

**VEGETATION IN RELATION TO
INTRODUCED MOUNTAIN GOATS IN
OLYMPIC NATIONAL PARK:
A TECHNICAL REPORT**

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CHAPTER 1:

INTRODUCTION

Plant-herbivore grazing systems have been the subject of increased study by ecologists during the last two decades. Herbivores have been shown to affect numerous attributes of vegetation including plant morphology, species composition, abundance, net primary productivity and the genetic makeup of plant populations (e.g. McNaughton 1983, Pastor et al. 1988, Frank and McNaughton 1992). The scale of plant-herbivore interactions ranges from effects on individual plants to ecosystems (Harper 1977; McNaughton 1979, 1983; Crawley 1983). Effects of herbivores have been documented in long-established natural ecosystems (Coppock et al. 1988) and where wild ungulates have been recently introduced (Caughley 1970, Leader-Williams et al. 1987).

Characteristically, ungulates and vegetation are linked by strong feedback loops between the dynamics of the plants and the dynamics of the animals (Caughley, 1970, 1976, 1979). Ungulate populations may be limited by available food resources, consequently, as their populations increase, available per capita resources (i.e. palatable plants) decrease. Natural mortality increases and natality decreases because of insufficient food. The plants "feedback" to cause a new, lower level of the animal population. Plants and ungulate populations oscillate with decreasing amplitude over time as dynamic equilibrium is achieved. Profound changes usually occur in the vegetation. Caughley (1970) describes this process for introduced Himalayan thar (*Hemitragus jemlahicus*) in New Zealand.

Mountain goats (*Oreamnos americanus*) were deliberately introduced at the northern end of the Olympic Mountains in the 1920s (Webster 1925, Moorhead and Stevens 1982, Scheffer 1993). The animals subsequently spread throughout the Olympic Range (Stevens 1983, Houston et al. 1986, 1991). Goats occur in the nearby Cascade Mountain Range but evidence indicates they were absent historically from the Olympic Peninsula (Scheffer 1993).

Stevens (1980) estimated the Peninsula-wide mountain goat population at 550-800 in 1980; aerial censuses (Houston et al. 1986, 1991a) resulted in population estimates of 1175 ± 171 (SE) in 1983 and 389 ± 106 (SE) in 1990. Several hundred animals were removed from Olympic National Park (ONP) from 1981-89. Mountain goats in the Olympics are distributed discontinuously in "nodes" or subpopulations (Stevens 1980, 1983; Houston et al. 1986).

Mountain goats are seasonally migratory in the Olympic Mountains (Stevens 1979, 1983). Subalpine and alpine areas above 1520 m are generally considered to be summer range, but animals are often

found at considerably lower elevations (610 m) on hot summer days (R. Olson, pers. com.). Mountain goats generally winter on steep south and southeast facing rock outcrops and cliffs below 1500 m but may also be found as low as 300 m (Stevens 1979) or above 1500 m in portions of their summer range (Schreiner pers. obs.). We defined mountain goat summer range as the region above 1520 m for purposes of this study.

Mountain goats are a generalist herbivore strongly associated with cliffs and rock outcrops (Chadwick 1983). Their food habits vary considerably between geographic regions. Diets are apparently dictated more by the available plant resource than by a preference for any particular species or growth form.

Previous studies of the interactions between mountain goats and their summer range in Olympic National Park clearly demonstrated that goats changed native ecosystems (i.e. the general null hypothesis that mountain goats have no effect on subalpine plant communities was rejected). Results showed that physical site characteristics such as rocky outcrops for escape routes and late melting snow for thermoregulation were the most important factors in habitat selection by goats and that plant community makeup was relatively unimportant (Stevens 1979, Pfitsch and Bliss 1985). As a consequence, mountain goats utilized all nine subalpine and alpine plant communities in one study area (Pfitsch and Bliss 1985). Plant community effects included reduced moss and lichen cover, increased soil disturbance and exposure of mineral soil from wallowing and trampling, and rearrangement of plant species composition in favor of ruderal (plants found mainly in disturbed areas, so-called disturbance-oriented species) (Pfitsch 1981, Pike 1981, Pfitsch et al. 1983, Reid 1983, Pfitsch and Bliss 1985). Also, three Olympic Peninsula and one Olympic Peninsula/Vancouver Island endemic plant taxa were consumed by goats (Pike 1981, Houston et al. 1984, Kaye 1989).

While the aforementioned studies demonstrated that introduced mountain goats altered native plant communities, these investigations were conducted primarily in one area of Olympic National Park over a four-year period. Consequently, a new series of investigations was begun in 1981 to expand our understanding of mountain goat/vegetation and soil interactions in time and space. Our objectives were to describe plant communities and large herbivore sign in mountain goat summer range (above 1520 m) and to test the following two general null hypotheses:

1. Reducing mountain goat densities will not result in changes to the relative abundance of plant species (i.e. plant community structure).

2. Mountain goats pose no threat to the long-term persistence of rare plants.

We employed a variety of independent study methods to achieve these objectives: 1) Extensive surveys of vegetation and herbivore use were conducted in high, medium and low goat density areas within the 43,500 ha of land free of glacial ice above 1520 m; 2) Permanent plots were established in three areas to quantify plant community responses to intentional reductions in goat density; 3) Potential effects of goats on the long-term persistence of rare plants were assessed using data on rare plant geography and abundance; 4) The demography and autecology of a particularly rare endemic taxon (*Astragalus australis* var. *olympicus*, Olympic Mtn. milkvetch) was investigated; and 5) A series of historical photographs was employed to qualitatively examine vegetation changes over a 70-year period, specifically the relationships between climate, human use, natural disturbance, and mountain goats.

CHAPTER 2:

STUDY AREA

The Olympic Peninsula (13,800 km²) is located in the northwest corner of the conterminous United States (Fig. 2-1). Bounded on three sides by saltwater and on the fourth by the broad lowlands of the Chehalis River Valley, the region is isolated from the Cascade Mountain range to the east. The study area, Olympic National Park (3,733 km²), includes about 87% of the mountainous core of the Olympic Peninsula. Biotic zones include marine intertidal communities, temperate coniferous rainforest, lowland, montane and subalpine coniferous forests, subalpine meadows, and alpine tundra. Elevations range from below sea level to over 2400 m.

Olympic National Park plays a crucial role in preservation of Olympic Peninsula biodiversity because the primeval landscape has been greatly altered by Euro-American settlement and activities over the last 150 years. The majority of the Olympic Peninsula's remaining undisturbed natural areas now occur within Olympic National Park, adjacent Wilderness Areas administered by Olympic National Forest and a few other small protected areas.

Climate

The climate of the Olympic Peninsula is extremely varied. The high mountains and proximity to the Pacific Ocean combine to produce the wettest location in the conterminous United States only 50 km distant from the driest site on the West Coast north of southern California (Jones 1936, Phillips and Donaldson 1972). The striking precipitation gradient (Fig. 2-2) results because the Olympic massif interferes with the flow of moisture laden air arriving off the Pacific Ocean. Moreover, the steepness of the mountains places alpine areas within 16 km of salt water.

Climate is generally maritime with cool, wet winters and relatively cool dry summers. Mountainous areas in the northeastern Olympics experience a somewhat more continental climate (Henderson et al. 1989). Eighty percent of annual precipitation occurs from October to March with only five percent occurring in July and August (Phillips and Donaldson 1972). The lowest recorded minimum temperatures at lower elevations, range between -16 and -19 °C. Average minimum January temperatures are near 0 °C while August maxima are in the vicinity of 21 °C. Temperatures average slightly cooler in the north than in the south.

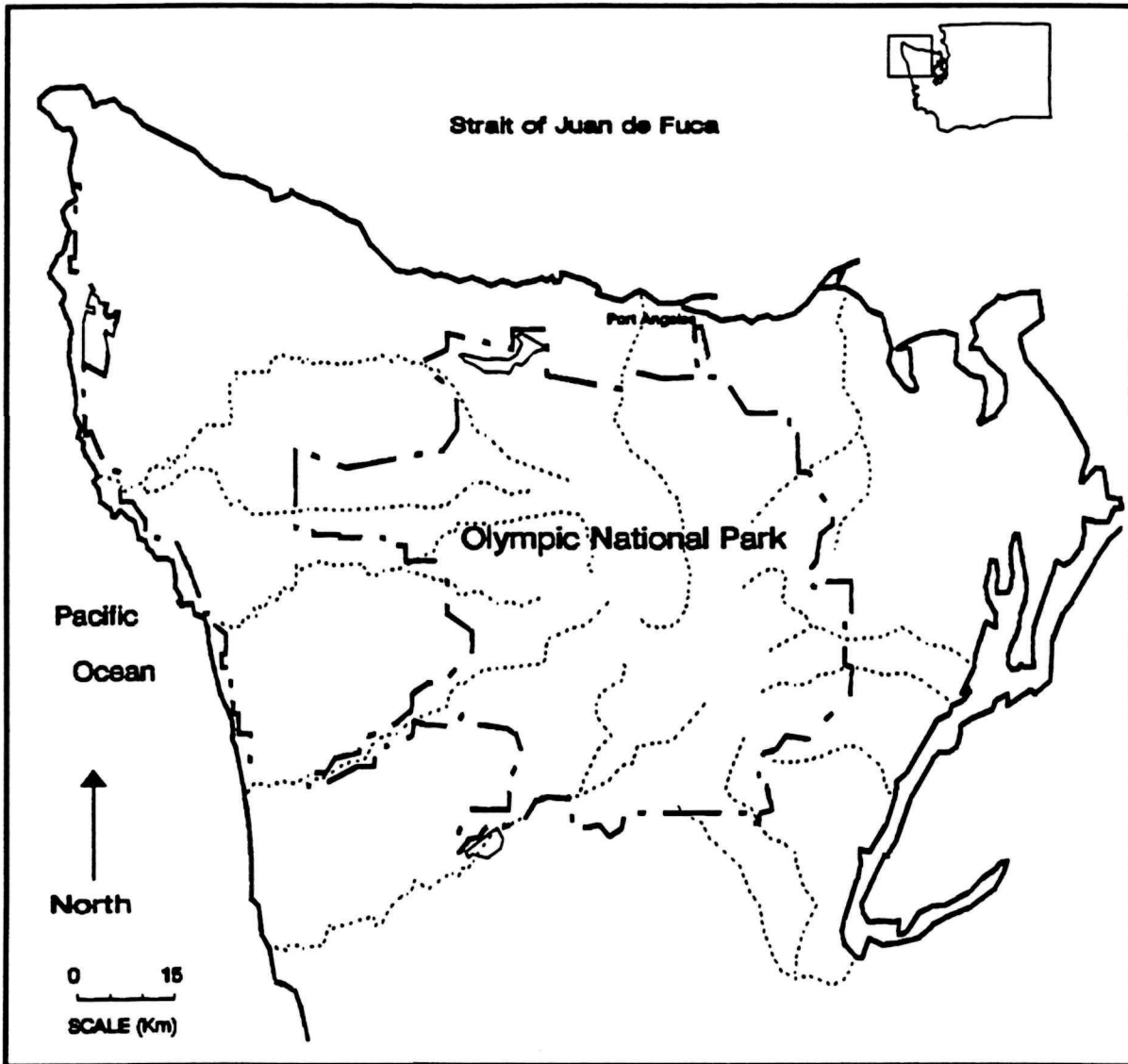


Figure 2-1. Location of Olympic National Park and the Olympic Peninsula in relation to Washington State.

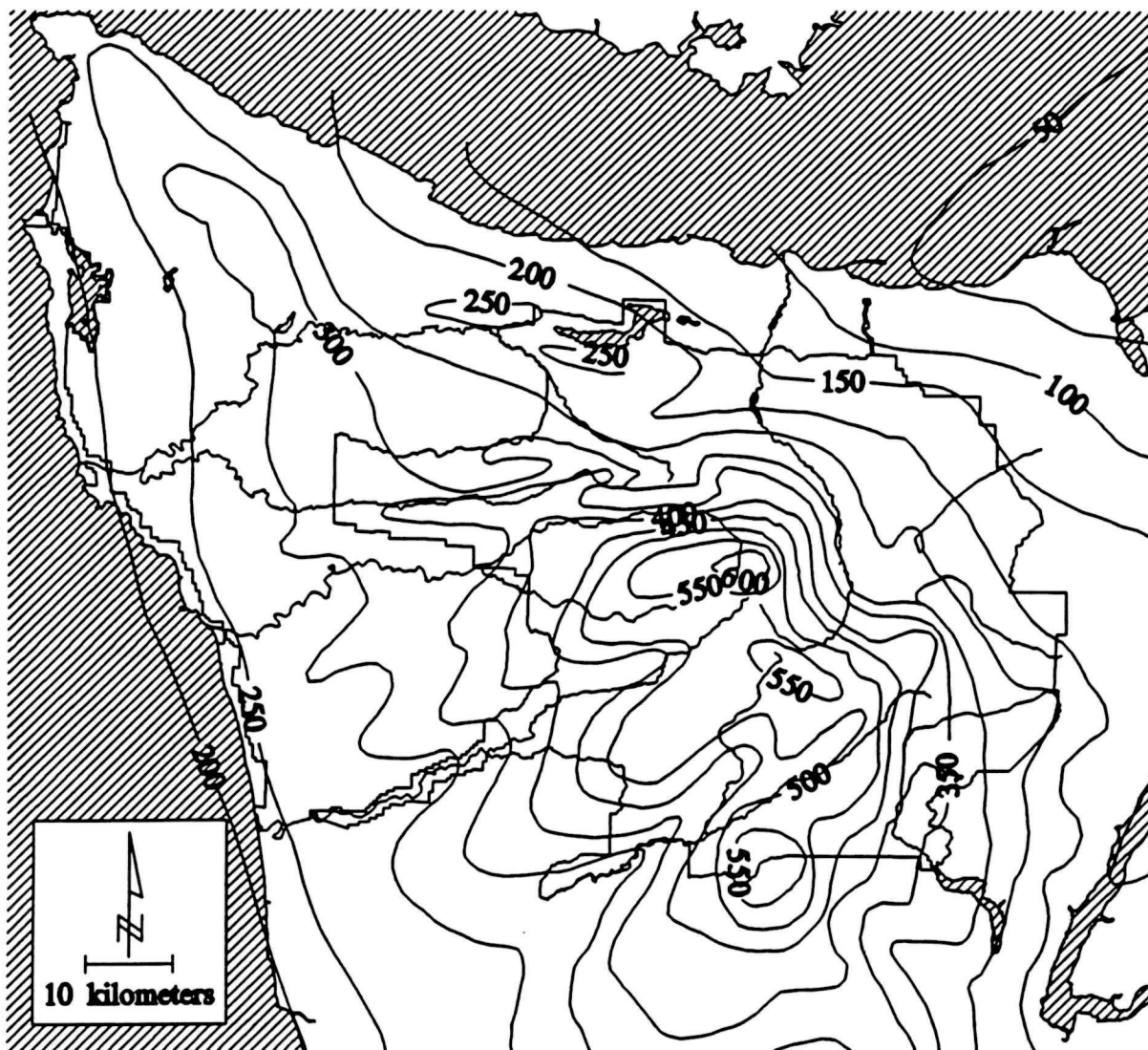


Figure 2-2. Map of mean annual precipitation (cm) on the Olympic Peninsula (based on Philips and Donaldson, 1972).

Geology

The Olympic Mountains were formed as a result of the collision between the suboceanic Juan de Fuca plate and the North American continent over an 18 million-year period beginning about 30 million years B.P. (Tabor 1975). As the oceanic plate was forced under the North American continent, layers of basalt, sandstone, and shale were scraped off the ocean floor and rode up over the continental margin. The basalt, originally volcanic seamounts in the Pacific Ocean, and some interlayered sediments were evidently pushed toward the northeast corner of the Peninsula and resulted in the modern-day Crescent Formation. As pressure between the two plates diminished, the lighter sandstones and shales, already piled up west of the basalt, bobbed up like a cork to form the mountainous core. Water draining in all directions from the newly formed mountains eventually created the radial drainage pattern seen today (Tabor 1975).

The Puget Sound region and presumably all or parts of the adjacent Olympic Mountains were subjected to periodic glaciation during the Wisconsin and earlier Ice Ages (Crandell 1965, Porter 1977, Barnosky 1981). The most recent Fraser Glaciation which began ca 21,000 years B.P, lasted for some 10,000 years and contained three periods or stades when ice advanced. Two stades, Evans Creek and Vashon, had a major effect on the Olympic Peninsula. The most recent stade (Sumas) was evidently of little consequence compared to two previous advances (Henderson et al. 1989).

The Evans Creek Stade of the Fraser Glaciation (25,000 - 17,000 B.P) was marked by advance of alpine glaciers in the Olympics and Cascades (Whitlock 1992). Glaciers flowed down most major Olympic Peninsula valleys, but apparently did not spread much beyond the confines of the valley walls (Heusser 1974). Western Olympic glaciers extended down-valley, perhaps as far as the Pacific Ocean (Henderson et al. 1989), while their northeastern Olympic counterparts extended only to the modern-day equivalent of the montane zone (Long 1975). Small basins give the appearance in some areas that glaciers were likely restricted to the headwalls. The line of perennial snow at the time alpine glaciers were present was at about 880 m in the western Olympics and 1200 m in the northeastern Olympics (Porter 1977). Consequently, land that was free of ice and snow existed at low elevations between river valleys, beyond the snouts of valley glaciers, and presumably at high elevations on ridges and rocky outcrops blown free of snow.

The Vashon Stade maximum which occurred ca 15,000 - 13,500 years B.P (Porter 1976), differed from Evans Creek in that it mainly involved the vast Cordilleran Ice Sheet. Ice pushed south from the Canadian Coastal Ranges through Puget Sound to near Olympia and west out the Strait of Juan de Fuca to Cape Flattery (Crandell 1965, Kruckeberg 1991). This continental ice was 1150 m thick just south of the present location of Port Angeles (Long 1975). Whitlock (pers. com.) believes it likely that the regional climate was similar to that of today when the Vashon ice was present. If this is true, alpine glaciers may not have extended far down valleys during the Vashon Stade, and land was accessible to plants and animals at unglaciated sites.

Biogeography

The varied climate, elevation, and isolation of the Olympics have combined to produce a fascinating biota. Comparisons with vascular flora from around the world suggest that the Olympics have lower than expected levels of endemism but may have greater species richness (Major 1988). Vascular plant diversity of the British Isles, for example, is very roughly equivalent to that of the Olympic Peninsula even though the Olympics have only about 1/20th the land area.

At first glance, plant species of the Olympics seem to correspond to those of the Cascade Mountain Range 100 kilometers or so to the east. Dominant coniferous species are mostly shared between the two areas (e.g. Douglas-fir, western hemlock, silver fir) as are a number of subalpine species (e.g. showy sedge, pink mountain heather). General appearances, however, may be deceiving. Subalpine meadows at Mount Rainier dominated by green fescue (*Festuca viridula*) look similar to Idaho fescue meadows in Olympic; species composition, however is fundamentally different. A comparison of the high elevation Olympic vascular flora (Buckingham and Tisch 1979) with that of the North Cascade Mountains (Douglas and Bliss 1977) shows that 24% of the Olympic species are not found in the North Cascades, and conversely, 36% of North Cascade species are not found in the Olympics.

Several animal and plant species of the Cascade Range were absent historically from the Olympic Peninsula. Missing mammals include the Canada lynx (*Felis lynx*), Cascade red fox (*Vulpes vulpes*), pika (*Ochotona princeps*), wolverine (*Gulo gulo*), golden-mantled ground squirrel (*Spermophilus lateralis*), grizzly bear (*Ursus horribilis*), mountain goat, and mountain sheep (*Ovis canadensis*). Notably, many of these are species of higher elevations in the Cascades, suggesting that the lowlands of Puget Sound region served as an effective filter to migration. Some relatively common plant species of the Cascades are also absent from the Olympics.

A number of organisms are found only on the Olympic Peninsula. Eight vascular plant taxa, five mammals, three fish, three beetles, two slugs, one salamander, one butterfly, and one grasshopper are endemic (Table 2-1). Five vascular plant taxa and several invertebrates have a slightly larger range, occurring on the Olympic Peninsula and Vancouver Island, 20 km to the north.

Several species such as whitebark pine (*Pinus albicaulis*), and Engelmann spruce (*Picea engelmannii*) occur as small populations in the Olympics. Engelmann spruce, for example, is a common constituent of spruce/fir forests in the Rocky Mountains and occurs from British Columbia to Oregon in the Cascades but occurs in only a few small populations in the dry northeastern portion of the Peninsula. During the Evans Creek Stage of the Fraser Glaciation, Engelmann spruce formed a parkland/tundra community in the lowlands just south of Puget Sound (Barnosky 1981). Species like Engelmann spruce appear to have found their way to the Olympics during periods when the Pacific Northwest climate was cooler and drier and were subsequently "stranded" by changing climate.

Vegetation

Several studies delineate Olympic Peninsula plant communities and vegetation. Jones (1936) provides the first broad description of communities and vascular plant taxa. Franklin and Dyrness (1988) synthesize major studies of the natural vegetation of Oregon and Washington, including the Olympics. Investigations of forest vegetation include the montane and subalpine zones (Fonda and Bliss 1969), river terraces (Fonda 1974, Luken 1979, McKee et al. 1982), community classifications of river valleys (Smith and Henderson 1986), and vegetation of Olympic National Forest (Henderson et al. 1989). General subalpine and alpine vegetation studies include works by Bliss (1969), Kuramoto and Bliss (1970).

Boundaries between vegetation zones on the Olympic Peninsula are largely a function of the east-west precipitation gradient (Fig. 2-3). The montane forest zone, for example, extends down to 230 m on the west side of the Peninsula and 800 m on the dry east side. Moreover, Pacific silver fir (*Abies amabilis*) is absent from montane forests on south slopes in the driest region of the Peninsula (Henderson et al. 1989).

Factors controlling forest vegetation include moisture, temperature, elevation, and natural disturbances such as fire, flooding, and wind (Fonda and Bliss 1969, Henderson et al. 1989). Low elevation forests are dominated mainly by Sitka spruce (*Picea sitchensis*), Douglas fir, or western

Table 2-1. Endemic fauna and flora of the Olympic Peninsula.

VERTEBRATESMammals

<i>Marmota olympus</i>	Olympic marmot
<i>Mustela erminea</i> ssp. <i>olympica</i>	Olympic ermine
<i>Scapanus townsendii</i> ssp. <i>olympicus</i>	Olympic snow mole
<i>Tamias amoenus</i> ssp. <i>caurinus</i>	Olympic yellow-pine chipmunk
<i>Thomomys mazama</i> ssp. <i>melanops</i>	Olympic Mazama pocket gopher

Amphibians

<i>Rhyacotriton olympicus</i>	Olympic torrent salamander
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Fish

<i>Novumbra hubbsi</i> ¹	Olympic mud minnow
<i>Oncorhynchus mykiss</i> ssp. <i>irideus</i> ²	"Beardslee" rainbow trout
<i>Oncorhynchus clarki</i> ssp. <i>clarki</i> ²	"Crescenti" cutthroat trout

INVERTEBRATESInsects

<i>Cicindela bellissima</i> ssp. <i>frechini</i>	Tiger beetle
<i>Hesperia comma</i> ssp. <i>hulbirti</i>	Hulbirt's skipper
<i>Nebria danmannii</i>	Mann's gazelle beetle
<i>Nebria acuta</i> ssp. <i>quileute</i>	Quileute gazelle beetle
<i>Nebria meanyi</i> ssp. <i>sylvatica</i> ³	Sylvan gazelle beetle
<i>Nisquallia olympica</i>	Olympic grasshopper
<i>Oeneis chryxus</i> ssp. <i>valerata</i> ³	Olympic arctic
<i>Scaphionotus johnsonii</i> ³	Johnson's snail eater

Millipedes

<i>Tubaphe levit</i> ³	Millipede
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Molluscs

<i>Hemiphillia burringtoni</i>	Burrington's jumping slug
<i>Hemiphillia dromedarius</i>	Arionid slug

PLANTSVascular Plants

<i>Aster paucicapitatus</i> ³	Olympic aster
<i>Astragalus australis</i> var. <i>olympicus</i>	Olympic Mt. milkvetch
<i>Campanula piperi</i>	Piper's bellflower
<i>Castilleja parviflora</i> ³ var. <i>olympica</i>	Magenta paintbrush
<i>Claytonia lanceolata</i> ³ var. <i>pacifica</i>	Lance-leaf springbeauty
<i>Erigeron flettii</i>	Flett's fleabane
<i>Erigeron peregrinus</i> ssp. <i>peregrinus</i> var. <i>thompsonii</i>	Thompson's wandering fleabane
<i>Pedicularis bracteosa</i> ³ var. <i>atrosanguinea</i>	Blood-red pedicularis
<i>Petrophytum hendersonii</i>	Henderson's rock spirea
<i>Saxifraga tischii</i> ³	Tisch's saxifrage
<i>Senecio neowebsteri</i>	Olympic Mt. groundsel

Table 2-1. (continued) Endemic fauna and flora of the Olympic Peninsula.

Vascular Plants (continued)*Synthyris pinnatifida*

Olympic Mt. synthyris

var. *lanuginosa**Viola flettii*

Flett's violet

Liverworts*Porella roellii* forma *crispata*³

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¹ Occurs south to the Chehalis River.² Formerly considered a distinct species; currently considered a lake adapted form of the subspecies.³ Also occurs on Vancouver Island.

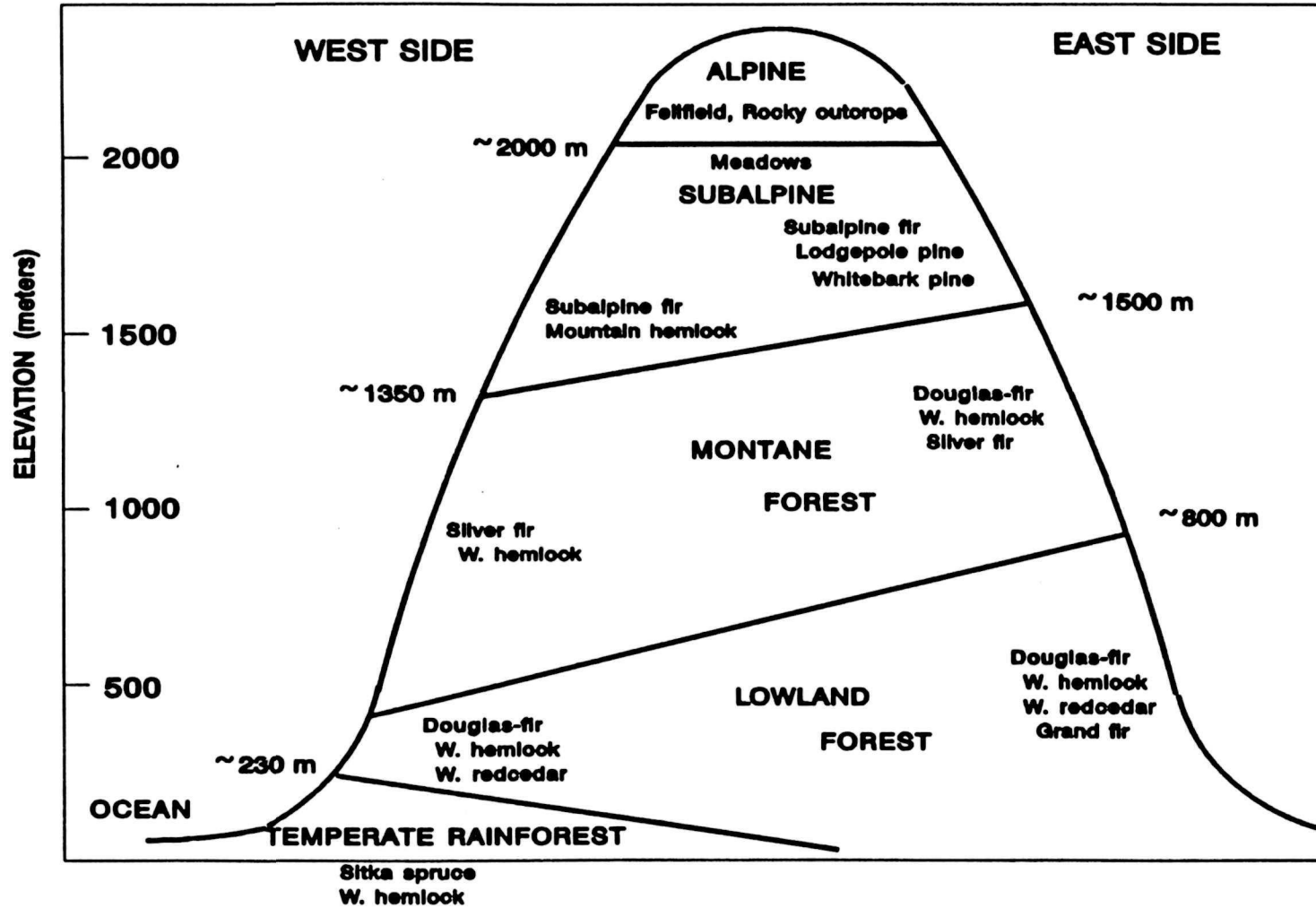


Figure 2-3. Idealized vegetation zones found on the Olympic Peninsula. East side vegetation is representative of dry sites in the northeastern Olympics. West side represents the sequence typically found in the central Peninsula. Individual sequences of life zones vary considerably between north and south slopes.

hemlock (*Tsuga heterophylla*), while montane forests are most often dominated by Pacific silver fir with western hemlock. Subalpine forest dominants include subalpine fir (*Abies lasiocarpa*) and mountain hemlock (*Tsuga mertensiana*) or lodgepole pine (*Pinus contorta*). Greater detail on forest vegetation of the Peninsula can be found in Fonda and Bliss (1969) and Henderson et al. (1989).

Olympic subalpine and alpine meadow vegetation is more complex than forested plant communities. Vegetation structure and composition depend on a variety of factors including snow retention (Bliss 1969, Canaday and Fonda 1974), temperature (Kuramoto and Bliss 1970), moisture (Kuramoto and Bliss 1970, Belsky and del Moral 1982, Pfitsch and Bliss 1985), disturbance (Bell and Bliss 1973, Belsky and del Moral 1982, Pfitsch and Bliss 1985), microenvironment (Peterson 1971, Loneragan and del Moral 1984), and competitive interactions (del Moral 1983a, 1985). The two factors most frequently cited as controlling vegetation patterns are moisture and soil disturbance. Most of these investigations were conducted in the north and northeastern part of Olympic National Park.

Kuramoto and Bliss (1970) provide the best overall description of Olympic Mountain subalpine meadow communities. They delineated eight community types ranging from the dry cushion plant community of wind-swept ridges to moist late snow melt sites dominated by the dwarf sedge, *Carex nigricans*. In between these two extremes, at the wetter end of the gradient, communities were dominated by *Phyllodoce empetrifomis*, *Carex spectabilis* or *Valeriana sitchensis*; *Lupinus latifolius*, *Luetkea pectinata*, *Cassiope mertensiana* and *Vaccinium deliciosum* were important constituents. At the drier end of the gradient they describe the dry grass-forb and mesic grassy communities where *Festuca idahoensis* was dominant or an important constituent. Standing crop in these communities ranged from a low of 50 g/m² in the dry grass-forb to 502 g/m² in the *Saussurea* forb community.

CHAPTER 3:

UPPER SUBALPINE AND ALPINE PLANT COMMUNITIES OF THE OLYMPIC MOUNTAINS

INTRODUCTION

Previous studies of subalpine and alpine vegetation of ONP were limited in scope or geographic extent so that they were not representative of the vegetation in mountain goat habitat parkwide. Consequently, this investigation was undertaken to increase our understanding of non-forested vegetation commonly found above 1520 m and to describe and classify plant communities in mountain goat summer range of ONP. Our study extends the subalpine meadow work of Kuramoto and Bliss (1970) to steeper slopes and to the less "meadowy" vegetation of rocky outcrops and talus slopes. There is overlap between our work and the regionally limited community studies of Belsky and del Moral (1982), Pfitsch and Bliss (1985), and Smith and Henderson (1986) but we concentrated in areas they did not investigate.

METHODS

Plant communities were sampled with reconnaissance (recon) plots similar to those described by Franklin et al. (1971a) and Henderson et al. (1989) for forest vegetation. The recon approach provides for plant cover estimates in broad classes similar to those of Daubenmire (1968). A key difference between the recon plot method used here and that of Daubenmire (1968) is that a single estimate of plant cover (by species) is obtained for the plot rather than from the mean of 50 small subplots. Consequently, while recon plot data are less precise, large areas (e.g. Olympic National Park) can be surveyed over a period of years rather than decades.

We used relatively small, variable sized plots (20-100 m²) because extensive areas of homogeneous vegetation were uncommon at high elevations in the Olympics. The generally rectangular or square plots were located in homogeneous vegetation that was representative of plant communities in the vicinity. We scrupulously avoided using the level of herbivore activity as a criterion for locating individual recon plots. No plots were placed near sites where salt had attracted goats. Replicate plots

were placed in each community type in areas where more than 50 plots were established (e.g. Mt. Dana, Grand Pass).

Variables recorded included plant cover by species, substrate characteristics, slope, aspect and elevation. Cover was estimated in the following classes: trace, <1, 1-5, 6-25, 26-50, 51-75, 76-95, and 96-100%. Small cover classes at each end of the scale prevented overestimates of species with low cover and underestimates of species with extremely high cover. The same classes were used to estimate the cover of mosses, lichens, litter, organic matter, bare soil (<2 mm particles), total rock, bedrock, and five size classes of loose rocks (>2 mm-4 cm, 5-10 cm, 11-20 cm, 21-70 cm, and >70 cm across).

Plant communities were classified into groups using Two-Way Indicator Species Analysis (TWINSpan), where samples with similar attributes (i.e. plots with similar cover and species composition) are placed in groups (Hill 1979, Gauch 1982). Results of the procedure are particularly instructive because plots are dichotomously classified using reciprocal averaging. Moreover, each cover class of each species (i.e. *Carex spectabilis* 1 = 1-5% cover, *C. spectabilis* 2 = 6-25% cover) is utilized in the classification. These so-called "pseudospecies" increase the ability of the program to differentiate communities (Hill 1979). The process of reciprocal averaging and division is repeated on successively smaller subgroups until a pre-determined number of divisions has been made or groups are too small. Results are frequently very similar to the more labor-intensive relevée method of Braun-Blanquet (Gauch 1982).

Relative percent cover calculated from cover class midpoints was used in the TWINSpan analysis so that plots with low total cover would be more comparable to those with higher cover values. Thus, plots with species that had similar relative abundance but different total cover would be classified close together. We downweighted the importance of plants with low relative cover values so these would not unduly influence the classification. Our data set included recon plots (n=705), permanent plots from Mount Angeles (n=6), Deer Park (n=1), and Mount Constance (n=5), as well as plot data from Belsky (1979, n=11) and Pfitsch et al. (1983, n=43).

Reconnaissance plots were placed in 22 areas of the park (Fig. 3-1). Regions of high and low precipitation (Fig. 2-2) and high (>3 goats/km²), medium (1-3 goats/km²), and low goat density (<1 goat/km²) were well represented. Plots were concentrated in the eastern half of the park where most goat summer range occurred (Houston et al. 1986).

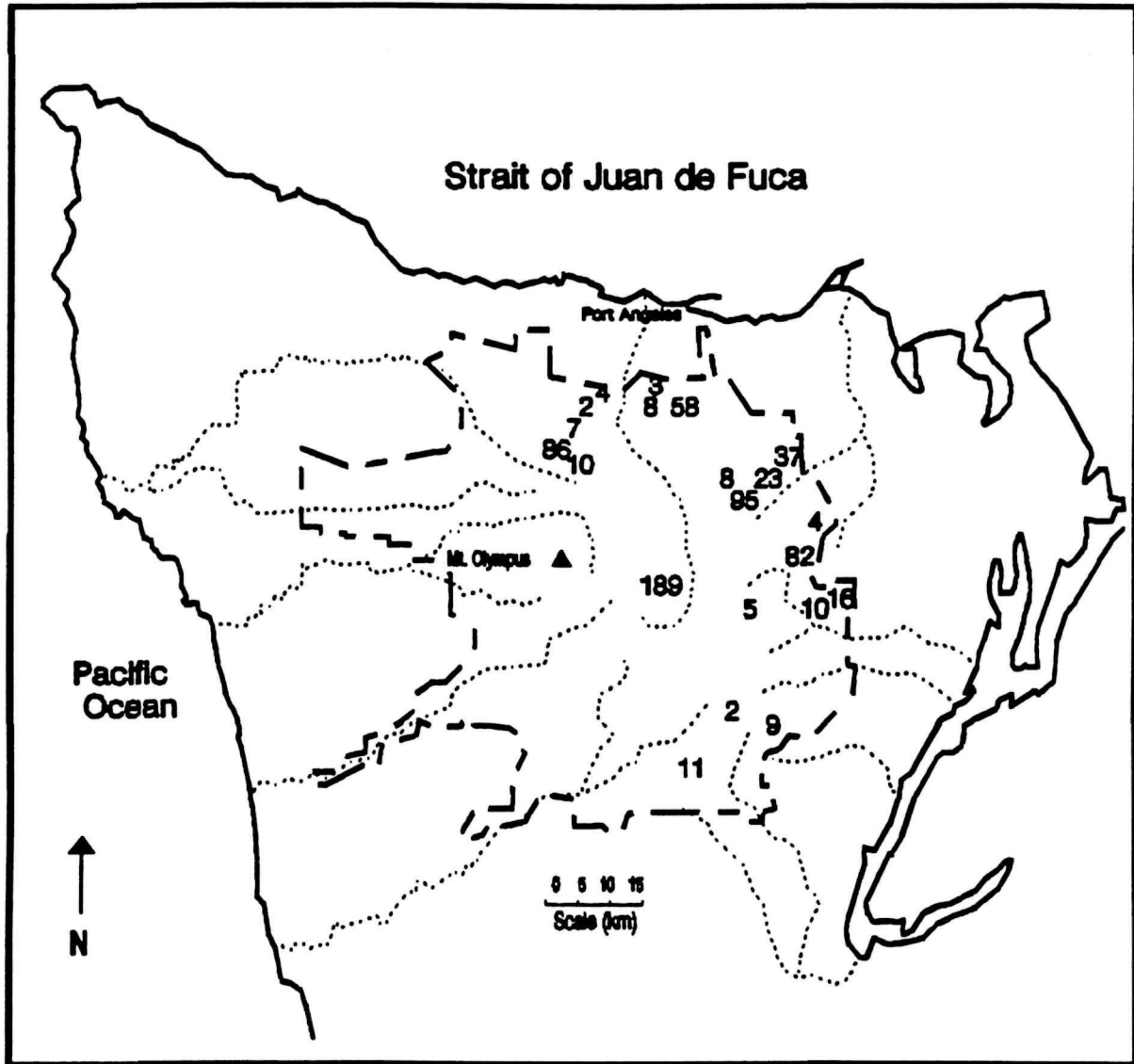


Figure 3-1. Location and number of recon plots established in the subalpine and alpine zones of Olympic National Park.

