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REPORT #44

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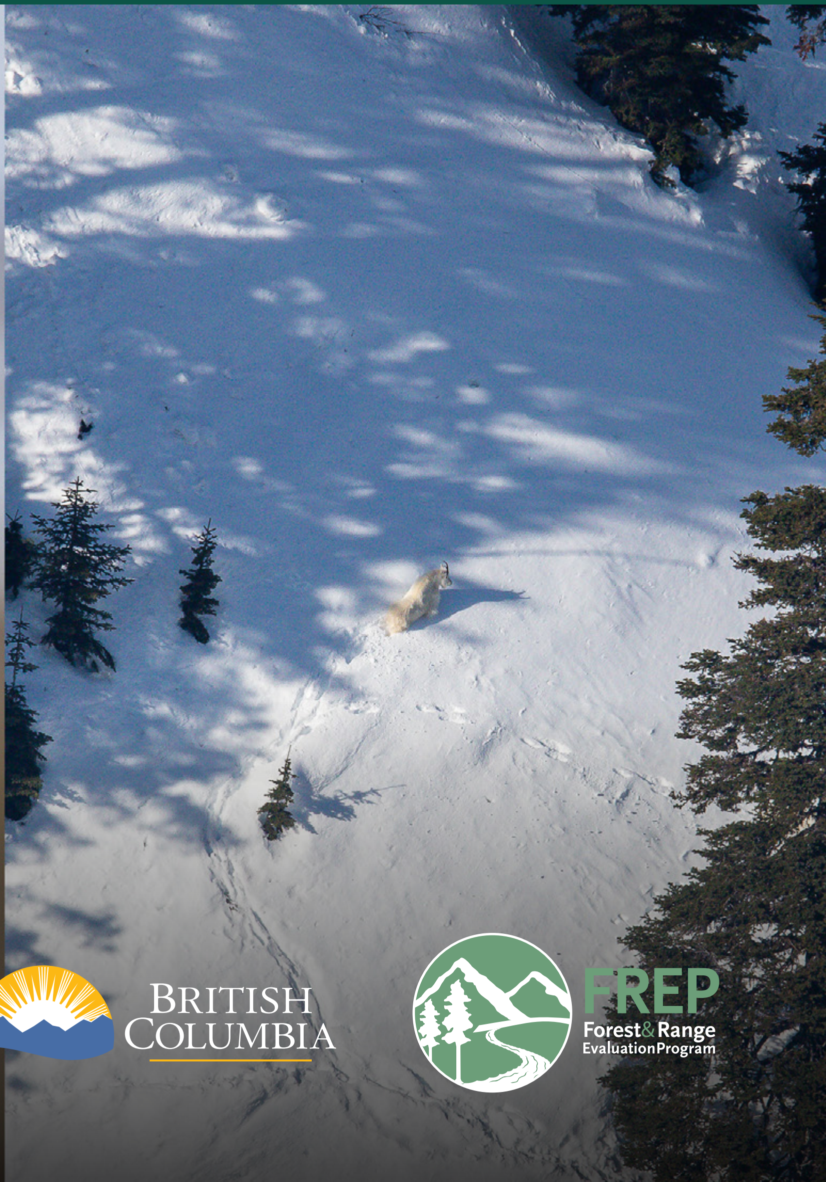
AN EVALUATION OF EFFECTIVENESS MONITORING METHODS FOR MOUNTAIN GOATS IN A COASTAL ECOSYSTEM

PREPARED BY:
Clifford G. Nietvelt



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EXECUTIVE SUMMARY

Mountain goats (*Oreamnos americanus*) are present in most of the high mountain ranges of British Columbia (BC). Over half of the world's population of mountain goats occur here and BC has a global responsibility for the conservation of this species. Mountain goats are a blue-listed species, meaning that they have characteristics that make them particularly sensitive or vulnerable to human activities (e.g., helicopter disturbance, resource extraction, recreation), natural events (e.g., wildfires or avalanches), and disease and parasites.

Ungulate winter ranges (UWRs) have been established under the *Forest Range and Practices Act* (FRPA) and are important in ensuring population resilience and the persistence of ungulates in BC. FRPA provides a legal mechanism for protecting designated UWRs from timber harvesting and establishes operational guidance through general wildlife measures for other resource associated activities. Winter ranges are intended to provide adequate habitat for over-winter survival of mountain goats and other ungulate species within timber supply constraints described in policy and developed through the timber supply review process.

As part of FRPA, the Forest and Range Evaluation Program (FREP) supports the sustainable management of BC's forest and range resources by monitoring and evaluating the condition of resource values and the effectiveness of resource practices. The FREP priority wildlife resource value evaluation question is:

> *Do ungulate winter ranges and wildlife habitat areas maintain the habitats, structures and functions necessary to meet the goals of the area and is the amount, quality and distribution of these areas contributing effectively with the surrounding land base (including protected areas and managed land base) to ensure the survival of the species now and over time?*

Existing winter aerial inventory and radio collar data collected in the South Coast from various inventories and studies were used to evaluate approaches to re-assess the effectiveness of mountain goat winter ranges. Standard winter range surveys can generate several metrics that are useful in the right context and, when possible, through the inclusion of supplemental collar and location information. Basic winter range surveys, which collect information on the number of mountain goats by age class and sex, and the number of tracks, allow biologists to calculate metrics useful for evaluating winter range use, understanding population trends, and interpreting the relative importance of functioning winter range areas within a larger geographic or population context. If available, telemetry data provides additional metrics to evaluate the effectiveness of winter ranges, including the spatial use of winter ranges, habitat use and selection, and survivorship. This report discusses monitoring design considerations and the use of metrics that address key management questions.

INTRODUCTION

Mountain goats (*Oreamnos americanus*) are present in most of the high mountain ranges of British Columbia (BC) (Shackleton 1999). Over half of the world's population of mountain goats occur here, and BC has a global responsibility for the conservation of this species (Côté and Festa-Bianchet 2003). Mountain goats are a blue-listed species, meaning that they are particularly sensitive or vulnerable to human activities such as helicopter disturbance (Côté 1996; Goldstein et al. 2005; Côté et al. 2013), industrial activity (Penner 1988) or natural events such as wildfires and avalanches (Smith 1986c; Nietvelt et al. 2018, Nietvelt et al. 2022), and disease and parasites (Blanchong et al. 2018).

In BC, two ecotypes of goats are recognized: coastal and interior (Hebert and Turnbull 1977). During winter coastal mountain goats are typically associated with steep slopes on southerly aspects, often with stands of old, large coniferous trees that intercept snow (Hebert and Turnball 1977; Fox et al. 1989; Taylor et al. 2006; Taylor and Brunt 2007). Interior mountain goats will either use high elevation wind-swept slopes or rocky bluffs at or below treeline in high snowfall areas when wind-swept slopes are unavailable (Hebert and Turnbull 1977; Poole et al. 2009). Interior goats also typically undergo elevational migrations seasonally, occupying habitats at or above treeline during summer and fall, and lower elevations during spring and early summer (Hebert and Turnbull 1977). These movements are thought to be linked to green-up vegetation and mineral licks (Mountain Goat Management Team 2010). Coastal goats may also undergo seasonal migrations linked to changes in the snowpack (Fox 1978; Smith 1986a). Note that interior goats in the West Kootenay area experience a precipitation pattern similar to coastal habitats and may pattern their behaviour similar to the coastal ecotype (Phelps et al. 1983).

Inventorying and estimating the population size of mountains goats is challenging regardless of the ecosystem (Smith and Bovee 1984; Poole 2007; Rice et al. 2009; White et al. 2016; Smith and DeCesare 2017). Detecting changes in mountain goat populations is also problematic because they are not evenly distributed across the landscape and sightability of goats is often poor (Poole 2007; White et al. 2016). Detecting population changes is critical as some areas in Montana and BC have declined over the last few decades (Smith and DeCesare 2017; DeCesare and Smith 2018; Nietvelt et al. 2022).

Changes to forest harvest regulations under the *Forest Practices Code of British Columbia Act* (FPC) and the *Forest and Range Practices Act* (FRPA) enabled the management of non-timber resource values such as ungulate winter ranges (UWRs). UWRs are defined as areas that contain habitat necessary to meet the winter habitat requirements of an ungulate species to ensure the survival and persistence of the species. UWRs established under the FPC and the Government Actions Regulation (GAR) of FRPA provide a legal mechanism for protecting these areas from timber harvesting and associated activities.

As part of FRPA, the Forest and Range Evaluation Program (FREP) supports the sustainable management of British Columbia's forest and range resources by monitoring and evaluating the condition of resource values and the effectiveness of resource practices in managing those resources. The FREP priority evaluation question for the wildlife resource value is:

> *Do ungulate winter ranges and wildlife habitat areas maintain the habitats, structures and functions necessary to meet the goals of the area and is the amount, quality and distribution of these areas contributing effectively with the surrounding land base (including protected areas and managed land base) to ensure the survival of the species now and over time?*

Wilson (2008 and 2012) conducted pilot studies to test the effectiveness of selected mountain goat winter ranges (MGWRs) in both coastal and interior environments. Winter ranges were examined and sampled at three areas: McNab Creek (Coast), Foxy Canyon (Skeena), and Sitkum Creek (Okanagan). In these study areas, five sets of data were collected:

1. Proportion of suitable/capable habitat managed as a MGWR (McNab Creek and Foxy Canyon),
2. Forest cover characteristics (all study areas),
3. Evidence of movement among winter ranges (Foxy Canyon),
4. Snow depth and consolidation (all study areas), and
5. Evidence of sustained winter use (all study areas; ground-based).

While this first attempt at effectiveness monitoring is quite thorough, there are several shortcomings with these pilot studies:

1. These data could not be collected in all areas (e.g., telemetry data) and there were no standards for data collection, making comparisons between areas and a meta-analysis difficult.
2. The majority (>90%) of goat winter range areas cannot be sampled on the ground, meaning the ground-based methods for collection of evidence of sustained winter use would yield incomplete data on the majority of winter ranges.
3. The metrics used for sustained use are not practical (see point 2), nor can they adequately monitor the population, relative importance/use of an area, or trend.
4. Evidence of movement between winter ranges using telemetry data is not as relevant as understanding what proportion of the mapped winter ranges are used by goats throughout the winter season.
5. If telemetry data are available, calculating mountain goat survivorship using radio collared goats is important to address the objective of survivorship of the species over time. Similarly, late winter and early spring surveys would allow a kid:adult ratio to be calculated – recruitment being an important population metric. These issues are not addressed by these pilot studies.

A fundamental component of the FREP monitoring question relates to, *…ensure the survival of the species now and over time*. This involves not just the presence or absence of goats on their winter ranges, but also includes metrics on goat abundance (relative or absolute) and survivorship, as declines of goats can occur for various reasons. The scope of this foundational question needs to be addressed first, before proceeding with further investigation. Moreover, unless large-scale habitat perturbations occur (e.g., wildfire), habitat change on winter ranges can be subtle and difficult to detect in the short term. Conversely, populations of mountain goats on anthropogenically affected ranges may respond rapidly to disturbances, such as recreation or industrial activities, resulting in alienation affects that ultimately reduce the effectiveness of the MGWRs. A habitat may appear to contain the features and structures necessary to function as a MGWR, but because of external disturbances or intrusions, that functionality can be compromised. Anthropogenic disturbance can cause temporary or seasonal avoidance (Jex 2007a), or complete abandonment, which in turn may cause population declines.

This report uses existing winter aerial inventory and radio collar data collected in the South Coast from multiple inventories and studies to evaluate approaches for assessing MGWR effectiveness.

The objectives of this analysis are to:

1. Use winter aerial survey and telemetry data to evaluate metrics for effectiveness monitoring.
2. Examine these metrics to determine their appropriate application; their ability to detect population trends, habitat use, and survivorship, and their use in answering effectiveness questions.
3. Evaluate the robustness of these data by examining the relationships between abundance metrics, landscape attributes, and statistical power.
4. Summarize how these metrics can be used for monitoring the effectiveness of MGWRs, answering key management questions, and influencing monitoring design.

STUDY AREAS

In the South Coast, six MGWR plans have been established under FRPA[1]:

- Sunshine Coast Forest District – a MGWR plan for TFL 39 (Block 1) totalling 13,028 ha was approved on August 11, 2010; the Sunshine Coast TSA Goat Plan (46,825 ha) was approved on March 7, 2012; and the Toba Community Forest Agreement (13,320 ha) was approved on September 20, 2013.
- Sea to Sky Natural Resource District – 48,474 ha of MGWR were protected on October 16, 2003, in the Soo TSA and an additional 12,617 ha were protected on July 5, 2007, in Tree Farm License (TFL) 38.
- Chilliwack Natural Resource District – 35,658 ha of MGWR were protected, and the Fraser TSA Mountain Goat Plan was signed by the Deputy Minister on March 10, 2008.

In addition, the Skagit Environmental Endowment Commission (SEEC) funded an inventory and subsequent mapping of MGWRs in 2007 (Jex 2007b). While these MGWRs are not part of the Fraser TSA Mountain Goat Plan, the monitoring data are included in this analysis (Jex 2007b; Nietvelt et al. 2010; Nietvelt 2012).

The Sunshine Coast Natural Resource District covers approximately 1.93 million ha of the total South Coast land base. Its climatic influences are predominantly maritime; however, some river systems at the head of coastal inlets can possess interior bioclimatic characteristics in their upper reaches (Gordon and Reynolds 2000; Figures 1 and 2).

The Sea to Sky Natural Resource District is approximately 1.1 million ha in size and its climatic influences are predominantly maritime, dominated by interior-cedar hemlock, coastal western hemlock, and mountain hemlock biogeoclimatic zones[2] (Figures 1 and 2).

The Chilliwack Natural Resource District varies considerably in climatic conditions. The northeast portion of the district has a drier, interior-type of climate, while the southwest portion receives a coastal influence (Freeman 2000; Jex 2007b). This coastal influence results in winters that are wet, mild, and often with high snowfall amounts at elevations > 900 meters (Freeman 2000; Jex 2007b). The Skagit River watershed is within the Chilliwack Natural Resource District, and encompasses Skagit Valley Provincial Park, the eastern portion of E.C. Manning Provincial Park, and the Cascade Recreation Area (Figure 1). These protected areas represent approximately 70% of the total Skagit River watershed on the Canadian side which is located approximately 170 km east of Vancouver and 25 km southeast of Hope (Fedoruk 2008). The Skagit River watershed is ecologically unique, as it contains coastal, interior, and transitional habitats (Barnard 1986; Figures 1 and 2).

