14
Summer (S)	Jun 15 – Aug 14
Fall (F)	Aug 15 – Oct 31
Rut (R)	Nov 01 – Dec 31

Habitat attribute data

All habitat attribute data were derived from GIS raster grids with 25 m resolution (Table 9.3). For detailed information on the source and construction of GIS map layers refer to Appendices A and B. The analysis area was larger than the study area to accommodate seasonal movements of sheep that crossed the Alaska Highway at the Rock Cut and Petersen Canyon (Chapter 7).

A Digital Elevation Model (DEM) was the basis for topographical attributes elevation, slope, aspect, distance to nearest escape terrain, curvature, ruggedness (Sappington et al. 2007), slope position (Jenness 2006; Weiss 2001), and solar radiation index (Keating et al. 2007). Aspect included two independent variables, east-west aspect and north-south aspect, with positive values being more east- or north-facing respectively and negative values reflecting west and south aspects.

Two Landsat TM Scenes from September 2000 and August 2001 were used to construct digital land cover base maps (Wheate et al. 2007). Provincial Forest Cover data and a Maximum Likelihood Classification technique were used to extract 8 land cover classifications relevant to this analysis (Appendices A and B). BC Ministry of Environment and Ministry of Forests data were compiled to identify areas last burned by wildfire or prescribed burn between 1990 and 2005.

Univariate regressions were conducted by population and season for each resource attribute independently, using location data for female sheep. Resultant *P*-values, Akaike's Information Criterion (AIC) values and overall significance of individual categorical terms (Chi square likelihood ratio test) were compared to identify useful explanatory variables for habitat model development (Appendices A and B).

The degree of similarity between habitat attributes was assessed with a tolerance scores matrix. Tolerance scores <0.2 indicated unacceptable levels of correlation (Menard 2002). Solar radiation index was correlated with north-south aspect. Because regressions indicated that solar radiation index was a better predictor we removed north-south aspect from the habitat selection models.

Table 9.3 Description of habitat attributes used as predictor variables in habitat selection models for male and female Stone's sheep.

Model	Attribute	Values	Description
Security	Ruggedness	Continuous 0 - 1	Vector ruggedness measure of change in slope across 2000 m nearest neighbour analysis on 25-m resolution DEM raster grid (Sappington et al 2007). Greater values indicate highly rugged terrain.
	Slope (°)	Continuous 0 – 90	Slope in degrees derived from 25-m resolution DEM raster grid
	Escape distance (m)	Continuous	Straight-line distance (m) to nearest slope ≥ 50°; derived from 25 m resolution DEM raster grid
	Slope position	6 categories	Topographic position index: a measure of change in elevation across 2000 m nearest neighbour analysis on 25 m resolution DEM raster grid (Jenness 2006; Weiss 2001). Categories: ridge, upper slope, mid slope, flat, lower slope, valley bottom.
Forage availability	Solar radiation	Continuous	Derived from 25 m resolution DEM raster grid slope and aspect (Keating 2007).
	East-West Aspect	Scaled -1 – 1	Scaled measure with flat (0) slopes showing no tendency to be east (1) or west (-1) aspects.
	Elevation (m)	Continuous 280 - 2,500	Elevation above sea level. Sentinel area 320 – 2,380 m; Stone area 440 – 2,130 m.
	Curvature	Continuous	Moving window (3x3 pixel) analysis on 25-m DEM raster to identify if central pixel represents concave (+) or convex (-) slope.
Forage type	Land cover	8 categories	Determined from satellite imagery mapping. Categories: rock (scree, talus and bedrock); alpine; conifer at treeline; mature conifer (20 - 100% canopy cover); deciduous tree; shrub; grass; fluvial (gravel debris fans and riparian areas).
	Burned areas	Categorical	Areas last burned by wildfire or prescribed burn between 1990 and 2005.

Habitat use data

We obtained Stone's sheep habitat use locations from Global Positioning System (GPS) radiocollars on male and female sheep in 2005 - 2010. Refer to Chapter 3 for a detailed description of sheep captures and radiocollar specifications.

We mapped location data for each individual using ArcGIS 9.3 (Environmental Systems Research Institute, Redlands, CA, USA) and visually scanned the data for obvious outliers beyond the continuous distribution of locations. We removed outliers but did not filter data by 2-dimensional (2-D) or 3-D location quality. We did not find evidence of GPS bias among habitat types between areas; the proportion of 2-D and 3-D locations in each habitat class was consistent in both areas, although all habitat classes had greater proportions of 2-D locations in the Stone area. Movement rates (m/h) were also consistent between 2-D and 3-D locations.

We excluded location data from the day of capture and subsequent day, to reduce potential habitat use bias associated with capture activities. We also excluded locations that did not match the expected fix schedule. For the Televilt collars (6 hr location frequency) we allowed a 4 minute window (356 min to 364 min) and for the ATS collars (7 hr location frequency) we allowed a 5 minute window (415 min to 425 min) to account for the time it took collars to acquire satellites and record a location. We calculated fix rates for each individual by year, season, and collar type, dividing the number of valid locations obtained by the expected number of locations in that period (adjusted to 6 hr or 7 hr interval depending on collar type). Mean fix rates per individual were pooled by sex to report fix rates for males and females. We report habitat use by sex and area as seasonal mean values observed for each attribute included in RSF habitat selection models.

Multi-scale sampling of habitat availability

Multi-scale analyses of habitat selection alleviate the biases associated with habitat availability estimates at a single scale and may show different patterns of selection across scales. Used and available habitat attributes are often more similar within small geographic areas than they would be across larger geographic scales. Constraining the sample of available habitats to small spatial scales is likely to limit the variation in sampled habitat attributes, diluting the ability to identify selection (Garshelis 2000). Evaluating selection across large scales, however, may have little value beyond predicting coarse-scale distribution of animals. By evaluating and comparing the characteristics of habitat use and habitat availability at various spatial scales, we can gain insight to how the distribution of resources and limiting factors influence animal behaviour and distributions.

Spatial scale was defined by a) movement distances between consecutive GPS collar locations; b) annual home ranges of sheep monitored >1 year; and c) study area. At the smallest scale, we measured habitat preferences within areas defined by 95th percentile sheep movement distances to compare with results for habitat selection by female Stone's sheep in the Besa-Prophet PTP area (Walker 2005). Next, we were interested in determining which attributes best explain seasonal range selection within individual home ranges. Finally, we measured habitat preferences across the entire area of management interest (study area) to predict coarse-scale distribution of sheep. Sampling intensity was equivalent at all 3 scales.

Movement buffer (MB) scale

We randomly sampled habitat availability within a movement buffer distance on each individual's locations. This is equivalent to Johnson (1980) third order selection and Manly (2002) sampling design III. We used a sampling ratio of 5 random locations for each sheep location (Walker 2005). Seasonal range sizes for both male and female sheep increased ten-fold from early winter to summer (Chapter 7). We also observed high variation in seasonal movement distances both among sheep and among seasons. We chose a constant movement buffer distance regardless of season because sampling intensity differs if a fixed proportion of used to random locations defines habitat availability among seasonal ranges that are not the same size (Arthur *et al.* 1996; Boyce *et al.* 2003). While it may be argued that this overestimates availability in winter when sheep movements are restricted by snow depths, we chose the 95th percentile of movement distances as the movement buffer because: 1) it is conservative compared to maximum distances moved between location fixes; 2) calculated movement distances were straight-line distances and therefore likely underestimate actual movement distances; and 3) the largest 5% of movement distances were distributed across all seasons (Chapter 7).

On average, 95% of an individual's movements were at rates < 300 m/hr (8 M: ≤ 297.8 ± 39.2 SE m/hr; 19 F: ≤ 224.6 ± 10.0 m/hr; Chapter 7). We rounded the average 95th percentile movement rates of males and females to the nearest 5 m then multiplied these by the largest interval between GPS collar fixes (7 hrs) to determine a movement buffer distance (M 2,100 m; F 1,575 m). This was justified because the majority (about 2/3) of female locations and all of the male locations were from ATS G2000 collars having 7 hr fix intervals.

Home range (HR) scale

We limited this analysis to individuals with at least one year of monitoring data. We randomly sampled habitat availability within each individual's home range boundary. This is equivalent to Johnson (1980) third order selection and Manly (2002) sampling design III. Home range boundaries were calculated as 100% minimum convex polygons (MCP) around GPS locations for each individual (Chapter 7). We maintained the same random location sampling intensity as in the MB scale by setting the sampling ratio according to home range size (e.g., a 1:5 ratio within a 2.1 km buffer radius [13.85 km^2 area] was equivalent to a 1:45 ratio within a 125 km^2 home range). Smaller home ranges had smaller sampling ratios to ensure that densities of random locations were equivalent across individual home ranges and across analysis scales. Sampling ratios therefore varied from 16 to 221 random locations per female sheep location (MCP home ranges 25.3 - 344.5 km^2) and 44 to 131 random locations per male sheep location (MCP home ranges 121.1 - 363.1 km^2). We assigned monitoring years to random locations proportionally based on number of sheep locations obtained in each monitoring year. Only one Sentinel male had ≥1 yr of monitoring data, but we chose to model habitat use anyway for general comparisons.

Study area (SA) scale

We pooled all sheep locations by sex and randomly sampled habitat availability within the study area (Johnson (1980) second order selection and Manly (2002) sampling design I). This spatial scale excluded sheep locations west and south of the Alaska Highway. Attributes of habitat availability were determined by sampling one random location per 2,500 m^2, equivalent to sampling every 4th pixel in the study area raster grid (Sentinel area 3,278 km^2 with 1,131,200 random locations; Stone area 1,947 km^2 with 778,800 random locations).

Model evaluation and resource selection coefficients

We used logistic regression generalized linear mixed models to estimate habitat selection coefficients independently for each combination of season, sex, area (population), and geographic scale. Given that individual and annual variation in habitat selection can be significant (Schooley 1994; Walker 2005), we chose mixed-effect models to produce population-averaged results. The strength of this approach is that it accounted for unbalanced sample sizes, temporal autocorrelation, individual differences and year effects.

We specified individuals as the data grouping structure (random intercepts) and allowed the effect of monitoring year to vary among individuals (random coefficients). Modeling the effect of year in this way also reduces any bias that may exist due to differences in GPS collars used in this study (Hebblewhite et al. 2007). Mixed-effects models have two primary advantages relevant to our analyses (Duchesne *et al.* 2010; Gillies *et al.* 2006). First, mixed models can improve model fit for data sets with unequal sample sizes even in the absence of any within-group correlation structures in hierarchical data. Second, where grouping structures exist in the data the estimates for mixed model parameters are independent of the sampling intensity for each group; variability among groups is accounted for and contributes to explained variance; and statistical inferences can be extrapolated to the population level, rather than being limited to the sampled individuals. Estimates of the fixed and random effects in mixed models portray the average effect sizes across the population and help to evaluate the biological implications of habitat selection at a broader scale. Given our goal of supporting science-based management decisions at the population level, identifying average or typical selection preferences was desirable.

We used the lme4 package in R statistical software to fit generalized linear mixed models by Laplace approximation (Bates *et al.* 2011; R Development Core Team 2011). Slope position and land cover categorical habitat attributes were evaluated as deviation contrasts, therefore selection coefficients reported for each category should be interpreted relative to the mean effect of the attribute (Menard 2002). Selection coefficients for burn areas are relative to 'unburned' areas, which included areas last burned prior to 1990. Confidence intervals were the preferred method for evaluating significance of model coefficients but could not be calculated for mixed effect models due to debate over number of degrees of freedom assigned to complex random effects terms. In our case, the number of degrees of freedom is constant across all analyses and Wald statistics were used as a guide for evaluating the relative significance of selection coefficients. We placed greater emphasis on results with higher levels of significance (*P*-value <0.01), but report significance at alpha levels 0.05, 0.01, and 0.001 in results tables for interpretation by the reader.

Within each scale of analysis, the 3 competing models were evaluated seasonally for each combination of sex and area (population), then ranked by Akaike's Information Criterion (AIC) value and relative AIC weights to determine which model best explained sheep habitat selection. AIC is a reflection of the amount of variance explained by the model and the number of parameters included in the model; lower AIC values indicate models that explain patterns in the data most efficiently (Burnham and Anderson 1998). Competing models with a difference in AIC values of <2.0 are considered equivalent (Burnham and Anderson 1998). We used the all-inclusive model to identify seasonal variation in selection for modeled habitat attributes by comparing changes in significance, sign, and magnitude of RSF coefficients across seasons (Boyce et al. 2003). We focused on comparing habitat selection patterns between sexes and between areas. Across the three scales of analysis, we compared the selection coefficients of the all-inclusive model to evaluate the influence of spatial scale on habitat selection by sheep.

We provide selection coefficients for Sentinel males (Appendix D) but focused primary analyses and results on addressing seasonal variation and sexual segregation in the Stone Range (comparable sample sizes and overlapping ranges), and geographic variation for Stone and Sentinel females (comparable sample sizes). We present primary results across spatial scales relative to the MB scale as reference because it was most equivocal to availability sampling methods used for RSF of Besa-Prophet females (Walker 2005), enabling regional comparisons. We also used early winter as the reference for seasonal comparisons because it is the smallest seasonal range (Chapter 7). Positive RSF values that are statistically significant indicate preference for the habitat attribute (i.e., use more than it is randomly available). Negative values that are statistically significant indicate avoidance (i.e., use less than it is randomly available).

RESULTS

Sample sizes

We collected location data for 40 adult Stone's sheep (24 F between March 2005 - March 2009; 16 M between May 2008 - May 2010; Table 9.4). We excluded from analyses 260 (0.6%) female locations and 146 (0.8%) male locations interpreted as errors, leaving 58,528 locations with 72.0% 3-dimensional fixes. The subset used for movement rate analyses (34,780 F and 16,207 M locations) included 74.1% 3-dimensional fixes. Fix rates averaged 83.5% for females (range 64.9 – 99.7%, n = 35 collars) and 83.6% for males (range 44.7 - 97.5%, n = 13 collars). GPS collared sheep represented 5.3% of the estimated number of adult sheep (n = 806) within the study area (Chapter 4). Location data obtained for females reflects known distribution of sheep across both the Sentinel and Stone areas (Chapters 4, 5, 7). This was also true for Stone males, but location data for Sentinel males may not be representative of all males in this population due to priority application of collars in proximity to the S8M PTP High Elevation Zone. Additionally, sample sizes were small for Sentinel males (1 male for home range scale analyses) due to capture limitations.

Table 9.4 Number of individuals and total locations used in seasonal resource selection function analyses at the movement buffer, home range and study area spatial scales, for male and female Stone's sheep in the Stone and Sentinel populations. Analyses at the home range scale were subset to individuals with at least one complete year of data.

Season	Movement buffer and study area scales				Home range scale			
	Stone		Sentinel		Stone		Sentinel	
	F	M	F	M	F	M	F	M
Individuals	9	12	15	4	6	7	13	1
Early winter	1707	2133	3128	453	1707	1858	3128	380
Late winter	3217	2969	5783	711	2657	2668	5334	466
Lambing	1572	1642	2429	401	1266	1286	2244	192
Summer	2861	2646	4419	798	2275	2236	4069	389
Fall	3450	2914	5340	1014	2668	2522	5048	504
Rut	2211	2044	3462	762	1927	1855	3462	388

Data for females spans 4 monitoring years (March 2005 – March 2009); males 2 years (May 2008 – May 2010).

Habitat use

S8MP Stone's sheep used steep (mean 29° - 37°), rugged, convex sites with high solar radiation year round, at mean elevations ranging from 1,400 m during lambing to 1,700 m in summer (Tables 9.5 and 9.6). Most (93%) GPS locations obtained for males and females were above 1,200 m elevation; for males in the S8M PTP High Elevation Zone this percentage was reduced to 86.7% (Table 9.7). Late winter ranges were steeper, more south-west facing, and at lower mean elevations than early winter ranges. West aspects were favoured over east aspects, in all seasons except summer. Use of vegetated alpine areas was predominant year-round. In summer, >84% of sheep locations were in alpine areas and rocky (talus - scree - bedrock) sites. Use of conifer and shrub was common (<35% of sheep locations per season; Tables 9.5 and 9.6). Use of conifer at treeline and grassy sites was also recorded, but less commonly used (<11% of locations per season). Fluvial sites (gravel debris fans and riparian areas) were rare in the study area but used consistently year-round. Deciduous tree cover was generally avoided, while use of burned areas varied seasonally.

Table 9.5 Summary of seasonal habitat use and perceived selection (positive, negative, neutral) relative to habitat availability for 12 male and 9 female Stone's sheep in the Stone population, tested with an all-inclusive habitat model. Habitat use reflects mean values for continuous attribute data and proportion of locations in each category for categorical attribute data. Numbered attributes indicate coding for categories of slope position [1-6] and land cover [4-88]. Availability was measured at random locations within 95th percentile movement distance buffers around sheep locations.

Attribute	Sex	Early Winter	Late Winter	Lambing	Summer	Fall	Rut
Ruggedness[2]	M	0.016 +	0.014 +	0.013 +	0.011 +	0.013 +	0.014 +
	F	0.014 +	0.014 +	0.016 +	0.018 +	0.013 +	0.015 +
Slope (°)	M	30.9 +	31.5 +	32.1 +	27.8 +	28.4 +	31.8 +
	F	36.8 +	37.0 +	33.2 +	29.0 n	30.7 +	34.1 +
Escape distance (m)	M	777 +	644 –	542 –	789 n	638 –	666 –
	F	337 –	359 –	389 –	431 –	460 –	372 –
[1] Ridge (%)	M	57.5 n	35.8 –	37.0 –	36.1 n	38.5 n	41.3 –
	F	49.4 –	33.6 –	30.7 –	60.3 –	37.7 n	49.5 +
[2] Upper slope (%)	M	21.4 +	20.8 +	23.8 +	16.8 +	16.1 +	24.6 +
	F	37.3 +	31.6 +	19.1 +	24.2 +	21.3 +	31.3 –
[3] Mid slope (%)	M	14.9 n	31.5 n	26.2 n	36.0 +	33.0 +	24.5 n
	F	12.8 +	31.0 +	38.8 +	4.1 n	33.1 n	14.3 –
[4] Flat (%)	M	0.1 –	0.1 n	0.2 –	0.1 n	0.2 n	0.1 n
	F	×	×	×	1.0 –	0.2 n	×
[5] Lower slope (%)	M	4.8 n	9.4 n	7.7 n	8.8 –	9.2 n	7.0 n
	F	0.6 +	3.1 +	9.0 +	7.3 +	5.3 n	1.9 –
[6] Valley bottom (%)	M	1.3 n	2.5 n	3.1 –	2.2 n	3.0 n	2.5 n
	F	0 –	0.7 –	2.4 n	3.1 –	2.4 –	2.9 n
Solar radiation[2]	M	0.634 +	0.599 +	0.666 +	0.471 +	0.551 +	0.630 +
	F	0.766 +	0.777 +	0.633 +	0.476 +	0.576 +	0.695 +
Aspect (East +, West –)	M	-0.319 –	-0.302 –	-0.227 –	0.028 n	-0.005 n	-0.217 –
	F	-0.336 –	-0.223 n	-0.106 n	0.051 +	-0.051 +	-0.257 n
Elevation (m)[3]	M	1514 +	1469 +	1404 n	1591 +	1465 +	1474 +
	F	1507 –	1441 –	1424 +	1640 +	1509 +	1512 +
Curvature (Convex +, Concave –)	M	0.383 +	0.233 +	0.387 +	0.216 n	0.249 n	0.342 n
	F	0.382 n	0.116 +	0.228 +	0.518 +	0.235 +	0.307 +
[4] Rock (%)	M	2.5 n	12.1 n	8.2 n	24.2 –	8.7 –	7.2 n
	F	3.3 n	3.0 n	20.2 n	34.0 –	7.2 n	1.1 n
[6] Conifer at treeline (%)	M	1.2 –	0.6 n	0.5 n	1.5 n	1.9 –	4.1 –
	F	6.9 n	7.8 –	1.4 n	0.7 n	1.8 n	7.8 –
[7] Deciduous tree (%)	M	×	<0.1 –	×	×	1.2 –	0.5 n
	F	×	<0.1 n	0.1 –	<0.1 –	<0.1 –	0.1 n
[11] Conifer tree (%)	M	7.9 n	10.9 n	14.0 –	3.5 –	12.9 +	23.1 n
	F	34.4 n	11.4 n	13.6 n	1.6 n	4.1 n	6.0 n
[44] Alpine (%)	M	76.1 n	63.3 n	62.6 n	59.7 n	56.2 –	37.0 n
	F	33.7 +	67.1 +	46.4 n	57.7 n	67.8 n	81.6 n
[46] Fluvial (%)	M	0.1 +	0.1 +	0.2 +	0.8 +	0.9 +	0.3 +
	F	×	0.1 +	0.3 +	0.1 n	0.1 +	0.2 +
[66] Grass (%)	M	1.5 n	4.0 n	9.4 n	0.9 +	4.0 +	6.8 n
	F	2.6 +	7.9 n	10.5 n	0.5 n	5.2 n	0.8 n
[88] Shrub (%)	M	10.8 n	9.0 n	5.1 +	9.6 n	14.4 n	21.0 n
	F	19.0 –	7.8 n	7.4 n	5.3 n	13.7 +	8.4 –
Burned areas (%)	M	17.8 –	20.5 –	31.3 –	4.3 +	22.6 +	16.7 –
	F	23.1 n	28.8 -	20.4 n	5.7 n	32.7 n	21.2 n

[1] + selected – avoided; n = neutral; × = not used. [2] Unit-less measures. [3] Elevation was modeled as a quadratic term; only mean elevations are reported here.

Table 9.6 Summary of seasonal habitat use and perceived selection (positive, negative, neutral) relative to habitat availability for 4 male and 15 female Stone's sheep in the Sentinel area, tested with an all-inclusive habitat model. Habitat use reflects mean values for continuous attribute data and proportion of locations in each category for categorical attribute data. Numbered attributes indicate coding for categories of slope position [1-6] and land cover [4-88]. Availability was measured at random locations within 95th percentile movement distance buffers around sheep locations.

Attribute	Sex	Early Winter	Late Winter	Lambing	Summer	Fall	Rut
Ruggedness[2]	M	0.333 +	0.024 +	0.017 +	0.014 n	0.013 n	0.019 +
	F	0.014 +	0.015 +	0.016 +	0.017 +	0.012 +	0.014 +
Slope (°)	M	30.5 n	31.4 n	33.9 +	33.2 n	28.6 –	34.4 +
	F	31.0 +	34.1 +	33.8 +	29.8 n	28.4 +	30.7 +
Escape distance (m)	M	561 –	568 –	655 –	306 –	439 –	476 –
	F	557 –	464 –	441 n	463 n	782 n	714 +
[1] Ridge (%)	M	26.4 n	12.6 –	15.0 n	58.0 n	11.1 n	50.1 n
	F	45.3 –	32.9 –	14.7 n	32.9 –	35.0 n	33.2 –
[2] Upper slope (%)	M	9.1 +	24.3 +	40.9 n	31.3 +	23.2 n	21.1 +
	F	30.6 +	29.4 +	22.4 n	19.8 +	22.3 +	34.0 +
[3] Mid slope (%)	M	14.1 n	23.1 +	43.4 +	10.4 +	65.2 n	25.4 n
	F	21.7 +	31.6 n	48.3 n	31.7 +	29.9 +	27.4 +
[4] Flat (%)	M	×	×	×	×	0.4 +	×
	F	<0.1 n	<0.1 n	<0.1 n	0.3 n	0.1 n	0.1 n
[5] Lower slope (%)	M	0.4 n	0.1 n	0.8 n	0.3 –	0.2 n	2.6 n
	F	2.0 n	5.0 n	11.1 n	11.0 n	9.1 –	4.4 n
[6] Valley bottom (%)	M	×	×	×	×	×	0.7 n
	F	0.4 –	1.1 –	3.6 n	4.2 n	3.7 n	1.0 –
Solar radiation[2]	M	0.436 +	0.562 +	0.693 +	0.386 n	0.424 +	0.435 +
	F	0.616 +	0.682 +	0.666 +	0.505 +	0.499 +	0.572 +
Aspect (East +, West –)	M	-0.161 –	-0.099 n	0.030 n	0.261 +	0.556 +	-0.098 –
	F	-0.075 –	-0.048 –	-0.065 –	0.086 +	0.186 +	-0.026 –
Elevation (m)[3]	M	1434 +	1524 +	1461 +	1706 +	1547 +	1473 +
	F	1574 +	1491 +	1431 +	1672 +	1583 +	1523 +
Curvature (Convex +, Concave –)	M	1.116 +	0.869 +	0.131 n	0.394 n	0.142 n	0.526 +
	F	0.382 +	0.491 +	0.198 +	0.388 +	0.233 +	0.342 +
[4] Rock (%)	M	21.2 n	12.0 –	11.2 n	25.9 –	6.7 +	10.2 n
	F	12.8 n	16.2 –	32.3 –	51.0 –	17.8 –	10.1 –
[6] Conifer at treeline (%)	M	11.2 +	8.3 n	12.2 n	3.0 –	7.3 –	2.9 n
	F	1.0 n	0.9 +	3.4 n	1.2 +	1.5 n	2.7 n
[7] Deciduous tree (%)	M	×	0.1 n	2.5 n	0.4 -	×	×
	F	0.8 –	5.0 –	1.8 –	0.2 –	1.6 –	2.4 –
[11] Conifer tree (%)	M	11.4 n	12.4 n	16.0 n	1.8 +	3.8 –	6.2 –
	F	1.7 n	5.0 +	8.0 +	1.5 +	3.5 +	4.9 +
[44] Alpine (%)	M	34.6 –	55.2 n	40.4 n	63.1 –	51.0 n	48.4 –
	F	62.2 –	52.9 –	36.8 –	41.9 –	59.6 –	58.3 –
[46] Fluvial (%)	M	×	×	×	×	×	×
	F	<0.1 +	0.1 +	0.2 +	0.5 +	0.3 +	0.1 +
[66] Grass (%)	M	1.8 n	3.9 n	5.0 +	x	0.9 n	7.4 +
	F	3.9 n	7.5 n	7.2 n	1.0 +	3.1 n	6.2 n
[88] Shrub (%)	M	19.9 n	7.2 n	12.7 n	5.8 –	30.4 +	24.9 +
	F	11.1 n	12.4 n	10.4 +	2.8 +	12.7 +	15.3 +
Burned areas (%)	M	4.0 –	12.1 +	11.0 n	0.1 n	13.7 x	0.1 n
	F	18.0 +	21.5 +	20.4 n	0.5 –	3.3 n	14.3 +

[1] + selected – avoided; n = neutral; × = not used. [2] Unit-less measures. [3] Elevation was modeled as a quadratic term; only mean elevations are reported here.

Table 9.7 Percentage of GPS locations from male and female Stone's sheep in alpine (>1,400 m), subalpine (1,200 - 1,400 m), and lower elevations seasonally.

	Early winter	Late winter	Lambing	Summer	Fall	Rut	Total locations
ALL SENTINEL FEMALES (elevation range 606 - 2,266 m)							
≥ 1,400 m	82.1%	66.6%	59.5%	92.8%	81.9%	73.1%	18,876 (76.9%)
1,200 - 1,399 m	13.9%	20.6%	26.4%	4.5%	12.1%	18.3%	3,745 (15.2%)
<1,200 m	4.0%	12.8%	14.1%	2.7%	6.0%	8.6%	1,940 (7.9%)
Total locations	3,128	5,783	1,445	4,102	4,374	2,531	24,561
ALL STONE FEMALES (elevation range 601 - 2,162 m)							
≥ 1,400 m	88.3%	64.6%	61.5%	95.3%	80.0%	85.9%	11,971 (78.8%)
1,200 - 1,399 m	9.6%	24.6%	23.9%	3.7%	18.3%	11.4%	2,366 (15.6%)
<1,200 m	2.1%	10.8%	14.6%	1.0%	3.7%	2.7%	848 (5.6%)
Total locations	1,707	3,384	1,572	2,861	3,450	2,211	15,185
STONE FEMALES in the S8M PTP High Elevation Zone (elevation range 1,034 - 1,722 m)							
≥ 1,400 m	91.2%	42.5%	69.8%	96.8%	64.0%	90.0%	2,244 (71.6%)
1,200 - 1,399 m	8.5%	50.7%	27.2%	2.9%	18.3%	10.0%	774 (24.7%)
<1,200 m	0.3%	6.8%	3.0%	0.3%	7.7%	0%	114 (3.6%)
Total locations	388	722	371	379	679	561	3,132
ALL STONE MALES and SENTINEL MALES (elevation range 608 - 2,276 m)							
≥ 1,400 m	81.6%	70.8%	60.0%	91.3%	75.3%	71.4%	14,202 (75.8%)
1,200 - 1,399 m	14.7%	22.9%	24.6%	6.9%	19.0%	22.3%	3,394 (18.1%)
<1,200 m	3.7%	6.3%	15.4%	1.8%	5.7%	6.3%	1,135 (6.1%)
Total locations	2,586	3,695	2,255	3,461	3,928	2,806	18,731
STONE MALES in the S8M PTP High Elevation Zone (elevation range 871 - 1,696 m)							
≥ 1,400 m	76.3%	44.5%	42.0%	73.3%	32.5%	54.5%	1,322 (48.1%)
1,200 - 1,399 m	16.2%	41.1%	40.5%	19.1%	53.1%	32.4%	1,063 (38.6%)
<1,200 m	7.5%	14.4%	17.5%	7.6%	14.4%	13.1%	366 (13.3%)
Total locations	266	513	467	329	849	327	2,751

Security, forage type, and forage availability model rankings

At the movement buffer scale in all seasons, for both areas and sexes, the all-inclusive model ranked first, explaining more of the variation in the sheep location data than competing models did (Table 9.8). Model rankings were most consistent among areas and sexes during the rut, with security out-ranking forage availability and forage type (land cover) ranking last. Differences between areas were most apparent in late winter when forage availability ranked second in the Stone area and security ranked second in the

Sentinel area. Overall, forage availability was a predominant influence on habitat selection across scales, but particularly at the study area scale. Forage type was most important in seasonal range selection within annual home ranges, and attributes associated with security become important seasonally at the movement buffer scale.