RESULTS

The classification scheme produced by TWINSpan contained a complex array of plant communities found above 1520 m (Fig. 3-2). Two communities with low total plant cover occurred at the extremes, one on highly disturbed, dry sites (*Astragalus* Scree), and the other on raw substrates where snow melt was very late (*Luetkea* - *Saxifraga tolmiei* community). Communities between these two extremes were arrayed along a broad snowmelt/moisture gradient. Drier sites contained the dwarf shrub *Phlox diffusa* as a dominant or codominant species while showy sedge, *Carex spectabilis*, dominated or was a major part of wetter sites. Position of the communities within this moisture gradient was influenced by the relative stability of the substrate, rock size, and glacial history. Plant cover and frequency of major species for each community type is presented in the Appendix A.

Scree and Talus Communities

Scree and talus slopes are a common feature of the Olympic Mountains due to the steep rocky terrain and predominance of soft sedimentary bedrock. Four plant communities were associated with scree and talus. One occurred on steep bare slopes near ridges, while the others were found mainly on colluvial debris fans below massive rock outcrops (i.e. mountains). Distinguishing features of the scree/talus communities were: 1) high proportions of rock fragments in the >2 mm - 4 cm and 5-10 cm classes, 2) steep, 30-35° slopes, 3) unstable substrates, and 4) 57-97% mineral soil and rock cover (Table 3-1). Additional factors that distinguished these four communities included aspect and elevation.

The driest of the four scree/talus communities was "dominated" by the endemic *Astragalus australis* var. *olympicus*. Present only in the driest region of the park, this community occurred on soils with a pH of 6.0 or higher (Kaye 1989). Total plant cover was low at 7%. The presence of other species with disjunct distributions in or near the *Astragalus* plots (e.g. *Oxytropis viscida*) suggest this community may be associated with former glacial refugia.

The three colluvial fan communities can be differentiated on the basis of aspect, elevation, and substrate. Slopes dominated by *Phacelia hastata* occurred on dry south facing slopes averaging 1737 m (5700 ft) elevation while, those dominated by the endemic *Senecio neowebsteri* were on slightly higher at 1814 m (5950 ft.) and occurred on cooler northwest to northeast facing slopes (Table 3-1).

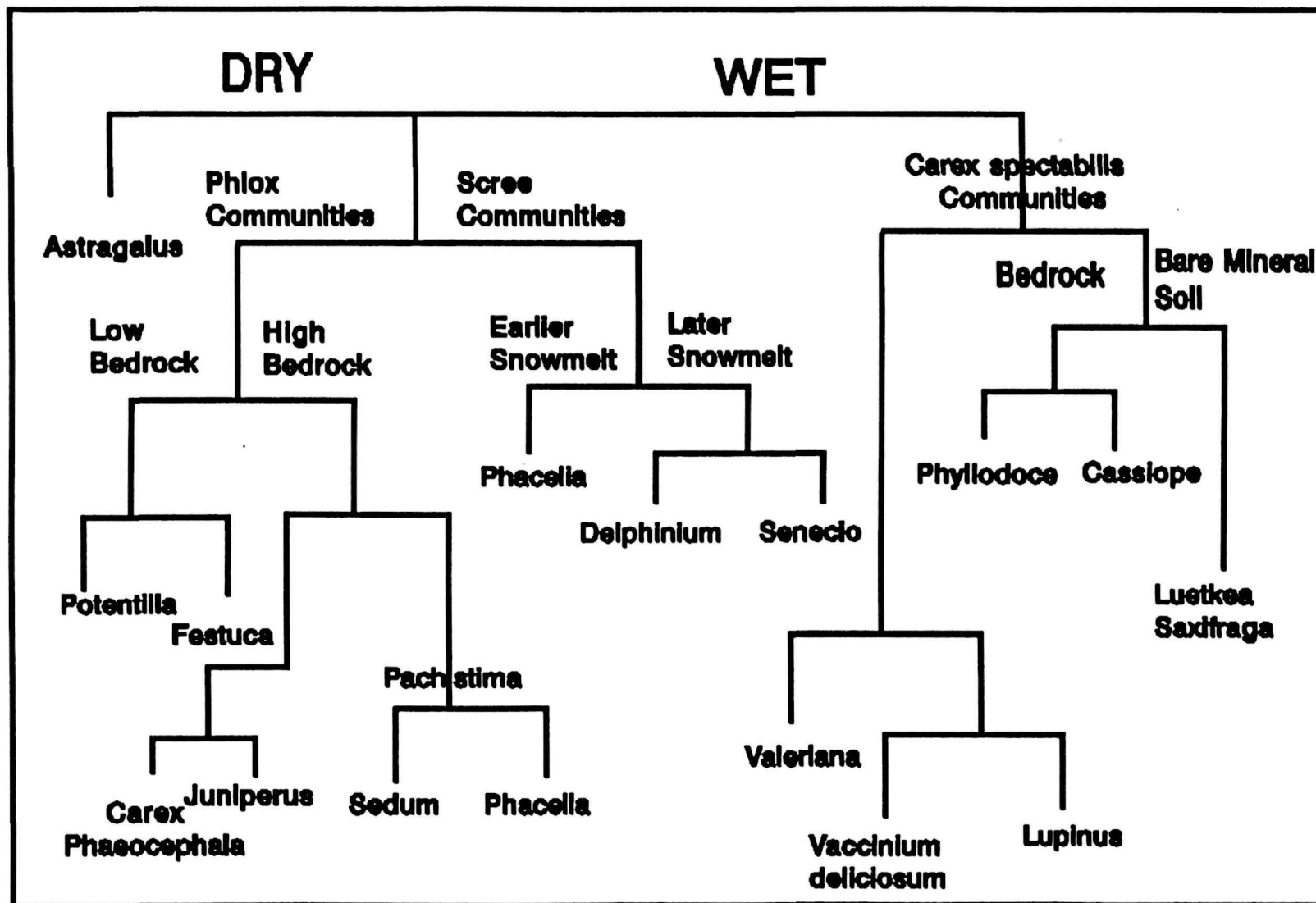


Figure 3-2. Olympic National Park subalpine and alpine plant communities found above 1520 m. Communities classified using program TWINSpan.

Table 3-1. Environmental and Substrate Characteristics by Community Type. Data represent means from recon plots.

Community Type	Slope (°)	Aspect	Elev. (m)	Total Rock	Bare Soil	Bedrock	Rock Size Class (cm)				Litter	Organic Matter
							<1-4	5-10	11-20	>20		
Scree and Talus Slopes												
Astragalus	30	SW	1698	90.1	9.3	6.9	62.3	12.2	5.2	3.5	0.6	0.1
Phacelia	35	SE-SW	1734	55.2	16.7	1.6	24.6	15.9	8.6	4.5	3.7	0.9
Delphinium	32	SE-SW	1868	78.6	13.8	0.4	42.3	20.2	10.0	5.7	0.3	0.1
Senecio	33	NE-NW	1813	81.3	10.9	0.2	39.6	25.0	10.8	5.7	0.4	0.3
Phlox diffusa Communities												
Phlox/Potentilla	22	ALL	1839	77.2	7.5	4.6	34.0	20.3	12.6	5.7	3.3	0.5
Phlox/Festuca	26	SE-SW	1698	42.4	13.3	2.1	23.7	11.5	3.4	1.7	8.4	0.8
Phlox/Carex	30	S-SW	1843	67.1	3.0	15.9	14.0	15.3	13.7	8.2	1.6	0.4
Juniper/Phlox	34	E - W	1813	59.9	4.5	20.8	8.7	11.7	7.1	11.6	5.6	3.3
Phlox/Pachistima	41	SE-SW	1717	70.1	11.5	31.0	16.6	8.2	6.3	8.6	2.2	0.6
Phlox/Pach/Phacelia	36	SE-SW	1677	60.9	23.7	17.6	19.7	10.8	5.2	7.6	1.8	0.3
Carex spectabilis Communities												
Carex/Valeriana	35	ALL	1617	32.3	5.6	0.3	12.2	7.8	7.4	4.6	11.7	7.7
Vaccinium	37	SE-NW	1678	18.5	5.3	2.0	5.8	4.4	3.3	3.0	15.0	6.3
Carex/Lupinus	31	E-SE	1796	45.9	4.8	8.6	18.7	8.9	4.7	5.1	7.7	3.1
Phyllodoce	30	NE-SE	1731	28.2	4.1	8.9	6.3	5.2	4.1	3.8	19.2	6.8
Cassiope	31	NW-NE	1830	57.6	7.0	17.6	15.3	9.4	6.7	8.6	5.3	0.8
Late Snow - Early successional												
Luetkea/Saxifraga	29	W-NW	1633	72.6	8.6	9.0	21.4	11.1	12.9	18.1	1.5	3.2

Delphinium glareosum dominated sites were found on south to northwest facing slopes at an average elevation of 1860 m. The majority of rocks at the surface in the *Senecio* and *Delphinium* communities fall in the > 2 mm - 4 cm and 5-10 cm size classes; a higher proportion of the substrate is bare mineral soil in sites where *Phacelia* dominates (Fig. 3-3). Total plant cover averaged 9, 25, and 55%, respectively in the *Senecio*, *Delphinium* and *Phacelia* communities.

***Phlox diffusa* Communities**

Six plant communities contained *Phlox diffusa* as the dominant or co-dominant species. These can be differentiated on the basis of slope and substrate characteristics (Fig. 3-3). Slope ranged from 22° in the *Phlox* - *Potentilla* community to 41° in the *Phlox* - *Pachistima* type (Table 3-1). Two communities with relatively low slope, (*Phlox* - *Potentilla*, *Phlox* - *Festuca*) have only a small percentage of bedrock at the surface (<5%) while the other four were usually located on steeper slopes with 16-31% bedrock. *Phlox diffusa* was the dominant species in five communities and codominated with *Juniperus communis* in the sixth.

Distribution and aerial extent of the *Phlox* communities reflect the influence of climate, substrate characteristics, and glacial history. The *Phlox* - *Festuca* community, for example, was limited to a narrow band beginning in the Hurricane Ridge area and extending southeast to Constance Pass. Isolated patches of this community occurred in what may have been glacial refugia near Mount Appleton and the ridge above Hoh Lake. Sites supporting this grassy meadow type were dry, but relatively stable with an average slope of 26° (Table 3-1). Bedrock content was low and plant cover relatively high (65%). The *Phlox* - *Potentilla* community occurred at higher elevation than the *Phlox* - *Festuca* type (1864 m, 6115 ft) often not far below ridge crests; these sites, often blown free of snow in winter, are alpine rather than subalpine.

Four of the *Phlox* communities occurred mainly on exposed bedrock. Plants typically occurred between cracks and in depressions within the bedrock where soil had accumulated. Slope stability was higher than that of scree communities because bedrock inhibits soil and rock movement; slope varied from 30-41°. Community types include *Phlox* - *Carex phaeocephala*, *Juniperus* - *Phlox*, and two phases of a *Phlox* - *Pachistima* type (one with *Phacelia hastata*). The *Phlox* - *Carex phaeocephala* type occurred only on Mount Dana and may represent an early successional community or a steeper, wet site version of the *Phlox* - *Potentilla* community. It was unusual because wetter site species, *Carex spectabilis* and *Lupinus latifolius*, codominated with the dry site species *Phlox diffusa* and *Carex phaeocephala*.

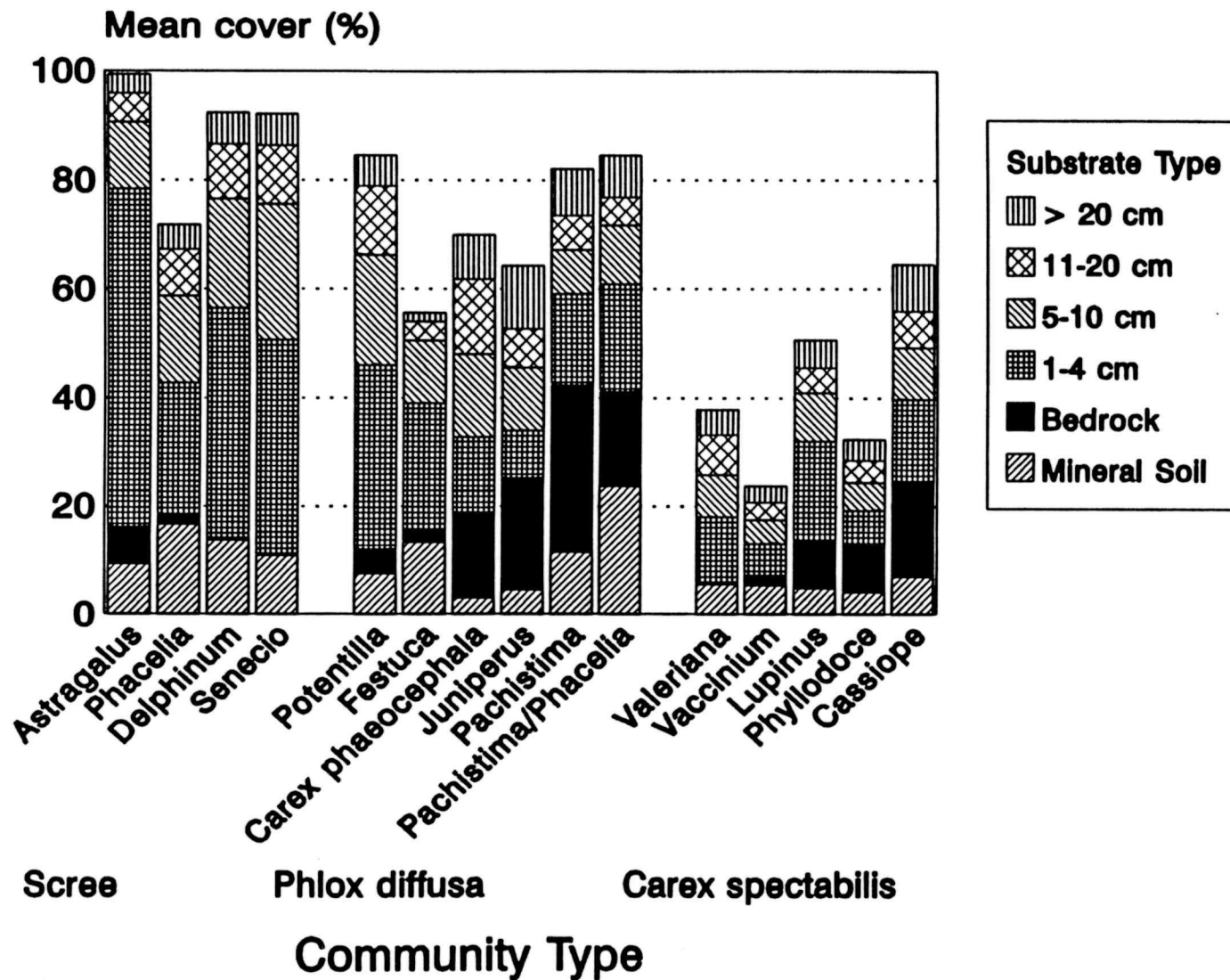


Figure 3-3. Substrate characteristics of subalpine and alpine communities of Olympic National Park.

***Carex spectabilis* Communities**

Environmental differences between some of the plant communities at the wetter end of the classification scheme were not distinct. *Carex spectabilis* dominated or was an important constituent of all communities in this group. The *Carex - Valeriana* and *Vaccinium deliciosum* types were found on very steep, 35-37° slopes from 1615-1675 m (5300-5500 ft.) elevation with little bedrock at surface (Table 3-1). The *Carex - Lupinus* was widespread and occurred primarily on east to southeast facing slopes averaging 1800 m (5900 ft.) elevation. The heath-dominated communities were present on southerly aspects at elevations averaging 1730 m (5680 ft) (*Phyllodoce*) or higher (1830 m; 6,000 ft), northern aspects (*Cassiope*).

There were differences between the substrate characteristics of the five *Carex spectabilis* communities (Fig. 3-3). Bedrock cover averaged 17% in *Cassiope* communities compared to ca 8.5% in *Phyllodoce* and *Carex - Lupinus* communities, and 2% or less in the *Vaccinium* and *Carex - Valeriana* types. Total rock cover was lowest in the *Vaccinium* and *Phyllodoce* communities.

The majority of plots classified in the showy sedge - heather community types were located in wetter areas of the park, west of the Elwha River and south of the Dosewallips River. One community, the *Vaccinium* type, was not observed, or sampled in the dry Mount Angeles - Deer Park area. The *Carex - Lupinus* community was sampled in all areas of the park although it was more common on north facing slopes in the Mount Angeles area as opposed to south facing slopes in regions receiving greater precipitation. Some communities such as the *Phyllodoce empetrifomis* type were more common in moderately sloped cirques and basins not sampled in this study (e.g. Seven Lakes Basin). These areas are not typical of goat summer range (Stevens 1979).

***Luetkea - Saxifraga* Community**

This community type was sampled infrequently. It occurred on west to northwest facing slopes with a fairly high proportion of the substrate made up of larger 11-70 cm rocks. Plant cover was low (26%). Sites where this type was present appeared to be recently colonized by plants.

DISCUSSION

Plant Communities

Sixteen non-forested plant communities were identified in the upper subalpine and alpine zones of ONP. A comparison of communities described in this study with those delineated by Kuramoto and Bliss (1970) and

Pfitsch and Bliss (1985) (Table 3-2) shows concurrence between several communities but additional community types were identified. Differences between the studies arise because: 1) Kuramoto and Bliss (1970) concentrated on subalpine meadows, 2) Pfitsch and Bliss (1985) examined communities in a comparatively small area, and 3) the number of plots sampled in this study was far greater (700+) compared to ~40 sampled by Kuramoto and Bliss (1970) and ~30 sampled by Pfitsch and Bliss (1985). Plant community patterns in goat summer range were often fine-grained (i.e. community types often change over distances of 5 m or less) due to interactions between substrate, time of snowmelt, slope stability, and precipitation.

The primary environmental factor controlling plant community composition and distribution in the study area appeared to be available moisture. Average annual precipitation, date of snow melt, aspect, and elevation combined to produce a particular local moisture regime. Previous investigators of Olympic subalpine and alpine vegetation reached similar conclusions (i.e. Fonda and Bliss 1969, Kuramoto and Bliss 1970, Canaday and Fonda 1974, Belsky and del Moral 1982, del Moral 1983b, Pfitsch and Bliss 1985, Smith and Henderson 1986).

Several other factors appeared to play secondary, but crucial roles in controlling plant community composition. Substrate characteristics such as particle size and the quantity of bedrock near the soil surface were strongly associated with several community types. Slope also seemed to contribute to community development. The nature of the interaction between substrate and available moisture remains unclear, but it may be that later snowmelt sites with bedrock near the surface facilitate development of heath communities while drier sites favor development of the *Phlox/Pachistima* community. Field observations also suggested that parent material (i.e. sedimentary, slate, or basalt) may play a role in determining plant community composition, although Kuramoto and Bliss (1970) reported no major differences in chemistry between soils developed on different parent materials. Substrate character may reflect soil stability which was identified by Bliss (1969), Bell and Bliss (1973), Hansen (1976), Belsky and del Moral (1982), del Moral (1984), Pfitsch and Bliss (1985) as contributing to Olympic subalpine and alpine vegetation patterns.

Plant community composition and distribution in the Olympics may also reflect the influence of past glacial events. Kuramoto and Bliss (1970), for example, suggested that the *Phlox/Festuca* community (mesic grassy) could be a remnant of communities that were more widespread during the warmer Altithermal period (4,000-10,000 BP). Additionally, the distribution of several plant species and communities point toward the former existence of glacial refugia in the north and northeastern Olympics. Plots containing the endemics *Astragalus australis* var. *olympicus* and *Synthyris pinnatifida* var. *lanuginosa*, for example, occurred only in the driest

Table 3-2. Comparison of plant communities in mountain goat summer range park-wide with Klahhane Ridge (Pfitsch 1981) and the subalpine and alpine meadow communities described by Kuramoto (1968).

Subalpine and Alpine Communities above 1520 m (This Study)	Klahhane Ridge Goat Summer Range (Pfitsch 1981)	Subalpine and Alpine Meadow Communities (Kuramoto 1968)
Scree and Talus Slopes		
<i>Astragalus</i>		
<i>Phacelia</i>	Unstable Herb Meadow	
<i>Delphinium</i>	Scree	
<i>Senecio</i>	Scree	
<i>Phlox diffusa</i> communities		
<i>Potentilla fruticosa</i>	~ ~ Ridge top fell field	
<i>Festuca idahoensis</i>	Phlox/Fescue	Mesic Grassy, Cushion Plant
<i>Carex phaeocephala</i>		
<i>Juniperus communis</i>	Ridge top fell field	
<i>Pachistima myrsinites</i>		
<i>Pachistima/Phacelia</i>		
<i>Carex spectabilis</i> Communities		
<i>Valeriana sitchensis</i>	Tall sedge, grass, herb	<i>Valeriana</i> moist
<i>Vaccinium deliciosum</i>		
<i>Lupinus latifolius</i>	~ ~ Lupine-sedge	Tall sedge
<i>Phyllodoce empetrifolmis</i>		Heath shrub
<i>Cassiope mertensiana</i>	Heather	
<i>Luetkea/Saxifraga</i>		
	<i>Luetkea</i> drainage	
No equivalents		
	Late Snow	Dry grass-Forb
		<i>Saussurea</i> moist
		Dwarf Sedge

region of the park. Palynological data are too incomplete to determine if these taxa were constituents of a formerly more widespread community. These species could easily have survived the Fraser Glaciation since they occur on or adjacent to ridges well above the former elevation of the Vashon continental ice. The picture is less clear with respect to the Evans Creek Stade when alpine glaciers expanded. One can at least speculate that these and other endemics may have persisted through the Evans Creek period because they occur in a dry mountainous region where alpine glaciers were less fully developed (Long 1975) and the ridge tops where these species occur were likely blown free of snow. These and other endemic species add an interesting aspect to the interpretations of subalpine and alpine plant community patterns in the Olympics.

CONCLUSION

Subalpine and alpine plant communities are exposed to harsh environmental conditions. High winds, cold temperatures, snow, short growing seasons, freeze-thaw cycles, nutrient-poor soils and a variety of soil moisture conditions all play a role in community and species development (Bliss 1971). Microenvironmental factors such as soil temperature, wind and moisture are particularly important to plant growth and reproduction in these zones (e.g. Bliss 1956, Johnson and Billings 1962, Holway and Ward 1965, Bliss 1971, Billings 1974). These processes also influence subalpine and alpine meadow vegetation of the Olympics (Bliss 1969, Kuramoto and Bliss 1970, Canaday and Fonda 1974, Loneragan and del Moral 1984). Additionally, substrate type and stability also contributed to plant community patterns at high elevations in the Olympics.

CHAPTER 4:

PLANT COMMUNITY - HERBIVORE RELATIONSHIPS

INTRODUCTION

Previous investigations demonstrated that mountain goats changed subalpine and alpine vegetation in the Mt. Angeles area of Olympic National Park (Olmsted 1979, Pike 1981, Pfitsch et al. 1983, Reid 1983, Pfitsch and Bliss 1985, Schreiner 1987). Goats were known to occur in other areas of the park (Houston et al. 1986, 1991a), but the relationship between goats, plant communities, and other herbivores in these areas was unknown. The following chapter reports results from an extensive survey of ungulate and marmot sign in the upper subalpine and alpine zones of ONP. Our objective was to quantify the presence of ungulates and marmots in plant communities above 1520 m.

METHODS

Evidence of animal use was recorded in the same "recon" plots used to classify plant communities in mountain goat summer range (Chapter 3). Animal sign in each plot was quantified by species to the extent possible. Scat piles, sets of tracks, wallow/bedding sites, and marmot dens found in each plot were counted. In addition, the number of wallow/bedding sites and marmot dens within 50 m of each plot and the number of trails crossing each plot were tallied. Animals in or near plots were noted.

A combination of factors was considered in determining which species of ungulate produced the sign. Roosevelt elk (*Cervus elaphus*) sign was identified by track and pellet size since both are considerably larger than those of mountain goats or black-tailed deer (*Odocoileus hemionus*). Tracks were identified as having been produced by goats or deer based on shape. Deer tracks taper and are narrower toward the front while goat tracks have little taper, tending to be square or rectangular. Wallows/bedding sites and pellet groups were assigned to mountain goats or deer based on the presence of other sign including identifiable tracks and the presence of hair (mainly goats). Mountain goat hair was a particularly useful indicator because goats annually shed winter coats in June and July, which left hair on rocks and plants in areas they frequented; hair did not persist through the

subsequent winter (Schreiner pers. obs.). Pellet groups, tracks and wallows were classified as "unidentified ungulate" when the species responsible was uncertain. Deer and unidentified ungulate sign were combined during analysis since most unidentified sign was probably deer, i.e. we used a conservative approach with respect to identification of goat sign.

A Grazing Index (GI) for each species was obtained by estimating the proportion of plants with evidence of substantial grazing in each plot in classes of: Trace, 1-5%, 6-25%, 26-50, 51-75, 76-100%. An individual plant was considered to be substantially grazed only if at least 25% of the foliage or stems had been cropped. In practice this meant that 25% of the culms in graminoids, 25% of the leaves in forbs, and 25% of the branches in shrubs had to be grazed before the proportion was estimated. Trace was entered when: 1) all plants (of a given species) in a plot had less than 25% of their foliage or stems cropped or 2) if only flower stalks were cropped. It was not our intent to estimate the amount of standing crop removed by herbivores. Instead, we sought to create an index of grazing that could be compared among plots, areas, and plant communities. Armstrong and MacDonald (1992) note that proportional estimates such as this are useful when comparing grazing levels between areas but that estimates of utilization (i.e. standing crop or biomass removed by herbivores) require intensive field studies.

Two indicators were used to characterize grazing on a plot basis. Average Grazing (AG) provided an estimate of how intensely a plot had been grazed using Grazing Index values for all species in a plot where:

$$\text{Average Grazing (AG)} = \frac{\text{Sum of the Grazing values (GI) for each species}}{\text{Number of Species}}$$

Percent of Species Grazed (PSG) was calculated by comparing the number of species with evidence of substantial grazing to the total number of species in a plot (i.e. species richness). High values of PSG indicated that herbivores grazed most of the species present in a plot and low values indicated that herbivores were more selective, grazing few of the available species. The index was calculated using only those species where more than 5% of the individuals of that species had been cropped at least 25% (i.e. GI > 5%). Therefore, incidentally grazed species were not included. The formula was:

$$\text{Percent of Species Grazed (PSG)} = \frac{\text{Number of Species with GI} > 5\%}{\text{Number of Species}} * 100$$

An index of herbivore selection of particular plant species was calculated by comparing plant

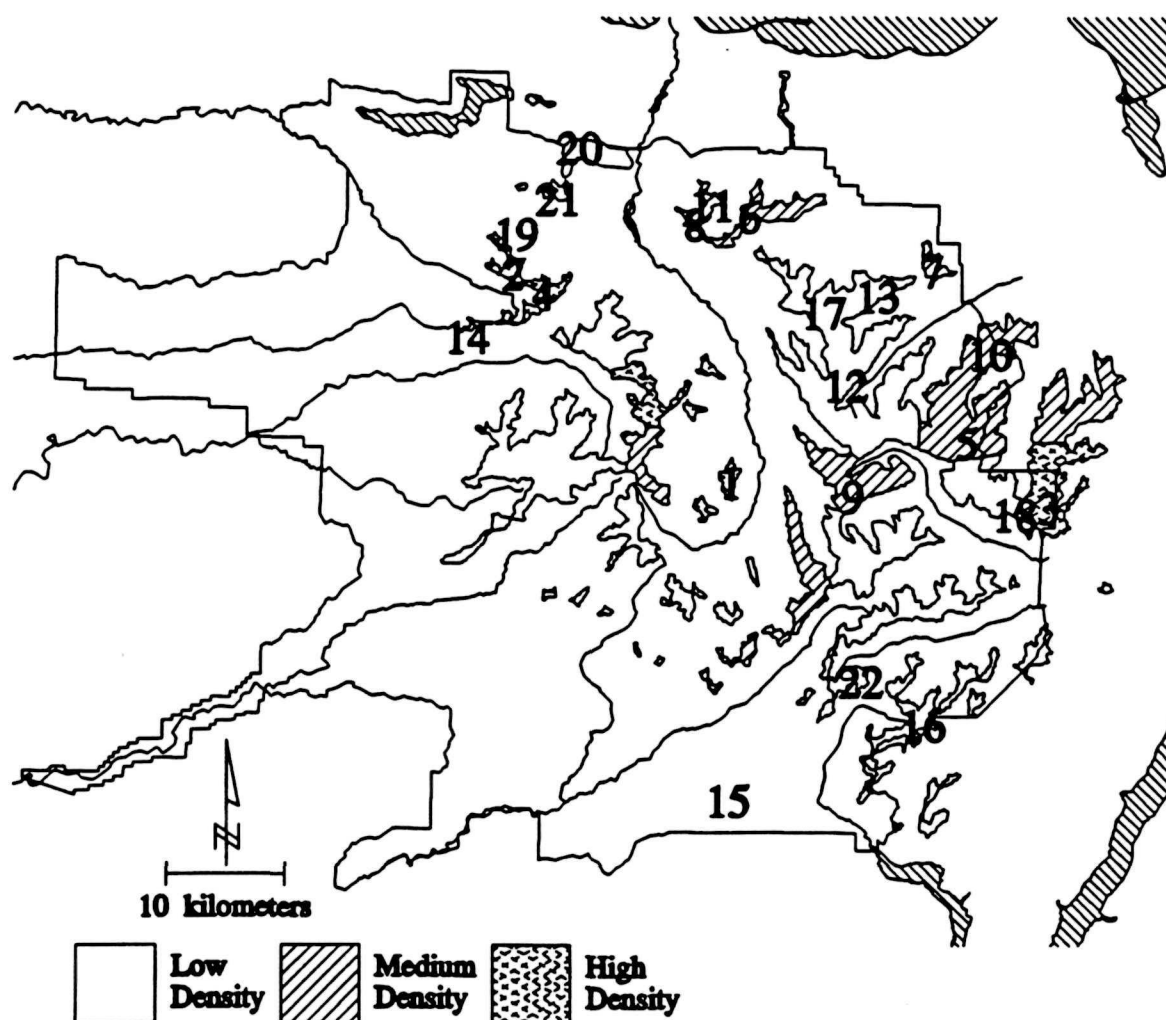
frequency to grazing frequency as follows:

$$\text{Species Relative Grazing Frequency (SRGF)} = \frac{\text{Grazing Frequency} * 100}{\text{Plant Frequency}}$$

Pfitch and Bliss (1985) describe a similar index, also called species relative grazing frequency (SRGF), based on 1 x 1 m quadrats. They classified species as "preferred" or "avoided" if $\text{SRGF} \geq 50$ or ≤ 25 , respectively. However, because they did not consider the relative availability of forage species, their index did not actually provide an estimate of relative preference or avoidance in the conventional sense (Crawley 1983). To allow comparisons with their work (and so we could use their "preferred" and "avoided" species in analyses), we have used similar criteria but have classified species as "selected" or "non-selected" (i.e. $\text{SRGF} \geq 50$ and $\text{SRGF} \leq 25$, respectively) using recon plot data.

An index of the frequency that different herbivore species used plant communities was created using pellet groups, tracks, wallow/bedding sites, and dens. This Herbivore Index (HI) was used to establish if a particular species of herbivore left sign in a recon plot. Each of the three species of ungulates (elk, deer, goats) were considered to have been present in a recon plot (i.e. $\text{HI} = 1$) if their pellet groups, tracks, or wallow/bedding sites occurred there. Marmots were considered present if a den was found in the plot. Tabulations were necessarily biased in favor of ungulates because their sign is more prominent than that of other animals. Marmot activity was underestimated because only dens were used as an indicator of their presence; tracks and scat piles were observed infrequently. Most evidence of mammals smaller than marmots resulted from direct observations, holes, or mounds of scat left over from winter activity.

Each of the 22 study areas was classified according to the estimated density of mountain goats (Fig. 4-1). Categories were high, medium and low density, which corresponded to > 3 , 1-3, and < 1 goats per square kilometer, respectively. Density estimates represent 1986 except for two areas where we had more specific information. The 1986 estimates reflect the 1983 mountain goat census (Houston et al. 1986), observations during live capture operations from 1984-85, and field observations by park staff (USDI 1987). In two cases (Mount Angeles 1982, Deer Park 1988) specific knowledge of subpopulation levels (e.g. the Deer Park goat was captured, sterilized, and removed) was used to assign plots to a particular goat density level. We believe there is good concurrence between the 1986 goat density estimates and actual goat density at the time plots were measured because most



KEY TO LOCATION NUMBERS

Code	Area Name (N)	Code	Area Name (N)
1	Mount Dana (189)	12	Grand/Lillian (97)
2	Mount Appleton (86)	13	Maiden Peak (23)
3	Mount Constance (16)	14	Hoh Lake Cirque (23)
4	Schoeffel Creek (14)	15	Six Ridge (11)
5	Royal Basin (82)	16	Mount Stone (9)
6	Mount Angeles (58)	17	Obstruction Peak (8)
7	Deer Park (36)	18	Constance Pass (12)
8	Hurricane Hill (8)	19	Crystal Ridge (7)
9	Sentinal Peak (5)	20	Baldy Ridge (4)
10	Greywolf Ridge (4)	21	Happy Lake Ridge(2)
11	Griff/Unicorn (3)	22	Mount Steel (2)

Figure 4-1. Location of recon plot study areas in relation to estimated mountain goat density from USDI (1987).

plots ($n = \sim 600$) were established from 1983-86. Natural mortality and goat removals from 1988-89 may reduce correspondence between estimated density and actual density for plots established from 1988-90. However, most of the 1988-90 plots were in areas already classified as low goat density. Goat density estimates used in the analyses were prepared independently of the process used to select study areas. Our initial selection of study areas was intended to include areas of high and low goat density based on the work of Stevens (1979, 1983) and perceptions of the field crew. An independent group of individuals provided the goat density estimates (i.e. USDI 1987) used for data analysis.

RESULTS

Considerable evidence of animal activity was observed during the study. Herbivores included elk, mountain goats, deer, marmots, chipmunks (*Tamias* spp.) pocket gophers (*Thomomys* spp.), voles (*Microtus* spp.), mountain beaver (*Aplodontia rufa*), and snowshoe hare (*Lepus americanus*). In addition, weasels (*Mustela* spp.), black bear (*Ursus americanus*), and coyotes (*Canis latrans*) or their sign were observed in five plots. Insect herbivory was noted everywhere but did not appear to account for the removal of large quantities of plant biomass.

General Patterns

Evidence of mountain goats was found in all 22 sample areas (Table 4-1). Mountain goat pellet groups, tracks or wallows (i.e. HI=1 for goats) were found inside 229 (33%) recon plots and within 50 meters of 310 (44%). The number of recon plots with goat sign in high, medium, and low goat density areas was 38, 51%, and 8%, respectively (Fig. 4-2a).

Marmot dens were found inside 33 (5%) and outside, i.e. within 50 m of 170 (24%) recon plots in 16 of the 22 study areas (Table 4-1). There was no obvious relationship between goat density and the number of plots with marmot dens; 5%, 2%, and 8% of plots in areas of high, medium, and low goat density, respectively, contained dens (Fig. 4-2a).

Sign of elk and deer occurred regularly in and around plots (Fig. 4-2b). Deer/unidentified ungulate sign was observed with the highest frequency, occurring in 82 (12%) of the plots. Elk sign was encountered infrequently (4 of the 22 sample areas), but was locally abundant. At Hoh Lake, for example, 39 percent of the recon plots contained elk sign. Similarly, 57 percent of the plots at Schoeffel Creek showed signs of elk use. Sign of other species including bear, mountain beaver,

Table 4-1. Number of recon plots with an Herbivore Index (HI) greater than 0 by species. Goat density estimates are from USDI (1987) except for Mt Angeles 1982 and Deer Park 1988.

