Habitat Modeling Using Path Analysis:

Delineating Mountain Goat Habitat in the Washington Cascades

By

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Accepted in Partial Completion

Of the Requirements for the Degree

Master of Science

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MASTER’S THESIS

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HABITAT MODELING USING PATH ANALYSIS: DELINEATING MOUNTAIN GOAT HABITAT IN THE WASHINGTON CASCADES

A Thesis Presented to

The Faculty of Western Washington University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science

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August 2010

ABSTRACT

A 70-90% decline in mountain goat (Oreamnos americanus) populations in Washington State over the past few decades has spurred the need for an improved understanding of seasonal goat-habitat relationships. Habitat use data have been collected from 46 radio-collared mountain goats across their native range in Washington State. Using Geographical Information Systems (GIS), I explored relationships between use and availability of habitat. To overcome issues of autocorrelation, I compared actual mountain goat paths with available paths of matched identical spatial topology and used multi-scale path analysis to explore various ecologically informed relationships between landscape structure and the movements of mountain goats at the home range scale. I extracted used and available (randomized) paths at 4 scales of analysis using square extraction windows of 0.06, 4.4, 15.2, and 56.2 ha that were centered on each point along the path. Matched case logistic regression allowed me to determine the spatially and temporally explicit scales that were the strongest predictors of seasonal and year-round mountain goat habitat from a suite of predictor variables. I found that for year-round habitat, mountain goats chose both abiotic and biotic components of their landscape including; parkland, areas of high solar loading, terrain that is rugged, and terrain that allows escape from predators. This analysis represents one of the most extensive landscape-level habitat relationship studies conducted on mountain goats. Additionally, my methodological approach is applicable to other species-habitat association analyses.

ACKNOWLEDGEMENTS

This work was part of a collaboration involving the Washington Department of Fish and Wildlife (WDFW), Western Washington University (WWU), the Sauk-Suiattle Indian Tribe (SSIT) the National Park Service (NPS), and the U.S. Forest Service (USFS). Funding for this project was provided by WDFW, grants from Huxley College of the Environment, Seattle City Light, and the American Alpine club. I would like to thank my advisor, Dr. David Wallin, and my committee members Dr. Clifford Rice, and Michael Medler for their expertise and support. I am also grateful to Samuel Cushman and Stephan Freelan for their technical expertise. Finally, I would like to thank my interns Anna Benson, Anne Marie Cooper, Ed Evanson, Laura Ewing, Miku Gleason, Jen MacArthur, and Will Wright for tirelessly collecting data in so many remote areas of Washington.

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PREFACE

Historical declines in mountain goat (*Oreamnos americanus*) populations in Washington State have generated interest in documenting resource selection to better understand habitat use in this area. The implementation of a sound regional management plan for the species will require detailed information on distribution, movements, and temporal and spatial variation in habitat use. Identifying habitat requirements and subsequently delineating the quantity and quality of available habitat allows predictions of potential mountain goat ranges in this region. Without an understanding of useable available mountain goat habitat, it is unclear how population fluctuations should be perceived and managed. In an effort to improve understanding of goat-habitat relationships and foster effective long-term management, I developed an extensive landscape-level habitat relationship study of mountain goats that functions as a starting point to address questions related to mountain goat home range requirements in Washington. In Chapter 1, I summarize the current knowledge of mountain goat ecology based on work done within this region and elsewhere in North America. I also include a general geographic description of the diverse study area. In Chapter 2, I incorporate those factors thought to be important to mountain goat habitat selection based on the literature reviewed in Chapter 1. I describe the findings of a novel approach to using remotely obtained GPS locations in combination with GIS grids to produce a habitat map based on a path level analysis.

CHAPTER 1

Study Area Geography

General

The Cascade Range stretches over 1,130 kilometers from northern California, to southern British Columbia, paralleling the Pacific Ocean, about 200 kilometers inland. The Washington Cascades are 580 kilometers in length and include massive snow-capped volcanoes, such as the highest volcanic massif, Mount Rainier 4,392 m. Other prominent peaks include Mt. St. Helens 2,550 m, Mt. Adams 3,742 m, and Glacier Peak 3,213 m, and Mt. Baker 3,286 m. The northern terminus of the Washington cascades is a 240 km stretch of mountains south along the Canadian border that houses inaccessible, remote non-volcanic peaks seldom over 3,000 m. The total rise of these peaks, summit above base, often exceeds that of the higher peaks of the Sierra Nevada or Colorado Rockies. The North Cascades receive heavy snowfall and have extensive glaciation. In addition to the heavy winter snows, the North Cascades are notorious for their thick vegetated slopes west of the crest that cover the deep, narrow valleys.

The Washington Cascades contain a diversity of topography and soils resulting in complex array of species and community patterns that forms a mosaic pattern unique to this region of the Cascades. There is a major topographic break that separates the northern and southern part of the range in Washington State that generally follows interstate - 90. Environmental gradients in the North Cascades are generally steep and lead to abrupt changes in microclimates and plant communities. Microclimates affect snowpack depth, particularly in the alpine and sub-alpine regions, which varies substantially and is a result of local topography. About four percent of the land base in

Washington State is alpine and sub-alpine habitat (Martin 2001). These alpine zones decrease in elevation from south to north and from interior to coastal areas. In the North Cascades, tree line increases from 2,000 m on the western side of the crest to 2,500 m on the eastern side and varies with aspect and latitude.

The North Cascades contain the greatest concentration of alpine glaciers in the lower 48 and hold 700 glaciers that yield 900 million m^3 of runoff each summer. The sensitivity of glaciers to small temperature changes means that glacier thinning trends are rapid, ubiquitous and inevitable. In the North Cascades, glaciers have lost 35%-50% of their volume in the last century (Pelto and Hedlund 2001).

Climate

Climate may influence demographic variability of goat populations in several ways including; selection where early winters cause variable juvenile mortality and selection where long winters may promote adult survivorship and stifle reproductive capabilities of females. Additionally, for many alpine obligates such as mountain goats, availability of spring forage may be crucial for breeding. Research indicates that spring weather and timing of access to new plant growth in spring is more important than winter conditions (Martin 2001). Timing of spring snowstorms can have a large effect on reproductive success and mortality (Mathews 1994).

The Cascade Range divides the coastal Pacific and the accompanying maritime climate from relatively temperate Central and Eastern Washington. Solar radiation load influences climate, particularly microclimate. The western slopes of the Cascades receive significantly more precipitation than the east, over 203 cm a year.

The Washington Cascades have a unique combination of high winter precipitation, oceanic air currents, and steep temperature and elevation gradients, making them one of the snowiest places on earth. Areas in the northern terminus of the range, around Mt. Baker receive the heaviest precipitation, up to 300 cm annually, the bulk of which is received as snow from October through March (Franklin and Dyrness 1973: 38-42). During the 1998-1999 winter, Mt. Baker 3,285 m, recorded the world record of 28.9 m of snow accumulation during a single winter (Martin 2001).

Climate warming will affect limits on the upper portions of alpine habitat which will trend upward in elevation over time. The increased elevation of tree line is also expected to fragment current alpine habitats and the populations living in them will be required to disperse longer distances to other alpine patches (Martin 2001). Additionally, moist climatic cycles reduce fire frequency and allow patches of isolated trees to grow together forming closed forests. Drought, depth, and duration of snow pack may either lower the tree line or allow trees to encroach on meadows and shrub lands creating more parkland habitat (Martin 2001). Climate influences are an important consideration when evaluating metapopulation viability in areas where subalpine parklands have reached the limits of their upper extent, and within the context of my large study area.

Flora

Landscape patterns influence grazing by large herbivores (Senft et al. 1987). Senft et al. (1987) theorizes that animals perceive consistent clusters of vegetation resulting from patterns of disturbance or soil type, shaped by geomorphic landscape attributes. Naturserve’s Ecological Systems of the United States (Comer et al. 2003) classification breaks down vegetation into systems that represent communities influenced by the same dynamic processes, such as fire, flooding or avalanches. Washington's Gap Analysis is based on these community representations and is consistent with the description of vegetation characteristics for the Cascades ecosystem from the classic text of Franklin and Dyrness (1988). Following is a description of those vegetation systems represented in my study area, the Cascades of Washington.

The Washington Cascades are primarily dominated by forests and vegetation composition that transition from east to west as a gradient. West of the cascade crest, *Tsuga heterophylla* (Western Hemlock) and *Pseudotsuga menziesii* (Douglas Fir) inhabit the lowlands. *Abies amabilis* (Silver Fir) increase in elevation approaching the sub alpine zone where *Tsuga mertensiana* (Mountain Hemlock) and *Abies lasiocarpa* (Subalpine Fir) dominate. Canopy cover decreases with an increase in elevation to parkland type ecosystems leading to tree line where alpine dwarf-shrubs and grasses predominate in high elevations both east and west of the crest. East of the crest, *Pinus ponderosa* (Ponderosa Pine) and *Abies grandis* (Grand Fir) cover lower elevations turning to *Pseudotsuga menziesii* and *Tsuga heterophylla* followed by *Abies lasiocarpa* with increasing elevation. In eastern portions of the Cascade Range, mid elevation trees are typical to that of the montane environment; however understory species are more associated with Rocky Mountain ecosystems (Sanborn 2007).

Sanborn (2007) further divided the Cascade vegetation categories into separate regions called sub-zones that represent areas where there were similarities in moisture, elevation, and temperature regimes. The following subzones encompass my study area and provide a broad picture of the variability in landscape from east to west and north to south. The North Cascades subzone is west of the crest and is characterized by rugged topography and relatively high rainfall. The Ross Lake area contains floristic elements of east and west of the crest as well as the Canadian Rockies. The Wenatchee subzone also contains transitional vegetation and is one of the most diverse subzones. The subzone representing the Okanogan area is completely east of the crest and as a result, in the rain shadow of the Cascades. Fire has played a major role in shaping the species composition in this environment. Finally, the southern and middle Cascade subzones contain the most diversity of all the subzones and are dominated by montane conifers. It houses large volcanic mountains (Mt. Rainier, Mt. Adams and Mt. St Helens) that influence the floristic composition in this area.

Vegetation cover in this area can be broken down into 5 broad categories based on Comer et al. (2003); sparsely or non-vegetated, subalpine parkland, grassland, shrubland (short and tall), and forests/woodland. Sparsely or non-vegetated landscapes comprise much of the escape terrain in the Cascades and consist of bedrock, scree, cliffs and icefields. Subalpine parkland generally occurs at 1,180-2,080 m in elevation. Grasslands consist of North Pacific Alpine and Subalpine Dry Grassland and ranges from 1,170-2,190 m. Shrubland consists of both short and tall subcategories, Alpine Dwarf Shrubland, meadow and tundra as well as Broadleaf landslide and avalanche chute respectively. Shrubland ranges from 600-1,380 m. Forests and Woodland occur at elevations ranging from 600-1480 m and include mixed conifer forests, as well as *Pseudotsuga menziesii*, *Abies amabilis*, *Pinus ponderosa*, *Pinus contorta* (Lodgepole pine), *Tsuga heterophylla*, *Tsuga mertensiana*, *Picea sitchensis* (Spruce), and *Larix occidentalis* (Western Larch).

Timberline can generally be characterized as Parkland and constitutes the interface where trees give way to alpine meadows under the pressure of increasingly inclement weather conditions. Trees in this ecotone occur as an extensive mosaic of patches that can extend at an elevational span of 300 to 500 m or more (Franklin and Dyrness 1973). This region is sometimes referred to as krummholz, the physical response to deep winter snowpack. Existence of this region is contingent on ample elevational space, mostly in the north Cascades and major peaks to the south. This interface, timberline, generally drops 110 m per degree of increase in latitude in a similar climatic environment (Daubenmire 1954) and aspect. There are four conifer types that dominant the krummholz region in the Washington Cascades including east, west and central; *Abies lasiocarpa, Tsuga, mertensiana, Pinus albicaulis* (Whitebark pine), *Picea englemannii* (Englemann spruce), and *Larix lyallii* (Subalpine larch) (Franklin and Dyrness 1973). This region has undergone rapid expansion in the last 50 years as trees invade alpine meadows throughout the Cascades (Franklin and Dyrness 1973).

The alpine zone consists of the highest continuous alpine cover for the west side of the North Cascades, and occurs around 2,176 m. Sheer rocky cliffs, glaciers and snowfields prevent the establishment of continuous vegetation at higher elevations. The eastern side of the mountains has progressively higher continuous vegetation at 2,600 m. Douglas (1971) defined the alpine zone as those areas devoid of upright trees including krummholz trees. The vegetation consists of low lying herbaceous and ericaeous plants, including succulents, dominated by sedges, cushion plants and heaths (Franklin and Dyrness 1973). This zone is narrow but growing as the line of permanent snow and ice retreats.

Mountain Goat Ecology

General

The Mountain goat is a mountain ungulate that occupies mountain ranges in the northwestern portions of North America. This includes the Cascades and Rocky Mountains as far south as Colorado and north to South Eastern Alaska. Current native ranges dip as far south as the Rocky Mountains in Central Idaho and also extend to South Eastern Alaska (Johnson 1983). In total there are about 75,000-115,000 introduced and native mountain goats, mostly in British Columbia and Alaska (Festa-Bianchet and Cote 2007).

Mountain goats adapt to a variety of alpine environments. Indeed, successful reintroductions have occurred in the Black Hills of South Dakota, as well as the Collegiate Range, San Juan, and Gore Ranges of Colorado (Wright 1977) and the Olympic mountains in Washington (Johnson 1983). Native mountain goats in Washington currently occupy both the Cascade and Selkirk Mountain Range, which is similar to their historic distribution in the state as early as the 1800's when the first mountain goats were documented in Washington (Johnson 1983, Wright 1977). Mountain goat habitat includes generally steep rocky sites with slopes 40 degrees or greater in close proximity to diverse forage and cover (Johnson 1983). Anderson (1940) was the first to document the natural history of mountain goats in Washington. Wadkins (1967) also contributed knowledge on their ecology in the eastern cascades of Washington (Wright 1977). In the project study area, little research has been done, however, a masters thesis by Wright (1977) quantitatively evaluated 8 habitat types in the Barometer mountain goat herd home range based on vegetation composition and physiographic characteristics.

Mountain goats in Washington occupy two very distinct ecosystems, the very wet areas of western Washington as well as the dry open areas in the eastern region of the state. Habitats in SE Alaska versus those found in the xeric areas of Idaho and Black Hills of South Dakota exemplify the spectrum of habitat diversity and adaptability of goats to the resources available to them. Though goat populations adapt to diverse regional variation, they generally prefer a band of habitat near tree line, which varies in elevation throughout Washington (Johnson 1983).

Social behavior is centered on a matrifocal construct where females, kids, and juveniles form distinct groups separate from adult males. An exception to this is during rut, in November and December, when large groups of both sexes reconvene. Large dominant males do most of the breeding and tend to females at recurring intervals of estrus, about 20 days (Geist 1964). Gestation lasts for about 186 days and birthing takes place in late May and early June when females remain secluded for up to 17 days postpartum (Hutchins et al. 1987). Kids are surprisingly quick to negotiate difficult terrain after just a few days and nurse frequently prior to weaning. Dominance hierarchies for both nanny and billy goat bands exist where dominant individuals are frequently older and larger (Chadwick 1977, Risenhoover and Bailey 1985). Social subordinates may incur an increase in directed aggressive behavior by dominant individuals particularly in winter when resources are limited (Petocz 1973).

Houston et al. (1994) synthesized several generalizations on the food habits of mountain goats for the Olympic Mountains as well as information drawn from other studies. He noted that goats consume a wide variety of plant species from below ground fern rhizomes, bulbs, tubers, and mosses to evergreen trees. Additionally, foraging goats select nutritional plant parts, frequently flowers, seed heads, and growing leaves. Grasses and forbs generally dominate the spring and summer diets while winter diets include proportionally more browse species such as shrubs and trees, particularly during severe winters.

Predators of mountain goats include coyotes, eagles, black bear, cougar and humans. Anthropogenic disturbance alters available habitat from which goats may choose home ranges. These disturbances include fire, fire suppression, logging, recreation, mining, associated road building, and climate change. Alpine habitat is at particularly high risk from the effects of climate change as subalpine and alpine plants do not recover from disturbance quickly (Festa-Bianchet and Cote 2007).

Home Range Characteristics

Mountain goat home ranges have been identified using a wide variety of home range estimate techniques. Comparison of these techniques is beyond the scope of this study; however, there are several estimates for mountain goats in different regions. Home ranges generally consist of wintering grounds, summer ranges and associated migration routes between non-overlapping seasonal ranges. Annual mountain goat home ranges in Montana occur between 6-25 km^2 for most ages and sexes (Rideout 1977). Johnson (1983) identifies goat home ranges in the Cascades of Washington as generally between 10-15 km^2. Some winter home ranges, such as those found in the Bitteroots of Montana are reduced to as little as 1 km^2 (Smith 1976). Rice, (unpublished data) reported that winter home areas range from 18 km^2 to 54 km^2 and those same core areas (defined by most intense 70% of use) range from 0.76 km^2 to 13 km^2. Summer home areas range from 34 km^2 to 65 km^2 and summer core areas range from 0.59 km^2 to 23 km^2. Year round range from 18 to 65 km^2 (mean 42 km^2), which represents 1,800 ha to 6,500 ha. Distances between summer and winter centroid of home ranges was also variable, median 1.8 km with a range of 0.1 – 19.8 km, 83% of those were less than 5 km.

Regardless of the size of the home range, mountain goats tend to establish home ranges in localized, highly preferred niches in which they return to seasonally and annually, while less desirable areas are visited sporadically (Johnson 1983). Mountain goats show high fidelity to established seasonal ranges in the Washington Cascades (pers. obs., Wright 1977) and the Olympic Mountains (Houston et al. 1994) as well as other areas (Rideout 1977, Smith 1976, Smith and Raedeke 1982, Brandborg 1955). For example, historical local accounts indicate that the Barometer mountain area has been used as wintering grounds since the 1930's and is still in use today (Wright 1977, pers. obs., 2008). In the Olympic Mountains study, summer home range fidelity was observed between 84% and 97% of the time (Houston et al. 1994). Goats in the Washington Cascades typically range from 600 m to 2,400 m in elevation, with most time spent below 2,100 m (Rice 2008). According to Wright (1977), goats on Barometer Mountain formed two distinct bands during summer that reconvened during rut in November and December to share the same winter range. Several authors have noted increased group sizes in winter (Wright 1977, Kuck 1970).

Goats may migrate less than a kilometer where the concurrence of winter and summer habitat is a matter of elevation. In other areas, suitable winter and summer habitat may be many kilometers apart. A study in the mountains surrounding the Robson Valley in East Central British Columbia found that three goats used separate winter and summer ranges that were separated by 8-13 km, however, most simply shifted in elevation in response to seasonal cues (Poole and Heard 2003). Long distance movements may not be indicative of migrating towards or away from a seasonal home range. For example, while goats use mineral licks generally within their home range, two goats used licks 6 and 14 km from their typical home range (Poole and Heard 2003). In this study area, two male goats displayed long distance movements; one from Goat rocks to Mt. Adams, another from Glacier Peak to Lake Chelan 40 km and 47 km respectively. Wright (1977) identified the Barometer mountain herd as migratory, using distinct winter and summer ranges. For one band, the summer range was located 15 km south of the winter range.

Escape Terrain

One of the most important determinants of mountain goat habitat is the presence of steep, rocky cliffs which predators are unable to access (Johnson 1983). This has been described as “escape terrain”, and will be referred to as such in this document. Mountain goats are associated with escape terrain, and typically stay within one-half mile of it (Johnson 1983). Foraging by mountain goats has been shown to range as far as 1.8 km from primary escape terrain, though goats return to escape terrain to bed down (Wright 1977). Habitat use by goats declines at greater distances from escape terrain. Based on a study by Poole and Heard (2003), goat use declined in areas >500 m from escape terrain. Gross et al. (2002) categorized suitable goat habitat as within 258 m from escape terrain. Variability in the reported distances from escape terrain are likely to be influenced by local topography and vegetation which in turn influence visibility and subsequently, predation risk.

Seasonal Habitat

Populations of large ungulates are most likely limited by forage availability, predation, and weather (Festa-Bianchet and Cote 2007). Goats seek thermal cover such as conifer stands, caves, or lower elevations during periods of inclement weather (Johnson 1983, Wright 1977). Thomas et al. (1979), found that for elk, optimal thermal cover was in coniferous dominated stands with canopy closure greater than 70%. Wadkins (1967) speculated that the most limiting environmental factor to goat populations is deep snow cover and that localized mountain goat declines are related to severe winters characterized by deep snow, leading to changes in age population structure (Wadkins 1967, Chadwick 1973, Edwards 1956). Snow accumulates less on south facing cliffy terrain allowing goats to have access to browse (Wright 1977). Some combination of escape terrain, windswept slopes, southerly aspects and snow melt or snow shedding characteristics are important for mountain goat wintering habitat (Wilson 2005). Slope roughness and insolation (solar loading) contribute to snow depth and quality. Geist (1971), Rideout (1974), and Smith (1977) indicated that snow shedding is an important characteristic of habitat choice by mountain goats. South-facing, dark colored rocks absorb and re-radiate solar radiation to the immediate area resulting in a microclimatic effect that may be important for mountain goat winter site selection. Additional research of habitat selection by coastal goats in British Columbia and southeastern Alaska has demonstrated coniferous forest use in winter adjacent to south facing escape terrain (Hebert and Turnbull 1977, Fox 1983, Smith 1986, Fox et al. 1989). Limited observations in the Olympic Mountains, WA also suggest coniferous forest use in winter on steep south and southeastern slopes below 1,500 m (Houston et al. 1994).

Seasonal movement behavior of individual goat bands is extremely variable (Chadwick 1973) subsequently seasonal variability in resource selection for individual mountain goats is also high (Rice 2008, Wright 1977). The diversity of the Cascade Range from east to west and its influence on goat ecology is no exception. Timing of spring vegetation green-up can affect growth and survival of a variety of ungulate species including bighorn sheep, alpine ibex, and mountain goats (Pettorelli et al. 2007, Wright 1977). Snow cover (seasonal precipitation), temperature and wind measurements may prove to be better predictors and possibly limiting factors not only of mountain goat movements and dispersal, but of productivity. Snow cover of greater than approximately 0.6 m (Geist 1971) and accumulation rates have been shown to influence forage selection by covering forage (Rominger 1988, Kinley 2003) and incurs higher energetic costs for locomotion (Dailey and Hobbs 1989, Ball et al. 2001).

Festa-Bianchet et al. (2007) recognized that seasonal changes of availability and quality of forage may be attributed to seasonality and highly variable timing of vegetation growth in spring as a result of yearly differences in snow cover. Seasonal resource selection may especially pertain to winter habitat where the varieties of selection opportunities are smaller. For example, biomass of a particular lichen species, along with snow depth, was found to influence habitat selection by woodland caribou (Johnson 2001). Evidence from mountain goats in Olympic National Park suggests high variation in the duration that goats used seasonal home-ranges. For example, traditional summer seasonal ranges were accessible in years during unusually low snowfall, areas that are typically inaccessible due to deep snowpack during winter (Houston et al. 1994). Rice (2008) challenged assumptions that goats primarily inhabit the subalpine and alpine environment with data for the Washington Cascade goat population demonstrating that goats spend the majority of their time at lower elevations during a long winter season. In the study by Rice (2008), the median length of season and elevation for summer was 4.60 months and 1,591 m and for winter 7.32 months with a median of 1,353 m respectively. Medians were widely dispersed for individual animals ranging from 808 m to 2,257 m for both winter and summer combined.