Table 9.8 Rank of 4 competing habitat selection models for male and female Stone's sheep across 6 seasons, 2 populations (Stone, Sentinel), and 3 spatial scales. [1]

Season	Model	Spatial Scale											
		Movement buffer				Home range				Study area			
		Stone		Sentinel		Stone		Sentinel		Stone		Sentinel	
		M	F	M	F	M	F	M	F	M	F	M	F
Early Winter	Security	3	2	2	3	4	4	2	3	4	3	3	4
	Forage type	4	4	3	2	2	3	4	2	3	4	4	2
	Forage availability	2	3	4	4	3	2	3	4	2	2	2	3
	All-inclusive	1	1	1	1	1	1	1	1	1	1	1	1
Late Winter	Security	3	3	2	2	4	4	2	4	4	3	4	4
	Forage type	4	4	4	4	2	3	4	2	3	4	3	2
	Forage availability	2	2	3	3	3	2	3	3	2	2	2	3
	All-inclusive	1	1	1	1	1	1	1	1	1	1	1	1
Lambing	Security	2	3	2	3	4	4	3	4	4	2		4
	Forage type	4	4	4	4	2	2	4	3	2	4		3
	Forage availability	3	2	3	2	3	3	2	2	3	3		2
	All-inclusive	1	1	1	1	1	1	1	1	1	1		1
Summer	Security	4	3	2	4	4	3	3	4	4	4	4	4
	Forage type	2	4	4	2	1	2	4	1	3	3	3	3
	Forage availability	3	2	3	3	3	4	2	3	2	2	2	2
	All-inclusive	1	1	1	1	2	1	1	2	1	1	1	1
Fall	Security	4	2	3	4	3	3	3	4	4	4		4
	Forage type	3	3	4	2	2	2	4	2	3	2		3
	Forage availability	2	4	2	3	4	4	2	3	2	3		2
	All-inclusive	1	1	1	1	1	1	1	1	1	1		1
Rut	Security	2	2	2	2	4	4	2	3	4	4	2	4
	Forage type	4	4	4	3	2	2	4	2	3	3	4	3
	Forage availability	3	3	3	4	3	3	3	4	2	2	3	2
	All-inclusive	1	1	1	1	1	1	1	1	1	1	1	1

[1] Rank was based on relative AIC weights; ΔAIC values were >2.0 for all competing models. Refer to Appendix C for complete model results.

Seasonal variation in selection and sexual segregation in the Stone population

Early winter and late winter

Based on the changes in magnitude of selection coefficients across seasons for each attribute respectively, selection by female sheep for greater ruggedness, steeper slope (mean 37°), more solar radiation, and more westerly aspects relative to random locations was most important in winter seasons (Table 9.5, Figures 9.2 and 9.3, Appendix D). West aspects and greater solar radiation became less important to females in late winter, with ruggedness equally important throughout the winter seasons. Selection by males was similar except that use of sites with convex curvature was also a significant predictor, while slope (mean 31°) and solar radiation were less important predictors in winter relative to selection in other seasons. In contrast to females, west aspects and convex curvature became more important to males in late winter and ruggedness less important. The greatest magnitude of selection by females for burned areas was observed in late winter (ß = -0.479 vs <0.192 in other seasons; Appendix D), suggesting strong avoidance despite no perceived selection in early winter. The magnitude of selection by males for burned areas was consistent year-round although differed in sign; burned areas were avoided by males in both early and late winter.

Males and females had inverse relationships in selection for elevation during both early and late winter (Figure 9.1). Males selected mid-elevations (mean 1514 m in early winter and 1469 m in late winter) while females selected lower (609 m minimum - 1,200 m) and upper (1,700 m - 1,929 m maximum) elevations (Figure 9.1, Table 9.5). They also showed inverse relationships with proximity to escape terrain in early winter; females were closer (ß = -0.001, mean distance 337 m) and males marginally further (ß = 1.709×10^{-5}; mean distance 777 m) than the average distance between random locations and escape terrain (Appendix D, Table 9.5). Both sexes were at marginally shorter escape distances than randomly predicted in late winter, but the magnitude of selection was smaller than in any other season.

Females favoured mid- and upper slope positions in winter more than in any other season, while males strongly selected upper slopes. Both sexes avoided ridges and females showed no use of flat areas. Females selected alpine areas in winter, with preference for grass, avoidance of shrub, and no use of fluvial or deciduous sites in early winter; fluvial sites were selected and conifer at treeline avoided in late winter. Males selected fluvial sites and avoided deciduous areas; conifer at treeline was avoided in early winter but neither selected nor avoided in late winter.

Effect of spatial scale on early and late winter habitat selection – For both sexes, expanding spatial scale resulted in the same positive selection but reduced magnitude for greater ruggedness and steeper slopes than randomly available, and stronger selection for more westerly aspects at mid- and upper-slopes, particularly at the home range scale (Figure 9.2). Although both sexes selected sites with greater solar radiation than randomly available, this became more important to females as scale was expanded. Conifer at treeline was more strongly avoided by females at the home range and study area scales in winter seasons; the same was true for males in early winter, with no apparent selection for or against conifer at treeline in late winter. Both sexes avoided burned areas at the movement buffer scale, but selected burned areas at the home range scale (early and late winter) and study area scale (late winter only).

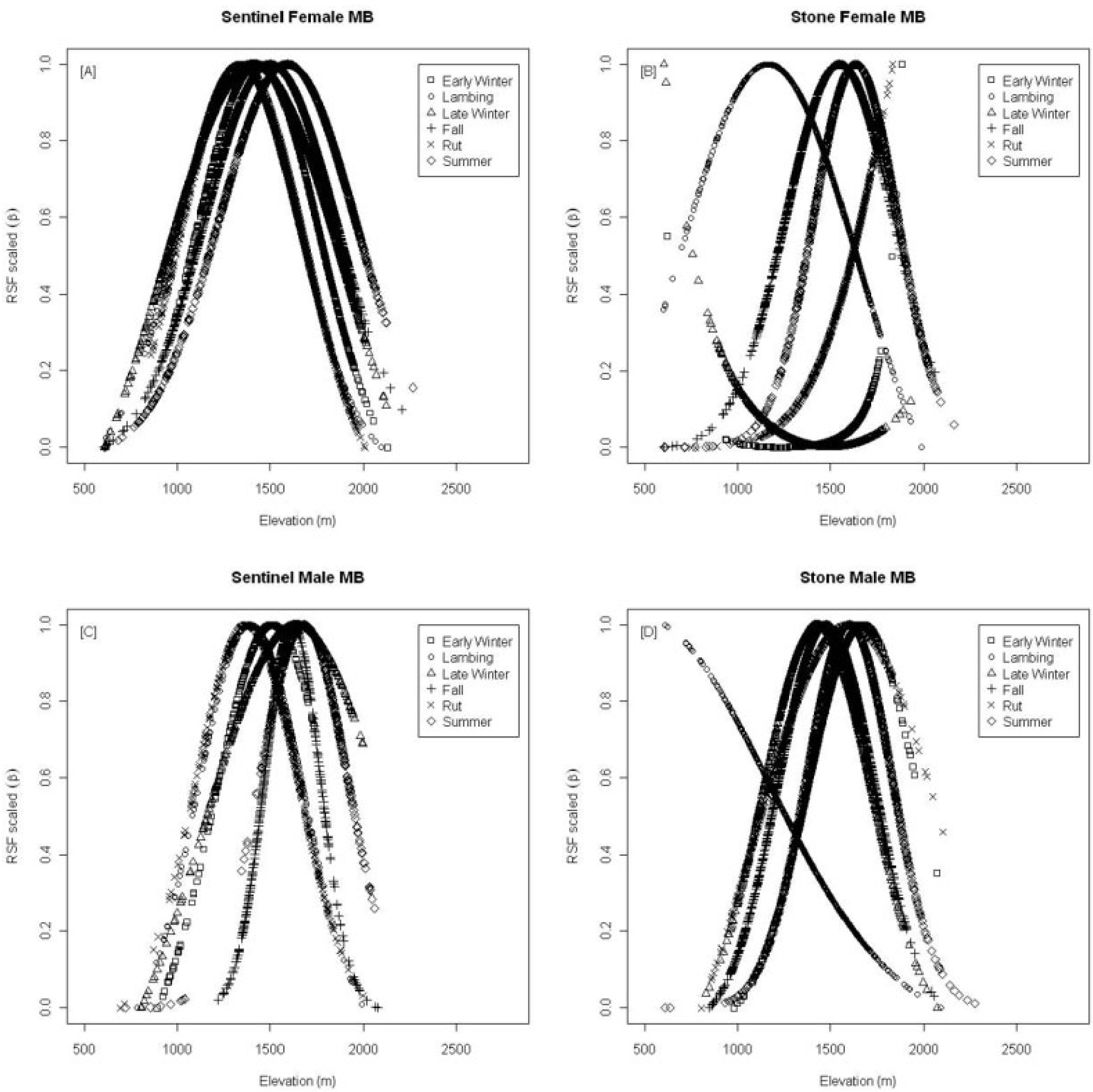

Figure 9.1 Scaled resource selection function (RSF) coefficients for elevation indicating the relative likelihood of selecting elevation assuming other attribute coefficients are held constant in the all-inclusive habitat selection model. Points are data from GPS locations of male and female sheep in the Stone and Sentinel populations.

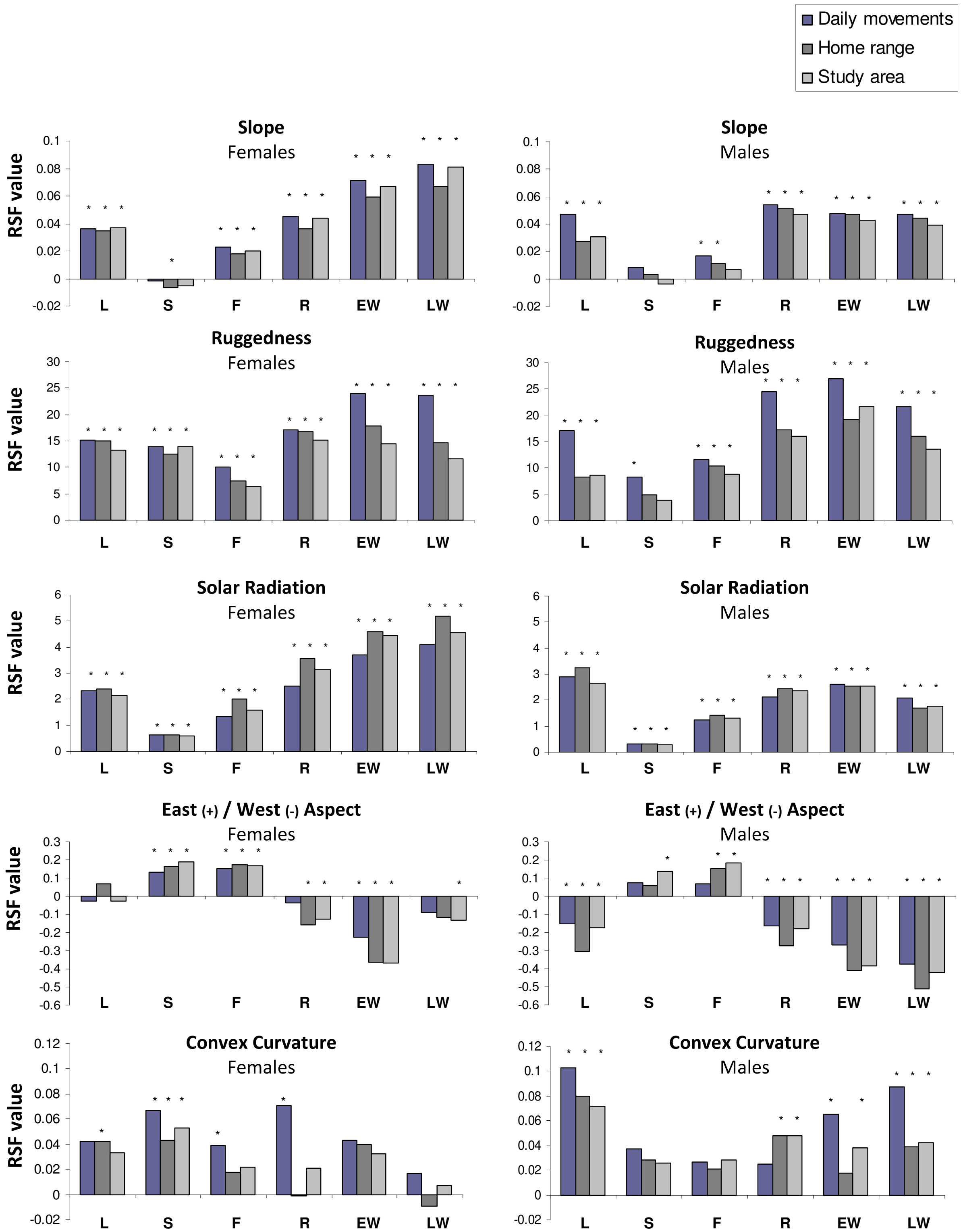

Figure 9.2 Comparison of Stone population male and female resource selection coefficients for topographical habitat attributes, measured across movement buffer, home range, and study area spatial scales.

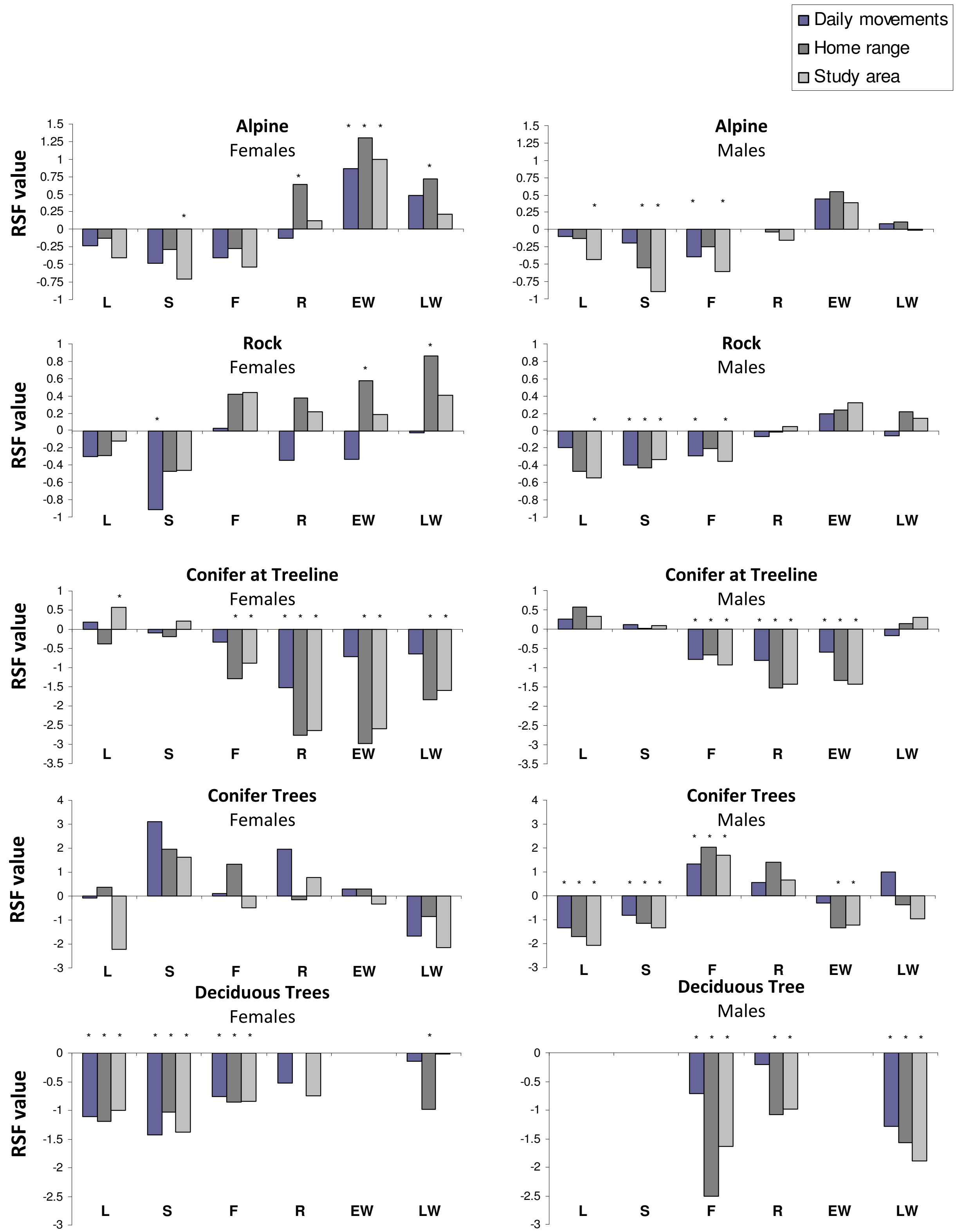

Figure 9.3 Comparison of Stone population male and female resource selection coefficients for land cover habitat attributes, measured across movement buffer, home range, and study area spatial scales (continued on following page).

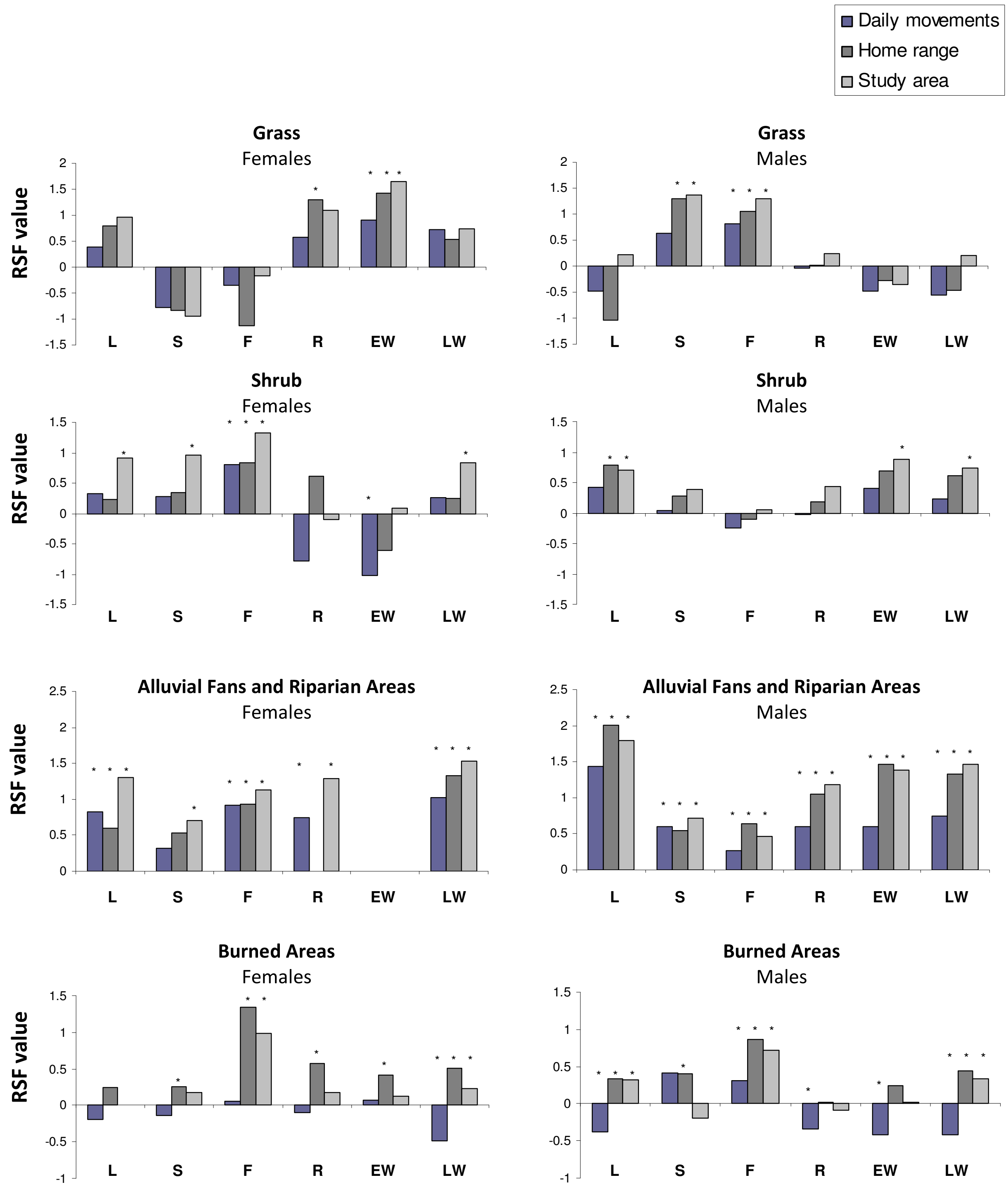

Figure 9.3 Comparison of Stone population male and female resource selection coefficients for land cover habitat attributes, measured across movement buffer, home range, and study area spatial scales (continued from previous page).

Lambing and summer

Habitat selection patterns for females during lambing were comparable to those observed in early winter, with females selecting steeper (mean 33.2°), more rugged sites with more solar radiation than randomly available, although less strongly than during winter seasons. Relative to winter, upper slopes and convex curvatures became more important to females, fluvial sites continued to be selected while deciduous was avoided, and conifer at treeline was no longer avoided. For males, convex curvatures, high solar radiation, shorter escape distances (mean distance 542 m), and avoidance of ridges were more important during lambing than in any other season. Selection for upper slopes and steeper, more rugged and westerly aspects than randomly available was similar to patterns observed in winter, but the strength of selection for these attributes was reduced. Males favoured fluvial and shrub sites, avoiding conifer and burned areas. Both sexes selected lowest elevations during lambing (M 1404 m; F 1424 m) and highest elevations (M 1591 m; F 1640 m) in summer.

Summer was the only season in which females showed no perceived selection for slope (mean 29°). In contrast to winter and lambing habitat selection, convex curvature, east aspects, and upper slopes were more important to females in summer, high solar radiation and closer escape distances (mean distance 431 m) less important but still significant, avoidance of deciduous sites persisted, and rock habitats were avoided. For males, selection for ruggedness, slope (mean 28°), and solar radiation persisted, but were weaker during summer than in any other season, with selection for upper slopes stronger than in any other season. Selection was neutral for escape distance (mean distance 789 m) and curvature. Similar to lambing, males selected fluvial sites and avoided conifer. Males also selected grass and burned areas in summer.

Effect of spatial scale on lambing and summer habitat selection – For females during lambing, spatial scale influenced selection for slope position (greater selection for upper and mid-slopes at home range scale), conifer at treeline (strong selection at study area scale and neutral at smaller scales), alpine (perceived avoidance at study area scale and neutral at smaller scales), shrub (increasing selection at expanding spatial scales), and burns (selecting burned areas at the home range scale only). The sign and magnitude of all other significant coefficients were roughly equivocal among scales. Similar trends were observed in summer for selection of alpine, shrub, and burned areas. Also in summer, selection for fluvial sites and avoidance of mid-slope positions became more important with expanding spatial scales.

For males during lambing, expanding the spatial scale produced roughly equivalent results, but with changes in magnitude of selection, except for use of conifer at treeline, rock, alpine, and burned areas. Males selected conifer at treeline at the home range scale but were neutral toward it at other scales. Neutral use of rock and alpine changed to perceived avoidance of these land cover classes at the study area scale. We observed selection for burns at the home range and study area scales, but avoidance of burns at the movement buffer scale. For males in summer, ruggedness, burned areas, and mid-slope positions became less important, closer escape distances more important, and alpine sites were avoided when spatial scale expanded.

Fall and rut

The largest magnitude of selection by females for aspect was observed in the fall ($\beta = 0.155$ vs <0.132 in summer and <0.227 in early winter), indicating greater selection for east aspects. The smallest magnitudes of selection by females for ruggedness and slope (mean 31°) were also observed in fall, suggesting that while these are both consistently important predictors for sheep distribution year-round, they may be least important to females in this season. Fall was also the only season in which females showed no perceived selection for ridges, rather than avoidance (relative to use of other slope positions). Females continued to show persistent selection for shorter escape distances (mean distance 460 m), upper slopes, increased solar radiation, and more convex curvatures relative to random locations, favouring shrub and fluvial sites and avoiding deciduous areas. Males also showed strong selection for east aspects, as well as ruggedness, slope (mean 28°), escape distance (mean distance 638 m), upper slope, and curvature values similar to summer habitat selection by males. Males showed much stronger relationships to land cover attributes in fall than any other season, selecting grass, fluvial, and conifer and avoiding all other land cover categories. As in summer, males selected burned areas more than randomly available; females were neutral in selection for burned areas. Both sexes selected mid-elevations during fall (M 1,465 m; F 1,509 m) and rut (M 1,474 m; F 1,512 m).

For both sexes, the transition to rut reflected intermediate values for significant attributes more similar to those selected in winter seasons than those selected in the fall. This is the only season in which females favoured ridges, avoiding all other slope positions, and showed the greatest magnitude of selection for convex curvatures ($\beta = 0.071$ vs < 0.042 in all other seasons). In contrast, selection by males for curvature was neutral in summer, fall and rut. Male selection for steeper slopes was more important during the rut (mean 32°) than in summer and fall, and equivalent to winter seasons. Aside from selection of fluvial sites and avoidance of conifer at treeline and burned areas, males showed neutral selection for land cover during the rut. Similar to males, females selected fluvial sites and avoided conifer at treeline, but also avoided shrub.

Effect of spatial scale on fall and rut habitat selection – With expanding spatial scale, the magnitude of selection for rugged, steep slopes declined, but burned areas became more important influences. At the home range scale, the greatest magnitude of selection for burned areas was observed in fall for both males and females ($\beta = 1.346$ F; 0.864 M), suggesting strongest preference for burns in this season. During the rut, selection for greater convex curvatures declined for females but increased for males as spatial scale was expanded. Also during the rut, female selection for greater solar radiation and more westerly aspects increased with spatial scale. Scale had no effect on selection by males during the rut.

Seasonal variation in selection and population differences for Stone and Sentinel females

Early winter and late winter

Females in both areas selected for increased ruggedness, slope (Stone mean 37°; Sentinel mean 33°; Table 9.6, Figure 9.4, Appendix D), solar radiation, and west aspects relative to random locations but while these attributes were more important in winter than in other seasons they were less important in the Sentinel area. In late winter, steeper slopes were more important to females in both areas than in any other season. West aspects and greater solar radiation became less important to Stone females in late winter, but more important to Sentinel females. Ruggedness was equally important throughout the winter seasons in both areas. Although Sentinel females selected shorter escape distances in winter than in other seasons (mean distance 557 m early winter; 464 m late winter; Table 9.6), Stone females were closer to escape terrain (mean distance 337 m early winter; 359 m late winter; Table 9.6). Slope position and elevation varied seasonally in the Stone area while Sentinel females favoured upper slope positions in all but lambing season and mid-elevations in all but late winter, when Sentinel females selected lower elevations (mean 1,491 m). During winter seasons Stone females selected mid-slope positions at both lower (609 m minimum - 1,200 m) and upper (1,700 m - 1,929 m maximum) elevations. Both Stone and Sentinel females selected fluvial sites and avoided deciduous areas consistently across seasons (Figure 9.5; Appendix D). In winter, Sentinel females also selected against rock and alpine, favouring conifer and conifer at treeline. Burned areas were more important to Sentinel females (at both MB and HR spatial scales) in early winter than in any other season, and were also selected in late winter. Burned areas were most strongly avoided by Stone females in late winter.

Effect of spatial scale on early and late winter habitat selection – For female sheep in both areas, expanding spatial scale resulted in the same patterns of positive selection for steep, rugged sites and stronger selection for sites with greater solar radiation. With expanding scale, Stone area females selected more westerly aspects and Sentinel females selected more easterly aspects. For females in both areas, mid- and upper slope positions were most important at the home range scale. Conifer at treeline was most strongly avoided by females at the home range scale in both early and late winter, in contrast to strong selection for this habitat category by Sentinel females at the movement buffer scale in early winter.

Lambing and summer

Solar radiation was more important to Sentinel females during lambing than in any other season (β = 2.147) and was also strongly selected by Stone females (β = 2.331). Females in both areas selected steep (Stone mean 33°; Sentinel mean 34°), rugged sites with westerly aspects and similar convex curvatures. Sentinel females selected mid-slopes rather than upper slopes. While shorter escape distances were important to Stone females (mean distance 389 m), Sentinel females showed no perceived selection for escape proximity (mean distance 441 m). Avoiding deciduous areas and selecting fluvial sites were common patterns in both areas; Sentinel females also selected conifer and shrub sites, apparently avoiding rock and alpine. Females in both areas were at lowest mean elevations during lambing (Stone 1,424 m; Sentinel 1,431 m) and highest mean elevations (Stone 1,591 m; Sentinel 1,672 m) in summer.

For both areas, summer was the only season in which females showed no perceived selection for steeper slopes (Stone mean 29°; Sentinel mean 30°), and selected easterly slopes with greater convex curvature. Selection persisted in both areas for rugged sites with greater solar radiation than randomly available, but these were less important than during lambing. Selection was significant for all categories of land cover in the Sentinel area, with fluvial, grass, shrub, and conifer sites favoured and perceived avoidance of rock, alpine, and deciduous sites. Burned areas were avoided more strongly by Sentinel females than in any other season.

Effect of spatial scale on lambing and summer habitat selection – For both Stone and Sentinel females during lambing, selection for shrub and conifer at treeline and avoidance of alpine areas were most prominent at the study area scale.. Both also selected mid- and upper slope positions most strongly at the home range scale. Selection of burned areas became apparent at the HR scale for all but Sentinel females in summer, when strong avoidance at the MB scale became neutral selection at the HR scale.

Fall and rut

Strongest selection by females for east aspects was observed during fall in both areas, with both ruggedness and slope (Stone mean 31°; Sentinel mean 28°) less important than in any other season. Females in both areas also favoured shrub and fluvial sites, avoiding deciduous trees. As in other seasons, Sentinel females also selected conifer but apparently avoided alpine, rock, and conifer at treeline. There was no perceived selection for burned areas by either Stone or Sentinel females.