AREA NAME	N	Number of plots (%) with HI>0							
		Goats		Marmots		Elk		Deer	
HIGH GOAT DENSITY (3+ goats/km ²)									
Mt. Dana	189	85	(45)	3	(2)	0	(0)	24	(13)
Mt. Appleton	86	26	(30)	9	(10)	3	(3)	2	(2)
Mt. Constance	16	5	(31)	0	(0)	0	(0)	0	(0)
Schoeffel Creek	14	1	(7)	3	(21)	8	(57)	1	(7)
Mt. Angeles-1982	7	2	(29)	-	-	-	-	-	-
TOTAL	312	119	(38)	15	(5)	11	(4)	27	(9)
MEDIUM GOAT DENSITY (1-3 goats/km ²)									
Royal Basin - 1981	53	12	(23)	-	-	-	-	-	-
Mt Angeles (Astrag)	44	26	(59)	0	(0)	0	(0)	5	(11)
Deer Park (Astrag)	25	12	(48)	0	(0)	0	(0)	4	(16)
Royal Basin - 1983	29	26	(90)	3	(10)	0	(0)	1	(3)
Hurricane Hill (Astrag)	6	2	(33)	0	(0)	0	(0)	0	(0)
Mt Angeles - 1985	7	7	(100)	0	(0)	0	(0)	0	(0)
Sentinel Peak	5	4	(80)	1	(20)	0	(0)	0	(0)
Greywolf Ridge	4	1	(25)	0	(0)	0	(0)	0	(0)
Deer Park - 1984	3	0	(0)	0	(0)	0	(0)	1	(33)
Griff (Astrag.)	3	2	(67)	0	(0)	0	(0)	1	(33)
Hurricane Hill	2	1	(50)	0	(0)	0	(0)	0	(0)
TOTAL	181	93	(51)	4	(2)	0	(0)	12	(7)
LOW GOAT DENSITY (<1 goat/km ²)									
Grand/Lillian	97	2	(2)	9	(9)	0	(0)	17	(18)
Maiden Peak	23	1	(4)	3	(13)	0	(0)	9	(39)
Hoh Lake Cirque	23	0	(0)	2	(9)	9	(39)	9	(39)
Six Ridge	11	0	(0)	0	(0)	3	(27)	2	(18)
Constance Pass	12	3	(25)	0	(0)	0	(0)	0	(0)
Mt. Stone	9	0	(0)	0	(0)	0	(0)	0	(0)
Deer Park - 1988	8	1	(13)	0	(0)	0	(0)	5	(63)
Obstruction Peak	8	1	(13)	0	(0)	0	(0)	0	(0)
Crystal Ridge	7	7	(100)	0	(0)	0	(0)	0	(0)
Baldy Ridge	4	1	(25)	1	(25)	0	(0)	0	(0)
Mt. Steele	2	0	(0)	1	(50)	0	(0)	1	(50)
Happy Lake Ridge	2	1	(50)	0	(0)	0	(0)	0	(0)
TOTAL	206	17	(8)	16	(8)	12	(6)	43	(21)
GRAND TOTAL	699	229	(33)	35	(5)	23	(3)	82	(12)

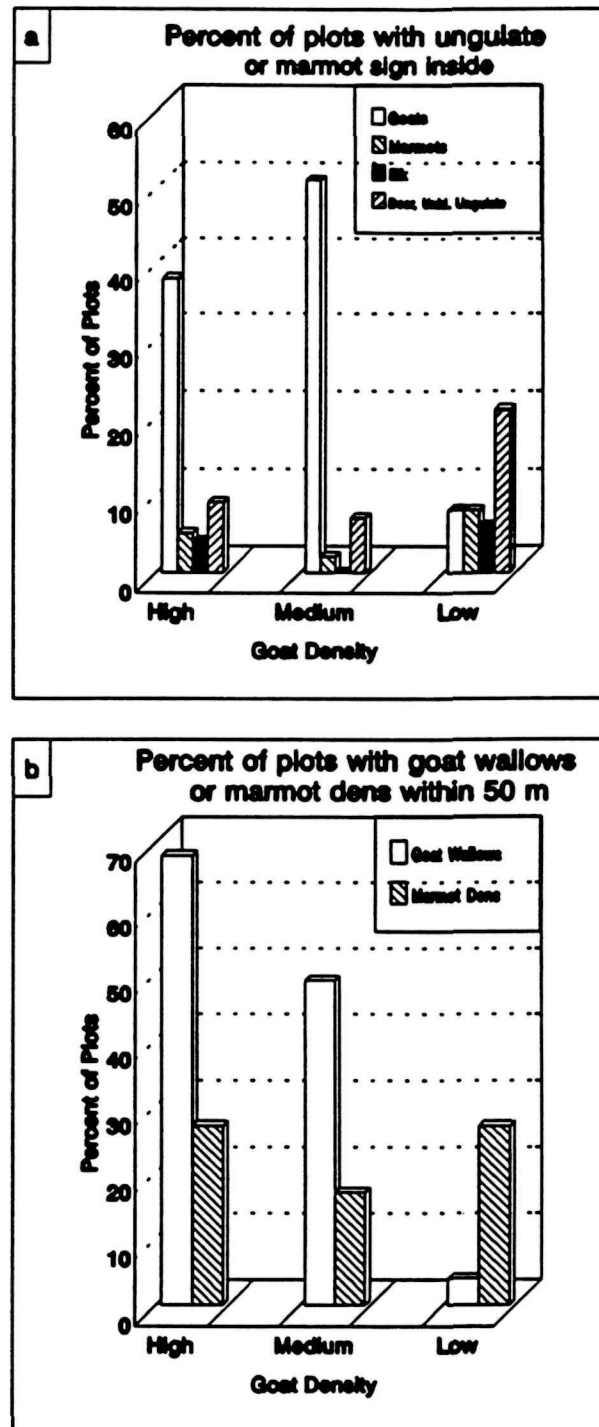


Figure 4-2. Percent of recon plots with HI > 0 for ungulates and marmots (a) and percent of plots where marmot dens or goat wallows were found within 50 m (b) in areas with high, medium, and low goat density.

voles, chipmunks and snowshoe hare was encountered infrequently compared to that of ungulates.

The larger sample size afforded by counting wallows and marmot dens within 50 m of recon plots increased the proportion of plots with sign of the four herbivores. Marmot dens were observed near 27, 17, and 27% of recon plots in high, medium and low goat density areas, respectively; for goat wallows, percentages were 68, 49 and 4. The percentage of plots with elk or deer/unidentified ungulate wallows/beds within 50 m of plots was generally low except at Hoh Lake. Eleven wallows outside of plots at Hoh Lake were identified in the field as deer/unidentified ungulate; we assume elk were responsible.

Soil Disturbance

Substantial soil disturbance may result from herbivore activity. Marmots, for example, excavate dens which displaces soil downhill from the entrance. A network of small trails may also interconnect dens in a marmot colony. Similarly, winter activities of mountain beaver often leave a web of trails that disturbs most of the ground surface over a 100 m² area. Large herbivores disturb soil through trampling, and creation of wallows and beds. All of these soil disturbances were observed in and around plots sampled in this study.

The most conspicuous soil disturbance encountered was wallow/bedding sites; most were attributable to mountain goats. Mountain goat wallow/bedding sites were well away from trees, high on slopes, with a "good view", presumably so that predators had little opportunity to "surprise" wallowing or resting goats. The typical wallow was a flat spot on a slope where vegetation had been eliminated. Surficial rocks were displaced to expose mineral soil. Most wallows were small, on the order of 1-3 m². The disturbed area often extended downslope an additional 1-2 m where material displaced to create the flat area was deposited. Larger wallows of up to 20 m² were also encountered. More than 700 wallows were counted, with 455, 235, and 21 in high, medium, and low goat density areas, respectively (Table 4-2).

Soil disturbances associated with elk and/or deer sign were also encountered. Over 100 wallows/beds attributed to elk, deer and unidentified herbivores were counted; 76 of these occurred at Hoh Lake where elk use was prevalent. In the high and medium goat density areas 22 wallows were observed.

Trampling by herbivores was evident in many plots (Table 4-2). The number and frequency of tracks, trails and pellet groups in each area serves as a rough measure of trampling disturbance. We

Table 4-2. Animal sign inside or within 50 meters of plots in subalpine and alpine plant communities. Data represents the total number of pellet groups, etc. tallied for each area. T = Tracks; P = Pellet groups; W = Wallow/bedding sites; IN = Inside recon plots; OUT = Within 50 m of recon plots.

LOCATION	N	Goat Sign				OUT W	Elk Sign				OUT W	Marmot Dens		Deer, Unknown				Trails IN
		T	P	W	IN		T	P	W	IN		Out	T	P	W	OUT W		
HIGH GOAT DENSITY (3+ goats/km2)																		
Mt. Dana	189	58	106	52	286	0	0	0	0	3	46	81	9	0	0	81		
Mt. Appleton	86	38	38	6	82	4	0	0	0	12	94	1	1	0	0	29		
Mt. Constance	16	11	1	0	13	0	0	0	0	0	1	0	0	0	0	1		
Schoeffel Creek	14	0	0	3	0	14	30	7	0	3	18		3	0	14	28		
Mt. Angeles-1982	7	-	4	-	13	-	-	-	-	-	0	-	-	-	-	-		
TOTAL	312	107	149	61	394	18	30	7	0	18	159	82	13	0	14	139		
MEDIUM GOAT DENSITY (1-3 goats/km2)																		
Royal Basin - 1981	53	-	31	-	18	-	-	-	-	-	21	-	-	-	-	-		
Mt Angeles (Astrag)	44	101	11	17	35	0	0	0	0	0	3	6	7	0	0	21		
Royal Basin - 1983	29	38	14	13	61	0	0	0	0	3	26	0	0	1	0	38		
Deer Park (Astragalus)	25	23	11	2	31	0	0	0	0	0	0	45	5	0	0	9		
Hurricane Hill (Astrag)	7	10	6	10	22	0	0	0	0	0	3	0	0	0	0	8		
Mt Angeles - 1985	6	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Sentinel Peak	5	8	1	1	5	0	0	0	0	1	2	0	0	0	0	5		
Greywolf Ridge	4	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0		
Deer Park - 1984	3	0	0	0	0	0	0	0	0	0	6	4	0	0	0	0		
Griff (Astrag.)	3	4	1	0	13	0	0	0	0	0	0	3	0	0	0	0		
Hurricane Hill	2	1	1	2	2	0	0	0	0	0	0	0	0	0	0	0		
TOTAL	181	189	76	45	190	0	0	0	0	4	61	58	12	1	0	81		
LOW GOAT DENSITY (<1 goat/km2)																		
Grand/Lillian	97	2	1	1	2	0	0	0	0	21	86	41	11	0	1	7		
Hoh Lake Cirque	23	0	0	0	2	3	16	2	0	4	29	9	18	8	66	31		
Maiden Peak	23	0	2	0	0	0	0	0	0	5	19	23	5	0	0	7		
Six Ridge	11	0	0	0	6	2	2	0	0	0	2	2	2	0	0	0		
Constance Pass	12	3	0	0	0	0	0	0	0	0	1	0	0	0	0	0		
Mt. Stone	9	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1		
Obstruction Peak	8	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0		
Deer Park - 1988	8	0	1	0	0	0	0	0	0	0	3	12	6	0	0	6		
Crystal Ridge	7	18	0	1	3	0	0	0	0	0	0	0	0	0	0	4		
Baldy Ridge	4	1	0	0	0	0	0	0	0	3	2	0	0	0	0	0		
Mt. Steele	2	0	0	0	2	0	0	0	0	1	5	0	2	0	2	2		
Happy Lake Ridge	2	2	0	0	1	0	0	0	0	0	0	0	0	0	0	1		
TOTAL	206	26	4	3	18	5	18	2	0	34	149	87	44	8	69	59		
GRAND TOTAL	699	322	229	109	602	23	48	9	0	56	369	227	69	9	83	279		

could not determine which large herbivore created trails, but patterns suggest that goats were often responsible. We counted 139 trails crossing 312 recon plots in high goat density areas compared to 59 in 206 plots in low density areas. Similarly, 149 goat pellet groups were tallied in high density plots as opposed to only 4 in low density plots. Deer/unidentified ungulate tracks exhibited no strong pattern; 87 sets of tracks were tallied in low goat density plots, and 58 and 82 sets in medium and high density areas, respectively.

Herbivore Use Patterns by Plant Community Type

All sixteen plant community types in mountain goat summer range were used by herbivores (Table 4-3). Mountain goat sign was present with the highest frequency followed by deer/unidentified ungulate, marmots and elk and small mammals. Deer/unidentified ungulate sign was encountered in all community types and mountain goat sign in all but one community type. However, mountain goat sign was encountered twice as often as any other herbivore in 12 of the 16 community types.

There seemed to be no strong relationship between the occurrence of goat or deer/unidentified ungulate sign and the plant communities of goat summer range. Evidence of mountain goats was observed in more than 40% of the plots classified as *Astragalus* Scree, *Cassiope*, *Phlox/Pachistima*, and *Delphinium* Scree and more than 20% of eight other community types (Table 4-3, Fig.4-3). Goat sign was not observed in the *Luetkea/Saxifraga* type and in only one plot of in the *Senecio* Scree. Deer/unidentified ungulate sign was observed in all 16 community types, but frequency was lower than that of goats. Most deer/unidentified herbivore sign occurred in the *Phlox/Festuca* (25%), *Carex/Lupinus* (24%) *Luetkea/Saxifraga* (20% but only 1 plot), and the *Phacelia* Scree (17%). Frequency ranged from 3-14% in the rest of the communities.

There was a stronger relationship between community type and the presence of elk sign than for goat or deer sign (Table 4-3). Elk sign was found in nine of the sixteen community types and was most often encountered in the three *Carex spectabilis* communities (*Valeriana*, *Vaccinium*, *Lupinus*) and the *Phacelia* Scree community type.

An examination of mean numbers of pellets group and marmot dens by community type (Fig. 4-4) suggests that herbivore use was most prevalent in communities where *Carex spectabilis* was dominant or a major constituent (Fig. 4-4). Other communities with moderate to high numbers of pellet groups or marmot dens included the *Phlox/Festuca*, *Phacelia* Scree and the two heath communities. The mean number of goat pellet groups was generally higher in areas thought to have high or medium

Table 4-3. Number of plots (%) with animal sign by plant community type in mountain goat habitat of Olympic National Park.

	N	Goats	Marmots	Elk	Deer/ Unknown Ungulate
SCREE COMMUNITIES					
Astragalus	50	28 (56)	0 (0)	0 (0)	4 (8)
Phacelia	41	17 (41)	5 (12)	3 (7)	7 (17)
Delphinium	13	6 (46)	0 (0)	0 (0)	1 (8)
Senecio	14	1 (7)	0 (0)	0 (0)	2 (14)
PHLOX COMMUNITIES					
Potentilla	45	12 (27)	0 (0)	0 (0)	6 (13)
Fescue	44	9 (20)	2 (5)	4 (9)	11 (25)
Carex phaeocephala	42	11 (26)	1 (2)	1 (2)	2 (5)
Juniperus	42	14 (33)	0 (0)	2 (5)	3 (7)
Pachistima/Sedum	76	24 (32)	0 (0)	0 (0)	2 (3)
Pachistima/Phacelia	15	7 (47)	1 (7)	0 (0)	2 (13)
CAREX SPECTABILIS COMMUNITIES					
Valeriana	39	8 (21)	6 (15)	6 (15)	4 (10)
Vaccinium deliciosum	30	9 (30)	4 (13)	3 (10)	4 (13)
Lupinus	94	31 (33)	12 (13)	0 (0)	23 (24)
Phyllodoce	56	23 (41)	3 (5)	3 (5)	7 (13)
Cassiope	34	17 (50)	1 (3)	0 (0)	3 (9)
Luetkea/Saxifraga	5	0 (0)	0 (0)	0 (0)	1 (20)
Total	640	217 (34)	35 (5)	22 (3)	82 (13)

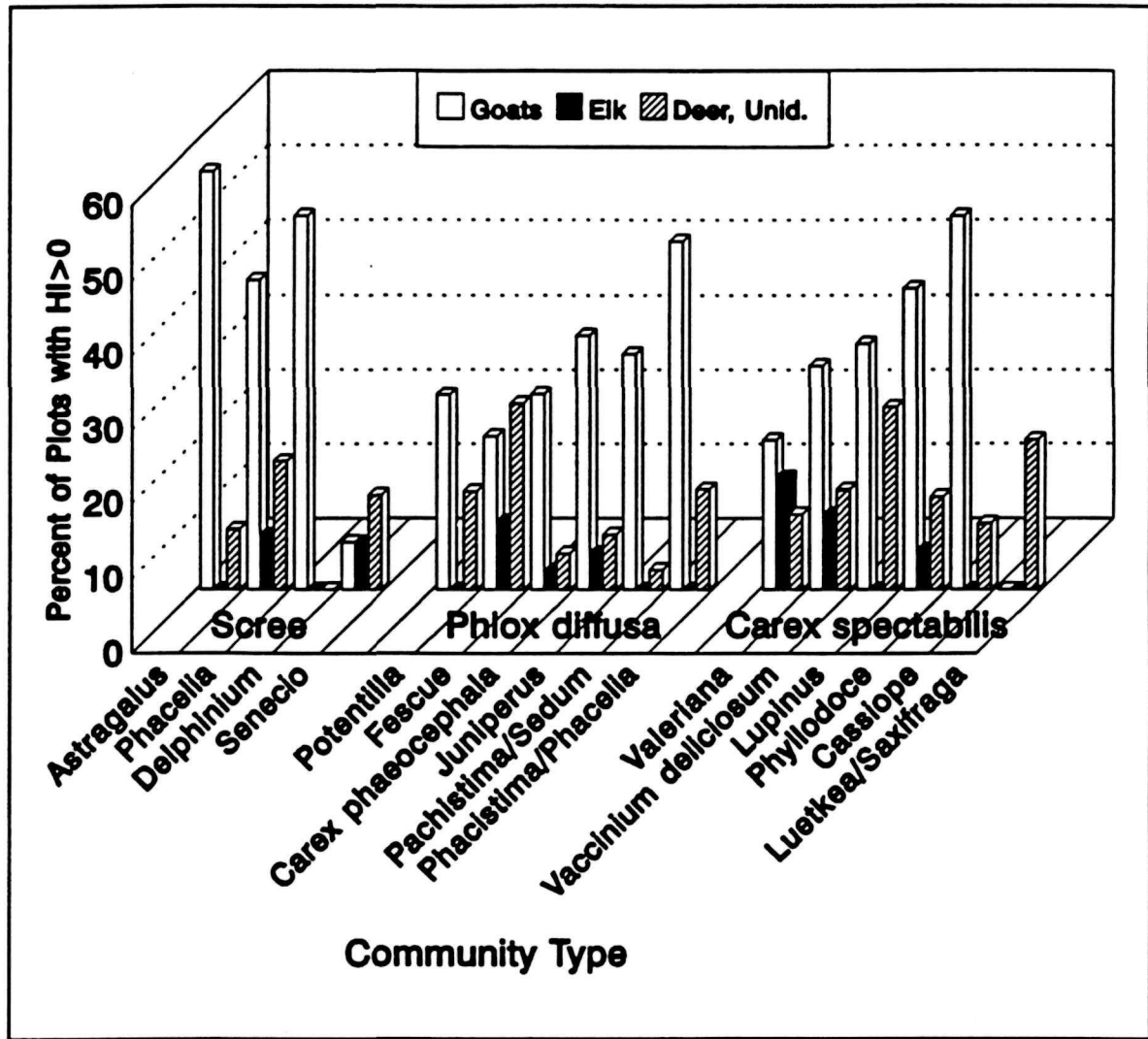


Figure 4-3. Number of recon plots with an Herbivore Index >0 for three species of ungulates by plant community type.

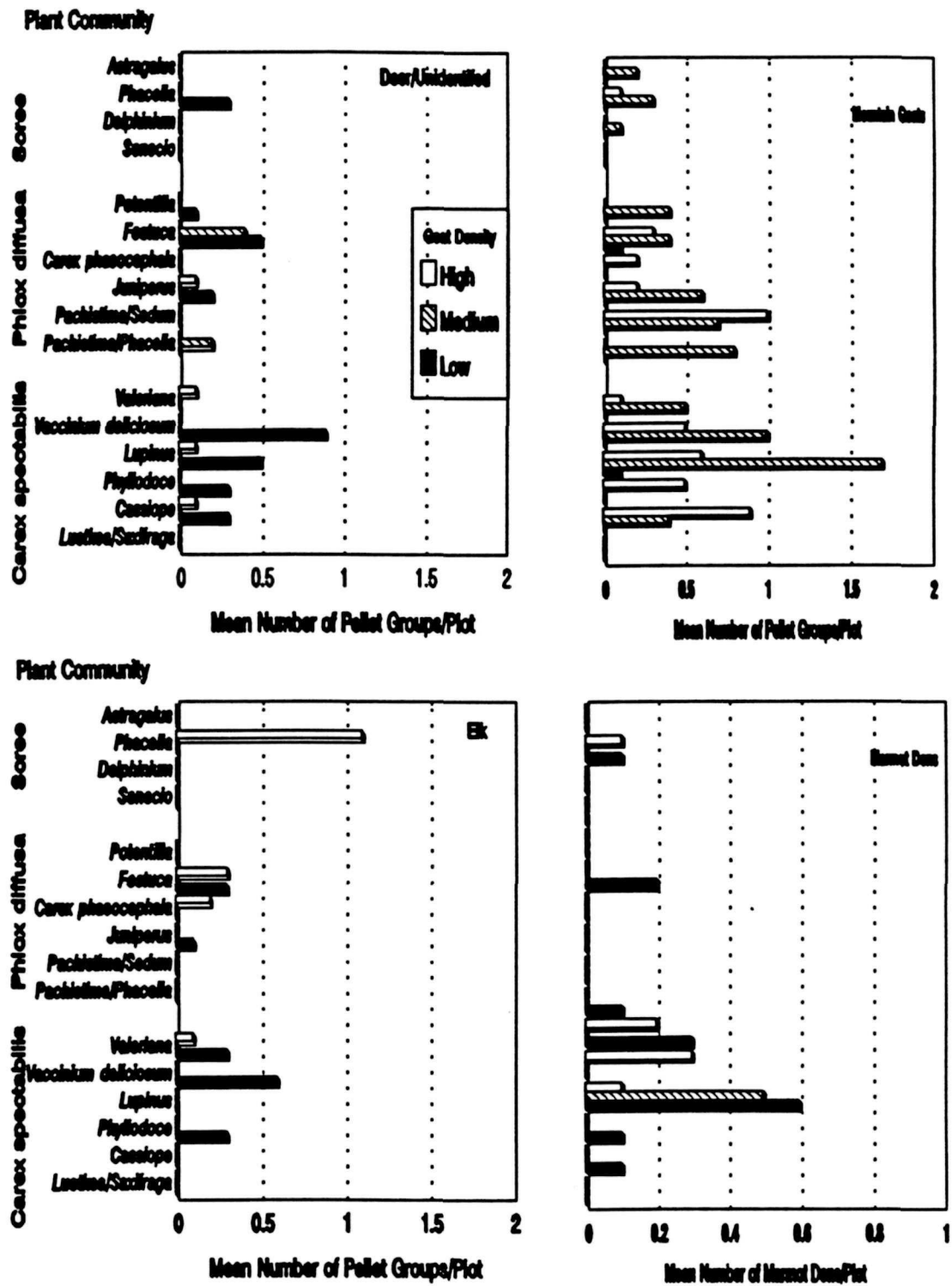


Figure 4-4. Mean number of ungulate pellet groups and marmot dens found in recon plots by community type.

goat density than in low density areas. Marmot dens occurred most frequently in the *Phacelia* scree, *Phlox/Festuca* and the three *Carex spectabilis* communities (*Valeriana*, *Vaccinium*, *Lupinus*). These five communities have relatively little bedrock at the soil surface.

Grazing

Determination of which herbivore species was responsible for consuming a plant was difficult in the absence of direct observations. Evidence of herbivores (i.e. sign) within or in the vicinity of plots where grazing occurred may be used to infer the animal species likely responsible for the grazing, but accuracy is not assured. Hence, results were interpreted conservatively.

Two measures, Percent of Species Grazed (PSG) and Average Grazing (AG) were used to provide a crude assessment of herbivory on a community type/estimated goat density basis (Fig.4-5). Values of PSG were highest in high or medium goat density areas across all community types. This indicates that for a particular community, there was apparently less selectivity by herbivores for particular plant species in areas thought to have high or medium goat density in comparison to areas thought to have low goat density. Average Grazing generally follows the same pattern except that AG was highest in low goat density areas in the *Senecio* and *Carex/Valeriana* community types. Moreover, AG for the *Carex/Vaccinium* community type in low goat density areas approached the values found in high density areas.

A rough idea of plant species selected by mountain goats on a parkwide basis was obtained by comparing the Species Relative Grazing Frequency (SRGF) and Average Grazing (AG) values of species that occurred in high, medium and low goat density areas (Table 4-4). Several species, including *Carex spectabilis*, *Poa secunda*, *Agoseris* spp., *Festuca idahoensis*, *Hedysarum occidentale*, *Valeriana sitchensis*, and the endemic *Aster paucicapitatus* had relatively high average grazing values in areas thought to have high goat density compared with medium or low goat density. Moreover, the SRGF for these species in the high density areas was at least 2.6 times greater than in low density areas. All these species except *Valeriana sitchensis* were also identified as "preferred" (i.e. selected) mountain goat forage by Pfitsch and Bliss (1985). A total of 33 species including a variety of rushes, forbs, grasses, sedges, and ferns plus one dwarf shrub were grazed with higher frequency in high than low goat density areas.

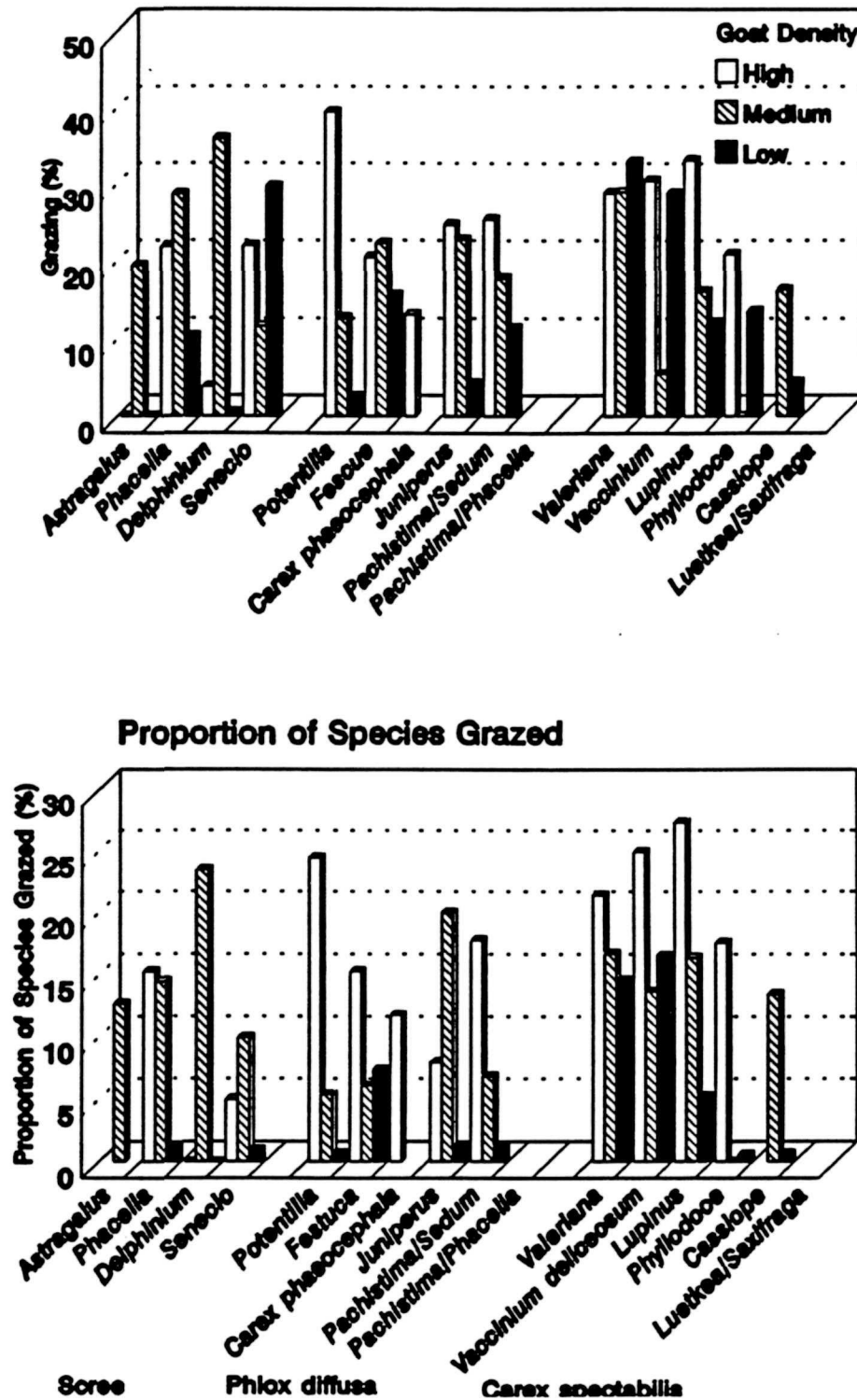


Figure 4-5. Grazing level indicators in high, medium, and low goat density areas by community type. Top: Average grazing (AG). Bottom: Proportion of Species Grazed (PSG).

Table 4-4. Average Grazing (AG), plant frequency, grazing frequency, and Species Relative Grazing Frequency (SRGF) in areas of high (H), medium (M), and low (L) goat density. Data are based on recon plots. Superscripts p and a indicate "preferred" and "avoided" species listed by Pfitsch and Bliss (1985) for Klahhane Ridge.

SPECIES	AG (%)			Frequency (N)						SRGF			SRGF Ratio	
	H	M	L	Plant			Grazing			H	M	L	H/L	M/L
Species with 10 or more occurrences in High, Medium, and Low goat density areas and a Species Relative Grazing Frequency (SRGF) at least 2x higher in High or Medium density areas compared to Low density areas. These species are apparently selected by goats on a parkwide basis.														
Car Spe ^P	12.7	2.3	6.6	158	30	75	126	20	21	80	67	28	2.8	2.4
Poa Sec ^P	7.6	1.3	0.7	103	58	37	52	16	4	50	28	11	4.7	2.6
Ago spp ^P	7.6	3.2	1.0	114	54	56	63	16	12	55	30	21	2.6	1.4
Fes Ida ^P	6.8	2.8	3.8	15	52	35	13	17	10	87	33	29	3.0	1.1
Hed Occ ^P	6.1	2.8	0.1	47	18	13	19	5	1	40	28	8	5.3	3.6
Val Sit	5.0	0.2	1.1	63	14	21	29	3	3	46	21	14	3.2	1.5
Ast Pau ^P	4.7	1.6	0.1	77	25	25	33	14	1	43	56	4	10.7	14.0
Eri Per ^P	3.4	0.4	1.4	97	19	28	44	7	6	45	37	21	2.1	1.7
Sit Hys	3.2	1.0		32	65	42	12	10		38	15			
Luz Par	3.1	1.3	T	50	11	25	18	4	3	36	36	12	3.0	3.0
Car Pha	2.8	0.6	T	74	22	30	27	12	1	36	55	3	10.9	16.4
Pha Has	2.3	1.5	0.9	73	66	29	30	15	4	41	23	14	3.0	1.6
Car Ros	2.2	1.3	2.8	41	23	11	24	5	3	59	22	27	2.1	0.8
Tri Spi	2.2	1.6		116	47	38	50	14		43	30			
Luz Cam	2.1	0.1	1.2	104	26	43	39	7	4	38	27	9	4.0	2.9
Ery Are ^a	2.0	0.7		95	67	46	27	9		28	13			
Hie Alb	1.8	0.4	0.7	34	23	11	18	3	2	53	13	18	2.9	0.7
Hie Gra ^a	1.8	0.2		141	31	38	49	8		35	26			
Phl Alp	1.8	0.6	0.2	31	10	18	13	4	2	42	40	11	3.8	3.6
Jun Par	1.6	0.4	T	86	34	16	44	9	1	51	26	6	8.2	4.2
Epi Alp	1.6	0.5	0.1	102	51	64	22	8	6	22	16	9	2.3	1.7
Ach Mil	1.3	0.6	T	56	108	74	19	16	1	34	15	1	25.1	11.0
Phl Dif ^a	1.2	2.2	T	201	135	88	44	21	2	22	16	2	9.6	6.8
Des Atr ^a	0.9	T	0.9	37	14	23	15	1	3	41	7	13	3.1	0.5
Cam Rot ^P	0.9	T	0.1	13	14	20	5	2	2	38	14	10	3.8	1.4
Epi Ang	0.8	0.4		28	24	22	10	5		36	21			
Art Lud	0.7	0.1		11	51	14	4	6		36	12			
Vio Adu	0.7	T	T	44	49	32	10	3	1	23	6	3	7.3	2.0
Cir Edu ^a	0.7	0.3	T	35	29	13	10	3	1	29	10	8	3.7	1.3
Pen Dav	0.5	1.5	T	59	39	21	14	9	1	24	23	5	5.0	4.8
Dou Lae	0.3		0.2	105	29	43	13		2	12		5	2.7	
Lue Pec ^a	0.2	0.5	T	139	27	38	25	8	1	18	30	3	6.8	11.3
Ver Cus	0.2	0.2	0.2	51	21	40	12	4	1	24	19	3	9.4	7.6
Ant Lan ^a	0.7	0.2		25	20	24	5	7		20	35			
Are Cap	0.4	0.1		66	25	24	10	1		15	4			
Jun Com ^a	0.1	0.3		55	31	31	8	4		15	13			
Ant Mic ^a	T	T		74	25	37	9	3		12	12			
Pha Ser	0.2	2.2		19	59	26	2	15		11	25			
Pen Pro	0.2	0.7		21	30	13	2	7		10	23			
Fes Ovi	0.2	0.7		39	18	20	3	7		8	39			
Sed Div	0.2	0.2		110	42	28	8	3		7	7			
Cry Cri	0.2	0.2		60	21	11	3	2		5	10			
Cas Mer	T	T		27	15	11	1	3		4	20			

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An examination of SRGF values for individual plant species by area (Fig. 4-6) reveals that there is relatively little consistency between the several sample areas¹. In high goat density areas, for example, *Deschampsia atropurpurea* was considered selected forage at Mt. Dana and non-selected at Mt. Appleton. Similarly, *Phlox diffusa* was non-selected in two areas and selected in one. Three species (*Carex spectabilis*, *Polygonum bistortoides*, *Silene parryi*) were selected in at least one high and one low goat density area. We assume these species are selected by goats as well as other herbivores. At Mount Constance and Deer Park, no species fit the selected criteria.

INTERPRETATION

A variety of indicators, including pellet groups, tracks, wallow/bedding sites, hair, grazing, and trails, hint at the extent to which herbivores interact with vegetation and soil above 1520 m in Olympic National Park. Evidence of mountain goat sign was most prevalent followed by marmots, deer/unidentified ungulate, and elk in decreasing abundance. Mountain goats evidently utilized or at least traveled through each sample area, including all that were rated as having low goat density. Marmot and deer/unidentified ungulate sign occurred in more than 50% of the sample areas while elk sign was encountered infrequently, occurring in just 4 of the 22 areas. Small mammal sign was also observed.

The frequency of herbivore sign in the different areas suggests that while there is at least regional overlap between marmot, deer, and goat summer range, elk utilize somewhat different areas. There may be an inverse, but not causal, relationship between the distribution of goats and elk. Areas where elk sign was prevalent (e.g. Hoh Lake) contained relatively little evidence of mountain goats and vice versa. Field observations suggest that preferred summer range of migratory elk differs from goats in that elk use meadows and forests associated with subalpine and upper montane cirques rather than the ridge tops and rocky outcrops occupied by mountain goats. Observations of Schroer (1987) support this interpretation of elk summer distribution.

¹ Note: The method used to classify species as selected or non-selected on a park wide basis made use of the relative difference in the value of SRGF in high, medium, and low goat density areas. This criterion (i.e. SRGF in high, medium, and low goat density areas) cannot be applied to individual areas because there were no goat density estimates for individual recon plots. Hence, we used the criteria described in Methods to determine selected and non-selected species ($SRGF \geq 50$, $SRGF \leq 25$) for individual areas (e.g. Mount Dana).

Figure 4-6. Selected (■) and non-selected (□) plant species in high, medium and low goat density areas of Olympic National Park.

SPECIES	AREA NAME																
	M	A	B	M	S	R	M	D	G	M	S	C	H				
	D	P	P	C	C	B	A	P	L	P	R	P	L				
Abi Las	■	■				■			■								
Ach Mil			■			■		■									
Ago spp.	■		■		■					■							
Ali Cre								■									
Ali Cer								■									
Ant Lan	■					■			■								
Ant Mic	■	■				■			■								
Ant Rac						■											
Ara spp								■									
Ara Cap	■							■									
Ara Mac		■				■											
Arn Lat		■				■											
Art Lud						■		■									
Art Nor		■								■							
Ast Aus								■									
Ast Fol		■															
Ast Pau						■											
Bro Sit								■									
Cam Pip								■									
Cam Rot								■									
Car Hoo						■											
Car Pha						■											
Car Ros	■	■				■											
Car Spe						■											
Cas His																	
Cas Mer						■											
Cas Min		■															
Cas Par		■															
Che Gra	■																
Cir Edu		■				■											
Cla Lan	■																
Cre Nan								■									
Cry Cri	■	■				■											
Del Gla	■					■											
Des Atr	■	■				■											
Des Cae								■									
Dou Lae	■	■						■									
Ely Gla				■	■	■		■									
Epi Alp	■	■		■	■	■		■									
Epi Ang								■									
Epi Gla						■		■									
Eri Com								■									
Eri Lan								■									
Ery Are						■		■									
Fes Ida			■			■		■									
Fes Ovi	■	■				■		■									
Fra Ves		■															
Hed Occ						■		■									
Hie Alb	■					■		■									
Hie Gra		■															
Hyd Fen						■											
Jum Com	■	■				■											
Jum Par	■																
Lom Mar		■		■				■									
Lue Pec	■	■															
Lui Hyp		■															
Lup Lat	■					■											
Lup Lep																	
Luz Cam		■															
Luz Par																	
Mer Pan		■															
Osm spp		■															
Pac Myr	■																
Pen Dav		■						■									
Pha Has			■			■		■									
Pha Ser						■		■									
Phl Alp								■									
Phl Dif	■	■	■			■		■									
Pin Mon						■											
Poa Cus																	
Poa Sec																	
Pol Bis	■	■	■		■												
Pol Hes																	
Pol Lon						■											
Pot Fru								■									
Sax Bro		■				■											
Sax Cae		■				■											
Sed Div	■	■				■		■									
Sed Lan																	
Sen Fle		■				■											
Sen Tri		■				■											
Sil Par	■	■	■			■											
Sit Hys								■									
Sme Cal								■									
Smi Ste								■									
Sol Mul						■											
Thl Fen		■															
Tri Spi																	
Vac Mem		■				■											
Val Sit						■											
Ver Cus		■				■											
Ver Vir																	
Ver Wor																	
Vic Ame						■		■									
Vio Adu		■	■			■		■									
Vio Fle																	
Vio Gla		■															

MD = Mount Dana
 AP = Mount Appleton
 BP = Klahhane Ridge
 MC = Mount Constance
 SC = Schoeffel Creek
 RB = Royal Basin
 MA = Mount Angeles
 DP = Deer Park
 GL = Grand Lake
 MP = Maiden Peak
 SR = Six Ridge
 CP = Constance Pass
 HL = Hoh Lake

* "Preferred" and "avoided" species listed by Pfitsch and Bliss (1985)

Soil Disturbance

Soil disturbance by mountain goats and other herbivores was documented in all sample areas. Disturbances in low goat density areas were attributed mainly to elk and marmot. Mountain goat wallow/bedding sites were common in high and medium goat density areas.