Population Dynamics

Though the geographic distribution of mountain goats has increased since European settlement due to introductions, total population size has decreased significantly from historic levels (Johnson 1995). Past research has identified declining population trends since the 1970's in certain areas of its historic range throughout the state (Johnson 1983). Population estimates in Washington were attempted initially in 1961 yielding an estimate of 7,000 huntable and 2,000 non-huntable mountain goats (Johnson 1983). Two jurisdictions oversee the state populations, Washington State Department of Fish and Wildlife and the Department of the Interior. Current estimates using modern survey techniques have documented approximately 2,000 to 3,000 mountain goats in the Washington Cascades (Table 1).Goat populations are thought to have been as high as 10,000 (Washington Department of Fish and Wildlife 2008) prior to European settlement. Historic population estimates are likely heavily biased towards accessibility by the observer. Human population influxes allowed for the initial observations from which estimates were derived, anthropogenic influences also undoubtedly changed the composition and quantity of goat populations.

CHAPTER 2

INTRODUCTION

Background

The largest native population of mountain goats in the contiguous United States resides in Washington State (Johnson 1983). Population declines have likely been due to a combination of factors, of which, overhunting is thought to be a key component (Rice and Gay 2010). WDFW identified two management issues that have implications for effectively restoring and managing the state's mountain goat population: refinement of population survey techniques, and identification of habitat requirements in the ecologically varied landscape of the Cascade Mountains (Rice pers. comm.). I examined the latter using GPS locations from collared mountain goats and a suite of landscape predictor variables considered important for habitat selection by mountain goats.

The project launched in 2002 as a collaborative effort between the Washington State Department of Fish and Wildlife (WDFW), Sauk-Suiattle Indian Tribe, United States Forest Service (USFS), National Park Service (NPS), and Western Washington University (WWU) to study mountain goats in Washington. This included a GPS collaring program to obtain location information for use in habitat analysis. I use data from these collars to identify areas in the Washington Cascades that mountain goats were selecting on a seasonal and annual basis. I apply a novel statistical approach to explore relationships between the use and availability of mountain goat habitat.

Mountain goat habitat is an inherently problematic landscape to access. As a result, obtaining mountain goat location information without disturbance is difficult, particularly during the winter season. The use of GPS collars permits less observational bias than conventional wildlife telemetry and aids in the understanding of seasonal and yearly home range variation in habitat use. However, pseudoreplication (lack of independence) is a common statistical violation in habitat studies involving GPS-tagged animals and resource selection using traditional logistic regression. I address these statistical violations common in point-based analyses by analyzing paths. This approach treats the set of GPS points along a path as the unit of observation rather than the point itself. Additionally, I incorporate a matched-case logistic regression design. The matched-case procedure allows integration of individual variation in resource selection by mountain goats across a biologically and topographically diverse mountain range while addressing the most serious of several statistical violations, namely that the observations are independent. As a result, my research provides a baseline to address issues critical to making informed decisions regarding reserve design, habitat conservation, reintroductions, and conservation of critical use areas, such as winter habitat.

Research Question

My objective is to understand mountain goat habitat selection at the home range scale. In addition to work by Wells (2006), it also represents one of the most extensive landscape-level habitat relationship studies conducted on mountain goats. The data from GPS-collared mountain goats for the entire Washington Cascade Range provides a unique opportunity to address questions at a spatial and temporal extent that has rarely been attempted. This has the advantage of inferring without being restricted to a smaller spatial domain or metapopulation where the dynamics governing response such as movement, may vary significantly. Data sets that span multiple temporal and spatial scales and broad spatial extents are relatively uncommon, likely due to the cost in obtaining them (Beever et al. 2006). The wealth of data from this study provides a baseline for future studies of mountain goat ecology, furthers understanding of resource requirements, and contributes information for management decisions and possible reintroduction efforts. Using this data set I examine two primary objectives:

1. Model and validate potential mountain goat habitat to predict suitable mountain goat habitat within the study area

2. Within this modeling framework, address how habitat selection by mountain goats varies on a seasonal basis.

Statistical Approach

There has been considerable research on resource selection functions (RSF) and the statistical methodology that best suits this type of analysis (Manly et al. 2002, Johnson 2006). Resource selection functions are a proportional value applied to a particular resource that is measured as a function of the probability of that resource being used (Manly et al. 1993). Resource selection functions are often developed using data collected from radio-collared animals where each animal location is treated as an independent observation. However, for any organism, pairs of locations are correlated at time scales ranging from minutes to a year or more. Lack of independence arises from a phenomenon known to geographers as Tobler's Law, where observations that are closer together have a tendency to be more similar (Fortin 2005). Autocorrelation can occur when movements are constrained by factors such as topographic or physical impediments. For example, in winter goats may be constrained by deep snow. Over annual time scales, spatial autocorrelation can occur due to seasonal home range fidelity.

Lack of independence among observations violates one of the key assumptions of most statistical approaches.

A common tactic to minimize autocorrelations involves deleting intermediate locations until the remaining points are thought to be independent (De Solla et al. 1999) However, there are inherent fallacies in this "time to independence" approach (Cushman 2005). Cushman's (2005) study examining elephant movements in Botswana showed that this method may not ever reveal a time to independence if an animal routinely follows seasonal home range fidelity patterns. As a result, incorporating time to independence into a predictive model may mask issues of autocorrelation, which, at all distances should be considered. Furthermore, the distance between points, as well as the arrangement of those points, holds valuable information about habitat selection as it relates to seasonality and movement. Discarding data between points not only discards valuable location information, but also disregards the spatial arrangement in the movement path taken.

Within the last ten years, telemetry has shifted towards the use of satellite GPS collars that can be downloaded remotely. These collars yield abundant data, however there has been no clear consensus regarding the best approach to dealing with the lack of independence in these datasets. I address this problem by using path analysis. Instead of using each animal location as the sampling unit, I use the entire movement path of an individual over some period of time as the sample unit. Treating the path as the unit of observation rather than the point incorporates relationships that mountain goats have with the landscape structures on which they depend for survival while addressing violations of independence. This sequential movement path allowed me to assess animal movement in relation to landscape features based on one sample per individual using logistic regression. My predictor variable set include various biotic and abiotic factors that describe their environment. Movement paths followed by mountain goats are complex combinations of these elements. Year-long path-level analysis yields species-level models that identify the importance of the juxtaposition of summer and winter habitat, which combined, are necessary for yearly goat home ranges. Seasonal path analysis, consisting of points for some subset of the year, can be used to evaluate temporal variation in habitat selection.

Resource selection studies using logistic regression can identify those resources that are used disproportionately in comparison with those available. I use matched-case regression to compare used and available points along a path to create the most parsimonious and biologically relevant model for year long and seasonal paths. A key assumption for this type of study is that the available data matches the scale at which a mountain goat perceives its environment.

Scale, Resource Selection and Terms

The term “scale” can take on many meanings in landscape ecology. Indeed, scale can refer to to grain and/or extent and can be used within temporal or spatial contexts. Classic landscape ecology papers highlight the need to explore patterns and processes at multiple scales (Levin 1992, Johnson et al. 2004, Meyer et al. 2006, and Turner 1991). Use of a single scale or an inappropriate scale whether temporal or spatial may lead to an incomplete understanding of the pattern or process under analysis (Wiens 1989, Levin 1992, Boyce 2003). For the purposes of this study, the spatial extent is defined as the study area, the Washington Cascades. Additionally, the term scale refers to the size of the landscape block from which I extract data. I determined this by path length (temporal scale) and a variety of predefined landscape blocks (spatial scale).

Resource selection has been analyzed at multiple scales for mountain ungulates in several studies (Apps 2001, Rettie and Messier, 1999, Rominger et al. 1988). These studies describe seasonal, scale-dependent species-habitat relationships and have proven useful in the management of mountain ungulate populations (Apps et al. 2001). For example, in a study of mountain caribou, (*Rangifer tarandus caribou*) selection was analyzed for terrain and forest attributes across four nested spatial scales, seasonal habitat selection was found to vary with spatial scale for most attributes (Apps et al. 2001). Summer habitat selection included selection for old Englemann Spruce and Subalpine Fir across all scales and gentle terrain only at fine scales. Additionally, caribou preffered north and east aspects at broad scales when selecting summer habitat. Rettie (1999) examined patterns at both coarse (seasonal) and fine (daily) scales for mountain caribou using radio telemetry. His findings reveal that there can be inter-annual variation in selection at coarser spatial scales and inter-seasonal variation in selection at finer spatial scales. Perceptual biases introduced by the researcher and the resolution of the data available may not match the scales at which a species perceives patterns and ultimately selects resources in their environment. Therefore, identifying scale constraints where resource selection may be optimally identified is pertinent and allows us to narrow down the contributing factors at the scale most important for habitat choice. I examined resource selection at different spatial and temporal scales to identify distribution patterns for mountain goats and make predictions about where they are likely to occur.

Habitat selection as it relates to space use may be broken down into 4 broad hierarchical categories. First order selection encompasses the species range and is defined by the distributions of populations and meta-populations. Second order selection is defined by the distribution of an individual or small group's home range. Third order selection involves selection within a home range and includes the selection of a particular patch type. Fourth order selection includes within-patch selection, such as foraging behavior (Johnson 1980). Population level landscape selection, termed first order selection, addresses such topics as reserve design, metapopulation viability, land use planning, and reintroductions. My analysis incorporates second order selection and is constrained by first order selection.

A priori, it is problematic to determine the scale at which habitat variables contribute most strongly to a given order of habitat selection. I surmised that different variables contribute to habitat selection most strongly at different spatial scales and the relative importance of any given variable is likely to vary seasonally. For example, access to small swaths of tall shrublands may be an important component of winter foraging selection when grasslands are mostly covered with winter snowpacks. Conversly, broad landscapes of alpine grassland may be an important feature of summer habitat selection. My analysis considers spatial and temporal scales by comparing used paths of GPS goat location data with available paths of matched identical spatial topology. These paths characterize the integration of space and time and are represented as year long, as well as summer and winter movement paths. This allowed me to test various ecologically informed relationships between landscape structure and patterns and mountain goat movements. Consequentially, I was able to identify the necessary juxtaposition of winter and summer habitat through scale optimization.

Seasons Defined

To explore the drivers behind seasonal movements, paths are broken into summer and winter segments as determined by Rice (2008). This temporally optimizes the identification of predictor variables that are selected for at different times of the year according to distinctions made by individual goats. Yearly and seasonal comparisons are made with matched used (real) and available (random) paths, where the paths are described either by the mean value of underlying landscape characteristics for all points along a path or the proportion of a given covertype for all points along the path.

Determining the optimal temporal windows to generalize seasonal habitat use by mountain goats is problematic due to stochastic events such as weather and individual behavior. Coulson et al. (2000) found that among three species of ungulates with contrasting life histories, winter weather has a major influence on fecundity rates and may be particularly important to alpine species (Saether 2002). Additionally, discrete spatial movements may be attributed to specific short term weather events or habitat patch distribution rather than seasonal movements (Rice 2008). Minimum and maximum elevation constraints and habitat availability for each individual also contribute to seasonal variability of habitat use by individual goats (Rice 2008). Consequently, I opted to define seasons on an individual and yearly basis by using an analysis of altitude movements that was recently completed by Rice (2008).

Seasons are often defined on the basis of fixed dates. However, fixed date divisions do not account for yearly or individual variation in seasonal habitat selection.

Rice, (2008) using data from the animals used in my study, found that mountain goats responded to seasonal environmental changes with altitudinal movements that are a reflection of ecological conditions more closely related to vertical rather than horizontal environments. Indeed differences in mountain environments with respect to climactic conditions and plant communties are coupled with elevation, more so than horizontal distances. Additionally, seasonal altitudinal and horizontal distances traveled was highly variable among individuals and years (figure 1). Therefore, a single elevation value or date cannot be used to separate winter and summer habitat for all individuals and years. In other words, a single GPS location may be ambiguous in terms of representing dispersal, summer or winter habitat.

Rice analyzed data from the aforementioned goat population in the Cascades, and partitioned summer and winter seasons using a narrowing iterative approach. He defined a season-year as year of the preceding summer, for example, February 2004 is winter of season-year 2003. For each season-year, there was one summer and one winter season. For each season year, assignment of summer and winter start dates was initially set to 01May and 01October respectively. The dates were then moved forward or backward in 6 steps of increasing resolution and adjusted according to each year and individual goat depending on those dates that showed the largest contrast using the Van der Warden Test. This allowed adaptive assignment of seasonality depending on individual goat behavior and seasonal inter- and intra-annual variability. Season assignment was allowed to vary for individual, year and season, resulting in a distinct season duration identified for each individual and each year.

Rice (2008) found that there was a wide range of variability in seasonal patterns and timing among individual goat responses to environmental changes. Winter start dates varied from year to year and distinctions of goats as migratory or not was also inconsistent. Seasons derived by elevation showed that mountain goat winter habitat use is longer than summer, indicating that the greater part of life is spent at lower elevations. Climate between years was variable and was identified as significantly different between years by season start dates for individual goats (Rice 2008). For example, the winter of 2005/06 was particularly dry. Rice's work showed that seasonal and individual variation was common; thus, I partitioned my data into winter and summer data sets for each individual and year based on his findings.

Treating each goat individually guided my choice of matched-case regression as my analysis procedure for seasonal data and was particularly important so the effect of this variability was accounted for in the seasonal predictive models.

METHODS

STUDY AREA

The study area encompasses 53,297 km^2 of the Cascade Range in Washington State (Figure 2). I derived site characteristics from GIS grids that included topographic variables from a 10 m DEM, and vegetation predictor variables from the Interagency Vegetation Mapping Project (IVMP) and Washington's Gap Analysis (GAP).

GIS VARIABLES

Mountain goats are herbivore generalists and topographic specialists. They consume most any forage available including: grasses, sedges, forbes, shrubs, ferns, mosses, lichens, and conifers (Taylor et al. 2005). For this reason, there are no known close associations with particular forage species; rather it is likely that factors influencing the ability to thermoregulate and habitats that provide protection from predators may be better predictors of goat habitat. Mountain goat distribution and resource use include abiotic and biotic components that may vary in their importance at different spatio-temporal scales.

General Variable Descriptions

I assessed two landcover data sets, IVMP (Interagency Vegetation Mapping Project) (O'Neil et al. 2002, Browning et al. 2003) and Washington's GAP Analysis (based on Comer et al. 2003). These two data layers compliment one another in that IVMP primarily describes vegetation structure and GAP categorizes functional relationships and composition of the vegetation. I assessed various abiotic components as well. Abiotic factors, such as topography, are the primary determinant of landscape distribution patterns for large herbivores by physically constraining movement. This minimization of movement influences the type of biotic resources that are selected (Bailey et al. 1996). Mountain goats in particular have been found to be highly coupled with topographic features in the landscape (Saunders 1955, Varley 1994) specifically using geomorphological attributes that may influence favorable microclimates to select preffered home ranges. One such topographical measure is escape terrain; terrain that is used to avoid predators, and is primarily steep areas of cliff rock. I quantified escape terrain in several ways, including percent slope, and terrain roughness (Vector Ruggedness Model [VRM]) (Sappington et al. 2007). Finally I used an additional measure, Potential Relative Radiation (PRR) (Pierce et al. 2005) an indicator of the amount of solar radiation that an area receives. PRR is a better measure than the commonly used surrogate aspect, and may identify sites of importance in providing thermal cover during winter months. I developed the PRR and VRM data sets using ArcGIS 9.2 (ESRI, Redlands, CA, USA) and associated script with a 10 m DEM (US Geological Survey [USGS] 1993). I converted all data to the same map projection and datum (UTM NAD27) and resampled each grid to the largest common pixel size of 30 m. Grid layers are described in detail below and shown in Table 2.

Vegetation

GAP

Washington's GAP data set is primarily derived from Landsat 7 ETM+ (Enhanced Thematic Mapper) imagery from circa 2000. It encompasses 50 ecological system categories derived from general plant associations (Sanborn 2007). I collapsed these 50 systems into 6 broad categories at a 30 m pixel size. The classification approach for all covertypes except the "other" category followed the International Terrestrial Ecological Systems Classification (ITESC) (Comer 2003). General headings for collapsed categories were maintained for clarity. The six categories include; Forests, Short and Tall Shrubland, Grasslands, Subalpine Parkland, and Sparsely Vegetated (table 2). I based community divisions primarily on adjacent habitat associations for each community type. Other information in the community descriptions I used for category determination included the classification confidence (most were moderate, two were strong, and one was weak), as well as general plant associations determined by natureserves documentation (Appendix 1). Appendix 1 illustrates the collapsed community systems thought to be important as potential predictors of goat habitat.

IVMP

The IVMP data set is in a 25 x 25 m pixel format derived from mid 1990's Landsat imagery and consists of four vegetation grids (O'Neil et al. 2002, Browning et al. 2003). Of these four layers, I opted to use only the % conifer cover layer due to low reported accuracy for the other three layers, as well as significant correlations between classes for these data layers. I resampled the IVMP grids to 30 m pixels in ArcGIS. The IVMP layers are provided as continuous layers in 1% increments, however I collapsed these continuous layers into three classes as recommended by the IVMP documentation. Classification accuracies for eastide Total Conifer Cover data layers as 68% and for westside data layers as 74% (O'Neil et al. 2002, Browning et al. 2003).

Abiotic

Escape Terrain

One of the most important determinants of mountain goat habitat is the presence of steep rocky cliff faces on which goats can maintain distance from, outmaneuver and visually observe potential predators (Cote et al. 2003, Gross et al. 2002, Johnson 1983, Taylor 2005). Descriptions of this terrain have collectively been called escape terrain, and it is generally quantified by measures of slope or combination of slope and a ruggedness index (McKinney et al. 2003). Escape terrain needs to provide good visibility, needs to be sufficiently rugged and steep to be inaccessible to predators, and needs to be relatively close other suitable habitat to permit timely access. There is no consensus on the proper way to quantify escape terrain (Gross 2002). The definition of escape terrain has varied according to geographic locale and method of analysis. For example, 25 degree slopes are reported at some locales (Varley 1994) while 60 degree slopes are reported in others

(Taylor and Brunt 2007). Discrepancy may be associated with differences in the method used to determine slope, such as analysis derived from field measurements, a 10 m DEM or a 30 m DEM. Regardless, escape terrain slopes are generally defined as >30 degrees. Goats generally tend to stay within 400 m of this type of terrain, however, they have been know to travel farther away to mineral licks (Fox 1989, Gross et al. 2002). Hamel and Cote (2007) found varying degrees of distance from escape terrain depending on season, and sex. The importance of escape terrain as a predictor variable, justifies a more in depth investigation of an appropriate definition for escape terrain. I evaluated several approaches.

To more objectively define escape terrain, I created eight candidate escape terrain grids each with slopes above a given value defined as escape terrain. Slope angles between 25 and 60 degrees (at 5 degree increments) were evaluated. For each candidate escape terrain grid, I extracted used and available goat locations for year-long and seasonal data. I used a Wilcoxon test (Burnham and Anderson 2002) to determine which escape terrain grid had the greatest difference between used and available goat locations.

Terrain Ruggedness (VRM)

Sappington (2007) has suggested that terrain ruggedness may be a useful way to quantify escape terrain since mountain ungulates may perceive several components of escape terrain in addition to slope alone. Several authors suggest that parturition occurs in topographically rougher terrain than typical escape terrain (Brandborg 1955; Wright 1977). These sites typically provide isolation for females and allow post-partum security which has been reported to range from eight to eighteen days (Chadwick 1973).

Quantifying landscape ruggedness in a habitat model may give important information missed in the derivation of topographic variables such as slope to define escape terrain.

Sappington (2007) demonstrated that the Vector Ruggedness Model (VRM) and slope are two different components of mountain ungulate habitat. The authors used VRM and logistic regression to examine the relative importance of slope and ruggedness in determining the relative probabilities of preferred habitat as a function of topographic variables. Sappington's study on bighorn sheep in 3 separate, physiographically different mountain ranges, found that among multiple variables, VRM remained consistently important in habitat selection across ranges, and more so than two other commonly used terrain ruggedness models. Distance to water and VRM were significant predictors of sheep locations in all three mountain ranges. Slope was a significant predictor of sheep locations in only two of the ranges. VRM consistently quantified ruggedness across several mountain ranges despite topological differences between those ranges (Sappington 2007).

Previous measures of landscape ruggedness included various functions using the density of contour lines or elevation change across a given area to create a terrain ruggedness map. These measures essentially quantified terrain by using simple measures of slope. Neither distinguishes steep even terrain (high slope, low ruggedness) from steep irregular terrain (high slope, high ruggedness) and are highly correlated with slope (Sappington 2007). This recently developed Vector Ruggedness model (VRM) uses vector analysis to measure terrain heterogeneity from a digital elevation model. Decoupling ruggedness from slope allows us to incorporate terrain ruggedness as a separate variable. This avoids issues of multicollinearity that plagued previous indices of terrain ruggedness. Using VRM in conjunction with slope yields a more quantitative assessment of escape terrain.

Additional studies using slope and VRM as measures of escape terrain for bighorn sheep have shown that both variables are important in seasonal habitat selection particularly during parturition, when mountain ungulates may select higher slope and greater ruggedness (Bangs et al. 2005a, b). The quality and quantity of habitat for parturition is particularly important when considering suitability of potential translocation sites (Zeigenfuss et al. 2000) to allow the greatest protection from predators on young animals. Additionally, VRM may be important in identifying movement corridors (McKinney et al. 2003). Sappington (2007) recommends the use of VRM in conjunction with slope at different scales to provide a quantitative assessment when determining the configuration of escape terrain.

I incorporated VRM into my study by running a script (Sappington 2007) developed to perform vector analysis using a 30 m DEM. This analysis took unit vectors orthogonal to each grid cell and decomposed them into x, y, and z axes. A 5, 5, 5 moving window was used to calculate the degree of a vector outcome based on the vector strength divided by the number of cells in the neighborhood. A 5,5,5 window balances complexity and landscape extent and avoids a smoothing effect on the landscape from using larger neighborhoods. Additionally, this window size is a biologically meaningful scale for mountain goats. The resultant value determines the ruggedness of the landscape by a dimensionless number ranging from 0 to 1, flat to rugged respectively.

Potential Relative Radiation (PRR)

Radiation influences vegetation composition (Pierce et al. 2005, Franklin et al. 2000) and is important for thermoregulation by animals. The identification of shaded areas in summer or sunny microhabitats in winter may assist in determining availability of thermoregulatory opportunities. Topographic orientation is often used as a surrogate for determining relative radiation. However, slope and aspect alone do not incorporate the heterogeneity of the landscape and microclimate influences such as adjacent local shading on vegetation patterns. Pierce et al. (2005) developed a method to measure PRR to derive seasonal radiation maps from a DEM. PRR includes daily and annual changes in solar orientation seasonally and shading effects from local topography. The authors found that PRR had greater explanatory power at the landscape level using this method compared to other estimates that did not accurately capture variability in radiation throughout the course of the month or year. PRR was found to correlate better than either transformed field or DEM aspect.