Greater ruggedness was more important, and escape distance less important, to Sentinel females during the rut than in any other season. Sentinel females selected sites at further escape distances than randomly available (mean distance 714 m); Stone females selected closer escape distances (mean distance 372 m). Stone females favoured sites with greater convex curvature and ridge slope positions than in other seasons. Selection persisted in both areas for rugged sites with greater solar radiation than randomly available and were more important than during the fall. Sentinel females strongly selected burned areas, while Stone females showed no perceived selection or avoidance of them.

Effect of spatial scale on fall and rut habitat selection – In both areas, expanding spatial scale resulted in stronger selection for greater solar radiation and upper elevation sites, selection for less convex curvatures, and more avoidance of conifer at treeline. Selection for burned areas and mid- to upper slope positions were greatest at the home range scale.

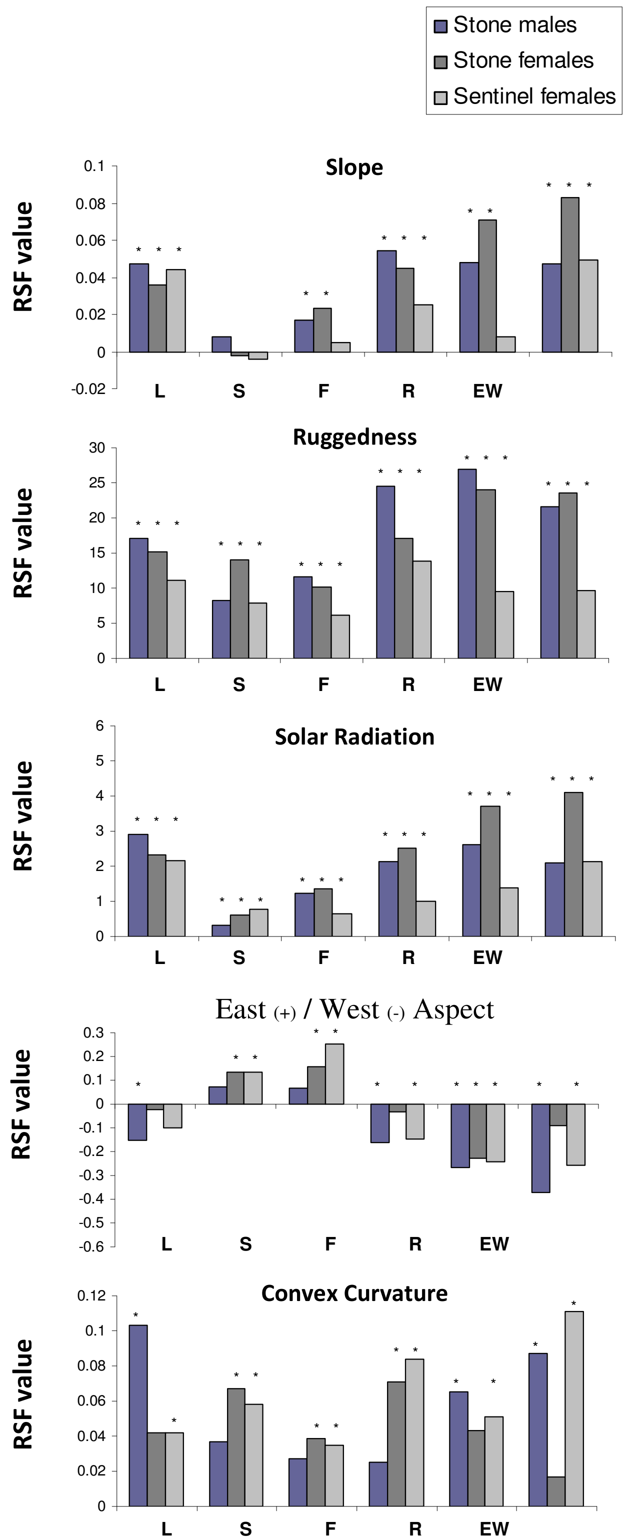

Figure 9.4 Comparison of Stone male, Stone female, and Sentinel female resource selection coefficients for topographical habitat attributes, measured at the movement buffer spatial scales.

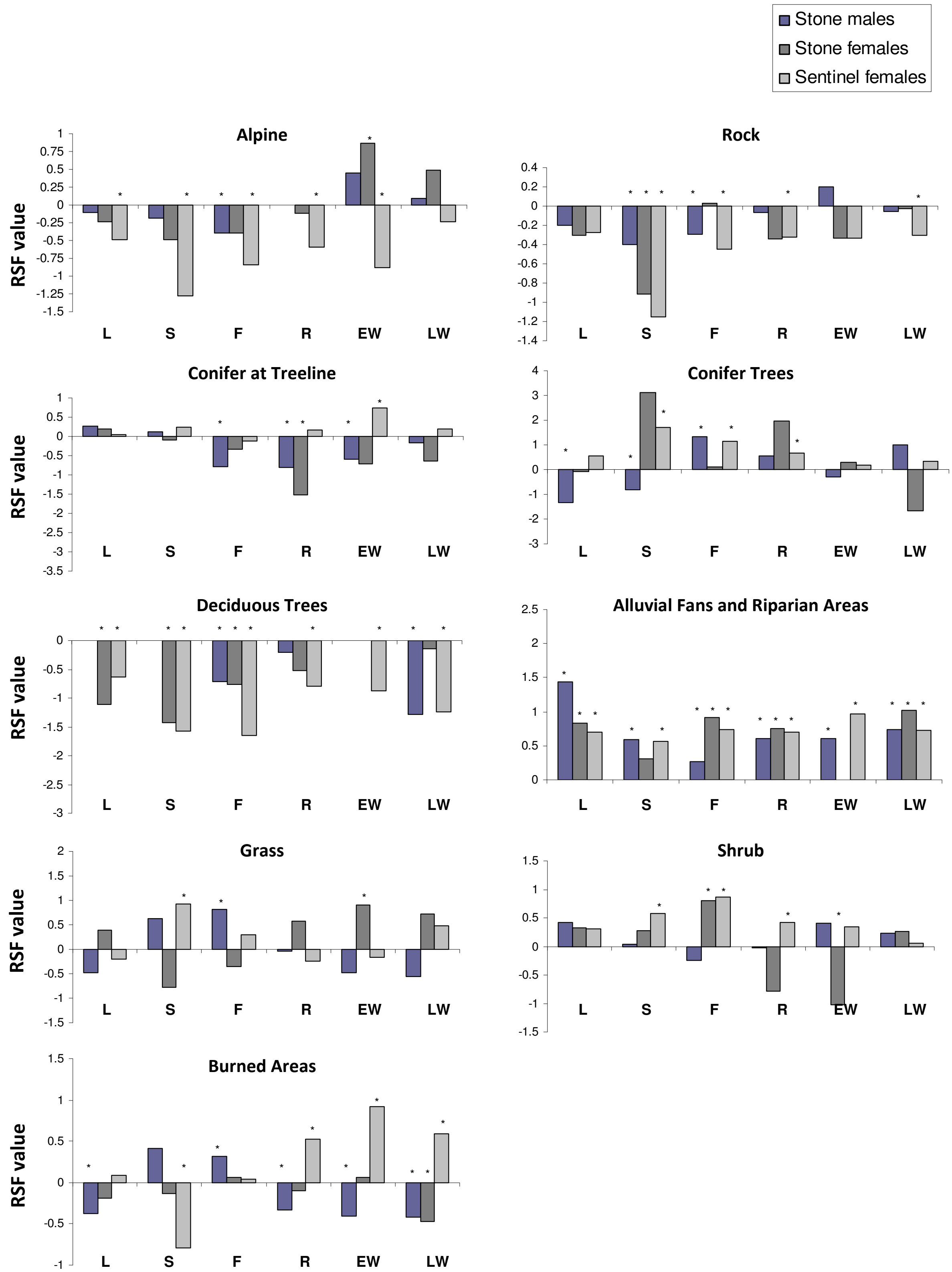

Figure 9.5 Comparison of Stone male, Stone female, and Sentinel female resource selection coefficients for land cover habitat attributes, measured at the movement buffer spatial scales.

DISCUSSION

Overall, habitat use and selection were most consistent for steep, rugged, upper slopes closer to escape terrain and with greater solar radiation and convex curvature than randomly available. Selection for fluvial sites and avoidance of deciduous areas, both rare land cover categories in the study area, were also consistent year-round. Topographical attributes associated with greater ruggedness, solar radiation, westerly aspects, and shorter distances to escape terrain were most important in winter habitat selection. Selection for east-west aspect, elevation, and burned areas were most variable seasonally at the movement buffer scale, but consistent selection for west aspects, upper elevations, and burned areas emerged at the home range scale. Selection against rock and alpine despite high frequencies of use likely reflected extensive distribution of these land cover classes, and we inferred that these habitat components were important but not limiting. Fluvial sites, including gravel debris fans, were rare in the study area but consistently selected at all spatial scales. We speculate that these were important as travel corridors.

We observed greater strength and more variation in seasonal selection patterns at smaller scales, particularly for males. Stone females were more closely associated with steep slopes, shorter escape distances and more use of conifer trees than both Stone males and Sentinel sheep, especially on winter ranges. Stone females also used conifer at treeline in winter more than Stone males and Sentinel females, but Sentinel males used conifer at treeline most heavily. Both Sentinel males and females keyed in on conifer at treeline during lambing, a habitat attribute thought to reduce predation risk and provide thermal cover. Persistent differences between males and females across spatial scales included greater avoidance of flat areas and valley-bottom slope positions by Stone females relative to Stone males. In the Sentinel population, persistent differences included males preferring sites closer to escape terrain than females in all but late winter and lambing, and females selecting fluvial sites year-round while males avoided them completely. Between populations, selection for elevation and slope position were more consistent year-round for Sentinel females than Stone females.

Habitat selection model rankings reflect a complex interaction among habitat attributes in determining habitat use probabilities across seasons and scales. Strong selection for topographical attributes which influence forage availability in winter, when snow depths are known to limit range use by sheep, had greatest prominence in winter selection. Ruggedness and slope attributes included in the security model also had greatest importance in winter habitat selection at the movement buffer scale. While security became less important at expanding spatial scales, forage type became a more important predictor of sheep distribution. The forage availability model often ranked higher than forage type at the movement buffer scale, suggesting that even if forage type (quantity and quality) is adequate, availability may be a more important influence on sheep distribution at small scales, particularly in winter. At small scales, topographical attributes are likely more important than forage type because of their influence on site moisture, temperature, etc. The increasing importance of forage type at larger spatial scales is consistent with microhabitat selection (e.g., specific sites or patches within land cover categories) in daily movement decisions and macrohabitat selection (e.g. land cover categories alone) in determining seasonal ranges. Spatial scale had the least impact on summer habitat selection, likely because in summer habitat availability is least restricted. Overall, forage availability was a predominant influence on habitat selection across scales, but particularly at the study area scale. Forage type was most important in seasonal range selection within annual home ranges, and attributes associated with security become important seasonally at the movement buffer scale.

Selection presumes active choice for particular habitat attributes. Interpretation may be most reliable for attributes that can be objectively and precisely measured across the landscape and which are fixed over time (e.g., attributes derived from digital elevation measures). Interpretation is less reliable for attributes measured and mapped at low resolution, or those whose influence varies across seasons and years (e.g., burned areas mapped at low resolution and vegetated land cover categories interpreted from satellite imagery taken at fixed times but applied to multi-year data). Perceived selection or avoidance of categorical attribute data are also more difficult to interpret intuitively, because selection relates to both scale and proportions of animal locations among categories. This is particularly true for data modeled as deviation contrasts, where selection for a particular land cover or slope position category was measured in relation to the overall mean effect of the land cover and slope position attribute groups. For example, statistically significant avoidance of rock and alpine areas by Sentinel sheep implies that these were not important land cover categories, despite heavy use (>85% of male and female summer locations were in these categories). Clearly, rock and alpine are predominant habitat attributes in summer, but habitat selection results reflect preferences relative to the overall effect of land cover on sheep distribution. Rock and alpine were determined to be less important to Sentinel sheep in summer than other land cover categories.

The value of burned areas to S8MP sheep cannot be reliably interpreted from RSF results. Although 0.1 – 33% of sheep locations seasonally were in areas that had been burned or partially burned between 1990 and 2005, the spatial distribution of burned areas, imprecise mapping at low resolution, and the broad span of the burn age class (15 yrs), must be considered when interpreting selection results. Burns for sheep typically target known winter ranges with the intention of improving forage quantity and quality, so they likely overlap areas where sheep already occur. Low resolution mapping of incomplete burns means that significant selection and use of burned areas by Stone's sheep may not necessarily be related to the forage opportunities intended by range burning, but rather the underlying topography. In some cases, range burning intended to improve winter forage for sheep has had limited benefits at least partially because burned areas were not available to sheep in winter, due to deep snow (Seip 1983). Further, use and selection for burned areas should be measured against a control and evaluated over much shorter time scales, with pre-and post-burn monitoring of changes in habitat use, but this was outside the scope of this study.

Mountain sheep tend to be consistent in use of specific habitat attributes and our habitat use results are comparable to observations made in other studies (Backmeyer 1991; Corbould 1998, 2001; Elliott 1978; Festa-Bianchet 1986a; Geist 1971; Hoefs 1976; Seip 1983; Seip and Bunnell 1985; Walker 2005; Wood 1995a, 2002; Wood *et al.* 2010). Habitat selection by S8MP females was consistent with habitat selection by adult female Stone's sheep in the Besa-Prophet PTP area (Walker 2005). Besa-Prophet females selected steeper slopes, ridges and south-facing aspects in all seasons. Rock and dry alpine vegetation were selected for all year, while burns were selected during winter, lambing and fall. Higher elevations were selected in summer, fall, rut and early winter, while lower elevations were selected during lambing.

Both high and lower elevations were selected in late winter, as we observed for Stone females. Because we did not observe the same pattern for Sentinel females, we hypothesize that this pattern may be related to population density on winter ranges. Density of sheep on Stone winter ranges was estimated to be twice that of Sentinel winter ranges (Chapter 4). As animal density increases in the most preferred habitat, subordinate individuals may develop alternate habitat use strategies.

Overall, we found more evidence of fine-scale selection and habitat segregation by males and females at the smallest spatial scales than at larger scales. Interpretations of habitat selection across large heterogeneous landscapes better explain the broad distribution of animals, particularly for species that exploit patchy habitats.

RESEARCH SUMMARY AND MANAGEMENT CONSIDERATIONS

Hengeveld, P.E. and J.C. Cubberley. 2011. Research summary and management considerations. Pages 145-156 *in* Stone's sheep population dynamics and habitat use in the Sulphur / 8 Mile oil and gas pre-tenure plan area, northern British Columbia, 2005 – 2010. Synergy Applied Ecology, Mackenzie, BC. 167 pp plus appendices.

PRIMARY CONCLUSIONS AND GENERAL MANAGEMENT CONSIDERATIONS

Management priorities to support long-term sustainability of S8M sheep populations should address the most practical, management-relevant components of Stone's sheep ecology, with a focus on core ranges and high density areas where disturbance impacts are likely to be most acute.

The Sulphur / 8 Mile study area supports nearly 18% of northeast BC's Peace Region Stone's sheep, with no evidence of declining populations in the study area. Census results detected a minimum of 939 sheep in the S8MP area during this study. This represented 17.9 % of 5,244 total sheep counted across the Peace region in 2007 - 2009 (Thiessen 2009). We estimated a stable population of about 1,200 sheep (95% confidence interval of 1,007 - 1,429 sheep). Total numbers reported for surveys conducted in the S8MP area in 1977 (997 sheep) and 2004 (888 sheep) were within the 95% confidence intervals of our population estimate.

- Survey timing has implications for population estimation. Population census during the end of the rut is more effective than late winter census. Total count was improved by increasing the census area to include 1,200 m - 1,400 m elevations at the lower boundary of alpine census polygons. Census should be conducted regularly, using consistent spatially-defined census areas, standard protocols and reporting of results.

Sheep in the S8M study area belong to at least 2 populations separated by the Toad River. Research data and historic observations from multiple sources showed excellent agreement regarding distribution of sheep in the S8MP area. There was no evidence of GPS collared sheep crossing the Toad or Racing Rivers but seasonal movement to ranges outside the study area occurred at the 'Rock Cut' (Alaska Highway west of Summit Lake) and at Petersen Canyon (Alaska Highway south of Muncho Lake).

- Manage as two distinct populations and maintain integrity of links to adjacent populations south and west of the study area.

Density-dependent effects on population dynamics were observed in the Stone population, where sheep density on alpine ranges was approximately double that of Sentinel sheep. Population density is an important aspect of ungulate ecology because of its influence on population dynamics. Density-dependent effects are changes in population dynamics in relation to population abundance and habitat carrying capacity. Determining carrying capacity and defining thresholds between low and high densities is difficult, but population responses to changes in density are often easily identified. Theoretically, density-dependence is a way for populations to self-regulate their size, in order to optimize per capita resource use. In the absence of other limiting factors, sheep populations may increase in density until high resource competition reduces the amount of available forage per individual. This can negatively affect individual body condition and population reproductive rates.

Evidence of density-dependence in the Stone population included lower over-winter lamb survival, a greater proportion of health-related mortalities, and more use of subalpine habitats by younger males. Density-dependent responses in Stone population dynamics suggest potential for rapid changes in sheep population dynamics even without any industrial development, if resource limitations (e.g., habitat capacity) or changes in other limiting factors (e.g., predation, harvest pressure) emerge.

Elk and moose were common on sheep ranges in the S8M PTP High Elevation Zone south of the Toad River. Functional responses to changes in multi-species relationships include potential for changes in predator/prey dynamics (displacement, opportunistic predation on sheep as secondary prey species) or habitat changes (competition effects, impacts on forage quantity and quality).

- Adopt conservative approaches to management actions or resource development that may influence distribution and density of other ungulates and predators on sheep ranges.
- Monitor density-dependent changes in sheep population dynamics and changes in multi-species dynamics.

Pregnancy rates and lamb recruitment indicate good population productivity and balance survival rate of adult females. With natural survival rate of 70 - 90% for adult females in the S8MP area, late winter ratios of at least 35 lambs to 100 adult females will support a stable or growing population, assuming equal sex ratio in lamb production. We observed a pattern of survival and recruitment that appears to be strongly driven by spring weather patterns. We found a strong negative correlation between survival of adult females and May precipitation at the end of each monitoring year. In contrast, other studies have reported that spring precipitation has a positive influence on newborn survival, lamb mass gain over the summer, and overwinter survival to 1 yr of age (Portier et al. 1998). If this is consistent over the long-term, the demographic effect of high adult female mortality in years with wet spring weather may be offset by positive population recruitment the following spring.

- Site-specific weather data should be part of population monitoring programs as an indicator of recruitment and survival.

More than 40% of adult female mortalities occur in late winter, particularly April and May.

- Minimize stressors in late winter.
- In the absence of clear data on lethal or chronic disturbance effects, avoiding or mitigating disturbance-caused stresses to sheep remains a conservative management approach (Heimer

1999). Disturbance due to aircraft can be significant because overhead flights by fixed-wing aircraft may simulate predation-risk from eagles, causing bunching, hiding, or threat-jump behaviours by sheep, and helicopters cause fleeing responses (Laberge Environmental Services 2002).

Primary cause of death varied between Sentinel and Stone populations. Snow conditions, falls, injuries, and health-related factors combined account for more deaths than predation.

Sheep deaths due to vehicle collisions are significant, preventable, and add to natural mortality. Road-related mortality can be as significant as predation, disease and harvest with respect to the long-term viability of sheep (Gunson *et al.* 2006). Road salt deposited by road maintenance crews may provide additional mineral salts that create or enhance naturally occurring mineral licks adjacent to road networks (Case 1938; LeBlond *et al.* 2007; Morgantini and Bruns 1988). In addition to providing required mineral sources, highway use may be part of metapopulation links important to genetic exchange among populations that overlap only at the lick (Heimer 1974). Highways can pose substantial barriers to gene flow between populations if traffic volumes are high (Epps et al. 2005). To improve reporting rates for vehicle-wildlife collisions, the BC Ministry of Transportation implemented a Wildlife Accident Reporting System (WARS) for highway maintenance contractors to collect information on wildlife mortalities along several highways in BC. Unfortunately, this system does not collect such information for the BC segment of the Alaska Highway, which is managed and maintained by the Government of Canada (Hesse 2006).

- Monitor and mitigate vehicle-related mortalities on the Alaska Highway, particularly at the Rock Cut and Petersen Canyon crossings.
- Potential for changes to salt formulations or alternate materials should be considered.
- Site-specific physical mitigation measures such as fences or wildlife passages combined with adjustments of speed limits can be costly, but endure for several decades and as such offer potential for long-term benefits and cost savings.
- Public awareness needs to be increased. Updated signage should be erected at the common crossing points to warn motorists. Posters in gas stations and information kiosks should also be considered.
- In backcountry areas, road dust and ground disturbance from construction or other industrial activities may expose minerals attractive to sheep and other ungulates, exacerbating the potential for wildlife-vehicle conflicts. Road development in backcountry areas could also expose or create accessible mineral sources.

Harvest of mature males exceeds conservative limits. Improved or increased access to backcountry areas is likely to be the most significant factor influencing harvest pressure and the potential need for more restrictive harvest regulations in the future.

- Monitor and manage harvest pressure commensurate with changes to backcountry access.

- Because male Stone's sheep are trophy-hunted, road and other access development could increase mortality from poaching, or increase vehicle collisions with sheep (Cole *et al.* 1997; McCallum and Dobson 2002; McGregor *et al.* 2008; Papouchis *et al.* 2001; Pynn 2007; Wiegand *et al.* 2005).

Herd health parameters are within reported normal range. While S8M sheep populations appear to be healthy, we caution that managing disease risk is a vital part of wild sheep management (Bunch *et al.* 1999; Heimer 1999; Jenkins and Schwantje 2004). Disease outbreaks are common in wild sheep populations, particularly those that come into contact with domestic animals or other wildlife that can carry pathogens infectious to sheep (Garde *et al.* 2005; WAFWA and WSWG 2007).

- Encourage opportunistic sampling of wildlife health indicators.
- Avoid contact with domestic livestock to reduce disease risks.
- Observations of unusual morphology, behaviour, or apparent signs of disease should be reported as soon as possible to public databases.

Most sheep use more than one distinct core area in their annual home ranges, with predictable fidelity to seasonal ranges. East to west movements across the Sentinel Range and north to south movements along the Stone Range follows the orientation of major ridges and drainages. Regularly used wildlife trails are clearly visible.

- Do not disrupt or impede wildlife use of trails.

Seasonal ranges are smallest in early winter, with males and females on the same winter ranges. Sheep distribution is strongly limited by what's available as low-snow or strongly windswept areas in winter. For both sexes, seasonal ranges in the S8MP were smallest in early winter (<10 km^2), roughly 10% the size of lambing, summer, and fall seasonal ranges.

- Protect and monitor high density winter ranges.
- Minimize disturbance to sheep when use of alternate habitats and ranges is limited by snow depth.

Most mineral licks were at the periphery of sheep home ranges. It is common for sheep to use artificial licks when they are made available, either as salt drops (Kjos 2010, Case 1938) or by-products of road maintenance and industrial activities (Morgantini and Bruns 1988; Seip 1983), however this can pose risk to populations if they influence spatial distributions (Case 1938). This may be particularly true if existing primary licks serve social as well as physiological functions. Further, licks can concentrate animals into small areas and are often frequented by several species (Ayotte et al. 2008). This may result in displacement or aggressive interactions, influence hunting mortality and predation risk at or on the way to licks, and increase risk of disease and pathogen transfer among individuals (Morgantini and Bruns 1988). Potential for use of artificial licks as displacement or enhancement tools has been discussed (Case 1938), but to our knowledge their effectiveness and ecological implications have not been sufficiently addressed. Such manipulations are experiments and, if implemented, should only be conducted in a controlled way to test and monitor impact hypotheses.

- Protect and monitor natural mineral licks.
- Limit dust and artificial mineral sources. Any use of industrial sites by sheep should be discouraged, monitored, and reported. Industrial by-products can have lethal toxicities and airborne dust can aggravate prevalence of *Mandibular osteomyelitis*, an infection commonly known as 'lumpy jaw'.

We found no geographic separation between male and female sheep, but fine-scale habitat differences. Sheep use steep (29° – 37°), rugged, warm aspect alpine and subalpine ranges, with 93% of locations above 1,200 m elevation year-round. We observed greater strength and more variation in seasonal selection patterns at smaller scales, particularly for males. Stone females were more closely associated with steep slopes, shorter escape distances and more use of conifer at treeline than both Stone males and Sentinel sheep, especially on winter ranges.

- Management for sheep is also likely to serve mountain goats.

PRE-TENURE PLAN MANAGEMENT CONSIDERATIONS

The following discussion is specific to the **Sulphur / 8 Mile Pre-Tenure Plan High Elevation Zone,** currently under review for potential amendments arising from this study.

Summary of the M-KMA pre-tenure plan framework

Pre-tenure plans are part of a results-based sustainable management framework for oil and gas operations in the M-KMA (MSRM 2004). They apply to areas of development as well as associated site access. Criteria and elements for management direction "form the basis for addressing the environmental, social and economic values in all PTP areas across the M-KMA" and are the fundamental characteristics of the sustainable management framework. Results that must be met are identified as Objectives, Indicators, and Targets. While targets defined the expected results (define maximum acceptable disturbance limits), indicators provide a means of measuring progress in achieving objectives. Targets identify acceptable disturbance limits, but do not specify where disturbance may or may not occur (where disturbance is to be allocated). PTPs are subject to review and potential amendments as new information becomes available to refine criteria, elements, objectives and indicators.

Vegetation maps based on Predictive Ecosystem Mapping (PEM) have been completed for M-KMA pre-tenure plan areas (EBA 2002; MSRM 2004). These form the basis of winter habitat capability maps for 5 species of PTP management interest (Stone's sheep, mountain goat, elk, moose, plains bison), and were combined to create biophysical zone designations in each PTP area. There is 6-class habitat rating system for each species, with separate digital map layers for each species. Stone's sheep and mountain goat high capability winter habitat is predominantly within the Steep Slope-Warm Aspect Biophysical Zone (MSRM 2004: 3-17).

Importance of the S8M PTP High Elevation Zone

North of the Toad River

Observations of Stone's sheep and other wildlife in the High Elevation Zone north of the Toad River were limited. Only one group of 4 sheep, including a collared female transplanted to the PTP by the Ministry of Environment in March 2005, was observed during the December 2006 and March 2007 censuses. Capture efforts (winters 2004/2005 - 2008/2009) to collar males and females in this area were not successful as no sheep were sighted. Reconnaissance flights in November 2007 and July 2008 did not detect any sheep. Absence of sheep from alpine ranges in this area is consistent with BC Government sheep harvest data and local knowledge reports. GPS-collared sheep did not move beyond the distribution of winter census observations in the S8MP area.

Seven elk (December 2006 census), 5 moose (December 2006 census), and 3 mountain goats (March 2007 census) were observed.

All data indicate low risk for potential impacts of industrial development on sheep populations.

South of the Toad River

All sheep age-sex groups use ranges in the High Elevation Zone south of the Toad River. Males, particularly young males, use the pre-tenure area more extensively than females do, but some female nursery groups are resident year-round on the Ram Mountain complex. The Ram Mountain complex provides winter range for sheep of all age-sex classes. During winter census, the ratio of lambs to females was higher in the S8M PTP High Elevation Zone (0.55) than the average for all Stone Range sheep (0.37).

Most (93%) GPS locations obtained for males and females in this study were above 1,200 m elevation. For males in the High Elevation Zone this percentage was reduced to 87%.

Moose and elk were the most abundant other ungulates observed incidentally during winter census, especially near treeline. Density of elk (0.44/km^2) above 1,200 m in the S8M PTP High Elevation Zone was close to sheep density (0.57/km^2). Moose density above 1,200 m was 0.22/km^2. Eighteen caribou and 1 goat were observed during the February 2009 census.

The Dunedin River corridor is subject to higher levels of human activity than other areas of the High Elevation Zone due to user maintained trail access that originates at the Alaska Highway. There appear to be a number of unmapped seismic lines. As in other parts of the study area, the High Elevation Zone has been subject to ad hoc management activities, including placement of mineral salts, prescribed burns, and predator control. The timing, extent, and ultimate effect of these activities are unknown.

All data indicate moderate to high risk for potential impacts of industrial development on sheep populations.

Management direction for the S8M PTP High Elevation Zone

For the S8M PTP area, the following elements have been identified under management direction for Conservation of Wildlife Diversity (Criterion 1), which aims to maintain the integrity, function and habitat of wildlife unique to the Sulphur/8 Mile pre-tenure plan area (MSRM 2004).

Element 1.1 Conservation of Stone's sheep in the High Elevation Zone

- Objectives, indicators, and targets to be defined through a PTP amendment process, incorporating information available from the S8MP Stone's sheep study and other applicable information.

Element 1.2 Conservation of mountain goat diversity in the High and Low Elevation Zones

- Objective: Habitat is sustained in winter habitat capability classes that range from 1-6 within each biophysical zone.
- Indicator: The amount (% and ha) of disturbance by habitat capability class.
- Target: For the Stone's sheep and mountain goat focal species, 98% of the winter habitat remains undisturbed in moderately high to high capability habitat. For each focal species, 95% of winter habitat remains undisturbed in moderate to nil capability habitat.

"Management direction for mountain goat diversity may also be amended in December 2009 as new information on mountain goats may be collected during the Stone's sheep study" (MSRM 2004).

Development of objectives, indicators, and targets could incorporate a defined Stone's sheep zone (similar to the Caribou zone defined in the Halfway-Graham PTP; MSRM 2004)[6], maximum disturbance limits associated with PTP biophysical zones, and recognition of specific areas with special biological significance. Wildlife managers and industry proponents should also be aware of the general management considerations discussed in earlier sections of this chapter.

[6] The Halfway-Graham caribou zone is recognized as a distinct element under Criterion 1. It highlights the area known to be inhabited by caribou during winter, but it does not contribute to or reduce the total hectares in the PTP or each PTP biophysical zone.

Definition of a Stone's sheep zone

A Stone's sheep zone in the S8M PTP could be defined by a movement buffer or 95% fixed kernel utilization distribution on sheep GPS locations (Figure 10.1). This would include summer and winter range for sheep that are resident in the S8MP area.