1 http://www.env.gov.bc.ca/wld/frpa/uwr/approved_uwr.html
2 https://www.for.gov.bc.ca/hre/becweb/

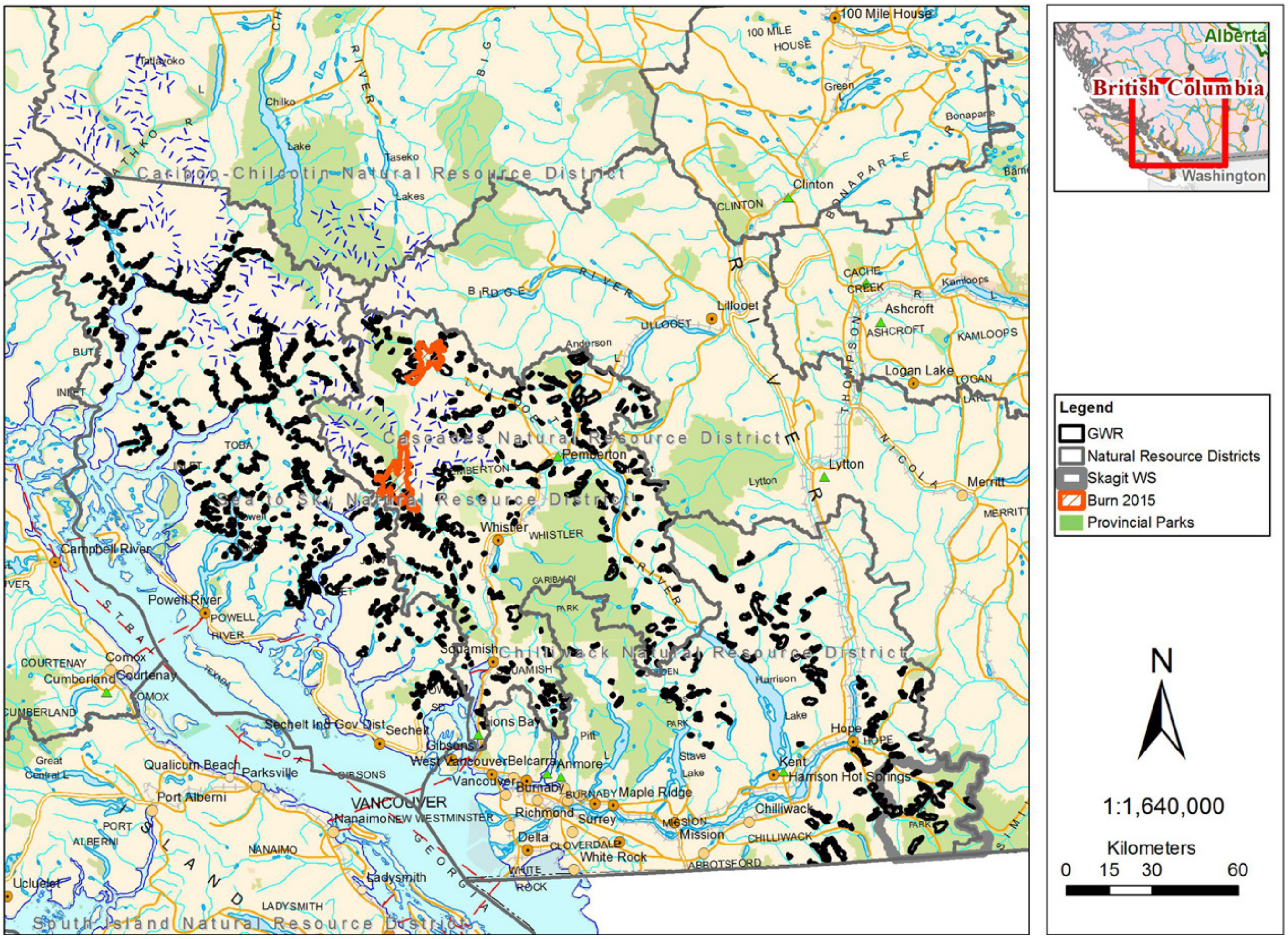

Figure 1. Mountain goat winter ranges (MGWRs) in the South Coast: Sunshine Coast, Sea to Sky, and Chilliwack Natural Resource Districts.

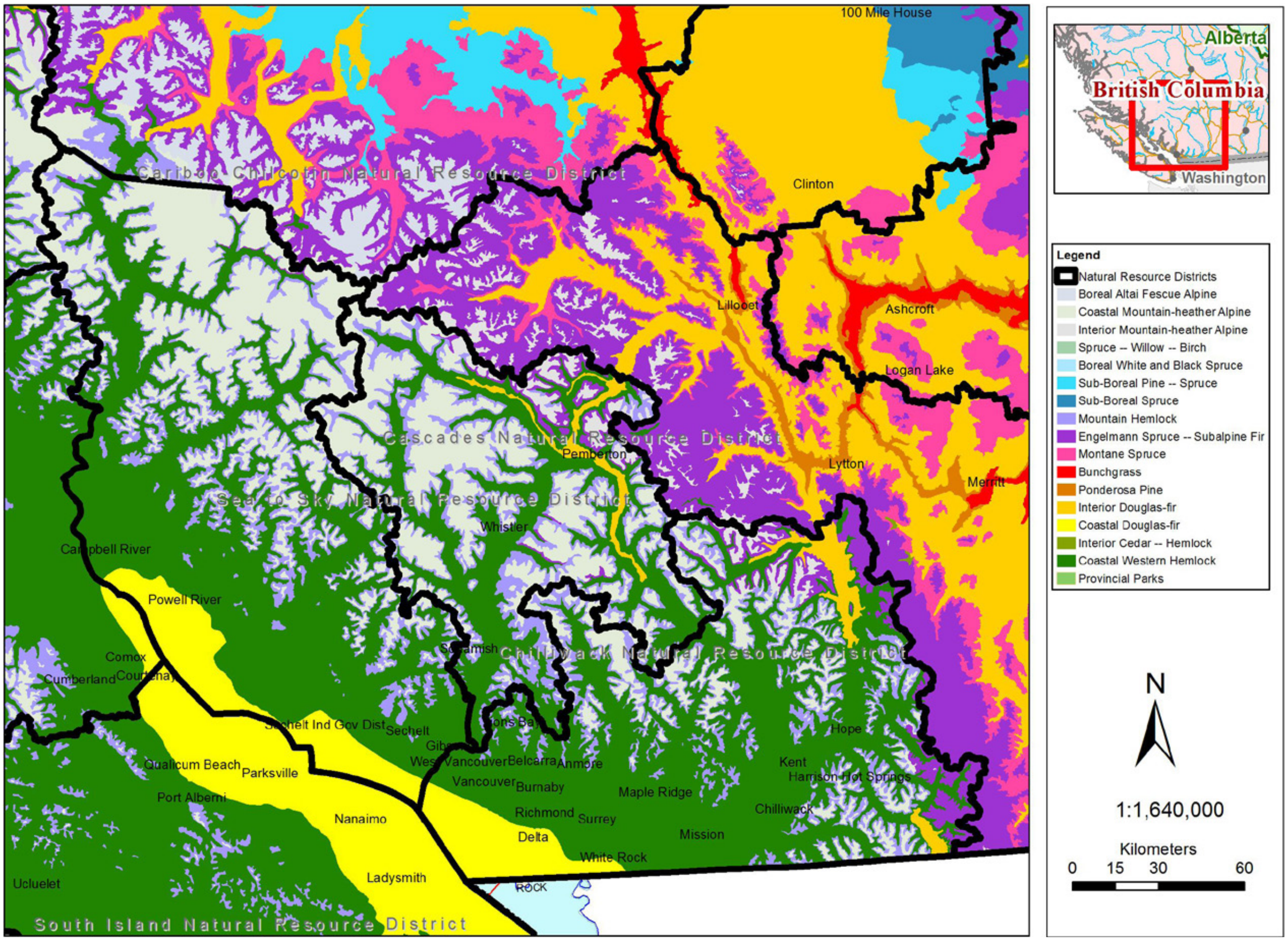

Figure 2. *Biogeoclimatic zones in the South Coast.*

METHODS

Data Sources

Data from 11 inventory flights from 2008-2017 were used in the analysis (a total of 72 individual MGWRs in all three natural resource districts). The number of MGWRs sampled in each district were:

- Sunshine Coast Natural Resource District (February 2009) – 25.
- Sea to Sky Natural Resource District (February 2016 to March 2017) – 24.
- Chilliwack Natural Resource District (January 2008 to March 2012) – 23.

Some of these data had previously been summarized and reported in the following reports and papers: Nietvelt et al. (2010); Nietvelt (2012); Nietvelt and Rochetta (2017); and Nietvelt et al. (2018).

Winter Range Inventory

Resource Inventory Standards Committee (RISC) methodology (RISC 2002) was used as a starting point. These methods are reported in Nietvelt et al. (2010), Nietvelt (2012), and Nietvelt et al. (2018). The flights were conducted during mid-day (1000 to 1500 hours) when goats and/or tracks are most easily observed. The surveys were conducted approximately 2-3 days after a snowfall, allowing time for tracks to accumulate. This increases the likelihood of detecting goat presence and of identifying the distribution of use among habitat types. A Bell 206 Jet Ranger helicopter with rear bubble windows was used for flights in the Chilliwack Natural Resource District and the Skagit River watershed and was equipped with a global positioning system (GPS), audio, and video for data capture. Valley Helicopters of Hope, British Columbia, have devised an audio-video data capture system whereby audio commentary by the observers and the GPS coordinates are transcribed in real-time to video. This video can be watched after the flight to confirm and revisit the observations and associated coordinates. This system served as a back-up to notes and GPS locations taken by the observers in the helicopter. The video camera was mounted under the helicopter, and it also provided a visual of the vegetation and topography with real-time GPS and audio. Shapefiles of these MGWRs were uploaded to an Archer Field PC with ArcPad 7.0 tethered to a Garmin GPS 60CSx, which provided navigation so that each MGWR was adequately sampled. A track file from the GPS was collected as a record of the flight path and can be used to both calculate an index of relative abundance and for repeating the flight line for long-term monitoring.

Surveys in the Sunshine Coast and Sea to Sky Natural Resource Districts used the same methodology, except an A-Star 350 helicopter was used (not a RISC standard), and an audio-video data capture system was not implemented. However, the flights conducted in 2016 and 2017 in the Sea to Sky Natural Resource District used an iPad (© Apple Inc.) preloaded with PDF maps and real-time GPS using Avenza Maps mobile app (http://www.avenza.com/pdf-maps) for navigation, with waypoints of mountain goat observations (animals or tracks) and flightpaths recorded using a Garmin GPS 60CSx.

When sets of tracks were encountered with no mountain goats visible, both the number of track-sets and individuals were documented. Since there is some overlap in the range of deer and mountain goats at the lower elevations of MGWRs, tracks were identified to species. When mountain goats (actual animals) were located, individuals were counted and classified by age and sex. Age and sex classification are as follows: adult females, adult males, juveniles (when possible), and kids or unknown adult (Smith 1988; Jex 2007b; Nietvelt et al. 2010). In MGWRs where canopy closure or terrain caused sightability to be low, the number of tracks were selected as an index of abundance.

Animal welfare during detections was paramount, and an immediate assessment of potential hazards was undertaken. If an animal was determined to be in a precarious location, the helicopter immediately moved away and at times, this may have affected successful classification.

Radio Telemetry

Radio telemetry data via GPS collars were used from the Mount Meager study for this report (Nietvelt et al. 2020a and b; Nietvelt et al. 2022). In August 2018 and 2019, a total of 31 mountain goats (21 females and 10 males) were radio collared via net gunning and equipped with a GPS radio collar (Vectronic Survey-2D Globalstar). GPS points of mountain goat locations were downloaded via the Vectronic Aerospace online web server. These collars obtain approximately two locations per day every 11 hours, allowing for randomized times for data collection.

DATA ANALYSIS

Abundance Measures

Winter range inventory data were used to calculate and compare two measures of abundance. A linear density (*LD*) was calculated, which is a combination of goats and tracks, as a metric of relative abundance (see Nietvelt et al. 2018). Linear density is calculated as follows:

$$LD = \sum_{i} (G + T) \Big/ \sum_{i} D$$

where *G* is the total number of goats sighted in the winter range *i*, *T* is the number of goats estimated from tracks, and *D* is the distance (km) sampled in the winter range *i*. As the sightability of actual goats in each winter range was highly variable, the *LD*, which integrated both the number of goats seen and number of tracks, acted as a measure for goat relative abundance (O'Donoghue et al. 1997; RISC 2002: 26; Bayne et al. 2008; Collier et al. 2008; Johnson 2008).

Mountain goat densities (goats per km^2) were calculated for MGWRs using the area of the delineated winter range (in km^2) as the denominator. This allows for a coarse comparison of mountain goat populations between areas and known densities of goats in coastal ecosystems, and allows a comparison to the *LD*. A caveat is that delineated MGWRs do not capture the entire extent of mountain goat habitat, hence the densities reported here are likely higher than what has been reported in previous studies.

The total count of mountain goats on established winter ranges were used as another measure of abundance. These counts were not corrected for sightability as there has not been a correction factor developed for winter surveys of mountain goats (e.g., Rice et al. 2009). As the goal was to examine trends in abundance and not determine absolute abundance estimates, this metric might suffice and should be considered despite potential for bias (Gonzalez-Voyer et al. 2001). For example, some winter ranges where sightability is good may have a reasonably consistent number of goats sighted each year, especially where large groups exist. It was assumed that the composition and abundance of mountain goats observed were predominantly individuals whose traditional home range overlapped the inventoried habitats (i.e., a relatively closed population) and that new immigrants/pioneering animals, or source/sink drivers, were not a significant component of the enumerated mountain goats used in this analysis.

The *LD* was validated against two data sets. First, the *LD* was regressed against mountain goat densities to determine if the track index is correlated to mountain goat densities on a larger scale. Second, *LD* was regressed against the number of goats and the number of tracks observed against the MGWR size and forest area. For many taxa, animal density correlates either positively or negatively with patch size (Bender et al. 1998; Connor et al. 2000; Bowman et al. 2002). If *LD* is to be used as a relative measure of abundance, this correlation should exist. Forest area was selected as a metric as per Nietvelt et al. (2018), who found a significant correlation between residual forest patch size and goat abundance. The rationale behind this is that the forested patch for coastal goats provides the requisite habitat goats need for snow interception and forage (Fox et al. 1989). Other measures of goat abundance were also regressed to test the relationship between abundance, MGWR, and forest patch size. These metrics include the number of goats, the number of tracks, and the number of goats plus tracks (uncorrected by distance or area).

Power analysis was used to estimate the sample size needed at a specified probability (power = $1 - \beta$) to determine (at the α level) if there is a significant difference or effect (effect size) (Gerrodette 1987; Johnson 1999). The power analysis was performed using winter flight data to find the statistical power at the given number of winter ranges and known population variance (note: the sample unit is a series of MGWRs in a predefined area). Hypothetical deviations were simulated from the mean by 50% and 75% (i.e., 5% and 7.5% change per year over a 10-year period), and a significance level of 80% and 90% (α = 0.20 and 0.10 or an 80% and 90% chance of detecting an effect). Adequate power should at least be 0.80 and 0.90 for 80% and 90% significance levels, respectively (Schieck 2002). It is important to understand the limitations of these data when quantifying changes in the observed and estimated mountain goat use of winter ranges through time, hence a power analysis is crucial (Cohen 1988; Thomas and Krebs 1997; Schieck 2002; Herbers et al. 2007; Nielsen et al. 2009). The power analysis was performed using the package *pwr* in R (R Core Team 2020: https://cran.r-project.org/web/packages/pwr/pwr.pdf).

Related to the power analysis is the coefficient of variation (*CV*), a statistical measure of the relative dispersion of data points in a data series around the mean (Patel et al. 2001). The *CV* is a ratio of the standard deviation (σ) and the mean (μ) and standardized as a percent, meaning that variances from different values can be compared. The *CV* is calculated as follows as a percent:

$$CV = \left(\frac{\sigma}{\mu}\right) \times 100$$

therefore, the higher the *CV*, the greater the variance.

Winter range surveys were initially designed as a presence/not detected survey to confirm that the delineated winter ranges had mountain goats (RISC 2002; Jex 2007b). As some populations of mountain goats occur at lower densities, such as in the Chilliwack Natural Resource District (Jex 2007b; Kelly and Reynolds 2016), detection of mountain goats on winter ranges may be less than 1.0 (i.e., <100%; MacKenzie et al. 2002; MacKenzie 2005a and b). Moreover, for mountain goat populations impacted by disturbance, such as wildfire, detection may also be imperfect (Nietvelt et al. 2018). A sampling scheme as proposed by MacKenzie (2005a) could be applied to the monitoring of MGWRs. The landscape unit (*U*) would be the MGWRs, and each unit would need to be surveyed *K* times within a short timeframe, and in this case, during the same winter season.