PRR may be particularly important in rugged terrain were other estimates may not reflect true radiation conditions. The method captures the solar geometry by incorporating the solar zenith and declination combined with a DEM so that seasonal PRR influences are reflected (Pierce et al. 2005). It estimates the effect of insolation on slopes by summing estimates of clear sky radiation over the day. This yields a dimensionless index that captures local topographic influences on the relative radiation load. I derived solar inclination angle from a combination of solar zenith and azimuth, in degrees every 6 hours for each month (Appendix 3). This represented the average solar period for each month of the growing season at latitude of 47.2 degrees north, the geographic latitudinal center of Washington. I then calculated the hourly hill shaded radiation grids from 10 m DEMs. This yielded a monthly average of potential relative radiation, 12 seasonal maps of the radiation load on the landscape. Of these 12 grids seasonal PRR maps were averaged based on Rice's (2008) work defining seasons and all maps were resampled to a 30 m grid size. Though winter and summer start dates varied, Rice calculated median winter start dates generally trending towards the end of October and summer start dates at the beginning of June (Rice 2008). Consequently, I collapsed each monthly PRR grid into one grid representing summer (June through October) and one grid representing winter (November through May).

GPS DATA

Mountain goats selected for GPS collars came from populations near the Canadian Border to as far south as Mount Adams, 114 km east to west and 301 km north to south (46deg19'- 48deg57' N, 120deg25'- 121deg58' W) (Rice 2008) (figure 2). These animals occupy habitat in several United States Forest Service (USFS) and National Park Service (NPS) jurisdictions, including: the Mount-Baker Snoqualmie Forest complex, Okanogan, Wenatchee, Gifford Pinchot National Forests, as well as North Cascades and Mt. Rainer National Park. The land base includes a total of 19 USFS and NPS administered wilderness Areas: Mount Baker, Pasayten, Noisy Diobsud, Stephen Mather, Lake Chelan-Sawtooth, Glacier Peak, Boulder River, Henry M. Jackson, Alpine Lakes, Norse Peak, William O. Douglas, Clearwater, Mount Rainier, Glacier View, Tatoosh, Goat Rocks, Mount Adams, Indian Heaven and Trapper Creek Wilderness Areas.

Goat location data for this analysis were obtained from 46 animals spanning the years 2002 through 2007. Eleven captures were completed using ground based darting techniques and 35 were darted from a helicopter. After sedation, Vectronic GPS Plus-4 gps tracking collars were fitted and set to obtain fixes every 3 hours. Compliance with the Washington Department of Fish and Wildlife's Policy on Wildlife Restraint or Immobilization (M6003) was followed for all captures by WDFW personel.

Data Pre-screening

Animal location data collected using GPS collars include two types of bias, locational error and error from a missed location (D'Eon et al. 2002, Frair et al. 2004). Both forms of bias are influenced by topographic obstructions and vegetation (D'Eon et al. 2002, Frair et al. 2004, Di Orio et al. 2003, D'Eon & Delparte 2005). In an attempt to address some of this bias I explored the application of data screening methods developed by Lewis et al. (2007), which I subsequently applied to my data set. Lewis et al. (2007) developed a strategy to remove individual data points that were likely to have large location errors in an effort to reduce misclassification in resource selection studies. His study quantified collar performance in the Purcell Mountains of northern Idaho using data from stationary collars and collared free-ranging black bears. Location error, PDOP values and proportion of 3D fixes were influenced by habitat variables (Lewis et al. 2007). Additionally, location errors were larger for 2D fixes and were more variable at higher PDOP values when compared with 3D fixes (Lewis et al. 2007). Lewis et al.'s (2007) study identified the largest location error of 557 m occured among 2D fixes, which were obtained under dense canopy cover and when topographic features blocked reception to some satellites. Conversely, with no topographic obstructions and sparse canopy cover, maximum location error for 2D fixes was 253 m. While location errors can bias analysis, so can missed fixes. Missed fixes occur because GPS collars do not log positions on a continuous basis. In order to save battery power, they are typically programmed to turn on for just a few minutes every few hours. Topographic obstructions and dense canopy cover can prevent them from obtaining a fix during the brief time that the GPS receiver is turned on. These missed fixes can occur disproportionately in certain cover types. For example, in a study on GPS-collared mountain goats in east central British Columbia, Poole and Heard (2003), estimated that missed fixes for their study underrepresented forest use by about 23%. Lewis et al. (2007) evaluated data screening options based on collar performance. Lewis et al. (2007) presented 4 options for data screening; 1. removing all locations with a Position Dilution of Precision (PDOP)>10, 2. removing all 2D locations with a PDOP> 5, 3. removing all 3D locations with PDOP>10 and 2D>5 and finally 4. removing all 2D locations. Given the four screening options, he found that eliminating 2Dfixes with a PDOP greater than 5 eliminated most outlier locations. This option purged 63% of all locations with errors greater than 300 m errors from their data. I chose to apply option 2 to my data to address this issue, acknowledging that locations screeened out may introduce additional bias by eliminating fixes associated with habitats with poor satellite reception.

Wells (2006) developed a statistical model to predict GPS position acquisition rate in my study area using the same Vectronics collars and mountain goat data. His model explained 20-30% of the variation in position acquisition rate on the basis of vegetation and topographic variables. He and other authors (e.g., Friar et al. 2004) suggested the inverse of predicted position acquisition rate could be used to weight locations obtained from GPS-collared animals to correct for the bias introduced by missed fixes. His model was developed using stationary collars. Subsequent work by

Cain et al. (2005) and Sager-Fradkin et al. (2007) have demonstrated that position acquisition rates for GPS-collared animals is generally much lower than for stationary collars, probably due to poorly understood details of microhabitat selection and suboptimal antenna orientation resulting from animal movement and posture. Given this issue and relatively low predictive power of Wells' model, I elected not to use his model to weight locations obtained from GPS-collared goats in my study.

Based on the work by Lewis et al. (2007), I assumed that removing 2D fixes with a PDOP value >5 allow the greatest retention of data while still removing large locational errors from my data set. Therefore, I modeled screening options based on Lewis' (2007) work, a site with relatively similar habitat characteristics and latitude. This screening choice is the most suitable option to retain the greatest number of locations, essentially balancing the tradeoffs of data retention, minimizing the potential for seasonal bias, while still eliminating inaccurate locations. After prescreening the data, I summarized and partitioned the resulting information into manageable temporal units.

LANDSCAPE ANALYSIS – Data Extraction

The Path Versus a Single Location as a Unit of Observation

Analysis of telemetry data has traditionally treated each location as an independent observation. However, there is autocorrelation among these sequential locations at temporal scales ranging from hours to the entire year. This lack of independence violates one of the key assumptions of virtually any statistical analysis of this data type; nevertheless, the issue is often ignored (Cushman et al. 2005).To address this, I used the entire movement path (consisting of multiple points over some time period), as the sample unit.

In addition to autocorrelation, choosing the appropriate window size for analysis is an important consideration. For example, it is not clear whether animals are making movement decisions based on the condition of individual points (e.g. a single 30 m by 30 m grid cell) or on the basis of the general conditions of some larger area surrounding that point. To address this later issue, I first created rescaled versions of each of my GIS layers using a moving window function. For continuous variables (e.g. ruggedness), I used a focal mean function and for categorical variables (e.g. landcover type), I calculated the percentage of pixels in the window that were in each category. I used square sampling windows that were 1, 3, 7, 13 and 25 pixels on a side. The output grids still have the same 30 m cell size as the original starting grids but the cell values are an indication of the condition of the surrounding cells. For example, when running a focal mean with a 3 by 3 window size on the ruggedness grid, the value for a given location in the output grid represents the mean ruggedness for the 9 grid cells centered on that location in the original 30 m resolution ruggedness grid. Including the original 30 m grids, this enabled me to evaluate habitat selection at five different spatial scales (0.09, 0.81, 4.4, 15.2, and 56.2 ha). Generating these grids is a CPU-intensive operation. For example, in the case of a focal mean calculation with a 7 x 7 window there are 49 add calculations and a divide calculation for every input pixel. A single grid may contain over 55,000,000 pixels.

My analysis involved the comparison of movement pathways of GPS-collared mountain goats to available habitat located nearby. Used paths are based upon year-long or season-long sets of locations from GPS-collared mountain goats. For each set of used locations, five available paths with identical spatial topology were created by randomly shifting and rotating the corresponding used path. These paths were shifted a random uniform distance between 0 and 30 km in a randomly selected direction from the centroid of the used path (mean of 15). These paths were then randomly rotated an angle between 0 and 360 degrees (Cushman pers. comm.). The characteristics of each pathway, both used and available, were described by extracting data for each of the vegetation and abiotic variables at all 5 spatial scales (Figure 3). For all variables, the path was described on the basis of the mean for all of the locations that made up the path (e.g., mean distance to escape terrain for all locations on the path or mean percentage of a given cover type for all locations that make up the path). Used paths were compared to available paths. Using the full-year paths, I initially screened each variable and each scale (to compare used and available paths) with a univariate Wilcoxon sign rank test. For each variable I retained the scale with the lowest significant ($p<0.05$) *P*-value for use in a matched case regression analysis. The Wilcoxon tests allowed me to determine the variables and scales that are the strongest predictors of mountain goat habitat to include in model building.

STATISTICAL PROCEDURE

I developed methods to maximize the discriminate ability and determine relative importance of habitat selection of different landscape variables discussed above. For example, matched case methodology for seasonal analysis allowed me to refine the possible variables that may influence habitat choice by partitioning the data set based on seasonal movements. To allow comparisons between used and available resource units, I created models following Manley et al.'s (1993) description of design 2 and sampling protocol C (SPC) using actual goat paths (used habitat) and available habitat paths (random paths-with the same topology as used goat paths) per each goat-year, summer and winter season. The goat-year is defined as one summer and consecutive winter per-individual. I produced five randomized matched habitat paths for each goat-year, and also separate paths for each summer and each winter season. The resource selection functions model the relative probability of habitat as a function of vegetation and abiotic variables using a matched case statistical procedure. Candidate habitat variables used in modeling include: descriptions of escape terrain, and potential relative radiation, as well as two land cover data sets based on the Interagency Vegetation Mapping Project (IVMP) and Washington's Gap Analysis (GAP) encompassing 6 broad categories measuring both vegetation structure and composition (O'Neil et al. 2002, Browning et al. 2003, based on Comer et al. 2003)

Scaling

Seasonal paths varied according to individual and were determined based on the seasonal scaling work of Rice (2008), who uses a measure of vertical movement to optimize the definition of summer and winter seasons. The median summer start dates for all goats and all years was 06 June and for winter, 19 October. The latest winter start date from 2003-2005 occurred on 01 November. Median season lengths were 4.60 months for summer and 7.32 months for winter, however dates varied considerably (Rice 2008). Mountain goat fix elevations ranged from 335-3,089 m with medians of 1,037-2,171 m. Exceptions to season assignment were made for 1 female and 2 male goats. One female residing on the eastside of the Cascade crest (048LCF) was assigned summer start dates based on the median of other females in this region because her movements included higher elevation winter fixes. Two males (009GRM and 039NPM) were dispersers and were assigned seasons after their dispersal.

I also attempted to use spatial scaling to optimize the modeling effort. I extracted data from used and available paths representing 5 scales of analysis: 0.09, 0.81, 4.4, 15.2, and 56.2 ha (1, 3, 7, 13, 25 pixel) square extraction windows, including the original 30 m data set. Identifying both temporal and scales such as the division of winter and summer, allowed me to take into account all necessary life requisites needed for mountain ungulate survival. For example, in an analysis on female bighorn sheep, Bangs et al. (2005) found that female bighorn sheep selected ruggedness at a 6.25 ha scale during spring when lambing occurred.

Logistic Regression Analysis

Following a complete non-parametric univariate analysis to select variables at the appropriate spatial scale, I compared environmental attributes at mountain goat locations to the attributes at random locations using logistic regression analysis. I ran regression procedures in SAS version 8 using the PROC LOGISTIC command. In logistic regression it is assumed that the units are correctly classified as selected (used=1 vs available=0). The logistic function is then fit by regression of 1's and 0's on predictor variables. Predictor variables $x_1, x_2 \ldots x_p$ are then analyzed using logistic regression to estimate use within the study area. Using a matched case procedure, the process of model building, assessment of fit, and interpretation of odds ratio is similar to basic logistic regression models, the difference being that the available locations are sampled in the vicinity of each of the used locations. I sampled matched design data by deriving a single value for each individual goat-year and goat-season. Matched case study design addresses the natural grouping of the data, the "longitudinal nature" of the data set. Points associated with individual goats are thus a reflection of an individual goat's responses at multiple points in time. Traditional logistic regression analysis typically produces standard errors that are underestimated and test statistics that are overestimated. Matched designs essentially deals with this by using available locations that are a reflection habitat that is available to a particular animal at a particular place and time; availability of a resource is essentially restriced in space. The resulting regression equations predict the probability of resource use on the basis of a series of habitat variables.

I considered the removal of abherent data as outliers have been found to substantially change the conclusions of regression analysis for matched designs. It has been recommended that, even with large data sets, identification of influential observations should be a necessary component of the matched case-control analysis (Moolgavkar et al. 2006). Data was visually checked in ArcGIS so that I could locate abherrent or ecologically impossible data. I subsequently identified and removed one outlier, goat-year path, from the data due to several of the random locations occurring in Canada; an area for which my GIS coverages are incomplete.

I developed a series of candidate models *a priori* according to likely biological importance of variables associated with mountain goat habitat (Appendix 2). I created competing models, including the global model, and compared them using Akaike's Information Criterion (AIC). AIC is a statistic based on the amount of information in the data that is explained by the independent variables discounted by the number of variables in a model.This is a representation of the difference between any given model and the most parsimonious model, as estimated by the lowest AIC value.

Model Validation

For the full-year, summer and winter datasets, 75% of the paths were randomly selected for use in model development with the remaining 25% of the paths reserved for model testing (Wells 2006, Gross 2002). Validation of the regression models includes two key components; reliability and discrimination (Pearce and Ferrier 2000). The former is how well the predicted probabilities reflect the observed resources selected while discrimination refers to the capability of the model to correctly distinguish between used and available sites. To understand the limitations and appropriateness of the each statistical model, I determined the discriminate ability of my most parsimonious model by calculating the area under the receiver operator characteristics curve (ROC) using the trapezoid rule. The logistic regression model provides a predicted probability that a given path is either a used goat path or an available path. At any given probability level some paths are correctly classified and others are incorrectly classified. The classification accuracy varies as a function of the probability level that is used as the "cutpoint." For the full range of probabilities, the ROC is a plot of the fraction of the goat paths that were correctly classified (true positives) against the fraction of random paths that were incorrectly classified (false positives). The area under this curve equals the estimate of overall predictive accuracy. For an ROC curve, a value of 0.5 indicates there is no improvement beyond random assignment based on explanatory variables and a value of 1.0 indicates perfect discrimination. The same data that goes into an ROC curve can also be used to determine the cutpoint or decision threshold that simultaneously maximizes the true positives while minimizing the false positives. This involves plotting two curves on the same graph. The first curve plots the true positives (fraction of goat paths that are correctly classified) over the full range of predicted probabilities. The second curve plots one minus the false positives (fraction of random paths that are correctly classified) over the full range of the predicted probabilities. The intersection of these two curves represents the optimum cutpoint.

Habitat Maps

As discussed above, the models were developed using the goat path as the unit of observation. The advantages of this approach have already been discussed. The disadvantage of path analysis is that it makes it problematic to generate a habitat map. To do so, I was forced to switch from a path to a moving window approach. The models that were developed for paths were applied to a square sampling window. The same predictor variables that are used in the path analysis were generated for this sampling window. The probability generated by the model is assigned to the central pixel in the sampling window, the window is shifted and the calculation is repeated. I selected a window size that was large enough to include a substantial portion of an animal's home range but was also small enough to be computationally feasible. I selected a window size of 25 x 25 pixels. This scale, 0.56 km^2, approximates the smallest size of a summer core home range, 0.59 km^2, for this population. This moving window approach yielded continuous probability maps based on the full-year and seasonal models. For each of these three maps, I used cutpoints derived from the model building datasets to generate categorical maps, that delineate habitat and non-habitat**.**

RESULTS

GPS Data

The original goat data included 236,946 fix attempts from 46 animals between 2002 and 2007. Twenty eight percent of the fix attempts were unsuccessful in that the GPS unit did not obtain a location due to interference of the satellite signal by topography or vegetaion. Some successful fixes were deleted for various reasons (Table 3). For example, goats traveling continuous distances greater than 6 km from the median of the seasonal distribution were considered outliers and removed from the data set (Rice 2008). Observations that included dispersal behavior were also removed and were identified by those individuals that did not return to a seasonal range (Rice 2008). Eliminating 2D fixes with a PDOP>5 as suggested by Lewis et al. (2007) purged 5.2% of the data. Overall, the outliers, goats with <10 months of data, dispersal behavior and 2D fixes with PDOP>5 accounted for deletion of 13.4% of the total successful fixes leaving 138,846 locations for use in my analysis. For comparison, Table 3 also shows the percent of data that would have been deleted by using several more aggressive screening options suggested by Lewis et al. (2007) that were previously discussed.

Data collected from 46 GPS collared mountain goats represented 33 adult females and 13 adult males ranging in age from 3 to 6 years old. Total fixes for each goat ranged from 919 to 5,837 with a mean of 3,018 fixes and a standard deviation of 1,378. Inspection of the data points showed little overlap in the areas used by collared goats. Data spanned a six year period with 2 to 3 years of data per goat. Most data were obtained during 2004 and 2005 (Table 4). There are 81,588 locations representing the winter season and 57,258 representing summer, for a total of 138,846 locations. Some collars functioned intermittently and most collars were only active for a window of the study period. Some collars failed after one year and other animals' collars functioned for over three years. When possible, animals with nonfunctioning collars were subsequently recaptured and re-collared. Consequently, data from some goats does not span the entire study period.

Escape Terrain

Prior to using univariate optimization to identify the appropriate scale for analysis I evaluated several alternative definitions of escape terrain. I compared escape terrain for used and available locations on each of the eight candidate escape terrain grids. All showed exceedingly low *P*-values using the Wilcoxon test. Subsequently, to determine which escape terrain grid had the greatest difference between used and available goat locations I relied on a combination of the lowest V-values (Table 5 and definitions of escape terrain in the literature. Though p-values were equally good for slopes from 30-45 degrees, and slopes of 35 degrees and greater had the lowest V-value, I wanted to include the largest amount of escape terrain so that small habitat patches with the potential to provide travel corridors to larger habitat would not be missed. Combining my results from the Wilcoxon analysis, and definitions of escape terrain consistent in the literature, I subsequently defined escape terrain as terrain above 30 degrees.

Univariate Optimization

Multiscale Analysis

Initially, I investigated the effects of a progressively larger moving window of analysis on habitat choice; 1, 3, 7, 13, and 25 pixels derived from a 30 m original for each variable. Theses scales were chosen to represent the possible landscape scales at which mountain goats might perceive and interact with their environment. To compare the predictive power of various window sizes, I chose the Wilcoxon sign rank test because it is a nonparametric test that allows comparisons when distributional assumptions cannot be met. This multiscale analysis generally identified the smallest scale, that is, the original 30 m DEM as having the greatest contrast between used and available paths as indicated by the P-value. When P-values were exceedingly low and indistinguishable from each other I subsequently relied next on the lowest V-value to indicate which variable had the largest difference in the medians. Some V-values were slightly lower at the 3X3 window size; however, the improvement over the 1X1 window size was negligible. Because of this, I chose to standardize the data set so that all variables were extracted from the 30 m x 30 m original size. This chosen subset of variables from the multiscale analysis (table 5), based on the lowest P-value, is indicated in bold. This subset is used in both the seasonal and full year analysis.

Matched Case Regression Analysis-Full Year

A priori, I selected eleven candidate models that included combinations of 8 variables that likely influenced the probability of mountain goat occurrence in complex landscapes (Table 7). For year-long habitat selection in the Washington Cascades, represented by points along a path, the model that best fit the data included parkland, ruggedness, potential relative radiation and escape terrain. This model had substantial support compared to other models, albeit, subalpine parkland, ruggedness and escape terrain were included in all of the top 4 models, with a combined AIC weight of 0.99 (Table 7).

Interpretation of ΔAIC scores follows general comparison rules when ranking competing models. The larger the delta AIC value, the less likely the model is the best approximation of habitat selection. The general conventions for interpreting ΔAIC scores is that models with scores ≤ 2 have substantial support, values 4 ≤ ΔAIC ≤ 7 have far less support, and models with ΔAIC >10 have little to no support (Burnam and Anderson 2002). In the context of the ΔAIC scores the top 2 models have substantial support. Additionally, Akaike weights (w_i) provide another measure of the strength, indicating that of the models considered, subalpine parkland, ruggedness, potential relative radiation and escape terrain, has a 51.5% chance of being the best model. The next most likely model has a 20.8% chance of being the best model (Table 7).

The global model (Table 8) was not the best model. Furthermore, all variables in the best fit model, are significant (P>0.05) (Table 8 and 9). All variables in the best fit model were significant (P>0.05) and respective coefficients were positive (Table 9).

Matched Case Regression Analysis - Seasonal (Winter and Summer)

For the seasonal data, I selected, *a priori*, twenty-five candidate models. I wanted to include the impacts of seasonality, more specifically, the effects of snowpack on habitat selection. Therefore, in addition to the previously tested landscape variables, I included an additional parameter, tall shrubland, to account for forage access to vegetation during winters with deep snowpacks. I evaluated the same set of twenty-five models for both winter and summer paths in an effort to reveal seasonal differences in the relative importance of different habitat features. The number of paths for the seasonal data was smaller than for the year-long data, n = 100 for winter and n = 95 for summer respectively. This was because meeting the criteria for season lengths was required, otherwise goat paths with less than the predefined season length were eliminated from the seasonal analysis. As with the year-long models, I used AIC to select the best model from models in the candidate set for winter and summer seasons (Tables 10 and 13).

For winter habitat selection, the model that best fit the data included grassland, subalpine parkland, mid and high canopy cover, potential relative radiation, ruggedness tall shrubland and escape terrain (Table 10). Of these variables, parkland, potential relative radiation, escape terrain and tall shrubland were also included in the top 8 models (ΔAIC < 4) (Table 10). Compared to the full year model, the winter model includes all the variables contained in the full year model in addition to grassland, mid and high canopy cover, potential relative radiation as well as tall shrubland. However, weighted AIC indicates that the top model has only a 16.3% chance of being the best model. In fact, the top two models are competitors at 16.3 % and 16.1% chance of being the best model. Additionally, the top competing 7 models share substantial support for being the best model (ΔAIC < 2).

The global model for the winter season (Table 11) was not the best model. Four variables in the global model, that were in the best fit model, were not significant ($P>0.05$) (Table 11). All variables in the best fit model with the exception of high canopy cover were significant ($P>0.05$). Contrary to expected selection direction, coefficients were negative for tall shrubland and high canopy cover indicating avoidance of these features during winter (Table 12).

Summer habitat models provided a different picture of resource selection. The model that best fit the data for the summer season included grassland, subalpine parkland, high canopy cover, ruggedness, escape terrain, and tall shrubland (Table 13). AIC weights for the summer model, similar to the winter model, indicated that support for a distinct top model is unclear. The two top models were only 22.0% and 18.3% likely to be the best models when considering the candidate set. Compared to the best winter model, the best summer model included all the variables contained in the winter model with the exception of potential relative radiation and mid canopy cover.