Additional consideration could be given to the elevations at which sheep are typically found. Stone's sheep are predominantly an alpine-dwelling species, but we found consistent use of subalpine elevations (1,200 – 1,400 m) by both sexes seasonally. Most (93%) GPS locations obtained for males and females were above 1,200 m elevation (Table 9.7 in Chapter 9). For males (but not females) in the High Elevation PTP zone south of the Toad River, this percentage was reduced to 86.7%.

In most cases locations below 1,200 m elevation are likely associated with seasonal movements between core high elevation ranges and use of low elevation mineral licks. Trails encountered at any elevation should be maintained such that wildlife use is not disrupted or impeded.

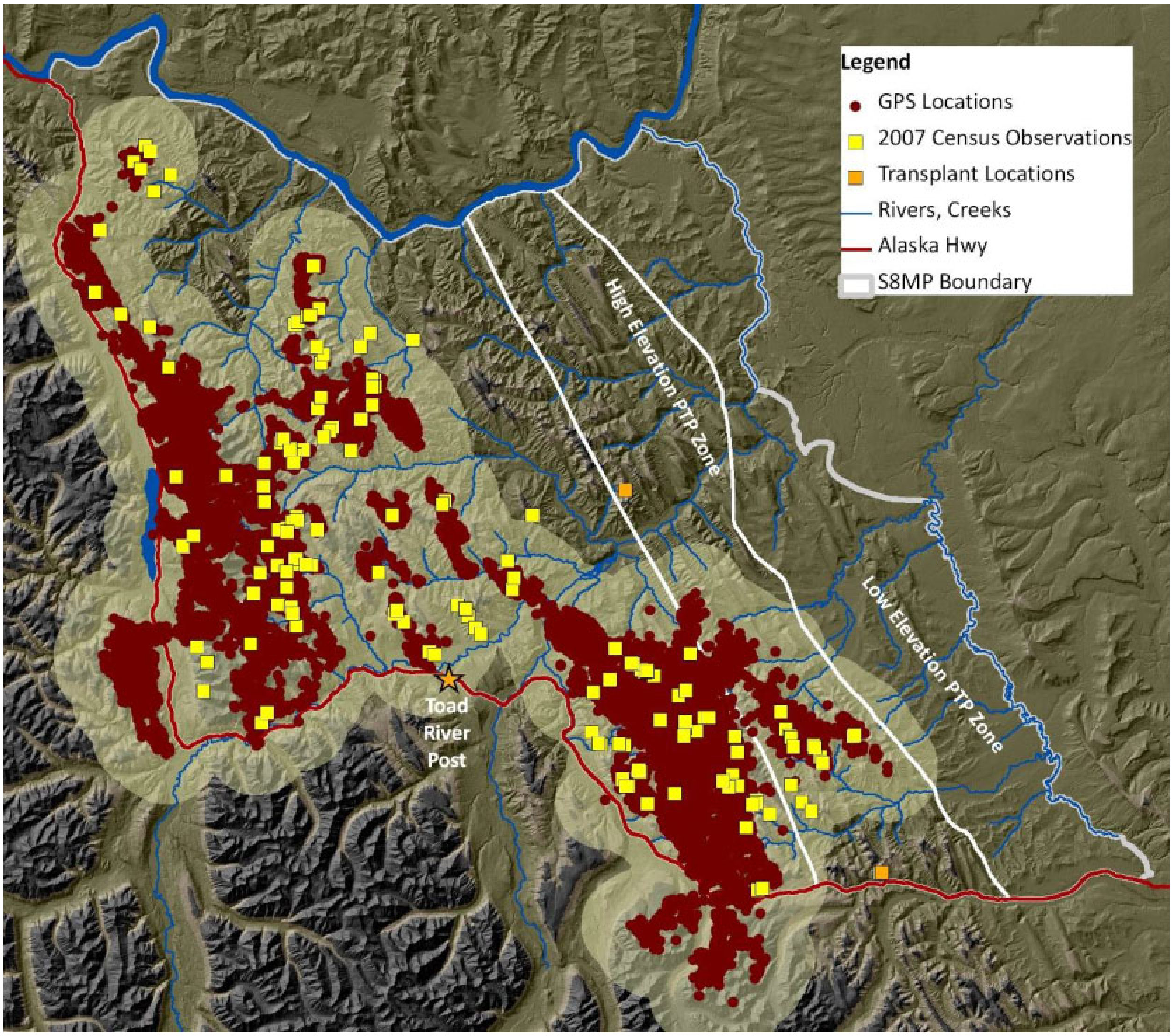

Figure 10.1 Example of a potential Stone's sheep management zone defined by a buffer on sheep GPS locations. Winter census observations (March 2007) are provided for comparison.

Validation of S8M PTP biophysical zones

Strong correlation between sheep distribution, solar radiation and steep slopes (Chapter 9) is reflected in high use of warm, steep biophysical zones in the S8M PTP area (Table 10.1 and 10.2).

Table 10.1 Percentage of GPS locations by biophysical zone for 6 male Stone's sheep that used the S8M Pre-Tenure Plan (PTP) High Elevation Zone south of the Toad River.

S8M PTP biophysical zone	Percent of PTP area	Locations per season[1]						Total
		EW	LW	L	S	F	R	
River	1.2							0
Low elevation wetland	0.5							0
Forested floodplain	0.5							0
Warm Aspect Forest (<45% slope)	17.9	11	15	21	6	42	21	116 (4.2%)
Cool Aspect Forest (<45% slope)	33.4	11	15	11	14	26	18	95 (3.4%)
Steep Warm Aspect (>45% slope)	18.8	207	407	351	81	586	208	1,840 (66.9%)
Steep Cool Aspect (>45% slope)	27.4	33	67	83	186	189	76	634 (23.0%)
High Elevation Plateau	0.4	4	9	1	42	6	4	66 (2.4%)
Total		266	513	467	329	849	327	2,751

[1] Seasons: Early winter (EW) January 1 – February 28; late winter (LW) March 1 – May 14; lambing (L) May 15 – June 14; summer (S) June 15 – July 31; fall (F) August 1 – September 30; rut (R) October 1 – December 31.

Table 10.2 Percentage of GPS locations by biophysical zones for 2 female Stone's sheep that used the S8M Pre-Tenure Plan (PTP) High Elevation Zone south of the Toad River.

S8M PTP biophysical zone	Percent of PTP area	Locations per season[1]						Total
		EW	LW	L	S	F	R	
River	1.2							0
Low elevation wetland	0.5							0
Forested floodplain	0.5							0
Warm Aspect Forest (<45% slope)	17.9		4	2		3		9 (0.3%)
Cool Aspect Forest (<45% slope)	33.4							0
Steep Warm Aspect (>45% slope)	18.8	325	667	258	251	530	432	2,463 (79.5%)
Steep Cool Aspect (>45% slope)	27.4	63	51	111	128	146	129	628 (20.3%)
High Elevation Plateau	0.4							0
Total		388	722	371	379	679	561	3,100

[1] Seasons: Early winter (EW) January 1 – February 28; late winter (LW) March 1 – May 14; lambing (L) May 15 – June 14; summer (S) June 15 – July 31; fall (F) August 1 – September 30; rut (R) October 1 – December 31.

Areas of special biological significance

The Ram Mountain complex in the Sulphur / 8 Mile Pre-Tenure Plan High Elevation Zone provides winter range and year-round habitat for male and female Stone's sheep. Some of these sheep move west seasonally to the Stone Mountain Range, and visit the Rock Cut mineral lick along the Alaska Highway.

CONCLUDING REMARKS

Consistent with the M-KMA vision and fundamental approaches to resource planning and management, we stress the importance of the following.

Management actions should be science-based

Management actions should be science-based and therefore explicitly measurable, with follow-up monitoring to gauge effectiveness. Industrial development should test and mitigate potential ecological impacts through an adaptive management framework. Management actions which are not properly documented are a poor use of available data including anecdotal and traditional knowledge sources, are missed opportunities for learning and adaptive management, and make it difficult to evaluate the context of scientific research results. All management actions and industrial development should be measured and monitored to evaluate outcomes and effectiveness.

Ecosystem approaches should be considered when establishing management objectives

Ecosystem approaches, rather than species-specific approaches, should be considered when establishing management objectives. Sheep have evolved to withstand severe winter conditions, but novel diseases and changes in predator-prey densities can have serious consequences for sheep populations. Resource development or management activities that can influence inter-species interactions should have clear objectives, be thoughtfully implemented, thoroughly documented, and monitored to assess effectiveness and influence on sheep population dynamics. A better understanding of factors that affect large ungulate distribution is fundamental to the long-term management and viability of Stone's sheep populations (Kunkel and Pletscher 2001; Maier *et al.* 2005; Parker and Gillingham 2007).

Metapopulation approaches are important to sustainable management of sheep

Metapopulation approaches are important to sustainable management of sheep populations because sheep tend to exist in discrete, isolated habitats and regional distributions are easily fragmented by backcountry access and development. Metapopulation approaches to management recognize ecological differences among populations and the importance of movement corridors among populations. Metapopulation approaches are also important to sustainable harvest management because harvest is not likely to be equally distributed across populations, due to variation in hunter access to backcountry areas and varied sheep population dynamics.

Cumulative impacts of multiple activities must be considered

Cumulative impacts of multiple activities must be considered in an integrated framework, but are often neglected when multiple project permit processes are evaluated independently. The M-KMA Conservation Area Design (CAD) framework offers a way to evaluate cumulative impacts at a coarse scale (Heinemeyer et al. 2004). Validation assessment using the telemetry information from the Besa-Prophet PTP area showed that CAD models were able to successfully predict high quality habitats for Stone's sheep from a regional perspective, with more than 95% of telemetry locations within the predicted high quality classes (Heinemeyer et al. 2004). Coarse-scale habitat values predicted by CAD models for the S8MP area appear to be a good fit with sheep distribution observed during this study. S8MP sheep GPS location data could be used to further validate the habitat ratings for these models.

The S8MP and Besa-Prophet RSF habitat selection analyses can serve as a basis for fine-scale cumulative effects modeling. Such modeling would create additional models for anthropogenic factors such as distance to wells, drills, roads, etc., and look at how existing and proposed developments affect model outputs for Stone's sheep habitat values.

Compensation-type mitigation may be difficult to achieve successfully

Compensation-type mitigation may be difficult to achieve successfully. The PTP framework currently recommends disturbance limits for high value habitat, but does not specify where habitat changes can or cannot occur, suggesting that disturbance can be mitigated with habitat restoration or augmentation. This approach is not likely to be effective for species with patchy distribution and severe range restrictions in high snow areas. Opportunities to define targets for site-specific management of important habitat features should be explored. These could be implemented as specific objectives and targets in PTP plans, or legislated as Wildlife Habitat Areas or Ungulate Winter Ranges.

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APPENDICES

APPENDIX A LAND COVER CLASSIFICATION FROM LANDSAT TM IMAGERY

A digital land cover layer for the S8M project area was produced under a separate M-KMA contract (project 2006-2007-06) with the University of Northern British Columbia to serve as input layers for habitat use and selection analyses (Wheate et al. 2007). All supporting documentation and land cover class codes supplied for this component is provided here for reference.

Muskwa-Kechika project 2006-2007-06: data report
Sulphur / 8 Mile area Stone's sheep habitat mapping

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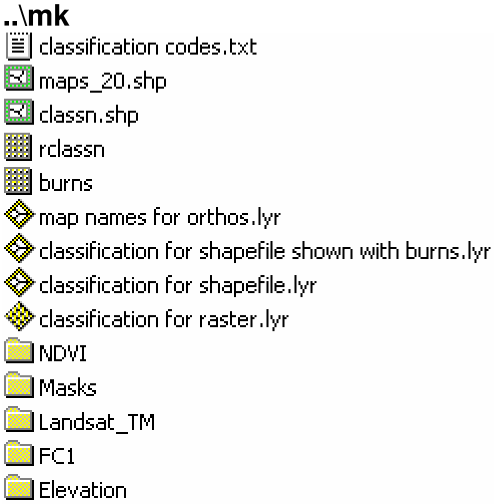
Data Overview

..\mk



The Vegetation Classification is contained in two formats: **classn.shp** vector, and **rclassn** raster format.

Classification class codes are described in **classification codes.txt.**

Burned areas are found as class 2 in **classn.shp** VEGCODE field. The raster **burns** contains burned areas as Value 1, all else 0. The raster **rclassn** contains no codes for burns.

maps_20.shp contains map sheets.

Spatial data layers are pre-symbolized as:

map names for orthos.lyr
classification for shapefile.lyr
classification for shapefile with burns.lyr
classification for raster.lyr

In order to create a data set that encompassed the northwest to southeast trending area of the sheep location, a large extent was used:

Min Easting: 327500
Max Easting 442700
Min Northing 6495000
Max Northing 6584600

All data are maintained in UTM ZONE 10 NAD83.

March 9, 2007

Few current Landsat TM Scenes that were cloud-free were available for the area.

Landsat TM data scenes that were used are as follows:

Scene One:
p51r19_7x20010814 August 14, 2001
AZIMUTH = 156.5451798
ELEVATION = 43.6222620

Scene Two:
p52r19_7x20000919 September 19, 2000
SUN_AZIMUTH = 163.4294723
SUN_ELEVATION = 31.3709292

The first scene was relatively cloud-free, but did not completely cover the area of interest. The second scene covered the area of interest, but had a snowfall at high elevations and a lower sun elevation than the first scene. The landcover in this mountainous area changes rapidly over short distances resulting in a complex mosaic of ground cover types. This is further compounded by the late season, mid-latitude illumination.

Gain calibration, haze reduction (incorporating temperature gradient and derived water vapour partial pressure from weather data gather on the date of scene acquisition at Muncho Lake) were combined with a Bidirectional Reflectance Distribution Function (BRDF) in an attempt to mitigate topographic effect and reduce atmospheric haze. The reflectance from a target varies depending on sun-topography-sensor geometry and the texture and composition of the surface ground cover also affects reflectance. BRDF mitigated the reflectance of pixels with extreme incident angles to more closely resemble reflectance from targets with moderate incident angles. These processes are detailed in Richter

It should be noted that the adjustment of differential illumination did not correct for self or cast shadows. While the methodology can be employed in these conditions, it appears that the variation of texture and composition of surface ground cover between the shadow and adjacent areas is too different as well as the the high percentage of shadow within the high alpine. As a result, there does not appear to be sufficient similar illuminated ground cover for the methodology to remove self and cast shadows. The process also requires a DEM of resoluation four-times better than the scene, which was not available. While reduction in differential illumination was noted on the corrected scenes, over-correction is always an artifact and was present on some ridges and gullies.

The original scenes are located in the **…\Landsat_TM** folder as

p51r19_543.tif
p52r19_543.tif

p52r19 larger shadows, snow cover, greater geographic extent (before and after haze removal and topographic effect reduction):

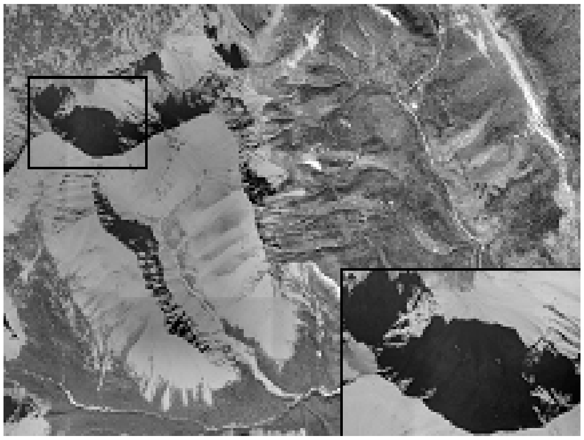
p51r19 smaller shadows, reduced snow cover, smaller geographic extent (before and after haze removal and topographic effect reduction):

Note overcorrection on ridges, and that self and cast shadowing remain in the images above.

An integrated approach to reduce shadow, reduce snow cover and also provide landcover classes for the entire area was employed. Where possible, classes visible in the earlier scene that are coincident with a portion of the large, later shadows and snow-covered alpine were extracted from the earlier, relatively snow-free scene and grafted onto the larger, later scene. Further shadow reduction was achieved through manual airphoto interpretation through histogram manipulation where ever possible.

A Maximum Likelihood Classification technique was used to extract a landcover classification. Class code definitions are contained in the file:

..\mk\classification codes.txt



Airphotos were examined and histogram manipulated to evaluate the landcover within large shadows. Where possible, these values were assigned to the classification.

Shadows and unclassified areas of small extent (less than four hectares) were selected by code and area and were dissolved into the adjacent neighbouring class with the largest common perimeter prior to filtering the classification for minimum polygon size of four hectares.

A Normalized Difference Vegetation Index was created for both scenes:

..\mk\ndvi\ndvi_p52r19 -
..\mk\ndvi\ndvi_p51r19

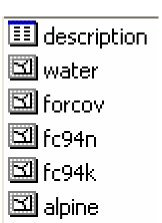
Analysis masks for the "no data" areas of both scenes are available:

…\mk\ work_p52r19
…\mk\ work_p52r19

These masks may be used in conjunction with ARCGIS Spatial Analyst.
They include the working area as values of 1, and non-working area as NODATA values.

Provincial Forest Cover was processed from FC1 *.e00 data and assembled in the folder **…\mk\FC1** as the following geodatabase files:

Spatial data are contained in **Vegetation_FC1.mdb**. The corresponding attribute tables are contained in **094N_tables.mdb** and **094K_tables.mdb**.
The spatial data layers are listed as follows (all are derived from FC1):



The table **description** contains the definition for the codes contained in the FC1 NP_DESC field (government forest cover non-productive for FC1) in the following table..

NP_DESC	DESCRIPTION
A	alpine
AF	alpine forest
C	cultivated/cleare
CL	clay bank
G	gravel bar
GR	gravel pit
L	lakes
M	wild haymeadow
MUD	mud flat
NA	rivers
NP	non-productive
R	rock
RIV	rivers
SWAMP	swamp
S	swamp
U	
ICE	icefield
SAND	sand
NPBR	non-productive
BRUSHNPBU	non-productive bush
TIDE	tidal flat
OR	open range

Elevation and derivatives are contained in the folder **…\mk\elevation** as follows:

rslope
rshade
raspect
prof_curv
plan_curv
gen_curv
dem
rshade.lyr

rslope – slope in degrees
rshade – shaded relief, symbolized in rshade.lyr
raspect – aspect
prof_curv – profile curvature
plan_curv – plan curvature
gen_curv – general curvature
dem – digital elevation model

All of the rasters have a common extent and cell size as the classification raster.

Class Codes Described in GRIDCODE, VEGCODE Fields or Raster Value:

0 unclassified

1 conifer (from closed canopy to as low as approx 20% trees, i.e. widely spaced, includes mature conifer forest riparian, may include some "krummholtz")

2 classes interpreted as old burns (VEGCODE Field only)

4 scree, bedrock, bare (will include dry alpine veg - possibly where bare transitions into an alpine class)

5 riparian: wetland shrub, sometimes with sparce conifer, sedge

6 conifer at treeline, some “krummholtz”, some conifer at treeline is in class 1 – possibly should be merged with class1

7 deciduous trees and/or shrubs

17 bouldery, dry alpine

18 shrub in alpine, also appears as shrub class at lower elevations, with krummholtz

27 shadow - some shadow in alpine was removed through airphoto interp

33 shrub in alpine, possibly similar to 18, but appears more deciduous shrub 18 and 33 could be grouped, 33 also exists as shrub class at lower elevations.

42 alpine tundra

46 water (taken from existing FC1 data, may not be comprehensive)

58 gravel, debris fans

59 Alaska highway - partial (not comprehensive, taken from existing FC1 data)

Burn Areas

Classes 7, 18, 33 and 42 are found in interpreted burn areas. These classes are given as-is in the field GRIDCODES. In the field VEGCODE, these classes are listed as class 2, indicating burns. This field may be used to fine-tune the designation of burns.

References

Ecosystems of British Columbia (1994): Ministry of Forests, Government of BC..
Lay, Roberta (2005): Use of Landsat TM and ETM+ to describe intra-season change in vegetation, with consideration for wildlife management. M.Sc. thesis, UNBC.
R. Richter (1998) "Correction of satellite imagery over mountainous terrain", Applied Optics, Vol. 37, 4004-4015
Seip, Dale (1983): Foraging ecology and nutrition of Stone’s sheep. Ph.D thesis, UBC.
Walker, Andrew (2005): Habitat selection and behavioural strategies of Stone’s sheep in Northern British Columbia. M.Sc. thesis, UNBC.

Field work and site identification for sheep habitat completed July 2006 in conjunction with Pam Hengeveld and Clint Cubberley, Synergy Applied Ecology

APPENDIX B DEVELOPMENT AND TESTING OF STUDY AREA MAP LAYERS

DEVELOPMENT OF STUDY AREA RESOURCE ATTRIBUTE MAPS

General approach

We developed study area resource attribute maps suitable for Stone's sheep habitat selection analyses (Chapter 9), following general methods applied to habitat selection analyses in the M-KMA Beas-Prophet area. Walker (2005) used RSF to determine seasonal habitat selection by female Stone's sheep and seasonal variation in selection by looking at attributes of topography, vegetation, and predation risk in the M-KMA Besa-Prophet PTP area. Topographical attributes included slope, aspect, elevation, curvature, in addition to vegetation type, vegetation quality, and predation risk from grizzly bears and wolves. Existing resource maps developed at provincial or regional scales have limited utility in wildlife habitat use analyses due to poor resolution at fine scales. This is particularly true for alpine-dwelling species because "existing data do a poor job of differentiating between alpine vegetated and non-vegetated habitats". We therefore relied on satellite imagery commissioned by the M-KMA. We used land cover classes determined from Landsat TM satellite imagery (Appendix A) and topographic variables determined from integrated satellite imagery, Terrain Resource Information Management (TRIM), Digital Elevation Model (DEM), Ministry of Forests forest cover, Biogeoclimatic Ecosystem Classification (BEC), and Vegetation Resources Inventory (VRI) data to serve as a foundation for study area stratification for census, and habitat use/availability analyses.

Topographical variables

Wheate *et al* (2007) compiled Digital Elevation Model (DEM) data for the S8MP area which served as the basis for the derivation of **elevation, slope, aspect, and surface curvature** (general, planiform, and profile) raster grids (Appendix A).

We converted aspect to independent eastness and northness values to account for the non-linear distribution of aspect values. We determined eastness values using equation: $sin((aspect * \pi)/180)$. Flat areas on the aspect grid coded as -1 were subsequently converted to values of 0, which should denote no tendency to be east (1) or west (-1). Similarly, northness values were determined using equation: $cos((aspect * \pi)/180)$.

We reproduced Keating's **Simple Solar Radiation Index** (SRI) for the study area using slope and aspect inputs (Keating et al. 2007). We smoothed the output coverage grid with a 5 by 5 nearest neighbour moving window to calculate mean SRI value for each raster cell.

A **slope position** raster layer was constructed utilizing a Topographic Position Index (TPI) as an intermediate to discriminate slope position categories based on a 2000 m neighbourhood (Jenness 2006;

Weiss 2001). TPI calculates the difference between each grid cell elevation value and the average elevation value of the user-defined neighbourhood around each grid cell. A 2000 m neighbourhood was chosen as we felt it best represented the appropriate scale to derive slope position that is relevant to British Columbia Biogeoclimatic (BEC) schema of the area and to Stone's sheep. Anomalous cells were converted to nearest neighbour cells using GIS post-processing routines. The slope position raster layer comprises 6 distinct categories. Because we employed a moving window, the area of data cells containing values within the slope position grid is smaller than the area of data on other grids due to the neighborhood used. This resulted in a border of No Data cells around the edge of the grid to maintain spatial orientation and allow for the layer to align with other data layers.

A **Vector Ruggedness Measure** (VRM) coverage was created using DEM inputs (Sappington et al. 2007). VRM is a topographic parameter derived using a novel approach and may be an important factor with respect to habitat selection by sheep. VRM calculates the 3-dimensional dispersion of vectors orthogonal to raster grid cells using trigonometric functions slope and aspect inputs to measure the magnitude of the resultant vector which is then standardized. VRM appears to provide a more accurate interpretation of landscape ruggedness than other methods such as surface area ratio (Hobson 1972), land surface ruggedness (Beasom 1983), measuring the density of contour lines (Jenness 2000, 2004) and fractal dimension (Mandelbrot 1983).

Lastly, much mountain ungulate research has placed importance on core habitat juxtaposition with security terrain (Côté and Festa-Bianchet 2003; Festa-Bianchet 1988a; Frid 1994; Hamel and Côté 2007; McKinney *et al.* 2003; Pérez-Barberia and Nores 1994; Risenhoover and Bailey 1985). To add this covariate into resource selection regression models, we calculated Euclidean **distance to nearest escape terrain** using GIS tools based on an input raster coverage of all terrain with slopes $\geq 50^{o}$ (degrees) at any elevation.

Land cover classes

Three land cover raster coverages were created using an iterative approach, integrating available spatial datasets and employing topographical rules to refine habitat classifications. We followed methods used to produce land cover map inputs for resource selection functions in the Besa-Prophet PTP area (Walker 2005, Lay 2005).

A digital land cover layer for the S8M project area was produced under a separate M-KMA contract with the University of Northern British Columbia (Wheate et al. 2007) to serve as input layers for habitat use and selection analyses. Two remotely sensed LandSat TM Scenes from September 2000 and August 2001 were used to identify vegetation types to construct the **land cover base map** (**rclassn**). A Bidirectional Reflectance Distribution Function (BRDF) was employed to calibrate gain, reduce haze associated with atmospheric constituents and minimize topographic effects common in a mountainous area. Discrete habitat polygons were derived from BC Forest Cover data employing a Maximum Likelihood Classification technique to resolve and extract land cover habitat classifications from the

LandSat image and compiled as GIS raster and vector data sets (Wheate et al. 2007). All supporting documentation and land cover class codes supplied for this component is included in Appendix A.

We developed and tested two modifications (**rclassn_V2 and Rsf_habs**) of the base map provided by Wheate 2007 to reconcile discrepancies between observed land cover and satellite image land cover classifications. Satellite image classifications included alpine habitats at elevations below treeline.

rclassn_V2 First, we applied terrain-based land cover classification rules suggested by Lay (2005), using slope position, BC Government Terrain Resources Information (TRIM), and BC Government Biogeoclimatic Ecosystem Classification (BEC) map data as references to reclassify satellite image delineations of "alpine" habitats that occurred at elevations below treeline (Table B.1). This resulted in the creation of two new classes: Open Grassland Low Shrub Mosaic (66) and Low Productivity Upland Conifer (77), and updates to riparian (5) and conifer (1 and 6)classes, to reconcile habitat types occurring on the analysis landscape but not readily defined by the existing habitat descriptions or terrain-based rules, as follows.

- Riparian (5) classes occurring on slopes >10^{o} were re-classed as shrub (18).
- In the Boreal White and Black Spruce (BWBS) BEC zone: Bouldery Dry Alpine (17) and Alpine Tundra (42) cells found in were re-classed to Scree Bedrock Bare (4) and Shrub (18), respectively.
- In the Spruce-Willow-Birch (SWBmk) variant, elevations <1300 m: Bouldery Dry Alpine (17) and Alpine Tundra (42) were assumed to not be alpine habitat types and were re-classed to Scree Bedrock Bare (4) and Open Grassland Low Shrub Mosaic (66) respectively.
- Bouldery Dry Alpine (17) and Alpine Tundra (42) cells were re-coded using an aspect filter to identify moist and dry variants (Lay 2005). Alpine Tundra (42) found on south facing slopes were converted to Bouldery Dry Alpine (17). Conversely, Bouldery Dry Alpine (17) found on north facing slopes were converted to Alpine Tundra (42).
- Conifer (1) found in alpine or parkland classes were re-classed as Conifer at Treeline (6). Conifer at Treeline (6) found in the BWBS zone were classed as Conifer (1). Because a small proportion of Conifer at Treeline (6) cells were found in the SWBmk <1400 m we applied an elevation filter to convert remaining Conifer at Treeline (6) cells <1400 m to Conifer (1).
- Cells of Conifer (1) likely contain "Low Productivity Spruce" on north facing slopes in the SWBmk and SWBmks (Lay 2005). We defined northerly aspects occurring between >315^{o} and <45^{o} and employed our slope position raster model to determine those cells located on middle, upper slopes and ridges above 1200 m in the SWBmk and SWBmks variants to filter these occurrences and re-class to Low Productivity Upland Conifer (77).

Table B.1 Percent of land cover types by BEC units contained in model 2 (**rclassn_v2**). Note that this version has a smaller 'data area' (14,638,659 pixels) than the original rclassn (16,192,115 pixels) grid due to the application of the slope position model in the reclassification process and the recoding of unclassified and shadow to missing data.

Grid code	Land cover class	BWBS	SWB	Alpine
1	Conifer	79.5	54.6	0.0
4	Scree/bedrock/bare	0.0	4.7	59.1
5	Riparian	1.3	0.3	0.0
6	Conifer at tree line	0.0	3.0	0.9
7	Deciduous trees/shrubs	2.4	3.3	0.0
17	Bouldery dry alpine	0.0	3.9	16.3
18	Shrub - coniferous leading	13.3	16.2	4.5
33	Shrub - deciduous leading	0.9	2.0	1.2
42	Alpine tundra	0.0	4.9	17.8
46	Water	2.0	1.2	0.1
58	Gravel/debris fans	0.3	0.5	0.2
59	Alaska Highway	0.2	0.4	0.0
66	Open grassland/low shrub	0.0	2.8	0.0
77	Low productivity upland conifer	0.0	2.2	0.0

Rsf_Habs A third land cover raster grid (rsf_habs) was constructed using the basic land cover raster incorporating slightly modified topographical rules to those previously employed, BEC data, and also integrating Vegetation Resource Inventory British Columbia Land Classification Schema (VRI; http://www.for.gov.bc.ca/hts/vridata/standards/index.html) recoded to match LandSat classifications. This was a hybridization of Wheate's rclassn with VRI data 1:20,000 stream orders 4 through 9. Post-processing using terrain-based rules to refine classifications and reduce anomalous single habitat pixels.