A method proposed by MacKenzie et al. (2002) was used to assess site (i.e., winter range) occupancy. This method is employed when a species in a particular area is difficult to detect and might take several surveys to find the species in question. For this report, it will be demonstrated when to use occupancy and detection probabilities as it pertains to MGWR assessments. For MGWRs that were flown >1 occasion during a season, the probability of detecting mountain goats on the winter range was calculated as Pr_j, where detection is binary (detected or not detected: 1 or 0) and is conducted over *j* surveys. A simple mathematical calculation was performed to determine the probability of detection for an individual MGWR:

$$Pr_j = \frac{(D_j + D_j \ \dots)}{K}$$

D_j is the detection (1 or 0) per survey (*j*), and *K* is the total number of surveys (in this case flights) in one season. The program PRESENCE (https://www.mbr-pwrc.usgs.gov/software/presence.html) was used to calculate estimates of occupancy probability, psi (ψ), and the average detection probabilities with associated standard errors (MacKenzie et al. 2002).

Demographic Analysis

In all surveys, mountain goats were classified by age and sex. Goats were classified as adult females, adult males, juveniles (when possible), and kids (Smith 1988) and unknown adults. The kid:adult[3] ratio was calculated to examine differences in recruitment between areas, as a low kid:adult ratio is an indicator of a potentially declining population, and can be used to estimate the population growth rate, λ, if female survivorship, *S*, is known and the kid:adult ratio is recruitment rate, *R* (Hebert and Langlin 1982; Hatter and Bergerud 1991).

The Kaplan-Meier (K-M) (Kaplan-Meier 1958) was used to calculate the cumulative survivorship of adult male and female goats that had been collared as part of a study in the Sea to Sky District (Nietvelt et al. 2020 a and b; 2022). The K-M estimate equation is:

$$\hat{S}_t = \prod \left(\frac{n_i - d_i}{n_i} \right),$$

where n_i is the number of goats alive and at risk at time *i*, d_i is the number of known dead at time *i*, and the summation is over *i* up to t^{th} time period.

The locations of mortalities of mountain goats were in relation to legally established MGWRs. This is a key indicator if mortalities are a problem and if so, where are they occurring in relation to the mapped, legally designated winter ranges.

Use of Winter Ranges

Winter is typically from November 1 until April 30 on the South Coast. This is consistent with the Tree Farm License 39 Goat Winter Range Plan and reflects the onset of on-the-ground snow accumulation (Nietvelt et al. 2020a and b; 2022). Furthermore, telemetry data from 2018 to 2021 indicated the timing of distinct range and elevational shifts by male and female mountain goats. Migration to and from winter ranges often occurred in October, or in some cases later, and terminated in May or sometimes June (Nietvelt et al. 2022).

Winter and summer use of the legally designated MGWRs were evaluated for male and female mountain goats for the one area (Mount Meager area in the Sea to Sky District) where overlapping telemetry data exists (Nietvelt et al. 2020a and b; and 2022). First, the telemetry points for male and female mountain goats were used to evaluate spatial use of the mapped MGWRs. The percent of these seasonal locations that occur within the mapped MGWRs were calculated. These data were used to identify areas of mountain goat use in habitats previously not mapped as part of the MGWR establishment process. It is expected that the majority (>50%) of telemetry points should occur within the legally designated polygon boundaries.

[3] Adults includes billies, nannies, and juveniles.

RESULTS

The 72 winter ranges sampled represent 9.0% of the total mapped MGWRs in the South Coast (Table 1) for the South Coast. The mean mapped winter range size sampled is highest in the Skagit River watershed and the Chilliwack Natural Resource District, and lowest in the Sunshine Coast Natural Resource District (Table 2).

Table 1. *The number and area (ha) of mountain goat winter ranges (MGWRs) in the South Coast*

District	No.	Area (Ha)	Plans
Chilliwack	108	35,658	Fraser TSA
Sea to Sky	278	61,091	TFL 38, Soo TSA
Sunshine Coast	406	73,173	Sunshine Coast TSA, TFL 39 block 1, Toba Community Forest Agreement
Skagit	10	6,925	Skagit Environmental Endowment Commission (SEEC) non-legal
TOTAL	**802**	**176,847**	

Table 2. *Mean mountain goat winter range (MGWR) size (ha) sampled in each natural resource district*

District	Mean MGWR area (ha) sampled	Range (ha)
Skagit 2008*	703	205 to 1,530
Skagit 2012*	769	205 to 1,530
Chilliwack 2008	765	271 to 1,530
Chilliwack 2009	576	58 to 1,530
Chilliwack 2010	719	271 to 1,530
Sunshine Coast 2009	202	38 to 544
Sea to Sky (Elaho)	362	52.5 to 860
Sea to Sky (Upper Lillooet)	548	41 to 1,411

*Located in the Chilliwack Natural Resource District

Winter Range Inventory Metrics

The *LDs* in all three natural resource districts located within the South Coast matched very strongly with uncorrected mountain goat densities (Figures 3 and 4). Both the *LD* and the densities show the same pattern in terms of abundance estimates, and there is a very strong correlation between the *LD* and the estimated densities ($r^2 = 0.76$, $P < 0.001$; Figure 5).

There are strong correlations between MGWR size and the various abundance metrics: *LD*, number of goats, number of tracks, and the number of goats plus tracks (Table 3). The forest area (ha) within each MGWR is also a strong predictor for these metrics.

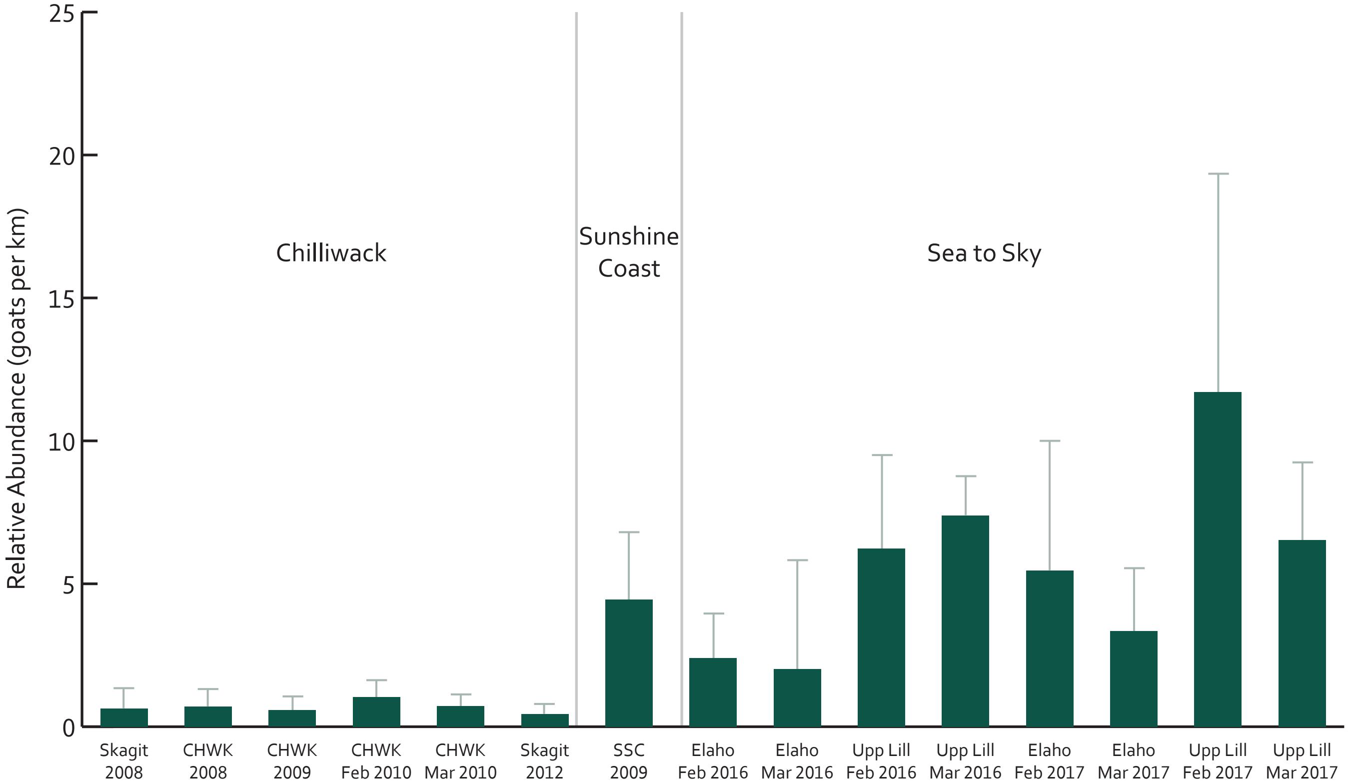

Figure 3. *A comparison of the relative abundance of mountain goats surveyed in each natural resource district. For the Sea to Sky District, abundance is only from mountain goat winter ranges (MGWRs) with <60% of the forest burned by wildfire in 2015*

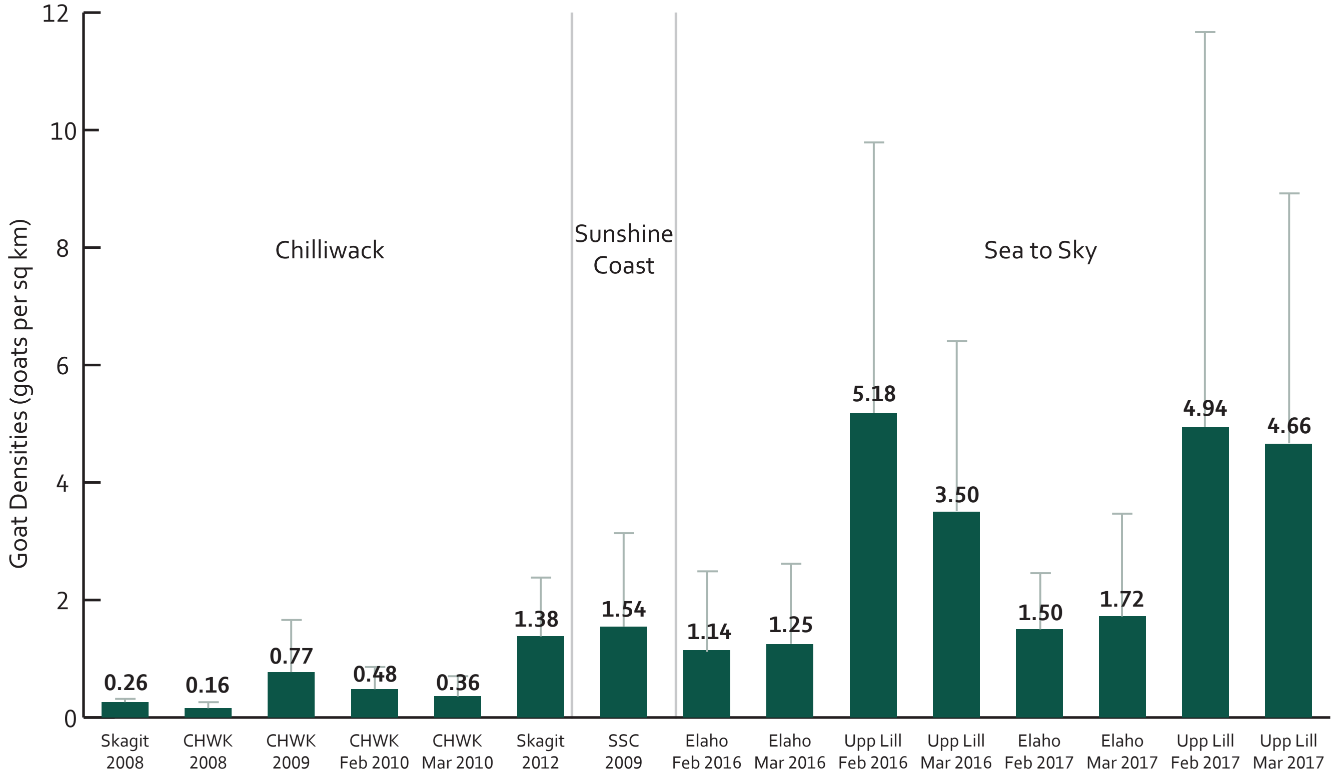

Figure 4. *Uncorrected mountain goat densities from surveys in all three natural resource districts. For the Sea to Sky District, abundance is only from mountain goat winter ranges (MGWRs) with <60% of the forest burned by wildfire in 2015*

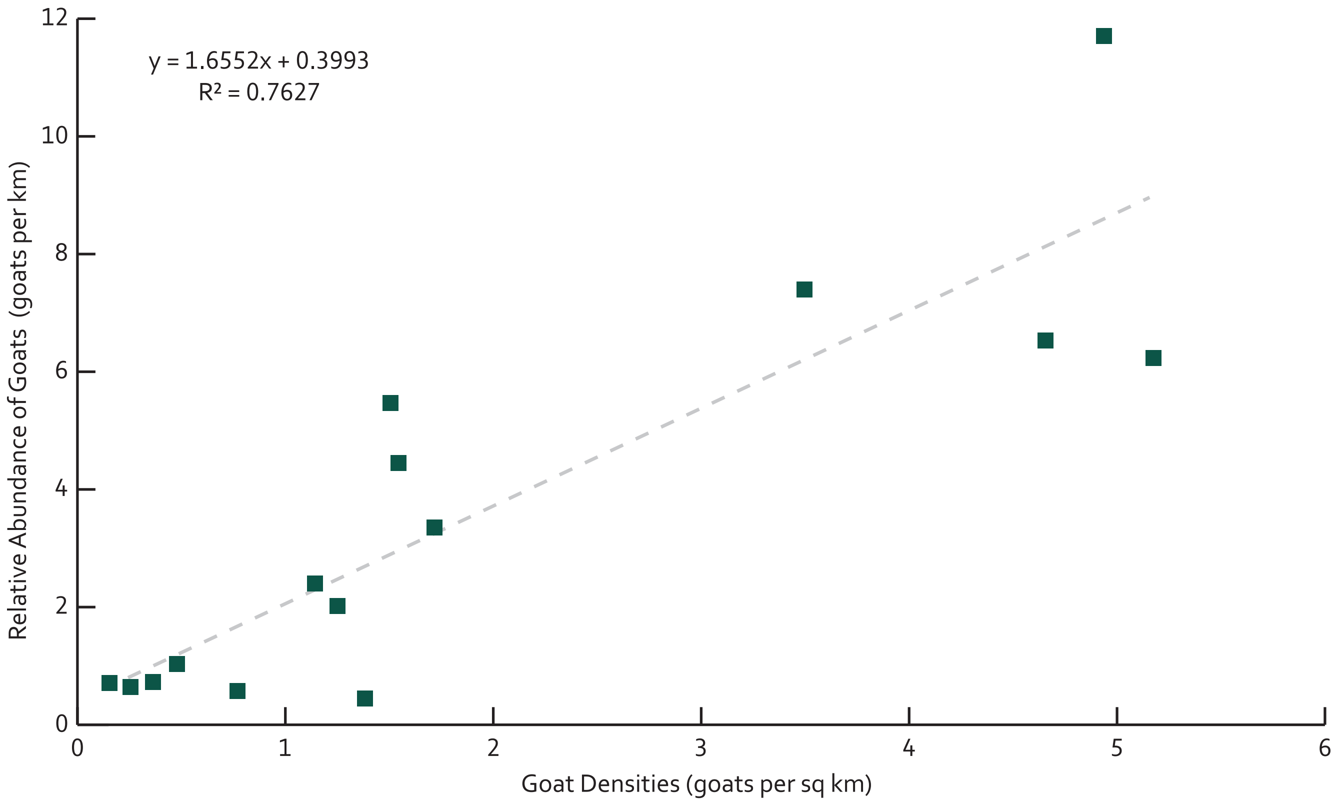

Figure 5. *Uncorrected mountain goat densities versus linear densities from surveys in all three natural resource districts (2008-2017)*