Herbivore trampling and wallowing activity obviously disturb soils (Begon et al. 1986). There are so many studies of the interaction between plant communities and the general subject of "disturbance" that entire books have been devoted to the subject (e.g. Pickett and White 1985). Disturbances influencing vegetation structure and composition may be small-scale, on the order of a few square centimeters (Harper et al. 1965), or large, covering thousands of hectares (e.g. the Yellowstone fires). Even though the precise effects of trampling and wallowing by mountain goats were not quantified, goat activities have undoubtedly increased disturbance levels. Evidence of goat disturbance was overwhelming compared to that of other herbivores in most areas where estimated goat density was high or medium.

Herbivore - Plant Community Relationships

Few studies have been conducted on herbivore use of subalpine and alpine vegetation within the summer range of mountain goats in Olympic National Park. Kuramoto and Bliss (1970) report that the Olympic marmot makes extensive use of mesic grassy communities (*Phlox/Festuca*), that deer grazed mainly in the mesic grassy, *Saussurea* forb, and tall sedge (*Carex/Lupinus*) communities, and that elk were most often observed using the *Valeriana* forb (*Carex/Valeriana*) and tall sedge communities. Wood (1973) found that marmot colonies were most often found in the *Carex spectabilis* (*Carex/Lupinus*), *Phlox/Festuca* and *Carex/Valeriana* communities and less often located in sites dominated by *Saussurea americana*, *Carex nigricans*, or *Phyllodoce empetrifomis*. The vole (*Microtus oregoni*) was trapped most frequently in *Carex spectabilis* meadows and less in *Carex/Valeriana* and *Saussurea* forb meadows (Sheehan 1978).

Our study supports observations of Kuramoto and Bliss (1970) with respect to plant community use by deer and elk. Deer/unidentified ungulate sign occurred most often in the *Carex spectabilis* (tall sedge, *Valeriana* forb) communities and in the *Phlox/Festuca* (mesic grassy) communities. The relatively small amount of elk sign encountered above 1520 m, however, suggests that at higher elevations at least, elk may use the *Phacelia* scree, and *Phyllodoce* (heath shrub) communities in addition to the tall sedge and mesic grassy communities.

Marmot dens in mountain goat summer range occurred in relatively few plant community types.

Three factors are hypothesized to be important selection criteria for marmots: 1) snow depth, 2) bedrock content of the soil, and, tentatively 3) some minimum level of standing crop in the community. The first factor is proposed because most marmot dens occurred in plant communities containing *Carex spectabilis*; all of which occurred at the wet, delayed snow melt end of the community gradient. These observations are similar to Wood (1973) and likely reflect the finding that marmots perish in their dens overwinter unless there was sufficient snow to provide insulation (Barasch 1973). The second factor is proposed because marmot dens were also observed in the relatively early snow melt *Phacelia* scree and *Phlox/Festuca* communities. In both cases, there is little bedrock near the surface; den construction would obviously be difficult in sites with abundant bedrock. The possibility that low standing crop plays a role in marmot selection of den sites is suggested because communities such as the Senecio scree have delayed snowmelt and little bedrock but have low plant cover (i.e. low standing crop). In all likelihood, a combination of these factors influences site selection by marmots.

Mountain goat use of the plant communities appeared to reflect selection for rock outcrops and cliffs rather than species composition. Goat sign was observed in 15 of the 16 community types with total plant cover ranging from 7 - 105%. Plant communities utilized by goats contained a remarkable number of plant species, many of which were not shared among community types.

Goat Forage and Interspecific Relationships

Results from this study suggest that while mountain goats may select certain plant species locally, there was little consistency between areas, i.e., a plant evidently selected in one region, might be non-selected in another. This too is interpreted to mean that summer range selection by mountain goats is based on habitat requirements such as rocky outcrops and sites for thermoregulation rather than species composition of plant communities. These results are consistent with studies of mountain goats throughout their native range (Adams and Bailey 1983, Brandborg 1955, Campbell and Johnson 1983, Casebeer et al. 1950, Fox et al. 1989, and others) and in the Olympics (Stevens 1979, Pfitsch and Bliss 1985).

Assessing competitive interactions between mountain goats and other herbivores is difficult because only three investigations have dealt with diets of subalpine and alpine herbivores of the Olympics. Wood (1973) found that marmot diets included *Festuca idahoensis*, *Polygonum bistortoides*, *Arenaria capillaris*, *Lupinus latifolius*, *Agoseris aurantiaca*, and *Silene parryi*, and Sheehan (1978) found that the vole *Microtus oregonii* consumed *Carex spectabilis*, *Polygonum bistortoides*, *Claytonia lanceolata*,

and *Erythronium montanum*. We note that mountain goats also ate *Festuca idahoensis*, *Agoseris* spp., and *Carex spectabilis*. In addition, we note that *Polygonum bistortoides* may be selected by goats but also appears to be consumed by other herbivores. Microhistological analysis of elk and deer pellets from two summer ranges in the park showed that diets were weighted to high quality herbaceous forage (Houston, unpubl. data). Several plant genera, (e.g. *Carex* spp., *Luzula* spp., *Vaccinium* spp.) were shared among the three ungulate species, and it seems likely that parkwide many more taxa would be consumed in common. In short, this means that elk, deer, mountain goats, marmots and voles consume some of the same species but that actual competition for forage cannot be proved or disproved with the existing data.

Habitat changes wrought by goat trampling and wallowing are likely to affect other herbivores, particularly small mammals. Such effects may seem inconsequential, but species such as *Microtus oregoni* are dependent on *Carex spectabilis* communities (Sheehan 1978) and may be affected locally by goats. Pfitsch (1981) and Pike (1981) found reduced flower (and therefore seed) production, leaf length, and standing crop of meadow species used by goats at Klahhane Ridge. These alterations may affect smaller species such as birds and insects, but we have no measure of these relationships. Clearly, mountain goats are widespread and have substantially increased soil disturbance levels through their trampling, wallowing and grazing activities. There is no doubt they have, at a minimum, modified micro-habitats in a variety of plant communities.

CHAPTER 5:

INTERACTIONS BETWEEN GOATS AND PLANT COMMUNITIES: RESPONSE OF VEGETATION TO REDUCTIONS IN GOAT DENSITY

INTRODUCTION

Studies of the interactions between herbivores and vegetation are often encumbered with problems of experimental design. Exclosure studies, for example, that purport to demonstrate herbivore effects may actually confound microenvironmental changes caused by the fence with the effects of herbivore exclusion (Daubenmire 1940, Heady 1968 and others). Clipping experiments designed to simulate the effects of herbivory usually do not account for the potential stimulating or depressing effect of saliva on plant growth (Crawley 1983).

The specifics of herbivore/plant community interactions are perhaps best delineated using experimental manipulation. This can be accomplished easily with livestock because the investigator has control of animal densities, but is more difficult with wild ungulate populations. In the present study, we reduced wild mountain goat populations and simultaneously measured vegetation to determine if plant communities or individual plant species responded to lower goat density. Mountain goats occur in relatively distinct subpopulations (Stevens 1980, Houston et al. 1986), so it was possible to manipulate individual subpopulations and thus repeat the study in areas with different environmental conditions and goat densities.

Permanent plots were established in three areas of the Olympic Peninsula that had relatively discreet subpopulations of mountain goats. Study sites were located in goat summer range at Klahhane Ridge, Mount Dana, and Avalanche Canyon (Fig. 5-1). Each area had relatively high initial goat density but differed in annual precipitation, plant community composition and the duration and extent of goat removals. Moreover, we were able to locate plots within each area that differed with respect to how goat use was affected by the general subpopulation reductions. Thus, we identified individual macro plots where goat use was high initially and declined as goat density was reduced as well as "control" plots where goat use was low initially and was relatively unaffected by reductions in the general subpopulation. The general null hypothesis was that reductions in mountain goat density would not result in changes to plant community structure (relative abundance of plant species).

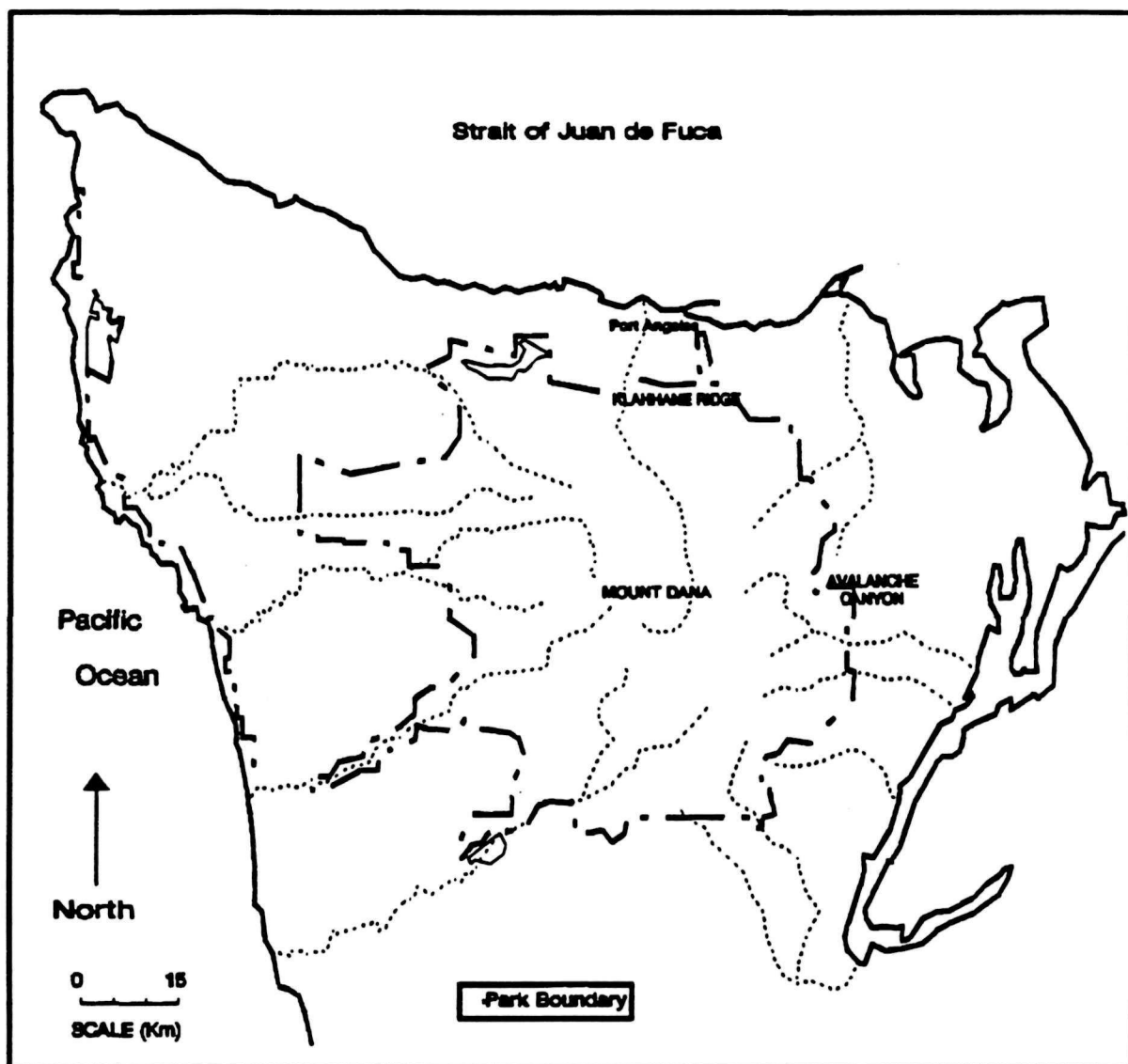


Figure 5-1. Location of the three areas used to study the response of vegetation to reductions in mountain goat density.

STUDY AREAS

The three study areas differed physiographically: 1) Klahhane Ridge runs east-west so most slopes face south or north, 2) Mount Dana is an isolated peak with aspects on all points of the compass, and 3) Avalanche Canyon is a north-south running valley with mainly east and west facing slopes. Site and goat density differences are outlined in Table 5-1 and Figure 5-2). Klahhane Ridge was the most intensive study site because of the thoroughness of goat removal and ease of access. Mount Dana was studied least intensively because access required 4-5 days foot travel.

Klahhane Ridge is located at the north end of Olympic National Park, about 12 km south of the Strait of Juan de Fuca. Pfitsch and Bliss (1985) identified nine plant community types ranging from windswept ridges dominated by cushion plants to late snow areas dominated by *Carex nigricans*. Two communities, *Phlox/Festuca* and Unstable Herb Meadow (*Phacelia Scree*), account for most of the unforested vegetation in the area. Both communities become snow-free by late May or early June and comprise 94% of available meadow vegetation early in summer and 59% in late summer. Permanent plots were placed in these two community types.

The Klahhane goat subpopulation is thought to have reached a peak density in the late 1970s and was systematically reduced from 1981-1985; further reductions were accomplished from 1988-89. The population reached medium density (1-3 goats/km²) in 1985 and low density (< 1 goat/km²) sometime between 1987 and 1990, probably following the removal of 17 goats in 1988. An estimated 3 goats remained in 1990 (Houston et al. 1991a).

Herbivores observed utilizing Klahhane Ridge included mountain goats, marmots and black-tailed deer. Goats were commonly observed using two plots (PP2,PP3) from 1983-86, occasionally using two plots (PP4,PP6) from 1983-86, and never using two plots (PP1,PP7). Black-tailed deer were seen using PP1 and PP7. Marmots occurred in the vicinity of P2 and P7. Deer seemed to increase utilization of the area in the vicinity of PP3, PP4 and PP6 from 1986-88.

Mount Dana is located in a high precipitation region, 17 km east of Mount Olympus. Plant communities on Mount Dana represent a subset of those found throughout goat summer range in the Olympics (Chapter 3). The TWINSPAN classification of recon plots (n=189) revealed eight plant community types. Dry site communities found elsewhere in the park (*Astragalus Scree*,

Table 5-1 Location, sample size, and general information of areas containing permanent plots.

Area	N	Sample Years	Goat Removal Years	N of C.Ts.*	Site Selection	Source of Selected or Non-selected Species	Samples per Year	Estimated Annual Precipitation (cm)
Klahhane Ridge North end of the Park	6	1983-86 1988 1989	1981-85 1988-89	2	Sites in high and low goat use areas in the two major communities described by Pfitsch and Bliss (1985)	Pfitsch and Bliss (1985)	3-6	110
Mount Dana Center of the Park	7	1984-86 1990 1992	1983 1985 1988-89	7	One representative of each of seven community types delineated by TWINSpan using 1983 data.	Recon plots (N=189)	1	400
Avalanche Canyon East Side of the park	6	1988-92	1988-89	3	Sites to be similar to those on Klahhane Ridge	Recon plots (n=16) No species fit the selected category	2	175

* Community Types

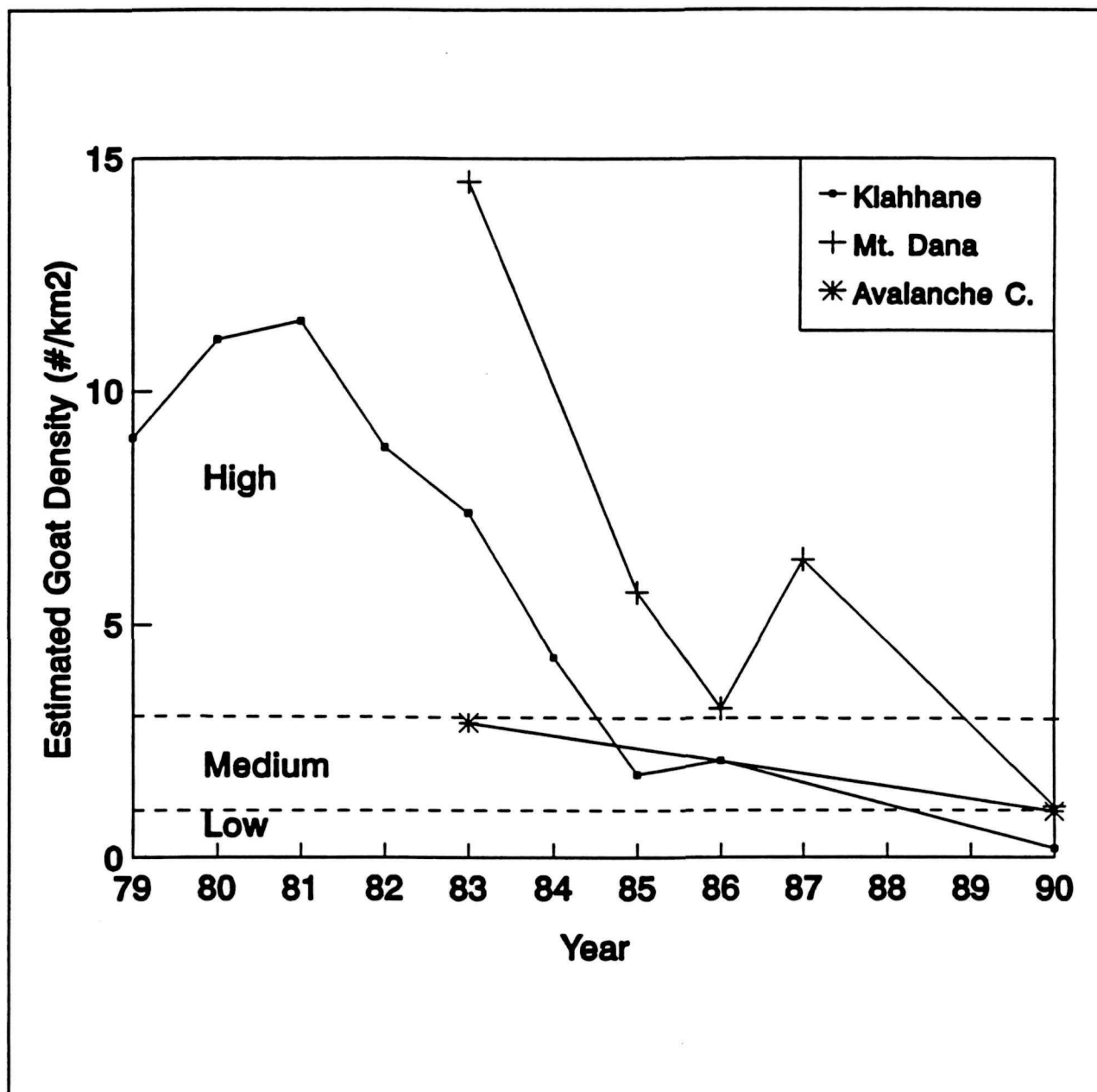


Figure 5-2 Estimated mountain goat density in three subpopulations of the Olympic Peninsula.

Phlox/Potentilla, *Phlox/Festuca* and *Phlox/Pachistima* types) were not encountered at Mount Dana. Additionally, some communities found in other areas (*Carex/Valeriana*, *Delphinium* Scree, *Senecio* Scree) were not well represented. Typical communities included *Phyllodoce empetriformis*, *Carex spectabilis/Lupinus latifolius*, and *Phlox diffusa/Carex phaeocephala*. Seven permanent plots were established in 1984 in the three typical communities, a rocky outcrop, two scree slopes and a talus community.

Mountain goats inhabiting Mount Dana are part of the Mount Dana-Mount Wilder subpopulation that was well-established in 1983 when the first helicopter count was obtained as part of the rangewide census (Houston et al. 1986). The subpopulation was estimated to contain 68 animals. Thirty-nine goats were removed from 1985-89 including 25 taken in 1985. The subpopulation remained at high density (> 3 goats/km²) until 1987 and reached low/medium density in 1990, presumably after 14 goats were removed from 1988-89. Only 5-6 animals were estimated to remain by 1990 (Houston et al. 1991a). Two goats and three freshly used goat wallows were observed during the 1990 and 1992 sample periods, respectively.

Herbivores utilizing the Mount Dana area included elk, mountain goats, deer, marmots and bear (actually an omnivore). Relatively limited observations during the study period (i.e. ~1 week per year in late July or Early August, 1983, 1984, 1990, 1992) indicated that mountain goats utilized snow patches, meadows, and rocky outcrops along the east and north flanks of Mount Dana and open areas just south and west of the summit. On hot summer days, mountain goats utilized east facing rock outcrops and debris chutes as low as 800 m. Extensive *Carex spectabilis* meadows below and southwest of the summit were used mainly by elk, bear and marmots. Deer, their beds and tracks were most commonly observed in subalpine fir forests and among subalpine fir clumps above the *Carex spectabilis* meadows and below the summit of Mount Dana. Thus, there was some overlap in the sites used by goats and marmots but little overlap in sites used by goats and those used by elk, deer or bear. Permanent plots were placed near the summit and on the east facing slopes.

Avalanche Canyon is located near the eastern border of Olympic National Park just west of Mount Constance. The region is incredibly rugged and is known for its scree slopes, loose rock and numerous prominent peaks (Olympic Mountain Rescue 1988). Vegetation is generally sparse, covering relatively little of the overall landscape. Plants occur mainly on scree, talus, rock outcrops and a few relatively stable benches. Species associated with later snowmelt talus slopes such as *Elmora racemosa* were relatively more common in Avalanche Canyon than at Klahhane or Dana. Individual reconnaissance plots were dominated by *Luetkea pectinata*, *Phyllodoce empetriformis*, *Carex spectabilis*, *Phlox diffusa*, *Phacelia hastata* or *Delphinium glareosum*. Meadows characteristic

of goat summer range elsewhere in the park (Chapter 3) were essentially absent.

Permanent plots were established in communities that were as similar as possible to those on Klahhane Ridge. Three plots were located in relatively unstable scree slopes dominated by *Phacelia hastata*, one in *Delphinium* Scree and two relatively stable sites dominated by *Phlox diffusa*. *Festuca idahoensis* was not a constituent of Avalanche Canyon plant communities. Permanent plots were placed in the two scree communities and in sites dominated by *Phlox diffusa*.

Avalanche Canyon is within the region occupied by the larger Mount Constance Area goat subpopulation and includes lands outside of ONP. Two helicopter counts resulted in population estimates of 99 and 36 in 1983 and 1990, respectively (Houston et al. 1991a). Twelve animals were removed from the area between 1988 and 1989 by NPS and several additional animals were taken by hunters outside the park. Goat density estimates indicate the population was on the border between high and medium in 1983 and between medium and low by 1990.

Herbivore use in Avalanche canyon was mainly by mountain goats. Elk and bear or their sign was not observed; marmots occurred occasionally and deer were seen infrequently. Observations of goats, hair and grazing in permanent plots and the surrounding area indicated they were the major herbivore in Avalanche Canyon and that goat use in the area remained more or less constant throughout the 1988-92 study period.

METHODS

Permanently marked plots were established in areas of homogeneous vegetation in each area. Plots were 100 m² unless a smaller 25-40m² plot had to be used because the area of homogeneous vegetation was small (i.e. Avalanche Canyon where plant cover was sparse). Vegetation characteristics in each plot were estimated on 6-12, 1 x 1m quadrats selected using a stratified-random design. Plant cover and grazing levels were estimated 3 times per year at Klahhane Ridge, 2 per year at Avalanche Canyon and 1 per year at Mount Dana. More than one sample/year was taken at Klahhane and Avalanche Canyon so that maximum plant cover in a each growing season could be estimated.

Cover was estimated using plot frames gridded with string so that each square represented 1% of the quadrat. The gridded frame helped minimize variability between estimates obtained by different investigators and provided for accurate estimates to the nearest 1 percent. Training sessions were

conducted each year to ensure that each member of the field crew estimated plant cover the same way. Cover classes were Trace = $<0.1\%$, $<1 = 0.1-0.5$, $1 = 0.5-1.0$, $2 = 1.1-2.0 \dots 100\%$. Grazing (i.e. GI) was estimated using the same approach as for recon plots (Chapter 4) with grazing classes of : Trace, 1-5, 6-25, 26-50, 51-75 and 76-100%.

Selected and non-selected forage species were determined separately for each area because forage chosen by mountain goats is known to be area specific (Johnson 1983; Chadwick 1983; Chapter 4). Klahhane Ridge selected and non-selected species were determined by Pfitsch and Bliss (1985). At Mount Dana and Avalanche Canyon we attempted to delineate selected and non-selected plant species using recon plots and criteria outlined by Pfitsch and Bliss (1985). That is, species that occurred in more than 10 plots were considered selected if SRGF was greater than 50 and non-selected if SRGF was less than 25. Results of these analyses showed that 9 species were selected and 15 non-selected at Mount Dana (Appendix B); no species fit the selected category for Avalanche Canyon. The inability to identify selected species at Avalanche Canyon probably resulted from the low number of recon plots (16) and/or low plant cover forcing goats to be non-selective. Instead, we categorized species into: 1) "recover" - those that were grazed only for the first two years and 2) "no recover" - those that were grazed more or less throughout the study period (Appendix B contains a list of these species). These categories provide a very crude approximation of selected/non-selected species groups utilized at Klahhane and Dana.

Six permanent plots (P1-6) were established on Klahhane Ridge and one at Deer Park (P7) in 1983 and studied until 1990. They were initially established in areas of high, moderate/low and low goat use based on previous observations of goat behavior. Moderate/low and low use plots were combined in the following analyses. Cover values represent the maximum of mid-July, early- and late-August samplings by species. Results from one plot (P5) were not included in the analysis because of proximity to a goat capture site where salt was used seasonally to bait goats into the site. The resulting concentrations of goats and people clearly affected vegetation in the immediate area.

Seven permanent plots were established on Mount Dana in 1984 to monitor the major plant communities over time. Cover was estimated in late July or early August 1984-1986, 1990, and for 5 plots in 1992. Data are presented for the five plots with complete records. Results are predisposed to greater phenological variability because sites could be sampled only once per season.

Plots at Mount Dana were divided into low/no goat use and high goat using the number of species grazed (NSG) more than 5% (i.e. $GI > 5\%$, See Chapter 4) in each 10 x 10 m plot as an indirect measure of the intensity of goat use. We noted that number of species grazed in high use plots at

Klahhane Ridge was initially higher than that in moderate/low use plots and declined as goat density was reduced (Fig. 5-3a). The value of NSG in the high use plots ultimately was equal to or less than that in moderate/low use plots. Consequently, since we had direct observations of goat use levels at Klahhane Ridge, and the value of NSG declined as density was reduced, we used NSG as an indirect measure of goat use levels at Mount Dana (and Avalanche Canyon), i.e. plots with initially high values of NSG that subsequently declined were called high use and plots where NSG did not change were designated low use (Fig. 5-3b).

Six permanent plots were established in Avalanche Canyon near Mount Constance in 1988. Four were located on steep, unstable scree slopes (P2, P3, P5, P6); two were on stable, rocky sites with some soil development (P1, P4). Cover was measured once in 1988 and in late-July and late-August 1989-1992. The maximum cover value for each species in each year was used for analysis.

Attempts to classify plots as high or low goat use at Avalanche Canyon using the number of species grazed were unsuccessful because the values of NSG fluctuated. The value declined in some plots, increased in others, and remained relatively stable in still others (Fig. 5-3). Therefore, we used a crude approximation of goat use levels using the grazing index. Plots were divided into two groups: 1) "decreasing use" where more grazing occurred during the first two years (1988-89, $n=2$) and 2) "stable/increasing use" where grazing remained ~ constant or tended to increase ($n=4$). We used 1988 and 1989 to delineate "declining use" because NPS staff removed goats from the Mount Constance Area goat population both years.

Precipitation during June, July and August measured at the nearest location with similar climate (but at lower elevation) was used as a measure of growing season quality. July and August records from Port Angeles and Quilcene were used for Klahhane and Avalanche Canyon, respectively. June and July precipitation at the Hoh Ranger Station were used for Mount Dana because sample dates were late July or early August. Precipitation records from Quilcene for 1992 were unavailable so we estimated a value based on regression with the Hoh Ranger Station data ($r^2 = 0.96$).

The null hypothesis was tested by comparing the response of selected and non-selected species (recover/no recover at Avalanche Canyon) and total plant cover between high and low goat use ("declining use" vs. "stable/increasing use" at Avalanche Canyon) plots over time. Despite a large expenditures of time and effort to describe vegetative changes over time, the data set is still comprised of only a small number of plots falling into any category at any one site. These small group sizes made it impossible to define their probability distribution, therefore parametric statistical analysis was inappropriate. Instead we calculated regression of plant cover on time and correlation

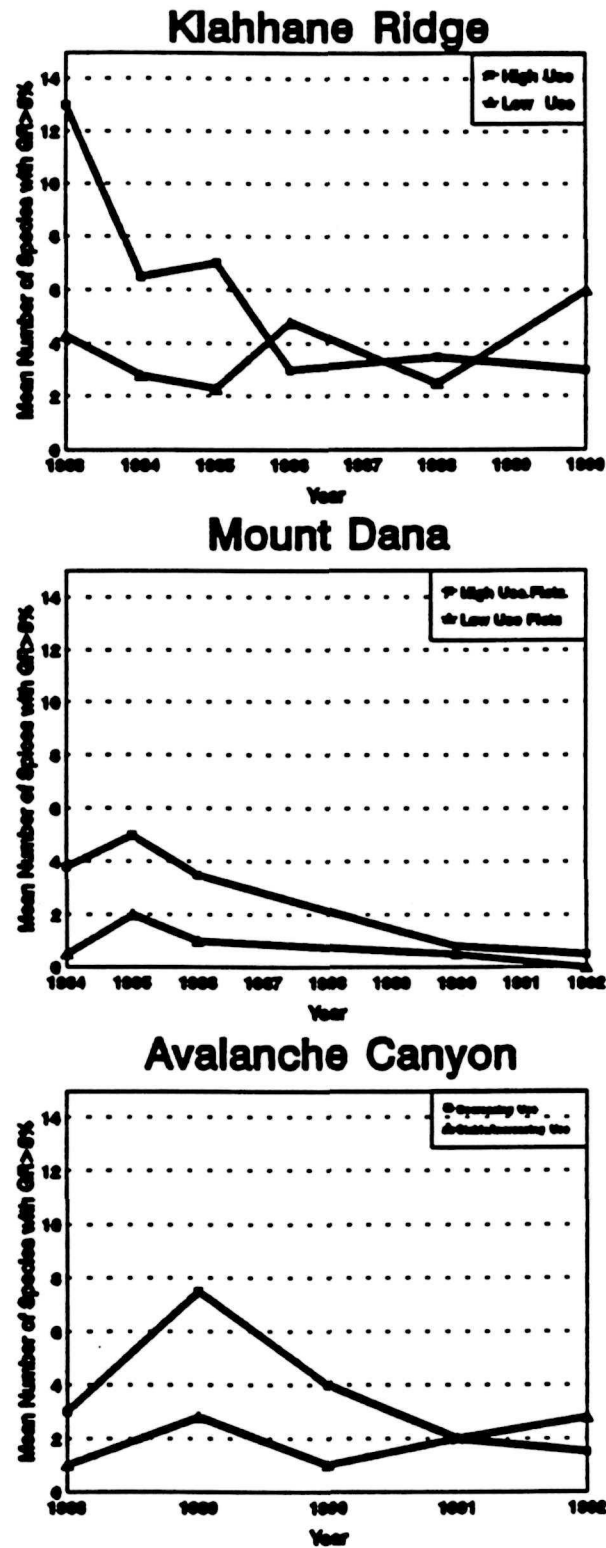


Figure 5-3. Mean number of species grazed > 5% in high and low use density plots at Klahhane Ridge, Mount Dana, and Avalanche Canyon.

coefficients of cover with weather variables and goat density as descriptive statistics summarizing the association among the variables for each plot. Significant differences between groups of plots (e.g. high vs. low use) and categories of species (e.g. selected vs. non-selected) for these descriptive statistics were analyzed using a non-parametric permutation test procedure (Mehta et al. 1988). The permutation test detects concentrations within *a priori* groups (i.e. if two or more groups come from the same distribution of random numbers), similar to *t* and *F* tests, but does not depend on assumptions of normality and homogeneous variances. We made only those comparisons that tested pre-determined hypotheses.

The probability associated with stating that two groups are different for the permutation test is determined by the probability of observing "extreme results" had groups been drawn at random from the available numbers (e.g. the probability that all of the positive numbers fall in one group and the negative numbers in the other at random. therefore, the probability for extreme results being observed is a function of the number of numbers being compared. For example, the minimum p value attainable for the comparison between group sizes of 4 and 2 is .0667. Consequently we used 0.10 as the critical p-value. In the special case where comparisons are between two treatments with two numbers each, the minimum p-value is 0.1667. In this case we use it as a significant difference and mark these with an asterisk.

RESULTS

Vegetation Change with Time

At Klahhane Ridge, approximately one-third of total plant cover (mean=34.4%, range= 21-43%) could be categorized as selected or non-selected by goats. Initially, selected species predominated in areas with low levels of goat use, having 29.7% cover versus 11.0% cover of non-selected species. In contrast, high goat use areas had similar cover of non-selected species (11.25%) and selected species (9.0%). As the goat population declined (Fig. 5-2), selected species in high goat use areas increased at a significantly faster rate (i.e. greater slope of regression) than selected species in low goat use plots ($p=0.0667$; Table 5-2; Fig. 5-4); non-selected species did not differ significantly between high and low use plots. Additionally, the rates of change of selected and non-selected species were significantly different from each other in high use plots ($p=0.1667$) but not in low use plots ($p=0.3143$). Total plant cover tended to increase in high use plots but decreased in low ($p=0.0667$, Table 5-2).

At Mount Dana, selected species had consistently positive slopes in plots experiencing high goat use. This contrasted significantly ($p=.097$) with non-selected species and total cover ($p=.0482$) in these plots (Table 5-3, Fig. 5-5). Comparison of selected species in low use plots versus high use plots could not be made because only one of the two plots contained selected forage species. There were no significant differences between low and high use plots for non-selected species or total plant cover.

Avalanche Canyon plots were compared as "decreasing use" (P1,P2) or "stable/increasing use" groups (P3, P4, P5, P6) and species expected to "recover" (grazed the first two years only) or "no recover" (grazed in years 3,4, or 5; Table 5-4; Fig. 5-6). We compared species grazed only in the first two years of the study with those that were grazed throughout or late in the study. Plant species that were grazed only during the first two years had significantly higher regression slopes than species that were grazed throughout or late in the study ($p=0.1667$) in plots experiencing declining goat use. These two groups were not significantly different from each other in plots with stable or increasing use.

Vegetation Change in Relation to Goat Density

Selected species and total plant cover at Klahhane Ridge were negatively correlated with goat density in high use plots (Table 5-2). Correlation coefficients were significantly different from those between selected species and total cover and goat density in low use plots ($p=0.0667$, selected; $p=0.0667$, total). There was no difference between the correlation of non-selected species in high and low

Table 5-2. Mean cover of selected and non-selected plant species and total plant cover in Klahhane permanent plots by level of goat use. The trend of cover through time is described as the regression of cover on year with slope b . Correlations coefficients (r) of cover with precipitation (ppt) and goat density (dens) are also given.

	Plot	Mean Cover (%)						Slope	r with:	
	#	1983	1984	1985	1986	1988	1990	(b)	ppt	dens
LOW GOAT USE										
Selected	P1	31.5	20.0	15.9	18.9	18.2	22.7	-0.68	0.10	0.73
	P4	29.0	21.8	18.4	25.8	24.5	26.8	0.21	0.13	0.35
	P6	18.1	13.6	14.6	17.8	-	17.5	0.16	0.47	0.21
	P7	40.1	25.3	24.5	24.3	25.3	30.3	-0.69	0.59	0.69
Non-selected	P1	2.8	2.2	1.3	1.9	1.0	1.8	-0.14	0.10	0.85
	P4	14.5	8.2	3.4	3.6	3.6	14.3	0.03	0.76	-0.59
	P6	23.5	8.5	6.0	4.5	-	10.9	-0.98	0.53	0.77
	P7	3.1	6.4	4.5	3.0	2.8	4.1	-0.14	-0.22	-0.10
Total	P1	70.7	51.8	40.8	41.5	44.6	54.3	-1.47	0.53	0.73
	P4	80.8	65.1	65.9	69.7	70.1	94.2	2.31	0.82	-0.08
	P6	96.4	71.2	66.7	67.1	-	73.2	-1.91	0.44	0.82
	P7	73.7	57.4	53.9	51.9	58.7	63.1	-0.59	0.66	0.65
HIGH GOAT USE										
Selected	P2	10.2	20.8	15.2	20.8	19.9	26.2	1.68	0.15	-0.80
	P3	7.8	12.9	11.8	16.2	18.2	18.4	1.44	0.13	-0.88
Non-selected	P2	7.2	7.0	9.8	12.9	10.0	11.4	0.59	0.01	-0.76
	P3	15.3	18.4	12.3	9.7	8.3	12.0	-0.89	0.76	0.59
Total	P2	36.1	55.0	52.6	56.6	51.9	62.4	2.43	0.00	-0.93
	P3	63.8	75.7	72.2	73.9	77.4	92.0	3.17	0.49	-0.81

Probability that groups represent random selections (critical value = 0.10):

Comparisons:

High Use, Selected	vs.	High Use, Non-selected	0.1667*	n.s.	n.s.
High Use, Selected	vs.	High Use, Total Cover	n.s.	n.s.	n.s.
High Use, Selected	vs.	Low Use, Selected	0.0667	n.s.	0.0667
High Use, Non-selected	vs.	Low Use, Non-selected	n.s.	n.s.	n.s.
High Use, Total Cover	vs.	Low Use, Total Cover	0.0667	n.s.	0.0667
Low Use, Selected	vs.	Low Use, Avoided	n.s.	n.s.	n.s.