- **Spatial data for water courses and the Alaska Highway were incomplete** and discontinuous within the basic LandSat analysis extent. In some instances, the extent of the Alaska Highway corridor was exaggerated (>19 pixels in width) and included gravel roads and stream channels. To correct this, we first replaced forest cover water and LandSat interpreted Alaska Highway class with neighbouring habitat classes and merged the resultant raster with VRI, 1:20,000 scale stream network data, and highway centre line work mapped at 25 m resolution during field activities. As streams of order 1 to 3 are often dry draws, flow sub-surface or intermittent within the S8MP area, only streams of order 4 to 9 were used to repair discontinuous VRI water courses.
- This step added stream line work on top of VRI water but also fills in the stream network such that it is represented by a sequence of contiguous cells that have no breaks or only diagonal joins with each other. Any streams left on the layer that are discontinuous or have only diagonal joins are remnant from VRI data and where the order of the stream is <4. **Additionally, this step benefited patch mapping during the creation of a fragmentation layer** as higher stream order (Strahler 1952) is correlated to increasing channel width with 4th order streams calculated to have a mean channel width of ≥9 m (Miller et al. 1996) and similar in effect to features such as seismic

lines and access roads. **Cells coded as Unclassified (0) and Shadow (27) were updated** with VRI classification data. We applied GIS tools to fill in areas <4 ha that had no classification. Tools were controlled so that nearest neighbor cells classed as water or shadow did not increase in overall number. Unclassified (0) and Shadow (27) patches >4 ha were reconstructed by combining the pre- and post-processing raster grids prior to additional steps. Shadow and unclassified cells were turned to rock (4) if they were above 2000 m on the assumption that there is very little vegetated habitat above this elevation.

- The remaining unclassified and shadow areas were coded as "No Data" to prevent inclusion during moving window post-processing of RSF layers. Because these cells do not constitute habitat types, this forces the moving window algorithm to incorporate only those cells with valid habitat values while retaining the expected number of cells in the divisor. Cells unaffected by the above rules retained their original interpreted LandSat land cover values.

We used topographical filters to re-class Riparian (5) cells occurring on slopes >10^{o} to Shrub (18), Bouldery Dry Alpine (17) and Alpine Tundra (42) <1300 m in SWBmks to Open Grassland Low Shrub (66), identify moist and dry aspects (Lay 2005) to convert appropriate cells to either Bouldery Dry Alpine (17) or Alpine Tundra (42). Bouldery Dry Alpine (17) and Alpine Tundra (42) in the BWBS was re-coded to Scree Bedrock Bare (4) and Open Grassland Low Shrub (66), respectively. Conifer (1) in the Alpine or in SWBmks was converted to Conifer at Treeline (6). Conifer at Treeline (6) in BWBS was re-coded to Conifer (1). Remaining Conifer at Treeline (6) in SWBmk and <1300 m was converted to Conifer (1). Conifer (1) occurring at aspects between >315^{o} to <45^{o} and slopes >10^{o} in SWBmk were re-coded to Low Productivity Upland Conifer (77). To reduce the increased incidence of orphaned cells introduced by our processing steps, we merged isolated cells with nearest neighbours.

Normalized difference vegetation index

Wheate *et al* (2007) also derived Normalized Difference Vegetation Index (NDVI) data for both LandSat scenes for the S8MP area. NDVI layers were cropped and re-referenced where necessary to contain the same number of rows and columns as other grids. We re-scaled NDVI grids to contain only values from 0 to 1 and smoothed coverages by employed a 5 by 5 moving window that calculated the mean.

Burned areas

The S8MP area contains large areas of fire-induced subalpine grassland. Major drainages including Sulphur Cr and Scaffold Cr were intentionally burned by the BC Fish and Wildlife Branch in 1978 (Seip 1983:10). Burn data (880 km^2; 21% of study area) interpreted from LandSat imagery did not have estimates of burn date (Wheate et al. 2007). We searched available sources for an updated spatial burn layer with date of burn and origin (prescribed or natural) attributes. We used VRI to generate an age-class coverage for the S8MP analysis extent and produced a combined Ministry of Environment / Ministry of Forests fire layer for burns whose date of last burn was between 1990 and 2005 inclusive (265 km^2, 6% of the study area). This resulted in a binary grid where 0 represents unburned cells and 1 are recent burns. Thirty-six percent (36.4%) of burns occurred in 2003 – 2005, 10.3% in 1998, and 53.3% in 1990 – 1992.

Habitat fragmentation

We constructed a raster coverage quantifying the relative level of habitat fragmentation within the analysis extent using a modified approach undertaken by Gustine (2005). We used our derived land cover classification layer as input and patch mapped using an 8 cell neighbourhood processed with a 13 by 13 rectangular moving window to calculate focal variety expressed as the count of unique habitat patch within the neighbourhood as a continuous integer.

GIS spatial data processing and definition of habitat classes for RSF analyses

Twenty-six independent raster grids depicting spatial data for topographical (n = 13) and land cover (n = 13) attributes were developed with resolution set to 25-m cell size. Grids comprise 16,515,072 cells over the full analysis extent to facilitate multi-scale analyses (Tables B.2 and B.3).

The original LandSat interpretation (**rclassn**; Figure B.1, Appendix A) identified 14 land cover types (total map area 16,515,072 cells). After terrain-based modeling and spatial processes were implemented (**rclassn_v2**), a total of 147,790 (<1%) land cover cells were re-classed. Remaining Shadow and unclassifed cells totaled 555,983 (3.4%); these cells were coded as missing data. Whenever possible, we employed a moving window to the coverage outputs to smooth homogenous patches by removing orphaned pixels or incorporating them into adjacent patches. All spatial data is maintained in Universal Transverse Mercator, North American Datum 1983.

Generally, aspect trends are similar between the northern and southern portions of the S8MP area. The Sentinel Range tends towards more north (mean=0.02, SD=0.69) and easterly aspects (mean=0.02, SD=0.69) as does the Stone Range which has slightly less northerly (mean=0.04, SD=0.68) and more east (mean=0.06, SD=0.73) aspects. The Sentinel Range has higher elevations and more expansive open alpine areas than the Stone Range. The overall S8MP area analysis extent has an elevation gradient of 2,220 m, with approximately 20% of the study area above tree line in open habitat. Mean VRM is greater in the Sentinel Range (0.0087, SD=0.014) than the Stone Range (0. 0.0054, SD=0.010) and maximum ruggedness measure 8% greater.

Although Stone's sheep have been visually observed licking on the highway shoulder, the Alaska Highway was not reconstructed within the final RSF land cover raster as few GPS points were recorded creating zero use in several seasons.

Hybridization of the modified Landsat model classifications with VRI data refined the land cover layer (**rsf_habs**) to 8 classes which serve as the vegetation layer for sheep RSF analyses (Figure B.2).

Table B.2 Topographical data grids produced for Stone's sheep resource selection function analyses.

Grid Name	Description
genC	Wheate's general curvature raster. The derivative of rate of change of the landscape. Values are typically the difference of planiform and profile curvature values.
plnC	Wheate's planiform curvature raster. A value characterizing the direction perpendicular to the direction of slope.
proC	Wheate's profile curvature raster. A value characterizing the direction of landscape slope.
Vrm	Vector Ruggedness Measure created following Sappington *et al*, 2007. A continuous value characterizing landscape ruggedness between 0-1.
slp_pos	6 category slope position raster grid with a 2000m circular neighborhood created using Jenness' TPI, 2006.
slp_pos_rcl_a	slope position raster grid with 4 categories resultant from GIS processing routines implemented on slp_pos raster.
Elev	Wheate's digital elevation model raster.
Raspect	Wheate's aspect grid. A continuous variable between 0-360 indicating Cardinal direction in degrees.
Rslope	Wheate's slope grid. A continuous variable between 0-90 indicating steepness in degrees.
Sri	Keating's Simple Solar Radiation Index, 2007 for study area (central latitude 58.84898543), derived from slope and aspect inputs.
sri5x5	The sri grid smoothed by a 5 by 5 moving window that calculated the mean. Values along the edges of the grid are based on incomplete neighborhoods (i.e. there is no edge buffer). The data area matches that of the input sri grid.
Eastness	The raspect grid converted to a representation of eastness using equation 1. Flat areas on the aspect grid coded as -1 were subsequently converted to values of 0 which should denote no tendency to be east (1) or west (-1).
Northness	The raspect grid converted to a representation of northness using equation 2. Flat areas on the aspect grid coded as -1 were subsequently converted to values of 0 which should denote no tendency to be north (1) or south (-1).
eucdist_esc_2	Euclidean distances to nearest escape terrain. The input raster represents all terrain with slopes greater than or equal to 50 degrees, at any elevation.

Table B.3 Land cover data grids produced for Stone's sheep resource selection function analyses.

Grid Name	Description
Burns	Wheate's old burns layer. No dates of burns indicated.
new_burns	A binary grid where 0 is unburned and 1 is recent burns. Combined MOE/MOF fire layer for burns whose date of last burn was between 1990 and 2005 inclusive, clipped to study area. Areas are exaggerated and highly erroneous.
Rclassn	Wheate's basic land cover classification raster identifying 15 categories.
rclassn_v2	A reclassified version of Wheate's rclassn raster created employing Lay's post-processing rules.
rcl_hybrd_d	A habitat layer that represents the hybridization of Wheate's rclassn with VRI data 1:20,000 stream orders 4 thru 9. Post-processing using terrain-based rules to refine classifications and reduce anomalous single habitat pixels.
rsf_habs	A slightly modified version of rcl_hyrbrd_d derived by grid reclassification to eliminate habitat categories that have zero use by sheep, all water, riparian and gravel/debris fans were pooled together into a water classification.
f_variety_frag_rg	A continuous grid representing habitat fragmentation based on rcl_hybrd_d and a modified approach to Gustine's coarse vegetation cover types. Post-processed using a 13 by 13 rectangular window and represents a count of unique habitat patches within the neighborhood.
ndvi_p51_full	Wheate's ndvi_p51 grid but modified so that it has the same dimensions as other grids in ascii format.
ndvi_p52crop	The ndvi_p52 grid but cropped of an excess NoData area so that it has the same dimensions as other grids.
ndvi52_rscale	The ndvi_p52crop grid converted to a 0 to 1 floating point grid by dividing each cell by 255.
ndvi52_5x5	The ndvi52_rscale grid smoothed by a 5 by 5 moving window that calculated the mean. Values along the edges of the grid are based on incomplete neighborhoods (i.e. there is no edge buffer). The data area matches the sri grid.
Vri	vri raster for study area created using data sourced in 2006
Bec	BEC raster for study area created using data sourced in 2006.

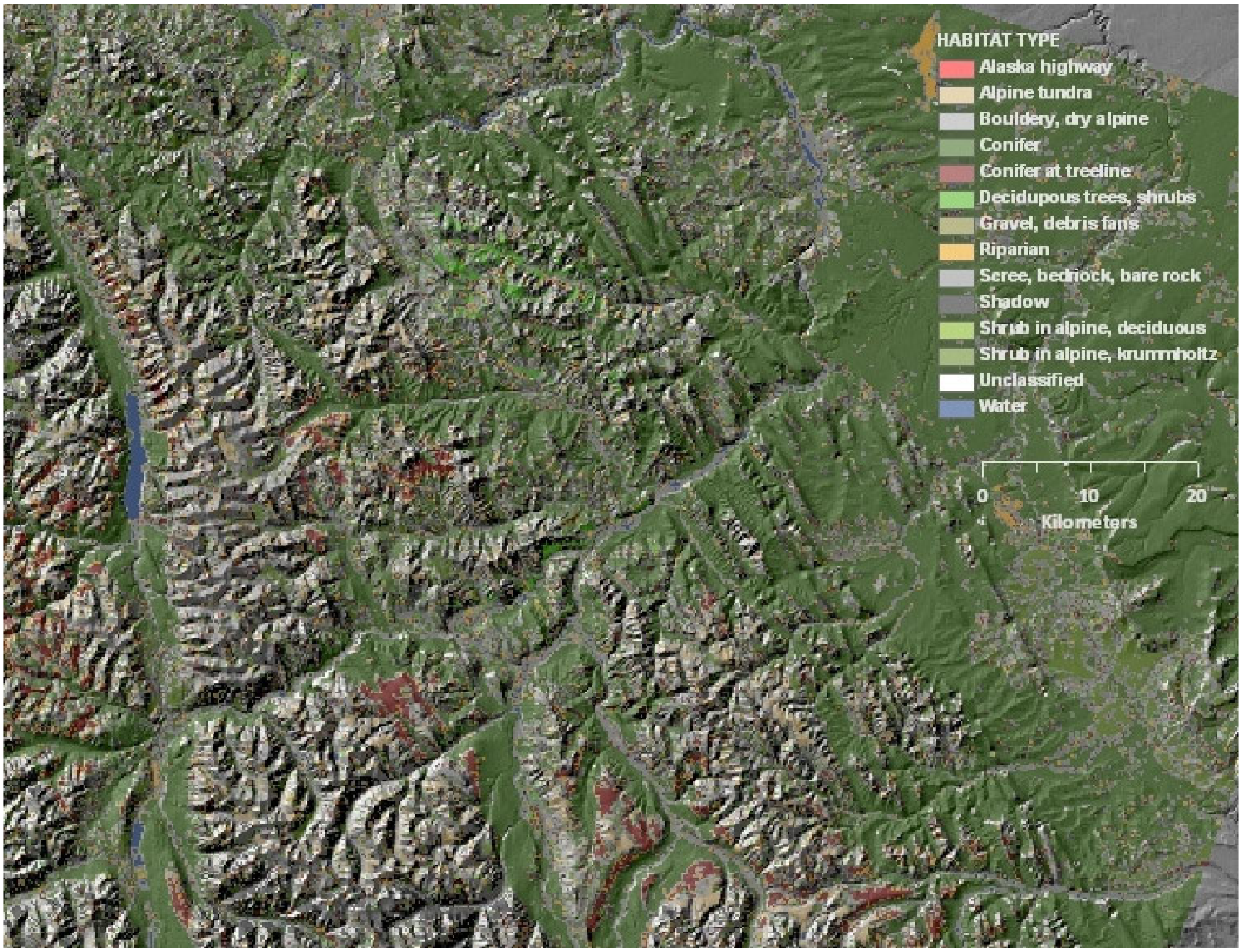


Figure B.1 The original LandSat-interpreted land cover model of the Sulphur / 8 Mile Stone's sheep project analysis extent. Fourteen discrete habitat types were identified.

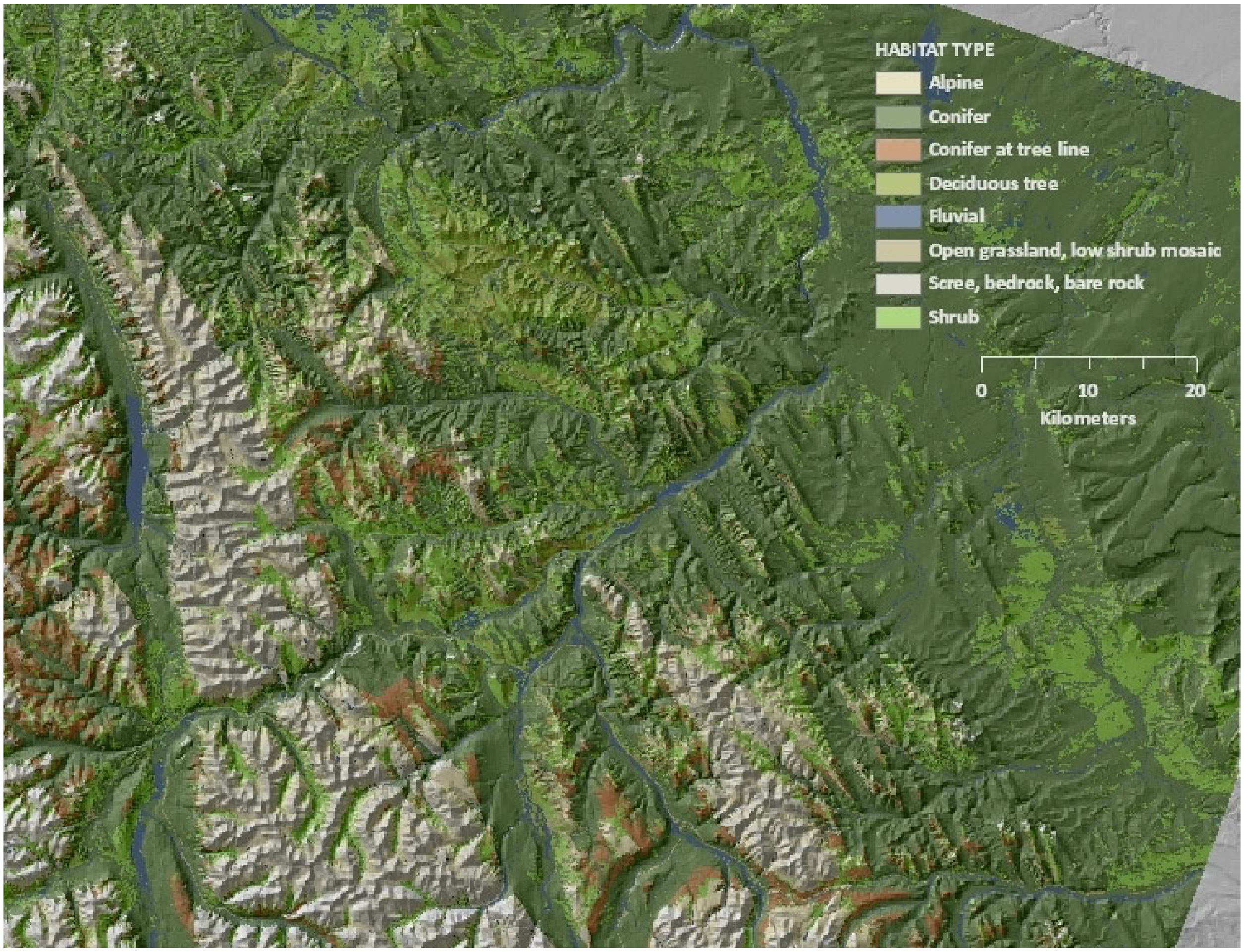


Figure B.2 The final land cover model of the Sulphur / 8 Mile Stone's sheep project analysis extent. Eight discrete habitat types were identified.

HABITAT CLASSIFICATION ACCURACY EVALUATION

Although field verification was conducted by Wheate *et al*. (2007) during land cover model preparation, no reference was made with respect to basic model accuracy in supporting documentation (Appendix A). As such, a second field verification exercise was designed a priori to evaluate a minimum of 10 sample locations per habitat class by helicopter. To reduce bias, the field crew had no prior knowledge of habitats predicted by our preliminary habitat model. We delineated areas that sheep use but differed in topographic relief (high relief, medium relief, larger valley bottoms) and placed sample points within the selected areas semi-randomly.

A 250 m exclusion buffer about each sample point was established to maintain spatial separation of sample sites and reduce the potential for spatial autocorrelation. To account for map and GPS positional error, acceptable sites included contiguous patches with at least 50 m radius of pure, homogenous habitat around the sample point. We evaluated only one sample site for a given habitat class within the buffer, the approximate size of the patch sampled for each habitat type, and kept a running tally of habitat types sampled using our established classification system. In addition, we applied the VRI BCLCS to the habitat plot as an independent measure to resolve potential ambiguity during analysis. As random-based sampling neared completion, we initiated directed searches for less abundant habitat types to ensure a minimum of 10 sample sites per habitat class.

As there is no single recognized method of evaluating and reporting land cover model accuracy, we employed 2 distinct quantitative analyses as suggested by Foody (2002). Cohen's *Kappa test (Cohen 1960),* often referred to as a confusion matrix, provides a measure of the proportion of all possible cases of classification presence or absence correctly predicted after accounting for chance effects. Cohen's Kappa statistic was calculated using a GIS Avenue script (Jenness and Wynne 2007). The Receiver Operating Characteristic (ROC) approach visually reports equivalent information as a confusion matrix but is considered more robust (Swets et al. 2000). The ROC curve is obtained by plotting sensitivity (true positives) on the *y* axis and 1 – specificity (false positives) on the *x* axis for all possible thresholds. The area under the ROC curve (AUC) as the measure of the prediction success is equal to the value of the Wilcoxon Mann-Whitney test statistic. ROC curves were derived using the ROCR package (Sing et al. 2005) in R statistical software (R Development Core Team 2011).

Accuracy of the basic land cover model was estimated at 53% based on area under the curve (AUC) calculated from ROC analysis (Figure B.3). Kappa test calculated an overall accuracy of 35% (khat=0.28).

Accuracy of the rclassn_v2 land cover model was estimated at 51% based on area under the curve (AUC) calculated from ROC analysis (Figure B.4). Kappa test calculated an overall accuracy of 36% (k_{hat} = 0.29).

Accuracy of the hyb_d_rsfhabs_merged2 land cover model was estimated at 49% based on area under the curve (AUC) calculated from ROC analysis (Figure B.5). Kappa test calculated an overall accuracy of 46% (k_{hat} = 0.36).

High producer's accuracy and low user's accuracy for a land cover type indicate it is over-represented on the land cover map compared to its actual distribution on the ground, while low producer's accuracy and high user's accuracy indicate under-representation on the land cover map compared to its actual distribution on the ground (Table B.4).

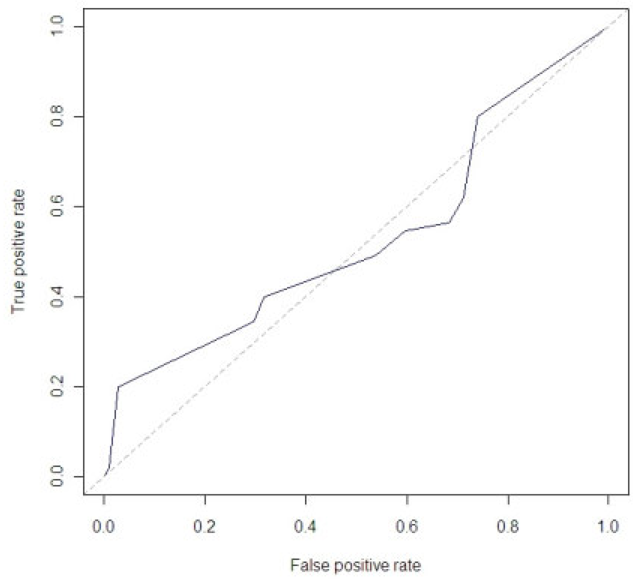


Figure B.3 Receiver Operating Characteristic (ROC) curve of Wheate's rclassn land cover raster model. Dashed line indicates line of chance.

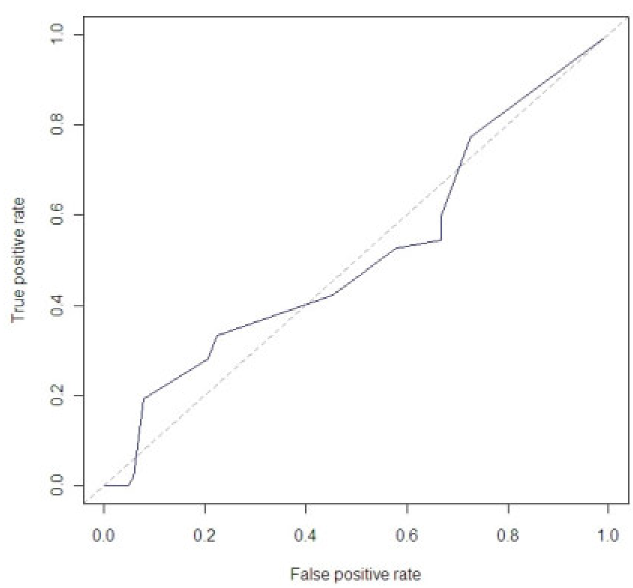


Figure B.4 Receiver Operating Characteristic (ROC) curve of the rclassn_v2 land cover raster model Dashed line indicates line of chance.

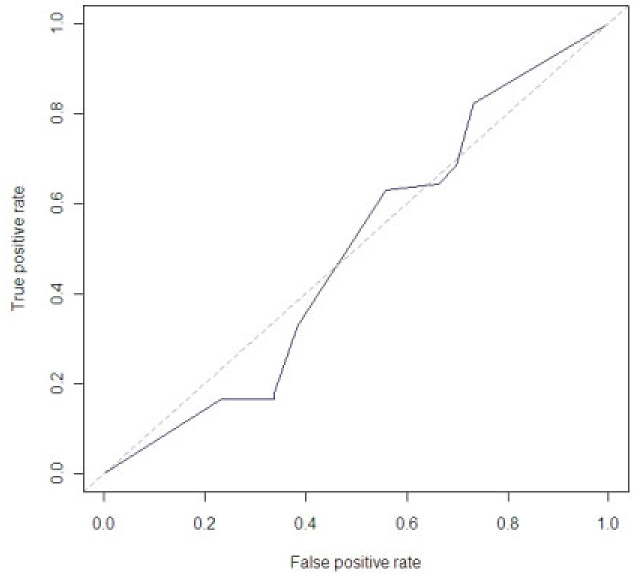


Figure B.5 Receiver Operating Characteristic (ROC) curve of the rsf_habs land cover raster model. Dashed line indicates line of chance.

Table B.4 Results of Cohen's kappa test (κ) on 8 individual land cover types in the final vegetation model.

Land Cover Type	Producer's Accuracy (%)	User's Accuracy (%)
Scree, bedrock, , bare rock	83.3	76.9
Conifer at tree line	17.6	50.0
Deciduous tree	9.1	10.0
Conifer	52.0	36.1
Alpine	70.9	59.4
Fluvial process	44.0	73.3
Open grassland, low shrub mosaic	0.0	0.0
Shrub	40.0	37.5

GENERALIZED SAMPLING FOR HABITAT 'USE' AND 'AVAILABLE' ATTRIBUTES

We conducted a generalized type 1 design analysis (Manly et al. 2002) to assess the relative proportion of use by male and female sample sheep, irrespective of season or population, compared to the proportion of discrete land cover type area available over the entire analysis extent. No filtering of GPS locations was done.

A subset of all GPS data recorded by collared female Stone's sheep accepted for RSF input (n=30,240) was used for preliminary analysis. Locations with erroneous fix times (i.e., out of synch with the expected fix frequency) were excluded. We allowed for variability of elapsed hours between fixes to account for the time it took for collars to acquire satellites and determine a fix based on manufacturer specifications. Televilt collars (6 hr fix frequency) were allowed a 4 minute window and ATS collars (7 hr fix frequency) were allowed a 5 minute window. Locations that occurred after a gap >10 collar fix cycles were excluded. Location data from day of capture, subsequent day and unrealistic movements between fixes were excluded. Due to the nature of the rules we employed, data accepted for movement analysis were automatically candidates for preliminary analysis. No filtering of 2D or 3D locations was done.

To reduce the potential to unnecessarily include uninformative parameters in final regression models (Arnold 2010), we performed simple univariate logistic regressions by population and season to provide preliminary insight with respect to potential explanatory variables to consider in statistical model development during final RSF analyses. For categorical variables, significance was determined using a log-likelihood Chi-square test between the model that includes the variable and a null model (Menard 2002). We used Akaike's Information Criterion (AIC) to rank explanatory variables (Anderson and Burnham 2002). Finally, we calculated tolerance scores to assess the degree of collinearity between explanatory variables. A threshold tolerance score of <0.2 indicated correlated variables (Menard 2002). Analyses were undertaken using the maptools package in R statistical software version 2.9.1 (R Development Core Team 2009).

Preliminary analyses of land cover use versus availability are independent of population and season and provide an index of how sheep location data are distributed among resource units identified in the project area analysis extent. Generally, the proportion of sheep locations in Alpine Tundra and open land cover types (eg. scree, bouldery alpine) is greater than the availability of those resource units in the study area analysis extent (measured as the proportion of area covered by the land cover types). Forested units such as conifer were used much less than are available (Figure B.6).

There appears to be a correlation between collar type and the occurrence of these large gaps in location fixes suggesting that it is more a feature of collars than of sheep habitat induced bias. Landscape attributes with the greatest explanatory power to best inform sheep habitat models based on preliminary univariate logistic regression are found in Table B.5. Only solar radiation index and northness had tolerance scores <0.2, indicating undesirable levels of correlation between these two variables and should not be included in the same habitat models.

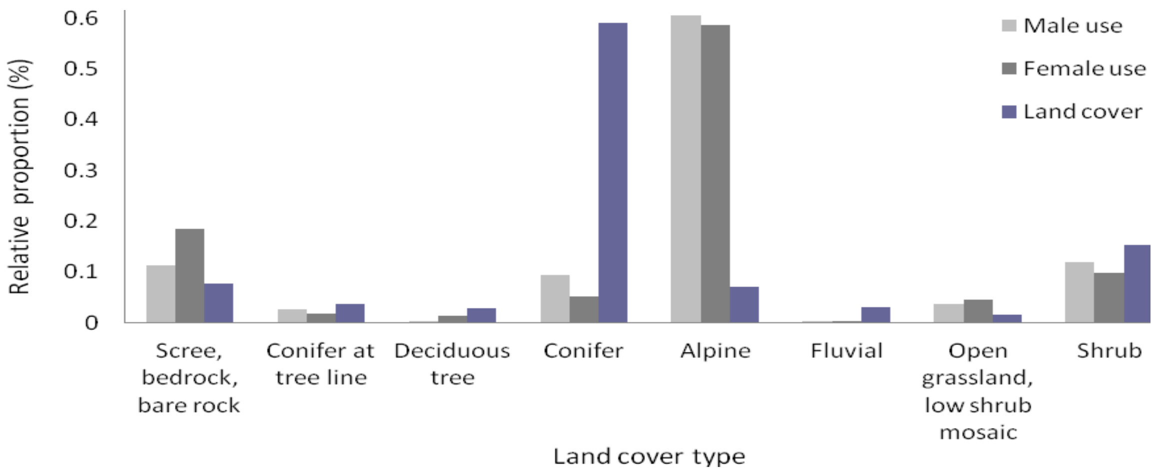


Figure B.6 Relative availability of each land cover type in the Sulphur / 8 Mile Stone's Sheep Project area analysis extent, measured as the proportion of area covered by each habitat relative to the proportion of female Stone's sheep locations in each habitat.

Table B.5 Continuous and categorical variables deemed to have the most explanatory power for Stone's sheep resource selection models within the Sulphur / 8 Mile Stone's Sheep Project area.