Table 3. *Correlations between track density and number of tracks versus mountain goat winter range (MGWR) size.* **Bold** *indicates statistically significant correlations*

Area surveyed	Year	Correlation (r)							
		Linear density and MGWR size	No. goats and MGWR size	No. tracks and MGWR size	No. goats + tracks and MGWR size	Linear density and forest area	No. goats and forest area	No. tracks and forest area	No. goats + tracks and MGWR size
Skagit	2008 (Jan)	0.42	NA+	0.42	0.42	0.39	NA+	0.43	0.44
Skagit	2012 (Mar)	0.47	NA+	0.48	0.52	0.47	NA+	0.58	**0.61***
Chilliwack	2008 (Mar)	0.54	NA	**0.81***	**0.83***	0.43	NA	0.72	0.75
Chilliwack	2009 (Apr)	0.033	NA	**0.80****	**0.80****	0.009	NA	**0.82****	**0.79****
Chilliwack	2010 (Feb)	**0.95*****	NA	**0.97*****	**0.98*****	**0.96****	NA	**0.95*****	**0.94*****
Chilliwack	2010 (Mar)	**0.86*****	0.69	**0.95*****	**0.95*****		0.71	**0.82***	**0.80***
Sunshine Coast	2009 (Mar)	0.23	0.46	**0.76*****	**0.74*****	0.14	0.05+	**0.67*****	**0.69*****
Sea to Sky	2016 (Feb)	**0.64***	**0.77***	0.09	**0.74***	0.42	**0.61***	0.057	0.46
Sea to Sky	2016 (Mar)	0.0053	0.58	0.15	**0.70***	0.17	**0.67****	**0.64****	**0.53****
Sea to Sky	2017 (Feb)	0.23	**0.72****	0.56	**0.79****	0.07	**0.98*****	**0.52****	**0.44***
Sea to Sky	2017 (Mar)	0.49	**0.76***	**0.79****	**0.83****	**0.59****	**0.87*****	**0.79*****	**0.75*****

*P < 0.05; **P < 0.01; *** P < 0.001; NA: not available due to low sample size; +: sightability of goats was poor.

Mountain Goat Detection and Occupancy Probabilities

There were variations in the detection of goats (animals and tracks) across the winter ranges (Table 4). During the two flights in the Skagit (2008 and 2012), goats were detected 76.9% and 72.7% of the time. Surveys in the Chilliwack in 2009 had detections of 90%, and goats were detected 100% of the time for surveys in the Sunshine Coast in 2009 and in Chilliwack (2008 and 2010), respectively. Goats were detected <100% of the time in the Sea to Sky; however, as described by Nietvelt et al. (2018), the impacts of large-scale wildfires significantly affected the mountain goat population where MGWRs that had ≥75% of the forest burned had much fewer (≥80% less) mountain goats.

Table 4. *Mountain goat winter ranges (MGWRs) where goats were detected (animals and tracks), 2008-2017*

Area surveyed	Year	No. MGWRs sampled	No. MGWRs detected	% MGWRs detected
Skagit	2008	13	10	76.9
Skagit	2012	11	8	72.7
Chilliwack	2008	6	6	100.0
Chilliwack	2009	10	9	90.0
Sunshine Coast	2009	25	25	100.0
Chilliwack	2010 (Feb)	7	7	100.0
Chilliwack	2010 (Mar)	7	7	100.0
Sea to Sky	2016 (Feb)	20	17	85.0*
Sea to Sky	2016 (Mar)	21	18	86.0*
Sea to Sky	2017 (Feb)	23	18	78.2*
Sea to Sky	2017 (Mar)	21	18	86.0*

*Impacted by fire.

The detection and occupancy probabilities for MGWRs with two flights conducted in one winter was 100% in the Skagit watershed (Pr_j and ψ = 1.0; Table 5). In the Sea to Sky District where fires impacted MGWRs in 2015, variations in detection and occupancy probabilities were observed (Tables 6 and 7). In 2016, repeated flights in the Elaho resulted in only one MGWR with no detections, while in the Upper Lillooet area, all MGWRs had mountain goats detected (Table 6). In 2017, MGWRs impacted by fire had been sampled, resulting in the Elaho having a lower average detection probability than Upper Lillooet (0.77 versus 0.95), although both areas had a similar occupancy probability (0.94 and 0.91; Table 7).

Table 5. *The detection probabilities, Pr_j, and occupancy probability (ψ) for a subset of mountain goat winter ranges (MGWRs) in the Skagit watershed (2008 and 2010)*

MGWR (i)*	Year	No. flights (K)	Detection probability (Pr_j)	Occupancy** probability (ψ) ± SE
MA 2 / SH 4	2008	2	1.0	1.0 ± 0.0
SH 1	2010	2	1.0	1.0 ± 0.0
SH 5	2010	2	1.0	1.0 ± 0.0
SH 6	2010	2	1.0	1.0 ± 0.0
SH 7	2010	2	1.0	1.0 ± 0.0
Average			**1.0 ± 0.0**	**1.0 ± 0.0**

*Ungulate winter range unit number. **Conditional psi (ψ).

Table 6. *The detection probabilities, Pr_j, and occupancy probability (ψ) for a subset of mountain goat winter ranges (MGWRs) in the Sea to Sky District, February and March 2016*

MGWR (i)*	Year	No. flights (K)	Detection probability (Pr_j)	Occupancy** probability (ψ) ± SE
Elaho				
7	2016	2	1.0	1.0 ± 0.0
30	2016	2	1.0	1.0 ± 0.0
31	2016	2	1.0	1.0 ± 0.0
26	2016	2	1.0	1.0 ± 0.0
58	2016	2	1.0	1.0 ± 0.0
57	2016	2	1.0	1.0 ± 0.0
41	2016	2	0.0	0.0 ± 0.0
25	2016	2	1.0	1.0 ± 0.0
40	2016	2	1.0	1.0 ± 0.0
Average			**1.0 ± 0.0**	**0.89 ± 0.10**
Upper Lillooet				
ME 3	2016	2	1.0	1.0 ± 0.0
ME 2	2016	2	1.0	1.0 ± 0.0
ME 4	2016	2	1.0	1.0 ± 0.0
UL8	2016	2	1.0	1.0 ± 0.0
UL10	2016	2	1.0	1.0 ± 0.0
UL11	2016	2	1.0	1.0 ± 0.0
RA7	2016	2	1.0	1.0 ± 0.0
RY8	2016	2	1.0	1.0 ± 0.0
7	2016	2	1.0	1.0 ± 0.0
30	2016	2	1.0	1.0 ± 0.0
Average			**1.0 ± 0.0**	**1.0 ± 0.0**

*Ungulate winter range unit number. **Conditional psi (ψ)

Table 7. *The detection probabilities, Pr_j, and occupancy probability (ψ) for a subset of mountain goat winter ranges (MGWRs) in the Sea to Sky District, February and March 2017*

MGWR (i)*	Year	No. flights (K)	Detection probability (Pr_j)	Occupancy** probability (ψ) ± SE
Elaho				
07	2017	2	1.0	1.0 ± 0.0
26	2017	2	1.0	1.0 ± 0.0
66	2017	2	1.0	1.0 ± 0.0
40	2017	2	0.5	1.0 ± 0.0
58	2017	2	0.0	0.45 ± 0.72
41	2017	2	0.5	1.0 ± 0.0
56	2017	2	0.5	0.0 ± 0.0
39	2017	2	0.5	1.0 ± 0.0
25	2017	2	1.0	1.0 ± 0.0
Average			**0.77 ± 0.13**	**0.94 ± 0.13**
Upper Lillooet				
ME 3	2017	2	1.0	1.0 ± 0.0
ME 2	2017	2	1.0	1.0 ± 0.0
ME 4	2017	2	1.0	1.0 ± 0.0
UL10	2017	2	1.0	1.0 ± 0.0
UL11	2017	2	1.0	1.0 ± 0.0
UL12	2017	2	0.5	1.0 ± 0.0
UL13	2017	2	0.0	0.028 ± 0.063
UL8	2017	2	1.0	1.0 ± 0.0
UL19	2017	2	1.0	1.0 ± 0.0
RA7	2017	2	1.0	1.0 ± 0.0
RY8	2017	2	1.0	1.0 ± 0.0
Average			**0.95 ± 0.053**	**0.91 ± 0.087**

*Ungulate winter range unit number. **Conditional psi (ψ).

Sightability

The sightability of mountain goats (actual animals) varied widely in all study areas (Table 8). The Skagit watershed had the lowest sightability, where goats were only sighted on 15.4% (*n* = 2) and 18.2% (n = 2) of the MGWRs. Surveys conducted in the Chilliwack and the Sunshine Coast Natural Resource Districts in 2008 and 2009 revealed that goats were seen on 28.0% to 33.3% of the MGWRs. In 2010, goats were seen on 42.8% of the MGWRs in the February survey, while in the March survey goats were seen on 71.4% of the MGWRs. Sightability of goats in the Sea to Sky Natural Resource District was much higher and more consistent across surveys, ranging from 76.5% to 81.2%. Forest cover does influence animal sightability, as there is a significant decrease in sightability as the percentage of forest cover in the MGWR increases ($r^2 = 0.43$, $P < 0.05$; Figure 6).

Table 8. *Mountain goat winter ranges (MGWRs) where mountain goats (animals, not just tracks) were sighted during winter range flights, and the percent of the MGWR forested in all three natural resource districts, 2008-2017*

Area surveyed	Year	No. MGWRs sampled	No. MGWRs where goats[1] were sighted	% MGWRs where goats[1] were sighted	Mean % of MGWR forest cover
Skagit	2008	13	2	15.4%	91.6%
Skagit	2012	11	2	18.2%	91.8%
Chilliwack	2008	6	2	33.3%	85.1%
Chilliwack	2009	10	3	30.0%	87.5%
Sunshine Coast	2009	25	7	28.0%	29.5%
Chilliwack	2010 (Feb)	7	3	42.8%	86.6%
Chilliwack	2010 (Mar)	7	5	71.4%	86.6%
Sea to Sky	2016 (Feb)	16	13	81.2%	33.3%
Sea to Sky	2016 (Mar)	17	13	76.5%	31.3%
Sea to Sky	2017 (Feb)	15	12	80.0%	32.7%
Sea to Sky	2017 (Mar)	14	11	78.6%	34.1%

[1]Animals not tracks

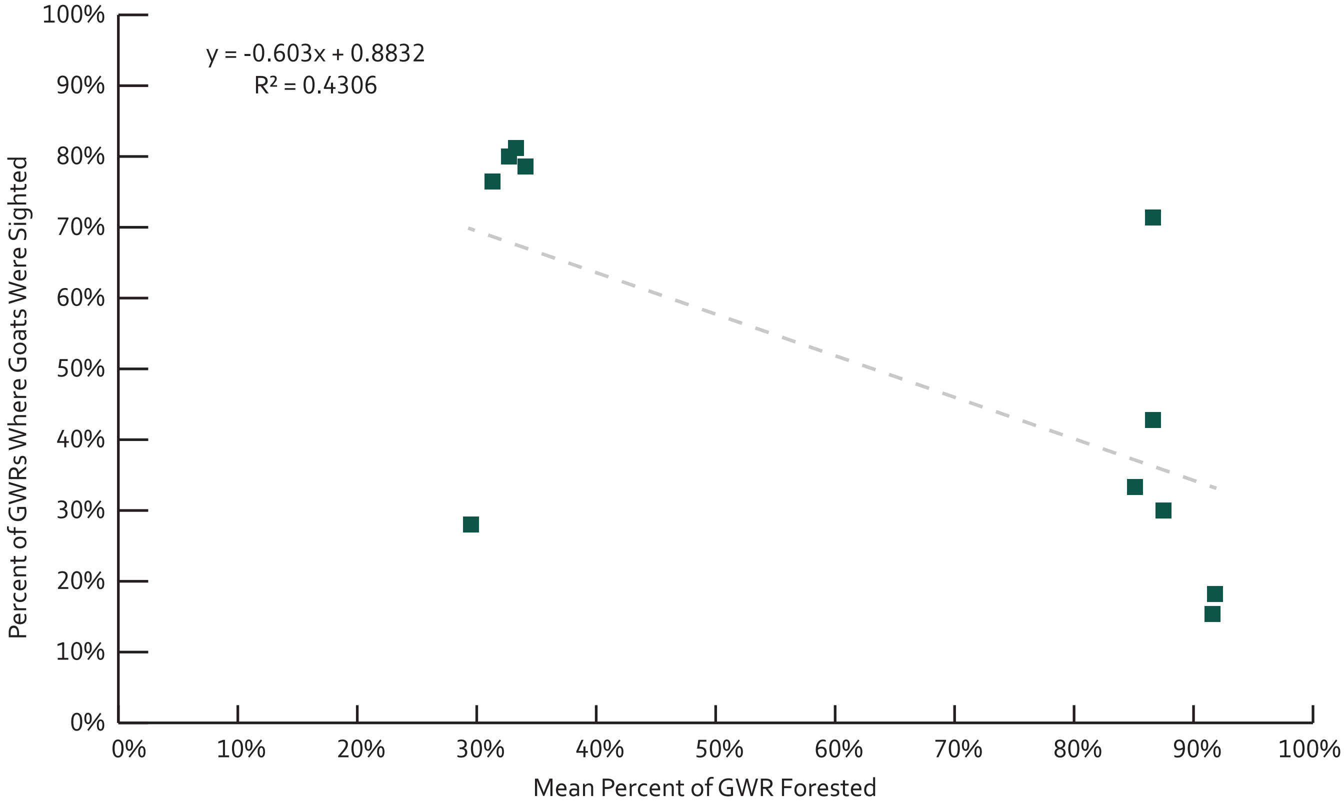

Figure 6. *The mean percent of mountain goat winter range (MGWR) forest cover versus MGWRs where goats (animals) were sighted for all surveys.*

Variance and Statistical Power

Variances ranged considerably depending on the survey. Two of the surveys in the Skagit had the highest CVs at just over 100%, while one of the Elaho surveys had a CV of 94.6%, and the Chilliwack 2008 and 2009 surveys had CVs of 90.8% and 91.2%, respectively (Table 9). The CVs for other surveys are < 70% (Table 9). When comparing the variance of another metric, the number of goats plus tracks, the variance for this in every survey except one, is higher, and in most cases substantially higher than the *LD* (Table 13).

Of the 15 surveys analyzed, five of the 15 (33.3%) had adequate statistical power for a 50% change (increase or decrease, two-tailed) and 12 of the 15 (80%) had adequate power for a 75% change (increase or decrease, two-tailed), at $\alpha = 0.20$ (Table 9). At $\alpha = 0.10$, three of the 15 surveys (20%) had adequate statistical power for a 50% change (increase or decrease, two-tailed), and four of the 15 (27%) had adequate power to detect a 75% change (increase or decrease, two-tailed).

When considering the statistical power to predict a decline (one-tailed), 10 out of the 15 surveys (67.7%) had adequate power to detect a 50% decline, while 14 out of the 15 surveys (93.3%) had adequate statistical power to detect a decline at $\alpha = 0.20$ (Table 10). At $\alpha = 0.10$, four of the 15 surveys (27%) had adequate power to detect a 50% decline, while 10 of the 15 surveys (66.7%) had the power to detect a 75% decline (Table 9). Figure 7 illustrates an example of statistical power and the number of MGWRs sampled.