Once again, the global model for the summer season (Table 14) was not the best fit model for this season and did not have substantial support for being the top model (ΔAIC> 2). All but one variable, in the global model, which was also included in the best fit model, was significant (P> 0.05) (Table 15). All variables in the best fit summer model with the exception of high canopy cover were significant (P> 0.05). Like the winter model, coefficients were negative for tall shrubland and high canopy cover (Table 15). Subalpine parkland, escape terrain, ruggedness and tall shrubland were all variables in the most parsimonious model and were also included in all of the top models (Table 13).

The distinction of the most parsimonious model for the winter and summer data set is more ambiguous than that of the full year data. All of the top models in all seasons consistently contained three of the same variables, notably; subalpine parkland ruggedness and escape terrain (Table 16). The importance of solar radiation was identified in all of the top winter models; conversely, ruggedness occurs in all the summer models, though the reverse is not the case. Among the suite of top winter models, there was negative selection for tall shrubland and high canopy cover and for top summer models, negative selection for tall shrubland (Table 16).

Mulitmodel Inference

For all of my data sets, models competed for top rank. To accommodate the top ranking models and still allow for inference based on the relative importance of variables, I averaged the top models. This approach, termed, multimodel inference, relies on weighting each parameter of the top models with a weight based on a confidence set of models (Burnham and Anderson 2002). I determined the confidence set by obtaining a 95% confidence set on the actual best model, summing the Akaike weights from largest to smallest until that sum is just >or equal 0.95. I recalculated model weights using only models within the confidence set into a composite model for yearly, winter and summer seasons (Table 17). Using these composite models, I calculated the predicted use probabilities for each used and available path in both the model building and testing dataset. I then calculated the area under the receiver operator characteristics (ROC) curve and determined an optimum cutpoint for each model using the model building datasets. Finally, using these cutpoints, I determined classification accuracy (Table 18). For all models and datasets, the area under the ROC curve was quite high, indicating very good discrimination for all models. Similarly, the classification accuracies are quite high. Since the model testing data were not used in any way for model building, the results from these datasets provide an unbiased estimate of model performance. Since the results (both area under the ROC and classification accuracies) for these datasets is nearly as good or better than the results obtained using the model building datasets, this suggests that the models are quite robust.

The composite models were also used to generate maps depicting the predicted probability of use. As described above, these maps were generated using a 25 by 25 pixel moving window. These maps (Figures 5-8) indicated the predicted probability of a goat occupying any portion of the study area year-round and seasonally. The year-round continuous probability map was derived from a composite logistic regression model that included the following landscape parameters; Subalpine parkland, landscape ruggedness, potential relative radiation and escape terrain (Figure 5). A small subset of the year round habitat map with collared mountain goat locations overlaid for comparison is shown in Figure 6. Maps depicting the continuous probability of mountain goat habitat for winter (figure 7) and summer (figure 8) were derived from composite logistic regression models averaged in the same manner as the year long models.

By appling the cut points derived from the model building datasets (Table 19) to the continuous probability maps, I created categorical maps that represent the landscape as either goat habitat or not (figures 9-12). These dichotomous maps identified 1,964 km^2 of habitat for the full year analysis, 2,606 km^2 of winter and 3,048 km^2 for summer respectively (table 19).

As a final assessment of the validity of applying the path-based model in a moving window framework, I overlayed the used and available points on the categorical maps. The resulting classification accuracy for these points is reported in table 20. The percent of available sites correctly classified as non habitat and percent of used sites classified as habitat for full year, winter and summer data sets based on cut-off values derived in table 18 did not show results that reflect good classification accuracies using this method. Additional work will be needed to evaluate the effect of different cutpoints on classification accurracy. Furthermore other approaches may be needed to generate maps from the path-based models.

DISCUSSION

In this study, I included variables in each of the three separate analyses based on expected ecological relevance for each season and full year set of data. I chose to forgo inputs that were highly stochastic, or logistically challenging to measure. Of these, human disturbance, weather, and snowpack likely affect the relative abundance of metapopulations and seasonal occurrence of mountain goats in any particular area. For example, the winter of 2004/2005 had a much different snowpack than average. I could have modeled years separately, though this would have inherent problems in subsequently weighting the models to account for snowpack data. Rather than modeling individual years, I attempted to indirectly account for the effects of snowpack on habitat selection. Previous research suggests that access to vegetation, such as tall shrubland, during deep snow events may be an important element of winter habitat selection by mountain goats (Festa-Bianchet and Cote 2007). Therefore, in addition to the landscape variables used for the full year data, I included an additional parameter, tall shrubland, for the seasonal models. I expected selection to be positive for tall shrubland during winter, reasoning that given deep snowpacks, such as those in the Cascades, any access to vegetation would be advantageous during winter months.

I also expected greater canopy cover to be selected during winter. A study on the habitat selection by moose found that moose tended to use closed canopy forests in winter, mainly old spruce stands. This study suggests closed canopy forests are important for snow interception, reducing snow depth and resulting in decreased energy costs (Ball et al. 2001). Research on Alpine ibex suggests yearly changes in total population size were correlated with seasonal average snow-depth primarily driven by adult survival from mild winters (Jacobson 2004). Coastal areas, that generally have deeper snowpacks than that of the interior, contain mountain goats that are generally associated with escape terrain on southern aspects with interspersed low volume stands of short trees, or with moderate volume stands of old large conifers (Herbert and Turnbull 1977, Taylor and Brunt 2007). Interior mountain goat ecotypes show high variability in space use during the winter season. These populations generally either overwinter on high elevation open, windswept slopes in areas of shallow snow packs, or as was the case in deep snow areas, did not seek mature forests with decreased snow depth (Poole et al. 2009). In the study by Poole et al., topographic variables were the primary determinants of goat habitat selection (Poole et al. 2009). Generally speaking, access to escape terrain, increased terrain ruggedness, southern exposures, and in some cases forest volume were the main determinants affecting witner habitat selection (Poole et al. 2009, Taylor and Brunt 2007). My results indicate avoidance of both high canopy cover and tall shrubland during both summer and winter. Though surprising, some research indicates scale of selection is an important consideration. Ball et al. (2001) found that habitat selection on a fine scale, such as daily feeding areas, is snow dependent. Conversely, the selection of whether or not a specific geographic locale will be exploited as a home range, is not. Selection of high canopy cover and tall shrubland by mountain goats may not be advantageous; rather these elements may impede visibility, which is important for predator avoidance.

Alternatively, the apparent avoidance of sites with high conifer cover, and perhaps tall shrub, may be an artifact of poor GPS collar performance in these sites. Wells (2006) analyzed the effect of vegetation structure on position acquisition rate using the same Vectronics GPS collars that were used in the current study. His predictor variables included the IVMP percent conifer cover layer that I used but he did not have access to the GAP vegetation layer. He found that the position acquisition rate was inversely related to percent conifer cover. Hence, my results could reflect poor GPS performance in these sites rather than true avoidance of these sites by goats.

Spatial scaling issues were initially addressed, based on the findings of several studies, through univariate optimization. Past attempts to extrapolate predictions using one spatial scale in a model have resulted in low predictive power and low classification accuracy (Beever et al. 2006). Additionally, multiscale RSF's applied to a study area are more predictive of species distributions than unconstrained single scale models. In a meta-analysis conducted by Meyer and Thuiller (2006), multiscale RSF's were better than single scale RSFs 66% of the time with landscape to regional scale (> 100 ha) home ranges. Multiscale models are also important when considering meta-population theory and the dispersal ability of a species through a matrix of poor surrounding habitat patches. Indeed, the patterns of animal distribution from resource selection studies reflect processes made at a variety of temporal and spatial scales (Bailey et al. 1996). In a multi-scale analysis, Boyce (2003) determined that for some species and environments, simple patch-scale analysis may not highlight the range of spatial variation in which the organism responds. Kie et al. (2002) evaluated the relationship between multiple landscape metrics at varying home range sizes for mule deer with habitats across California. They found that at successively smaller spatial scales, models explained less of the variation in home ranges. In another study, Johnson et al. (2001) examined spatial and temporal heterogeneity of caribou environments with respect to their foraging behavior and how selection decisions varied across spatial scales. At fine scales (feeding sites), caribou in forested and alpine environments selected areas where the biomass of a particular lichen species was greatest and snow depth was least. The temporal scales at which they were selected varied. This indicated that foraging behavior was driven by forage abundance or accessibility of the forage and spatial scale effects varied for selection at the feeding site, patch and landscape (Johnson et al. 2001). Foraging selection generally operates at finer scales while predation, dispersal and other population level process operate at larger scales (Bowyer and Kie 2006, Boyce 2006). Boyce (2003) recommended that for mobile animals that range across heterogeneous environments, such as mountain goats, integrating multiple scales of predictor variables into resource selection models may be prudent, though selection of a particular resource will be more likely to vary when there is a high degree of topographical relief, such as that which mountain goats occupy. Meyer and Thuiller (2006) advise that multiscale RSF's should be incorporated into studies attempting to map species distributions. Not only should studies used to develop a species distribution map use more than one scale, these scales should reflect the life-history and dispersal/movement patterns of the species under study (Vaughan and Ormerod 2003, Beever et al. 2006, Meyer and Thuiller 2006). These recommendations guided the methodological development for my analysis, hence the initial multiscale analysis. In hindsight, multiscale analysis may have proven more useful for a fine scale study. However, constraints on available digital data as well as the size of the study area made fine scale analysis impractical. Furthermore, management objectives required analysis of a larger area than could practically be accomplished using fine scale analysis. Additionally, scales larger than the available 30 m grid data were no more predictive; therefore, I opted to implement this analysis using only data standardized to grid cells of 30 meters in size.

The available mountain goat GPS data determined the extent and the domain of availability (random paths) of habitat for this analysis. It also had the advantage of being collected at 3 hr intervals over several years so that temporal scales were addressed as a result of a sequential series of events. This is important because, when the temporal resolution or extent is not considered, variation in resource use on a seasonal or annual scale may be missed or misinterpreted (Beever et al. 2006). Deciding on the domain of availability in which goats choose home ranges should follow the specific objectives for management of the particular resource or organism (Vaughan and Ormerod 2003, Meyer and Thuiller 2006, Beever et al. 2006). This study was developed to address region-wide, inter-annual resource selection by mountain goats and was guided by management objectives noted by Washington Department of Fish and Wildlife's (WDFW) game management plan.

An objective of WDFW's game management plan (2009-2015) is to document the amount and distribution of suitable goat habitat across the Cascade landscape. Achieving this objective requires an understanding of the elements of topography and vegetation that are essential to meet goat life history requirements. A further WDFW objective is to achieve detectable population increases by 2015 throughout the Cascades (Washington Department of Fish and Wildlife 2008). WDFW developed several strategies to manage the Washington mountain goat population. These include; maintaining hunting closures in units with less than 100 goats, mitigate causes of population declines as new information becomes available, and developing a relocation plan for populations in need of augmentation that have suitable habitat. This plan will encompass a rationale and justification for relocation as well as priority areas for relocation (Washington Department of Fish and Wildlife 2008). My work identified the suitable elements and combination of those elements of habitat necessary for potential home ranges. It does not however attempt to identify viability of metapopulations, rather it identifies the landscape available for these populations to be established.

Future Efforts

Future efforts may benefit from focusing on knowledge gleaned from this study as well as considerations from concurrently developed research projects on resource selection by mountain ungulates. Though my analysis intended to describe “average” habitat selection across all ages, sex, years and dominance categories, highlighting specific examples that support nuances of habitat selection is important. For example, it is known that adequate summer and winter habitats, within reasonable proximity, as well as travel corridors between them, are a necessary requisite for population persistence. Shannon (2008) discussed several factors that contributed to unsuccessful bighorn sheep reintroductions, including improper juxtaposition of key habitat elements and lack of one or more critical seasonal ranges. Though data for this study was partitioned by season, partitioning by sex is also biologically relevant. For example female mountain goats, like other mountain ungulates, consistently use steeper, more rugged terrain, during the kidding season than males (Bleich et al. 1997). Hamel and Cote (2007) found that space use by female goats with young during the month of June was on average 20 m closer to escape terrain than females without young. Because kids are particularly vulnerable to predation during June, their first month of life, it is likely that lactating females were trading forage abundance for safer areas during this time. There are also differences in the mobility of nanny bands compared to other cohorts of goats. For example, Festa-Bianchet and Cote (2007) found that nursery groups were much more mobile and that adult males tended to remain in a smaller spatial distribution for their Caw Ridge population. They speculate this is an antipredator strategy and that home range size and carrying capacity for females may have more to do with access to larger areas of escape terrain than summer forage availability. This difference is not known to occur in winter. Future research would benefit from long term studies including the effects of sex on habitat selection to ensure natal areas are adequately accounted for as the effects of sex and age on population persistence and structure is intimately tied to population growth rate, and may be independent of resource availability. Understanding mountain goat population dynamics may certainly benefit from long-term studies (Festa-Bianchet and Cote 2007).

Though useful for management of current seasonal ranges, my model may not accurately describe historic or future habitat selection given changing climate conditions. Annual vegetative productivity has shaped the ecology and evolution of Pleistocene herbivores including mountain goats whose behavior and physiology seem to be especially associated with seasonal pulses (Geist 1987). Because weather determines the pulse of annual forage supply, it is appropriate to consider future climate conditions in the context of available habitat and in anticipation of adaptive management. Water content in the Cascades due to snow is expected to decrease by an average of 38% to 46% by the 2040s and 56% to 70% by the 2080s. The consequences of this projection will likely affect seasonal stream flow timing in snowmelt dominated watersheds due to the decrease in snowpack (Littell J. et al. 2009). Additionally, an upward shift in treeline may force populations to rely on continually shrinking islands of habitat. Subsequently, the future of what mountain goat habitat may look like and the resulting potential for translocations and other adaptive management techniques is an important consideration. James and Moskal (2008), describe a technique for using EVI (Enhanced Vegetation Index) extraction from MODIS (Moderate-resolution Imaging Spectroradiometer) to provide a snapshot of the quality and quantitiy of habitat and to identify habitat predictor variables correlated with mountain goat home ranges. This may prove useful in identifying current habitat and potential declining trends in habitat condition.

Inbreeding and habitat identification may also be influenced to some degree by management history. For example, within the area between highway 2 and I-90 between 1948-1970, approximately 800 mountain goats were harvested (Rice, pers. comm.). Additionally, 50% of goats shot in Washington between 1970 and 1985 were female (Johnson 1986). Both aspects of harvest will likely affect population dynamics in this region for decades to come. At ths same time, habitat selection may vary somewhat for heavily hunted populations compared to populations that have not been hunted. Research by Shirk (2009) indicates that the northern and southern portions of the Washington mountain goat range study area exhibit low heterozygosity and allelic diversity and high inbreeding levels. Low diversity in the south is consistent with the amount of mapped available habitat. This region of habitat is at the southern end of the coastal mountain goat range (Shirk 2009), and is also dominated by islands of habitat, those wich surround the dispersed volcanoes in this region. This combination of topographical characteristics may impede the ability of mountain goats to disperse between populations and breed. Inbreeding depression is also evident in the northwestern terminus of the Washington Mountain Goat

Population in the area around Mt. Baker (Shirk 2009). Dispersal into an out of this area is impeded by the Frasier lowlands to the north, the Skagit valley to the south and Ross and Baker lakes to the east. Importantly, the management plan for mountain goats in British Columbia recognized decreased numbers and distributions of goats along the southern border of British Columbia. For example, the Similkameen/Ashnola populations are either absent or occurring at low numbers, notably half of what existed in the early 1980's (Mountain Goat Management Team 2010). Though the British Columbia and Washington Cascades are a coherent geologic unit, political boundaries influence the ease with which analysis can be performed and resulting inferences can be made across borders. In the context of findings by Shirk (2009), and British Columbia's Mountain Goat Management Team (2010) future proactive management and recovery of these populations should consider the effects of management north of the border. Additionally, I propose that the question of why there are few goats in the Picket Range may be better approached from both sides of the border.

Future modeling efforts may also want to consider the separation of cover habitat as two functional categories, that which supplies thermal cover, and that which provides visibility to escape predators. Visibility to escape predators is a component to this study's definition of escape terrain, but was not the primary focus. Rather, the focus was on topography rather than view-shed. View-shed is an additional element of predator avoidance that may be successfully incorporated as a predictor variable in future analsysis. Festa-Bianchet and Cote (2008), documented almost all of the successful predation attempts in or within 50 m of forest cover. They also found that the type of goat cohort differed in forest use. Nanny bands were seen in forested areas only 8.8% of the time while male groups were seen 45% of the time in forested areas. In my study it appears that seasonally, goats are selecting away from forested environments. Though one must acknowledge the inherent gps bias associated with forested environments.

GPS and observational bias aside, it is clear that habitat selection by mountain goats is not as dependent on vegetation composition as it is on vegetation structure since mountain goats are generalist herbivores (Cote and Festa-Bianchet 2003). Although the presence of escape terrain likely influences patterns of vegetation use, diets may not be dictated by a preferential selection of a particular species but rather, more by available plant resources in general. Mountain goats may select particular species of plants locally, however, those same species of plants may not be selected in another region. Several studies have noted consistent selection for physical habitat elements, such as escape terrain rather than particular plant communities or species composition (Brandborg 1955, Adams and Bailey 1982, Fox et al. 1989, Stevens 1979, Pfitsch and Bliss 1985). For example, Pfitsch and Bliss (1985) in a study on mountain goats in the Olympic Mountains found that goats used all nine subalpine and alpine plant communities in one region. Findings by Hebert and Turnbull (1977) indicate differences in seasonal habitat use by coastal versus interior mountain goat populations. I propose that at least for the seasonal data, any additional analysis of habitat should include viewshed as a predictor variable and should consider not only partitioning data by sex but also by goat ecotype. This would promote the appropriate identification of mountain goat wintering areas based on locality rather than on inferences from a region-wide study area.

From a methodological standpoint, point level analysis is generally the accepted method of data extraction for these types of analyses. Indeed, it would be useful as a comparison to this path-level approach using the same data. This would reveal trends associated with the use of autocorrelated data and the influences this may have on the outcome probability in a resource selection function. Another approach may be to extract data from a polygon that defines the extent of the home range, defining extraction as area, rather than path. An area such as a square sampling window centered on each individual animals home range and sized to the average size of a home range, may be used in this context revealing habitat selected in terms of home range extent, rather than home ranges defined as cirquitous pathways. Finally, a remote sensing approach, could use maximum likelihood classifiers or principle component analysis to describe habitat characteristics selected by mountain goats.

Our methodological approach represents potential improvements in identifying resource selection within the construct of pattern instead of distinct location units. These models compete to explain movement and habitat selection throughout the year and for respective seasons. The matched case logistic regression approach provided the advantage of mapping predictive spatial distributions as a function of the characteristics of the environment. Path analysis allowed data integration as spatial units of time, rather than instances, providing a dimensional representation of complex habitat use. Though computationally intensive, path analysis revealed the suitability of goat habitat in context of the surrounding neighborhood rather than a single point. In ecological terms, path analysis is a more realistic representation than considering habitat on a pixel-by-pixel basis.

TABLES

Table 1. Mountain goat estimates for various zones in Washington State, excluding the Olympics and Selkirks based on estimates and surveys from 2004-2007 combined 90% CI.

Zone	Estimate 90% CI 2004-2007
Mt. Baker	424-461
North Cascades National Park	61-99
Okanogan	91-120
Pasayten	16-35
Mt. Chopaka	10-30
Snowking Mtn.	20-40
Darrington	83-131
Glacier Peak	5-30
East Central Cascades	120-224
Lake Chelan	150-265
Sultan River	14-40
Olympics	264-316
Snoqualmie	24-75
East Alpine Lakes	48-81
Cedar and Green Rivers	16-28
Southeast Cascades	243-284
Mt. Rainier	136-196
Packwood	364-391
Mt. St. Helens	15-25
Mt. Adams	105-265
All	**2291-3056**

Table 2. GIS data grids representing initial habitat variables used to select candidate models for mountain goat habitat from the Cascade Range study area, WA.

VARIABLE	DESCRIPTION	Analysis Type
LANDCOVER OR VEGETATION CATEGORY	**COMPOSITIONAL OR STRUCTURAL FEATURES OF VEGETATION**	
GAP ANALYSIS (GAP) Subzone variant	Categorizes functional relationships and compositional associations of vegetation based on Landsat 7 ETM+ (Enhanced Thematic Mapper) imagery from circa 2000	**Proportion of cover type**
Forests and Woodland	1. Douglas and Silver fir, Ponderosa and Lodgepole pine, Hemlock, Spruce-fir, Larch, mixed conifer	
Shrubland (short and tall)	2. Alpine dwarf shrub, meadow, tundra (short) 3. Broadleaf landslide, avalanche chute (tall)	
Grassland	4. Alpine and subalpine grassland	
Subalpine	5. Subalpine parkland	
Sparsely OR non-vegetated	6. Bedrock, scree, cliff and icefield	
INTER-AGENCY VEGETATION MAPPING PROJECT (IVMP)	Identifies structural attributes of vegetation based on landsat data from mid 1990's	**Proportion of cover type**
Total Conifer Cover (CON)	7.Conifer cover 0-100% 3 categories	
ABIOTIC FEATURES	**TOPOGRAPHIC OR RADIATION FEATURES**	
ESCAPE TERRAIN	8. Slopes > 30 degrees	**Proportion of cover type**
TERRAIN ROUGHNESS (VRM)	9. Landscape roughness 3 dimensional vector dispersion	**Focal Mean**
POTENTIAL RELATIVE RADIATION (PRR)	10. Seasonal radiation based on topographical context	**Focal Mean**

Table 3. Percentage of goat data deleted from original data set of 236,946 fix attempts, as well as comparison of data in study by Lewis et al. 2007.

Data screening explanation	Percent deleted from total fixes
Unsuccessful fix attempts	28 %
Outliers	0.7%
Goats with <10 month record	6.2%
Dispersal behavior	1.3%
2D fixes PDOP >5	5.2%
***2D fixes PDOP >5**	8.6%
***All PDOP>10**	8.1%
***3DPDOP>10, 2DPDOP>5**	13.3%
*** All 2D**	34.8%

* Indicates data from study by Lewis et al. 2007 with a mean fix rate of 91.8%

Table 4. Goat GPS collar fix locations partitioned by year and season.

Year	Total yearly point counts	Summer point counts	Winter point counts
2002	703	630	1,279
2003	13,263	7,042	17,524
2004	45,759	20,305	37,034
2005	51,509	21,104	17,688
2006	21,973	8,842	5,693
2007	5,639	1,576	129
Total	138,846	59,499	79,347

Table 5. Evaluation of alternative definitions of "escape terrain" on the basis of slope. Using a 10 m DEM, slopes above a given angle were defined as escape terrain. The proportion of the path in escape terrain for points along used and available full-year paths were compared using the Wilcoxon sign rank test (n = 129 goat-years). In all cases the mean was significantly greater for available paths at P<0.00001.