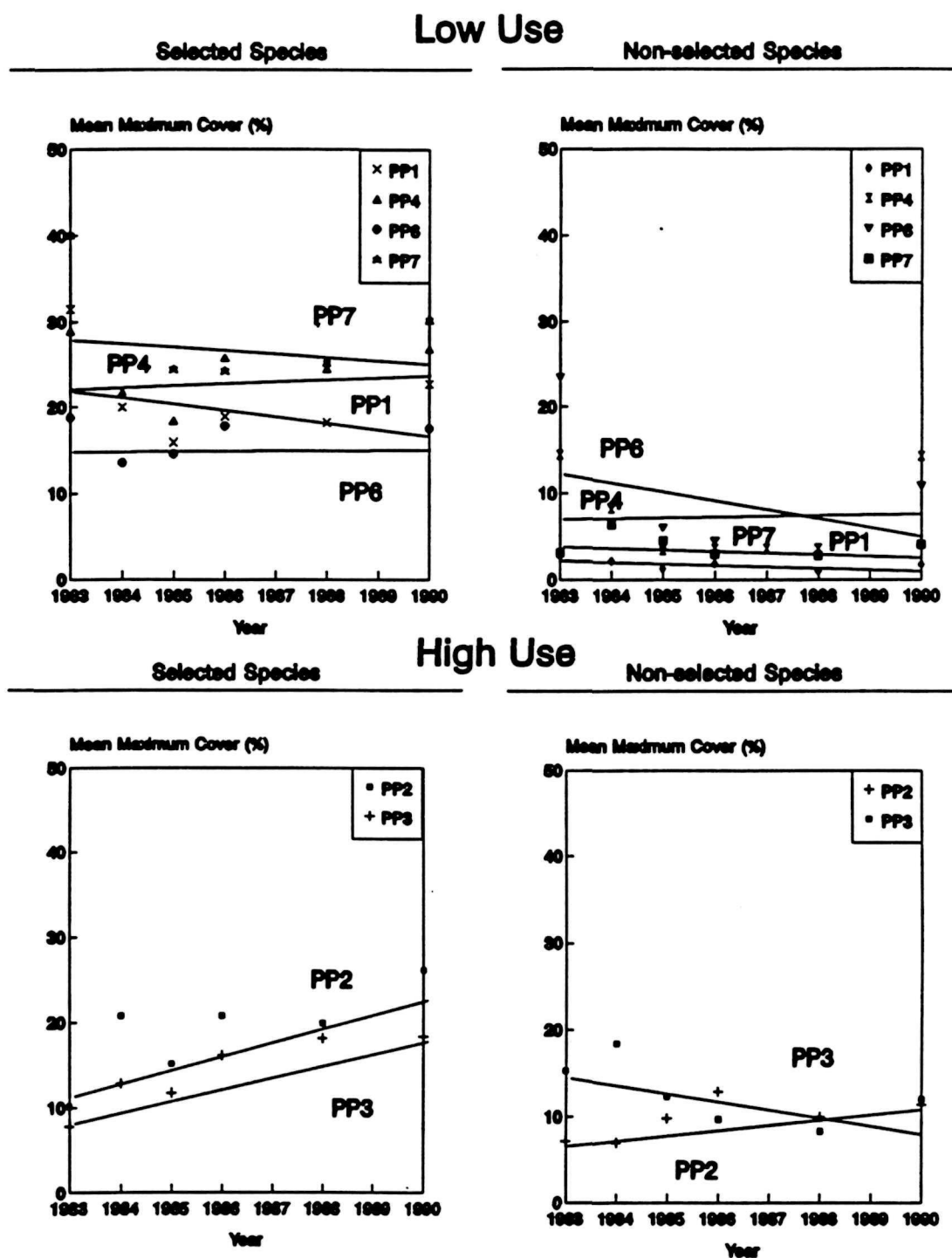


Figure 5-4 Regression of mean plant cover over time for selected and non-selected species in low and high goat use permanent plots on Klahhane Ridge.

Table 5-3. Mean cover of selected and non-selected plant species and total plant cover in Klahhane permanent plots by level of goat use. The trend of cover through time is described as the regression of cover on year with slope b . Correlations coefficients (r) of cover with precipitation (ppt) and goat density (dens) are also given.

	Plot #	Mean Cover (%)					Slope b	r with:	
		1983	1984	1985	1990	1992		ppt	dens
LOW GOAT USE									
Selected	P1	0.0	0.0	0.0	0.0	0.0	0.00	-	-
	P3	8.8	7.7	8.6	7.5	9.3	0.04	-0.37	0.17
Non-selected	P1	7.6	8.3	8.0	7.3	7.9	-0.03	-0.81	-0.58
	P3	8.8	9.6	9.5	6.1	9.8	-0.11	0.85	0.18
Total	P1	19.7	17.1	22.7	16.6	18.3	-0.26	0.04	0.16
	P3	57.9	49.7	59.3	45.0	46.1	-1.48	-0.07	0.62
HIGH GOAT USE									
Selected	P2	7.6	5.6	9.5	9.6	11.3	0.52	0.41	-0.57
	P4	23.3	22.8	28.8	27.4	30.3	0.77	0.04	-0.75
	P7	1.8	1.9	2.0	2.0	2.3	0.05	-0.07	-0.75
Non-selected	P2	45.5	45.6	44.9	27.5	33.2	-2.18	-0.56	0.66
	P4	18.1	15.0	9.6	7.2	11.2	-0.86	-0.68	0.89
	P7	8.4	8.3	9.4	6.8	9.2	-0.03	-0.58	0.05
Total	P2	60.4	59.9	66.9	44.2	51.6	-1.92	-0.43	0.45
	P4	48.6	43.9	46.7	39.0	46.6	-0.43	-0.57	0.57
	P7	17.2	17.7	18.9	19.5	22.0	0.52	0.06	0.48

Probability that groups represent random selections (critical value = 0.10):

Comparison:

High Use, Selected	vs.	High Use, Non-selected	0.0970	n.s.	0.0188
High Use, Selected	vs.	High Use, Total Cover	0.0482	n.s.	0.0603
High Use, Non-selected	vs.	Low Use, Non-selected	n.s.	n.s.	n.s.
High Use, Total Cover	vs.	Low Use, Total Cover	n.s.	n.s.	n.s.

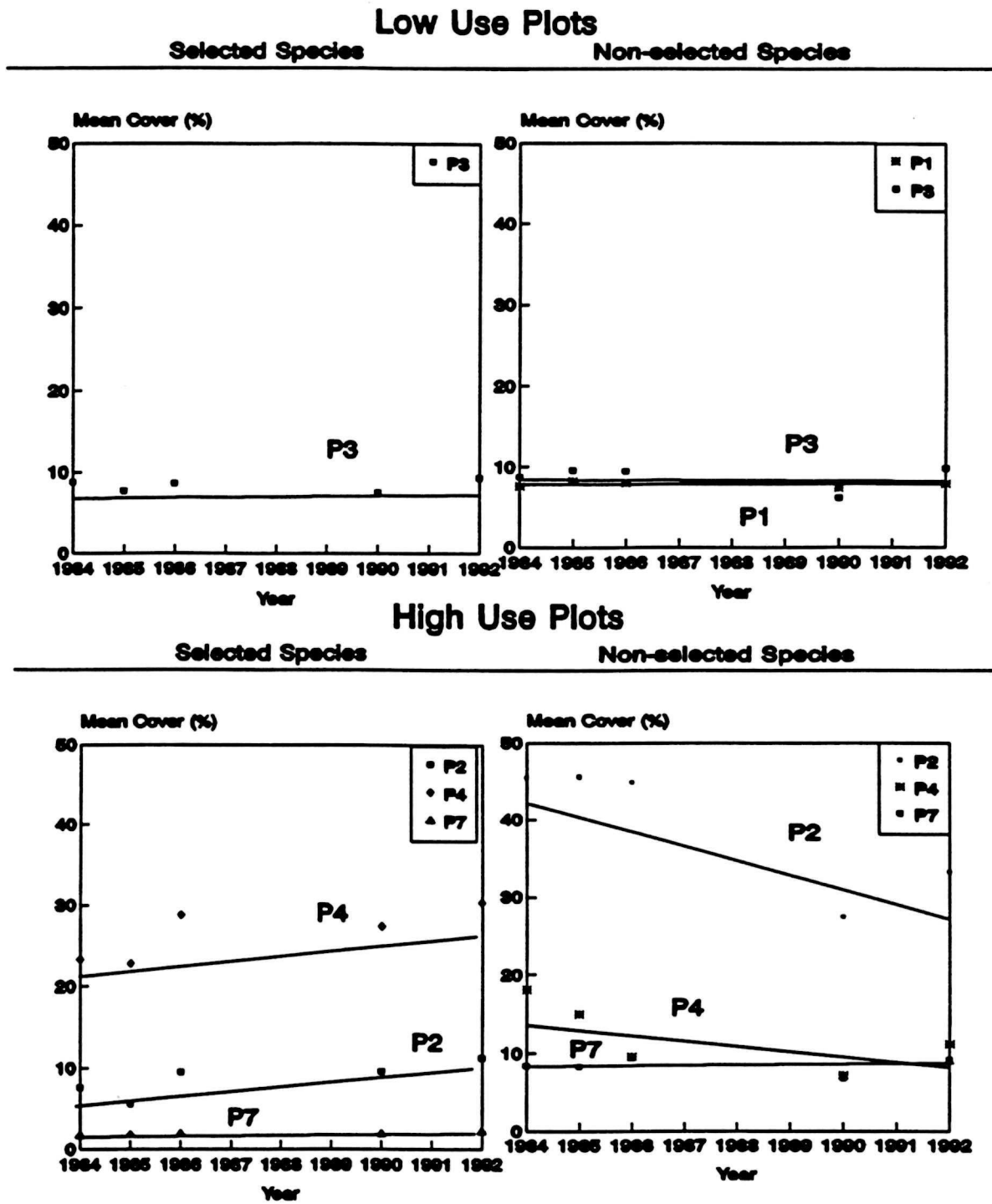


Figure 5-5 Regression of mean plant cover over time for selected and non-selected species in low and high goat use permanent plots on Mount Dana.

Table 5-4. Mean cover of species expected to recover or not recover and total plant cover in Avalanche Canyon permanent plots by declining or stable/increasing level of goat use. The trend of cover through time is described as the regression of cover on year with slope b . Correlations coefficients (r) of cover with precipitation (ppt) is also given. Correlations with goat density were not possible.

	Plot #	Mean Cover (%)					Slope b	r with ppt
		1988	1989	1990	1991	1992		
DECLINING GOAT USE								
Recover	P1	3.7	6.5	6.4	7.9	6.2	0.64	0.83
	P2	12.7	21.8	22.7	29.5	23.9	3.01	0.80
No Recover	P1	7.0	11.5	13.2	13.3	8.0	0.38	0.89
	P2	0.8	2.2	1.9	1.2	1.8	0.10	0.02
Total Cover	P1	33.4	41.4	41.2	51.0	38.7	2.02	0.95
	P2	32.7	60.8	57.6	66.2	63.4	6.68	0.61
STABLE/INCREASING GOAT USE								
Recover	P3	5.7	12.9	17.3	15.7	19.3	3.00	0.38
	P4	8.2	15.5	16.5	14.5	9.1	0.08	0.71
	P5	1.2	3.6	3.5	4.6	4.4	0.74	0.60
	P6	12.3	17.5	17.5	13.5	15.5	0.24	0.06
No Recover	P3	5.8	10.6	13.0	15.7	17.6	2.87	0.43
	P4	18.6	41.5	38.1	38.5	32.5	2.48	0.65
	P5	3.1	8.6	7.6	13.3	7.3	1.31	0.90
	P6	2.9	4.8	7.6	6.5	8.7	1.33	0.16
Total Cover	P3	30.9	52.6	56.5	56.4	59.8	6.16	0.50
	P4	55.6	81.8	79.8	85.7	75.3	4.77	0.76
	P5	20.7	36.1	34.5	39.5	34.6	3.12	0.72
	P6	18.1	28.6	28.9	26.6	29.6	2.10	0.35

Probability that groups represent random selections (critical value = 0.10):

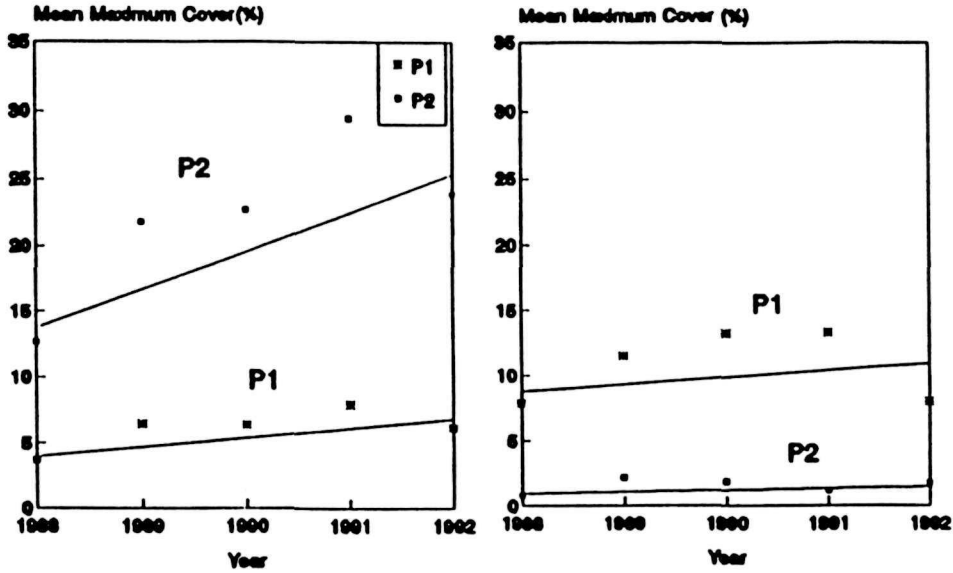
Comparisons:

Dec. Use, Recover	vs.	Dec. Use No Recover	0.1667*	n.s.
Dec. Use, Recover	vs.	Dec. Use Total	n.s.	n.s.
Dec. Use, Recover	vs.	St./Inc. Use, Recover	n.s.	n.s.
Dec. Use, No Recover	vs.	St./Inc. Use, No Recover	0.1667*	n.s.
Dec. Use, Total cover	vs.	St./Inc. Use, Total	n.s.	n.s.
St./Inc. Use, Recover	vs.	St./Inc. Use, No Recover	n.s.	n.s.

Decreasing Use

Species expected to Recover

Species not expected to Recover



Stable or Increasing Use

Species expected to Recover

Species not expected to Recover

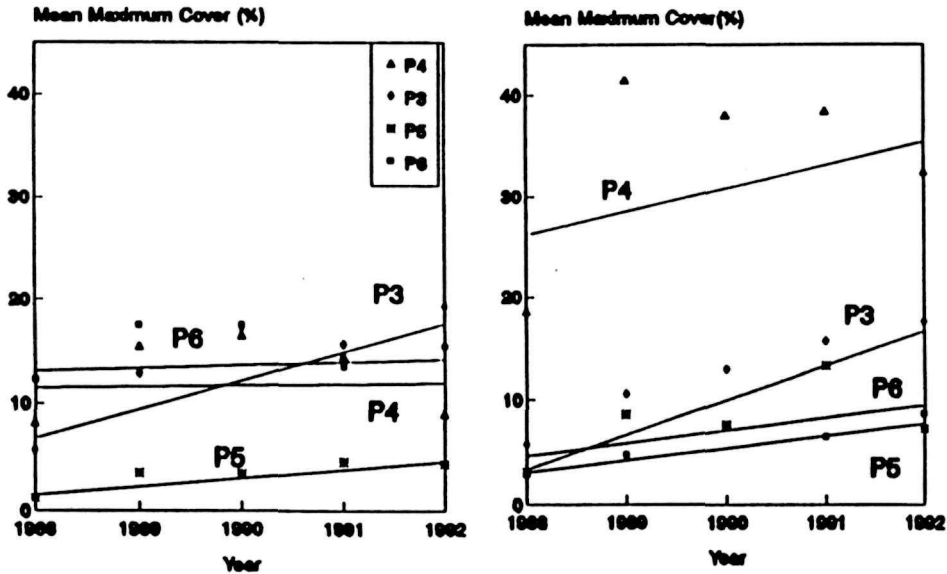


Figure 5-6. Regression of mean maximum plant cover over time for species expected to recover and species not expected to recover in plots with decreasing and stable/increasing goat use permanent plots in Avalanche Canyon.

use plots with goat density ($p=0.267$).

Yearly goat density estimates were also available for Mount Dana where selected species cover was negatively correlated with goat density in high use plots; these coefficients were significantly different from the positive correlation between goat density and non-selected species ($p=0.0188$) or total plant cover ($p=0.0603$).

Goat density estimates in the Avalanche Canyon area (1983, 1990) did not correspond with years of vegetation sampling (1988-92) so the association between goat density and plant cover could not be determined.

Vegetation Change in Relation to Precipitation

Klahhane Ridge vegetation data showed higher correlation coefficients between plant cover and precipitation in low use plots than in high use plots, but the difference between them was not significant ($p=0.13$; Table 5-2).

Correlations between precipitation and cover were uninformative at Mount Dana perhaps because summer precipitation at the Hoh River did not reflect of growing season quality for this site. Percent cover declined substantially in 1990 even though this year had the highest seasonal rainfall of any during the study. Cover losses occurred mainly in low-growing wintergreen shrub species. The appearance of the foliage on *Phlox diffusa* and *Phyllodoce empetrifomis* in 1990 suggested that winter desiccation occurred sometime between 1986 and 1990 and caused the decline in total plant cover. Dead leaves on these two species were similar to the desiccated leaves observed on trees in the north end of the park during low snow pack years (Schreiner, pers. obs.).

Avalanche Canyon plant cover had relatively high correlation coefficients with precipitation in all cover categories (Table 5-4). There were no significant differences between species groups or between decreasing and stable/increasing use plots.

Effect of Goat Removal on Community Structure

Festuca idahoensis and *Achillea millefolium* are major components of the plant communities at Klahhane Ridge. They have been shown to have a competitive relationship mediated by herbivory. That is, *A. millefolium* dominated when *F. idahoensis* is grazed and vice versa (del Moral 1985). Our study showed that *F. idahoensis* increased in plots where goat use was initially high in the two major

plant communities of Klahhane Ridge (Table 5-5; Fig. 5-7). This response was significantly different from the response of *F. idahoensis* in low use plots ($p=0.0667$; Table 5-5). As goat densities were reduced, *A. millefolium* decreased in high goat use plots but not in low use plots ($p=0.0667$, high versus low; Fig. 5-7).

A. millefolium is a ruderal species (i.e. disturbance-oriented), favored by goat herbivory (Pfitsch 1981, Reid 1983). Hence, it initially had higher cover in high use plots (9.0%) than low (2.1%). In addition, cover of *A. millefolium* was positively correlated with goat density in high use plots, which differed from correlations in low use plots ($p=0.1667^*$; Table 5-5). This contrasts with the negative relationship between *F. idahoensis* cover and goat density in high use plots. Correlation coefficients between *F. idahoensis* cover and goat density in high vs. low use plots were significantly different ($p=0.0667$). There were no significant associations with precipitation, although correlation coefficients tended to be higher in low use plots (Table 5-5).

The relative abundance of different plant species in Klahhane Ridge permanent plots changed over time in high use plots but not in low use plots (Fig. 5-8). *Achillea millefolium* dominated PP 2 (high use) with ~10% cover in 1983 while *Cirsium edule* and *Phlox diffusa* codominated with about 6% cover. By 1990 *Cirsium* and *Phlox* shared dominance (~9% cover) and *Festuca idahoensis* had ~7% cover; *Achillea* had decreased to about 6%. *Phlox diffusa* remained dominant from 1983-90 in PP3 (high use) but *Festuca* increased from 3% to nearly 12% by 1990. *Erigeron subtrinervis* increased from 3 to 10% while the ruderal *A. millefolium* decreased from ~7% to ~3% over the same time period. Relative cover relationships between species in the four low use plots remained essentially constant, with the exception of *Orthocarpus imbricatus*, an annual species. *O. imbricatus* tended to decrease from 1983-86 and increase from 1986-90. Plant community structure, composition and dominance relationships in the high plots appeared to be approaching that of the low use plots toward the end of the study period.

Several species at Mount Dana exhibited trends (Fig. 5-9). The early successional species *Lupinus latifolius* decreased by one-half or more in two plots (P2, P4). *Carex spectabilis* increased 5-8% in plot 2, while *Juncus parryi* cover increased from ~4 to ~8% in P4, and *Aster paucicapitatus* increased from less than 0.5% to 2% between 1984 and 1992 in P7; all three are selected mountain goat forage. Other trends included a reduction in cover of *Phlox diffusa* between 1986 and

Table 5-5. Cover of *Festuca idahoensis* (Fes ida) and *Achillea millefolium* (Ach mil) in Klahhane permanent plots. Plots represent two plant communities (phlox-fescue and unstable herb) experiencing high and low goat use. The trend through time is described by the regression of cover on year with slope b. Correlations (r) with precipitation (ppt) and goat density (dens) are also given.

	Plot #	Mean Cover (%)						Slope (b)	r with:	
		1983	1984	1985	1986	1988	1990		ppt	dens
PHLOX-FESCUE, HIGH USE										
Fes ida	P3	3.2	4.9	6.4	10.0	11.4	12.7	1.41	0.30	-0.87
Ach mil		8.2	7.4	4.8	3.6	2.3	3.3	-0.78	-0.11	0.92
UNSTABLE HERB, HIGH USE P2										
Fes ida		2.8	5.8	5.2	7.6	6.3	7.3	0.49	-0.12	-0.86
Ach mil		9.8	14.2	9.5	9.0	4.2	6.3	-0.99	-0.49	0.50
PHLOX-FESCUE, LOW USE										
Fes ida	P1	17.5	10.5	8.5	10.1	8.3	9.3	-0.83	0.19	0.91
	P4	15.8	9.2	11.3	13.9	12.4	14.4	0.16	0.57	0.19
	P6	11.0	7.5	9.8	11.3	-	8.8	-0.11	-0.08	0.25
	P7	32.3	15.8	18.3	17.5	18.3	20.8	-0.79	0.52	0.70
Ach mil	P1	-	1.0	3.0	1.2	1.2	2.1	0.03	0.39	-0.56
	P4	0.0	0.0	0.0	0.0	0.0	0.0	0.00	-	-
	P6	0.0	0.0	0.0	0.0	0.0	0.0	0.00	-	-
	P7	6.2	3.6	3.2	3.6	6.1	5.9	0.20	0.75	0.31

Probability that groups represent random selections (critical value = 0.10):

Comparisons:

High Use vs. Low Use, Fes ida

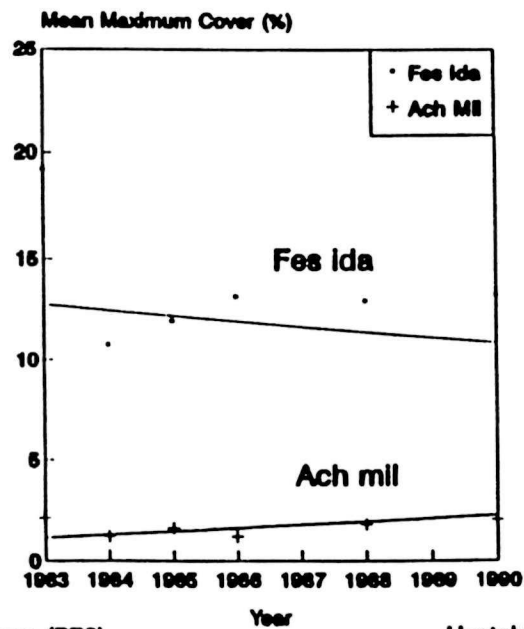
0.0667 n.s. 0.0667

High Use vs. Low Use, Ach mil

0.0667 n.s. 0.1667*

Low Use

Phlox-Fescue (P1,4,6,7)



High Use

Phlox-Fescue (PP3)

Unstable Herb (PP2)

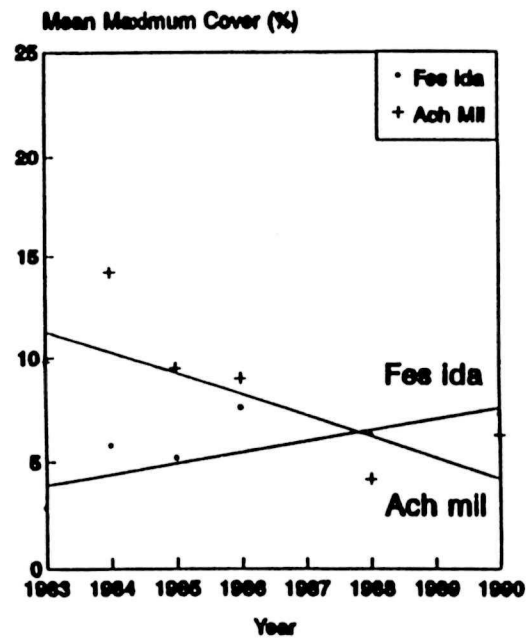
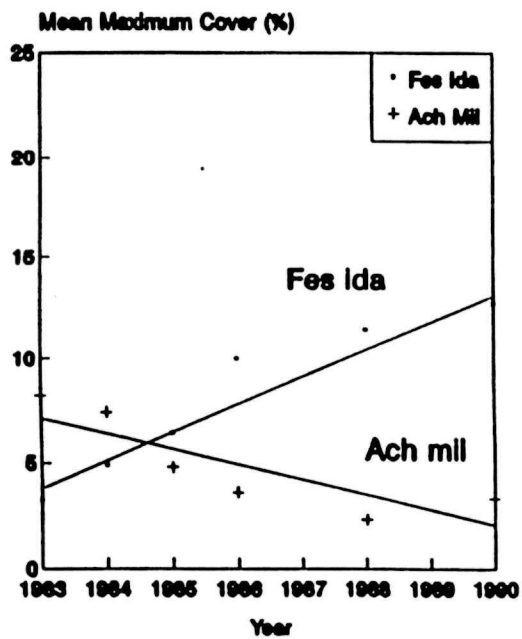


Figure 5-7. Regression of mean plant cover over time for *Festuca idahoensis* (Fes Ida) and *Achillea millefolium* (Ach Mil) by community type in low and high goat use permanent plots on Klahhane Ridge.

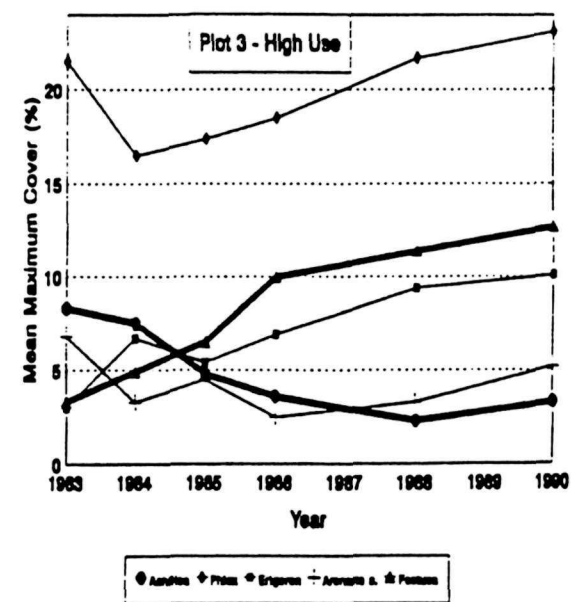
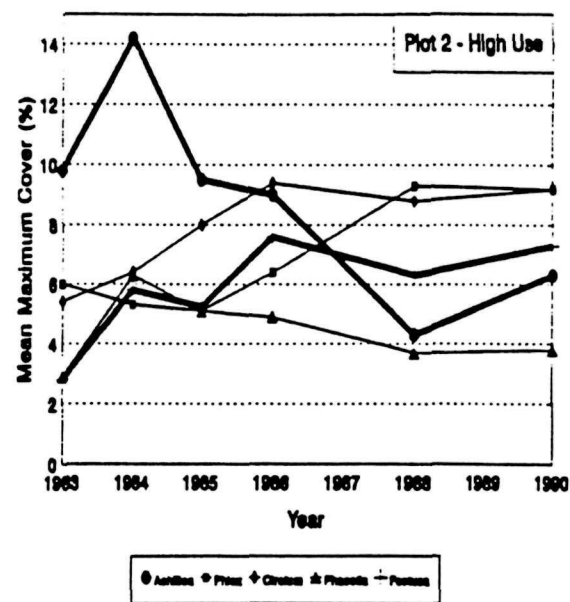
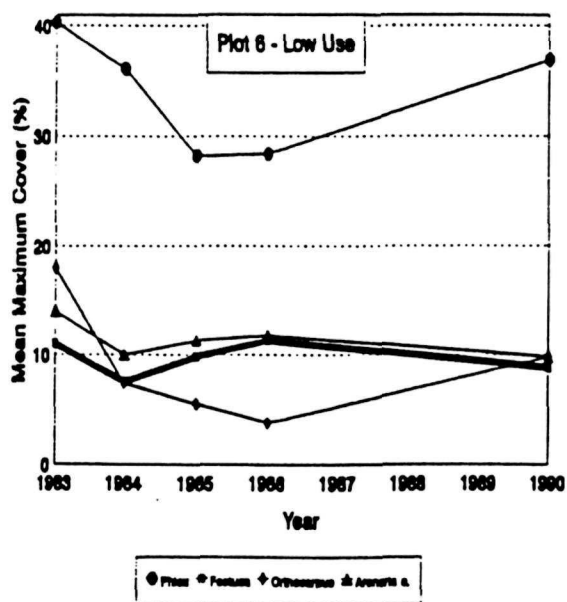
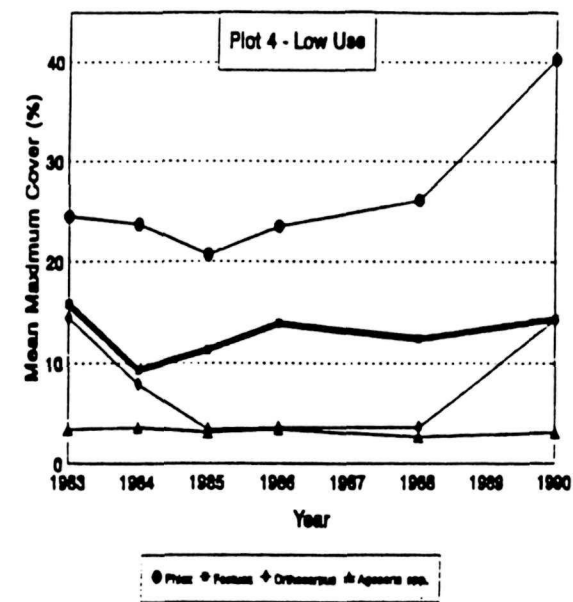
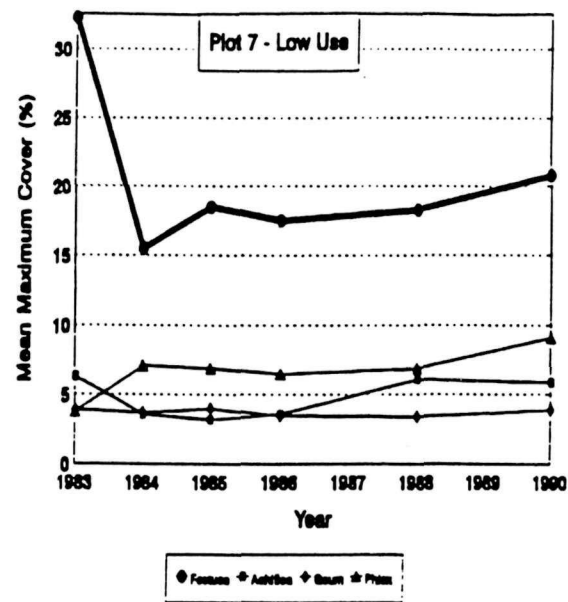
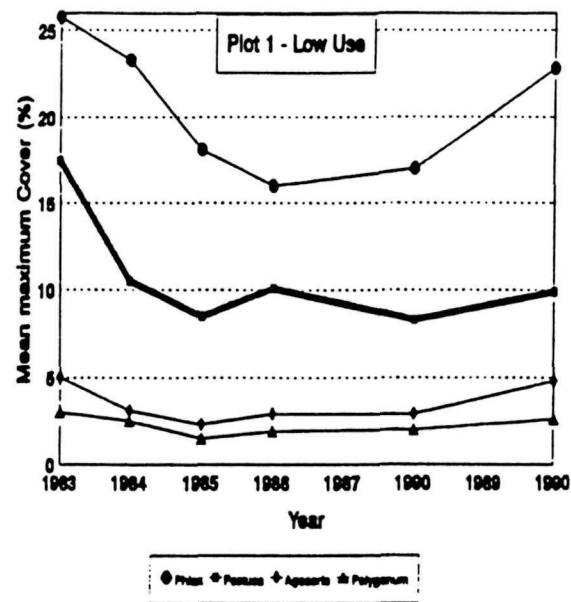


Figure 5-8. Mean maximum plant cover over time by species and goat use in permanent plots on Klahhane Ridge.

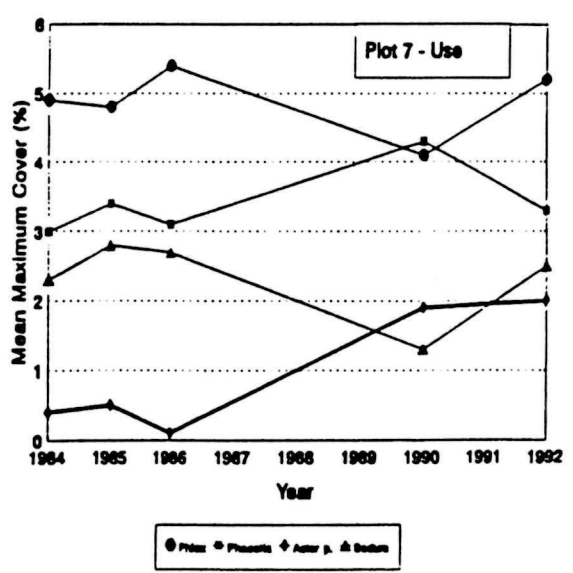
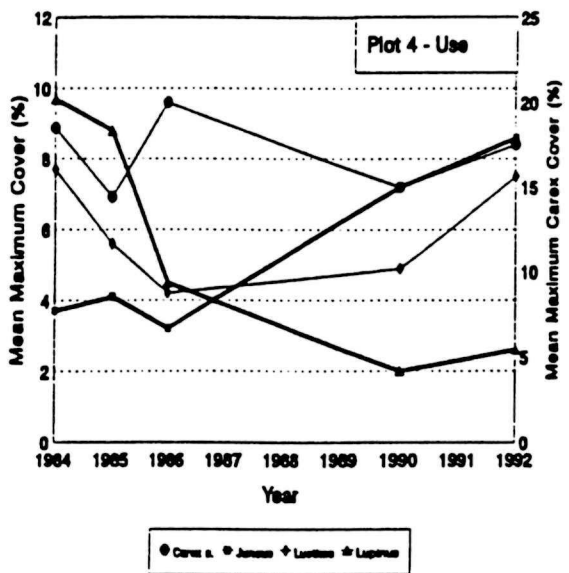
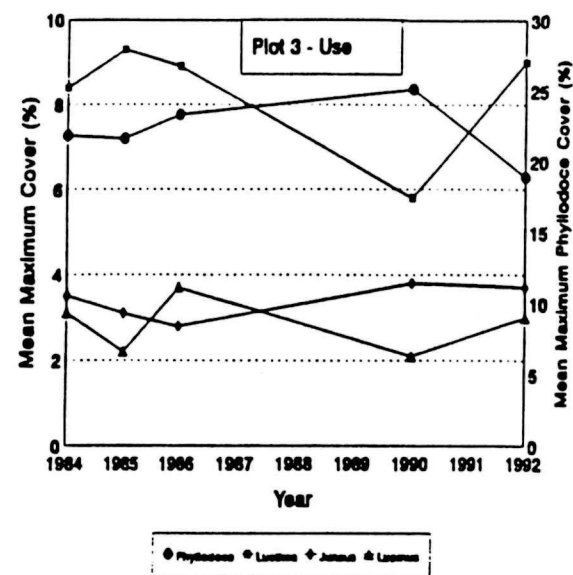
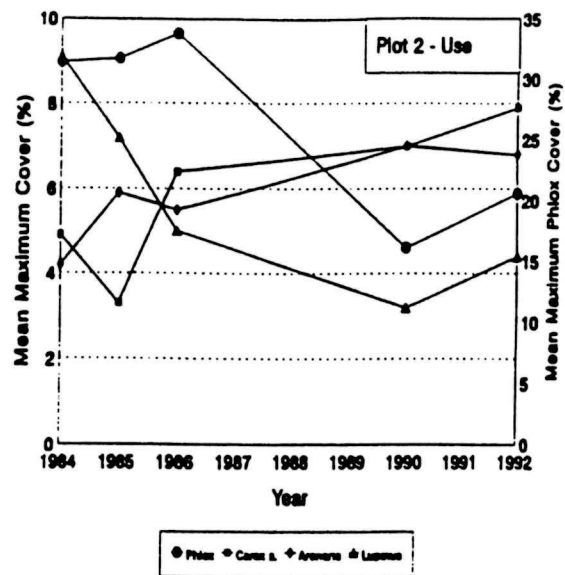
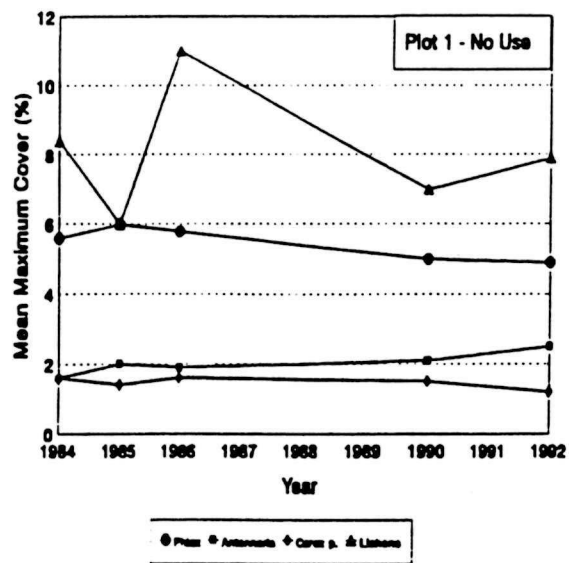


Figure 5-9. Mean plant cover over time by species and goat use in permanent plots on Mount Dana.

1990, and a decrease in cover of *Luetkea pectinata* from 1984-86 followed by an increase from 1986-92 in P4. Community dominance relationships changed in P4 where *Lupinus* codominated with *Carex spectabilis* in 1984 but *Juncus parryi* was codominant in 1992. A similar change in dominance occurred between *Lupinus latifolius* and *Carex spectabilis* in P2.