For surveys where MGWRs were sampled twice in a winter, statistical power to detect a change or decline was achieved less often. Repeated flights in the Chilliwack Natural Resource District in February and March 2010 had one of the five MGWRs with enough power to detect a 50% decline, while four of the five MGWRs had the power to detect a 75% decline at $\alpha = 0.20$ (Table 10).

In the Sea to Sky District, six of the 16 MGWRs (40%) sampled in 2016 had the power to detect a 50% change (increase or decrease, two-tailed) and eight out of the 16 GWRs (half) had the power to detect a 75% change (increase or decrease) at $\alpha = 0.20$ (Table 11). At $\alpha = 0.10$, only four and five of the 16 MGWRs sampled (25% and 31%) had the power to detect a change (increase or decrease) at 50% and 75% declines (Table 12). For detecting declines, eight and five of the MGWRs (50% and 31%) had the power to detect a 50% decline at $\alpha = 0.20$ and 0.10, and 11 and eight of the MGWRs (69% and 50%) had the power to detect a 75% decline (Table 11).

Similar results in the 2017 Sea to Sky surveys were observed, where nine of the 20 MGWRs (45%) had the power to detect a 50% change (increase or decrease, two-tailed) and 10 out of the 20 MGWRs (half) had the power to detect a 75% change (increase or decrease) at $\alpha = 0.20$ (Table 12). At $\alpha = 0.10$, only four and five of the 16 MGWRs sampled (25% and 31%) had the power to detect a change (increase or decrease) at 50% and 75% declines (Table 13). For detecting declines, 11 and nine of the GWRs (55% and 45%) had the power to detect a 50% decline at $\alpha = 0.20$ and 0.10, 12 and 10 (60% and 50%) of the GWRs had the power to detect a 75% decline (Table 12).

__Table 9.__ Linear density, variance, and statistical power for mountain goat winter ranges (MGWRs) sampled from 2008-2017 in all study areas. Values in bold have adequate statistical power to detect changes in abundance (50%-75% declines) in a predefined landscape

Area surveyed*	Year	Mean goats/km in MGWR	CV (%)	Sample size (n)[1]	Power (α = 0.20) two-tail		Power (α = 0.10) two-tail		Power (α = 0.20) one-tail		Power (α = 0.10) one-tail	
					Δ 50%	Δ 75%	Δ 50%	Δ 75%	Δ 50%	Δ 75%	Δ 50%	Δ 75%
Skagit	2008 (Jan)	0.64	115.8%	13	0.58	**0.83**	0.42	0.70	0.75	**0.92**	0.58	**0.83**
Chilliwack	2008 (Mar)	0.71	90.8%	6	0.48	0.70	0.32	0.53	0.68	**0.86**	0.48	0.71
Chilliwack	2009 (Apr)	0.58	91.2%	10	0.65	**0.90**	0.49	0.79	**0.81**	**0.96**	0.65	**0.90**
Sunshine Coast	2009 (Feb)	4.4	53.8%	25	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**
Chilliwack	2010 (Feb)	1.04	54.1%	7	**0.84**	**0.98**	0.7	**0.94**	**0.94**	**1.0**	0.84	**0.98**
Chilliwack	2010 (Mar)	0.99	64.7%	7	0.74	**0.94**	0.57	0.85	**0.88**	**0.98**	0.74	**0.94**
Skagit	2012 (Mar)	0.38	100.5%	13	0.4	0.6	0.26	0.45	0.58	0.77	0.4	0.61
Sea to Sky (Elaho)	2016 (Feb)	2.6	60.8%	7	0.76	**0.96**	0.60	**0.88**	**0.89**	**0.99**	0.76	**0.96**
Sea to Sky (Elaho)	2016 (Mar)	2.0	69.7%	8	0.73	**0.94**	0.57	0.86	**0.87**	**0.98**	0.73	**0.94**
Sea to Sky (Upper Lillooet)	2016 (Feb)	3.3	53.4%	8	**0.89**	**0.99**	0.77	0.97	**0.96**	**1.0**	**0.89**	**0.99**
Sea to Sky (Upper Lillooet)	2016 (Mar)	7.4	52.0%	8	**0.96**	**1.0**	**0.91**	**1.0**	**0.99**	**1.0**	**0.96**	**1.0**
Sea to Sky (Elaho)	2017 (Feb)	5.0	94.6%	7	0.48	0.72	0.33	0.57	0.66	**0.86**	0.48	0.72
Sea to Sky (Elaho)	2017 (Mar)	3.4	66.5%	10	0.56	**0.81**	0.40	0.67	0.74	**0.92**	0.56	0.81
Sea to Sky (Upper Lillooet)	2017 (Feb)	11.7	65.9%	11	0.63	0.88	0.47	0.77	**0.80**	**0.95**	0.63	0.88
Sea to Sky (Upper Lillooet)	2017 (Mar)	6.5	42.7%	8	**0.96**	1.0	**0.90**	**1.0**	**0.99**	**1.0**	**0.96**	**1.0**

*The subset of MGWRs sampled (see Methods)

[1]Sample size *n* = number of MGWRs

Table 10. *Linear density, variance, and statistical power for repeated flights (n = 2) of mountain goat winter ranges (MGWRs) sampled in the Chilliwack Natural Resource District, February, and March 2010. Values in bold have adequate statistical power*

MGWR	Mean goats/ km	CV (%)	No. of flights	Power (α = 0.20) two-tail		Power (α = 0.10) two-tail		Power (α = 0.20) one-tail		Power (α = 0.10) one-tail	
				Δ 50%	Δ 75%	Δ 50%	Δ 75%	Δ 50%	Δ 75%	Δ 50%	Δ 75%
MA-2 / SH-4	1.71	30.2%	2	0.53	0.72	0.28	0.41	0.83	**0.96**	0.53	0.72
SH-1	0.41	74.9%	2	0.42	0.59	0.22	0.32	0.72	**0.88**	0.42	0.59
SH-5	0.68	40.9%	2	0.25	0.35	0.13	0.18	0.46	0.61	0.25	0.35
SH-6	0.92	30.04%	2	0.41	0.57	0.21	0.31	0.70	**0.87**	0.41	0.57
SH-7	0.68	39.2%	2	0.53	0.72	0.28	0.41	**0.83**	**0.96**	0.53	0.72

Table 11. *Linear density, variance, and statistical power for repeated flights (n = 2) of mountain goat winter ranges (MGWRs) sampled in the Sea to Sky Natural Resource District, February and March 2016. Values in bold have adequate statistical power*

MGWR	Mean goats/km	CV (%)	No. of flights	Power (α = 0.20) two-tail		Power (α = 0.10) two-tail		Power (α = 0.20) one-tail		Power (α = 0.10) one-tail	
				Δ 50%	Δ 75%	Δ 50%	Δ 75%	Δ 50%	Δ 75%	Δ 50%	Δ 75%
07	3.54	12.3%	2	**1.0**	**1.0**	**0.92**	**0.99**	**1.0**	**1.0**	**0.92**	**0.99**
30	2.50	110.0%	2	0.20	0.36	0.10	0.13	0.38	0.48	0.20	0.26
31	1.61	20.2%	2	0.72	**0.89**	0.42	0.58	**0.96**	**1.0**	0.72	**0.89**
26	3.10	54.4%	2	0.32	0.46	0.17	0.24	0.58	0.75	0.32	0.46
25	3.15	66.6%	2	0.28	0.38	0.14	0.20	0.51	0.66	0.28	0.38
57	0.57	70.7%	2	0.27	0.37	0.14	0.19	0.50	0.64	0.27	0.37
58	2.27	42.4%	2	0.40	0.56	0.21	0.30	0.69	**0.86**	0.40	0.56
40	1.45	15.7%	2	**0.84**	**0.96**	0.52	0.71	**0.99**	**1.0**	0.83	**0.96**
ME 3	7.34	34.6%	2	0.47	0.66	0.25	0.37	0.77	**0.93**	0.47	0.66
ME 2	4.94	0.00%	2	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**
ME 4	9.62	84.5%	2	0.23	0.32	0.12	0.16	0.44	0.56	0.23	0.31
UL10	3.70	0.0%	2	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**
UL11	5.95	47.1%	2	0.36	0.51	0.19	0.28	0.64	**0.81**	0.36	0.51
UL8	11.18	20.2%	2	0.72	**0.90**	0.42	0.59	**0.96**	**1.0**	0.72	**0.90**
RA7	3.98	3.3%	2	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**
RY8	7.80	3.7%	2	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**

Table 12. *Linear density, variance, and statistical power for repeated flights (n = 2) of mountain goat winter ranges (MGWRs) sampled in the Sea to Sky Natural Resource District, February and March 2017. Values in bold have adequate statistical power*

MGWR	Mean goats/ km	CV (%)	No. of flights	Power (α = 0.20) two-tail		Power (α = 0.10) two-tail		Power (α = 0.20) one-tail		Power (α = 0.10) one-tail	
				Δ 50%	Δ 75%	Δ 50%	Δ 75%	Δ 50%	Δ 75%	Δ 50%	Δ 75%
07	2.46	40.7%	2	0.41	0.58	0.22	0.32	0.70	**0.88**	0.41	0.58
26	6.67	10.9%	2	**0.96**	**1.0**	0.69	0.87	**1.0**	**1.0**	**0.96**	**1.0**
66	14.21	113.1%	2	0.19	0.25	0.10	0.13	0.37	0.47	0.19	0.25
25	3.33	17.7%	2	**0.79**	**0.94**	0.47	0.66	**0.98**	**1.0**	**0.79**	**0.94**
58	0.23	0.0%	2	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**
40	1.61	141.4%	2	0.17	0.22	0.10	0.11	0.33	0.41	0.17	0.22
41	0.54	141.4%	2	0.17	0.22	0.10	0.11	0.33	0.41	0.17	0.22
56	0.0	0.0%	2	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**
39	0.0	141.4%	2	0.17	0.21	0.10	0.11	0.40	0.61	0.21	0.35
ME 2	10.49	8.3%	2	**0.99**	**1.0**	**0.82**	**0.96**	**1.0**	**1.0**	**0.99**	**1.0**
ME 3	7.78	51.7%	2	0.34	0.48	0.17	0.25	0.60	0.78	0.34	0.48
ME 4	17.31	91.4%	2	0.22	0.30	0.11	0.15	0.42	0.54	0.22	0.30
UL10	3.89	6.7%	2	**1.0**	**1.0**	**0.90**	**0.99**	**1.0**	**1.0**	**1.0**	**1.0**
UL11	10.32	87.0%	2	0.23	0.31	0.12	0.16	0.43	0.56	0.23	0.31
UL12	0.18	141.4%	2	0.17	0.22	0.10	0.11	0.34	0.41	0.17	0.22
UL13	0.0	0.0%	2	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**
UL19	0.81	0.0%	2	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**
UL8	7.35	0.0%	2	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**
RY8	6.16	28.3%	2	0.63	**0.82**	0.35	0.50	**0.86**	**0.97**	0.56	0.75
RY7	9.63	24.5%	2	0.56	0.74	030	0.44	**0.91**	**0.99**	0.63	**0.82**

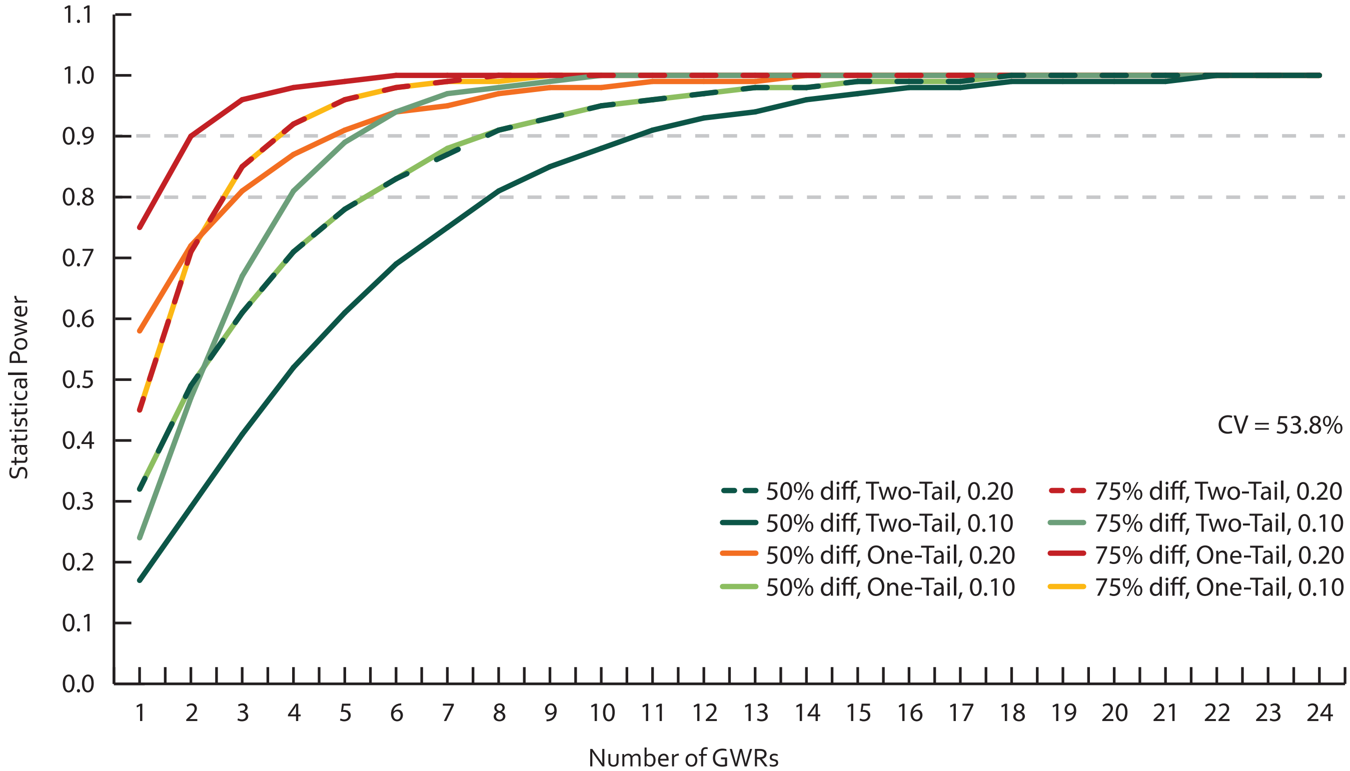

Figure 7. *An example of statistical power for α = 0.10 and 0.20 and the number of mountain goat winter ranges (MGWRs) sampled using the 2009 Sunshine Coast data*

Table 13. *A comparison of the variance (coefficient of variation [CV]) between the linear density and raw counts (numbers of goats + tracks) for all surveys. Bold values indicate a lower variance*

Area surveyed	Year	*LD* (mean goats/km)	CV (%)	Mean goats + tracks[1]	CV (%)
Skagit	2008 (Jan)	0.64	**115.8%**	6.8	118.1%
Chilliwack	2008 (Mar)	0.71	**90.8%**	8.7	105.9%
Chilliwack	2009 (Apr)	0.58	91.2%	5.9	**73.4%**
Sunshine Coast	2009 (Feb)	4.4	**53.8%**	19.4	89.9%
Chilliwack	2010 (Feb)	1.04	**54.1%**	19.4	102.6%
Chilliwack	2010 (Mar)	0.99	**64.7%**	18.1	117.5%
Skagit	2012 (Mar)	0.38	**100.5%**	4.9	144.7%
Sea to Sky (Elaho)	2016 (Feb)	2.6	**60.8%**	7.3	121.1%
Sea to Sky (Elaho)	2016 (Mar)	2.0	**69.7%**	6.4	112.2%
Sea to Sky (Upper Lillooet)	2016 (Feb)	3.3	**53.4%**	23.4	88.2%
Sea to Sky (Upper Lillooet)	2016 (Mar)	7.4	**52.0%**	16.2	88.7%
Sea to Sky (Elaho)	2017 (Feb)	5.0	**94.6%**	9.2	100.6%
Sea to Sky (Elaho)	2017 (Mar)	3.4	**66.5%**	7.1	131.9%
Sea to Sky (Upper Lillooet)	2017 (Feb)	11.7	**65.9%**	23.7	92.1%
Sea to Sky (Upper Lillooet)	2017 (Mar)	6.5	**42.7%**	16.5	110.6%

[1]Not corrected for distance

In some cases, between survey discrepancy was quite high. Surveys in the Chilliwack Natural Resource District had differences between successive LD surveys ranging from 25.3% to 33.2%, while 2017 counts in the Sea to Sky District deviated by 43.5% and 43.8%, respectively (Table 14). The 2016 surveys in the Sea to Sky District had a much lower between survey variation of 14.8% and 18.7% (Table 14).