	25 deg	30 deg	35 deg	40 deg	45 deg	50 deg
V-value	12	7.5	0	12.5	68.5	253

Table 6. Univariate multi-scale analysis comparing used and available locations using a Wilcoxon sign rank test. Data were extracted from a square sampling window that was 1, 3, 7, 13 or 25 pixels on a side (30 m pixels). Results are presented for the scale with the lowest V-index. All means were significantly different at *P*<0.0001. Variables were used to develop matched case logistic regression models to predict mountain goat habitat from the Cascade Range study area, WA. See text for discussion of variable selection and candidate models.

VARIABLE	V-Score	*P*-Value	Scale	Used	Avail.
LANDCOVER					
GAP ANALYSIS (GAP)					
Mid Elevation Forests	1035	5.874e-15	1x1	40.14	56.95
Grassland	3539.5	7.954e-05	1x1	4.58	2.40
Subalpine	7343	4.441e-16	1x1	33.44	19.39
Tall Shrubland	9346	8.513e-16	1x1	27.12	44.71
INTER-AGENCY VEGETATION MAPPING PROJECT (IVMP)					
Category 2 conifer cover 33-66%	6036	0.0015	1x1	25.54	21.68
Category 3 conifer cover 66-100%	767	< 2.2e-16	1x1	22.48	41.36
TOPOGRAPHIC FEATURES					
ESCAPE TERRAIN	5141.5	< 2.2e-16	3x3	1059	951
TERRAIN ROUGHNESS (VRM)	7594	4.21e-11	1x1	0.06	0.04
POTENTIAL RELATIVE RADIATION (PRR)	7979	9.903e-14	3x3	483	330

Table 7. Candidate models of mountain goat habitat selection in the Washington Cascades based on full-year paths (n=129 goat-years). Number of variables (K), AICc scores, delta AIC scores and AIC weights. Models are ordered from lowest AIC scores to highest.

Model	Variables	K	AIC_c	ΔAIC_c	w_i
1	park prr vrm et	5	247.029	0.000	0.515
2	park vrm et	4	248.847	1.817	0.208
3	grass park con33 con66 prr vrm et	8	249.283	2.254	0.167
4	mef grass park con33 con66 prr vrm et	9	250.511	3.482	0.090
5	park prr et	4	253.512	6.482	0.020
6	prr vrm et	4	294.874	47.844	0.000
7	et	2	315.113	68.083	0.000
8	con33 con66	3	446.535	199.505	0.000
9	mef grass park	4	474.998	227.969	0.000
10	park	2	484.341	237.311	0.000
11	prr	2	492.580	245.550	0.000

mef = mid elevation forests, grass = grassland, park = subalpine parkland, con33 = conifer cover from 33-66%, con66 = conifer cover from 66-99.9%, prr = potential relative radiation, vrm = vector ruggedness model, et = escape terrain.

Table 8. The global model and coefficients of mountain goat habitat selection in the Washington Cascades based on full-year paths (*n*=129 goat-years).

Variable	DF	Estimate	Standard Error	Wald 95% Confidence Limits	
Intercept	1	-14.8087	1.8245	-18.3848	-11.2327
mef	1	-0.0024	0.0103	-0.0225	0.0178
grass	1	-0.0092	0.0181	-0.0446	0.0262
park	1	0.0545	0.0105	0.0340	0.0750
con33	1	0.0008	0.0181	-0.0363	0.0348
con66	1	-0.0118	0.0139	-0.0392	0.0155
prr	1	0.0011	0.0007	-0.0002	0.0025
vrm	1	27.3875	9.4372	8.8909	45.8841
et	1	14.0284	1.7473	10.6036	17.4531

Mef = mid elevation forests, grass = grassland, park = subalpine parkland, con33 = conifer cover from 33-66%, con66 = conifer cover from 66-99.9%, prr = potential relative radiation, vrm, vector ruggedness model, et = escape terrain.

Table 9. The most parsimonious model of mountain goat habitat selection in the Washington Cascades based on full-year paths (n=129 goat-years). Based on the lowest AICc scores and associated coefficients used to predict potential mountain goat habitat for a full year across the Cascades of Washington.

Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits	
Intercept	1	-15.7541	1.5853	-18.611	-12.5940
park	1	0.0579	0.0094	0.0394	0.0785
prr	1	0.0012	9.1061	-0.0002	0.0026
vrm	1	24.6712	8.9192	8.4701	43.4329
et	1	14.5965	1.6486	11.7688	18.2147

park = subalpine parkland, vrm, vector ruggedness model, et = escape terrain

Table 10. Winter season candidate models, number of variables (K), AIC scores, delta AICc scores and AIC weights (n=100 goat-years). Models are ordered from lowest AIC scores to highest.

Model	Model Explanation	K	AIC_c	ΔAIC_c	w_i
1	grass park con33 con66 prr vrm et ts	9	250.50	0.000	0.163
2	park con66 prr vrm et ts	7	250.53	0.025	0.161
3	et ts con66 vrm grass park prr	8	250.85	0.348	0.137
4	et ts con33 con66 park prr	7	251.00	0.498	0.127
5	et ts con66 park prr	6	251.18	0.681	0.116
6	mef park con66 prr vrm et ts	8	251.74	1.238	0.088
7	mef grass park con33 con66 prr vrm et ts	10	251.79	1.289	0.086
8	et ts park prr	5	252.67	2.164	0.055
9	park con66 vrm et ts	6	254.60	4.094	0.021
10	et ts con66 vrm grass park	7	254.68	4.175	0.020
11	park prr vrm et	5	255.92	5.418	0.011
12	park prr et	4	256.41	5.907	0.009
13	park vrm et ts	5	257.23	6.730	0.006
14	park vrm et	4	262.97	12.467	0.000
15	et ts con66 vrm grass	6	263.64	13.138	0.000
16	et ts con66 vrm	5	265.99	15.485	0.000
17	et ts con66	4	269.65	19.146	0.000
18	vrm et ts	4	280.09	29.588	0.000
19	et ts	3	284.02	33.513	0.000
20	prr vrm et	4	286.48	35.977	0.000
21	et	2	305.09	54.588	0.000
22	con33 con66	3	481.46	230.962	0.000
23	mef grass park ts	5	512.90	262.400	0.000
24	prr	2	513.28	262.774	0.000
25	park	2	519.55	269.046	0.000

mef = mid elevation forests, grass = grassland, park = subalpine parkland, con33 = conifer cover from 33-66%, con66 = conifer cover from 66-99.9%, prr = potential relative radiation, vrm = vector ruggedness model, et = escape terrain, ts=tall shrubland

Table 11. The winter season global model and coefficients (n=100 goat-years).

Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**	
Intercept	1	-14.7868	1.8352	-18.3837	-11.1898
mef	1	-0.0034	0.0104	-0.0237	0.0169
grass	1	-0.0199	0.0174	-0.0540	0.0143
park	1	0.0305	0.0124	0.0061	0.0549
con33	1	0.0227	0.0168	-0.0103	0.0557
con66	1	-0.0151	0.0106	-0.0359	0.0057
prr	1	0.0011	0.0007	-0.0001	0.0024
vrm	1	11.5071	7.6093	-3.4069	26.4211
et	1	16.0444	1.8123	12.4924	19.5964
ts	1	-0.0483	0.0175	-0.0826	-0.0141

mef = mid elevation forests, grass = grassland, park = subalpine parkland, con33 = conifer cover from 33-66%, con66 = conifer cover from 66-99.9%, prr = potential relative radiation, vrm = vector ruggedness model, et = escape terrain, ts=tall shrubland

Table 12. The most parsimonious habitat model for the winter season based on the lowest AICc scores and associated coefficients used to predicted potential mountain goat habitat across the Cascades of Washington (n=100 goat-years).

Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**	
Intercept	1	-14.9821	1.7483	-18.4087	-11.5556
grass	1	-0.0177	0.0162	-0.0496	0.0141
park	1	0.0329	0.0102	0.0128	0.0529
con33	1	0.0215	0.0164	-0.0108	0.0537
con66	1	-0.0158	0.0104	-0.0362	0.0046
prr	1	0.0012	0.0006	-0.0001	0.0024
vrm		11.1249	7.5141	-3.6025	25.8523
et	1	16.0430	1.8132	12.4891	19.5968
tshb	1	-0.0461	0.0160	-0.0775	-0.0146

grass = grassland, park = subalpine parkland, con33 = conifer cover from 33-66%, con66 = conifer cover from 66-99.9%, prr = potential relative radiation, vrm = vector ruggedness model, et = escape terrain, ts=tall shrubland

Table 13. Summer season candidate models, number of variables (K), AIC scores, delta AICc scores and AIC weights (n=95 goat-years). Models are ordered from lowest AIC scores to highest.

Models	**Model Explanation**	**K**	**AIC_c**	**ΔAIC_c**	**w_i**
1	**et ts con66 vrm grass park**	7	231.57	0.00	0.220
2	**park con66 vrm et ts**	6	231.95	0.37	0.183
3	**park vrm et ts**	5	232.70	1.13	0.125
4	**et ts con66 vrm grass park prr**	8	232.73	1.15	0.124
5	**park con66 prr vrm et ts**	7	233.05	1.47	0.106
6	**grass park con33 con66 prr vrm et ts**	9	233.76	2.19	0.074
7	**mef park con66 prr vrm et ts**	8	234.37	2.80	0.054
8	**mef grass park con33 con66 prr vrm et ts**	10	235.14	3.56	0.037
9	**park vrm et**	4	236.42	4.84	0.020
10	**et ts park prr**	5	236.86	5.29	0.016
11	**park prr vrm et**	5	236.93	5.35	0.015
12	**et ts con66 park prr**	6	237.22	5.65	0.013
13	**et ts con33 con66 park prr**	7	238.26	6.68	0.008
14	**park prr et**	4	239.14	7.57	0.005
15	**et ts con66 vrm grass**	6	243.68	12.11	0.001
16	**et ts con66 vrm**	5	245.80	14.22	0.000
17	**et ts con66**	4	255.93	24.36	0.000
18	**vrm et ts**	4	259.25	27.68	0.000
19	**et ts**	3	267.84	36.26	0.000
20	**prr vrm et**	4	276.95	45.38	0.000
21	**et**	2	290.32	58.74	0.000
22	**con33 con66**	3	449.38	217.81	0.000
23	**mef grass park ts**	5	465.94	234.36	0.000
24	**park**	2	474.58	243.00	0.000
25	**prr**	2	485.54	253.96	0.000

mef = mid elevation forests, grass = grassland, park = subalpine parkland, con33 = conifer cover from 33-66%, con66 = conifer cover from 66-99.9%, prr = potential relative radiation, vrm = vector ruggedness model, et = escape terrain, ts=tall shrubland

Table 14. The summer season global model and coefficients. (n=95 goat-years).

Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits	
Intercept	1	-14.9277	1.912	-18.6752	-11.1802
mef	1	-0.0021	0.0105	-0.0227	0.0185
grass	1	-0.0274	0.0212	-0.069	0.0142
park	1	0.0331	0.0117	0.0102	0.056
con33	1	-0.0094	0.0167	-0.042	0.0233
con66	1	-0.0215	0.0142	-0.0495	0.0064
prr	1	0.0003	0.0008	-0.0013	0.0018
vrm	1	19.1915	7.6116	4.273	34.11
et	1	16.7387	1.9835	12.8512	20.6263
ts	1	-0.0481	0.0183	-0.0839	-0.0122

mef = mid elevation forests, grass = grassland, park = subalpine parkland, con33 = conifer cover from 33-66%, con66 = conifer cover from 66-99.9%, prr = potential relative radiation, vrm = vector ruggedness model, et = escape terrain, ts=tall shrubland

Table 15. The most parsimonious habitat model for the summer season based on the lowest AIC_c scores and associated coefficients used to predicted potential mountain goat habitat across the Cascades of Washington (n=95 goat-years)..

Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits	
Intercept	1	-15.2167	2.5043	-20.1251	-10.3082
park	1	0.0353	0.0150	0.0059	0.0648
con66	1	-0.0213	0.0149	-0.0505	0.0078
vrm	1	19.2181	7.5942	4.3337	34.1026
et	1	16.7427	2.5855	11.6752	21.8102
ts	1	-0.0478	0.0133	-0.0738	-0.0218
grass	1	-0.0262	0.0143	-0.0543	0.0018

park = subalpine parkland, con66 = conifer cover from 66-99.9%, vrm = vector ruggedness model, et = escape terrain, ts=tall shrubland, grass = grassland,

Table 16. Top model comparison for full year, winter and summer data, number of variables (K), AIC scores, delta AIC scores and AIC weights **indicates top model, *indicates other models in the confidence set (**ΔAIC** <2)

Models	Full Year		Winter		Summer	
	ΔAICc	w_i	**ΔAICc**	w_i	**ΔAICc**	w_i
mef grass park con33 con66 prr vrm et tshb			1.289*	0.086		
grass park con33 con66 prr vrm et						
grass park con33 con66 prr vrm et tshb			0.00**	0.163		
park prr vrm et	0.401*	0.362				
park vrm et	0.00**	0.443				
mef park con66 prr vrm et tshb			1.238*	0.088		
park con66 prr vrm et tshb			0.025*	0.161	1.47*	0.106
park con66 vrm et tshb					0.37*	0.183
park vrm et tshb					1.13*	0.125
et tshb con66 vrm grass park					0.00**	0.220
et tshb con66 vrm grass park prr			0.348*	0.137	1.15*	0.124
et tshb con66 park prr			0.681*	0.116		
et tshb con33 con66 park prr			0.498*	0.127		

mef = mid elevation forests, grass = grassland, park = subalpine parkland, con33 = conifer cover from 33-66%, con66 = conifer cover from 66-99.9%, prr = potential relative radiation, vrm = vector ruggedness model, et = escape terrain, ts=tall shrubland

Table 17. Composite models for full year, winter and summer data used in building mountain goat habitat probability maps. Obtained using a 95% confidence set.

	Full Year Winter Summer
Models	
Full Year	-15.22191+0.05741(park)+0.00197(prr)+27.40797(VRM)+14.02072(ET)
Winter	-14.64458+0.03714(park)-0.01632(con66)+7.86816(VRM)+17.30875(ET)-0.04505(TSHB)- 0.00770(grass) +0.00903(con33)+0.00142(prr))
Summer	-15.40449+0.03707(park)-0.01280(con66)+17.84274(VRM)+16.64623(ET)-0.04184(TSHB)-0.00941(grass)

mef = mid elevation forests, grass = grassland, park = subalpine parkland, con33 = conifer cover from 33-66%, con66 = conifer cover from 66-99.9%, prr = potential relative radiation, vrm = vector ruggedness model, et = escape terrain, ts=tall shrubland

Table 18. Model performance accuracies reported for model testing data sets based on the use of the cutpoint derived from the model building dataset. AUC shows the area under the receiver operator characteristics curve.

	AUC	Optimum Probability Cutpoint	ClassificationAccuracy (%)	
Models				
			Used	**Available**
Full Year				
Build	0.94	0.32	89.0	89.0
Test	0.95		79.0	95.0
Winter				
Build	0.95	0.44	88.0	88.0
Test	0.91		74.0	91.0
Summer				
Build	0.91	0.203	88.0	88.0
Test	0.94		85.0	92.0

Table 19. Amount of habitat based on cut-off value derived from continous probability Mountain goat habitat maps.

	Full Year	Winter	Summer
Habitat (km^2)	**1,964**	**2,606**	**3,048**

Table 20. Percent of available sites classified as non-habitat and percent of used sites classified as habitat for full year, winter, and summer datasets based on cut-off values derived in table 18.

	Full Year		Winter		Summer	
Build	**Habitat**	**Non-Habitat**	**Habitat**	**Non-Habitat**	**Habitat**	**Non-Habitat**
Available		72.0		77.0		73.0
Used	41.0		42.0		44.0	
Test						
Available		74.0		79.0		76.0
Used	30.0		40.0		45.0	

FIGURES

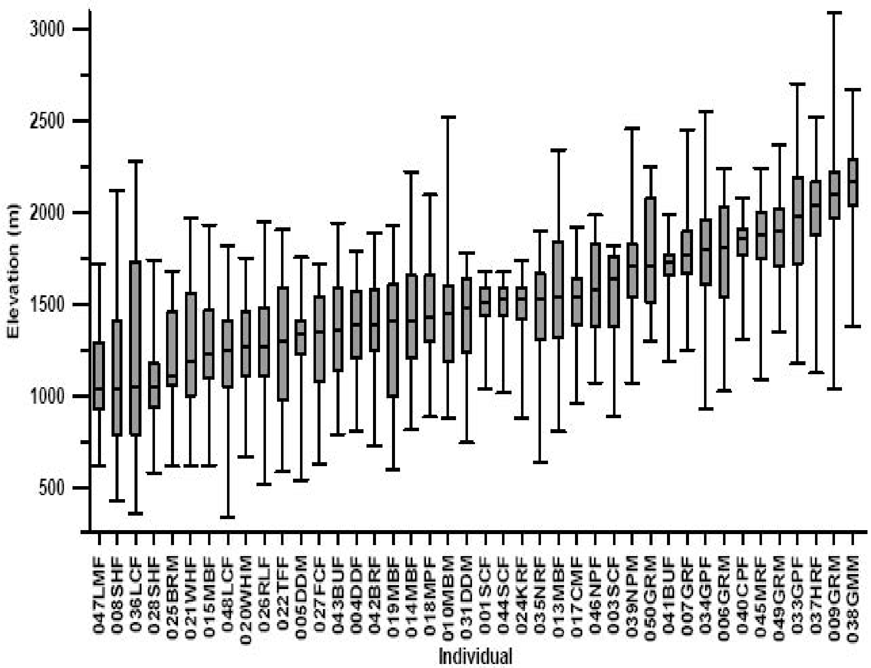

Figure 1. Distribution of elevation records for each mountain goat showing median, 25th and 75th percentiles, and maximum and minimum (Washington, USA, 26 Sep 2002 to 22 Sep 2006) (Rice 2007).

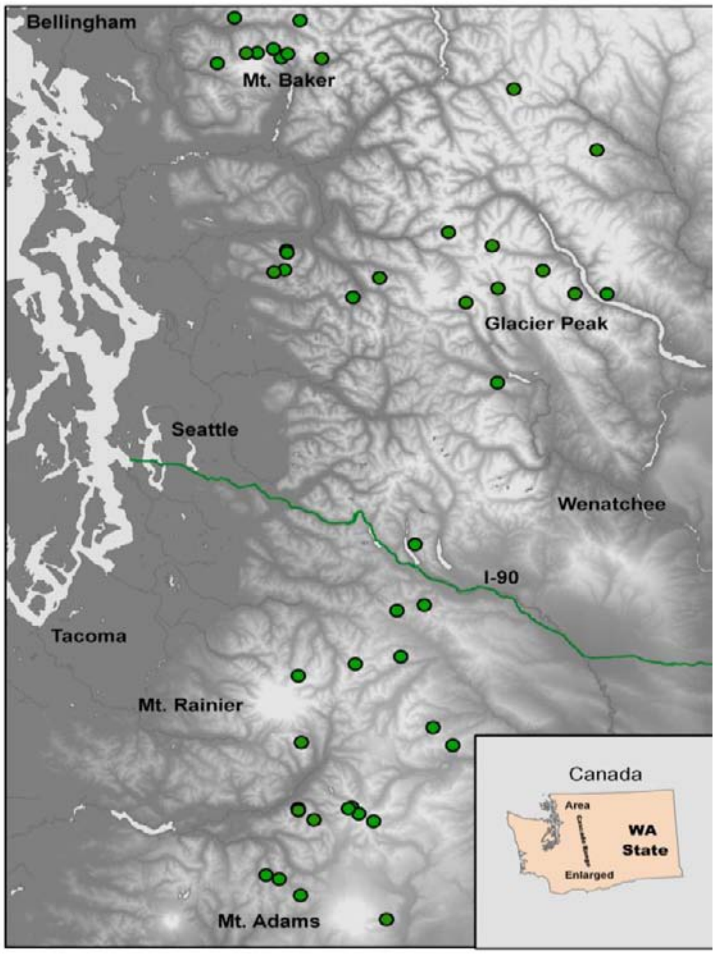

Figure 2. Median mapped mountain goat locations, Cascades, WA, USA.

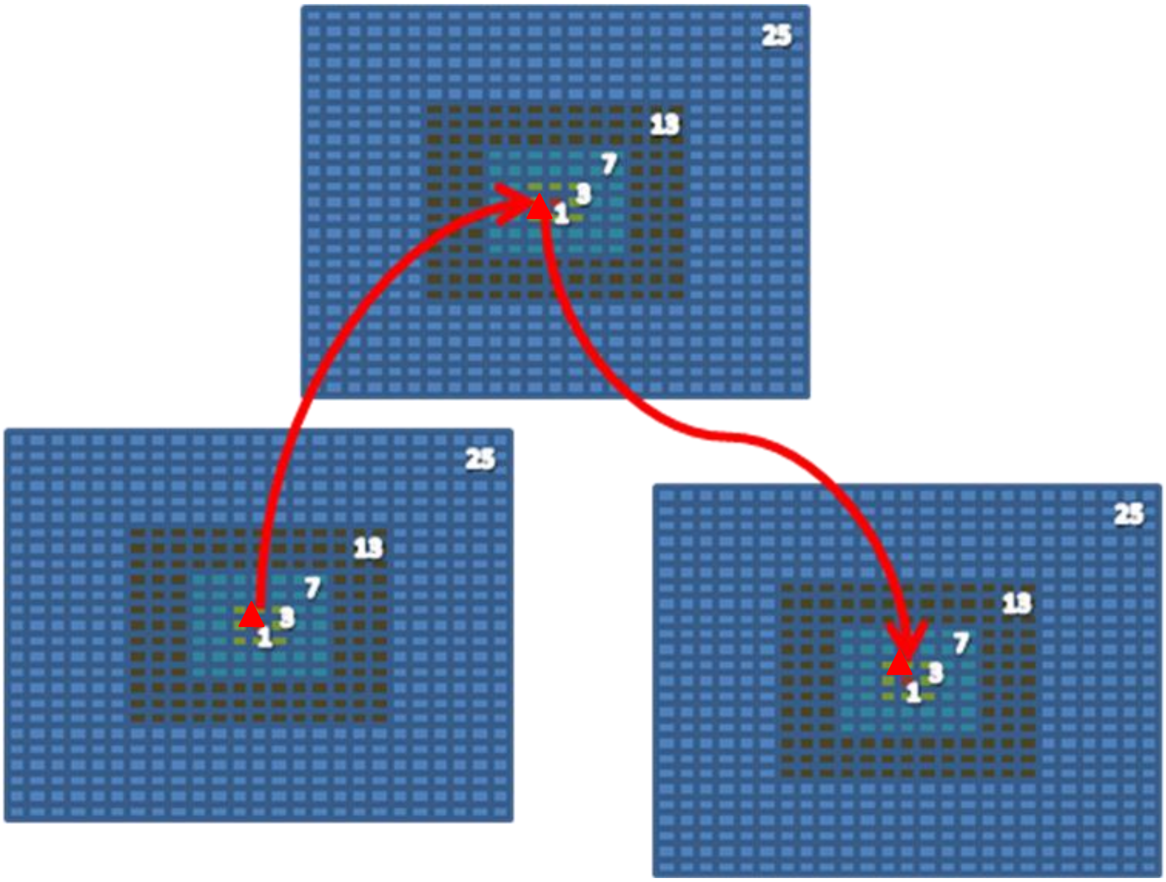

Figure 3. Example of path level analysis for 5 separate spatial scales. ▲represent locations obtained from GPS-collared animals at interval of 3+ hrs. Precise movement track between each of these three discreet locations is unknown.