Plant community structure underwent few changes over time in Avalanche Canyon (Fig. 5-10). *Phlox diffusa* and *Phacelia hastata* dominated plots from 1988-92. Percent cover of *Cirsium edule* increased from 10-20% in one plot with declining use (P2) and increased from ~3% to over 10% in one plot with stable/increasing use (P3). Increases were also recorded for *Elmera racemosa* (P2,P3), *Achillea millefolium* (P5), *Phacelia hastata* (P4), and *Epilobium alpinum* (P6). Except for P3, relative cover of community constituents changed little. There was little consistency between species cover changes and whether or not plots experienced declining or stable/increasing levels of goat use.

INTERPRETATION

Mountain goat summer range is characterized by plant communities that are shaped by soil moisture availability and substrate stability (Belsky and del Moral 1982; Pfitsch and Bliss 1985, Chapter 3). Small groups of mountain goats (group size averages about 3 animals in the Olympics) moving through subalpine areas increase substrate disturbance as they forage on most plant communities, with their grazing concentrated on locally selected species. For example, goats spent 87% of their foraging time on open meadows and scree slopes on Klahhane Ridge during summer (Pfitsch and Bliss 1985). In addition, mountain goats exhibit wallowing behavior; wallows displace soil and kill vegetation; plant community composition also changes along wallow margins (Pfitsch 1981).

Permanent plots were established in three areas of Olympic National Park to examine the effects of mountain goats on subalpine vegetation. Each area had relatively high initial goat densities, but studies varied in sampling design and intensity. Klahhane Ridge represented the most intensive study area with the greatest number of plots, the greatest number of sample years, multiple samples/year, the most complete removal of mountain goats, and replicate plots in two plant communities. The record at Mount Dana is fairly long, spanning eight years, but samples were not replicated by community type, they were measure only once per year, and mountain goat density remained high for most of the study period. Plots at Avalanche Canyon had multiple observations per sample year but the record spans only five years, the mountain population was not reduced to the same extent as the other two areas, and goats were observed in plots throughout the study. Considering the strengths

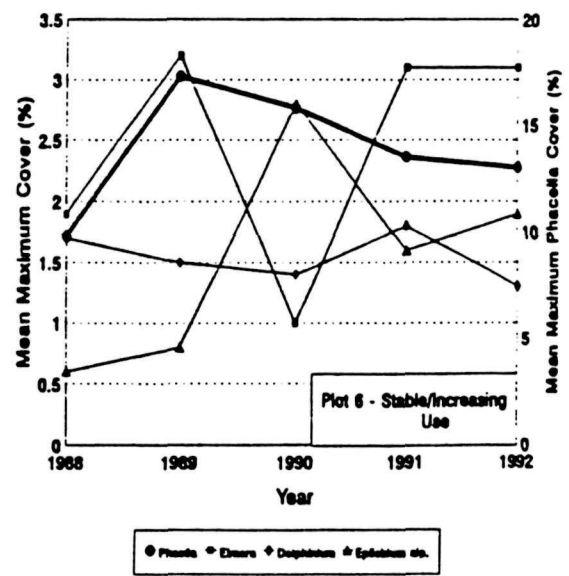
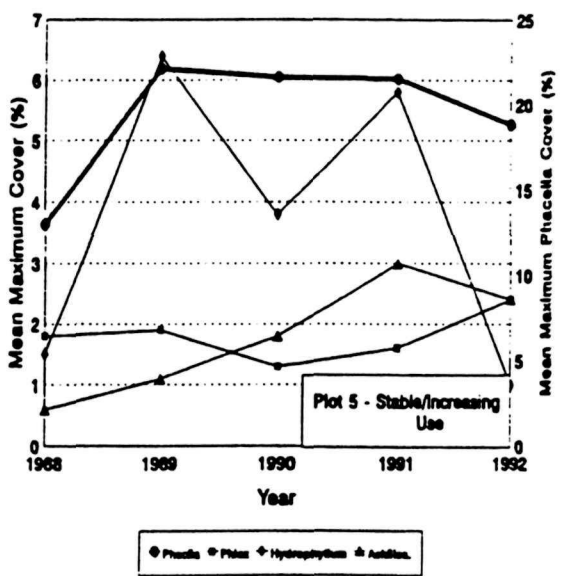
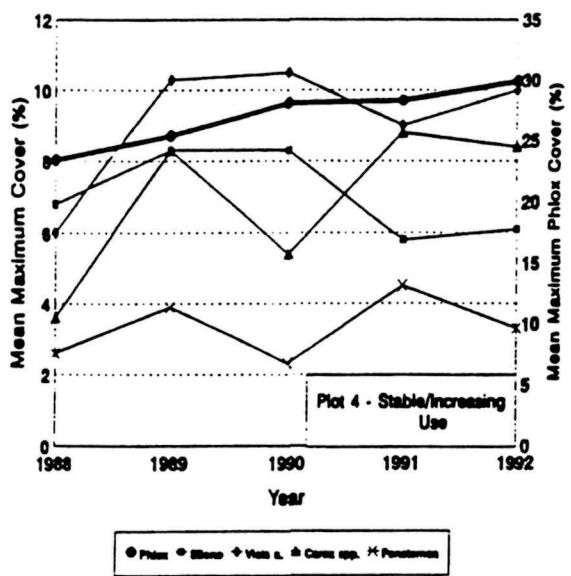
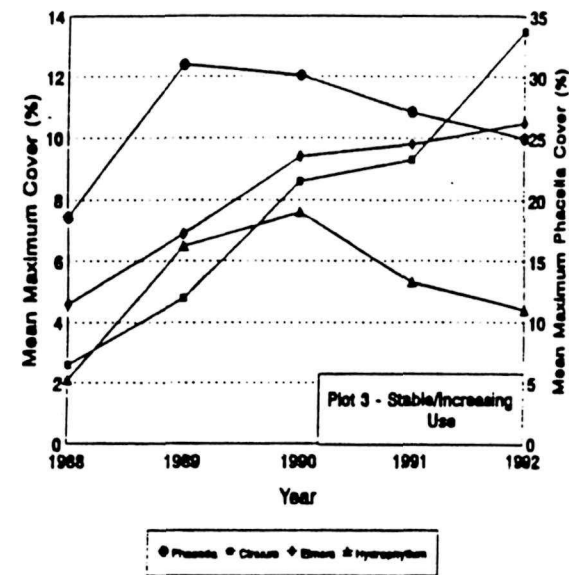
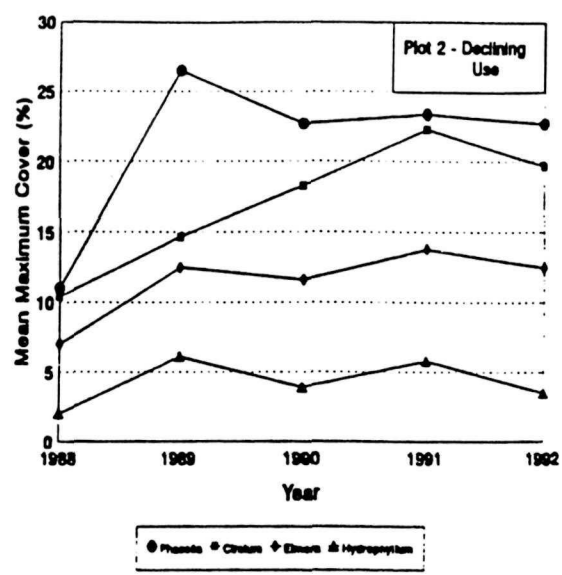
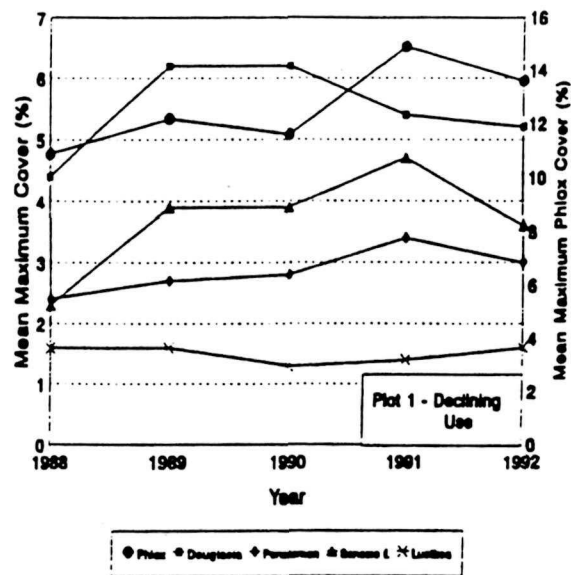


Figure 5-10. Mean maximum plant cover over time by species and goat use in Avalance Canyon.

and weaknesses of all areas, the strongest evidence for the effects of mountain goats on vegetation comes from plots at Klahhane Ridge.

Goat density had a strong negative association with total plant cover in high use plots at Klahhane Ridge. In contrast, total plant cover in low use plots at Klahhane was best explained by summer precipitation (i.e. growing conditions). There was no association between total cover and goat density at Mount Dana. In addition, there was no significant difference in the relationship between total cover and precipitation for declining-use versus stable/increasing use at Avalanche Canyon. The lack of association between goat density and total cover at Mount Dana or Avalanche Canyon may have resulted from goats being present late in the study.

While total plant cover may be relatively slow to respond to goat removals, community structure as reflected in species relative abundance responded more rapidly. Results from Klahhane Ridge showed that the removal of mountain goats resulted in an increase in the mean cover of selected species, particularly *Festuca idahoensis*. Goat herbivory is deemed responsible for a change in the competitive relationship between *F. idahoensis* and *Achillea millefolium*. The trend for selected species to increase as goat density declined was also observed at Mount Dana. Selected and non-selected species were not delineated at Avalanche Canyon, but species that were grazed only early in the study increased more than those grazed throughout the study.

The rate of selected and non-selected species responses in high goat use areas of Klahhane Ridge appeared to be partially a function of goat habitat preference. Increased cover of selected species occurred earliest in PP3 which was a site frequently used by goats when their population was high. However, few goats were observed on the site after 1984. By contrast, selected species in an unstable herb meadow (P2) which continued to be used by goats at least through 1986 increased cover at a later date, presumably because a lower goat population density was required before use of that plot was affected. This illustrates the complexity of herbivore-vegetation relationships where the response of vegetation depended on both habitat selection and density of the herbivore.

Vegetation in mountain goat summer range responded to reductions in mountain goat density in three study areas of Olympic National Park. The null hypothesis that plant community structure would not respond to changes in mountain goat density was rejected. Moreover, the effects of goats on vegetation have been demonstrated on what was largely summer range where resources (i.e. plants) were least likely to limit the population (Pfitch and Bliss 1985, Houston and Stevens 1988). Goat

effects on winter range, especially plant communities on cliffs and rock outcrops, could have been even more dramatic. Winter ranges were not sampled here because they were poorly defined and extremely dangerous to sample.

CHAPTER 6:

RARE PLANTS IN MOUNTAIN GOAT SUMMER RANGE

INTRODUCTION

The Washington State Natural Heritage Program (WNHP) lists 395 vascular plant species and varieties as rare in Washington State (WNHP 1990), 106 (27%) of these occur on the Olympic Peninsula, an area representing less than 8% (13,800 km²) of the surface area of the State. Olympic National Park has an even higher concentration of these plants with 77 (19%) species on just over 2% (3,700 km²) of the State. Rare plants are an important natural resource that are expected to provide answers to biogeographical and general evolutionary questions (e.g. Stebbins and Major 1968, Karron 1989), and contain a valuable store of the genetic information that comprises global biodiversity. Rare plants contribute measurably to the biodiversity of the Olympic Peninsula by making up about 9% of the ~1200 native vascular flora.

Rarity is a more difficult concept to define than it may first appear. Rabinowitz (1981) delineates seven forms of rarity using a matrix of geographic range (wide or narrow), habitat tolerance (wide or narrow) and local population size (large or small). Harper (1981) recognized these attributes of rarity but also noted that time must be considered because common plants may become rare and rare plants may become common. The definition of rarity ultimately depends on the size of the geographic area under consideration and the perspective of the individual creating the definition.

Kruckeberg and Rabinowitz (1985) describe causes of rarity by observing that plants may become rare when they exhaust stores of genetic variability, or when local populations become genetically distinct through polyploidy or by reproductive isolation and evolution. Reproductive isolation may occur when plants occupy distinct habitat patches such as serpentine soils or sand dunes. Once a plant population becomes reproductively isolated, time, chance and natural selection may produce a new species. Rare plants of the Olympic Peninsula have become so through several of these processes. Some have a wide geographic range but are locally rare, some are reproductively isolated, and others have narrow habitat requirements. Species that occur only on the Olympic Peninsula (endemics) are of considerable interest to biologists and naturalists.

Endemic species are those that are found in only one geographic area. They may or may not be rare. Douglas-fir, for example, is endemic to western North America but can hardly be called rare. Narrow endemics, those found only in a small geographic area such as the Olympic Mountains, however, are often also rare (Kruckeberg and Rabinowitz 1985). Narrow endemics may be abundant locally but are quite rare when considered in a broader geographic context. At least thirteen vascular plant taxa found in the Olympics are narrow endemics. Eight are found only on the Olympic Peninsula and five are found only on the Peninsula and Vancouver Island (See Table 2-1).

The diversity of rare and endemic taxa on the Olympic Peninsula must relate to the isolation of a mountain range that contains diverse habitats. The formation of the Olympic Mountains 12-30 million years ago (Tabor 1975) provided an isolated mountain group for organisms to colonize and to later diverge into separate taxa. The mountains interact with weather systems to create a rain shadow across the Olympics; this in turn produces extremely wet and quite dry habitats in close proximity. Habitat diversity is increased further by elevations from sea level to more than 2400 meters which allow development of maritime climate-influenced communities and alpine communities - again in close proximity. In short, the Olympics contain suitable habitat for a diverse set of organisms, particularly plants. Additionally, it is likely that several of the rare taxa found in the Olympics once had broader distributions and persisted through glacial periods in the Olympics because of this diversity of habitats (Chapter 2).

Concern for the rare plant flora of the Olympics resulted from the discovery that some endemic plant taxa were consumed by introduced mountain goats. Pike (1981) found that three endemics exhibited increased standing crop when they were protected from goats and Houston et al. (1984) detected fragments of the endemic *Campanula piperi* in goat fecal samples. The *Campanula* comprised 0.4% an 0.6% of mountain goat fecal samples from January-March and August-September, respectively. That this species was detected at all in goat diets was remarkable given that the plant occurs with extremely low cover. Additionally, direct observations and permanent plots indicated that goats consumed and sometimes wallowed on the endemic *Astragalus australis* var. *olympicus* (Chapter 7).

The following investigation was conducted to determine the degree of overlap between mountain goat and rare plant habitats and to provide a general test of the null hypothesis that mountain goats pose no threat to the long-term persistence of rare plants in Olympic National Park.

METHODS

Our investigation consisted of: 1) determining which WNHP-listed taxa occurred on the Olympic Peninsula, 2) determining if early "recon" plots contained in WNHP plants, 3) conducting recon plot surveys for rare plants in high elevation areas (1988-90), and 4) examining permanent plot data for the presence of any WNHP plants. We based our searches on the 1990 list produced by the Washington Natural Heritage Program (WNHP 1990).

Distribution

The general distribution and abundance of WNHP-listed plants was determined using elevation and location data from three primary sources: 1) ONP herbarium collections, 2) "recon" plots (Chapter 3) and 3) detailed plant location records compiled during preparation of the Catalog of Vascular Plants of the Olympic Peninsula (Buckingham and Tisch 1979) and maintained by the senior author. An updated catalog is in preparation in collaboration with ONP; records through the 1992 field season were employed. Information used for preparation of the catalog included, but was not limited to the historical records of Henderson (1892), Piper (1906), Jones (1936) and searches of numerous herbaria, including the University of Washington, Washington State University, Western Washington University, Saint Martins College, Pacific Lutheran University, Peninsula College and the British Columbia Provincial Museum in Canada.

Goat - Rare Plant Relationships

Reconnaissance plots were established to describe plant communities and herbivore use (Chapter 3). Plots established from 1981-86 were placed in areas of high and low goat use to describe plant communities. About 75 plots were established from 1985-86 to describe *Astragalus australis* var. *olympicus* communities. From 1988-90, 84 plots were located in goat summer range not previously sampled at sites with a high probability of finding rare plants, based on previous records. Details of siting and measuring variables in reconnaissance plots are described in Chapters 3 and 4.

Additionally, examination of the species lists for the three permanent plot study areas (Klahhane, Dana, Avalanche Canyon) revealed that some rare plants occurred. Plant cover over time is presented here; methods are detailed in Chapter 5.

RESULTS

Rare plants listed by WNHP occur throughout the Olympic Peninsula (Fig. 6-1). A total of 106 taxa were found with 77 known to occur within ONP. Most of these taxa appear to be quite rare on the Peninsula with 30 known from only 1 area, and 12 from 2 areas. Sixty-six percent (71) of the taxa were reported from five or fewer sites on the Olympic Peninsula.

Distribution

Even though WNHP plants occur at many locations on the Olympic Peninsula, some areas have particularly high diversity (Fig. 6-2). At Lake Ozette in the northwest corner of the Peninsula, for example, 14 taxa occur. High concentrations of WNHP plants also occur in the north and northeastern parts of the Olympic Mountains at Mount Angeles (22), Elk Mountain (14), Blue Mountain (17), Royal Basin (16), Charlia Lakes (14), and in the Buckhorn/Iron Mountain region (26).

The distribution of WNHP-listed plants by elevation is bimodal (Fig. 6-3). Average reported elevations of WNHP plants were 305 m (n=38), 305-1520 m (n=27), and greater than 1520 m (n=37). Four taxa were reported without elevation data (e.g. "Olympic Mountains", Piper).

Thirty-three (43%) of the 77 WNHP taxa found in Olympic National Park occur at an average elevation that is within mountain goat summer range (i.e. above 1520 m, Table 6-1). Nine taxa are known from only one park location and a total of 17 occur 5 or fewer times in the park. The only known Olympic Peninsula locations of four taxa are within the park (*Botrychium lunaria*, *Douglasia nivalis* var. *dentata*, *Salix brachycarpa* ssp. *brachycarpa* var. *brachycarpa*, *Dryas drummondii* var. *drummondii*).

All of the Olympic Peninsula endemic vascular plant taxa (n=8) are listed as rare by WNHP (1990). Seven of eight endemics have an average elevation from 1500 - 1870 m indicating they occur generally at high elevations (Fig. 6-3). One endemic, *Erigeron peregrinus* ssp. *peregrinus* var. *thompsonii* occurs below 100 m elevation (Appendix C). Additionally, three of the four Olympic Peninsula/Vancouver Island endemic taxa have an average elevation of more than 1520 m.

Goat - Rare Plant Relationships

Goat censuses show that their summer range and rare plant distribution overlap (Fig. 6-4). Evidence

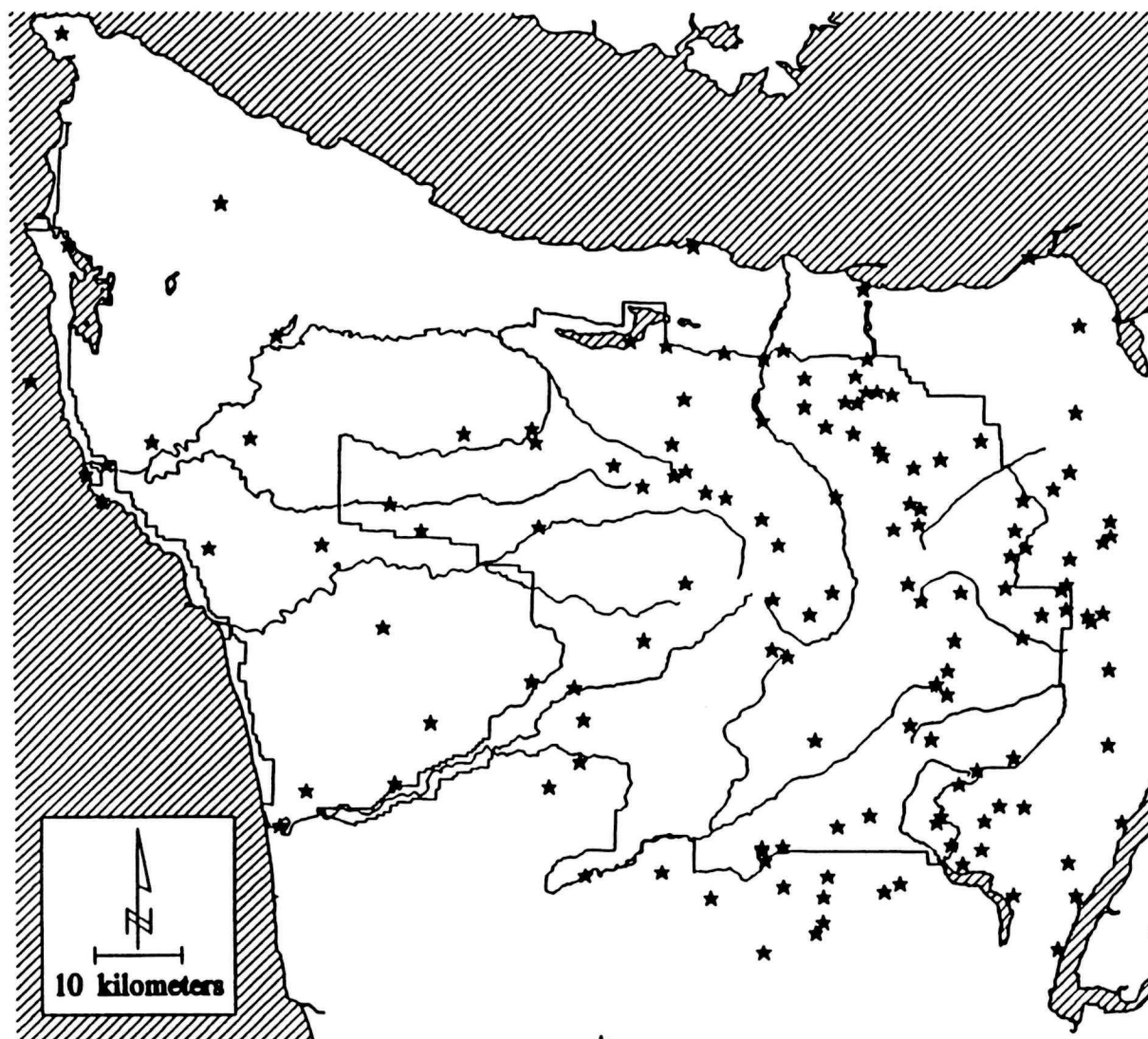


Figure 6-1. Known Olympic Peninsula locations of vascular plant taxa listed by the Washington Natural Heritage Program (WNHP 1990).

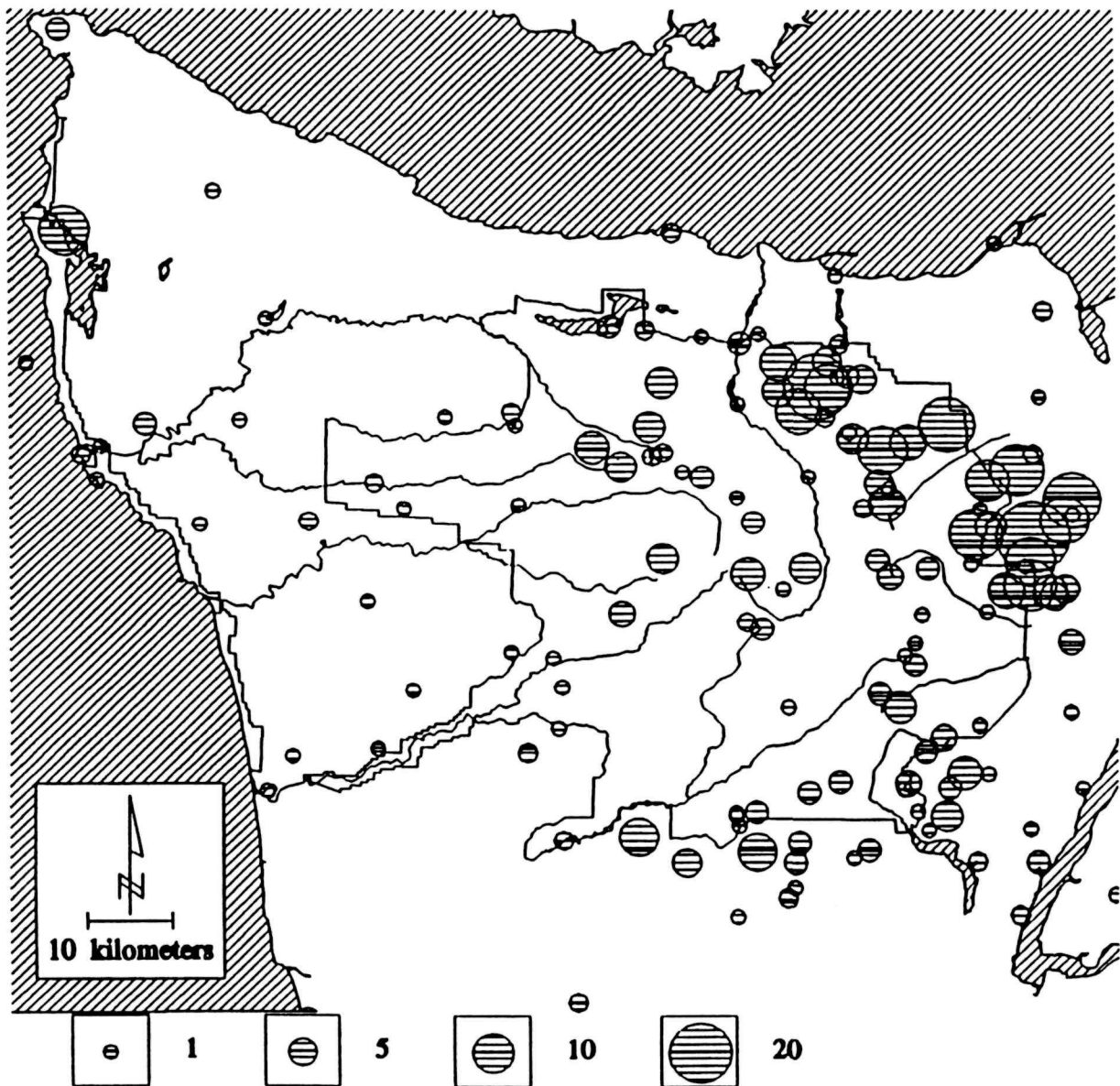
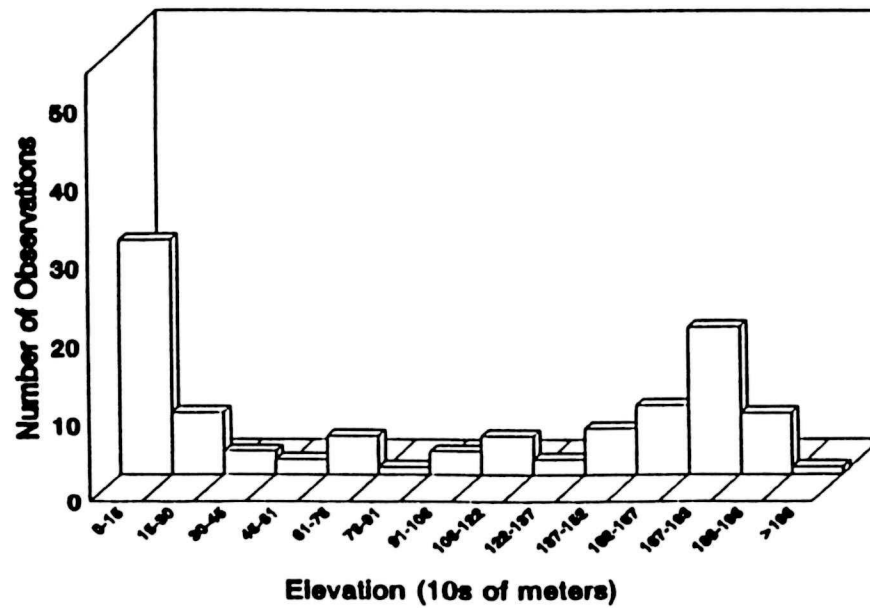


Figure 6-2. Number of WNIIP-listed vascular taxa found at collection areas on the Olympic Peninsula. Size of the circles is proportional to the number of plant taxa found at each site.

Elevation Distribution of WNHP-listed taxa



Elevation Distribution of Olympic Peninsula Endemics

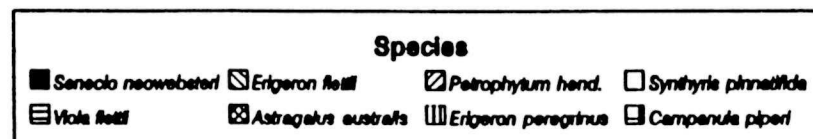
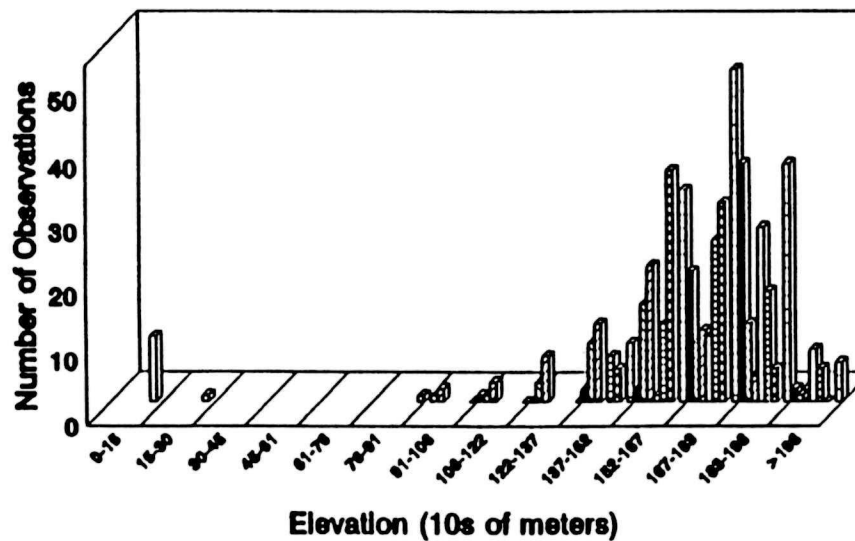


Figure 6-3. Elevation distribution of rare plants on the Olympic Peninsula.
Top - Washington Natural Heritage Program taxa; Bottom - Endemic taxa.

Table 6-1. Olympic Peninsula WNHP-listed vascular plant taxa with an average elevation within mountain goat summer range. WNHP (1990) categories: (2) - Threatened, (3) - Sensitive, (4) - Monitor, and (4a) - Monitor for listing. Total = Number of Areas where the plant is known to occur on the Olympic Peninsula; Average = Average elevation (m); P = Number of known Olympic National Park locations; B = Number of known locations on the border with ONP, i.e. may or may not be in the park; O = Number of known locations outside ONP; U = Precise location unknown (e.g. "Clallam County").

Species [Species Code] (WNHP Status)	Total	Average Elevation	P	B	O	U
Species known from 5 or fewer locations in Olympic National Park						
<i>Botrychium lunaria</i> [BOLU] (3)	1	1768	1	0	0	0
<i>Douglasia nivalis</i> var. <i>dentata</i> [DONIDE] (4)	1	1829	1	0	0	0
<i>Salix brachycarpa</i> ssp. <i>brachycarpa</i> var. <i>brach</i> [SABRBR] (4)	1	1905	1	0	0	0
<i>Dryas drummondii</i> <i>drummondii</i> [DRDRDR] (3)	1	2057	1	0	0	0
<i>Pellaea breweri</i> [PEBR] (3)	2	1631	1	0	1	0
<i>Poa rupicola</i> [PORU] (4)	2	1846	1	0	1	0
<i>Botrychium pinnatum</i> [BOPI] (3)	3	1591	1	0	2	0
<i>Carex obtusata</i> [CAOBT] (3)	5	1800	1	0	4	0
<i>Zigadenus elegans</i> ssp. <i>elegans</i> [ZIELEL] (4a)	6	1795	1	0	5	0
<i>Poa suksdorfii</i> [POSU] (4)	3	1788	2	0	1	0
<i>Saxifraga debilis</i> [SADE] (3)	3	1798	2	0	1	0
<i>Erigeron flettii</i> [ERFL] (4)	19	1580	2	3	14	0
<i>Phlox hendersonii</i> [PHHE] (4)	10	1908	4	0	6	0
<i>Lloydia serotina</i> ssp. <i>serotina</i> [LLSESE] (4)	11	1676	4	0	7	0
<i>Astragalus australis</i> var. <i>olympicus</i> [ASAUOL] (2) ¹	5	1554	4	0	1	0
<i>Asplenium viride</i> [ASVI] (4)	8	1696	5	1	2	0
<i>Saxifraga tischii</i> [SATI] (4a) ²	8	1856	5	1	2	0
Species known from 6 or more locations in Olympic National Park						
<i>Oxytropis viscida</i> var. <i>viscida</i> [OXVIVI] (3)	6	1734	6	0	0	0
<i>Poa arctica</i> ssp. <i>grayana</i> [POARGR] (3)	8	1539	6	0	2	0
<i>Arnica nevadensis</i> [ARNE] (4)	10	1759	8	1	1	0
<i>Salix arctica</i> [SAARC] (4)	10	1789	8	0	2	0
<i>Poa paucispicula</i> [POPAU] (4)	10	1687	9	0	1	0
<i>Carex raynoldsii</i> [CARAY] (4)	11	1667	6	0	5	0
<i>Synthyris pinnatifida</i> var. <i>lanuginosa</i> [SYPILA] (3) ¹	14	1867	8	1	5	0
<i>Arnica rydbergii</i> [ARRY] (4)	16	1676	10	0	6	0
<i>Geum triflorum</i> var. <i>campanulatum</i> [GETRCA] (4)	18	1654	11	0	7	0
<i>Erigeron compositus</i> var. <i>discoides</i> [ERCODI] (4)	18	1784	13	0	0	5
<i>Senecio neowebsteri</i> [SENE] (4)	23	1824	16	1	6	0
<i>Orthocarpus imbricatus</i> [ORIM] (4)	24	1683	16	1	6	1
<i>Viola flettii</i> [VIFL] (4)	36	1751	19	3	13	1
<i>Petrophytum hendersonii</i> [PEHE] (4) ^{1,3}	46	1500	24	2	17	3
<i>Campanula piperi</i> [CAPI] (4)	47	1698	27	4	16	0
<i>Aster paucicapitatus</i> [ASPA] (4) ²	47	1574	34	1	11	1
<i>Pedicularis bracteosa</i> var. <i>atrosanguinea</i> [PEBRAT] (4) ^{2,4}	4	1547	4	0	0	0
Species that <u>may</u> occur in Olympic National Park						
<i>Senecio lugens</i> [SELU] (4)	8	1769	0	1	7	0
<i>Draba longipes</i> [DRLO] (3)	1	1890	0	1	0	0
Species not known to occur in Olympic National Park						
<i>Draba cana</i> [DRCA] (3)	1	1829	0	0	1	0
<i>Astragalus microcystis</i> [ASMI] (3)	2	1813	0	0	2	0

¹ Olympic Peninsula endemic.

² Olympic Peninsula-Vancouver Island endemic.

³ We list this species as a goat summer range plant because it occurs mainly on rocky outcrops.

⁴ Incomplete data

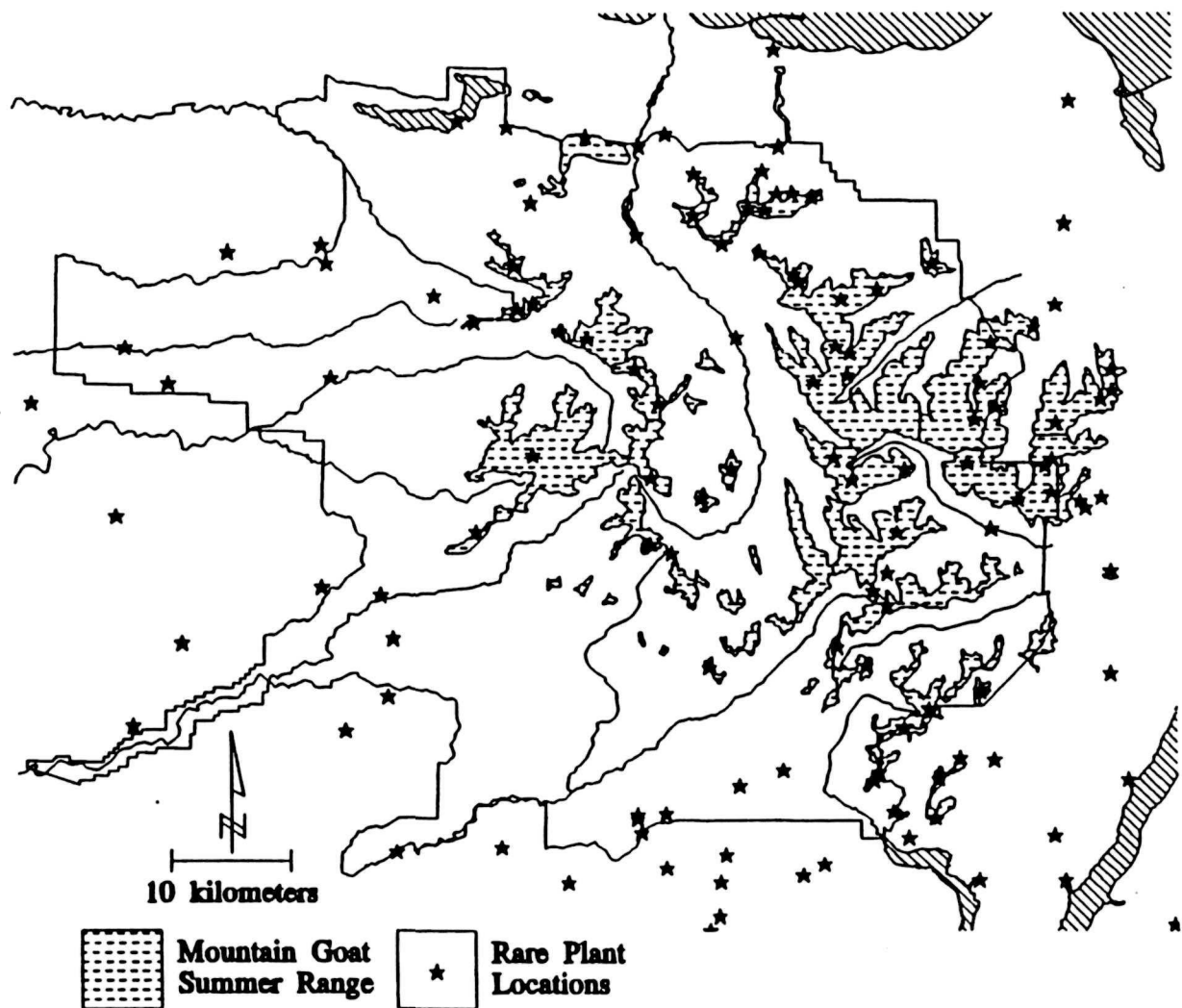


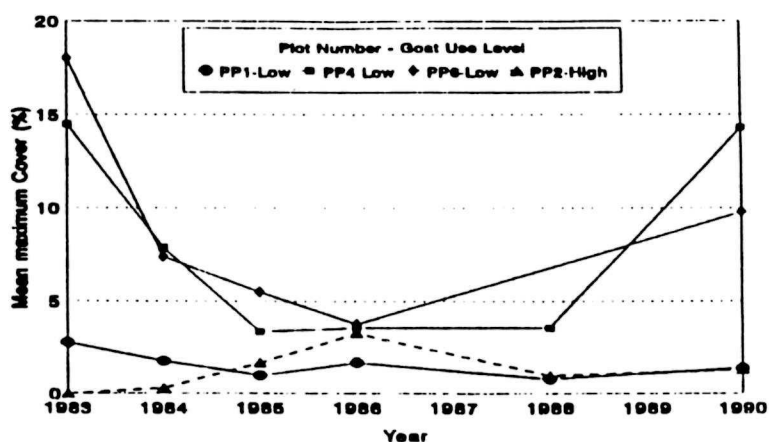
Figure 6-4. Known collection locations for WNHP-listed taxa in relation to mountain goat summer range on the Olympic Peninsula.

of mountain goat use was still visible in reconnaissance plots in 1988 and 1990 even though by 1990 the Peninsula goat population had decreased from an estimated 1175 ± 171 (SE) in 1983 to 389 ± 106 (SE) animals in 1990 (Houston et al. 1991a). All but one (Mount Steel/Mount Hopper where there were only two plots) of the twenty-two areas surveyed with recon plots contained rare plants; all exhibited evidence of mountain goats (Chapter 4). Specific relationships between mountain goats and rare plants were difficult to assess because few rare taxa occurred in either recon plots or permanent plots at Klahhane Ridge, Mount Dana, and Avalanche Canyon.