Continuous	Categorical
General curvature	Slope position
Elevation	Land cover
Slope	Recent burns
Eastness	
Northness	
Vector ruggedness measure	
Solar radiation index (without smoothing)	
Distance to escape terrain	

DISCUSSION

Land cover model performance has been problematic within the S8MP analysis extent. Much effort has been expended to increase model confidence but success has been limited. As such, we chose the model with the best agreement between accuracy tests. Differentiation based on topographical and BEC zonation to land cover types such as boreal and upland conifer and deciduous trees/shrubs did not increase land cover model accuracy. Pooling similar habitats increased model accuracy but not to the degree desired. Reclassifying the final land cover layer will benefit fitting RSF models by reducing the number of coefficients to be estimated by pooling ecologically similar habitats together according to our current knowledge about S8M landscape, Stone's sheep, and to help avoid empty cells due to the presence of rare or little used habitats. However, trade-offs as a result of combining similar land cover types have led to a generalization of some vegetation types. Shrub (18) and Shrub (33) are described as 'shrub in alpine' types, but, they also occur extensively in valleys and on montane slopes (i.e., uplands below the subalpine zone) as well. Within northeast BC, SWB is considered a subalpine zone and the BWBS is a boreal zone. Despite several inquiries, a more descriptive account of the lineage of the basic LandSat model may have alleviated potentially confounding steps in final land cover model preparation.

It appears that measuring and reporting the accuracy of a classification system applied to remote sensing data is highly variable in the literature. Because of its simplicity, and the ability to correct chance agreement between categories, metrics derived from a confusion matrix are the most widely accepted measures for accuracy evaluation among the remote sensing community. A strength of the kappa statistic is the ability to report the calculated accuracy within each category of the predictive land cover model as well as the overall accuracy. As well, confusion matrices are sensitive to data anomalies and the tendency to overestimate chance agreement may result in an underestimate of map accuracy (Foody 2002). ROC considered a straightforward and appropriate method for evaluating classification model performance (Hamel 2008). ROC remains robust given frequent changes to classifications even when there is disparity in the frequency of classification distributions (Fawcett and Flach 2005). Its main advantage over other measures is that the AUC provides a single measure of model accuracy independent of selection threshold (Phillips et al. 2006).

Employing these two methods have provided us with a measure of confidence in the accuracy estimates. Despite the low overall accuracy open Alpine land cover variants have been consistently mapped accurately as an individually type than other variants such as Deciduous tree. Given the importance of topographical features (Walker et al. 2007), open Alpine and the relative unimportance of Deciduous tree to Stone's sheep the overall performance of the land cover model may not be a significant source of error or bias in the final analysis.

Test sample size and achieved level of model accuracy tend to be subjective rather than derived from statistical or demonstrated practicable considerations. Recommendations for sample sizes for accuracy assessment are on the order of 50 - 100 per land cover class, with the larger per class sample sizes for schemes that result in large numbers (>12) of classes. Thomlinson *et al* (1999) set a target of an overall accuracy of 85% with no class less than 70% accurate (Foody 2002). The overall accuracy target of 85% is rarely met, Lay (2005),for instance, achieved an overall accuracy of 77.3% with several individual classes having producer's accuracy as low as 60%.

We acknowledge that relying on larger, homogenous land cover patches rather than areas of transition for ground truthing has the potential to bias the accuracy assessment. Accuracy evaluation is affected by systemic bias born from researcher such as reference data that is not representative of all land cover variants and errors made when ground truthing. Because sampling may not representative of the entire model extent, the reported accuracy may only be relevant for a limited area of the land cover model.

These reasons constitute our reluctance to use training data as a cost saving measure for land cover model verification.

Range burning is conducted in the Peace region to increase habitat quality and trophy production of Stone's sheep (Elliott 1978). Prescribed range burns are extensive in the S8M area and may explain the discrepancy noted between BEC and VRI data with respect to the proportion of open alpine types Treed habitats should be detectable by the LandSat scenes. However, the Landsat TM imagery used for delineation of discrete resource units is >10 yr old, and a range burning program has been, and continues to be, conducted within the S8M Project area by MoE and guide-outfitters. VRI data is re-inventoried from aerial photos on an estimated 10-20 year interval or as funding is available and has historically been updated bi-annually (http://www.for.gov.bc.ca/hts/vri/intro/index.html), therefore, it is assumed that these areas of tundra signify a loss of tree cover since the acquisition air photos that current VRI data is based. Mapping of burned areas are of low resolution and exaggerated to reduce involvement of inter-agency mop-up activities as a cost saving measure. The interpretation of the significance of burned areas to Stone's sheep will require additional effort as the relative importance of these areas may be related to the underlying topography and land cover classification underlying the burn may be used as a reference working towards final RSF analysis. Additional work may also be conducted with the distance to escape terrain grid (eucdist_esc_2) since the first version had no explanatory power while the second version performed well, although the definition of escape terrain was arbitrary. Our patch mapped fragmentation layer was not included in RSF analyses (Chapter 9) but contributed to regression models related to Stone's sheep mortality (Chapter 6).

The intensity with which the availability of habitat attributes is sampled for requires additional analysis. Our computer processor capability can easily accommodate the current anticipated sampling intensity of 5 random points per sheep 'use' point. The number of random is somewhat arbitrary and could be abandoned in favor of an iterative approach that samples intensively enough that estimates of availability become stable. However, this may prove too onerous since some attributes are more variable than others, some attributes are continuous and some categorical may make a single metric of stability difficult to determine.

Finally, much consideration of the scale at which availability of attributes is sampled is required. We intend to employ a movement potential point buffer approach at the finest scale, while annual home range of all points for animals that have at least 1 yr of data and S8M study area analysis extent will be used for broader scales.

APPENDIX C HABITAT SELECTION MODEL RANKINGS

AIC ranking of candidate habitat selection models for male and female Stone's sheep in 2 populations (Stone Range, Sentinel Range), at three spatial scales.

Table C1 a - d. AIC ranking of candidate habitat selection models, movement buffer (MB) spatial scale.
Table C2 a - d. AIC ranking of candidate habitat selection models, home range (HR) spatial scale.
Table C3 a - d. AIC ranking of candidate habitat selection models, study area (SA) spatial scale.

Table C1 a. STONE Range MALES, movement buffer (MB) spatial scale.

Season	Model	n	Dev	LL	K	AIC	ΔAIC	AICw	Rank
Lambing	Security	9804	7344	-3672	9	7368	1158	<0.01	2
	Forage type	9804	7541	-3770	9	7563	1353	<0.01	4
	Forage availability	9804	7361	-3681	5	7379	1169	<0.01	3
	All-inclusive	9804	6162	-3081	23	6210	0	1.0	1
Summer	Security	14690	12521	-6260	9	12545	890	<0.01	4
	Forage type	14690	12177	-6088	9	12199	544	<0.01	2
	Forage availability	14690	12267	-6133	5	12285	630	<0.01	3
	All-inclusive	14690	11607	-5803	23	11655	0	1.0	1
Fall	Security	17322	14221	-7110	9	14245	1202	<0.01	4
	Forage type	17322	14191	-7096	10	14215	1172	<0.01	3
	Forage availability	17322	14151	-7076	5	14169	1126	<0.01	2
	All-inclusive	17322	12993	-6497	24	13043	0	1.0	1
Rut	Security	12222	9160	-4580	9	9184	787	<0.01	2
	Forage type	12222	10066	-5033	10	10090	1693	<0.001	4
	Forage availability	12222	9406	-4703	5	9424	1027	<0.01	3
	All-inclusive	12222	8347	-4173	24	8397	0	1.0	1
Early Winter	Security	12754	8734	-4367	9	8758	963	<0.01	3
	Forage type	12754	10181	-5090	9	10203	2408	<0.001	4
	Forage availability	12754	8726	-4363	5	8744	949	<0.01	2
	All-inclusive	12754	7747	-3873	23	7795	0	1.0	1
Late Winter	Security	17741	14178	-7089	9	14202	1582	<0.01	3
	Forage type	17741	14722	-7361	10	14746	2126	<0.01	4
	Forage availability	17741	13993	-6996	5	14011	1391	<0.01	2
	All-inclusive	17741	12570	-6285	24	12620	0	1.0	1

N = number of locations; Dev = model deviance; LL = Log-likelihood; K = number of model parameters; AIC = Akaike's Information Criterion; ΔAIC = difference in AIC values relative to best model; AIC w = relative weight of AIC values; Rank = model rankings based on AIC weights.

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Table C1 b. SENTINEL Range MALES, movement buffer (MB) spatial scale

Season	Model	n	Dev	LL	K	AIC	ΔAIC	AICw	
Lambing	Security	2329	1739	-870	7	1759	188	<0.01	2
	Forage type	2329	1989	-995	9	2011	440	<0.01	4
	Forage availability	2329	1817	-908	5	1835	264	<0.01	3
	All-inclusive	2329	1527	-764	21	1571	0	1.0	1
Summer	Security	4605	3213	-1606	7	3233	178	<0.01	2
	Forage type	4605	3572	-1786	8	3592	537	<0.01	4
	Forage availability	4605	3220	-1610	5	3238	183	<0.01	3
	All-inclusive	4605	3013	-1506	20	3055	0	1.0	1
Fall	Security	5958	4700	-2350	8	4722	875	<0.01	3
	Forage type	5958	5010	-2505	7	5028	1181	<0.01	4
	Forage availability	5958	4251	-2125	5	4269	422	<0.01	2
	All-inclusive	5958	3805	-1903	20	3847	0	1.0	1
Rut	Security	4502	3245	-1622	8	3267	266	<0.01	2
	Forage type	4502	3569	-1785	8	3589	588	<0.01	4
	Forage availability	4502	3555	-1777	5	3573	572	<0.01	3
	All-inclusive	4502	2957	-1479	21	3001	0	1.0	1
Early Winter	Security	2586	1631	-816	7	1651	158	<0.01	2
	Forage type	2586	1673	-836	8	1691	198	<0.01	3
	Forage availability	2586	1826	-913	5	1846	353	<0.01	4
	All-inclusive	2586	1451	-726	20	1493	0	1.0	1
Late Winter	Security	4014	3084	-1542	7	3104	239	<0.01	2
	Forage type	4014	3339	-1669	9	3361	496	<0.01	4
	Forage availability	4014	3158	-1579	5	3176	311	<0.01	3
	All-inclusive	4014	2821	-1410	21	2865	0	1.0	1

N = number of locations; Dev = model deviance; LL = Log-likelihood; K = number of model parameters; AIC = Akaike's Information Criterion; ΔAIC = difference in AIC values relative to best model; AIC w = relative weight of AIC values; Rank = model rankings based on AIC weights.

Table C1 c. STONE Range FEMALES, movement buffer (MB) spatial scale

Season	Model	n	Dev	LL	K	AIC	ΔAIC	AICw	Rank
Lambing	Security	14558	12373	-6187	8	12397	1288	<0.001	3
	Forage type	14558	12424	-6212	10	12448	1339	<0.001	4
	Forage availability	14558	11877	-5938	5	11895	786	<0.001	2
	All-inclusive	14558	11059	-5529	23	11109	0	1.0	1
Summer	Security	16860	13752	-6876	9	13776	931	<0.001	3
	Forage type	16860	13944	-6972	10	13968	1123	<0.001	4
	Forage availability	16860	13698	-6849	5	13716	871	<0.001	2
	All-inclusive	16860	12795	-6398	24	12845	0	1.0	1
Fall	Security	20533	16697	-8348	9	16721	1448	<0.001	2
	Forage type	20533	16703	-8351	10	16727	1454	<0.001	3
	Forage availability	20533	16802	-8401	5	16820	1547	<0.001	4
	All-inclusive	20533	15223	-7612	24	15273	0	1.0	1
Rut	Security	13216	8818	-4409	8	8840	1088	<0.001	2
	Forage type	13216	9918	-4959	10	9942	2190	<0.001	4
	Forage availability	13216	8991	-4496	5	9009	1257	<0.001	3
	All-inclusive	13216	7704	-3852	23	7752	0	1.0	1
Early Winter	Security	10155	5787	-2893	8	5809	1012	<0.001	2
	Forage type	10155	7335	-3667	8	7355	2558	<0.001	4
	Forage availability	10155	5807	-2904	5	5825	1028	<0.001	3
	All-inclusive	10155	4753	-2376	21	4797	0	1.0	1
Late Winter	Security	19209	12343	-6172	8	12365	2226	<0.001	3
	Forage type	19209	15148	-7574	10	15172	5033	<0.001	4
	Forage availability	19209	12318	-6159	5	12336	2197	<0.001	2
	All-inclusive	19209	10091	-5046	23	10139	0	1.0	1

N = number of locations; Dev = model deviance; LL = Log-likelihood; K = number of model parameters; AIC = Akaike's Information Criterion; ΔAIC = difference in AIC values relative to best model; AIC w = relative weight of AIC values; Rank = model rankings based on AIC weights.

Table C1 d. SENTINEL Range FEMALES, movement buffer (MB) spatial scale

Season	Model	n	Dev	LL	K	AIC	ΔAIC	AICw	
Lambing	Security	14558	12373	-6187	9	12397	1288	<0.001	3
	Forage type	14558	12484	-6212	10	12448	1339	<0.001	4
	Forage availability	14558	11877	-5938	5	11895	786	<0.001	2
	All-inclusive	14558	11059	-5529	24	11109	0	1.0	1
Summer	Security	26415	23162	-11581	9	23186	1412	<0.01	4
	Forage type	26415	22314	-11157	10	22338	564	<0.01	2
	Forage availability	26415	22894	-11447	5	22912	1138	<0.01	3
	All-inclusive	26415	21724	-10862	24	21774	0	1.0	1
Fall	Security	31811	27678	-13839	9	27702	2249	<0.001	4
	Forage type	31811	26110	-13055	10	26134	681	<0.01	2
	Forage availability	31811	27656	-13828	5	27674	2221	<0.001	3
	All-inclusive	31811	25403	-12701	24	25453	0	1.0	1
Rut	Security	20709	16727	-8363	9	16751	1199	<0.0001	2
	Forage type	20709	16805	-8403	10	16829	1277	<0.0001	3
	Forage availability	20709	17222	-8611	5	17240	1688	<0.0001	4
	All-inclusive	20709	15502	-7751	24	15552	0	1.0	1
Early Winter	Security	18712	14397	-7199	9	14421	1585	<0.001	3
	Forage type	18712	14042	-7021	10	14066	1230	<0.001	2
	Forage availability	18712	14705	-7352	5	14723	1887	<0.001	4
	All-inclusive	18712	12786	-6393	24	12836	0	1.0	1
Late Winter	Security	34555	27164	-13582	9	27188	3246	<0.0001	2
	Forage type	34555	27518	-13759	10	27542	3600	<0.0001	4
	Forage availability	34555	27179	-13589	5	27197	3255	<0.0001	3
	All-inclusive	34555	23892	-11946	24	23942	0	1.0	1

N = number of locations; Dev = model deviance; LL = Log-likelihood; K = number of model parameters; AIC = Akaike's Information Criterion; ΔAIC = difference in AIC values relative to best model; AIC w = relative weight of AIC values; Rank = model rankings based on AIC weights.

Table C2 a. STONE Range MALES, home range (HR) scale.

Season	Model	n	Dev	LL	K	AIC	ΔAIC	AICw	Rank
Lambing	Security	112343	12868	-6434	9	12892	2907	<0.001	4
	Forage type	112343	11697	-5848	9	11719	1734	<0.001	2
	Forage availability	112343	12287	-6144	5	12305	2320	<0.001	3
	All-inclusive	112343	9937	-4969	23	9985	0	1.0	1
Summer	Security	191482	22105	-11053	9	22129	1513	<0.001	4
	Forage type	191482	20594	-10297	9	20616	0	1.0	1
	Forage availability	191482	21253	-10626	5	21274	658	<0.001	3
	All-inclusive	191482	20597	-10299	23	20645	29	<0.001	2
Fall	Security	209982	25853	-12927	9	25877	5809	<0.001	3
	Forage type	209982	24325	-12163	10	24349	4281	<0.001	2
	Forage availability	209982	25934	-12967	5	25952	5884	<0.001	4
	All-inclusive	209982	23018	-11509	24	23068	0	1.0	1
Rut	Security	157544	18343	-9172	9	18367	3141	<0.001	4
	Forage type	157544	17738	-8869	10	17762	2536	<0.001	2
	Forage availability	157544	18153	-9077	5	18171	2945	<0.001	3
	All-inclusive	157544	15176	-7588	24	15226	0	1.0	1
Early Winter	Security	161754	17631	-8816	9	17655	3757	<0.001	4
	Forage type	161754	16925	-8462	9	16947	3049	<0.001	2
	Forage availability	161754	17544	-8772	5	17562	3664	<0.001	3
	All-inclusive	161754	13850	-6925	23	13898	0	1.0	1
Late Winter	Security	230415	27162	-13581	9	27186	3982	<0.001	4
	Forage type	230415	25862	-12931	10	25886	2682	<0.001	2
	Forage availability	230415	26458	-13229	5	26476	3272	<0.001	3
	All-inclusive	230415	23154	-11577	24	23204	0	1.0	1

N = number of locations; Dev = model deviance; LL = Log-likelihood; K = number of model parameters; AIC = Akaike's Information Criterion; ΔAIC = difference in AIC values relative to best model; AIC w = relative weight of AIC values; Rank = model rankings based on AIC weights.

Table C2 b. SENTINEL Range MALES, home range (HR) scale

Season	Model	n	Dev	LL	K	AIC	ΔAIC	AICw	
Lambing	Security	7567	1562	-781	7	1582	358	<0.001	3
	Forage type	7567	1703	-852	7	1721	497	<0.001	4
	Forage availability	7567	1469	-734	5	1487	263	<0.001	2
	All-inclusive	7567	1184	-592	19	1224	0	1.0	1
Summer	Security	10326	2741	-1371	6	2759	316	<0.001	3
	Forage type	10326	3148	-1574	5	3162	719	<0.001	4
	Forage availability	10326	2712	-1356	5	2730	287	<0.001	2
	All-inclusive	10326	2409	-1204	16	2443	0	1.0	1
Fall	Security	16259	3991	-1995	7	4011	650	<0.001	3
	Forage type	16259	4391	-2195	6	4407	1046	<0.001	4
	Forage availability	16259	3887	-1944	5	3905	544	<0.001	2
	All-inclusive	16259	3323	-1661	18	3361	0	1.0	1
Rut	Security	15908	3164	-1582	7	3184	286	<0.001	2
	Forage type	15908	3515	-1758	8	3535	637	<0.001	4
	Forage availability	15908	3447	-1724	5	3465	567	<0.001	3
	All-inclusive	15908	2856	-1428	20	2898	0	1.0	1
Early Winter	Security	15669	2610	-1305	7	2630	846	<0.001	2
	Forage type	15669	3386	-1693	8	3406	1622	<0.001	4
	Forage availability	15669	3184	-1592	5	3202	1418	<0.001	3
	All-inclusive	15669	1742	-871	20	1784	0	1.0	1
Late Winter	Security	15658	3668	-1834	6	3686	492	<0.001	2
	Forage type	15658	3985	-1993	8	4005	811	<0.001	4
	Forage availability	15658	3823	-1911	5	3841	647	<0.001	3
	All-inclusive	15658	3154	-1577	19	3194	0	1.0	1

N = number of locations; Dev = model deviance; LL = Log-likelihood; K = number of model parameters; AIC = Akaike's Information Criterion; ΔAIC = difference in AIC values relative to best model; AIC w = relative weight of AIC values; Rank = model rankings based on AIC weights.

Table C2 c. STONE Range FEMALES, home range (HR) scale.

Season	Model	N	Dev	LL	K	AIC	ΔAIC	AICw	Rank
Lambing	Security	87231	12384	-6192	8	12406	1652	<0.001	4
	Forage type	87231	12190	-6095	10	12214	1460	<0.001	2
	Forage availability	87231	12361	-6180	5	12379	1625	<0.001	3
	All-inclusive	87231	10706	-5353	23	10754	0	1.0	1
Summer	Security	156643	21398	-10699	9	21422	1632	<0.001	3
	Forage type	156643	21188	-10594	10	21212	1422	<0.001	2
	Forage availability	156643	21650	-10825	5	21668	1878	<0.001	4
	All-inclusive	156643	19740	-9870	24	19790	0	1.0	1
Fall	Security	197938	26170	-13085	9	26194	4927	<0.001	3
	Forage type	197938	23513	-11756	10	23537	2270	<0.001	2
	Forage availability	197938	26445	-13223	5	26463	5196	<0.001	4
	All-inclusive	197938	21217	-10608	24	21267	0	1.0	1
Rut	Security	149338	17000	-8500	8	17022	5747	<0.001	4
	Forage type	149338	16490	-8245	10	16510	5235	<0.001	2
	Forage availability	149338	16826	-8413	5	16844	5569	<0.001	3
	All-inclusive	149338	11231	-5616	23	11275	0	1.0	1
Early Winter	Security	134389	14994	-7497	8	15016	5706	<0.001	4
	Forage type	134389	14901	-7450	8	14921	5611	<0.001	3
	Forage availability	134389	14291	-7145	5	14309	4999	<0.001	2
	All-inclusive	134389	9266	-4633	21	9310	0	1.0	1
Late Winter	Security	190516	23262	-11631	8	23284	8582	<0.001	4
	Forage type	190516	22953	-11477	10	22977	8275	<0.001	3
	Forage availability	190516	21900	-10950	5	21918	7216	<0.001	2
	All-inclusive	190516	14654	-7327	23	14702	0	1.0	1

N = number of locations; Dev = model deviance; LL = Log-likelihood; K = number of model parameters; AIC = Akaike's Information Criterion; ΔAIC = difference in AIC values relative to best model; AIC w = relative weight of AIC values; Rank = model rankings based on AIC weights.

Table C2 d. SENTINEL Range FEMALES, home range (HR) scale.

Season	Model	N	Dev	LL	K	AIC	ΔAIC	AICw	
Lambing	Security	197404	23528	-11764	9	23552	3220	<0.001	4
	Forage type	197404	22751	-11375	10	22775	2443	<0.001	3
	Forage availability	197404	22441	-11220	5	22459	2127	<0.001	2
	All-inclusive	197404	20282	-10141	24	20332	0	1.0	1
Summer	Security	369430	42935	-21468	9	42959	3563	<0.001	4
	Forage type	369430	39372	-19686	10	39396	0	1.0	1
	Forage availability	369430	41418	-20709	5	41436	2040	<0.001	3
	All-inclusive	369430	40454	-20227	24	40504	1108	<0.001	2
Fall	Security	470410	53218	-26609	9	53242	5214	<0.001	4
	Forage type	470410	49391	-24696	10	49415	1387	<0.001	2
	Forage availability	470410	53152	-26576	5	53170	5142	<0.001	3
	All-inclusive	470410	47978	-23989	24	48028	0	1.0	1
Rut	Security	334445	35647	-17823	9	35671	5332	<0.001	3
	Forage type	334445	32974	-16487	10	32998	2659	<0.001	2
	Forage availability	334445	36738	-18369	5	36756	6417	<0.001	4
	All-inclusive	334445	30289	-15145	24	30339	0	1.0	1
Early Winter	Security	289852	30894	-15447	9	30918	6076	0	3
	Forage type	289852	27720	-13860	10	27744	2902	0	2
	Forage availability	289852	31917	-15958	5	31935	7093	0	4
	All-inclusive	289852	24792	-12396	24	24842	0	1.0	1
Late Winter	Security	465216	53898	-26949	9	53922	11141	<0.001	4
	Forage type	465216	49069	-24535	10	49093	6312	<0.001	2
	Forage availability	465216	53407	-26704	5	53425	10644	<0.001	3
	All-inclusive	465216	42731	-21365	24	42781	0	1.0	1

N = number of locations; Dev = model deviance; LL = Log-likelihood; K = number of model parameters; AIC = Akaike's Information Criterion; ΔAIC = difference in AIC values relative to best model; AIC w = relative weight of AIC values; Rank = model rankings based on AIC weights.

Table C3 a. STONE Range MALES, study area (SA) scale.

Season	Model	n	Dev	LL	K	AIC	ΔAIC	AICw	Rank
Lambing	Security	763220	19493	-9747	9	19517	3192	<0.001	4
	Forage type	763220	18561	-9281	9	18583	2258	<0.001	2
	Forage availability	763220	18901	-9451	5	18919	2594	<0.001	3
	All-inclusive	763220	16277	-8139	23	16325	0	1.0	1
Summer	Security	764048	29478	-14739	9	29502	5248	<0.001	4
	Forage type	764048	25707	-12854	9	25729	1475	<0.001	3
	Forage availability	764048	24884	-12442	5	24902	648	<0.001	2
	All-inclusive	764048	24206	-12103	23	24254	0	1.0	1
Fall	Security	773855	32696	-16348	9	32720	4417	<0.001	4
	Forage type	773855	31547	-15773	10	31597	3268	0.001	3
	Forage availability	773855	30546	-15273	5	30564	2261	0.001	2
	All-inclusive	773855	28253	-14126	24	28303	0	1.0	1
Rut	Security	772999	23684	-11842	9	23708	4111	<0.001	4
	Forage type	772999	22702	-11351	10	22726	3129	<0.001	3
	Forage availability	772999	21878	-10939	5	21896	2299	<0.001	2
	All-inclusive	772999	19547	-9773	24	19597	0	1.0	1
Early Winter	Security	763712	23761	-11881	9	23785	5562	<0.001	4
	Forage type	763712	22325	-11162	9	22347	4124	<0.001	3
	Forage availability	763712	21089	-10545	5	21107	2884	<0.001	2
	All-inclusive	763712	18175	-9088	23	18223	0	1.0	1
Late Winter	Security	773926	32797	-16398	9	32821	5658	<0.001	4
	Forage type	773926	30728	-15364	10	30752	3589	<0.001	3
	Forage availability	773926	29806	-14903	5	29824	2661	<0.001	2
	All-inclusive	773926	27113	-13556	24	27163	0	1.0	1

N = number of locations; Dev = model deviance; LL = Log-likelihood; K = number of model parameters; AIC = Akaike's Information Criterion; ΔAIC = difference in AIC values relative to best model; AIC w = relative weight of AIC values; Rank = model rankings based on AIC weights.

Table C3 b. SENTINEL Range MALES, study area (SA).

Season	Model	n	Dev	LL	K	AIC	ΔAIC	AICw	
Lambing	Security	950819	6427	-3214	7	6447	817	<0.001	3
	Forage type	950819	6485	-3242	9	6507	877	<0.001	4
	Forage availability	950819	6050	-3025	5	6068	438	<0.001	2
	All-inclusive	950819	5586	-2793	21	5630	0	1.0	1
Summer	Security	927551	10650	-5325	7	10670	1429	<0.001	4
	Forage type	927551	10562	-5281	8	10582	1341	<0.001	3
	Forage availability	927551	9879	-4940	5	9897	656	<0.001	2
	All-inclusive	927551	9199	-4599	20	9241	0	1.0	1
Fall	Security	912558	14090	-7045	8	14112	3025	<0.001	4
	Forage type	912558	13912	-6956	7	13930	2843	<0.001	3
	Forage availability	912558	12270	-6135	5	12288	1201	<0.001	2
	All-inclusive	912558	11045	-5522	20	11087	0	1.0	1
Rut	Security	978040	10825	-5412	8	10847	1040	<0.001	2
	Forage type	978040	11114	-5557	8	11134	1327	<0.001	4
	Forage availability	978040	10996	-5498	5	11014	1207	<0.001	3
	All-inclusive	978040	9763	-4881	21	9807	0	1.0	1
Early Winter	Security	889454	6333	-3167	7	6353	727	<0.001	2
	Forage type	889454	7180	-3590	8	7200	1574	<0.001	4
	Forage availability	889454	6690	-3345	5	6708	1082	<0.001	3
	All-inclusive	889454	5584	-2792	20	5626	0	1.0	1
Late Winter	Security	951128	10232	-5116	7	10252	1091	<0.001	4
	Forage type	951128	10172	-5086	9	10194	1033	<0.001	3
	Forage availability	951128	10162	-5081	5	10180	1019	<0.001	2
	All-inclusive	951128	9117	-4558	21	9161	0	1.0	1

N = number of locations; Dev = model deviance; LL = Log-likelihood; K = number of model parameters; AIC = Akaike's Information Criterion; ΔAIC = difference in AIC values relative to best model; AIC w = relative weight of AIC values; Rank = model rankings based on AIC weights.

Table C3 c. STONE Range FEMALES, study area (SA) scale.

Season	Model	N	Dev	LL	K	AIC	ΔAIC	AICw	Rank
Lambing	Security	701334	18041	-9021	8	18063	1813	<0.001	2
	Forage type	701334	18830	-9415	10	18854	2604	<0.001	4
	Forage availability	701334	18623	-9311	5	18641	2391	<0.001	3
	All-inclusive	701334	16202	-8101	23	16250	0	1.0	1
Summer	Security	773755	29408	-14704	9	29432	5247	<0.001	4
	Forage type	773755	27112	-13556	10	27136	2951	<0.001	3
	Forage availability	773755	25682	-12841	5	25700	1515	<0.001	2
	All-inclusive	773755	24135	-12068	24	24185	0	1.0	1
Fall	Security	774395	35587	-17794	9	35611	6980	<0.001	4
	Forage type	774395	32935	-16467	10	32959	4328	<0.001	2
	Forage availability	774395	33043	-16522	5	33061	4430	<0.001	3
	All-inclusive	774395	28581	-14291	24	28631	0	1.0	1
Rut	Security	701980	22335	-11167	8	22357	6185	<0.001	4
	Forage type	701980	21866	-10933	10	21890	5718	<0.001	3
	Forage availability	701980	20799	-10399	5	20817	4645	<0.001	2
	All-inclusive	701980	16124	-8062	23	16172	0	1.0	1
Early Winter	Security	675590	16874	-8437	8	16896	5630	<0.001	3
	Forage type	675590	17526	-8763	8	17546	6280	<0.001	4
	Forage availability	675590	15370	-7685	5	15388	4122	<0.001	2
	All-inclusive	675590	11222	-5611	21	11266	0	1.0	1
Late Winter	Security	702974	29812	-14906	8	29834	8218	<0.001	3
	Forage type	702974	31589	-15795	10	31613	9997	<0.001	4
	Forage availability	702974	27808	-13904	5	27826	6210	<0.001	2
	All-inclusive	702974	21568	-10784	23	21616	0	1.0	1

N = number of locations; Dev = model deviance; LL = Log-likelihood; K = number of model parameters; AIC = Akaike's Information Criterion; ΔAIC = difference in AIC values relative to best model; AIC w = relative weight of AIC values; Rank = model rankings based on AIC weights.