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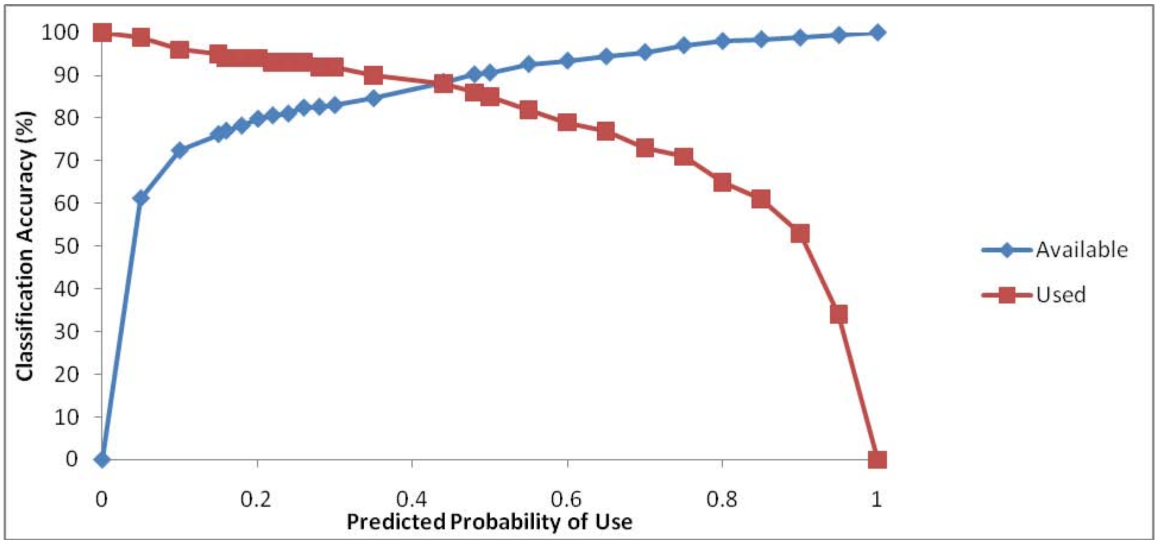

Figure 4a. Classification accuracy for used and available sites over the full range of predicted use for the composit full-year model and the model-building dataset. The curves converge at a probability of 0.32 and an accuracy of 89% for both used and available paths. This probability of 0.32 can be used as a "cutpoint" to transform a continuous probability map into a binary (habitat/non-habitat) map.

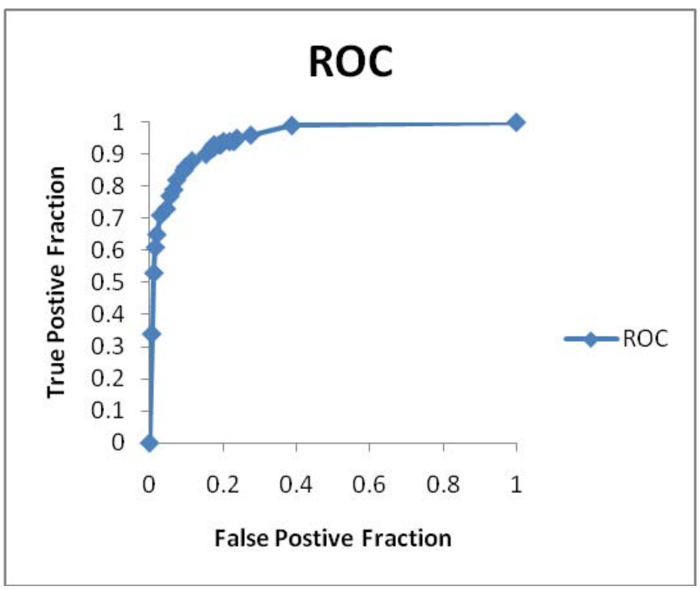

Figure 4b. ROC curve for full year data.

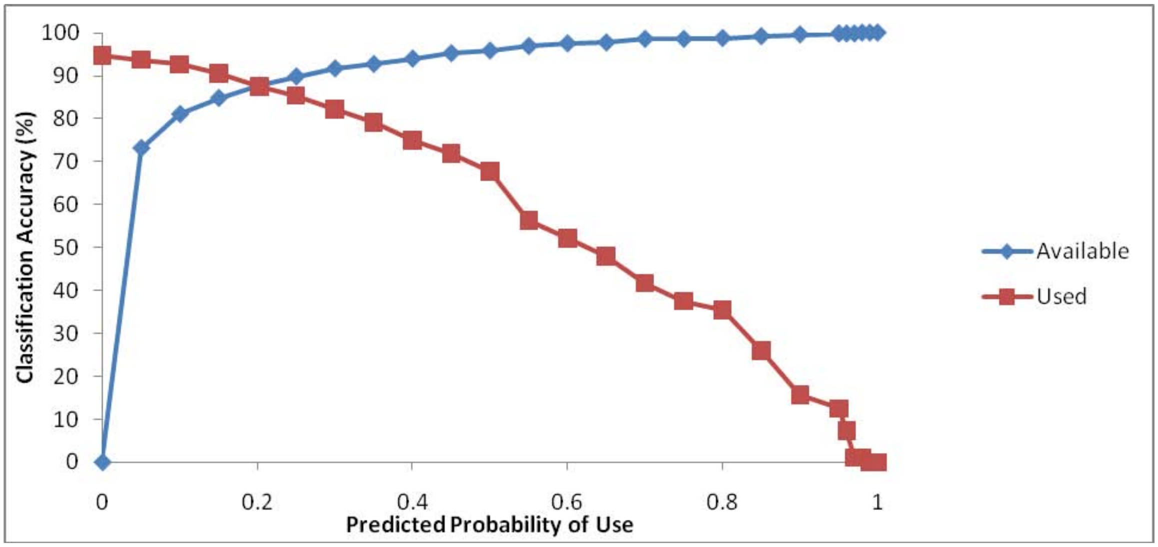

Figure 4c. Classification accuracy for used and available sites over the full range of predicted use for the composit summer model and the model-building dataset. The curves converge at a probability of 0.203 and an accuracy of 88% for both used and available paths.

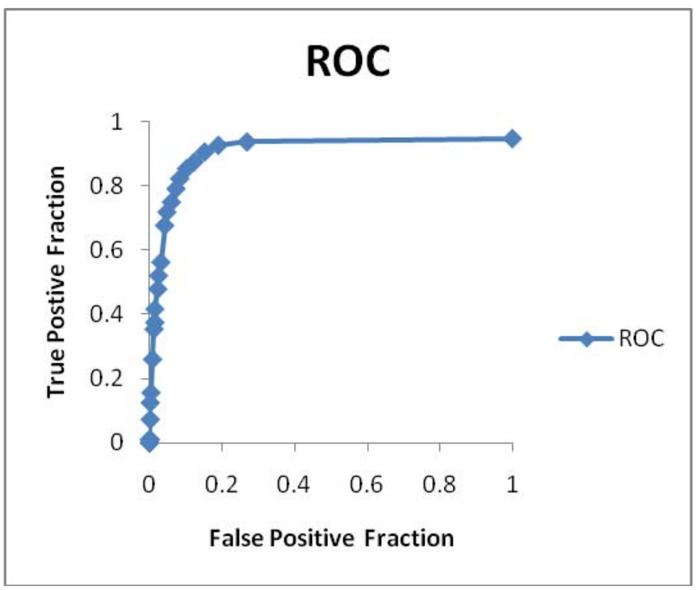

Figure 4d. ROC curve for summer data.

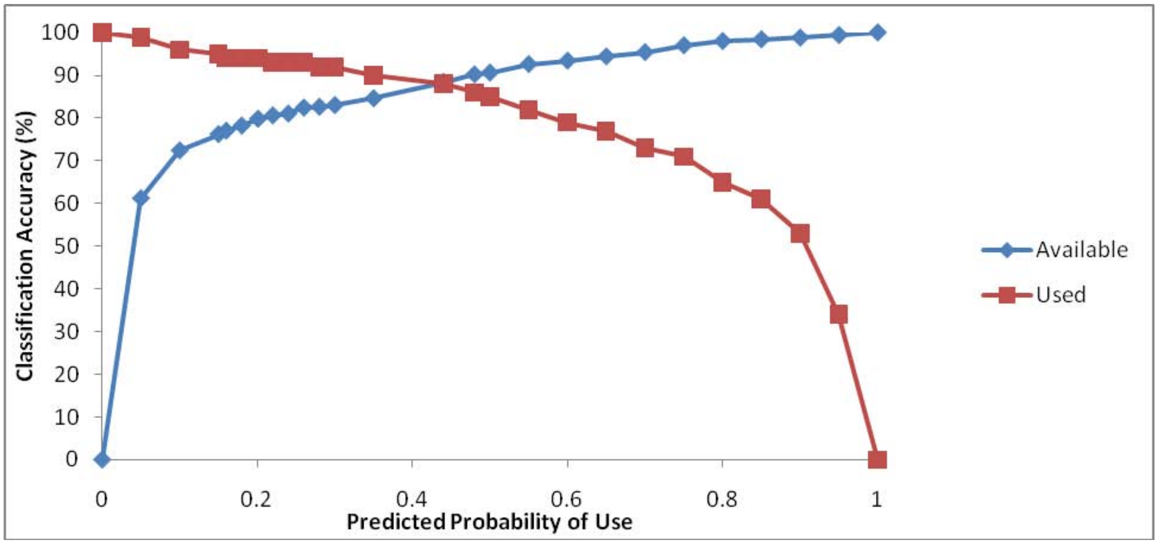

Figure 4e. Classification accuracy for used and available sites over the full range of predicted use for the composit summer model and the model-building dataset. The curves converge at a probability of 0.44 and an accuracy of 88% for both used and available paths.

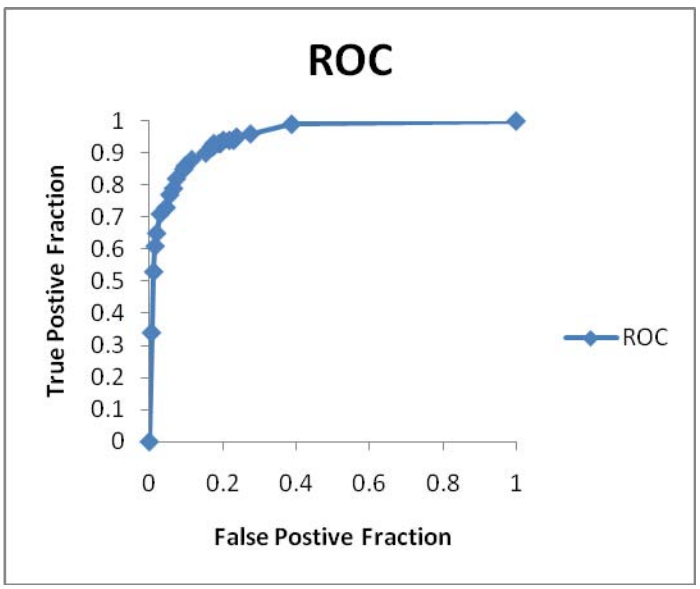

Figure 4f. ROC curve for summer data.

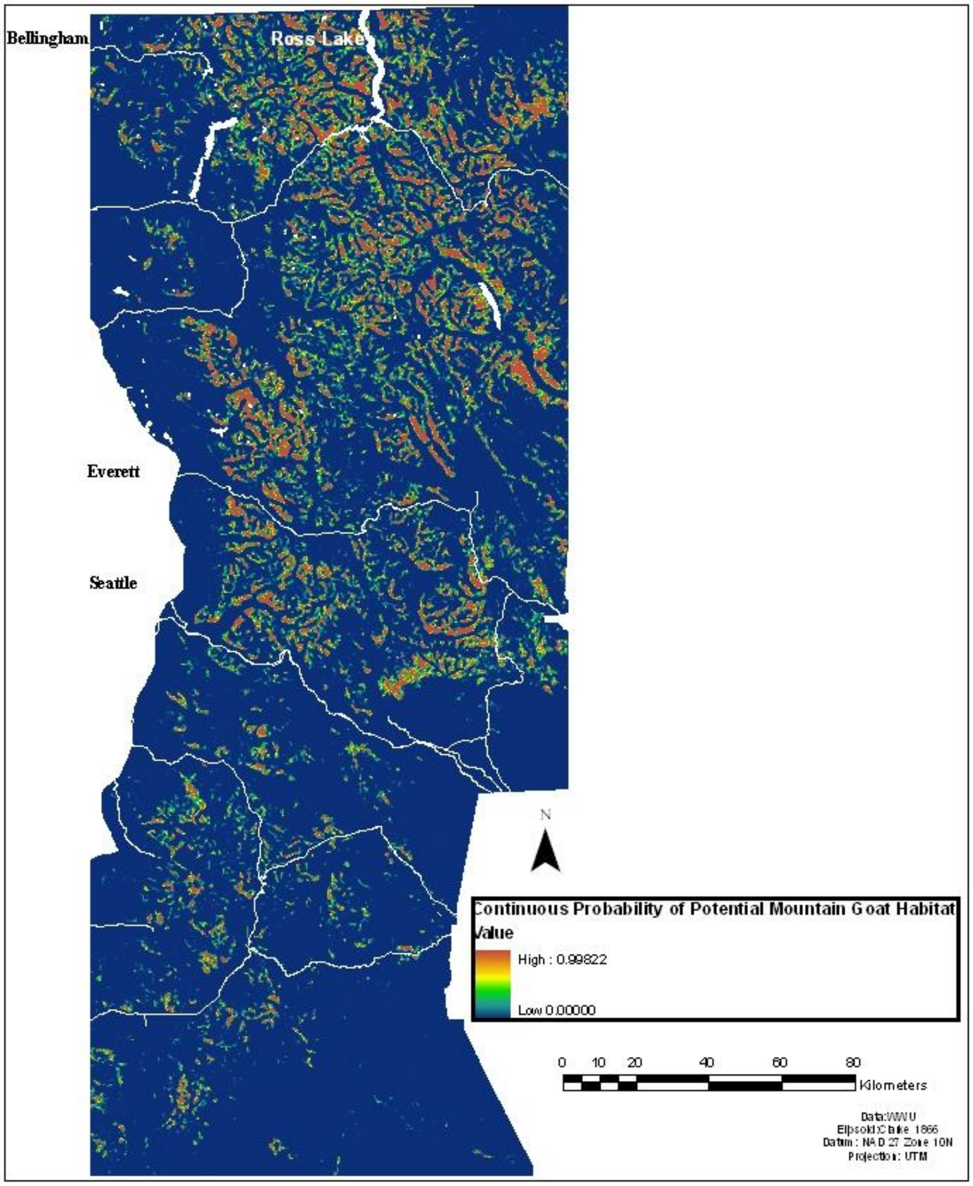

Figure 5. Continous Probability of Potential Mountain Goat Habitat derived from a composite logistic regression model that include the following landscape parameters; Subalpine Parkland, Potential Relative Radiation, and Landscape Ruggedness, Escape Terrain

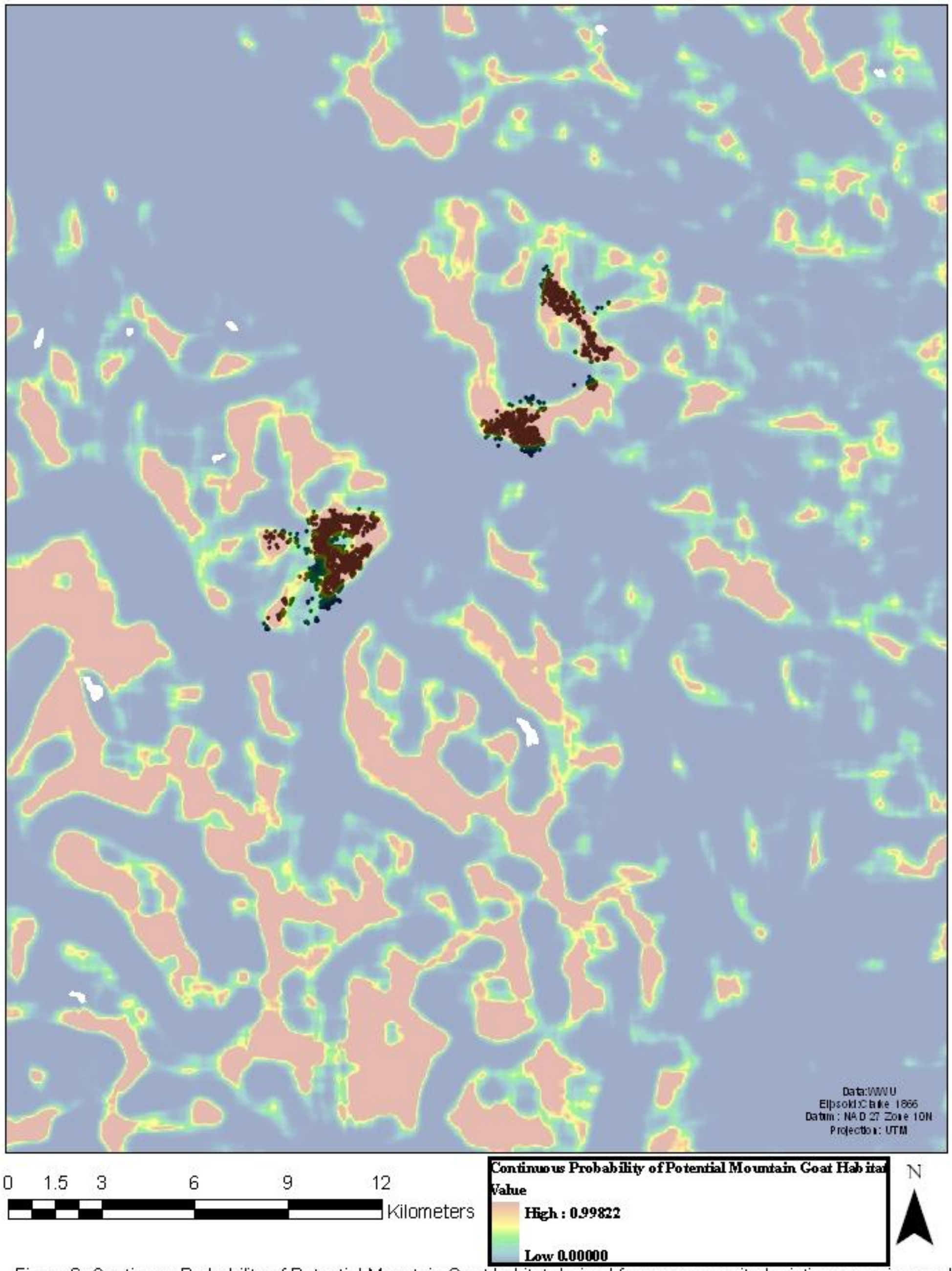

Figure 6. Continous Probability of Potential Mountain Goat habitat derived from a composite logistic regression model that include the following landscape parameters; Subalpine Parkland, Potential Relative Radiation, Landscape Ruggedness, and Escape Terrain. Northern portion of the study Area. Used Mountain Goat locations overlaid for comparison.

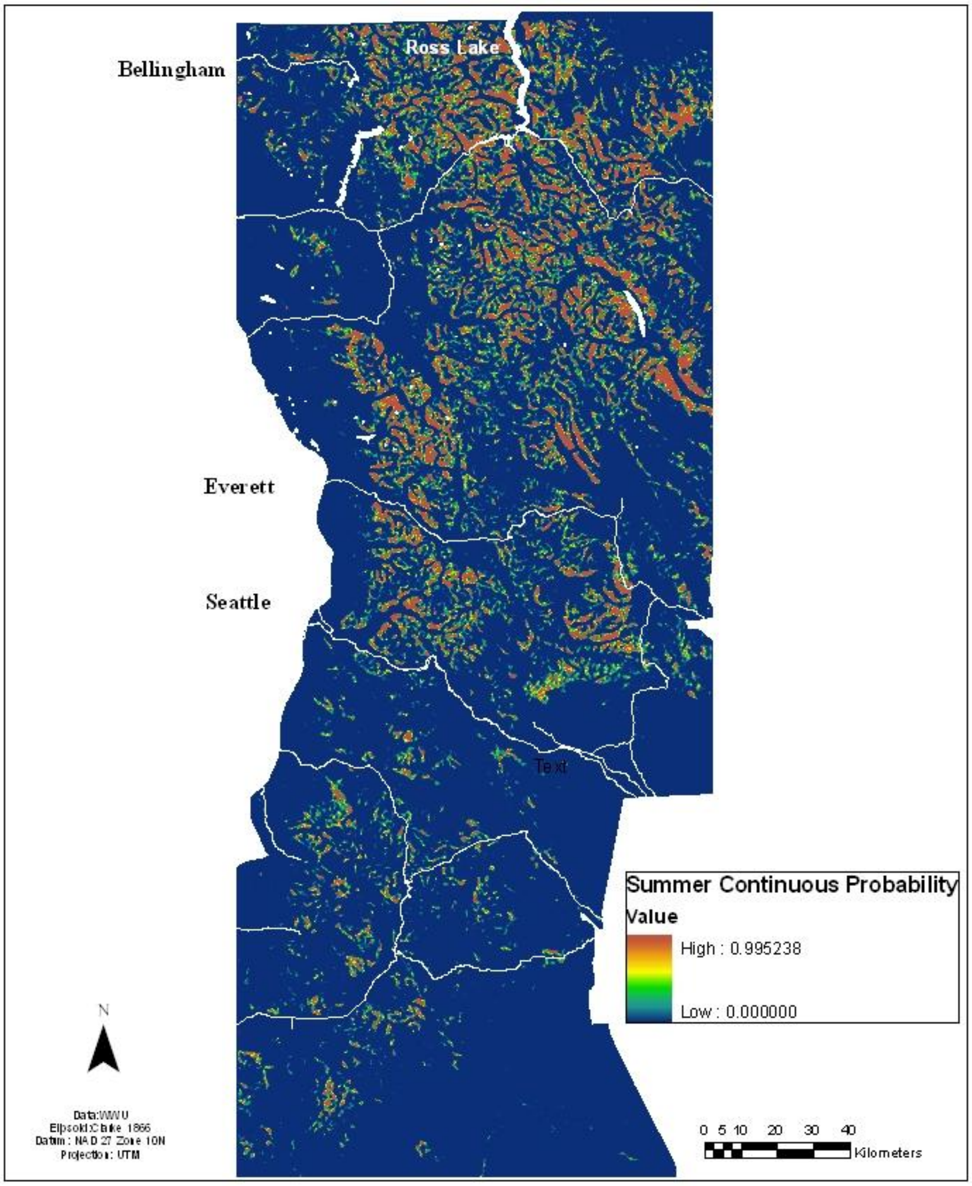

Figure 7. Continous Probability of Potential Mountain Goat Summer Habitat derived from a composite logistic regression model that include the following landscape parameters;
Grassland, Subalpine Parkland, Conifer Cover from 66-100%, Landscape Ruggedness, Escape Terrain, and Tall Shrubland