Table 14. *Between year and within season differences (paired) in linear density (LD) of mountain goats surveyed in the Chilliwack (CHWK) and Sea to Sky (S2S) Natural Resource Districts*

Area surveyed	District	Year	Mean *LD* (goats per km)	SD	Difference between surveys (%)
Skagit	CHWK	2008	0.64	0.75	-33.2%
Skagit	CHWK	2012	0.43	0.37	
Silver Hope	CHWK	Mar 2008	0.71	0.65	-25.3%
Silver Hope	CHWK	Mar 2009	0.53	0.53	
Silver Hope	CHWK	Feb 2010	1.03	0.63	-29.2%
Silver Hope	CHWK	Mar 2010	0.73	0.43	
Elaho	S2S	Feb 2016	2.18	1.67	-14.8%
Elaho	S2S	Mar 2016	1.86	1.48	
Upper Lillooet	S2S	Feb 2016	6.23	3.33	+18.7%
Upper Lillooet	S2S	Mar 2016	7.40	3.84	
Elaho	S2S	Feb 2017	3.17	4.69	-43.8%
Elaho	S2S	Mar 2017	1.78	2.08	
Upper Lillooet	S2S	Feb 2017	8.59	8.38	-43.5%
Upper Lillooet	S2S	Mar 2017	4.85	3.70	

Demographics

The kid:adult ratios varied between surveys and years. Kid:adult ratios were low in the Chilliwack District in March 2010. Repeated surveys in the Sea to Sky District in 2016 and 2017 were consistent between surveys (Table 15). The Upper Lillooet study area had approximately double the kid:adult ratio than did the Elaho study area (Table 15). Overall, kid:adult ratios were moderate in the Sunshine Coast, Chilliwack (February 2010), Upper Lillooet (February 2016, February and March 2017), Elaho (March 2016), and high in the Upper Lillooet (March 2016) and the Skagit (2008 and 2012), although the surveys in the Skagit had low sightability and small sample size (Table 15).

The Kaplan-Meier survivorship was poor, with cumulative estimates of 0.65 for adult females and 0.55 for males (Table 16). The overall survivorship for this sample of collared adult goats is 0.60.

All collared mountain goat mortalities occurred within or close to (<1 km) the legally designated and mapped winter ranges (Figure 8). Of the 12 mortalities, nine (75%) occurred <1 km from the mapped winter ranges, two within a protected area, and one migrating to a winter range. Most mortalities (86.7%) occurred during the autumn and winter (Figure 9).

Table 15. *Age, sex, and number of mountain goats observed during winter range flights, 2008-2017*

Area and survey	Age and sex						
	Nanny	Billy	Adult unknown	Juvenile	Kid	Total	Kid: adult
Sunshine Coast							
2009	6	1	8	5	6	26	0.30
Chilliwack							
2010 (Feb)	3	2	3	-	2	10	0.25
2010 (Mar)	-	2	16	2	1	21	0.050
Skagit							
2008	4	1	-	2	4	11	0.57
2012	1	-	1	-	1	3	0.50
Sea to Sky							
2016 (Feb) Elaho	6	-	15	4	3	28	0.14
2016 (Mar) Elaho	6	-	33	3	9	51	0.23
2016 (Feb) Upper Lillooet	36	1	57	22	28	144	0.30
2016 (Mar) Upper Lillooet	41	1	35	7	36	120	0.47
2017 (Feb) Elaho	3	-	21	-	4	29	0.17
2017 (Mar) Elaho	3	-	34	2	5	44	0.14
2017 (Feb) Upper Lillooet	21	1	61	-	30	113	0.36
2017 (Mar) Upper Lillooet	18	3	82	1	27	131	0.26

Table 16. *Mountain goat Kaplan-Meier cumulative survivorship (S_t) of 31 adults, 21 females and 10 males, 2018-2021*

Sex	N	S(t)	95% CI
Female	21	0.65	0.40-0.81
Male	10	0.56	0.20-0.80
Total	**31**	**0.60**	**0.40-0.75**

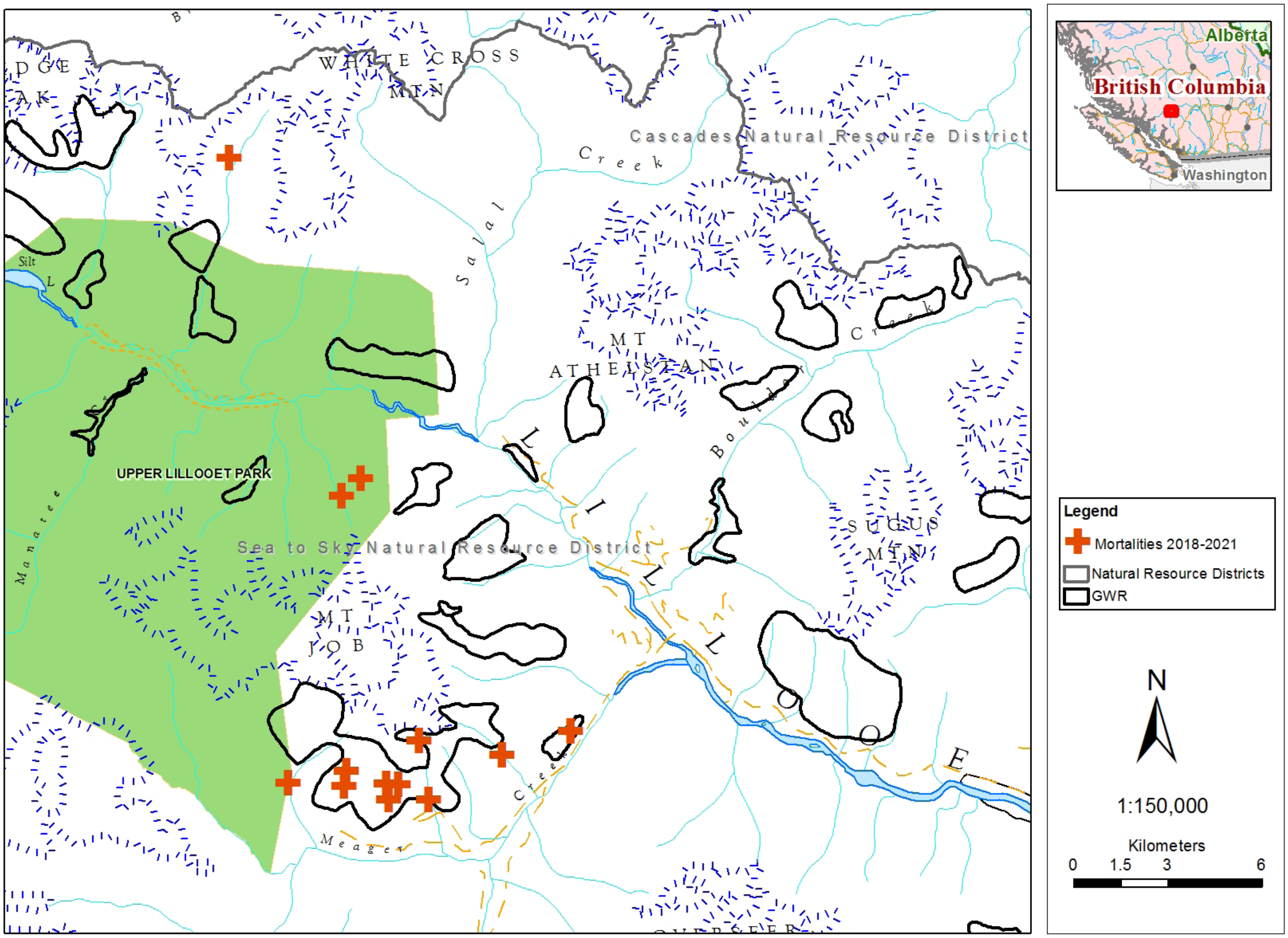

Figure 8. *Locations of all mountain goat mortalities relative to the legally designated and mapped winter ranges in the South Coast*

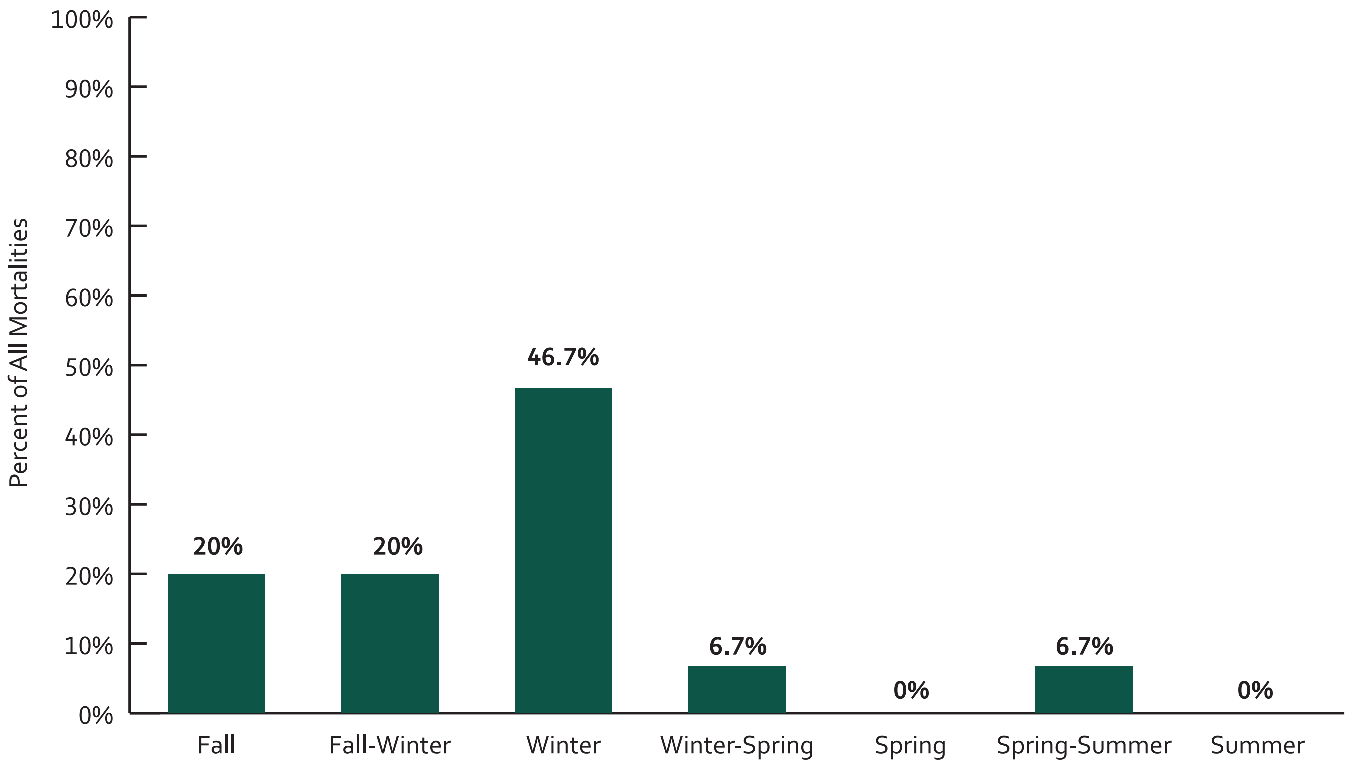

Figure 9. *The percent of all mortalities by season in which the mortalities occurred*

Mountain Goat Use of Winter Ranges

For winter use, 71.1% (*n* = 8,667) of the female mountain goat locations were within legally designated and protected winter ranges (Table 17). Approximately 22.2% (n = 1,921) occurred outside of MGWRs and provincial parks, while 6.8% occurred within parks (Table 17). During summer female goats showed less use of the MGWRs, where 56.3% (*n* = 4,727) of the locations are in legally designated and protected MGWRs, while 36.4% occurred outside of MGWRs and parks (Table 17). Male mountain goats were strongly associated with legally designated and protected winter ranges, where 85.2% (*n* = 3,037) occurred within winter ranges boundaries, while 4.6% (*n* = 165) were located within parks and 10.2% (*n* = 363) outside of MGWRs and parks (Table 18). Summer locations of male mountain goats were predominantly outside of the winter ranges and parks, where 51.8% (*n* = 1,612) were outside of these areas, while 37.4% (n = 1,163) and 10.7% (n = 334) of the locations occurred within MGWRs and parks, respectively (Table 18). Figure 10 illustrates the winter space use within and adjacent to a legally designated UWR.