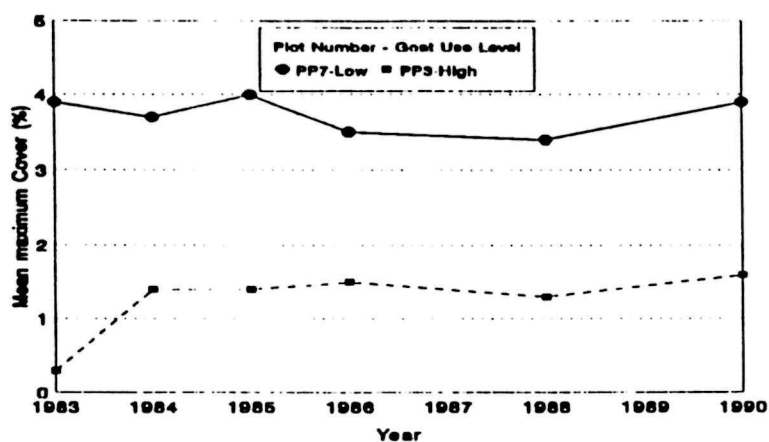
Permanent plots in the three areas where goat densities were reduced contained five rare plant taxa. Interactions between goats and the endemic *Viola flettii* and an unidentified *Botrychium* (possibly *B. lanceolatum*) could not be assessed because they occurred with low cover (0.1% or less) in Avalanche Canyon. Moreover, these taxa were not observed in the plots every year. *Orthocarpus imbricatus* at Klahhane Ridge (Fig. 6-5) decreased and then increased in two low goat use plots (PP4, PP6), remained constant in a third low use plot (PP1), and increased from 1983-86 and then decreased in a high use plot (PP2). It is not possible to determine if these fluctuations were in response to goat density. Percent cover of *Geum triflorum* fluctuated little in both a high and low goat use plots at Klahhane Ridge (Fig. 6-5) and appeared to be unresponsive to goat density. In contrast, *Aster paucicapitatus* (Fig. 6-5) appeared to respond at Mount Dana (P7), increasing from 0.4 to 2.0% cover as goat density was reduced, but no response was detected at Klahhane Ridge where cover increased slightly in a low use plot (PP1) and stayed relatively constant in a high use plot (PP2).

Sixteen plant taxa listed as rare by WNHP were present in recon plots (Table 6-2). Rare plants were not distributed evenly among high, medium and low goat density areas so an assessment of goat/rare plant interactions is problematical. The Olympic Peninsula endemic *Campanula piperi*, for example, occurred in 5, 33, and 17 recon plots in high, medium and low goat density areas, respectively and was not grazed. This may indicate either that *Campanula* was not-selected by goats or that there were not enough plots in high density areas to make an assessment. Other species with lower frequency (or did not occur) in high density compared to medium or low goat density areas included *Viola flettii*, *Geum triflorum* and *Oxytropis viscida*; no evidence of grazing was observed. Two species where there was less disparity between the number of occurrences in high, medium and low density areas, *Senecio neowebsteri* and *Orthocarpus imbricatus*, give some indication that goats grazed them, but low plant frequency and grazing frequency makes it impossible to be certain.

Mean Maximum Cover of *Orthocarpus imbricatus* on Klahhane Ridge



Mean Maximum Cover of *Geum triflorum* on Klahhane Ridge



Mean Cover of *Aster paucispitatus*, Klahhane Ridge (PP) and Mount Dana (MD)

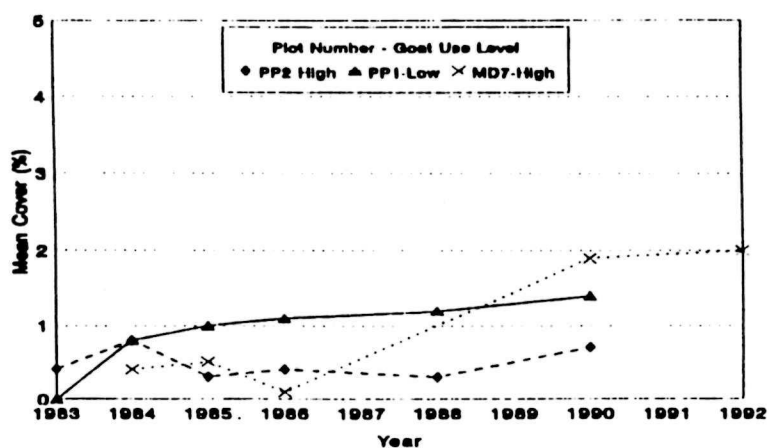


Figure 6-5. Mean plant cover of WNHP-listed taxa over time in low and high use permanent plots at Klahhane Ridge and Mount Dana.

Table 6-2. Average Grazing (AG), plant and grazing frequency, Species Relative Grazing Frequency (SRGF) of vascular plant taxa listed by the Washington Natural Heritage Program (WNHP 1990) in subalpine reconnaissance plots of Olympic National Park.

SPECIES	Average Grazing			Frequency (N)									SRGF			Ratios	
	(I)			Plant			Grazing										
	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L	H/L	M/L
<i>Aster paucicapitatus</i> ¹	4.7	1.6	0.1	77	25	25	33	14	1	42.9	56.0	4.0	10.7	14.0			
<i>Senecio newwebsteri</i> ²	0.2	T	0.7	5	6	15	1	2	2	20.0	33.3	13.3	1.5	2.5			
<i>Orthocarpus imbricatus</i>	T	0.0	0.0	9	8	11	2	0	0	22.2	0.0	0.0	=	0.0			
<i>Astragalus australis</i>		0.6			76			19		--	25.0	--	--	--			
<i>Pedicularis bracteosa</i> ¹	T			6			2			33.3	--	--	--	--			
<i>Petrophytum hendersonii</i>	T	0.0	0.0	8	1	3	1	0	0	12.5	0.0	0.0	=	0.0			
<i>Campanula piperi</i>	0.0	0.0	0.0	5	33	17	0	0	0	0.0	0.0	0.0	0.0	0.0			
<i>Geum triflorum</i>	0.0	0.0	0.0	1	8	6	0	0	0	0.0	0.0	0.0	0.0	0.0			
<i>Viola flettii</i>	0.0	0.0	0.0	1	8	12	0	0	0	0.0	0.0	0.0	0.0	0.0			
<i>Draba loncharpa</i>	0.0	0.0		1	1		0	0		0.0	0.0	--	--	--			
<i>Erigeron flettii</i>	0.0		0.0	2		1	0		0	0.0	--	0.0	0.0	--			
<i>Phlox hendersonii</i>			0.0			1			0	--	--	0.0	--	--			
<i>Botrychium lanceolatum</i>	0.0			1			0			0.0	--	--	--	--			
<i>Synthyris pinnatifida</i>		0.0	0.0		1	10		0	0	--	0.0	0.0	--	0.0			
<i>Polygonum newberryi</i>			0.4			9			4	--	--	44.4	--	--			
<i>Oxytropis viscida</i>		0.0	0.0		4	4		0	0	--	0.0	0.0	--	0.0			
<i>Claytonia lanceolata</i> ¹	0.2	0.0	0.0	48	1	4	9	0	0	18.8	0.0	0.0	=	--			
<i>Erigeron compositus</i> ³	T	T	0.0	3	44	29	1	1	0	33.3	2.3	0.0	=	=			

¹ Olympic Peninsula - Vancouver Island endemics.

² Olympic Peninsula endemic species are listed in bold.

³ One variety of these species is listed by WNHP - identity in recon plots is unknown.

Grazing on two endemic taxa appears to be attributable to mountain goats. The Olympic Peninsula/Vancouver Island endemic *Aster paucicapitatus* was grazed in 12 of the 18 recon plots where it occurred in Royal Basin, a medium goat density area, but was not grazed in the 21 low density area recon plots at Grand Pass. Since deer and marmot sign were encountered in both areas and goat sign was far more prevalent at Royal Basin than Grand Pass (See Table 4-1, page 29), goats are implicated as the herbivore responsible for the grazing (elk sign was not observed in either area). Additionally, *A. paucicapitatus* was one of 33 species considered a selected forage of mountain goats on a park-wide basis (Chapter 4). Grazing on *Astragalus australis* var. *olympicus*, a particularly rare endemic of the Olympic Peninsula, also appeared to be from mountain goats. This species was grazed in all three medium goat density areas where it occurred. The *Astragalus* did not occur in any low density areas but numerous goat wallows, tracks and pellet groups near the plots indicate that goats were most likely responsible for the grazing (Chapter 7).

INTERPRETATION

The bimodal elevation distribution of rare plants on the Olympic Peninsula suggests that these species exist in refugia from both modern and historical influences. Species that occur at low elevations are most "common" along lake shores, in bogs or other non-forested habitats (e.g. *Lycopodium inundatum* at Lake Ozette). Higher elevation species occur mostly above timberline in the subalpine and alpine zones. Both the low and high elevation habitats offer refugia from the coniferous forests that occur from sea level to the subalpine zone. Additionally, both the low elevation west-side habitats and the wind-swept ridges and rocky outcrops at high elevations appear to have remained free of ice during the two major advances of glaciers during the Fraser Glaciation (22,000 - 17,000 and 15,000 - 13,500 years B.P., Chapter 2). Modern distributions of rare taxa suggest these species exist in refugia from forests, past glacial events, or both.

Mountain goats occupy a different niche than other herbivores on the Olympic Peninsula, one which overlaps the distribution of many rare taxa and seven of eight Peninsula endemics. Subalpine and alpine environments are stressful to plants. Growth and reproduction must be accomplished in a short growing season often on unstable substrates (Bliss 1971, Bell and Bliss 1973, Belsky and del Moral 1982). Grazing and trampling by mountain goats alters plant growth, community structure, and interspecific competitive relationships through removal of herbage and increased levels of disturbance (Pfitsch 1981, Reid 1983, Pfitsch and Bliss 1985, Chapters 4 and 5). Also, goat grooming behavior

involves wallowing which eliminates vegetation, displaces soil, and changes community composition (Stevens 1979, Pfitsch et al. 1983, Schreiner 1987, Chapter 5). Most wallows are relatively small on the order of 1-3 m², but they may cover a substantial proportion of meadows (7%, Pfitsch 1981). The effect of wallowing on the individual plant is usually devastating.

Evidence indicates that at either high (Futayama and Wasserman, 1980) or low (Houston, 1982) herbivore densities, incidentally consumed forage species may suffer intensive grazing. These forages may be eliminated because they exert no feedback control on herbivore population size. Caughley (1982) provided an eloquent model of this effect, noting that in a hypothetical one herbivore-one plant species system that the herbivore and plant must reach a dynamic equilibrium (or the herbivore goes extinct). Further, in a one herbivore - two plant system (assuming that the two plant populations have different growth rates), "The extinction of one of the two plants is a direct consequence of its sharing the area with the other. ... It goes extinct when sharing the area because the herbivore numbers and hence grazing pressure are maintained at a higher level than would be possible if the slower growing plant were the only food available." (Caughley 1982:311). Thus, rare plants may be at risk due to mountain goats for at least two reasons: 1) mountain goat population densities likely are not controlled by plant abundance on summer ranges (Houston and Stevens 1988), let alone rare plant abundance, and 2) goats are generalist herbivores with the capacity to consume most plant species, including rare plants.

Forty-three percent of the ONP vascular plants listed by the Washington Natural Heritage Program occur in mountain goat summer range. Two endemic species appear to be grazed by goats, one is considered a selected forage. The long-term persistence of the rarest species may be jeopardized as the result of increased disturbance caused by mountain goats, and because the quantity of rare plants available as forage is too meager to influence the goat population. We reject the general null hypothesis, that mountain goats pose no threat to the long-term persistence of rare plants based on the weight of indirect evidence.

Data presented here cannot provide direct evidence of whether or not goats will drive rare plants to extinction. We have inferred the existence of a problem, but cannot predict the outcome for individual taxa. An assessment of the potential for long-term persistence of individual taxa requires intensive study of habitat requirements and demography. The following chapter presents preliminary results from this type of study conducted on the endemic *Astragalus australis* var. *olympicus*.

CHAPTER 7:

INTERACTIONS BETWEEN RARE PLANTS AND MOUNTAIN GOATS: A CASE STUDY OF *Astragalus australis* var. *olympicus* AN OLYMPIC PENINSULA NARROW ENDEMIC

INTRODUCTION

Astragalus australis var. *olympicus* (Olympic Mountain milkvetch), is a rare endemic plant known only from the dry northeastern part of the Olympic Mountains. The meta-population of 3800-4000 individuals occurs at 1525-1825 meters elevation in Olympic National Park as 11 subpopulations (Kaye, 1989; Note: a new subpopulation outside the park was recently discovered) in areas that may have represented refugia from maximum Pleistocene glaciation (ca. 12,000 B.P.). Habitat includes south facing subalpine talus, windswept ridges and knolls on calcium bearing substrate. This taxon is one of eight vascular plant taxa endemic to the Olympics. *A. australis* var. *olympicus* is listed as threatened by the Washington State Natural Heritage Program (WNHP 1990), as well as a Category 1 candidate for the federal endangered species list (U.S. Fish and Wildlife Service, 1985).

Observations of mountain goat grazing, trampling, and wallowing in *A. australis* var. *olympicus* subpopulations, raised considerable concern over the long-term fate of *Astragalus* in ONP.

Investigations into the population dynamics and habitat requirements of the species were begun in 1985. Much the following taxonomic and phytogeographic information is adapted with permission from Kaye (1989).

Taxonomy

In 1900, A.D.E. Elmer collected what became the type specimen of *Astragalus australis* var. *olympicus* from the "Olympic Mountains, Clallam County" (Elmer 2531). Two years later, John Storr Cotton published a description of *A. olympicus* based on this specimen (Cotton 1902). Since this name had previously been applied to two species, one in Greece (Pallas 1800) and one in Armenia (Bunge 1869), Jones (1923) substituted *A. cottonii* for *A. olympicus* in his revision of the genus. It was clear to Jones that *A. cottonii* was closely related to *A. aboriginum*, a species distributed in North America from arctic Alaska south in the Rocky Mountains to Utah and east to the Gaspé Peninsula in Canada.

In his monumental Atlas of North American *Astragalus*, Barneby (1964) welcomed Polunin's (1959) suggestion to combine arctic forms of *A. aboriginum* with *A. australis*. Moreover, Barneby (1964) agreed with Jones (1923) who thought *A. cottonii* might not be sufficiently different from *A. aboriginum* to warrant classification as a separate species. Isely (1983) grouped all forms of *A. aboriginum* in North America into *A. australis*. The Olympic endemic was classified as var. *olympicus* mainly by virtue of its inflated seed pods, while all other *A. aboriginum* were classified as var. *glabriusculus*. *A. australis* now has a circumboreal distribution.

Synonymy

Astragalus olympicus Cotton (1902) non Pallas (1800) nec Bunge (1869);

A. cottonii Jones (1923);

Atelophragma cottonii (Jones) Rydberg (1928);

Astragalus australis (L.) Lam. var. *olympicus* (Cotton) Iseley (1983).

Phytogeography and Communities

A. australis var. *olympicus*, or its precursor, may have reached the Olympic Mountains from the north. The distribution of *A. australis* is very similar to that of another Olympic Mountain rare plant, *Oxytropis viscida* var. *viscida*. Barneby (1964) suspected they followed the same migration routes. It is likely both taxa reached the Olympic Peninsula via Beringia and then south from unglaciated central Alaska during a Pleistocene glacial interval (Barneby 1964). The Pleistocene (about 1.75-0.01 million years ago) was marked by recurrent glaciations, followed by relatively warm interglacial periods. Many scientists believe the division of geologic time into the Holocene (beginning ca 10,000 years ago) and the Pleistocene is geologically meaningless; we are still in an ice age, but in an interglacial period (Pielou, 1991). In any case, *A. a. olympicus* probably did not arrive here by long distance dispersal from the closest population of *A. a. glabriusculus*, in the Wallowa Mountains of NE Oregon, about 500 km distant.

Olympic isolation left a population of *A. australis* with a unique combination of traits. The inflated seed pod of var. *olympicus* sets it apart from var. *glabriusculus*, though the pods of some Alaskan forms are "decidedly tumid" (Barneby, 1964). Although var. *olympicus* has not been isolated long enough to evolve into a separate species, as some of the other Olympic endemics, the distinct inflated pods could represent an important dispersal adaptation. While flat pods can either expel seeds explosively, be eaten, or simply drop from the plant, inflated legume pods can do the same and also can be dispersed by wind (Ridley, 1930). With further isolation, this variety may evolve into a

separate species, as speciation through reproductive isolation is fairly common in montane floras (Hickman, 1968; Favarger, 1972; Ives, 1974; Stebbins, 1982).

Today, *A. australis* var. *olympicus* and associated species fit rather loosely into the cushion plant community described by Kuramoto and Bliss (1970). Species common to cushion plant communities and often found growing with *Astragalus* include *Phlox diffusa*, *Festuca idahoensis*, *Allium crenulatum*, and *Lomatium martindalei* (Kaye 1989). Overall, Kaye (1989) identified seven cover types with *Astragalus* as a constituent. In addition to the cushion plant type, these included communities dominated by *Crepis nana* with a total plant cover averaging 2 percent; bedrock sites with *Saxifraga bronchialis* and the endemic *Petrophytum hendersonii*; and open sites near tree clumps of *Chamaecyparis nootkatensis* or *Pseudotsuga menziesii*. A feature held in common by all sites was calcareous substrate with pH almost always over 6.0.

Here, we present population trends, examine goat use and impacts and present an assessment of the extent of habitat available to *A. a. olympicus*, and how much of that available habitat is occupied by the rare plant. The latter is critical to understanding how much ecological space is available to this narrow endemic.

METHODS

From 1981 to 1989, mountain goats densities were reduced in most areas where *Astragalus* occurs (Houston et al. 1991b). One hundred eighty one-animals were removed from the Mount Angeles subpopulation 1981-85. Four more animals were removed from the Mount Angeles are in 1986 and an additional 20 from 1988-89. The pre-removal goat population in the Mt. Angeles area was about 229 goats (Houston and Stevens, 1988). One goat was sterilized and removed from Blue Mountain in 1988, essentially eliminating that subpopulation (Houston et al. 1991b).

Reconnaissance Plots

Characteristics of the physical and biological environment of *Astragalus* subpopulations were quantified using reconnaissance (recon) plots identical to those described in Chapter 2 during the summers of 1985 and 1986. Percent cover and grazing for each species was estimated in classes and animal use noted. Environmental parameters recorded were: slope, aspect, elevation; percent cover of bare mineral soil, litter, organic matter, bedrock, and five size classes of bare rock fragments. In

addition, the plots were visually separated into quadrats to facilitate the enumeration of all *Astragalus* individuals. Plot dimensions were also recorded.

Intensive sampling was conducted in the Blue Mountain and Mount Angeles areas where most *Astragalus* occurs. All sub-populations, with the exception of one containing ca. 200 plants north of Blue Mountain on Dinosaur Ridge, were sampled; nearly one third of all *Astragalus* plants were included in reconnaissance plots. Plots were located in areas of physical site homogeneity which included at least one *Astragalus* individual, and were distributed over the complete range of environmental conditions observed in each sub-population.

Permanent Plots

In 1985, ten of the 25 m² reconnaissance plots were marked permanently in order to measure *Astragalus* population trends. Starting in 1987, plot sides were marked temporarily with short steel nails at one meter intervals, and cotton string was used to grid the entire 5 X 5 meter plot into 25 1 x 1 meter squares. The *Astragalus* individuals in each square meter were mapped and counted, noting grazing and physical injuries to each plant. An intensive search was made to locate *Astragalus* seedlings in each plot. The ten plots were distributed as follows: 2 - Unicorn Peak; 1 - Griff Peak; 3 - Blue Mountain NE; 2 - Blue Mountain Summit; and 2 - Hurricane Hill. In 1985, 1986, and 1989 the gridded 1 X 1 meter squares were simply censused, with plant injury noted and no intensive seedling search made.

Habitat Analysis

To determine how much *Astragalus* habitat was present and occupied in Olympic National Park we performed three analyses. First, 687 Olympic Mountain subalpine recon plots², including 79 *Astragalus* plots were classified by TWINSpan (Chapter 3) into community groups based on plant cover. Second, we performed a non-parametric discriminant analysis to discover how well the environmental variables we measured in the recon plots define *Astragalus* habitat. The discriminant analysis works by comparing the classifications by both plant cover, and by environmental variables (e.g. slope, aspect, rock fragment size). If the plant classification (TWINSpan) agrees with the environmental variable classification (i.e., the same plots are placed in the same groups by both), then the environmental variables adequately explain the plant community differences. If *Astragalus* occurs

² Recon plots used in these analyses did not include those established in 1988 and 1990 or those that had incomplete data on substrate characteristics (i.e. percent cover of bare mineral soil, bedrock, etc.). Thus, the number of recon plots used here does not match numbers presented in Chapter 3 or Chapter 4

in a separate plant community that is also explained by a distinct set of environmental variables then these variables represent *Astragalus* habitat. Finally, if few other plots (without *Astragalus*) fit in the group with this set of environmental variables then *Astragalus* is probably occupying most of its available habitat. Third, we used logistic regression to determine which environmental variables contributed most to explaining the differences between recon plots containing *Astragalus* and the other Olympic Mountain subalpine recon plots. Statistical procedures were reviewed by L. Conquest (pers. comm., 1990).

RESULTS

We recorded 1442 *Astragalus* individuals (36% of the estimated population) in 79 recon plots. Permanent plots revealed that *Astragalus* subpopulations generally declined from 1986 to 1990 then increased in 1991 (Fig. 7-1). Seedling establishment was variable and was highest in 1990 and 1991 (Fig. 7-2). Seedling survivorship varied little between years.

Mountain goat sign was found inside and adjacent to many recon plots established in *Astragalus* subpopulations. Twenty-two goat pellet groups were found in 11 plots in 3 subpopulations and 87 wallows/beds were found near 37 plots in 6 subpopulations (Table 7-1). *Astragalus* plants in 20 plots in 6 of the 11 subpopulations were grazed. Goat activity was particularly evident in the Mount Angeles *Astragalus* subpopulations, even though the goat population there had been substantially reduced; goat sign was found inside or within 50 m of 70% of the Mount Angeles recon plots.

Permanent plot data showed that *Astragalus* plants were injured (grazed or trampled) by goats. Injury was sporadic but sometimes intense (Fig. 7-3). Some injuries were obviously caused by goats (i.e. abundant goat sign adjacent to grazed or trampled *Astragalus* plants); the source of other injuries could not be determined. In 1986 goat wallows were found in three permanent plots. Two wallows at Blue Mountain NE buttress were responsible for two plant deaths. At Unicorn Peak, a wallow also killed two plants. The extensive injury (mostly grazing, but 6 plants were trampled) to plants at the Unicorn subpopulation in 1987 was entirely attributable to mountain goats. In permanent plots 101 and 102, where most of the damage took place, 26 of 50 sub-plots had goat tracks in them, 18 others had "tracks" recorded; given the overwhelming abundance of goat sign, these were most likely also goat tracks. Grazing was evident on 89 (72%) of the individuals in the

Number of Astragalus Plants in Permanent Plots

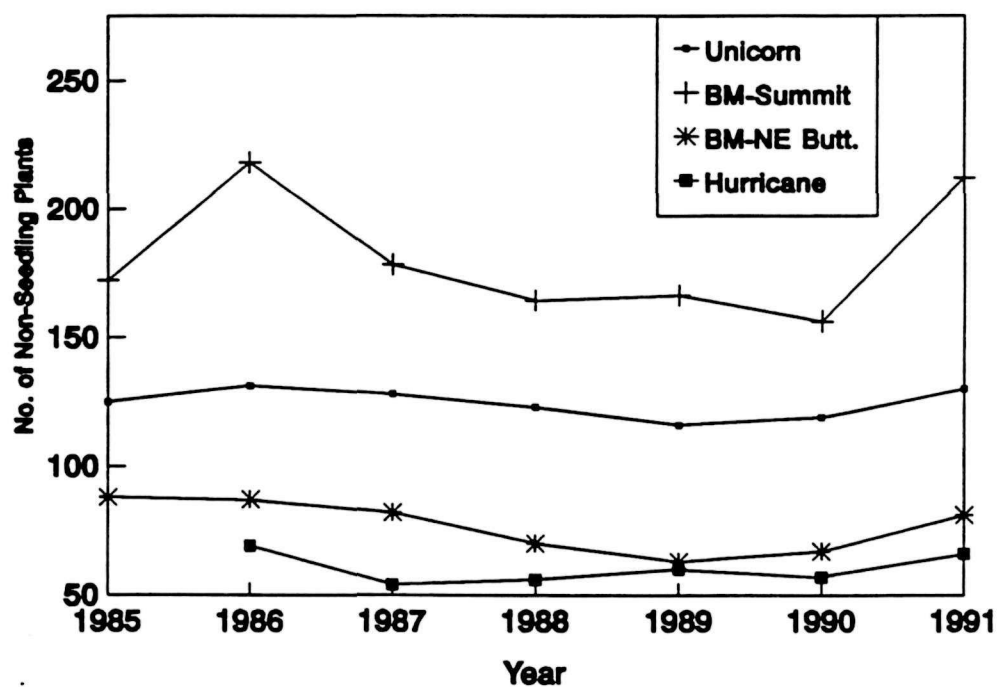


Figure 7-1. The number of non-seedling *Astragalus* individuals in permanent plots in four subpopulations.

Astragalus Seedling Survival

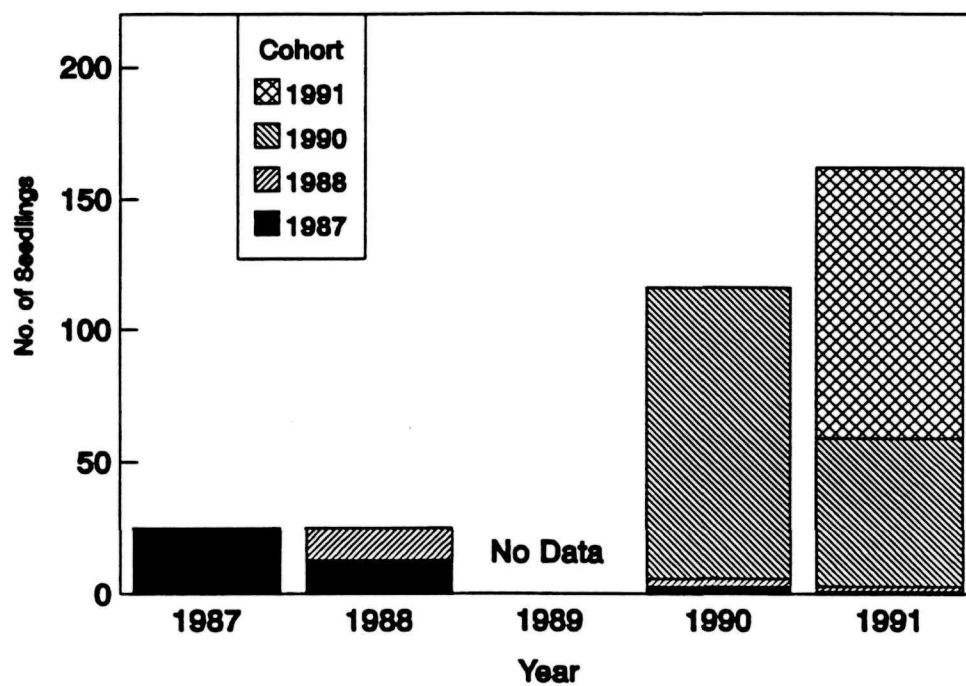


Figure 7-2. *Astragalus* seedling survival in four subpopulations.

Table 7-1. Evidence of mountain goat use in and around recon plots established in subpopulations of *Astragalus australis* var. *olympicus*, 1985-86.

Subpopulation Name	Number of Plots	Number of Wallows within 50 meters of plots	Number of Pellet Groups inside plots	Number of Plots with grazing on <i>Astragalus</i>
Blue Mountain				
Summit	6	10	9	0
Northeast	21	7	0	3
Mount Angeles				
Northwest	17	27	0	8
First Top	6	0	3	0
Heather Park	6	1	0	3
Second Top	14	31	10	3
Unicorn/Griff Peak	3	11	0	2
Hurricane Hill	6	0	0	1
Total	79	87	22	20

Injury to *Astragalus* Plants

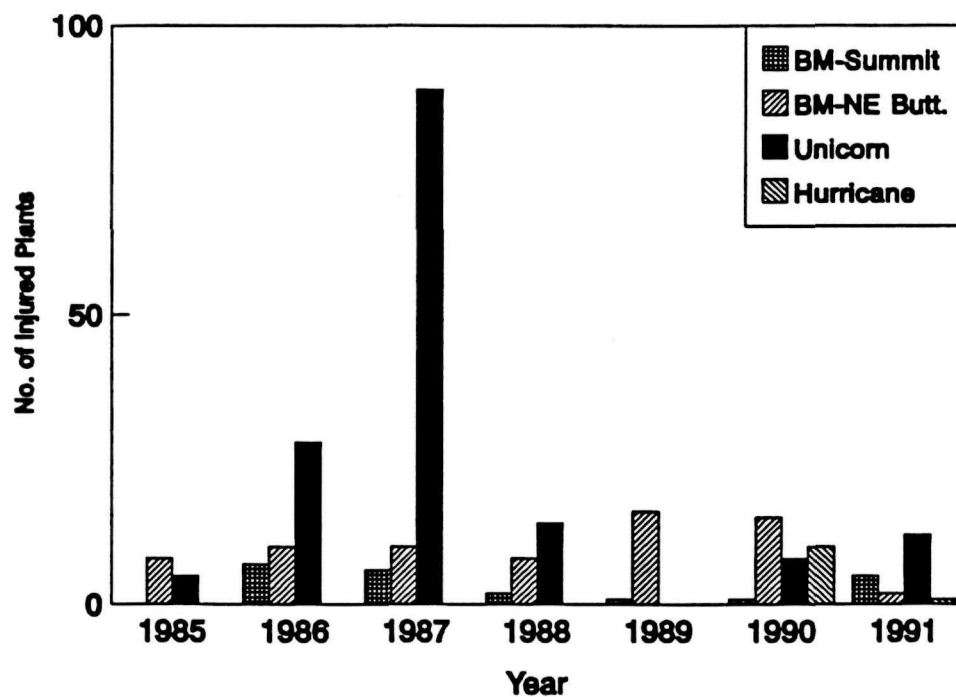


Figure 7-3. Number of injured *Astragalus* plants in ten permanent plots.

three permanent plots; much of this grazing was noted as "76-100% grazed" or "severely grazed". In addition to a goat wallow and "goat scrape" there was an "area of heavy goat disturbance" inside permanent plot 101 (plots 101 and 102 are about 30 meters apart on the same slope). Evidently goats moved through the area, stopped to graze and wallow in one of the *Astragalus* subpopulations.

Habitat Analysis

TWINSPAN results suggested that four major groups were readily discernible based on plant species presence and abundance, one of which was composed entirely of *Astragalus* recon plots. The four groups are roughly arranged along a moisture/disturbance gradient with unstable, dry plots at one extreme and late snow melt plots at the other. All plots in the group at the dry extreme (44) contained *Astragalus*, a slightly wetter group contained 44% (35) of the *Astragalus* plots as well as 284 additional plots dominated by species such as spreading phlox (*Phlox diffusa*) and Idaho fescue (*Festuca idahoensis*). The two groups at the wetter end of the gradient, containing no *Astragalus*, were dominated by showy sedge (*Carex spectabilis*), pink mountain heather (*Phyllodoce empetriformis*) or Merten's mountain heath (*Cassiope mertensiana*).

Astragalus plots were classified distinctly by both plant cover and environmental variables. Based on the environmental variables, 37% of the 35 *Astragalus* plots classified outside of the *Astragalus* TWINSPAN group belong with the rest of the *Astragalus* plots. Combining the results from both analyses, 84% of one group is represented by *Astragalus* plots while 22% are in another, indicating that few other plots have the same environmental conditions as *Astragalus* plots; *Astragalus* habitat is limited in extent and relatively fully occupied.

Environmental variables determined most important by the logistic regression in distinguishing *Astragalus* recon plots from other Olympic subalpine recon plots were: slope, aspect, percent cover of bare mineral soil, total rock, and the > 2 mm - 4 cm rock fragments. Complex interaction between these variables define *Astragalus* habitat. Average slope of *Astragalus* recon plots is 28°, average aspect is 201° (almost due SSW), average bare mineral soil cover is 11.9%, average total rock cover is 81.9% and average > 2 mm - 4 cm rock fragment percent cover is 56.3%.

Blue Mountain plots contained an average of three times more *Astragalus* plants per square meter than the plots at Mount Angeles (1.01 vs. 0.31; $p < 0.01$, Mann-Whitney U-test). The logistic regression equation used to describe characteristics of *Astragalus* habitat was used to test the hypothesis that

habitat differences were responsible for the observed density differences between Blue Mountain and Mount Angeles. The equation predicted that the mean probability of a plot containing *Astragalus* at Blue Mountain and Mount Angeles was 0.47 and 0.53 respectively, with no significant difference (Mann-Whitney U-test, $p=0.40$). In other words, habitat characteristics, as measured in recon plots, did not account for the difference in *Astragalus* density between the two areas. The major difference between these two areas appears to be the historical density of mountain goats.

INTERPRETATION

The *Astragalus australis* var. *olympicus* population trend shown by permanent plots represents only a short-term picture. Population and seedling establishment data showed that some years were better than others for this plant. However, considerably longer study will be required to determine population trend. A successful year for seedling establishment may mean little to the long-term trend because survival of a particular cohort will diminish with time. In the present study, approximately 25 seedlings were established in 1987, by 1991 less than 5 remained alive. Consequently, even though 1990 and 1991 were relatively good years for seedling establishment, their long-term survival is not assured.

Astragalus habitat requirements in the Olympic Mountains appeared to substantially overlap with habitat considered ideal for mountain goat populations to reach high densities. Stevens (1979) described goat habitat utilization in the Olympics by breaking habitat into three components: 1) features used by goats for thermoregulation including northern exposures, snow, soil for wallows, forest canopy, and late season water supply; 2) forage in the form grass and forb meadows; and 3) the presence of rocky cliffs and bluffs for escape, bedding and kidding. Stevens (1979) reported that ideal goat habitat contained all three features close together and that on Klahhane ridge (near Mt. Angeles) all the features were present in almost any square kilometer. Five *Astragalus* subpopulations are on another ridge of Mt. Angeles where these features are also present in virtually every square kilometer. Two other subpopulations nearby (Unicorn Peak) exhibited high goat use. These 7 subpopulations represent 62% of the known individuals.

A. a. olympicus seems to be restricted to the region it currently occupies because habitat suitable for this taxon is limited elsewhere on the Olympic Peninsula. We do not know how fully *Astragalus* occupies available sites within its current range. Additionally, we do not know if it should it be

present at densities of 2 plants per square meter or 10. *Astragalus* density in reconnaissance plots at Blue Mountain was triple that at Mount Angeles, with no discernable habitat quality difference. Blue Mountain does not provide the high quality mountain goat habitat (little permanent snow for thermoregulation, dry in the late summer, and only small rocky outcrop areas) that is common around Mount Angeles, and consequently few goats have ever been recorded there. Goats have mostly been observed traveling through or resting at the NE buttress (one of the few rocky outcrop areas). The goat population at Mount Angeles, however, rapidly increased during the 1960's and was high from the late 1970's until removal in the early half of the 1980's (Houston and Stevens, 1988; Houston et al. 1991a). Our perception of how fully *Astragalus* occupies habitat on a local scale (i.e. plant density where found) is that it may have been reduced by goat interference, especially at Mount Angeles.