Table C3 d. SENTINEL Range FEMALES, study area (SA) scale.

Season	Model	N	Dev	LL	K	AIC	ΔAIC	AICw	
Lambing	Security	1092691	30622	-15311	9	30646	3792	<0.001	4
	Forage type	1092691	30014	-15007	10	30038	3184	<0.001	3
	Forage availability	1092691	29250	-14625	5	29268	2414	<0.001	2
	All-inclusive	1092691	26804	-13402	24	26854	0	1.0	1
Summer	Security	1094664	51241	-25620	9	51265	8921	<0.001	4
	Forage type	1094664	44343	-22172	10	44367	2023	<0.001	3
	Forage availability	1094664	43592	-21796	5	43610	1266	<0.001	2
	All-inclusive	1094664	42294	-21147	24	42344	0	1.0	1
Fall	Security	1095563	62652	-31326	9	62676	11740	<0.001	4
	Forage type	1095563	54587	-27292	10	54611	3675	<0.001	3
	Forage availability	1095563	53952	-26976	5	53970	3034	<0.001	2
	All-inclusive	1095563	50886	-25443	24	50936	0	1.0	1
Rut	Security	1093711	42121	-21061	9	42145	7010	<0.001	4
	Forage type	1093711	38269	-19135	10	38293	3158	<0.001	2
	Forage availability	1093711	38999	-19499	5	39017	3882	<0.001	3
	All-inclusive	1093711	35085	-17543	24	35135	0	1.0	1
Early Winter	Security	1093380	36973	-18487	9	36997	7846	<0.001	4
	Forage type	1093380	32368	-16184	10	32392	3241	<0.001	2
	Forage availability	1093380	34052	-17026	5	34070	4919	<0.001	3
	All-inclusive	1093380	29101	-14550	24	29151	0	1.0	1
Late Winter	Security	1096021	61652	-30826	9	61676	11747	<0.001	4
	Forage type	1096021	57334	-28667	10	57358	7429	<0.001	2
	Forage availability	1096021	58733	-29367	5	58751	8822	<0.001	3
	All-inclusive	1096021	49879	-24940	24	49929	0	1.0	1

N = number of locations; Dev = model deviance; LL = Log-likelihood; K = number of model parameters; AIC = Akaike's Information Criterion; ΔAIC = difference in AIC values relative to best model; AIC w = relative weight of AIC values; Rank = model rankings based on AIC weights.

APPENDIX D RESOURCE SELECTION FUNCTIONS FOR SEASONAL HABITAT SELECTION

Resource selection function coefficients for seasonal habitat selection by male and female Stone's sheep in 2 populations (Stone Range, Sentinel Range), at 3 spatial scales (MB - movement buffer scale; HR - home range scale; SA – study area scale).

Table D1 a - f. Resource selection function coefficients for Stone Range males.
Table D2 a - f. Resource selection function coefficients for Sentinel Range males.
Table D3 a - f. Resource selection function coefficients for Stone Range females.
Table D4 a - f. Resource selection function coefficients for Sentinel Range females.

Table D1 a. STONE Range. Resource selection functions at 3 spatial scales for MALE Stone's sheep during LAMBING, May 15 – Jun 15. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	17.094	2.061	***	8.276	1.836	***	8.619	1.532	***
Slope	0.047	0.004	***	0.027	0.004	***	0.031	0.003	***
Escape distance	-0.001	7.140×10^{-5}	***	-5.883×10^{-4}	6.453×10^{-5}	***	-0.001	5.448×10^{-5}	***
[1] Ridge	-0.848	0.166	***	-1.094	0.162	***	-0.426	0.148	**
[2] Upper slope	0.479	0.125	***	1.160	0.108	***	0.407	0.101	***
[3] Mid slope	0.216	0.123		0.373	0.111	***	0.217	0.103	*
[4] Flat	-0.371	0.113	**	-0.423	0.104	***	-0.341	0.100	***
[5] Lower slope	1.022	0.475	*	0.817	0.428		0.600	0.425	
[6] Valley bottom	-0.498	0.131	***	-0.834	0.126	***	-0.456	0.117	***
Solar radiation	2.891	0.137	***	3.260	0.145	***	2.661	0.112	***
East-West	-0.152	0.050	***	-0.304	0.050	***	-0.172	0.040	***
Elevation	0.001	1.53×10^{-3}		0.008	0.002	***	0.018	0.001	***
Elevation^2	-1.053x10-6	5.49×10^{-7}		-4.405×10^{-6}	6.409×10^{-7}	***	-6.859×10^{-6}	4.754×10^{-7}	***
Curvature	0.103	0.020	***	0.080	0.016	***	0.072	0.013	***
[4] Rock	-0.198	0.148		-0.475	0.204	*	-0.550	0.138	***
[6] Conifer at treeline	0.266	0.155		0.561	0.192	**	0.326	0.136	*
[7] Deciduous tree	×	×		×	×		×	×	
[11] Conifer tree	-1.332	0.326	***	-1.720	0.385	***	-2.067	0.318	***
[44] Alpine	-0.107	0.127		-0.129	0.180		-0.427	0.120	***
[46] Fluvial	1.441	0.123	***	2.012	0.171	***	1.799	0.112	***
[66] Grass	-0.484	0.534		-1.034	0.871		0.214	0.510	
[88] Shrub	0.414	0.145	**	0.786	0.187	***	0.705	0.128	***
Burned areas	-0.379	0.093	***	0.330	0.084	***	0.322	0.067	***

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D1 b. STONE Range. Resource selection functions at 3 spatial scales for MALE Stone's sheep during SUMMER, Jun 16 – Jul 31. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	8.244	1.577	***	4.862	1.486	**	3.817	1.318	**
Slope	0.008	0.003	**	0.003	0.00253		-0.004	0.002	
Escape distance	4.571×10^{-5}	4.01×10^{-5}		3.214×10^{-4}	3.488×10^{-5}	***	1.294×10^{-4}	3.168×10^{-5}	***
[1] Ridge	-0.327	0.163	*	-0.311	0.157	*	-0.041	0.153	
[2] Upper slope	1.088	0.115	***	0.812	0.111	***	0.473	0.107	***
[3] Mid slope	0.416	0.116	***	0.221	0.114		0.030	0.111	
[4] Flat	0.184	0.108		0.228	0.107	*	0.170	0.105	
[5] Lower slope	-1.331	0.491	**	-1.023	0.489	*	-0.908	0.486	
[6] Valley bottom	-0.031	0.120		0.073	0.118		0.277	0.116	*
Solar radiation	0.333	0.0874	***	0.326	0.0840	***	0.292	0.076	***
East-West	0.073	0.0336	*	0.059	0.0315		0.139	0.029	***
Elevation	0.031	0.00228	***	0.036	0.00227	***	0.041	0.002	***
Elevation^2	-9.688×10^{-6}	7.06×10^{-7}	***	-1.112×10^{-5}	7.052×10^{-7}	***	-1.223×10^{-5}	6.139×10^{-7}	***
Curvature	0.037	0.0154	*	0.028	0.0141	*	0.026	0.013	*
[4] Rock	-0.398	0.0863	***	-0.427	0.0872	***	-0.334	0.080	***
[6] Conifer at treeline	0.126	0.0885		0.014	0.0865		0.088	0.079	
[7] Deciduous tree	×	×		×	×		×	×	
[11] Conifer tree	-0.810	0.157	***	-1.164	0.163	***	-1.330	0.151	***
[44] Alpine	-0.187	0.123		-0.547	0.121	***	-0.900	0.116	***
[46] Fluvial	0.592	0.0756	***	0.544	0.0735	***	0.717	0.068	***
[66] Grass	0.635	0.227	**	1.303	0.206	***	1.375	0.205	***
[88] Shrub	0.042	0.213		0.278	0.208		0.385	0.202	
Burned areas	0.412	0.143	**	0.407	0.110	***	-0.188	0.105	

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D1 c. STONE Range. Resource selection functions at 3 spatial scales for MALE Stone's sheep during FALL, Aug 1 – Oct 31. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	11.647	1.393	***	10.405	1.196	***	8.796	1.103	***
Slope	0.017	0.003	***	0.011	0.002	***	0.007	0.002	**
Escape distance	-4.342×10^{-4}	4.54×10^{-5}	***	-3.928×10^{-4}	3.891×10^{-5}	***	-5.548×10^{-4}	3.644×10^{-5}	***
[1] Ridge	-0.306	0.132	*	-0.663	0.129	***	-0.113	0.120	
[2] Upper slope	0.831	0.096	***	1.175	0.096	***	0.481	0.086	***
[3] Mid slope	0.275	0.096	**	0.510	0.099	***	0.080	0.089	
[4] Flat	-0.018	0.088		0.018	0.093		0.010	0.084	
[5] Lower slope	-0.553	0.391		-0.784	0.421		-0.503	0.377	
[6] Valley bottom	-0.229	0.099	*	-0.255	0.102	*	0.046	0.094	
Solar radiation	1.225	0.085	***	1.429	0.083	***	1.297	0.075	***
East-West	0.066	0.032	*	0.154	0.030	***	0.184	0.027	***
Elevation	0.022	0.002	***	0.023	0.0015	***	0.036	0.001	***
Elevation^2	-7.450×10^{-6}	5.39×10^{-7}	***	-8.347×10^{-6}	5.037×10^{-7}	***	-1.165×10^{-5}	4.660×10^{-7}	***
Curvature	0.027	0.014	*	0.021	0.012		0.028	0.010	**
[4] Rock	-0.293	0.084	***	-0.209	0.078	**	-0.359	0.064	***
[6] Conifer at treeline	-0.779	0.104	***	-0.677	0.095	***	-0.934	0.082	***
[7] Deciduous tree	-0.718	0.144	***	-2.504	0.241	***	-1.627	0.126	***
[11] Conifer tree	1.344	0.357	***	2.041	0.228	***	1.698	0.177	***
[44] Alpine	-0.392	0.089	***	-0.242	0.077	**	-0.602	0.066	***
[46] Fluvial	0.269	0.078	***	0.634	0.070	***	0.459	0.056	***
[66] Grass	0.820	0.223	***	1.054	0.202	***	1.303	0.188	***
[88] Shrub	-0.251	0.121	*	-0.096	0.108		0.063	0.097	
Burned areas	0.311	0.078	***	0.864	0.061	***	0.714	0.055	***

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D1 d. STONE Range. Resource selection functions at 3 spatial scales for MALE Stone's sheep during RUT, Nov 1 – Dec 31. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	24.487	1.875	***	17.306	1.386	***	16.103	1.264	***
Slope	0.054	0.004	***	0.051	0.003	***	0.047	0.003	***
Escape distance	-1.534×10^{-4}	5.35×10^{-5}	**	-3.003×10^{-4}	4.581×10^{-5}	***	-2.808×10^{-4}	3.959×10^{-5}	***
[1] Ridge	-0.481	0.184	**	-0.871	0.176	***	-0.160	0.169	
[2] Upper slope	0.519	0.144	***	1.164	0.130	***	0.417	0.128	**
[3] Mid slope	0.247	0.140		0.670	0.131	***	0.283	0.129	*
[4] Flat	-0.251	0.133		-0.267	0.130	*	-0.271	0.128	*
[5] Lower slope	0.264	0.609		-0.107	0.595		-0.097	0.594	
[6] Valley bottom	-0.298	0.147	*	-0.588	0.144	***	-0.172	0.141	
Solar radiation	2.127	0.110	***	2.432	0.100	***	2.379	0.093	***
East-West	-0.162	0.042	***	-0.276	0.038	***	-0.181	0.034	***
Elevation	0.006	0.002	**	0.024	0.002	***	0.035	0.002	***
Elevation^2	-1.873×10^{-6}	6.655×10^{-7}	**	-8.732×10^{-6}	6.841×10^{-7}	***	-1.153×10^{-5}	6.056×10^{-7}	***
Curvature	0.025	0.017		0.048	0.013	***	0.048	0.011	***
[4] Rock	-0.067	0.142		-0.020	0.130		0.045	0.117	
[6] Conifer at treeline	-0.818	0.187	***	-1.522	0.159	***	-1.427	0.149	***
[7] Deciduous tree	-0.207	0.194		-1.084	0.198	***	-0.991	0.169	***
[11] Conifer tree	0.554	0.618		1.404	0.501	**	0.653	0.414	
[44] Alpine	-0.001	0.139		-0.035	0.127		-0.148	0.116	
[46] Fluvial	0.605	0.136	***	1.046	0.119	***	1.182	0.108	***
[66] Grass	-0.045	0.558		0.025	0.520		0.243	0.515	
[88] Shrub	-0.019	0.174		0.186	0.157		0.442	0.147	**
Burned areas	-0.335	0.085	***	0.023	0.077		-0.086	0.069	

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D1 e. STONE Range. Resource selection functions at 3 spatial scales for MALE Stone's sheep during EARLY WINTER, Jan 1 – Feb 28. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	27.002	1.911	***	19.153	1.381	***	21.722	1.176	***
Slope	0.048	0.004	***	0.047	0.003	***	0.043	0.003	***
Escape distance	1.709×10^{-4}	5.56×10-5	**	4.758×10^{-5}	4.332×10^{-5}		1.106×10^{-4}	3.536×10^{-5}	**
[1] Ridge	-0.482	0.211	*	-1.030	0.195	***	-0.473	0.189	*
[2] Upper slope	0.714	0.134	***	1.423	0.113	***	0.758	0.110	***
[3] Mid slope	0.151	0.129		0.476	0.116	***	0.254	0.113	*
[4] Flat	-0.562	0.121	***	-0.660	0.117	***	-0.624	0.115	***
[5] Lower slope	0.456	0.511		0.314	0.489		0.333	0.488	
[6] Valley bottom	-0.276	0.142		-0.522	0.135	***	-0.249	0.133	
Solar radiation	2.597	0.124	***	2.555	0.108	***	2.551	0.097	***
East-West	-0.268	0.045	***	-0.409	0.039	***	-0.384	0.035	***
Elevation	0.020	0.003	***	0.044	0.003	***	0.066	0.003	***
Elevation^2	-5.980×10^{-6}	1.022×10^{-6}	***	-1.476×10^{-5}	9.585×10^{-7}	***	-2.13×10^{-5}	9.352×10^{-7}	***
Curvature	0.065	0.018	***	0.018	0.013		0.038	0.011	***
[4] Rock	0.196	0.174		0.240	0.173		0.322	0.162	*
[6] Conifer at treeline	-0.594	0.226	***	-1.333	0.202	***	-1.417	0.195	***
[7] Deciduous tree	×	×		×	×		×	×	
[11] Conifer tree	-0.282	0.243		-1.324	0.292	***	-1.211	0.226	***
[44] Alpine	0.444	0.177	*	0.544	0.179	**	0.388	0.168	*
[46] Fluvial	0.600	0.168	***	1.462	0.161	***	1.378	0.155	***
[66] Grass	-0.475	0.896		-0.276	0.865		-0.343	0.862	
[88] Shrub	0.410	0.229		0.687	0.232	**	0.883	0.224	***
Burned areas	-0.412	0.086	***	0.244	0.076	**	0.022	0.067	

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D3 f. STONE Range. Resource selection functions at 3 spatial scales for MALE Stone's sheep during LATE WINTER, Mar 1 – May 14. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	21.624	1.397	***	16.104	1.096	***	13.632	1.070	***
Slope	0.047	0.00274	***	0.044	0.002	***	0.039	0.002	***
Escape distance	-3.622×10^{-6}	5.12×10^{-5}	***	-2.484×10^{-4}	3.884×10^{-5}	***	-3.344×10^{-4}	3.529×10^{-5}	***
[1] Ridge	-0.739	0.166	***	-0.880	0.165	***	-0.197	0.156	
[2] Upper slope	0.664	0.135	***	1.144	0.127	***	0.351	0.126	**
[3] Mid slope	0.259	0.134		0.463	0.129	***	0.179	0.127	
[4] Flat	-0.004	0.128		-0.035	0.125		-0.023	0.124	
[5] Lower slope	0.004	0.607		-0.482	0.594		-0.394	0.593	
[6] Valley bottom	-0.184	0.137		-0.211	0.133		0.084	0.131	
Solar radiation	2.094	0.092	***	1.709	0.080	***	1.752	0.074	***
East-West	-0.372	0.034	***	-0.512	0.031	***	-0.419	0.029	***
Elevation	0.017	0.002	***	0.032	0.002	***	0.040	0.002	***
Elevation^2	-5.951×10^{-6}	6.234×10^{-7}	***	-1.155×10^{-5}	6.214×10^{-7}	***	-1.325×10^{-5}	5.428×10^{-7}	***
Curvature	0.087	0.014	***	0.039	0.010	***	0.042	0.010	***
[4] Rock	-0.057	0.191		0.212	0.175		0.146	0.159	
[6] Conifer at treeline	-0.177	0.196		0.151	0.177		0.316	0.162	
[7] Deciduous tree	-1.279	0.276	***	-1.564	0.260	***	-1.888	0.250	***
[11] Conifer tree	1.005	1.12		-0.377	0.939		-0.965	0.884	
[44] Alpine	0.088	0.189		0.117	0.175		-0.014	0.158	
[46] Fluvial	0.745	0.186	***	1.326	0.169	***	1.469	0.154	***
[66] Grass	-0.558	0.547		-0.469	0.639		0.200	0.526	
[88] Shrub	0.232	0.204		0.605	0.188	**	0.737	0.172	***
Burned areas	-0.417	0.071	***	0.440	0.062	***	0.333	0.056	***

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D2 a. SENTINEL Range. Resource selection functions at 3 spatial scales for MALE Stone's sheep during LAMBING, May 15 – Jun 14. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	13.822	3.097	***	18.541	3.774	***	12.566	2.075	***
Slope	0.073	0.009	***	0.070	0.014	***	0.051	0.006	***
Escape distance	-0.001	1.36×10^{-4}	***	-8.941×10^{-4}	2.046×10^{-4}	***	-1.561×10^{-4}	8.450×10^{-5}	
[1] Ridge	-1.148	0.466	*	-0.930	0.772		-1.733	0.438	***
[2] Upper slope	0.384	0.235		-0.780	0.344	*	0.079	0.179	
[3] Mid slope	0.966	0.184	***	0.966	0.287	***	1.103	0.162	***
[4] Flat	×	×		×	×		×	×	
[5] Lower slope	-0.203	0.185		0.744	0.281	**	0.551	0.161	***
[6] Valley bottom	×	×		×	×		×	×	
Solar radiation	2.825	0.284	***	3.413	0.322	***	3.180	0.220	***
East-West	0.168	0.098		0.445	0.132	***	0.291	0.078	***
Elevation	0.017	0.003	***	0.098	0.015	***	0.034	0.003	***
Elevation^2	-6.099×10^{-6}	1.26×10^{-6}	***	-3.029×10^{-5}	4.732×10^{-6}	***	-1.054×10^{-5}	1.120×10^{-6}	***
Curvature	0.047	0.033		-0.008	0.037		0.013	0.020	
[4] Rock	-3.36×10^{-4}	0.176		-0.894	0.213	***	-0.287	0.141	*
[6] Conifer at treeline	-0.590	0.239	*	-0.016	0.234		-1.346	0.178	***
[7] Deciduous tree	-0.168	0.191		×	×		0.631	0.149	***
[11] Conifer tree	0.350	0.412		0.263	0.203		-0.282	0.282	
[44] Alpine	-0.225	0.177		1.494	0.225	***	0.469	0.142	***
[46] Fluvial	×	×		×	×		×	×	
[66] Grass	0.551	0.173	**	×	×		0.400	0.119	***
[88] Shrub	0.082	0.339		-0.847	0.158	***	0.413	0.224	
Burned areas	0.588	0.246	*	2.674	0.346	***	1.451	0.173	***

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D2 b. SENTINEL Range. Resource selection functions at 3 spatial scales for MALE Stone's sheep during SUMMER, Jun 15 – Jul 31. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	-2.365	2.515		-9.896	3.371	**	-2.451	2.014	
Slope	-0.002	0.006		-0.028	0.008	***	0.009	0.004	*
Escape distance	-0.001	1.81×10^{-4}	***	-0.003	2.471×10^{-4}	***	-6.739×10^{-4}	1.025×10^{-4}	***
[1] Ridge	-1.392	0.576	*	-0.108	0.133		-2.447	0.533	***
[2] Upper slope	1.323	0.231	***	-0.322	0.114	**	1.498	0.185	***
[3] Mid slope	0.838	0.214	***	0.430	0.089	***	1.151	0.187	***
[4] Flat	×	×		×	×		×	×	
[5] Lower slope	-0.770	0.206	***	×	×		-0.202	0.197	
[6] Valley bottom	×	×		×	×		×	×	
Solar radiation	0.312	0.177		-0.029	0.198		-0.140	0.119	
East-West	0.572	0.068	***	0.850	0.086	***	0.491	0.051	***
Elevation	0.031	0.0056	***	0.060	0.010	***	0.062	0.004	***
Elevation^2	-9.230×10^{-6}	1.608×10^{-6}	***	-1.558×10^{-5}	2.954×10^{-6}	***	-1.759×10^{-5}	1.296×10^{-6}	***
Curvature	0.057	0.025	*	0.036	0.034		0.029	0.019	
[4] Rock	-1.294	0.252	***	-0.350	0.180		0.004	0.168	
[6] Conifer at treeline	-1.737	0.269	***	-0.229	0.157		-0.651	0.154	***
[7] Deciduous tree	-1.338	0.272	***	×	×		0.668	0.205	**
[11] Conifer tree	7.033	0.988	***	×	×		-1.250	0.487	*
[44] Alpine	-1.384	0.294	***	0.854	0.293	**	0.621	0.268	*
[46] Fluvial	×	×		×	×		×	×	
[66] Grass	×	×		×	×		×	×	
[88] Shrub	-1.280	0.257	***	-0.275	0.128	*	0.609	0.135	***
Burned areas	-1.620	1.431		×	×		-2.154	1.002	*

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D2 c. SENTINEL Range. Resource selection functions at 3 spatial scales for MALE Stone's sheep during FALL, Aug 1 – Oct 31. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	3.670	2.271		-2.219	2.827		4.888	1.688	**
Slope	-0.029	0.005	***	-0.061	0.00618	***	-0.017	0.003	***
Escape distance	-0.002	1.67×10^{-4}	***	-0.002	1.700×10^{-4}	***	-0.002	1.049×10^{-4}	***
[1] Ridge	-1.294	0.605	*	0.511	0.831		-3.246	0.576	***
[2] Upper slope	-0.197	0.263		-0.984	0.310	**	0.145	0.192	
[3] Mid slope	-0.101	0.224		-0.523	0.294	**	1.084	0.185	***
[4] Flat	0.675	0.215	**	0.997	0.286	***	1.581	0.179	***
[5] Lower slope	0.917	0.600		×	×		0.435	0.432	
[6] Valley bottom	×	×		×	×		×	×	
Solar radiation	0.496	0.163	**	0.276	0.193		0.038	0.127	
East-West	0.968	0.068	***	1.374	0.088	***	1.167	0.057	***
Elevation	0.073	0.00569	***	0.069	0.008	***	0.084	0.005	***
Elevation^2	-2.255×10^{-5}	1.832×10^{-6}	***	-2.059×10^{-5}	2.498×10^{-6}	***	-2.597×10^{-5}	1.538×10^{-6}	***
Curvature	0.053	0.021	*	0.042	0.028		0.017	0.016	
[4] Rock	0.422	0.114	***	-0.262	0.113	*	0.599	0.091	***
[6] Conifer at treeline	-1.085	0.158	***	-0.077	0.177		-2.114	0.137	***
[7] Deciduous tree	×	×		×	×		×	×	
[11] Conifer tree	-0.398	0.152	**	0.403	0.161	*	0.101	0.122	
[44] Alpine	-0.176	0.176		0.327	0.224		-0.038	0.155	
[46] Fluvial	×	×		×	×		×	×	
[66] Grass	-0.116	0.112		×	×		0.149	0.093	
[88] Shrub	1.354	0.368	***	-0.391	0.103	***	1.303	0.302	***
Burned areas	×	×		×	×		×	×	

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D2 d. SENTINEL Range. Resource selection functions at 3 spatial scales for MALE Stone's sheep during RUT, Nov 1 – Dec 31. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	19.231	2.369	***	17.830	2.482	***	14.916	1.395	***
Slope	0.056	0.006	***	0.050	0.009	***	0.059	0.004	***
Escape distance	-0.001	1.24×10^{-4}	***	-7.836×10^{-4}	1.318×10^{-4}	***	-7.546×10^{-4}	8.246×10^{-5}	***
[1] Ridge	-0.758	0.382	*	-1.848	0.326	***	-1.001	0.364	**
[2] Upper slope	1.080	0.136	***	1.634	0.142	***	1.304	0.114	***
[3] Mid slope	0.290	0.139	*	0.450	0.149	**	0.452	0.122	***
[4] Flat	×	×		×	×		×	×	
[5] Lower slope	-0.094	0.128		-0.236	0.135		-0.055	0.118	
[6] Valley bottom	-0.518	0.216	*	×	×		-0.700	0.203	***
Solar radiation	0.795	0.144	***	0.369	0.169	*	0.053	0.117	
East-West	-0.267	0.069	***	-0.639	0.083	***	-0.178	0.050	***
Elevation	0.018	0.003	***	0.008	0.003	**	0.029	0.002	***
Elevation^2	-6.550×10^{-6}	9.300×10^{-7}	***	-4.109×10^{-6}	1.054×10^{-6}	***	-9.922×10^{-6}	7.883×10^{-7}	***
Curvature	0.063	0.0212	**	0.094	0.026	***	0.054	0.015	***
[4] Rock	-0.154	0.101		0.120	0.119		0.569	0.084	***
[6] Conifer at treeline	0.200	0.158		0.557	0.182	**	-0.949	0.127	***
[7] Deciduous tree	×	×		×	×		×	×	
[11] Conifer tree	-0.784	0.213	***	-0.457	0.220	*	-0.433	0.186	*
[44] Alpine	-0.806	0.164	***	-1.134	0.207	***	-0.941	0.142	***
[46] Fluvial	×	×		×	×		×	×	
[66] Grass	0.580	0.104	***	0.276	0.119	*	0.679	0.082	***
[88] Shrub	0.965	0.184	***	0.638	0.179	***	1.075	0.136	***
Burned areas	-1.380	1.15		-2.791	1.014	**	-3.216	1.002	**

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D2 e. SENTINEL Range. Resource selection functions at 3 spatial scales for MALE Stone's sheep during EARLY WINTER, Jan 1 – Feb 28. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	25.957	3.285	***	24.001	2.751	***	26.743	1.385	***
Slope	0.012	0.009		-0.051	0.010	***	0.021	0.005	***
Escape distance	-0.001	1.91×10^{-4}	***	-0.001	1.552×10^{-4}	***	-0.001	8.629×10^{-5}	***
[1] Ridge	-1.120	0.561	*	-4.082	0.589	***	-2.491	0.535	***
[2] Upper slope	0.898	0.238	***	4.362	0.276	***	2.545	0.193	***
[3] Mid slope	0.093	0.238		1.037	0.271	***	0.295	0.216	
[4] Flat	×	×		×	×		×	×	
[5] Lower slope	0.130	0.221		-1.317	0.246	***	-0.349	0.205	
[6] Valley bottom	×	×		×	×		×	×	
Solar radiation	0.989	0.222	***	0.577	0.213	**	-0.289	0.162	
East-West	-0.358	0.102	***	-0.673	0.103	***	-0.285	0.068	***
Elevation	0.016	0.005	***	0.014	0.005	**	0.045	0.004	***
Elevation^2	-5.294×10^{-6}	1.619×10^{-6}	**	-9.297×10^{-6}	1.653×10^{-6}	***	-1.670×10^{-5}	1.317×10^{-6}	***
Curvature	0.103	0.034	**	0.043	0.031		0.056	0.017	***
[4] Rock	-0.336	0.149	*	-0.561	0.163	***	-0.160	0.117	
[6] Conifer at treeline	1.723	0.237	***	2.692	0.212	***	0.940	0.140	***
[7] Deciduous tree	×	×		×	×		×	×	
[11] Conifer tree	-0.283	0.199		-0.380	0.189	*	0.606	0.144	***
[44] Alpine	-0.701	0.190	***	-0.597	0.193	**	-0.968	0.150	***
[46] Fluvial	×	×		×	×		×	×	
[66] Grass	0.178	0.149		-0.109	0.145		0.363	0.112	**
[88] Shrub	-0.583	0.340		-1.046	0.348	**	-0.781	0.308	*
Burned areas	-1.028	0.332	**	-0.061	0.314		0.553	0.251	*

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D2 f. SENTINEL Range. Resource selection functions at 3 spatial scales for MALE Stone's sheep during LATE WINTER, Mar 1 – May 14. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	12.422	2.237	***	12.171	2.135	***	16.572	1.356	***
Slope	0.005	0.006		-0.008	0.007		0.023	0.004	***
Escape distance	-0.001	1.28×10^{-4}	***	-0.002	1.407×10^{-4}	***	-3.547×10^{-4}	6.971×10^{-5}	***
[1] Ridge	-2.940	0.760	***	-0.976	0.090	***	-3.141	0.752	***
[2] Upper slope	1.488	0.266	***	1.118	0.076	***	1.655	0.256	***
[3] Mid slope	1.024	0.266	***	-0.143	0.091		1.064	0.258	***
[4] Flat	×	×		×	×		×	×	
[5] Lower slope	0.428	0.262		×	×		0.423	0.258	
[6] Valley bottom	×	×		×	×		×	×	
Solar radiation	1.686	0.164	***	1.359	0.173	***	1.435	0.139	***
East-West	0.033	0.068		-0.250	0.076	***	-0.027	0.054	
Elevation	0.007	0.002	**	0.046	0.006	***	0.022	0.002	***
Elevation^2	-2.137×10^{-6}	7.415×10^{-7}	**	-1.649×10^{-5}	1.865×10^{-6}	***	-6.695×10^{-6}	6.624×10^{-7}	***
Curvature	0.076	0.025	**	0.069	0.024	**	0.075	0.016	***
[4] Rock	-0.860	0.158	***	-0.717	0.196	***	-0.503	0.140	***
[6] Conifer at treeline	-0.271	0.188		0.627	0.218	**	-0.748	0.147	***
[7] Deciduous tree	0.245	0.173		×	×		0.823	0.137	***
[11] Conifer tree	0.566	0.419		0.342	0.183		-1.350	0.329	***
[44] Alpine	0.032	0.145		0.645	0.178	***	0.290	0.129	*
[46] Fluvial	×	×		×	×		×	×	
[66] Grass	0.297	0.128	*	0.233	0.158		0.908	0.101	***
[88] Shrub	-0.009	0.223		-1.130	0.609		0.580	0.191	**
Burned areas	0.605	0.178	***	1.055	0.188	***	1.637	0.127	***