Table 17. *The number of GPS locations for 15 female mountain goats and the number of locations in mapped mountain goat winter ranges (MGWRs), parks, and unprotected Crown land areas during winter and summer (November 1, 2018 to October 31, 2021)*

	Winter 2018-2021		Summer 2019-2021	
Location of points	No. of locations	% of total	No. of locations	% of total
Within MGWRs	6,160	71.1%	4,727	56.3%
Within parks	586	6.8%	619	7.4%
Outside of parks & MGWRs	1,921	22.2%	3,055	36.4%
Total locations	8,667	100.0%	8,401	100.0%

Table 18. *The number of GPS locations for the 11 male mountain goats collared in 2019 and the number of locations in mapped mountain goat winter ranges (MGWRs), parks, and unprotected Crown land areas during winter and summer (November 1, 2018 to October 31, 2021)*

	Winter 2018-2021		Summer 2019-2021	
Location of points	No. of locations	% of total	No. of locations	% of total
Within MGWRs	3,037	85.2%	1,163	37.4%
Within parks	165	4.6%	1,612	51.8%
Outside of parks & MGWRs	363	10.2%	334	10.7%
Total locations	3,565	100.0%	3,109	100.0%

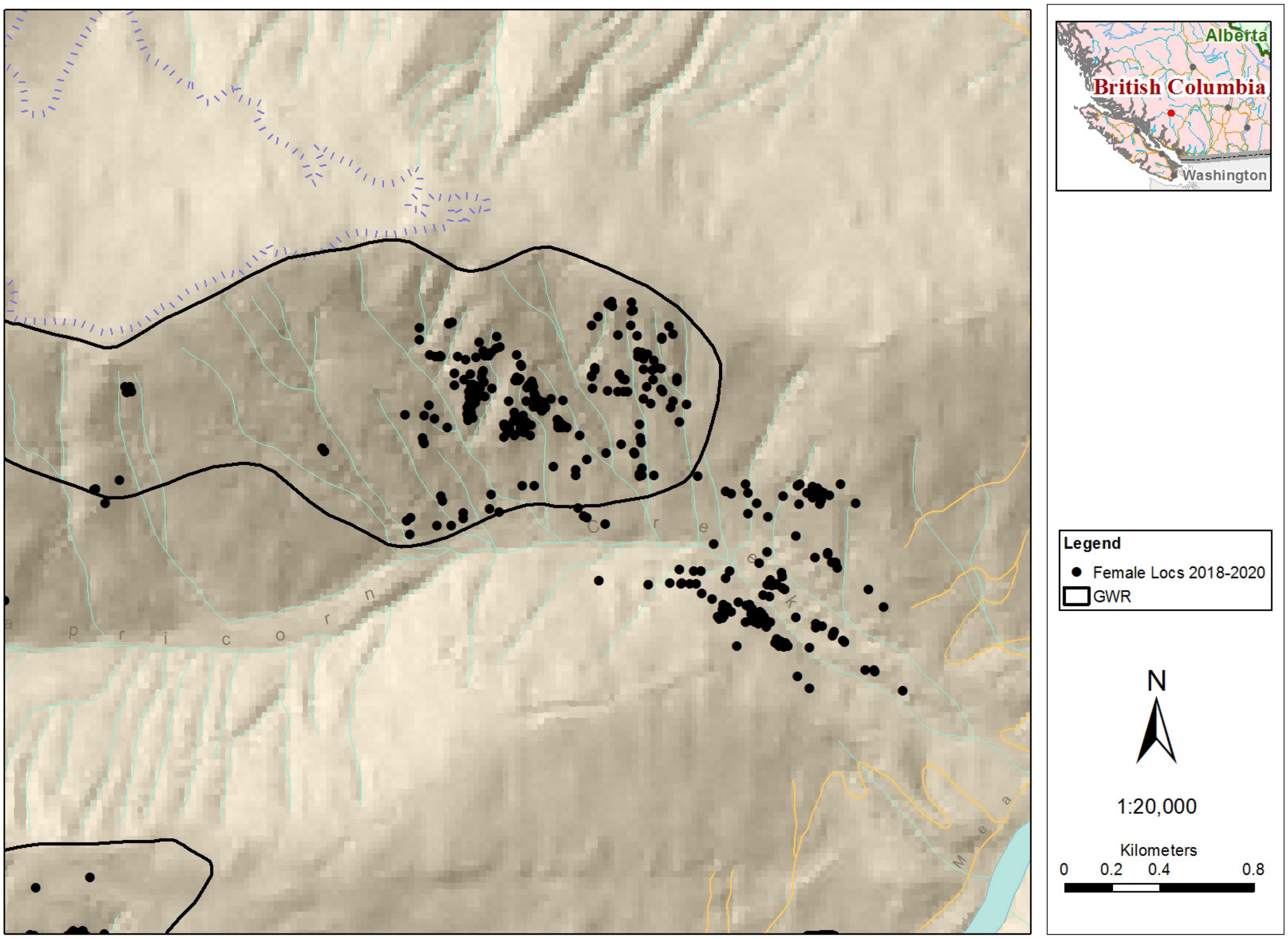

Figure 10. *An example of female mountain goat GPS collar locations obtained (2018-2020 winters) in relation to a designated mountain goat winter range (MGWR) polygon*

DISCUSSION

These analyses evaluated various metrics that can be used for effectiveness monitoring associated with mountain goat use of designated MGWRs in coastal ecosystems. Standard winter range surveys can generate several metrics that are useful in answering some key management questions, and when available, telemetry data can be used to further expand the scope of management questions that can be addressed. Winter range surveys, which collect information on the number of goats by age class and sex, number of tracks, and the distance sampled in each winter range will allow biologists to calculate metrics useful in evaluating not only mountain goat use of these winter ranges, but also an understanding of population trends. If available, telemetry data can provide additional metrics to evaluate the effectiveness of winter ranges, including spatial use, habitat use, and survivorship.

Winter Aerial Surveys: Abundance Measures

Winter aerial surveys of mountain goats provided five metrics for monitoring:

1. Linear density (goats/km of survey transect),
2. Goat density (goats/km^2 of survey transect/winter range area),
3. Goat counts (uncorrected) and track counts (uncorrected, estimated),
4. Detection and occupancy probabilities (presence/not detected with >one survey), and
5. Kid:adult ratios.

Linear densities are a measure of relative abundance, which is highly correlated to population size (RIC 1998). Where indices highly correlate with population abundance they can be used to evaluate population trend (Caughley 1977; RIC 1998; McKelvey and Pearson 2001; Engeman 2003; Johnson 2008). Johnson (2008) defined an index based on Caughley (1977) as *a variable that correlates strongly with abundance or density of a species in an area*, and in many cases, may be the most efficient and cost-effective method to assess population change (Engeman 2003). While the use of indices is debated in the scientific literature (Anderson 2001), they may be an adequate surrogate for absolute counts or to minimally describe qualitative observations considered during the formation of expert opinion on trends. Stronger correlations were found between combined goats and track counts and goat abundance without standardizing by linear sampling distance. However, this metric has a much higher variance than does the *LD*.

In the case of goats in coastal ecosystems, *LD* was used as it integrates the number of tracks, which is informative for MGWRs where goats are not sighted.. It is a continuous variable that can be monitored over time.

Across multiple surveys, a positive (in some cases significant) correlation was found between goat abundance (*LD*, number of goats, number of tracks, goats plus tracks) and MGWR size. There is empirical and theoretical evidence which demonstrates that animal population density is positively correlated with patch size (Bender et al. 1998; Connor et al. 2000; Bowman et al. 2002).

As with the *LD*, differences in mountain goat population size are also reflected in the goat densities. The *LD* correlates strongly with goat densities, and the *LD* and densities mirror each other when surveys from all three districts are compared.

Estimates of winter mountain goat densities in this report using South Coast data generally align with those from other studies. In Southeast Alaska, Fox (1984) found an average density of 1.3 goats per km^2, with a range from 0.5 to 4.7 goats per km^2. Similarly, Smith and Bovee (1984) found that goat densities were 4.4 and 2.3 goats per km^2 on winter range and year-round habitats respectively, in coastal Alaska. Fox (1984) summarized that reported goat densities vary between 0.03 per km^2 to 14 per km^2 in Southeast Alaska. Jessen et al. (2022) summarized coastal mountain goat densities in British Columbia, which averaged 0.45 goats per km^2. It must be noted that the scale for which densities are estimated is a major factor, as summer densities are generally lower because animals are not constrained to habitats with winter range characteristics (see Nietvelt et al. 2022).

In this analysis using South Coast data, densities on individual MGWRs ranged from <0.14 to 19.6 goats per km^2. However, densities are calculated for goats on the legally mapped winter ranges rather than all available habitat, which likely yields higher density estimates than reported elsewhere. Goat densities do vary seasonally, and summer density estimates are typically lower (goats having large home ranges in the summer as they are not as restricted by deep snow) (Taylor et al. 2006; Nietvelt et al. 2020a and b; 2022). Overall, there is variation on how biologists have calculated mountain goat densities, and season and estimates of habitat can change these results and only serve as a relatively crude comparison (see Smith and Bovee 1984).

Detection and Occupancy

Mountain goat detection was <100% between 2008 and 2012 in the Skagit River watershed and Chilliwack Natural Resource District. Goats are more likely to be present but not detected where population densities are low. Some surveyed winter ranges in the Sea to Sky District were impacted by wildfire, and those with ≥75% % of the forest burned had no or low detection (Nietvelt et al. 2018). Surveys conducted in the Chilliwack (2010 February and March) and the Sunshine Coast Districts had 100% detection.

Detection and occupancy should *not* be the sole focus of any mountain goat survey. For monitoring purposes, biologists should understand mountain goat densities within and across the target survey areas, and sampling stratification decisions should be consistent to facilitate meaningful comparisons across space and time.

While estimating mountain goat abundance can be challenging, the detection of mountain goats is *not* a challenge in suitable habitat (Rice et al. 2009). Occupancy surveys were designed for species where detection is less than perfect, and multiple site visits are required in one season to calculate detection probabilities (MacKenzie et al. 2002). The detection probability may also serve as a surrogate for changes in abundance (MacKenzie et al. 2002). In most goat surveys, winter ranges are flown once, and while presence can be established, *absence cannot* (McKenzie 2005a). Therefore, an estimate of occupancy *cannot* be established from winter ranges that are only inventoried *once* in a season (MacKenzie et al. 2002). Single surveys yield "presence/not detected" information, and do not permit estimates of occupancy (RISC 2002; Gu and Swihart 2004). Occupancy modelling might be useful if areas have impacted by a major perturbation or disturbance are expected to have resulted in range avoidance or abandonment and may compliment relative and or absolute abundance measures where densities are low.

Sightability

Sightability of mountain goats (animals) was poor in the Skagit, Chilliwack, and Sunshine Coast study areas. Low sightability was documented previously by Jex (2007b), Nietvelt et al. (2010), and Nietvelt (2012) in the Chilliwack Forest District in both winter and summer. In the Skagit and Chilliwack, low sightability is likely due to high forest cover, which range between 85.1% to 91.8% in those MGWRs. A negative correlation was found between the percent of winter ranges that were forested versus the percent of winter range where goats were sighted. This was also likely confounded by lower mountain goat densities in these areas (Kelly and Reynolds 2016).

Sightability of mountain goats in general can be problematic regardless of the ecosystem and time of year for multiple reasons (Poole 2007; Rice et al. 2009). Rice et al. (2009) found that sightability during aerial summer surveys was most affected by group size, terrain obstruction, and vegetation cover in the North Cascades of Washington. However, these authors determined that group size was the key factor affecting sightability. Rice et al. (2009) also found that terrain obstruction (e.g., crevasses, caves, overhanging ledges, and other rock formations) was second to group size in determining sightability. Goats were observed seeking cover in terrain features in response to survey disturbance. Vegetation obstruction was not as strong of a covariate as either group size or terrain obstruction because individuals were commonly found in areas with sparse vegetation. This contrasted greatly to the South Coast study areas, where winter habitats are characterized by high forest cover. Mountain goats may also seek thermal refugia like caves or mature forest even in the absence of survey disturbance as was observed in some Alaska surveys (Fox 1978).

While not always feasible, some biologists have found that ground counts are more accurate, providing higher numbers than aerial counts. For example, Fox (1984) found that summer ground counts in Southeast Alaska were very consistent and resulted in higher estimates (32% more) than aerial surveys. In this case ground surveyors walked ridge lines and sampled for ~18 hours per day which is more intensive than aerial counts conducted used a fixed-wing aircraft. In contrast, Foster (1982) found that ground surveys resulted in only half (50%) of the total count of mountain goats as compared to aerial surveys using a fixed wing aircraft. Generally, Côté and Festa-Bianchet (2003: 1071) suggest that ground surveys should be conducted where possible, as they are more precise than aerial surveys overall. McDevitt et al. (2021) extended the idea of ground counts further by using a ground-based survey accompanied by a spatially balanced random sample to estimate the abundance of an unmarked, low-density population of mountain goats. These authors developed a novel analytical approach that gives an abundance estimate without bias.

When possible, ground surveys should be incorporated into a sampling design, even if for a small portion of the total number of winter ranges. In areas where goat winter ranges are accessible and visible from the ground multiple counts and more precise classification by age and sex are possible.

Variance and Statistical Power

The *LD* had lower variance than metrics such as goats plus tracks (not standardized by distance or area), despite the latter having a strong correlation with MGWR and forest patch size. The *LD* will have greater power to detect change as it is a standardized metric. The goats plus tracks metric may have higher variance owing to observer bias in counting tracks because sightability of mountain goats in coastal ecosystems is sometimes low.

Variance influences power to detect change (increase or decrease) as does the number of winter ranges sampled. Five of the 15 surveys had coefficients of variation >90%. However, the power to detect declines on a survey scale *is* possible where variance is high as shown here with lower power ($\alpha = 0.20$). Since *LD* and ultimately the number of goats does correlate to MGWR size, one could stratify MGWRs and calculate the *LD* or abundance by size class, which will lower the variance and increase statistical power.

Where two flights per season are conducted on the same winter range adequate power is sometimes achievable to reasonably detect local changes in population size. The repeated flights in the Chilliwack Natural Resource District only had one MGWR with adequate power with a 50% decline, while four of the five MGWRs (80%) had adequate power with a 75% decline. Repeated surveys in the Sea to Sky Natural Resource District had a much greater number of winter ranges that had adequate power. These are associated with a very low variance with CVs in the 20% range or less.

Due to problems in sightability, variability of mountain goat densities within a sampling season has also been observed in other studies. Poole (2007) found that densities varied considerably for repeated summer surveys for an interior ecotype with sightability greater than most coastal ecosystems.

While one-tailed tests with $\alpha = 0.20$ can cause Type I error [and the perception of population decline where it is in fact stable (Gerrodette 1987)], these risks are often outweighed by the management consequences of failing to detect a concerning trend. Consider a winter range with good previous sightability and an estimated 20 goats, but after multiple subsequent surveys using similar effort and timing (e.g., fall or spring surveys), only six goats are detected. It would be safe to assume this winter range has experienced a decline.

Conducting a power analysis using pilot or previous inventory data will help design long-term monitoring schemes that detect change across several winter ranges. This is a key step for anticipating how variable results can be, and for improving monitoring methods.

Demographics

Kid:adult ratios provide standardized productivity and recruitment estimates. For winter surveys, (February-March), kid:adult ratio is a reliable indicator of potential recruitment into the population, although mortalities of kids can still occur up to parturition [late May-early June (see Festa-Bianchet et al. 1994).] Spring and/or summer surveys in contrast will give some insight to productivity (Festa-Bianchet et al. 1994). Therefore, surveys could be conducted in the summer and then in the subsequent late-winter or early spring to calculate both winter mortality and potential recruitment.

Kid:adult ratios are useful when the mountain goat population is declining [i.e., the kid:adult ratio is low (e.g., < 20)], whether considered on a particular winter range or at a broader population scale. This may indicate there is an issue with low kid recruitment and/or productivity, versus declines driven by reduction in adult survival. Declines in kid production is shown to be negatively correlated with winter severity during pregnancy (Adams and Bailey 1982; Swenson 1985); April-May snowfall and snow depth (Thompson 1980; Hopkins et al. 1992); predation; and even as a response to predation risk and stress (Dulude-de Broin et al. 2019).

In other ungulates, declines in young:female/adult ratios can also be influenced by human disturbance. In North Dakota, Wiedmann and Bleich (2014) found that recreational hiking resulted in a substantial negative trend in recruitment rate, and a decline in abundance of female bighorn sheep (*Ovis canadensis*) in that natal range area. Similarly, Phillips and Alldredge (2000) studied the effects of backcountry hiking on elk during the calving season in Colorado. These authors found a linear decrease in calf production with increasing levels of human disturbance. In a follow-up study, Shively et al. (2005) studied elk calf production after the removal of disturbance and found that production returned to pre-disturbance levels.

Adult survivorship is also a key metric that obtained from radio collared goats. Data from collared male and female goats (Nietvelt et al. 2020a and b; and 2022) revealed a cumulative survivorship estimate of 0.60 combined; 0.65 for females and 0.56 for males. These estimates are extremely low when compared to other areas. In Coastal Alaska, White et al. (2011) found that adult female survivorship was >0.80 for yearlings to adults, and 0.718 for females 9+ years old. Male survivorship was similar for yearlings to adults, and males 9+ years had a much lower survivorship of only 0.607. Low adult survival may indicate a declining population and warrants further investigation into the causes of mortality and potential mitigation measures to prevent declines (Lehman et al. 2020). Recruitment and survivorship information can be used together to calculate a population trend metric, lambda (λ). A simple way to calculate λ is from Hatter and Bergerud (1991) using the *R/M* equation (see Appendix 1 for calculations).