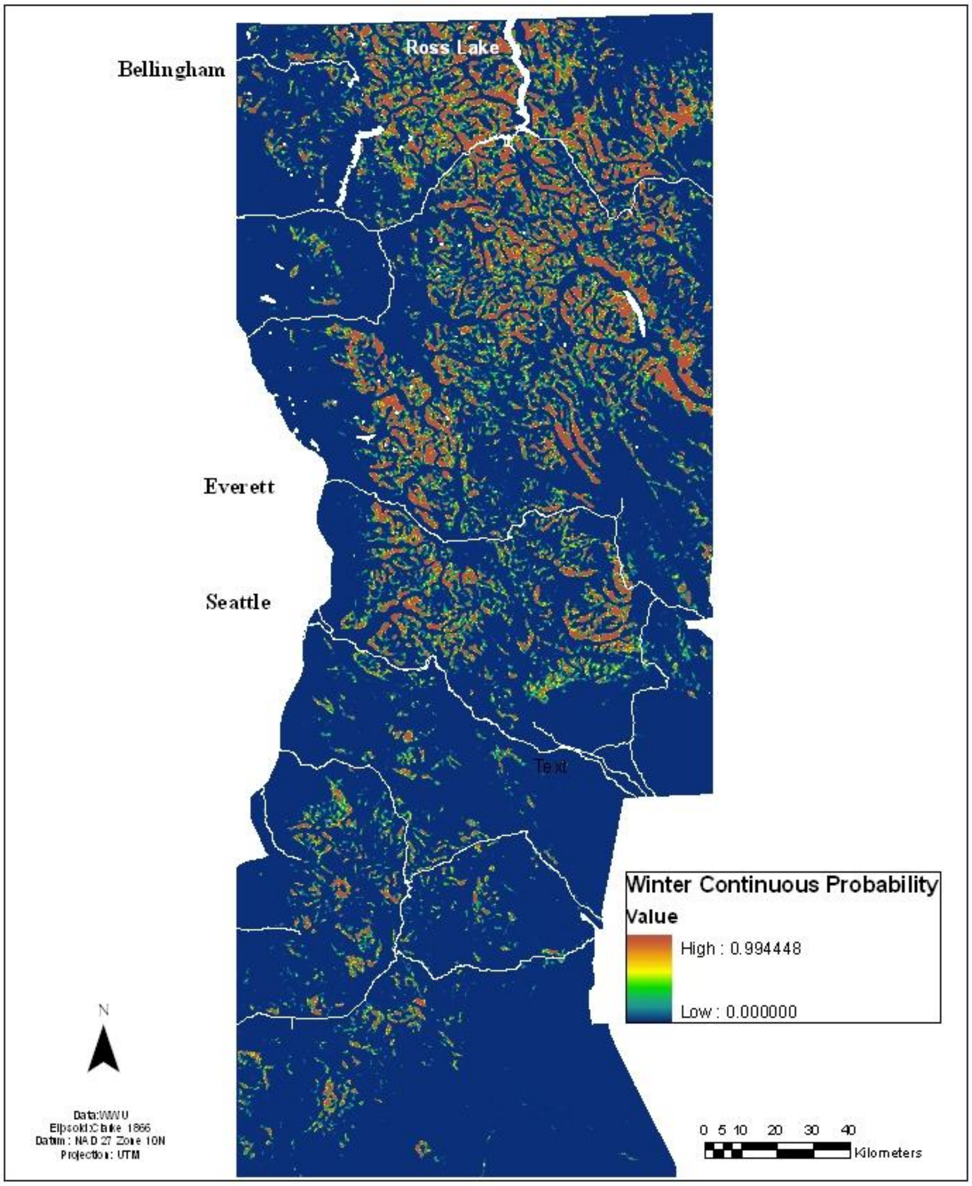

Figure 8. Continous Probability of Potential Mountain Goat Winter Habitat derived from a composite logistic regression model that include the following landscape parameters; Grassland, Subalpine Parkland, Conifer Cover from 33-100%, Landscape Ruggedness, Escape Terrain, Potential Relative Radiation, and Tall Shrubland

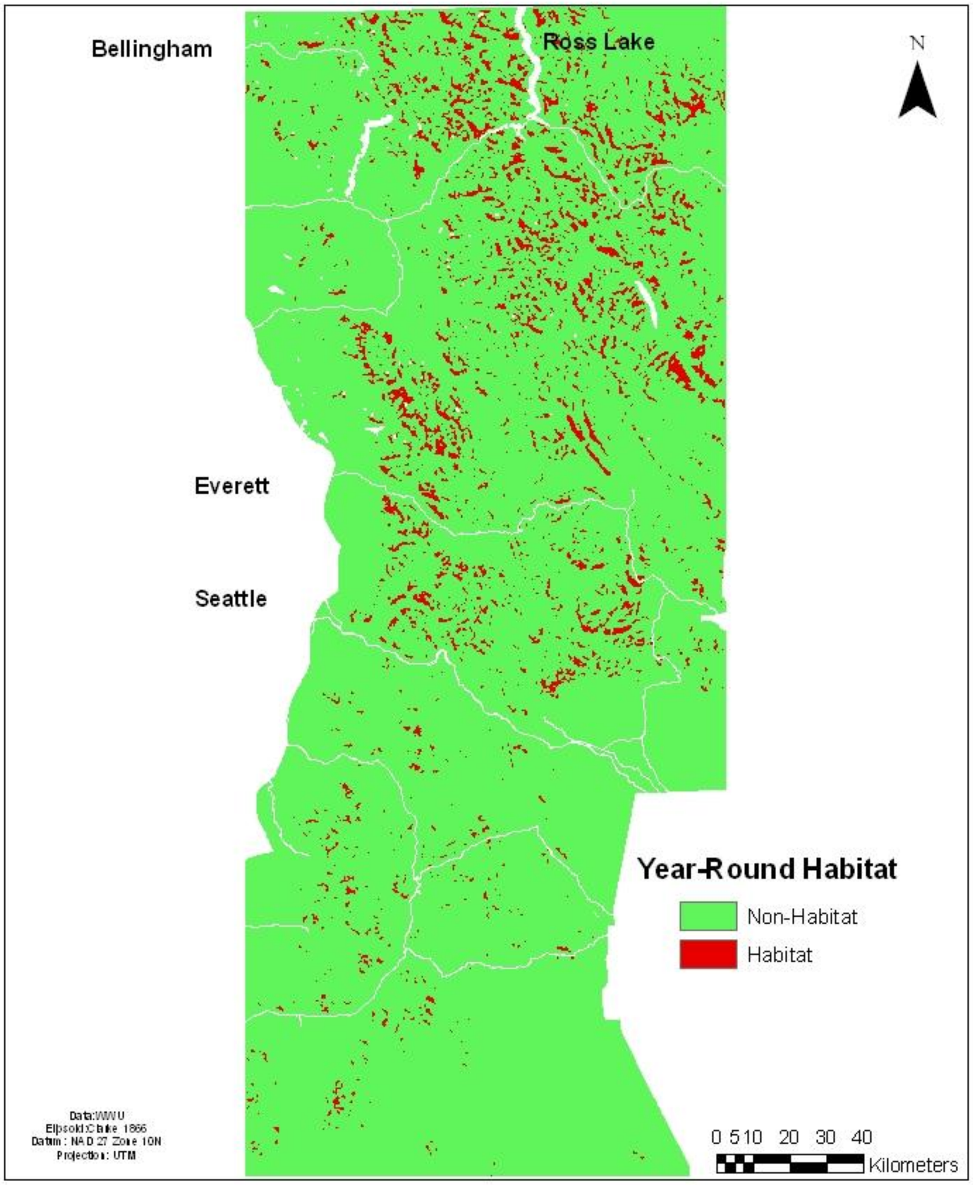

Figure 9. Categorical map of potential year-round mountain goat habitat derived from a cutpoint of 0.32

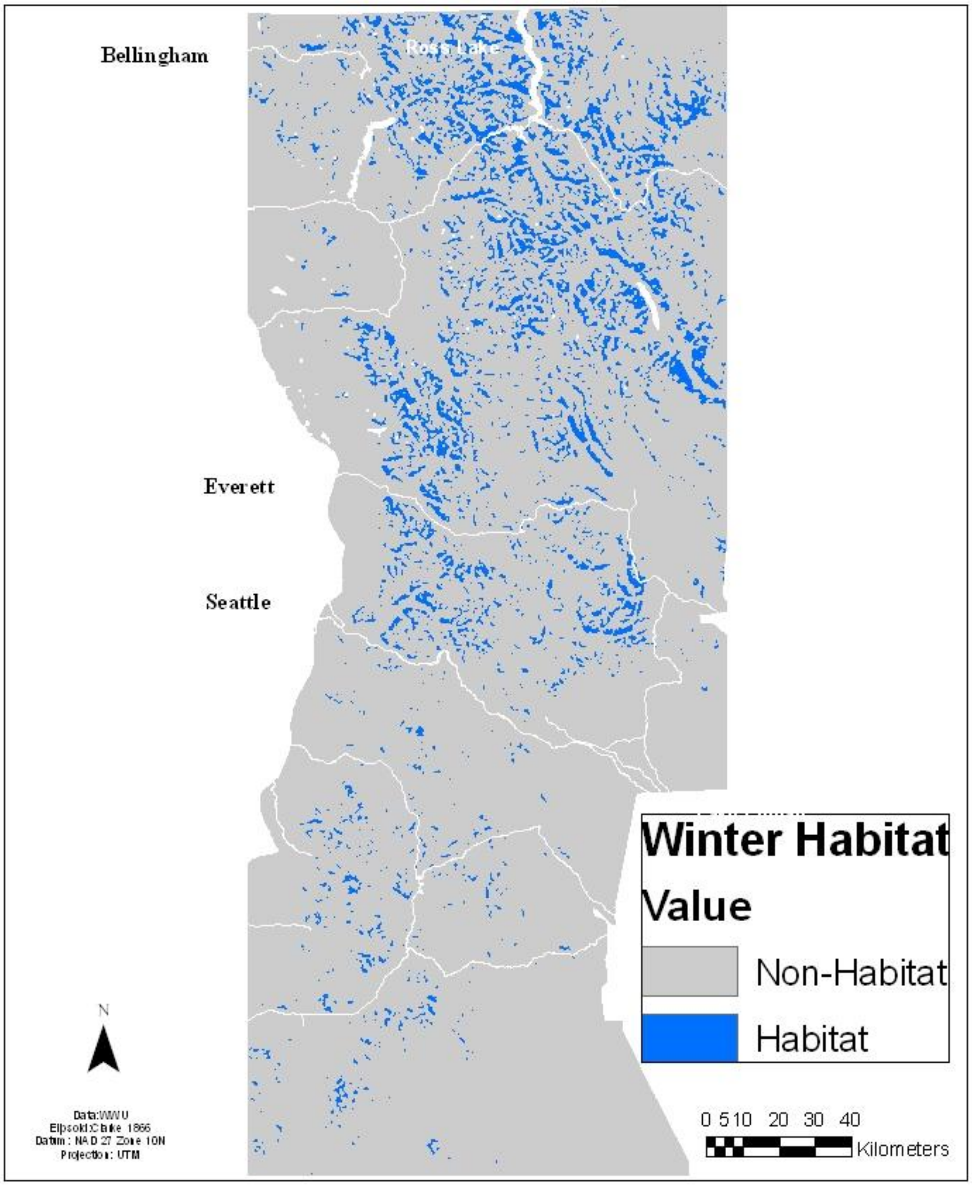

Figure 10. Categorical map of potential mountain goat winter habitat based on a cutpoint of 0.44.

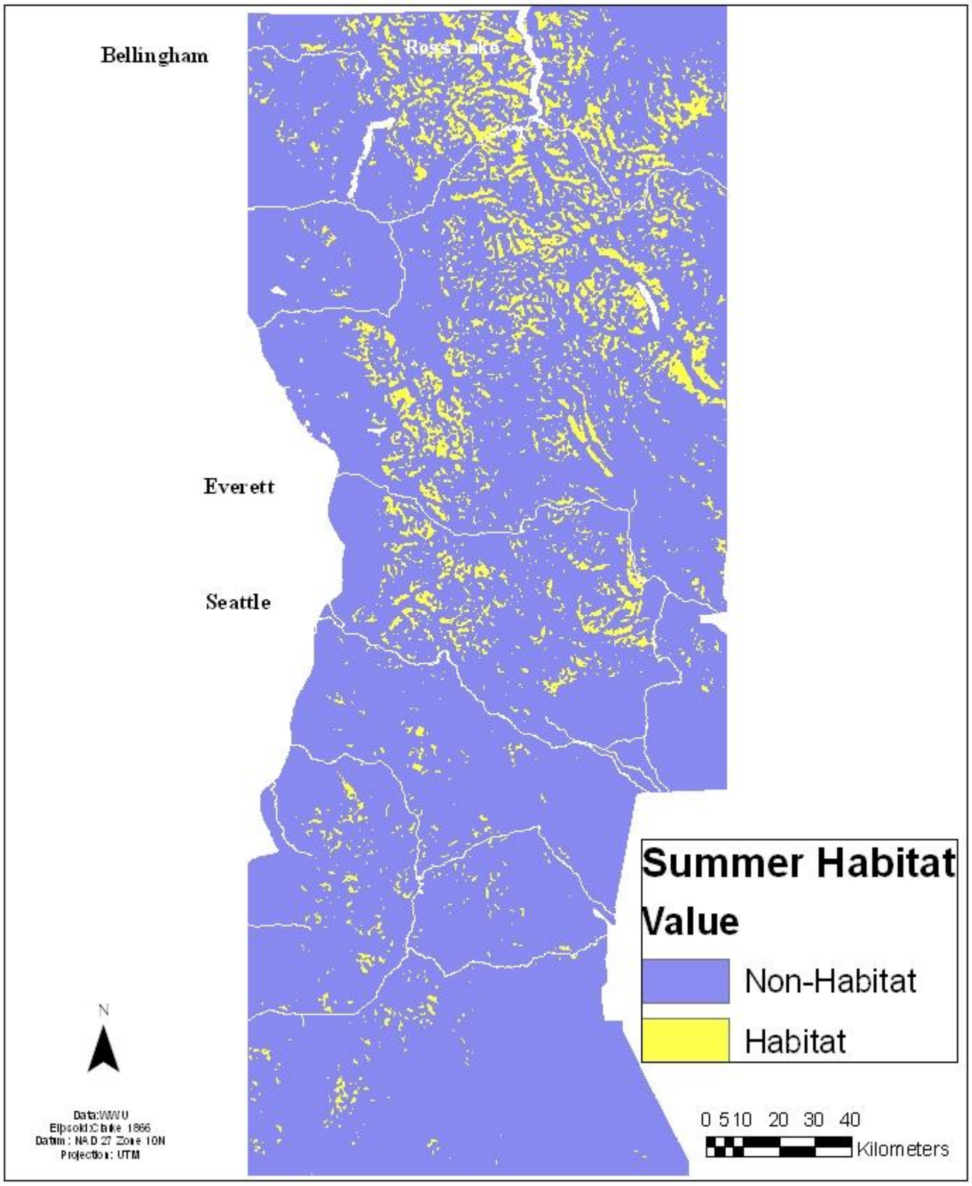

Figure 11. Categorical map of potential mountain goat summer habitat based on a cutpoint of 0.203

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APPENDIX

Appendix 1: Collapsed Community systems thought to be important as potential predictors of goat habitat, used in habitat analysis.

1. Collapsed into: Mid-Montane Forests (2)
CES204.098 North Pacific Dry-Mesic Silver Fir-Western Hemlock-Douglas-fir Forest
CES204.097 North Pacific Mesic Western Hemlock-Silver Fir Forest

2. Collapsed into: Tall Shrubland (7)
CES204.846 North Pacific Broadleaf Landslide Forest and Shrubland
CES204.854 North Pacific Avalanche Chute Shrubland
CES204.087 North Pacific Montane Shrubland
CES306.994 Northern Rocky Mountain Lower Montane Mesic Deciduous Shrubland
CES200.998 Temperate Pacific Subalpine-Montane Wet Meadow
CES204.866 North Pacific Montane Riparian Woodland and Shrubland
CES306.832 Rocky Mountain Subalpine-Montane Riparian Shrubland

3. Collapsed into: Grassland (3)
CES204.099 North Pacific Alpine and Subalpine Dry Grassland
CES204.089 North Pacific Herbaceous Bald and Bluff
CES306.806 Northern Rocky Mountain Subalpine-Upper Montane Grassland

4. Collapsed into: Subalpine Parkland (2)
CES204.837 North Pacific Maritime Mesic Subalpine Parkland
CES306.807 Northern Rocky Mountain Subalpine Dry Parkland

1. Collapsed into: Mid-Montane Forests (2)

**Scientific Name: North Pacific Dry-Mesic Silver Fir-Western Hemlock-Douglas-fir Forest
Unique Identifier: CES204.098 Summary: This forested system occurs only in the Pacific Northwest mountains, primarily west of the Cascade Crest. It generally occurs in an elevational band between *Pseudotsuga menziesii - Tsuga heterophylla* forests and *Tsuga mertensiana* forests. It dominates mid-montane dry to mesic maritime and some submaritime climatic zones from northwestern British Columbia to northwestern Oregon. In British Columbia and in the Olympic Mountains, this system occurs on the leeward side of the mountains only. In the Washington Cascades, it occurs on both windward and leeward sides of the mountains (in other words, it laps over the Cascade Crest to the "eastside"). Stand-replacement fires are regular with mean return intervals of about 200-500 years. Fire frequency tends to decrease with increasing elevation and continentality but still remains within this typical range. A somewhat variable winter snowpack that typically lasts for 2-6 months is characteristic. The climatic zone within which it occurs is sometimes referred to as the "rain-on-snow" zone because of the common occurrence of major winter rainfall on an established snowpack. *Tsuga heterophylla* and/or *Abies amabilis* dominate the canopy of late-seral stands, though *Pseudotsuga menziesii* is usually also common because of its long life span, and *Chamaecyparis nootkatensis* can be codominant, especially at higher elevations. *Abies procera* forests (usually mixed with silver fir) are included in this system and occur in the Cascades from central Washington to central Oregon and rarely in the Coast Range of Oregon. *Pseudotsuga menziesii* is a common species (unlike the mesic western hemlock-silver fir forest system) that regenerates after fires and therefore**

is frequent as a codominant, except at the highest elevations; the prevalence of this species is an important indicator in relation to the related climatically wetter North Pacific Mesic Western Hemlock-Silver Fir Forest (CES204.097). *Abies lasiocarpa* sometimes occurs as a codominant on the east side of the Cascades and in submaritime British Columbia. Understory species that tend to be more common or unique in this type compared to the wetter North Pacific Mesic Western Hemlock-Silver Fir Forest (CES204.097) include *Achlys triphylla, Mahonia nervosa, Xerophyllum tenax, Vaccinium membranaceum, Rhododendron macrophyllum,* and *Rhododendron albiflorum*. *Vaccinium ovalifolium*, while still common, only dominates on more moist sites within this type, unlike in the related type where it is nearly ubiquitous. Classification Comments: Unlike North Pacific Mesic Western Hemlock-Silver Fir Forest (CES204.097), the dominant natural process here is stand-replacing fires which occur on average every 200-500 years. Where old-growth does exist, it is mostly "young old-growth" 200-500 years in age. Natural-origin stands less than 200 years old are also common. More mixed-severity fires occur to the south in this system, so structure, patch size and proportions will be different; further north is more stand-replacing fires. In mapzone 7 this system will get modeled as 2 different BpS because of the differences in regimes. In Oregon there are more mixed-severity fires.

Scientific Name: North Pacific Mesic Western Hemlock-Silver Fir Forest
Unique Identifier: CES204.097 Summary: This forested system occurs only in the Pacific Northwest mountains entirely west of the Cascade Crest from coastal British Columbia to Washington. It generally occurs in an elevational band between *Pseudotsuga menziesii - Tsuga heterophylla* or hypermaritime zone forests and *Tsuga mertensiana* forests. It dominates mid-montane maritime climatic zones on the windward side of Vancouver Island, the Olympic Peninsula, and wettest portions of the North Cascades in Washington (north of Snoqualmie River). Windthrow is a common small-scale disturbance in this system, and gap creation and succession are important processes. Stand-replacement fires are relatively infrequent to absent, with return intervals of several hundred or more years. More mixed-severity fires occur in the southern parts of this system, so that forest structure, patch size and proportions will be different from northern stands. Further north, stand-replacing fires are also infrequent but are a more common fire event. A somewhat variable winter snowpack that typically lasts for 2-6 months is characteristic. The climatic zone within which it occurs is sometimes referred to as the "rain-on-snow" zone because of the common occurrence of major winter rainfall on an established snowpack. *Tsuga heterophylla* and/or *Abies amabilis* dominate the canopy of late-seral stands, and *Chamaecyparis nootkatensis* can be codominant, especially at higher elevations. *Thuja plicata* is also common and sometimes codominates in British Columbia. *Pseudotsuga menziesii* is relatively rare to absent in this system, as opposed to the similar but drier North Pacific Dry-Mesic Silver Fir-Western Hemlock-Douglas-fir Forest (CES204.098). The major understory dominant species is *Vaccinium ovalifolium*. Understory species that help distinguish this system from the drier silver fir system (they are much more common here) include *Oxalis oregana, Blechnum spicant,* and *Rubus pedatus*.
Classification Comments: Jan Henderson suggests using 90 inches mean precipitation at sea level (with modification for topographic moisture) to distinguish wet and dry silver fir systems. Fire regime is significantly different at regional scale between the dry and mesic; this difference appears to be consistent throughout the range of the types. The mesic rarely, if ever, burns; it is dominated by what is sometimes called "old old-growth" stands that run from 700 to over 1000 years in age. Research in British Columbia indicates these coastal rainforests may burn an average of once every 2000 years. The major processes then are small-scale gap dynamics, not stand-replacement fires. This difference is related to climate, not site moisture, with the mesic having a very wet climate that is more coastal, less continental, with cooler summers, and warmer winters on average.

2. Collapsed into: Tall Shrubland *(7)*

Scientific Name: North Pacific Broadleaf Landslide Forest and Shrubland
Unique Identifier: CES204.846
Classification Confidence: 1 – Strong Summary: These forests and shrublands occur throughout the

northern Pacific mountains and lowlands, becoming less prominent in the northern half of this region. They occur on steep slopes and bluffs that are subject to mass movements on a periodic basis. They are found in patches of differing age associated with different landslide events. The vegetation is deciduous broadleaf forests, woodlands, or shrublands, sometimes with varying components of conifers. *Alnus rubra* and *Acer macrophyllum* are the major tree species. *Rubus spectabilis, Rubus parviflorus, Ribes bracteosum*, and *Oplopanax horridus* are some of the major shrub species. Shrublands tend to be smaller in extent than woodlands or forests. Small patches of sparsely vegetated areas or herbaceous-dominated vegetation (especially *Petasites frigidus*) also often occur as part of this system. On earthflows, once stable, vegetation may succeed to dominance by conifers. Classification Comments: Early-successional shrubby patches dominated by *Alnus* or *Acer* not associated with landslide disturbance are removed from this system and are placed within the forest types they are successional to, for example see North Pacific Maritime Dry-Mesic Douglas-fir-Western Hemlock Forest (CES204.001). More stable patches generally belong to North Pacific Montane Shrubland (CES204.087). For other disturbance driven shrublands, see North Pacific Avalanche Chute Shrubland (CES204.854).