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D3 a. STONE Range. Resource selection functions at 3 spatial scales for FEMALE Stone's sheep during LAMBING, May 15 – Jun 14. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	15.155	1.742	***	14.948	1.447	***	13.150	1.307	***
Slope	0.036	0.004	***	0.035	0.004	***	0.037	0.003	***
Escape distance	-0.001	1.044×10^{-4}	***	-8.351×10^{-4}	9.009×10^{-5}	***	-0.002	7.948×10^{-5}	***
[1] Ridge	-0.871	0.153	***	-1.636	0.167	***	-0.563	0.139	***
[2] Upper slope	0.553	0.080	***	1.517	0.0751	***	0.426	0.060	***
[3] Mid slope	0.264	0.077	***	0.804	0.077	***	0.185	0.064	**
[4] Flat	×	×		×	×		×	×	
[5] Lower slope	0.266	0.062	***	0.188	0.0623	**	0.147	0.053	**
[6] Valley bottom	-0.211	0.091	*	-0.873	0.0962	***	-0.196	0.079	*
Solar radiation	2.331	0.118	***	2.415	0.118	***	2.146	0.100	***
East-West	-0.026	0.046		0.070	0.044		-0.024	0.039	
Elevation	0.005	0.001	***	0.011	0.002	***	0.016	0.001	***
Elevation^2	-2.154×10^{-6}	4.847×10^{-7}	***	-5.004×10^{-6}	6.244×10^{-7}	***	-6.002×10^{-6}	4.424×10^{-7}	***
Curvature	0.042	0.015	**	0.042	0.0123	***	0.033	0.011	**
[4] Rock	-0.302	0.178		-0.289	0.177		-0.120	0.164	
[6] Conifer at treeline	0.190	0.175		-0.391	0.171	*	0.568	0.161	***
[7] Deciduous tree	-1.112	0.252	***	-1.197	0.250	***	-0.994	0.237	***
[11] Conifer tree	-0.082	0.933		0.371	0.927		-2.227	0.883	*
[44] Alpine	-0.237	0.164		-0.126	0.165		-0.407	0.156	**
[46] Fluvial	0.827	0.168	***	0.598	0.164	***	1.308	0.153	***
[66] Grass	0.386	0.448		0.799	0.433		0.959	0.426	*
[88] Shrub	0.329	0.178		0.236	0.176		0.913	0.161	***
Burned areas	-0.192	0.097	*	0.240	0.090	**	0.005	0.078	

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D3 b. STONE Range. Resource selection functions at 3 spatial scales for FEMALE Stone's sheep during SUMMER, Jun 15 – Jul 31. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	14.011	1.190	***	12.586	1.053	***	13.857	0.942	***
Slope	-0.002	0.002		-0.007	0.00236	***	-0.005	0.002	*
Escape distance	-5.43×10^{-4}	6.818×10^{-5}	***	-5.476x10-4	7.681x10-5	***	-0.001	5.459×10^{-5}	***
[1] Ridge	-0.645	0.127	***	-0.696	0.182	***	-0.036	0.116	
[2] Upper slope	0.659	0.074	***	0.617	0.0786	***	0.165	0.059	**
[3] Mid slope	0.081	0.074		-0.122	0.0819		-0.319	0.064	***
[4] Flat	-0.171	0.065	**	-0.313	0.0755	***	-0.325	0.058	***
[5] Lower slope	0.795	0.239	***	0.990	0.260	***	0.910	0.203	***
[6] Valley bottom	-0.720	0.092	***	-0.623	0.112	***	-0.395	0.084	***
Solar radiation	0.621	0.080	***	0.645	0.0806	***	0.602	0.069	***
East-West	0.132	0.031	***	0.162	0.0311	***	0.191	0.027	***
Elevation	0.033	0.002	***	0.041	0.00265	***	0.058	0.002	***
Elevation^2	-1.010×10^{-5}	7.351×10^{-7}	***	-1.192x10-5	7.900x10-7	***	-1.711×10^{-5}	7.077×10^{-7}	***
Curvature	0.067	0.011	***	0.043	0.0109	***	0.053	1.010	***
[4] Rock	-0.911	0.235	***	-0.474	0.206	*	-0.465	0.180	**
[6] Conifer at treeline	-0.099	0.230		-0.186	0.190		0.213	0.172	
[7] Deciduous tree	-1.421	0.299	***	-1.038	0.287	***	-1.380	0.254	***
[11] Conifer tree	3.107	1.360	*	1.955	0.989	*	1.622	0.895	
[44] Alpine	-0.486	0.261		-0.281	0.246		-0.714	0.211	***
[46] Fluvial	0.313	0.227		0.536	0.187	**	0.700	0.169	***
[66] Grass	-0.780	0.673		-0.836	0.672		-0.940	0.638	
[88] Shrub	0.278	0.328		0.343	0.388		0.964	0.287	***
Burned areas	-0.135	0.106		0.254	0.0993	***	0.183	0.091	*

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D3 c. STONE Range. Resource selection functions at 3 spatial scales for FEMALE Stone's sheep during FALL, Aug 1 – Oct 31. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	10.092	1.358	***	7.414	1.234	***	6.439	1.101	***
Slope	0.023	0.002	***	0.018	0.002	***	0.020	0.002	***
Escape distance	-0.001	5.77×10^{-5}	***	-0.001	6.822×10^{-5}	***	-0.001	4.772×10^{-5}	***
[1] Ridge	-0.122	0.127		-1.036	0.145	***	-0.043	0.116	
[2] Upper slope	0.316	0.087	***	1.237	0.082	***	0.167	0.076	*
[3] Mid slope	0.145	0.085		0.639	0.083	***	0.125	0.077	
[4] Flat	0.077	0.078		-0.020	0.078		0.061	0.073	
[5] Lower slope	0.059	0.338		0.356	0.324		0.068	0.322	
[6] Valley bottom	-0.474	0.099	***	-1.177	0.112	***	-0.378	0.092	***
Solar radiation	1.357	0.081	***	2.000	0.083	***	1.586	0.069	***
East-West	0.155	0.031	***	0.172	0.030	***	0.169	0.026	***
Elevation	0.019	0.002	***	0.031	0.002	***	0.049	0.002	***
Elevation^2	-6.14×10^{-6}	6.426×10^{-7}	***	-1.063×10^{-5}	6.680×10^{-7}	***	-1.544×10^{-5}	6.210×10^{-7}	***
Curvature	0.039	0.011	***	0.018	0.010		0.022	0.009	*
[4] Rock	0.027	0.166		0.418	0.195	*	0.441	0.155	**
[6] Conifer at treeline	-0.330	0.178		-1.277	0.203	***	-0.878	0.162	***
[7] Deciduous tree	-0.763	0.198	***	-0.857	0.239	***	-0.841	0.186	***
[11] Conifer tree	0.102	0.960		1.337	0.953		-0.470	0.888	
[44] Alpine	-0.401	0.176	*	-0.269	0.206		-0.539	0.166	**
[46] Fluvial	0.912	0.164	***	0.932	0.191	***	1.127	0.152	***
[66] Grass	-0.349	0.539		-1.123	0.891		-0.162	0.525	
[88] Shrub	0.802	0.179	***	0.837	0.206	***	1.323	0.167	***
Burned areas	0.061	0.062		1.346	0.056	***	0.980	0.051	***

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D3 d. STONE Range. Resource selection functions at 3 spatial scales for FEMALE Stone's sheep during RUT, Nov 1 – Dec 31. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	17.121	1.914	***	16.849	1.462	***	15.089	1.314	***
Slope	0.045	0.003	***	0.036	0.003	***	0.044	0.003	***
Escape distance	-0.001	9.222×10^{-5}	***	-0.002	9.776×10^{-5}	***	-0.002	7.017×10^{-5}	***
[1] Ridge	1.542	0.167	***	-2.349	0.575	***	0.521	0.111	***
[2] Upper slope	-0.405	0.104	***	2.480	0.170	***	0.635	0.054	***
[3] Mid slope	-0.317	0.088	***	1.941	0.170	***	0.546	0.056	***
[4] Flat	×	×		×	×		×	×	
[5] Lower slope	-0.477	0.743	***	0.324	0.173		-0.536	0.063	***
[6] Valley bottom	-0.342	0.140	*	-2.397	0.358	***	-1.165	0.129	***
Solar radiation	2.515	0.125	***	3.558	0.122	***	3.143	0.102	***
East-West	-0.035	0.047		-0.157	0.043	***	-0.125	0.037	***
Elevation	0.016	0.004	***	0.083	0.005	***	0.070	0.003	***
Elevation^2	-3.716×10^{-6}	1.290×10^{-6}	**	-2.770×10^{-5}	1.538×10^{-6}	***	-2.261×10^{-5}	1.018×10^{-6}	***
Curvature	0.071	0.015	***	-0.001	0.012		0.021	0.011	
[4] Rock	-0.344	0.175	*	0.373	0.116	**	0.213	0.140	
[6] Conifer at treeline	-1.521	0.267	***	-2.768	0.196	***	-2.652	0.219	***
[7] Deciduous tree	-0.530	0.218	*	×	×		-0.749	0.187	***
[11] Conifer tree	1.973	0.852	*	-0.136	0.187		0.787	0.666	
[44] Alpine	-0.124	0.169		0.635	0.130	***	0.120	0.144	
[46] Fluvial	0.751	0.167	***	×	×		1.295	0.127	***
[66] Grass	0.574	0.481		1.289	0.085	***	1.093	0.414	**
[88] Shrub	-0.779	0.264	**	0.607	0.253	*	-0.107	0.245	
Burned areas	-0.096	0.076		0.573	0.073	***	0.178	0.064	**

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D3 e. STONE Range. Resource selection functions at 3 spatial scales for FEMALE Stone's sheep during EARLY WINTER, Jan 1 – Feb 28. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	23.981	2.662	***	17.824	1.742	***	14.458	1.666	***
Slope	0.071	0.005	***	0.059	0.004	***	0.067	0.004	***
Escape distance	-1.255×10^{-3}	1.35×10^{-4}	***	-0.001	9.918×10^{-5}	***	-0.002	8.760×10^{-5}	***
[1] Ridge	-1.234	0.369	***	-1.742	0.316	***	-0.622	0.313	*
[2] Upper slope	0.725	0.173	***	2.371	0.114	***	1.134	0.108	***
[3] Mid slope	1.219	0.156	***	1.757	0.111	***	1.236	0.108	***
[4] Flat	×	×		×	×		×	×	
[5] Lower slope	0.415	0.138	**	-0.031	0.116		-0.055	0.115	
[6] Valley bottom	-1.125	0.284	***	-2.355	0.267	***	-1.693	0.267	***
Solar radiation	3.715	0.175	***	4.595	0.154	***	4.460	0.146	***
East-West	-0.227	0.066	***	-0.364	0.052	***	-0.370	0.050	***
Elevation	-0.024	0.005	***	0.049	0.004	***	0.081	0.004	***
Elevation^2	9.765×10^{-6}	1.531×10^{-6}	***	-1.716×10^{-5}	1.273×10^{-6}	***	-2.63×10^{-5}	1.273×10^{-6}	***
Curvature	0.043	0.019	*	0.040	0.013	**	0.032	0.0121	**
[4] Rock	-0.336	0.141	*	0.575	0.130	***	0.188	0.125	
[6] Conifer at treeline	-0.719	-0.328	*	-2.980	0.239	***	-2.598	0.238	***
[7] Deciduous tree	×	×		×	×		×	×	
[11] Conifer tree	0.287	0.197		0.287	0.178		-0.327	0.174	
[44] Alpine	0.870	0.134	***	1.305	0.113	***	0.994	0.109	***
[46] Fluvial	×	×		×	×		×	×	
[66] Grass	0.908	0.108	***	1.420	0.093	***	1.656	0.089	***
[88] Shrub	-1.020	0.283	***	-0.607	0.284	*	0.087	0.274	
Burned areas	0.067	0.0918		0.411	0.080	***	0.119	0.072	

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D3 f. STONE Range. Resource selection functions at 3 spatial scales for FEMALE Stone's sheep during LATE WINTER, Mar 1 – May 14. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	23.615	1.714	***	14.600	1.363	***	11.635	1.238	***
Slope	0.083	0.003	***	0.067	0.003	***	0.081	0.003	***
Escape distance	-7.347×10^{-4}	6.912×10^{-5}	***	-0.00208	9.463×10^{-5}	***	-0.001	5.769×10^{-5}	***
[1] Ridge	-1.634	0.201	***	-3.674	0.466	***	-0.898	0.172	***
[2] Upper slope	0.524	0.090	***	2.348	0.129	***	0.404	0.059	***
[3] Mid slope	0.898	0.077	***	1.815	0.127	***	0.705	0.057	***
[4] Flat	×	×		×	×		×	×	
[5] Lower slope	0.689	0.067	***	0.715	0.124	***	0.374	0.056	***
[6] Valley bottom	-0.478	0.108	***	-1.204	0.158	***	-0.585	0.094	***
Solar radiation	4.093	0.122	***	5.180	0.132	***	4.554	0.106	***
East-West	-0.089	0.043	*	-0.114	0.042	**	-0.134	0.035	***
Elevation	-0.006	0.002	**	0.011	0.002	***	0.031	0.001	***
Elevation^2	2.011×10^{-6}	6.357×10^{-7}	**	-5.347×10^{-6}	5.476×10^{-7}	***	-1.053×10^{-5}	4.957×10^{-7}	***
Curvature	0.017	0.013		-0.009	0.010		0.007	0.009	
[4] Rock	-0.025	0.179		0.865	0.197	***	0.408	0.167	*
[6] Conifer at treeline	-0.641	0.212	**	-1.833	0.214	***	-1.589	0.185	***
[7] Deciduous tree	-0.137	0.201		-0.992	0.300	***	-0.012	0.184	
[11] Conifer tree	-1.677	0.930		-0.868	0.920		-2.138	0.890	*
[44] Alpine	0.483	0.175	**	0.725	0.195	***	0.222	0.165	
[46] Fluvial	1.027	0.175	***	1.327	0.190	***	1.534	0.160	***
[66] Grass	0.713	0.682		0.533	0.893		0.743	0.639	
[88] Shrub	0.256	0.183		0.244	0.202		0.833	0.170	***
Burned areas	-0.479	0.066	***	0.504	0.061	***	0.235	0.052	***

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D4 a. SENTINEL Range. Resource selection functions at 3 spatial scales for FEMALE Stone's sheep during LAMBING, May 15 – Jun 14. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	11.199	1.265	***	9.775	1.056	***	8.387	0.945	***
Slope	0.044	0.003	***	0.044	0.003	***	0.039	0.003	***
Escape distance	1.953×10^{-5}	5.879×10^{-5}		-4.778×10^{-4}	5.233×10^{-5}	***	-0.001	5.188×10^{-5}	***
[1] Ridge	-0.063	0.198		-0.500	0.193	**	0.177	0.191	
[2] Upper slope	0.128	0.186		0.939	0.178	***	-0.110	0.176	
[3] Mid slope	0.136	0.180		0.668	0.175	***	0.192	0.174	
[4] Flat	0.030	0.175		0.163	0.171		0.213	0.171	
[5] Lower slope	-0.183	0.848		-0.996	0.835		-0.690	0.836	
[6] Valley bottom	-0.043	0.181		-0.275	0.177		0.217	0.176	
Solar radiation	2.147	0.091	***	2.359	0.085	***	2.349	0.081	***
East-West	-0.098	0.037	**	0.039	0.034		0.017	0.032	
Elevation	0.013	0.001	***	0.021	0.001	***	0.023	0.001	***
Elevation^2	-4.889×10^{-6}	4.236×10^{-7}	***	-8.436×10^{-6}	4.250×10^{-7}	***	-8.173×10^{-6}	3.626×10^{-7}	***
Curvature	0.042	0.011	***	0.041	0.009	***	0.042	0.009	***
[4] Rock	-0.274	0.093	**	-0.334	0.088	***	-0.394	0.085	***
[6] Conifer at treeline	0.039	0.087		-0.031	0.084		0.498	0.081	***
[7] Deciduous tree	-0.632	0.128	***	-0.332	0.124	**	-0.204	0.118	
[11] Conifer tree	0.557	0.191	**	0.458	0.170	**	-0.978	0.149	***
[44] Alpine	-0.489	0.096	***	-0.588	0.097	***	-0.761	0.092	***
[46] Fluvial	0.698	0.088	***	0.715	0.082	***	0.989	0.077	***
[66] Grass	-0.212	0.408		0.070	0.399		0.564	0.399	
[88] Shrub	0.313	0.109	**	0.042	0.102		0.286	0.096	**
Burned areas	0.083	0.100		0.875	0.087	***	1.303	0.077	***

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D4 b. SENTINEL Range. Resource selection functions at 3 spatial scales for FEMALE Stone's sheep during SUMMER, Jun 15 – Jul 31. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	7.961	0.858	***	7.417	0.714	***	7.617	0.683	***
Slope	-0.004	0.002	*	-0.003	0.002		-0.006	0.002	***
Escape distance	-7.631×10^{-5}	3.879×10^{-5}	*	-1.670×10-5	3.486×10^{-5}		1.412×10^{-4}	3.522×10^{-5}	***
[1] Ridge	-0.257	0.092	**	-0.191	0.090	*	0.498	0.084	***
[2] Upper slope	0.527	0.074	***	0.648	0.066	***	-0.109	0.063	
[3] Mid slope	0.213	0.071	**	0.193	0.065	**	-0.192	0.064	**
[4] Flat	-0.070	0.065		-0.027	0.060		-0.076	0.060	
[5] Lower slope	-0.294	0.281		-0.480	0.257		-0.317	0.257	
[6] Valley bottom	-0.120	0.073		-0.144	0.068	*	0.196	0.066	**
Solar radiation	0.782	0.059	***	0.640	0.052	***	0.619	0.050	***
East-West	0.134	0.024	***	0.248	0.023	***	0.255	0.022	***
Elevation	0.012	0.001	***	0.023	0.001	***	0.026	0.001	***
Elevation^2	-3.773×10^{-6}	3.480×10^{-7}	***	-6.673×10^{-6}	3.742×10^{-7}	***	-7.040×10^{-6}	3.349×10^{-7}	***
Curvature	0.058	0.008	***	0.046	0.007	***	0.046	0.007	***
[4] Rock	-1.155	0.114	***	-1.130	0.104	***	-0.960	0.102	***
[6] Conifer at treeline	0.245	0.094	**	0.272	0.082	***	1.038	0.080	***
[7] Deciduous tree	-1.578	0.144	***	-0.802	0.136	***	-0.712	0.136	***
[11] Conifer tree	1.700	0.340	***	0.800	0.340	*	-1.768	0.334	***
[44] Alpine	-1.276	0.130	***	-1.020	0.136	***	-1.022	0.131	***
[46] Fluvial	0.559	0.093	***	0.587	0.079	***	1.079	0.076	***
[66] Grass	0.919	0.232	***	0.685	0.220	**	1.329	0.209	***
[88] Shrub	0.586	0.163	***	0.607	0.173	***	1.015	0.152	***
Burned areas	-0.789	0.231	***	-0.342	0.208		-0.164	0.209	

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D4 c. SENTINEL Range. Resource selection functions at 3 spatial scales for FEMALE Stone's sheep during FALL, Aug 1 – Oct 31. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	6.083	0.949	***	5.095	0.800	***	2.920	0.784	***
Slope	0.005	0.002	**	0.005	0.002	**	2.895×10^{-4}	0.002	
Escape distance	-3.811×10^{-5}	2.438×10^{-5}		3.27×10^{-4}	2.17×10^{-5}	***	3.770×10^{-4}	2.051×10^{-5}	***
[1] Ridge	0.181	0.107		-0.365	0.099	***	0.402	0.099	***
[2] Upper slope	0.680	0.088	***	1.409	0.082	***	0.283	0.082	***
[3] Mid slope	0.291	0.087	***	0.692	0.082	***	0.228	0.082	**
[4] Flat	-0.034	0.085		0.091	0.080		0.150	0.080	
[5] Lower slope	-1.120	0.394	**	-1.507	0.375	***	-1.277	0.376	***
[6] Valley bottom	0.002	0.091		-0.321	0.086	***	0.214	0.086	*
Solar radiation	0.660	0.058	***	0.644	0.053	***	0.703	0.051	***
East-West	0.251	0.023	***	0.428	0.021	***	0.443	0.020	***
Elevation	0.012	8.85×10^{-4}	***	0.018	8.91×10^{-4}	***	0.022	7.876×10^{-4}	***
Elevation^2	-4.001×10^{-6}	2.847×10^{-7}	***	-5.87×10^{-6}	2.807×10^{-7}	***	-5.957×10^{-6}	2.469×10^{-7}	***
Curvature	0.035	0.009	***	0.018	0.008	*	0.020	0.008	*
[4] Rock	-0.448	0.060	***	-0.250	0.056	***	-0.110	0.053	*
[6] Conifer at treeline	-0.111	0.065		-0.731	0.062	***	-0.344	0.061	***
[7] Deciduous tree	-1.646	0.111	***	-1.351	0.112	***	-1.190	0.107	***
[11] Conifer tree	1.142	0.138	***	2.066	0.118	***	-0.250	0.105	*
[44] Alpine	-0.844	0.080	***	-1.396	0.089	***	-1.054	0.080	***
[46] Fluvial	0.743	0.058	***	0.784	0.053	***	1.004	0.050	***
[66] Grass	0.300	0.232		0.060	0.218		0.686	0.219	**
[88] Shrub	0.863	0.095	***	0.817	0.094	***	1.257	0.084	***
Burned areas	0.039	0.108		0.784	0.084	***	1.135	0.083	***

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D4 d. SENTINEL Range. Resource selection functions at 3 spatial scales for FEMALE Stone's sheep during RUT, Nov 1 – Dec 31. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	13.843	1.159	***	8.604	0.917	***	6.684	0.896	***
Slope	0.025	0.002	***	0.023	0.002	***	0.017	0.002	***
Escape distance	1.20×10^{-4}	3.446×10^{-5}	***	2.036×10^{-4}	2.918×10^{-5}	***	8.285×10^{-5}	2.680×10^{-5}	**
[1] Ridge	-0.760	0.191	***	-1.371	0.189	***	-0.603	0.189	**
[2] Upper slope	1.073	0.132	***	1.884	0.128	***	0.682	0.127	***
[3] Mid slope	0.836	0.129	***	1.375	0.127	***	0.873	0.127	***
[4] Flat	-0.096	0.126		0.115	0.126		0.227	0.127	
[5] Lower slope	-0.545	0.581		-1.344	0.591	*	-1.010	0.592	
[6] Valley bottom	-0.509	0.140	***	-0.698	0.140	***	-0.169	0.140	
Solar radiation	1.013	0.074	***	1.257	0.067	***	1.412	0.066	***
East-West	-0.148	0.030	***	0.011	0.025		0.104	0.025	***
Elevation	0.012	0.001	***	0.019	0.001	***	0.023	9.597×10^{-4}	***
Elevation^2	-4.46×10^{-6}	4.000×10^{-7}	***	-6.585×10^{-6}	3.480×10^{-7}	***	-6.799×10^{-6}	3.110×10^{-7}	***
Curvature	0.084	0.011	***	0.038	0.009	***	0.042	0.009	***
[4] Rock	-0.325	0.090	***	0.012	0.088		0.102	0.086	
[6] Conifer at treeline	0.162	0.105		-1.157	0.099	***	-0.888	0.099	***
[7] Deciduous tree	-0.790	0.128	***	-0.629	0.123	***	-0.533	0.121	***
[11] Conifer tree	0.663	0.158	***	1.566	0.138	***	-0.190	0.124	
[44] Alpine	-0.588	0.106	***	-0.787	0.105	***	-0.717	0.106	***
[46] Fluvial	0.703	0.091	***	0.790	0.087	***	0.976	0.084	***
[66] Grass	-0.244	0.507		-0.354	0.509		0.191	0.510	
[88] Shrub	0.419	0.119	***	0.559	0.105	***	1.059	0.104	***
Burned areas	0.524	0.079	***	1.851	0.064	***	1.984	0.058	***

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D4 e. SENTINEL Range. Resource selection functions at 3 spatial scales for FEMALE Stone's sheep during EARLY WINTER, Jan 1 – Feb 28. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	9.445	1.252	***	4.935	1.043	***	1.901	1.013	
Slope	0.008	0.003	**	0.009	0.002	***	0.004	0.002	
Escape distance	-1.962×10^{-4}	4.536×10^{-5}	***	-7.753×10^{-5}	3.69×10^{-5}	*	-2.196×10^{-4}	3.547×10^{-5}	***
[1] Ridge	-0.910	0.301	**	-1.918	0.295	***	-1.167	0.295	***
[2] Upper slope	1.514	0.185	***	2.486	0.179	***	1.454	0.178	***
[3] Mid slope	0.944	0.184	***	1.585	0.179	***	1.194	0.179	***
[4] Flat	-0.004	0.182		0.386	0.179	*	0.455	0.179	*
[5] Lower slope	-0.842	0.841		-1.489	0.835		-1.347	0.837	
[6] Valley bottom	-0.702	0.207	***	-1.050	0.204	***	-0.590	0.204	**
Solar radiation	1.402	0.082	***	1.893	0.075	***	2.028	0.075	***
East-West	-0.245	0.033	***	-0.033	0.028		0.064	0.027	*
Elevation	0.013	0.002	***	0.022	0.001	***	0.026	0.001	***
Elevation^2	-4.540×10^{-6}	5.058×10^{-7}	***	-7.410×10^{-6}	4.39×10^{-7}	***	-7.713×10^{-6}	3.979×10^{-7}	***
Curvature	0.051	0.013	***	0.036	0.010	***	0.046	0.010	***
[4] Rock	-0.337	0.144	*	0.174	0.142		0.310	0.141	*
[6] Conifer at treeline	0.747	0.152	***	-0.577	0.146	***	-0.199	0.145	
[7] Deciduous tree	-0.876	0.208	***	-0.967	0.203	***	-0.839	0.202	***
[11] Conifer tree	0.195	0.253		0.913	0.232	***	-0.879	0.219	***
[44] Alpine	-0.882	0.180	***	-0.982	0.180	***	-0.950	0.180	***
[46] Fluvial	0.968	0.142	***	1.273	0.139	***	1.551	0.137	***
[66] Grass	-0.160	0.869		-0.445	0.877		-0.117	0.879	
[88] Shrub	0.345	0.173	*	0.611	0.163	***	1.122	0.161	***
Burned areas	0.919	0.082	***	2.257	0.065	***	2.314	0.058	***

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.

Table D4 f. SENTINEL Range. Resource selection functions at 3 spatial scales for FEMALE Stone's sheep during LATE WINTER, Mar 1 – May 14. Numbers indicate coding for categories of slope position [1-6] and land cover [4-88]; selection coefficients reflect deviation contrasts.

	Movement buffer scale			Home range scale			Study area scale		
Attribute	β	SE		β	SE		β	SE	
Ruggedness	9.693	0.879	***	6.703	0.788	***	5.550	0.720	***
Slope	0.049	0.002	***	0.048	0.002	***	0.043	0.002	***
Escape distance	-4.042×10^{-4}	3.819×10^{-5}	***	-4.074×10^{-4}	3.451×10^{-5}	***	-6.395×10^{-4}	3.164×10^{-5}	***
[1] Ridge	-0.633	0.164	***	-1.195	0.163	***	-0.356	0.158	*
[2] Upper slope	0.674	0.129	***	1.671	0.125	***	0.596	0.124	***
[3] Mid slope	0.294	0.127	*	1.034	0.124	***	0.437	0.124	***
[4] Flat	-0.166	0.125		0.153	0.123		0.101	0.123	
[5] Lower slope	0.264	0.598		-0.845	0.590		-0.718	0.592	
[6] Valley bottom	-0.432	0.134	**	-0.818	0.134	***	-0.060	0.130	
Solar radiation	2.116	0.062	***	2.649	0.061	***	2.723	0.058	***
East-West	-0.258	0.026	***	0.021	0.023		0.098	0.021	***
Elevation	0.006	7.20×10^{-4}	***	0.010	$6.902\times10\text{-}^{4}$	***	0.013	$5.258\times10\text{-}^{4}$	***
Elevation^2	-2.129×10^{-6}	2.400×10^{-7}	***	-3.948×10^{-6}	2.250×10^{-7}	***	-3.835×10^{-6}	1.737×10^{-7}	***
Curvature	0.111	0.008	***	0.079	0.007	***	0.086	0.007	***
[4] Rock	-0.309	0.067	***	0.074	0.062		0.027	0.060	
[6] Conifer at treeline	0.181	0.071	*	-0.985	0.067	***	-0.519	0.066	***
[7] Deciduous tree	-1.231	0.137	***	-1.191	0.132	***	-1.197	0.131	***
[11] Conifer tree	0.316	0.101	**	1.108	0.092	***	0.066	0.075	
[44] Alpine	-0.232	0.077	**	-0.420	0.076	***	-0.753	0.074	***
[46] Fluvial	0.731	0.064	***	0.773	0.060	***	1.133	0.057	***
[66] Grass	0.484	0.331		0.526	0.314		0.793	0.315	*
[88] Shrub	0.060	0.081		0.114	0.073		0.449	0.070	***
Burned areas	0.595	0.055	***	1.615	0.046	***	2.064	0.042	***

Significance determined from Wald statistic *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

× indicates categories excluded from analyses due to zero counts for sheep habitat use locations.