All mountain goat mortalities in the Meager study occurred within 1 km of the mapped designated winter ranges (Nietvelt et al. 2022). Most of these occurred during the autumn and winter months when goats are on their winter ranges. Given the high seasonal fidelity to the winter habitat (see Use of Winter Ranges) and the smaller winter home ranges sizes (~1.0 km^2; Nietvelt et al. 2022) when mountain goats are most restricted and vulnerable, winter mortalities are of concern. Mortality locations are best used to understand correlates of mortality and to development mitigation measures such as greater setbacks for helicopter and recreational disturbance (e.g., heli-logging, heli-skiing, snowmobiling), reducing human access, and conserving the amount and composition of forested security cover within MGWRs.

Use of Winter Ranges

Female and male mountain goats had a high fidelity to winter habitat and >50% of GPS collar locations were within the mapped designated winter ranges (see Nietvelt et al. 2022). Female use of the mapped winter ranges did not differ between summer and winter. Male use of the mapped winter ranges during winter was extremely high (>80%), while in summer males dispersed and only 34% of locations were in the mapped winter range polygons. It was apparent that female goats used areas outside of the identified winter ranges in both winter and summer. Taylor and Brunt (2007) found that female goats demonstrated high fidelity to winter ranges in coastal British Columbia, similar to Nicholas (1985) who found that female goats in Alaska also returned to their respective winter ranges.

Telemetry data provides an understanding of resource use by mountain goats. This information can aid in the modification of existing MGWR orders, and/or assist the initial identification, delineation, mapping, and establishment of winter ranges using methods such as resource selection functions (Manly et al. 2002), or simply mapping steep slopes (>40°) with warm aspects using a digital elevation model within GIS software (see Nietvelt et al. 2022).

Factors Affecting Winter Range Effectiveness

Several factors affect winter range effectiveness. Snow interception cover is critical for goats in coastal environments (Taylor and Brunt 2007; Wilson 2005). While snowfall accumulation is significant in coastal environments, the nature of coastal snow (moisture content and composition) and the persistence can also affect habitat use by goats (Hebert and Turnbull 1977; Fox and Smith 1988; Fox et al. 1989; Smith 1994; Gordon and Reynolds 2000). Researchers have found that persistent snow can negatively affect kid survival (Brandborg 1955; Rideout 1974; Smith 1986b; Adams and Bailey 1982). Snow depth can also delay green-up, affecting the timing of new plant growth and overall forage availability (Hebert and Turnbull 1977; Festa-Bianchet and Côté 2008).

Given the importance of snow interception cover for the coastal ecotype of mountain goats, forest removal can dramatically and negatively impact winter range use. Nietvelt et al. (2018) found that intense wildfires that removed trees resulted in a reduction in the number of goats and in the occupancy rate on those winter ranges. These declines could be a result of shifting animals relocating to new winter range and/or of actual population declines driven by reductions in survival or reproduction.

Mountain goats are also easily disturbed by human activity and resource extraction. Mountain goats are highly sensitive to helicopter disturbance, more so than most other species of ungulates (Festa-Bianchet and Côté 2008), with some demographic cohorts showing no tolerance to any sort of human-caused industrial disturbance (Penner 1988). Mountain goats react to helicopter disturbance at distances up to ≥ 1,500 m, and Festa-Bianchet and Côté (2008) recommend that helicopters should not fly within two km of mountain goat habitat. The two km buffer is also recommended by the Northern Wild Sheep and Goat Council (2020), and the BC Mountain Goat Management Plan (Hurley 2004; Mountain Goat Management Team 2010). Festa-Bianchet and Côté (2008) suggest that repeated helicopter flights over an area may result in the abandonment of a range by goats, thus reducing or at a minimum alienating the available habitat (reducing habitat effectiveness). Other disturbances are less well-studied, such as the impacts of forestry, mining, human recreation, and independent power projects (Pendergast and Bindernagel 1977; Foster and Rahs 1983; Joslin 1986). Pendergast and Bindernagel (1977) suspected that coal exploration correlated with a decline in mountain goat populations. These authors could not link the exact mechanism to this decline, but it appeared to be the ease of human access. Joslin (1986) examined changes in the mountain goat population in relation to energy exploration activity. This author and found that an increase in energy exploration activity (e.g., seismic lines) coincided with a decline in adult female numbers, kid numbers, and productivity, with the productivity of females declining significantly ($r = 0.906$) in association with a cumulative increase in seismic activity.

Anthropogenic disturbances can play a large role in animal health. Animal health in this case is not diseases per se, but the stress and disturbance caused by anthropogenic activities, which may lead to poor physical condition, suppressed reproduction, and the use of suboptimal habitats. The effects of human disturbance have been shown in other ungulates such as elk, where calf production decreased due to increased human activity (see Phillips and Alldredge 2000; Shively et al. 2005).

Risk, stress, and breeding suppression in mountain goats has been demonstrated. Dulude-de Broin et al. (2019) found that predation risk had a direct positive effect on the average annual faecal glucocorticoid concentration in the population, and this negatively affected the proportion of reproductive females. This ultimately resulted in breeding suppression of mountain goats in the studied population. It must be considered that observed declines of mountain goats on winter ranges might be linked to stress and disturbance, and this should warrant further investigation.

MONITORING DESIGN

Effectiveness monitoring should adhere to proper experimental protocol. This requires the use of treatments and controls, and, if baseline data are available, a before-after-control-impact (BACI) design (Underwood 1991; Erikson et al. 2004). Treatments could be prescriptive and specific (fine scale) that address impacts that are very localized impacts, or very broad (coarse scale) which is more consistent with a landscape-level effect. Prescriptive treatments could be various anthropogenic or natural influences that can affect mountain goat behaviour and habitat selection which can then provide an evaluation of MGWR effectiveness. These influences and impacts can include logging, wildfire, helicopter disturbance, disease, and winter recreation. At a much broader scale, treatments could also be designed as "disturbed" versus "undisturbed" (e.g., road density, core area function, and landscape permeability or intactness) or between populations impacted by wildfire or disease, provide a passive means of evaluating their influence of goat behaviour, physiology, or vital rates. Table 19 outlines both monitoring schemes.

Table 19. *Examples of specific treatments for mountain goat winter range (MGWR) effectiveness monitoring*

Main treatment effects	
Disturbed	Undisturbed
Treatment descriptions	
• Wildfire • Helicopter activity up to 1,500 m from a winter range • Winter recreation (motorized/non-motorized) • Logging • Road and trail access, density, proportion of unroaded area in watershed	• Disturbance will be minimal • MGWRs should be in the same ecotype for comparison • MGWR size does play a factor in variance

Nietvelt et al. (2018) used a similar study design to examine the impacts of wildfire on mountain goats in winter ranges. However, like any natural experiment (see Sagarin and Pauchard 2009), the treatments (amount burned), were along a gradient rather than an absolute level of change/impact (i.e., burned, or unburned). That study was informative as the authors found that mountain goat abundance was strongly correlated to residual forest patch size (a surrogate of the functional core area reflecting availability of food and snow interception cover). In other words, the higher percentage of the winter range area that was burned, the lower the abundance of mountain goats using the area.

Future work and pilot studies may include:

1. Comparing summer range surveys and winter range surveys for total counts and kid:adult ratios, and
2. Comparing the results from winter range surveys from the ground versus aerial flights.

SUMMARY AND FUTURE DIRECTION

This report evaluates common metrics used for effectiveness monitoring of MGWRs in coastal ecosystems that go beyond "presence/not detected". Current RISC (2002) standards state:

> *Winter surveys, unless to determine seasonal distribution, are not recommended because of difficulties related both to habitat selection and the cryptic aspects of white animals on a white background.*

Current standards recommend different methods for different population metrics or biogeoclimatic zones (Table 20). While many other ungulate species, such as elk, are surveys conducted in winter, mountain goats in coastal ecosystems typically have population inventories conducted in late summer or in the fall (Table 20). While some of these surveys may have a higher total count, which is useful for setting harvest allocations, surveys conducted at these times of the year do not address some of the questions that pertain to the function and effectiveness of established and mapped winter ranges.

Table 20. *Survey timing by biogeoclimatic zone (**bold** = coastal ecosystems) for mountain goats as per RISC (2002: 8)*

Biogeoclimatic zone[1]	Survey objective[2]	Survey method[3]	Survey timing
All	P, C	TC	July
MH, BWBS, SWB, **AT**	P, C	TC	Aug – Sept
MS, ESSF, SBPS	P, C	TC	Sep – Oct
CWH, ICH, IDF	P, C	TC	Oct – Nov

[1]**MH** = mountain hemlock, **AT** = alpine tundra, **CWH** = coastal western hemlock

[2]P = presence/not detected presence/not detected (distribution), C=sex/age composition

[3]TC = total count

This analysis demonstrates that winter range surveys completed in late winter can generate metrics that are useful in mountain goat habitat management. Surveys conducted in the late summer or fall as per RISC (2002) compliment winter surveys. For example, summer kid:adult ratios (productivity), can further inform understandings of over-winter survival and population recruitment. Furthermore, population trend information can be collected on specific winter ranges that might not be as specific as one would get during a summer/fall survey due to mountain goats being distributed over larger areas in the summer/fall versus winter (Nietvelt et al. 2022). However, trends from both summer/fall and winter should be compared to examine winter range versus population scale trends.

When conducting winter range surveys, the following data should be the *minimum* collected:

1. Total counts of goats by sex and age class: nannies, billies, juveniles, kids, and calculate kid:adult ratios;
2. The estimated number of individual sets of tracks (this is essential when you only see tracks and no animals), and the location and elevation of those tracks/groups of tracks as these data can assist with informing measures of detection or sightability; and
3. A GPS track file of the flight path.

If winter ranges are already established and the distribution of goats is well known, a simple presence/not detected survey *will not* suffice, as this does not yield population trend or classified count information. This does not permit formal occupancy analyses and limits their use for management and large-scale meta-analysis. (MacKenzie et al. 2002).

Where available, telemetry information compliments evaluation of winter range effectiveness and function. Data from GPS-collared mountain goats can shed light on:

1. Habitat use – home range, use of the mapped winter ranges, landscape connectivity/migration routes and timing of movements to-and-from the winter ranges, seasonal habitat selection, natal sites/natal range, and disturbance-caused habitat alienation or even abandonment.
2. Survivorship – estimated from the mortalities, locations of mortalities, and possible sources of predation. Survivorship can be used in conjunction with recruitment information to calculate a crude population growth rate (λ).

Understandings of habitat use can be broad in scope and, in terms of effectiveness monitoring, can be related back to habitat suitability and MGWR function. Survivorship of collared goats integrates with kid:nanny ratios and is critical when population declines are occurring to inform which sex and age cohort are most affected and responsible for the declines. Table 21 outlines potential metrics for effectiveness monitoring obtained from winter range surveys and radio-collared mountain goats, along with summary guidance regarding these data.

Table 21. *Various metrics useful in mountain goat winter range (MGWR) effectiveness monitoring*

Monitoring question/ management use	Metric	Data source and description	Summary of data and guidance
• Evidence of sustained use • Population trend	Linear density, *LD* (goats/km)	**Winter range survey:** number of goats plus tracks and distance sampled per MGWR. The survey distance is calculated from a GPS track file.	This is a standardized measure of relative abundance and is useful when the sightability of actual goats is low. In many areas, the variance is low and can have good statistical power for measuring population change with statistical robustness.
• Evidence of sustained use • Population trend	Goat densities (goats/km^2)	**Winter range survey:** count of goats on the winter ranges when sightability is good.	Mountain goat densities can be calculated per winter range (number of goats ÷ winter range area). If the habitat is mapped, then the area of highly suitable habitat would be the denominator. As well, concentrations of mountain goat use help identify important microsites and population risk if those microsites are lost to development or disturbance.
• Evidence of sustained use • Population trend	Goat counts (uncorrected) and track counts	**Winter range survey:** count of the number of goats and tracks on a winter range with location data.	The number of goats on a winter range is useful for monitoring change over time, especially on winter ranges with good sightability and consistent counts. Track counts are integrated into the *LD*, and tracks indicate presence if actual goats are not sighted. These data offer a response variable when disturbance vectors are identified. Population time series allow for calculation of growth rate, λ, and intrinsic rate of increase, *r*, from annual inventory data.
• Population trend	Kid:adult ratios	**Winter range survey:** from the total count. **Summer-fall survey:** from population counts.	Used to compare differences in kid survival and recruitment between areas. Low ratios indicate possible population declines and warrant further investigation. If available, summer-fall counts are used to compute kid survivorship. In conjunction with radio collar data, the population trend can be calculated. Requires standardization of related to inclusion of sub-adult or juvenile observations in the adult class when comparing across surveys or areas.
• Evidence of sustained use • Population trend	Detection probabilities (Pr_j, 0-1.0), occupancy probability (ψ)	**Winter range survey:** from inventory of the MGWRs (goats and tracks detected).	Requires two or more flights to calculate detection and occupancy probabilities. Values range from 0 (no goats or tracks detected) to 1.0 (goats detected on each survey). Changes in detection and occupancy should be monitored over time, especially if winter ranges are impacted by wildfire, disturbances, etc.
• Evidence of sustained use • Movement between winter ranges • Proportion of suitable and capable habitat	Habitat use	**Radio-collared goats:** GPS locations.	If there are collared goats in an area, evaluate seasonal habitat including: timing and patterns of movements to the winter range (migration), location of natal ranges/kidding areas and parturition sites (from the locations of nannies in May and June), and habitat selection and use of the mapped winter ranges (site fidelity and habitat function). This can be useful for identifying and refining winter range boundaries, or to infer risks of impacts from adjacent activities.
• Population trend	Survivorship and cause-specific mortality	**Radio-collared goats:** number of radio-collared goats that have died over a duration of time.	Calculate annual and cumulative survivorship for males and females, sources, or locations of mortality. Poor survivorship is an indicator of population decline. This, in combination with kid:adult ratios, informs population trends when using the R/M equation for calculating the population growth rate, *λ*, and intrinsic rate of increase, *r* (Hatter and Bergerud (1991).

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APPENDIX 1

Recruitment and survivorship information can be used together to calculate a population trend metric, lambda (λ). A simple way to calculate λ is from Hatter and Bergerud (1991) using the *R/M* equation (see Appendix 1).

$$\lambda = \frac{S}{1 - R}$$

where *S* is the estimated female goat Kaplan-Meier (K-M) survivorship calculated from the radio collared sample, and *R* is the mean recruitment as previously described. In areas where mountain goats are radio collared, gathering later winter and early spring recruitment information is essential. A λ value of 1.0 means the population is stable, <1.0 the population is declining, and >1.0 the population is growing. To calculate the intrinsic rate of increase, *r*, it is simply:

$$r = LN(\lambda)$$

The intrinsic rate of increase calculates the growth of a population on a per capita basis at each instant of time (Voronov 2005). The intrinsic rate of increase, *r*, and the population growth rate, λ, can be also calculated from inventory data without the need for radio collar survivorship (*S*) estimates using the following equations:

$$r = \frac{LN[(N_2/N_1)]}{(t_2 - t_1)}$$

This formula calculates the intrinsic rate of increase, *r* (Voronov 2005). In this equation, N_1 is the initial population at time t_1, and N_2 is the resultant population at the end of time t_2. To calculate λ, it is the exponent of *r*:

$$\lambda = exp\ (r)$$