Scientific Name: North Pacific Avalanche Chute Shrubland
Unique Identifier: CES204.854
Classification Confidence: 2 – Moderate Summary: This tall shrubland system occurs throughout mountainous regions of the Pacific Northwest, from the southern Cascades and Coast Ranges north to south-central Alaska. This system occurs on sideslopes of mountains on glacial till or colluvium. These habitats range from moderately xeric to wet and occur on snow avalanche chutes at montane elevations. In the mountains of Washington, talus sites and snow avalanche chutes very often coincide spatially. On the west side of the Cascades, the major dominant species are *Acer circinatum, Alnus viridis ssp. sinuata, Rubus parviflorus*, and small trees, especially *Chamaecyparis nootkatensis*. Forbs, grasses, or other shrubs can also be locally dominant. *Prunus virginiana, Amelanchier alnifolia, Vaccinium membranaceum* or *Vaccinium scoparium*, and *Fragaria* spp. are common species on drier avalanche tracks on the east side of the Cascades (Ecosystems Working Group 1998). The main feature of this system is that it occurs on steep, frequently disturbed (snow avalanches) slopes. Avalanche chutes can be quite long, extending from the subalpine into the montane and foothill toeslopes.

Scientific Name: North Pacific Montane Shrubland
Unique Identifier: CES204.087 Summary: This system occurs as small to large patches scattered throughout the North Pacific region, but it is largely absent from the windward sides of the coastal mountains where fires are rare due to very wet climates. It is defined as long-lived seral shrublands that persist for several decades or more after major wildfires, or smaller patches of shrubland on dry sites that are marginal for tree growth and that have typically also experienced fire. This system occurs on ridgetops and upper to middle mountain slopes and is more common on sunny southern aspects. It occurs from about 152 m (500 feet) elevation up to the lower limits of subalpine parkland. Vegetation is mostly deciduous broadleaf shrubs, sometimes mixed with shrub-statured trees or sparse evergreen needleleaf trees. It can also be dominated by evergreen shrubs, especially *Xerophyllum tenax* (usually considered a forb). Species composition is highly variable; some of most common species include *Acer circinatum, Arctostaphylos nevadensis, Acer glabrum, Vaccinium membranaceum, Ceanothus velutinus, Holodiscus discolor, Shepherdia canadensis, Sorbus* spp., and *Rubus parviflorus*. On the west side of the Cascades, *Gaultheria shallon* is an important dominant.

Scientific Name: Northern Rocky Mountain Montane-Foothill Deciduous Shrubland
Unique Identifier: CES306.994
Classification Confidence: 3 – Weak Summary: This shrubland ecological system is found in the lower montane and foothill regions around the Columbia Basin, and north and east into the northern Rockies. These shrublands typically occur below treeline, within the matrix of surrounding low-elevation grasslands and sagebrush shrublands. They also occur in the ponderosa pine and Douglas-fir zones, but rarely up into the subalpine zone (on dry sites). The shrublands are usually found on

steep slopes of canyons and in areas with some soil development, either loess deposits or volcanic clays; they occur on all aspects. Fire, flooding and erosion all impact these shrublands, but they typically will persist on sites for long periods. These communities develop near talus slopes as garlands, at the heads of dry drainages, and toeslopes in the moist shrub-steppe and steppe zones. *Physocarpus malvaceus, Prunus emarginata, Prunus virginiana, Rosa* spp., *Rhus glabra, Acer glabrum, Amelanchier alnifolia, Symphoricarpos albus, Symphoricarpos oreophilus*, and *Holodiscus discolor* are the most common dominant shrubs, occurring alone or any combination. *Rubus parviflorus* and *Ceanothus velutinus* are other important shrubs in this system, being more common in montane occurrences than in subalpine situations. Occurrences in central and eastern Wyoming can include *Artemisia tridentata ssp. vaseyana* and *Cercocarpus montanus*, but neither of these are dominant, and where they occur, the stands are truly mixes of shrubs, often with *Amelanchier alnifolia, Prunus virginiana*, and others being the predominant taxa. In moist areas, *Crataegus douglasii* can be common. *Shepherdia canadensis* and *Spiraea betulifolia* can be abundant in some cases but also occur in Northern Rocky Mountain Subalpine Deciduous Shrubland (CES306.961). *Festuca idahoensis, Festuca campestris, Calamagrostis rubescens, Carex geyeri, Koeleria macrantha, Pseudoroegneria spicata*, and *Poa secunda* are the most important grasses. *Achnatherum thurberianum* and *Leymus cinereus* can be locally important. *Poa pratensis* and *Phleum pratense* are common introduced grasses. *Geum triflorum, Potentilla gracilis, Lomatium triternatum, Balsamorhiza sagittata*, and species of *Eriogonum, Phlox*, and *Erigeron* are important forbs.
Classification Comments: Seral shrub fields of comparable composition that typically will develop into a seral stage with trees (within 50 years) are excluded from this shrub system and are included in their appropriate forest system.

Scientific Name: Temperate Pacific Subalpine-Montane Wet Meadow
Unique Identifier: CES200.998 Summary: Montane and subalpine wet meadows occur in open wet depressions, basins and flats among montane and subalpine forests from California's Transverse and Peninsular ranges north to the Alaskan coastal forests at varying elevations depending on latitude. Sites are usually seasonally wet, often drying by late summer, and many occur in a tension zone between perennial wetlands and uplands, where water tables fluctuate in response to long-term climatic cycles. They may have surface water for part of the year, but depths rarely exceed a few centimeters. Soils are mostly mineral and may show typical hydric soil characteristics, and shallow organic soils may occur as inclusions. This system often occurs as a mosaic of several plant associations with varying dominant herbaceous species that may include *Camassia quamash, Carex bolanderi, Carex utriculata, Carex exsiccata, Dodecatheon jeffreyi, Glyceria striata (= Glyceria elata), Carex nigricans, Calamagrostis canadensis, Juncus nevadensis, Caltha leptosepala ssp. howellii, Veratrum californicum*, and *Scirpus* and/or *Schoenoplectus* spp. Trees occur peripherally or on elevated microsites and include *Picea engelmannii, Abies lasiocarpa, Abies amabilis, Tsuga mertensiana*, and *Chamaecyparis nootkatensis*. Common shrubs may include *Salix* spp., *Vaccinium uliginosum, Betula nana*, and *Vaccinium macrocarpon*. Wet meadows are tightly associated with snowmelt and typically are not subjected to high disturbance events such as flooding.
Classification Comments: Rocky Mountain Alpine-Montane Wet Meadow (CES306.812) occurs to the east of the coastal and Sierran mountains, in the semi-arid interior regions of western North America. Boreal wet meadow systems occur further north and east in boreal regions where the climatic regime is generally colder than that of the Rockies or Pacific Northwest regions. Floristics of these three systems are somewhat similar, but there are differences related to biogeographic affinities of the species composing the vegetation.

Scientific Name: North Pacific Montane Riparian Woodland and Shrubland
Unique Identifier: CES204.866
Classification Confidence: 2 – Moderate Summary: This system occurs throughout mountainous areas of the Pacific Northwest coast, both on the mainland and on larger islands. It occurs on steep streams and narrow floodplains above foothills but below the alpine environments, e.g., above 1500 m (4550 feet) elevation in the Klamath Mountains and western Cascades of Oregon, up as high as 3300 m (10,000 feet) in the southern Cascades, and above 610 m (2000 feet) in northern Washington. Surrounding habitats include subalpine parklands and montane forests. In Washington they are

defined as occurring primarily above the *Tsuga heterophylla* zone, i.e., beginning at or near the lower boundary of the *Abies amabilis* zone. Dominant species include *Pinus contorta var. murrayana, Populus balsamifera ssp. trichocarpa, Abies concolor, Abies magnifica, Populus tremuloides, Alnus incana ssp. tenuifolia (= Alnus tenuifolia), Alnus viridis ssp. crispa (= Alnus crispa), Alnus viridis ssp. sinuata (= Alnus sinuata), Alnus rubra, Rubus spectabilis, Ribes bracteosum, Oplopanax horridus, Acer circinatum*, and several *Salix* species. In Western Washington, major species are *Alnus viridis ssp. sinuata, Acer circinatum, Salix, Oplopanax horridus, Alnus rubra, Petasites frigidus, Rubus spectabilis,* and *Ribes bracteosum*. These are disturbance-driven systems that require flooding, scour and deposition for germination and maintenance. They occur on streambanks where the vegetation is significantly different than surrounding forests, usually because of its shrubby or deciduous character.

Scientific Name: Rocky Mountain Subalpine-Montane Riparian Shrubland
Unique Identifier: CES306.832
Classification Confidence: 2 – Moderate Summary: This system is found throughout the Rocky Mountain cordillera from New Mexico north into Montana, and also occurs in mountainous areas of the Intermountain region and Colorado Plateau. These are montane to subalpine riparian shrublands occurring as narrow bands of shrubs lining streambanks and alluvial terraces in narrow to wide, low-gradient valley bottoms and floodplains with sinuous stream channels. Generally it is found at higher elevations, but can be found anywhere from 1700-3475 m. Occurrences can also be found around seeps, fens, and isolated springs on hillslopes away from valley bottoms. Many of the plant associations found within this system are associated with beaver activity. This system often occurs as a mosaic of multiple communities that are shrub- and herb-dominated and includes above-treeline, willow-dominated, snowmelt-fed basins that feed into streams. The dominant shrubs reflect the large elevational gradient and include *Alnus incana, Betula nana, Betula occidentalis, Cornus sericea, Salix bebbiana, Salix boothii, Salix brachycarpa, Salix drummondiana, Salix eriocephala, Salix geyeriana, Salix monticola, Salix planifolia*, and *Salix wolfii*. Generally the upland vegetation surrounding these riparian systems are of either conifer or aspen forests

3. Collapsed into: Grassland (3)

Scientific Name: North Pacific Alpine and Subalpine Dry Grassland
Unique Identifier: CES204.099 Summary: This high-elevation, grassland system is dominated by perennial grasses and forbs found on dry sites, particularly south-facing slopes, typically imbedded in or above subalpine forests and woodlands. Disturbance such as fire also plays a role in maintaining these open grassy areas, although drought and exposed site locations are primary characteristics limiting tree growth. It is most extensive in the eastern Cascades, although it also occurs in the Olympic Mountains. Alpine and subalpine dry grasslands are small openings to large open ridges above or drier than high-elevation conifer trees. In general, soil textures are much finer, and soils are often deeper under grasslands than in the neighboring forests. These grasslands, although composed primarily of tussock-forming species, do exhibit a dense sod that makes root penetration difficult for tree species. Typical dominant species include *Festuca idahoensis, Festuca viridula*, and *Festuca roemeri* (the latter species occurring only in the Olympic Mountains). This system is similar to Northern Rocky Mountain Subalpine-Upper Montane Grassland (CES306.806), differing in its including dry alpine habitats, more North Pacific floristic elements, greater snowpack, and higher precipitation.

Scientific Name: North Pacific Herbaceous Bald and Bluff
Unique Identifier: CES204.089 Summary: This system consists of mostly herbaceous-dominated areas located primarily on shallow soils from eastern Vancouver Island and the Georgia Basin south to at least the southern end of the Willamette Valley and adjacent slopes of the Coast Ranges and western Cascades, excluding areas adjacent to the outer coastline (hypermaritime climate). They are largely, if not completely, absent from the windward side of Vancouver Island, the Olympic Peninsula, and the Coast Ranges of Washington and Oregon. Due to shallow soils, steep slopes, sunny aspect, and/or upper slope position, these sites are dry and marginal for tree establishment and

growth except in favorable microsites. Rock outcrops are a typical small-scale feature within balds and are considered part of this system. Sites with many favorable microsites can have a "savanna" type structure with a sparse tree layer of *Pseudotsuga menziesii* or, less commonly, *Quercus garryana*. The climate is relatively dry to wet (20 to perhaps 100 inches annual precipitation), always with a distinct dry summer season when these sites usually become droughty enough to limit tree growth and establishment. Seeps are a frequent feature in many balds and result in vernally moist to wet areas within the balds that dry out by summer. Vegetation differences are associated with relative differences in soil moisture. Most sites have little snowfall, but sites in the *Abies amabilis* zone (montane *Tsuga heterophylla* in British Columbia) can have significant winter snowpacks. Snowpacks would be expected to melt off sooner on these sunny aspect sites than surrounding areas. Fog and salt spray probably have some influence (but less than in the hypermaritime) on exposed slopes or bluffs adjacent to saltwater shorelines in the Georgia Basin, where soils on steep coastal bluffs sometime deviate from the norm and are deep glacial deposits. Slightly to moderately altered serpentine soils occur rarely. Fires, both lightning-ignited and those ignited by Native Americans, undoubtedly at least occasionally burn all these sites. Lower elevation sites in the Georgia Basin, Puget Trough, and Willamette Valley probably were burned somewhat more frequently and in some cases intentionally. Because of this fire history, the extent of this system has declined locally through tree invasion and growth, as areas formerly maintained herbaceous by burning have filled in with trees. Grasslands are the most prevalent vegetation cover, though forblands are also common especially in the mountains. Dwarf-shrublands occur commonly, especially in mountains or foothills, as very small patches for the most part, usually in a matrix of herbaceous vegetation, most often near edges. Dominant or codominant native grasses include *Festuca roemeri, Danthonia californica, Achnatherum lemmonii, Festuca rubra* (near saltwater), and *Koeleria macrantha*. Forb diversity can be high. Some typical codominant forbs include *Camassia quamash, Camassia leichtlinii, Triteleia hyacinthina, Mimulus guttatus* (seeps), *Plectritis congesta, Lomatium martindalei, Allium cernuum*, and *Phlox diffusa* (can be considered a dwarf-shrub). Important dwarf-shrubs are *Arctostaphylos uva-ursi, Arctostaphylos nevadensis*, and *Juniperus communis*. Small patches and strips dominated by the shrub *Arctostaphylos columbiana* are a common feature nested within herbaceous balds. Significant portions of some balds, especially on rock outcrops, are dominated by bryophytes (mosses) and to a lesser degree lichens.

Scientific Name: Northern Rocky Mountain Subalpine-Upper Montane Grassland
Unique Identifier: CES306.806 Summary: This is an upper montane to subalpine, high-elevation, lush grassland system dominated by perennial grasses and forbs on dry sites, particularly south-facing slopes. It is most extensive in the Canadian Rockies portion of the Rocky Mountain cordillera, extending south into western Montana, eastern Oregon, eastern Washington and Idaho. Subalpine dry grasslands are small meadows to large open parks surrounded by conifer trees but lack tree cover within them. In general, soil textures are much finer, and soils are often deeper under grasslands than in the neighboring forests. Grasslands, although composed primarily of tussock-forming species, do exhibit a dense sod that makes root penetration difficult for tree species. Disturbance such as fire also plays a role in maintaining these open grassy areas. Typical dominant species include *Leymus innovatus (= Elymus innovatus), Koeleria macrantha, Festuca campestris, Festuca idahoensis, Festuca viridula, Achnatherum occidentale (= Stipa occidentalis), Achnatherum richardsonii (= Stipa richardsonii), Bromus inermis ssp. pumpellianus (= Bromus pumpellianus), Elymus trachycaulus, Phleum alpinum, Trisetum spicatum*, and a variety of Carices, such as *Carex hoodii, Carex obtusata*, and *Carex scirpoidea*. Important forbs include *Lupinus argenteus var. laxiflorus, Potentilla diversifolia, Potentilla flabellifolia, Fragaria virginiana*, and *Chamerion angustifolium (= Epilobium angustifolium)*. This system is similar to Northern Rocky Mountain Lower Montane, Foothill and Valley Grassland (CES306.040) but is found at higher elevations and is more often composed of species of *Festuca, Achnatherum*, and/or *Hesperostipa* with additional floristic components of more subalpine taxa. Occurrences of this system are often more forb-rich than Southern Rocky Mountain Montane-Subalpine Grassland (CES306.824).

4. Collapsed into: Subalpine Parkland (2)

Scientific Name: North Pacific Maritime Mesic Subalpine Parkland
Unique Identifier: CES204.837
Classification Confidence: 2 – Moderate Summary: This system occurs throughout the mountains of the Pacific Northwest, from the southern Cascades of Oregon to the mountains of south-central Alaska. It occurs at the transition zone of forest to alpine, forming a subalpine forest-meadow ecotone. Clumps of trees to small patches of forest interspersed with low shrublands and meadows characterize this system. Krummholz often occurs near the upper elevational limit of this type where it grades into alpine vegetation. Associations include woodlands, forested and subalpine meadow types. It occurs on the west side of the Cascade Mountains where deep, late-lying snowpack is the primary environmental factor. Major tree species are *Tsuga mertensiana, Abies amabilis, Chamaecyparis nootkatensis,* and *Abies lasiocarpa*. This system includes British Columbia Hypermaritime and Maritime Parkland (*Tsuga mertensiana*). Dominant dwarf-shrubs include *Phyllodoce empetriformis, Cassiope mertensiana*, and *Vaccinium deliciosum*. Dominant herbaceous species include *Lupinus arcticus ssp. subalpinus, Valeriana sitchensis, Carex spectabilis*, and *Polygonum bistortoides*. There is very little disturbance, either windthrow or fire. The major process controlling vegetation is the very deep long-lasting snowpacks (deepest in the North Pacific region) limiting tree regeneration. Trees get established only in favorable microsites (mostly adjacent to existing trees) or during drought years with low snowpack. It is distinguished from more interior dry parkland primarily by the presence of *Tsuga mertensiana* or *Abies amabilis* and absence or paucity of *Pinus albicaulis* and *Larix lyallii*.

Scientific Name: Northern Rocky Mountain Subalpine Woodland and Parkland
Unique Identifier: CES306.807

Classification Confidence: 2 – Moderate Summary: This system of the northern Rockies, Cascade Mountains, and northeastern Olympic Mountains is typically a high-elevation mosaic of stunted tree clumps, open woodlands, and herb- or dwarf-shrub-dominated openings, occurring above closed forest ecosystems and below alpine communities. It includes open areas with clumps of *Pinus albicaulis*, as well as woodlands dominated by *Pinus albicaulis* or *Larix lyallii*. In the Cascade Mountains and northeastern Olympic Mountains, the tree clump pattern is one manifestation, but these are also woodlands with an open canopy, without a tree clump/opening patchiness to them; in fact, that is quite common with *Pinus albicaulis*. The climate is typically very cold in winter and dry in summer. In the Cascades and Olympic Mountains, the climate is more maritime in nature and wind is not as extreme. The upper and lower elevational limits, due to climatic variability and differing topography, vary considerably; in interior British Columbia, this system occurs between 1000 and 2100 m elevation, and in northwestern Montana it occurs up to 2380 m. Landforms include ridgetops, mountain slopes, glacial trough walls and moraines, talus slopes, landslides and rockslides, and cirque headwalls and basins. Some sites have little snow accumulation because of high winds and sublimation. *Larix lyallii* stands generally occur at or near upper treeline on north-facing cirques or slopes where snowfields persist until June or July. In this harsh, often wind-swept environment, trees are often stunted and flagged from damage associated with wind and blowing snow and ice crystals, especially at the upper elevations of the type. The stands or patches often originate when *Picea engelmannii, Larix lyallii*, or *Pinus albicaulis* colonize a sheltered site such as the lee side of a rock. *Abies lasiocarpa* can then colonize in the shelter of the *Picea engelmannii* and may form a dense canopy by branch layering. Major disturbances are windthrow and snow avalanches. Fire is known to occur infrequently in this system, at least where woodlands are present; lightning damage to individual trees is common, but sparse canopies and rocky terrain limit the spread of fire. These high-elevation coniferous woodlands are dominated by *Pinus albicaulis, Abies lasiocarpa*, and/or *Larix lyallii*, with occasional *Picea engelmannii*. In the Cascades and Olympics, *Abies lasiocarpa* sometimes dominates the tree layer without *Pinus albicaulis*, though in this dry parkland *Tsuga mertensiana* and *Abies amabilis* are largely absent. The undergrowth is usually somewhat depauperate, but some stands support a near sward of heath plants, such as *Phyllodoce glanduliflora, Phyllodoce empetriformis, Empetrum nigrum, Cassiope mertensiana*, and *Kalmia polifolia*, and can include a slightly taller layer of *Ribes montigenum, Salix brachycarpa, Salix glauca, Salix planifolia, Vaccinium membranaceum, Vaccinium myrtillus*, or *Vaccinium scoparium* that may be present to

codominant. The herbaceous layer is sparse under dense shrub canopies or may be dense where the shrub canopy is open or absent. *Vahlodea atropurpurea (= Deschampsia atropurpurea), Luzula glabrata var. hitchcockii*, and *Juncus parryi* are the most commonly associated graminoids. Classification Comments: There is a proposal to either split the dry, subalpine *Pinus albicaulis* woodlands of the Blue Mountains (Oregon) and northern Nevada into a different system; or else to include them in Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland (CES306.819). For Landfire, these *Pinus albicaulis* woodlands were included in this subalpine parkland system, but ecologically and floristically they are more similar to Rocky Mountain dry subalpine woodlands. In addition, there is a proposal and discussion that tree ribbon spruce-fir woodlands in scattered ranges of southern Wyoming are more ecologically "parklands"; possibly those areas could be included in this system.

Appendix 2: Model explanations chosen apriori, thought to be important as potential predictors of goat habitat, used in habitat analysis.

Model	Models	Model Explanation
1	mef grass park con33 con66 prr vrm et tshb	Global Model
2	grass park con33 con66 prr vrm et tshb	Global w/out mef
3	mef grass park tshb	Vegetation composition
4	con33 con66	Vegetation structure
5	prr vrm et	Abiotic variables
6	park prr vrm et	Abiotic & Parkland
7	park prr et	Topographic & Parkland 1
8	park vrm et	Parkland & Topographic 2
9	park	Single-variable Parkland
10	et	Single-variable Escape Terrain
11	prr	Single-variable Solar load
12	mef park con66 prr vrm et tshb	High Canopy w/out grass
13	park con66 prr vrm et tshb	Parkland, High Canopy, Abiotic & Tall Shrub
14	park con66 vrm et tshb	Parkland, High Canopy, Topographic & Tall Shrub
15	park vrm et tshb	Parkland, Topograhic & Tall Shrub
16	vrm et tshb	Topograhic & Tall Shrub
17	et tshb	Escape Terrain & Tall Shrub
18	et tshb con66	Escape Terrain, Tall Shrub & High Canopy
19	et tshb con66 vrm	Topographic, Tall Shrub & High Canopy
20	et tshb con66 vrm grass	Topographic, Tall Shrub, High Canopy & Grassland
21	et tshb con66 vrm grass park	Topographic, Tall Shrub, High Canopy & Grassland, Parkland
22	et tshb con66 vrm grass park prr	Abiotic, Tall Shrub, High Canopy & Grassland, Parkland
23	et tshb con66 park prr	Escape Terrain, Tall Shrub, High Canopy, Parkland & Solar load
24	et tshb con33 con66 park prr	Escape Terrain, Tall Shrub, Mid and High Canopy, Parkland & Solar load
25	et tshb park prr	Escape Terrain, Tall Shrub, Parkland & Solar load

mef = mid elevation forests, grass = grassland, park = subalpine parkland, con33 = conifer cover from 33-66%, con66 = conifer cover from 66-99.9%, prr = potential relative radiation, vrm = vector ruggedness model, et = escape terrain, tshb=tall shrubland