Astragalus has at least co-existed with introduced mountain goats in the Olympic Mountains. However, we were unable to determine the overall long-term effects goats have had on its population dynamics. Goat impacts observed in both the reconnaissance and permanent plots were from a substantially reduced goat population. Two plants were killed by a wallowing goat at Blue Mountain, where goats numbered fewer than 10 animals. In the Unicorn Peak *Astragalus* subpopulation, there was no apparent relationship between goat density and whether or not goats injured or killed *Astragalus* plants. Here, we observed no goat impact in 1985 (when the Mt. Angeles area goat density was estimated at 4.3 animals/km²), two goat-caused deaths in 1986 (goat density - 1.8/km²), and abundant goat sign and grazing on *Astragalus* in 1987 (goat density estimated at 2.1/km²). In other words, goat impacts on *Astragalus* were sporadic, sometimes intense, and have unknown long-term consequences to the survival of this plant. Given the direct impact of goats on *Astragalus* plants, and the co-existence of goats and *Astragalus*, it is our judgement that the hypothesis that mountain goats pose no threat to the long-term survival of this taxon should be rejected.

CHAPTER 8:

REPEAT PHOTOGRAPHY

INTRODUCTION

Subalpine and alpine vegetation of the Olympic Peninsula has received a fair amount of scientific attention in the last twenty-five years. Study topics have included the ecology of meadows and forests (Fonda and Bliss 1969, Kuramoto and Bliss 1970, Canaday and Fonda 1974, Milliren 1983), vegetation processes (Bliss 1969, Peterson 1971, Belsky and del Moral 1982), the role of disturbance (Bell and Bliss 1973, Schreiner 1974, 1982, Hansen 1976, Agee and Smith 1984), herbivory (Wood 1973, Watson 1976, Sheehan 1978, Pike 1981, Reid 1983, del Moral 1984, Pfitsch and Bliss 1985, Schreiner 1987), and tree invasion (Woodward et al. 1991, Fonda pers. comm.). Although Schreiner (1982) conducted a plant succession study over 8 years and Woodward et al. (1992) are examining the rates and causes tree invasion subalpine meadows, an examination of longer-term changes in subalpine and alpine vegetation patterns has not been done.

The most accurate way to measure quantitative changes in vegetation over time is with repeated samples from permanent plots. Ecologists often compare similar sites that differ with respect to the elapsed time since the last disturbance when permanent plots do not exist. Investigators assume that these artificial "chronosequences" reflect change over time. Studies of this type offer insight into changes over time but are subject to uncertainty because it is impossible to perfectly replicate the sites, climatic conditions at the time of disturbance, or the disturbance itself (Horn 1975, Connell and Slatyer 1977). An alternative, less quantitative approach that avoids this criticism is repeat photography where the identical landscape is compared at two or more points in time.

Repeat photography has been used elsewhere to characterize landscape changes over time. Gruell (1980,1983), for example, described changes in wildlife habitat in the Rocky Mountains as it related to fire. Houston (1982) delineated changes in the vegetation of Yellowstone National Park, and Johnson (1987) discusses changes in Wyoming rangelands. In the Olympics, Schreiner (1981) used photographs to document plant recovery and soil erosion in backcountry campsites, and Spicer (1986) mapped variations in alpine glaciers since the turn of the century.

The following section reports results from an ongoing study of long-term changes in subalpine vegetation on the Olympic Peninsula. Photographs from the northern end of the Park near Klahhane Ridge are presented because work is largely complete in this area. The objective of this part of the study was to delineate long and short term changes in vegetation and soils with respect to climate, fire, mountain goats, people, and other natural disturbances (e.g. landslides). Photo comparisons elsewhere in the park are still underway.

METHODS

A systematic search was conducted for photographs of subalpine and alpine areas of the Olympics. Sources included the Clallam County Historical Society, park files, the two O'Neill expeditions (1885, 1890), and early mountaineers, pioneers, rangers, etc. known to travel the mountains (e.g. E.B. Webster, the Cameron family, "Doc" Ludden, etc.). G. Evans located many photographs during her historic resources study (Evans 1983). Many people generously shared their photos (Appendix C).

Our approach was to compare photographs taken before goats were introduced and when they were at low density with photographs taken when density was high. Later, photos taken when density was high were compared to those taken after the goat population was reduced by natural causes and an experimental live-capture program (see Houston et al. 1991b).

Photographs were selected for picture quality and age rather than preconceptions that a re-photograph would produce a specific result. Fuzziness was the main reason photographs were rejected although some pictures were not used because the view was too distant or too hazy for changes to be observed; the location of some scenes could not be determined. Several visits to a given site were sometimes required to obtain the best correspondence of plant phenology and snow patch patterns. Dominant plant species in each scene were recorded at the time scenes were rephotographed.

The procedure followed for analyzing photographs was to first characterize several general features of the scene and then to describe changes between the two photos. General features included, predominant aspect, type of view (distant, moderately distant, close), plant community type(s), and whether or not the scene was the same as shown in other pairs. Differences (if any) in each community were described and then tallied as an increase, decrease or no change in the following categories:

1. Total plant cover.
2. Percent cover of ruderal species (*Achillea millefolium*, *Cirsium edule*, *Phacelia hastata*).
3. Cover of plants indicating community stability (*Festuca idahoensis*)
4. Cover of shrubs (primarily *Juniperus communis*)
5. Number of trees and tree height (i.e. invasion, mortality, or growth)
6. Cover of bare ground/rock.
7. The number of trails or wallows.
8. The cover of relatively fine soils and pebbles. This included material less than ~2 cm or so - most of these changes are obvious where fines are either exposed or replaced by gravel or cobble size rocks.
9. Soil erosion or deposition as indicated by increased or decreased exposure of roots and large rocks.

Many photographic scenes contained more than one plant community so comparisons of more than one community were possible from a single pair. The foreground for example, might show a ridgetop community while the background shows a north facing slope of subalpine fir (*Abies lasiocarpa*). The term "community view" refers to individual communities within a picture. "Photographic pair" is used to refer to pictures of the same landscape taken at two different times.

Two different photographic pairs sometimes contained views of the same site from a different angle. In other words, the same "community view" was contained in two different pairs, but from a different perspective. Only one community view was counted. Fuzzy community views contained in the foreground or background of some pictures were not included in the counts.

Interpretations of differences between photographs are conservative. Unless a single cause of change was clearly identifiable (e.g. fire) all contributing factors were considered. Categories driving changes included goats, people, natural events such as fire and climate change, or a combination such as goats and people. Plant community names follow those of Pfitsch and Bliss (1985) where possible.

Temperature and precipitation data were obtained from the Port Angeles weather station, 12 km north of the study area (NOAA, 1910-1991). Snow depth data are for April from the Hurricane Ridge snow course, 3 km south west of Mount Angeles (Soil Conservation Service 1960, ONP records). April records were used because they were closest to the growing season and therefore give a crude indication of soil moisture available to plants the following summer. Snow pack trends were extended

further into the past using data from Park Creek in the Cascade Mountains. Climatic trends were plotted using a technique called Locally Weighted Regression Scatter Plot Smoothing (LOWESS, Chambers et al. 1983).

Sixty-six photographic pairs illustrate landscape changes from ~1915-20 to 1990. This interval covers the time before goats were introduced (1925-29) through the sub-population peak in the late 1970s to 1990 when Houston et al. (1991a) estimated that 3 goats remained in the Klahhane Ridge census unit. The comparisons cover the region from First Top south to the Hurricane Ridge Road and east along Klahhane Ridge to the ridge south of Lake Angeles. Several recent scenes targeted wallows in Big South Meadow; these were not used in the analysis of long-term changes. Eleven scenes are presented, the remainder appear in two volumes (Burger 1991). The photo comparisons document changes on goat summer range (spring-fall). We have no comparisons of vegetation changes on major winter range sites.

RESULTS

Plant and soil changes can be attributed to several causes (Table 8-1). Short-term differences, often attributable to goats and human trampling, were superimposed on longer term changes driven mainly by climate or fire. It was sometimes difficult to precisely delineate factors driving vegetative changes.

Climatic and Fire Effects

Weather from 1915-1990 exhibited several fluctuations (Fig. 8-1). Periods of low summer precipitation (July - August) occurred from 1915-29, 1941-45, 1957-60, 1968-73, and 1980-86. Snow pack also fluctuated but highs and lows did not necessarily parallel the fluctuation in summer precipitation. From 1968-73, for example, a relatively high April snow pack was followed by low summer precipitation. At Hurricane Ridge, April snow pack declined steadily from 1949, reached a 30-year low from 1979-80, and has remained low. Mean July-August temperature increased fairly rapidly (~12-14° C) from 1910-25, continued a more gradual increase to ~1960 and seems to have fluctuated near 15° C from ~1960-90.

Table 8-1. Changes in vegetation and soils identified by community type. Results represent the number of times a change was observed for each community type within a particular photographic pair. Since most photographs contained more than one plant community, changes in each community were tallied.

YEAR / PLANT COMMUNITY	No. of Views	CHANGES IN PLANT COVER												SOIL CHANGES/WALLOWS												CAUSE OF CHANGE*					
		Total Dist. Stable												Bare Fine Wal- Trails Soil Trail &																	
		No Trees	Cover	Spp.	Spp.	Shrubs	No	Grnd	Soil	ows	Trails	Soil	Trail &	Ero-	Wallow	G	P	N	G&P	N&G or P											
Chg	+	-	+	-	+	-	+	-	+	-	Chg	+	-	+	-	+	-	+	-	sion	Present										
1915-20 vs. 1986	12	4	7	0	1	0	0	0	0	0	1	0	7	0	3	0	0	0	0	1	0	1	1	1	0	10	0	1			
Cushion Plant	1		1										1													1					
Late Snowmelt	1		1										1													1					
Scree	4	3	1										2						1			1	1	1	2		1				
Shrubby Cinquefoil	1				1							1														1					
Subalpine Fir	4		4										2		2											4					
Unstable Herb	1		1										0		1											1					
1940-49 vs. 1985	5	1	3	0	1	0	0	0	0	0	0	0	3	0	1	0	0	1	0	0	0	0	0	0	0	4	0	1			
Late Snowmelt	1		1										0				1										1				
Scree	2		1	1									2													2					
Subalpine Fir	1			1									1													1					
Unstable Herb	1				1										1											1					
1950-56 vs. 1982	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0				
Festuca	1					1									1											1					
1950-56 vs. 1985-86	7	0	1	1	0	4	1	0	0	0	1	1	1	4	0	0	0	1	0	1	0	0	0	4	0	2	1	0			
Late Snowmelt	1			1																						1					
Cushion Plant	2					2						1	2				1		1							1					
Festuca	1					1							1													1					
Scree	1		1										1	1												1					
Unstable Herb	2					1	1					1													2						
1960s vs. 1981-82	19	10	2	1	1	7	0	1	0	0	1	1	6	7	0	1	0	1	0	2	0	2	1	6	0	7	1	3			
Cushion Plant	4				1	3						1	3													1					
Fescue	3		1			2							1	2												1	2				
Late Snowmelt	2		2	1	1								2													2					
Rock outcrops	4		2			2		1					2	1		1					1		2		2						
Scree	4		4										1				1		2			1	3				1				
Subalpine Fir	1			1									1													1					
Tall Forb/Grass	1		1																		1					1					
1960s vs. 1985-86	10	4	1	0	0	1	0	1	0	1	1	0	4	4	0	1	0	0	0	1	0	1	0	2	2	2	4	0			
Cushion Plant	2		1			1										1					1					1					
Fescue	2						1		1				2													2					
Rock Outcrop	2		2										1	1					1					1	1						
Scree	2		1										2													1	1				
Subalpine Fir	2			1							1		1	1												1	1				
1970s vs. 1981-82	10	1	1	0	3	6	2	1	0	1	2	0	3	2	0	0	1	0	0	0	0	3	2	5	0	4	1	0			
Fescue	3				1	2	1				2		1			1					2		1		1	1					
Late Snowmelt	1		1										1													1					
Scree	3		1		1	1	1	1					2								1		1		2						
Unstable Herb	3				1	3					1			1								2	3								
1970s vs. 1985-86	13	8	0	1	2	0	2	0	0	1	0	0	5	0	2	0	4	1	4	0	1	0	5	7	0	4	1	1			
Cushion Plant	3		3										2				1									1					
Juniper/Forb	1			1	1										1												1				
Late Snowmelt	2		2										1		1										1						
Rock Outcrops	1												1													1					
Scree	4		2		1		1						1			2		2		1		2	3		1						
Unstable Herb	2		1				1				1					1	1	2				2	1			1					

Table 8-1. (Continued)

YEAR / PLANT COMMUNITY	No. of Views	CHANGES IN PLANT COVER												SOIL CHANGES/WALLOWS												CAUSE OF CHANGE*								
		Total				Dist.				Stable				Bare				Fine				Wal-				Trails				Soil Trail &				N&G
		No		Trees		Cover		Spp.		Spp.		Shrubs		No		Grnd		Soil		ows		Trails		Soil		Trail &		Ero-	Wallow	N&G				
		Chg	+	-	+	-	+	-	+	-	+	-	Chg	+	-	+	-	+	-	+	-	+	-	+	-	+	-	sion	Present	G	P	N	G&P	or P
1981-82 vs. 1985-86	25	13	0	0	8	2	1	0	2	0	0	0	9	1	5	0	1	1	0	0	1	4	3	11	0	4	3	4						
Cushion Plant	3	1			2										1		1					1		1		1	1							
Fescue	6	3			2	1							3	1	1							1		2		1	1	2						
Late Snowmelt	2	1											2																					
Rock outcrops	4	2			2		1		1				2	2									2		2		1							
Scree	6	4			1	1							1						1			1	2	1	3		1	1						
Unstable Herb	4	2			1				1				1	1									2	3		1								
1980-81 vs. 1990	5	0	0	0	5	0	0	1	4	0	0	0	0	0	5	0	1	0	0	0	0	0	0	5	0	0	0	0						
Fescue	1				1			1	1						1									1										
Rock outcrops	2				2				1						2		1							2										
Unstable Herb	2				2				2						2									2										
1985-86 vs. 1990	5	0	0	0	5	0	0	2	3	0	1	0	1	0	4	0	1	0	0	1	0	2	0	3	0	0	1	1						
Cushion Plant	1				1			1	1						1		1						1		1									
Fescue	2				2				2						2								1				1							
Late Snowmelt	1				1			1			1		1											1										
Scree	1				1										1					1				1										

* G = Goats, P = People, N = Natural events, GP = Goats and People, N+GP = Natural events and Goats or People.

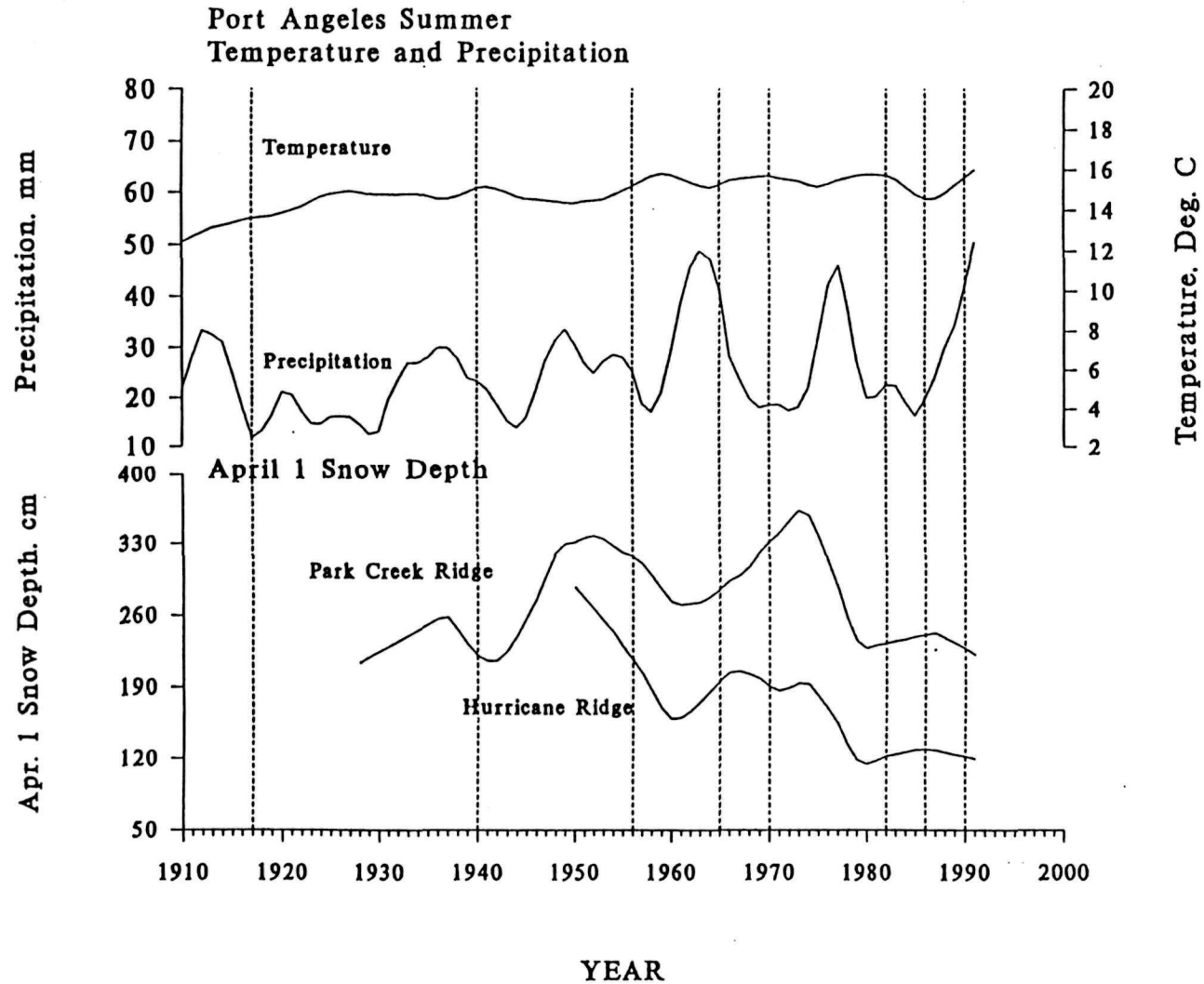


Figure. 8-1. Annual precipitation and mean annual temperature for Port Angeles, Washington from 1910-1991 and April 1 snow depth at Hurricane Ridge and Park Creek. Data were smoothed using a .15 factor LOWESS (Chambers et al. 1983).

Vegetative changes induced by climate differences were visible mainly on north facing slopes initially photographed from ~ 1915-1940 (Plate 1, Heather Park). Heath-shrub communities dominated by *Phyllodoce empetrifomis* and *Cassiope mertensiana* were invaded by subalpine fir, especially in concave landscapes where snow accumulates (Plate 2). Herbaceous vegetation increased in some late snow bank sites and stayed remarkably unchanged in others (Plate 3). No tree invasion was observed in the drier Ridgetop Fellfield, Unstable Herb Meadow, or *Phlox/Festuca* communities areas. The results of forest succession following fires are visible in several photographs (Plate 4).

Goat Effects

Modifications of vegetation and soils by mountain goats were visible even though goat effects were superimposed on those driven by climate, fire, and people. Differences were most visible on south and east facing slopes and appeared to be influenced by goat density. Results were organized into three periods of goat density on Klahhane Ridge: 1) 1981-82, just after peak goat densities; 2) 1985-86, medium density (following removal of 181 goats) and 3) 1990, low density (following more removals, an estimated 3 goats remained).

Photographic pairs of the 1950s-1970s compared to 1981-82 in Unstable Herb meadow, Ridge top fellfield and *Phlox/Festuca* communities consistently show increased bare mineral soil, reduced total plant cover, formation of wallows, and an increase in the number of trails (Plates 5-8, Table 4). Three of four views of scree slopes from the 1960s show an increase in the number of wallows or formation of new trails (Table 8-1). Of the 30 plant community "views" in these pictures, 11 (37%) show no change, 14 (47%) show reduced total plant cover, and 10 (33%) have more bare mineral soil (Table 8-2). These changes are attributable to goats in 12 (40%) cases, "natural" causes in 11 (37%), and to a combination of natural causes and/or goats and people in 5 (17%).

Vegetation and soil changes were more variable with 1985-86 comparisons (Table 8-2) because both long and short time intervals were included (i.e. 5-70 years). Goat density at the time the initial photographs were taken ranged from 0 (pre-goat) to the highest (late 1970s, Houston and Stevens 1988); density declined from 1981-84. Nearly one-half the plant community views (42%) showed no change; a few show tree invasion (17%). Scenes from the 1960s compared to 1985-86 showed an increase in the amount of bare soil. Those from the 1970s tended to show a decrease in the number of wallows and that the mineral soil component (fines) at the surface of active wallows have disappeared from scree slopes (Plate 9). Increases in total plant cover occurred more frequently than other changes between 1981-82 and 1985-86.

Table 8-2. Changes observed between photographic scenes. No Chg = Summary of differences between photographic scenes by years. Results represent the number of times a change was observed for each community type within a particular photographic pair. Since most photographs contained more than one plant community, changes in each community were tallied.

YEAR	No. of Views	VEGETATIVE CHANGES										SOIL CHANGES								CAUSES*								
		No Chg	Trees +	-	Total Cover +	-	Dist. Spp. +	-	Stable Spp. +	-	Shrubs +	-	No Chg	Bare Grnd +	-	Fine Soil +	-	Wallows +	-	Trails +	-	Ero- sion	G	P	N	GP	N+ GP	
Comparisons with 1981-82																												
1950s	1	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-	-
1960s	19	10	2	1	1	7	-	1	-	-	1	1	6	7	-	1	-	1	-	2	-	2	6	-	7	1	3	
1970s	10	1	1	-	3	6	2	1	-	1	2	-	3	2	-	-	1	-	-	-	-	3	5	-	4	1	-	
TOTAL		30	11	3	1	4	14	2	2	-	1	3	1	9	10	-	1	1	1	-	2	-	5	12	-	11	2	3
Percent of Total			37	10	3	13	47	7	7	-	3	10	3	30	33	-	3	3	3	-	7	-	17	40	-	37	7	10
Comparisons with 1985-85																												
1915-20	12	4	7	-	1	-	-	-	-	-	1	-	7	-	3	-	-	-	-	1	-	1	1	-	10	-	1	
1940s	5	1	3	-	1	-	-	-	-	-	-	-	3	-	1	-	-	1	-	-	-	-	-	-	4	-	1	
1950s	7	-	1	1	-	4	1	-	-	-	1	1	1	4	-	-	-	1	-	1	-	-	4	-	2	1	-	
1960s	10	4	1	-	-	1	-	1	-	1	1	-	4	4	-	1	-	-	-	1	-	1	2	2	2	4	-	
1970s	13	8	-	1	2	-	2	-	-	1	-	-	5	-	2	-	4	1	4	-	1	-	7	-	4	1	1	
1981-82	25	13	-	-	8	2	1	-	2	-	-	-	9	1	5	-	1	1	-	-	1	3	11	-	4	3	4	
TOTAL		72	30	12	2	12	7	4	1	2	2	3	1	29	9	11	1	5	4	4	3	2	6	25	2	26	9	7
Percent of Total																											1	
Comparisons with 1990																												
1980-81	5	-	-	-	5	-	-	1	4	-	-	-	-	-	5	-	1	-	-	-	-	-	5	-	-	-	-	
1985-86	5	-	-	-	5	-	-	2	3	-	1	-	1	-	4	-	1	-	-	1	-	2	3	-	-	1	1	
TOTAL		10	-	-	-	10	-	-	3	7	-	1	-	1	-	9	-	2	-	-	1	-	2	8	-	-	1	1
Percent of Total			0	-	-	100	-	-	30	70	-	10	-	10	-	90	-	20	-	-	10	-	20	80	-	-	10	10

* G = Goats, P = People, N = Natural events, GP = Goats and People, N+GP = Natural events and Goats or People.

Short term comparisons of the 1981-2 and 1985-6 photos with those of 1990 (Table 8-2) show that vegetation apparently responded to reduced goat density. Increased total plant cover was visible in all ten views. Moreover, of the ten views, three suggest a decrease in ruderal species while seven show an increase in the abundance of a Idaho fescue. Soil changes appear to reflect increased substrate stability where nine of the 10 views exhibit a decrease in the cover of bare ground. Changes were attributed to reduced goat density in eight of the ten views.

INTERPRETATION

Tree Invasion

Tree invasion similar to that seen on Klahhane Ridge has been reported for other regions of the Olympics (Fonda and Bliss 1969, Kuramoto and Bliss 1970) and numerous areas in the Pacific Northwest (Brink 1959, Franklin et al. 1971b, Lowery 1972, Henderson 1974, Rochefort et al. 1993). It appears that meadow invasion in the Cascade Range has centered around the 1930s (Franklin and Dyrness 1988). Photographic comparisons from Klahhane Ridge sometimes showed massive invasions of subalpine fir that could have taken place during the same time period.

Intensity of the tree invasions reported by Kuramoto and Bliss (1970) and Henderson (1974) varied by plant community type. Both investigators reported that most invasion took place in communities containing *Phyllodoce empetrifomis*; drier sites and later snowmelt sites showed little invasion. Tree invasion in the Klahhane Ridge area followed an identical pattern. Summer drought causing early snowmelt (1915-29) and apparent low winter snow pack at about the same time seems to have expedited invasion. Woodward et al. (unpublished data), however, have discovered that considerable tree invasion occurred in these meadows during the early 1960s when low winter snowpack coincided with high summer precipitation.

Goats vs. Climate as the Primary Cause of Change

Landscape changes associated with introduced mountain goats were dependent on goat density and plant community type. Several plant community types exhibited virtually no detectable response to the introduction of mountain goats, e.g. north facing slopes dominated by *Phyllodoce empetrifomis* and late snow melt communities with *Antennaria lanata* or *Carex nigricans* (Plates 4,10; Table 8-1). These types of sites, ranked last in goat preference by Stevens (1979), are either resistant to goat use or, more likely, received little goat use in spite of high goat densities, or changes were simply not

visible.

At peak densities, goats in the Klahhane Ridge area were observed using small rocky outcrops on south facing slopes among stands of subalpine fir (Plate 11). According to Stevens (1979), while goats regularly used north facing slopes among subalpine fir to maintain lower body temperatures during summer hot spells, they infrequently used south slopes among the trees. The level of use on south facing rocky outcrops among the trees, however, was sufficient to cause a substantial reduction in plant cover. One such rocky outcrop mid-slope south of Klahhane Ridge exhibited dramatic recovery

between 1980 and 1986 (Plate 11). Increased cover on this site occurred sooner than other, more preferred sites. This particular rocky outcrop was apparently among the first to be abandoned by goats as densities were lowered - hence the rapid recovery. Species exhibiting increased cover included *Artemisia ludoviciana* and *Bromus sitchensis*.

Changes where major plant community components such as *Artemisia ludoviciana* were greatly reduced or eliminated by herbivory are best illustrated by Plate 8 beginning in 1970. These comparisons, of an Unstable Herb Meadow community in the North Cirque, show loss of the *Artemisia* by 1982, it's continued absence (or cover so low it is virtually undetectable) in 1985, and it's reappearance in 1990, when an estimated 3 goats remained in the area. This type of change might be attributed to annual variations in weather except that: 1) the photographs span seasons of both high and low precipitation (*Artemisia* was abundant in 1970, a dry summer following wetter summers, and was greatly reduced by 1982 which was also a dry summer following wetter summers), 2) permanent plot data do not show the wholesale loss of *Artemisia* which would be expected if weather was the cause (Schreiner 1987), and 3) *Artemisia* remained undetectable in the 1985 North Cirque photos even though it had reappeared by 1985 in another Klahhane Ridge site (i.e. in another location, *Artemisia* was undetectable in 1980 and reappeared in 1985 along with several other species because effective goat density had been reduced there sooner, see Plate 11). In other words, *Artemisia* cover seemed to reflect goat densities and not weather or snow pack patterns. That *Artemisia* was a selected goat forage species (Pfitch and Bliss 1985) further reinforces this interpretation.

A final question that needs to be addressed is "Why do the photographs from the 1940 and earlier show few changes due to goats?" The answer is that these photos are nearly all distant views of north facing slopes. The distance prevented detailed comparisons. Of the two available detailed views of

north-facing slopes, one showed a massive invasion of subalpine fir (Plate 2), and the other showed almost no vegetation to begin with, but did show signs of goat activity in 1986.

Results of the photographic comparisons showed that both introduced goats and climate have influenced vegetation and soils in the Klahhane Ridge area. Climatic changes were reflected by subalpine fir invasion of heath-shrub communities which make up about 7 percent of that portion of the goat summer range mapped by Pfitsch (1981). An additional 2 percent of the area was mapped as the Late Snow community type which exhibited no changes due to goats or climate. Changes in communities where vegetation was lost and then regained paralleled changes in goat density. Climate was largely ruled out as driving the major changes in these community types. Photographic comparisons, then, also lead to rejection of the null hypothesis: that reducing mountain goat densities will not result in changes to the relative abundance of plant species. Moreover, photographic comparisons documented changes in the relative abundance of plant species as mountain goat densities *increased*.

PLATE 1

Pair 62

LOCATION: View to the northwest of Heather Pass/First Divide and First Top, from the ridge east of Second Top (elev. 5900').

PHOTOGRAPHERS:

E.B. Webster (R. Dalton coll.), circa 1915-20s (from B/W copy neg.)

J. Burger, July 19, 1986 (50mm lens on Tech-Pan)

VEGETATIVE CHANGES:

Interval of ca. 65-70 years.

Middleground and background - The formerly bare slope in the center and right foreground is now being invaded by subalpine firs and lupine. However, the late snowmelt area at the lower left corner is still bare. Nor have subalpine firs become established in the area of the pass where snags persisted in the Webster photograph. The maintained trail is visible by 1986. The forested areas around the pass appear much more dense, though this may be caused just by individual tree growth rather than new tree establishment.

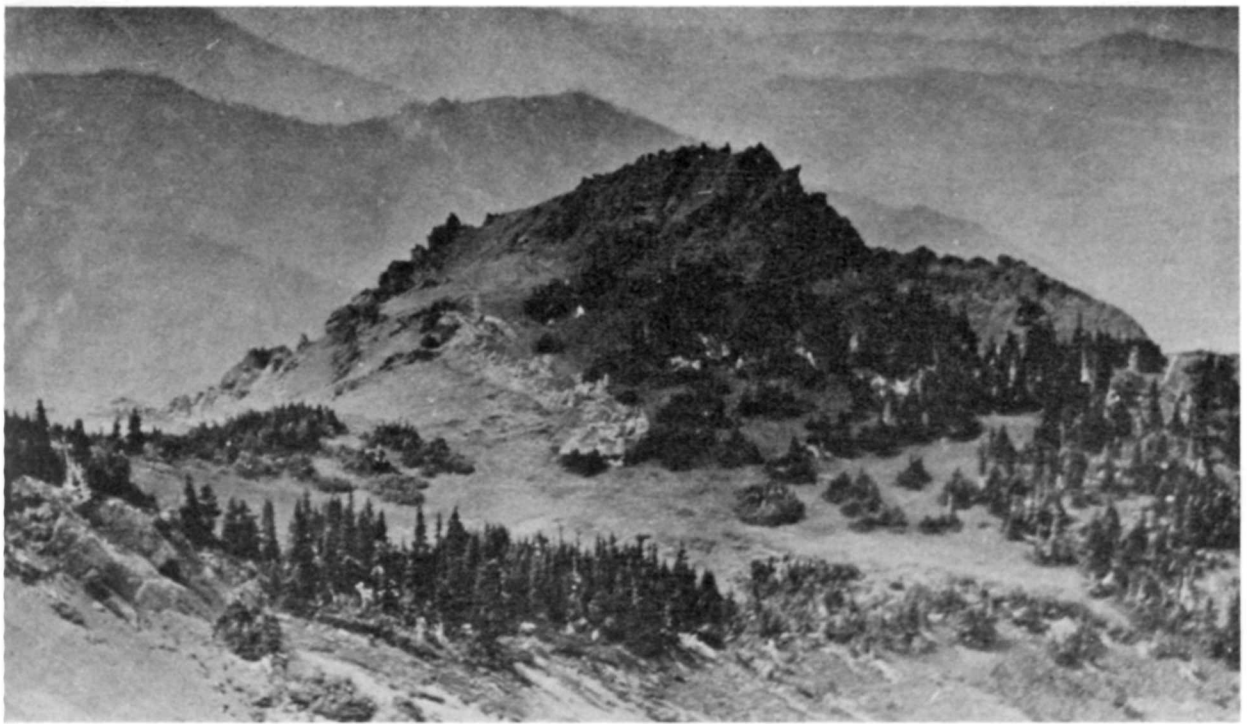


PLATE 2

Pair 65

LOCATION: Ed Webster and the view of the cirque north of Second Top (the peak south of Heather Pass/First Divide) taken from the trail east of the pass (elev. 5500').

PHOTOGRAPHERS:

T. Chambers coll., circa 1915-20s (from B/W copy neg.)

J. Burger, July 19, 1986 (28mm lens on Tech-Pan)

VEGETATIVE CHANGES:

Interval of ca. 65-70 years.

Foreground and middleground - The meadow has been invaded by subalpine firs and lupine. The solifluction lobes are no longer visible (though the increased plant cover may obscure them). By 1986 there are also subalpine firs established in formerly bare areas in the upper meadow. The maintained trail is visible in the lower right corner of the 1986 image.

Background - The far late snowmelt slope is still bare. Though a series of years with light snowpack probably allowed the tree establishment in the meadow, this area apparently received enough snow to prevent tree invasion.



PLATE 3

Pair 6

LOCATION: View to the northeast from the slope just north of Heather Pass/First Divide with the lowland around Sequim in the background (elev. 5650').

PHOTOGRAPHERS:

E.B. Webster (R. Dalton coll.), circa 1915-20s (from B/W copy neg.)

J. Burger, July 19, 1986 (50mm lens on Tech-Pan)

VEGETATIVE CHANGES:

Interval of ca. 65-70 years.

Foreground and middleground - Since the original photograph is slightly fuzzy, it is difficult to make exact comparisons. The foreground has large clumps of *Potentilla fruticosa* in 1986 which weren't evident in the original. However, the small, dark plant clumps visible in the original are no longer present. The only other change is the subalpine fir growth.

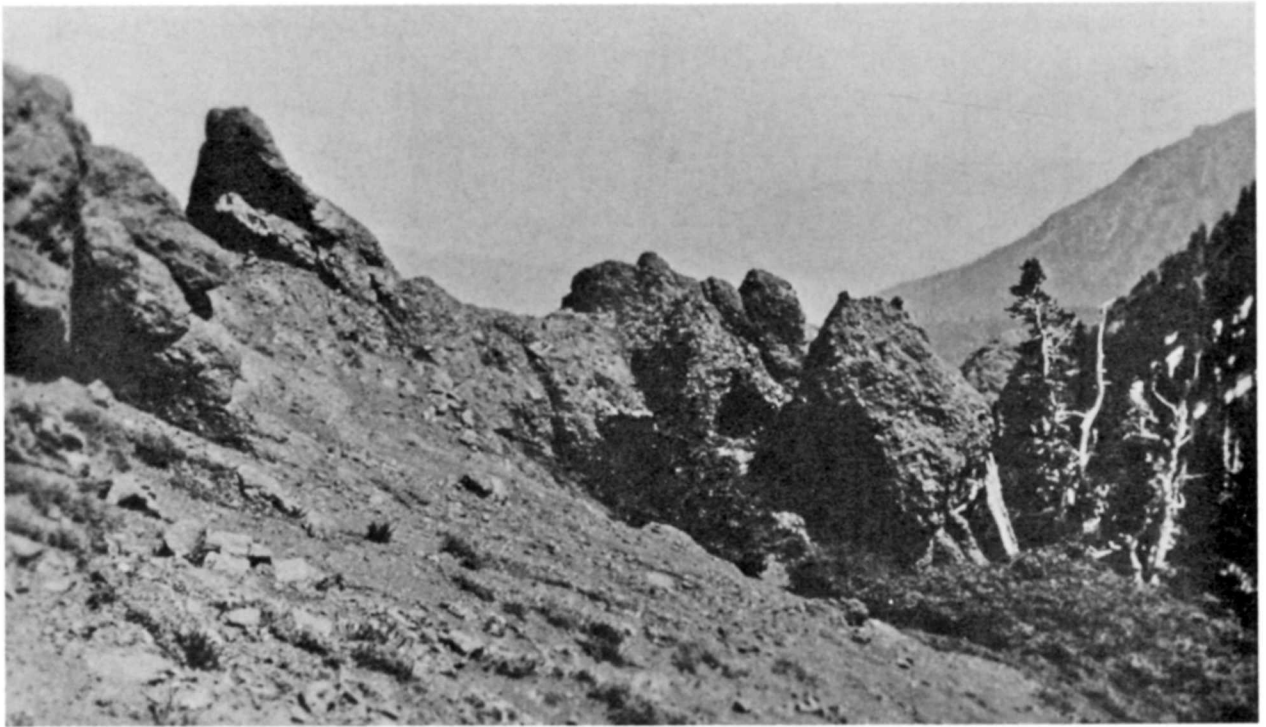


PLATE 4

Pair 44

LOCATION: Klahhane Ridge, view to the northwest over the meadow where the trail begins its descent toward Lake Angeles with the rocky shoulder of Second Peak in the background (elev. 5900').

PHOTOGRAPHERS:

C.N. Webster, circa 1940 (from B/W neg.)

J. Burger, August 24, 1985 (50mm lens, from color)

VEGETATIVE CHANGES:

Interval of ca. 45 years.

Middleground and background - By 1985 there is more bare ground along the lip of the meadow. On the left edge of the 1985 photograph a wallow is visible. There has been considerably regrowth among the burned snags both on the meadow lip and in the far right background burn.



PLATE 5

Pair 16a

LOCATION: North side of Klahhane saddle, about 5 m out trail toward Heather Park (elev. 5900').

PHOTOGRAPHERS:

J.W. Thompson (#1), 1960-64 (from color)

D.B. Houston, August 12, 1981 (from color)

VEGETATIVE CHANGES:

Interval of ca. 20 years.

Though the phenology seems similar, some of the differences in abundance of flowering plants may be due to climatic conditions or phenology.

Foreground and middleground - There are fewer flowering plants evident in 1981 (primarily *Phlox diffusa*, *Penstemon davidsonii*, and *Erigeron compositus*), and there is a general decrease in plant cover.

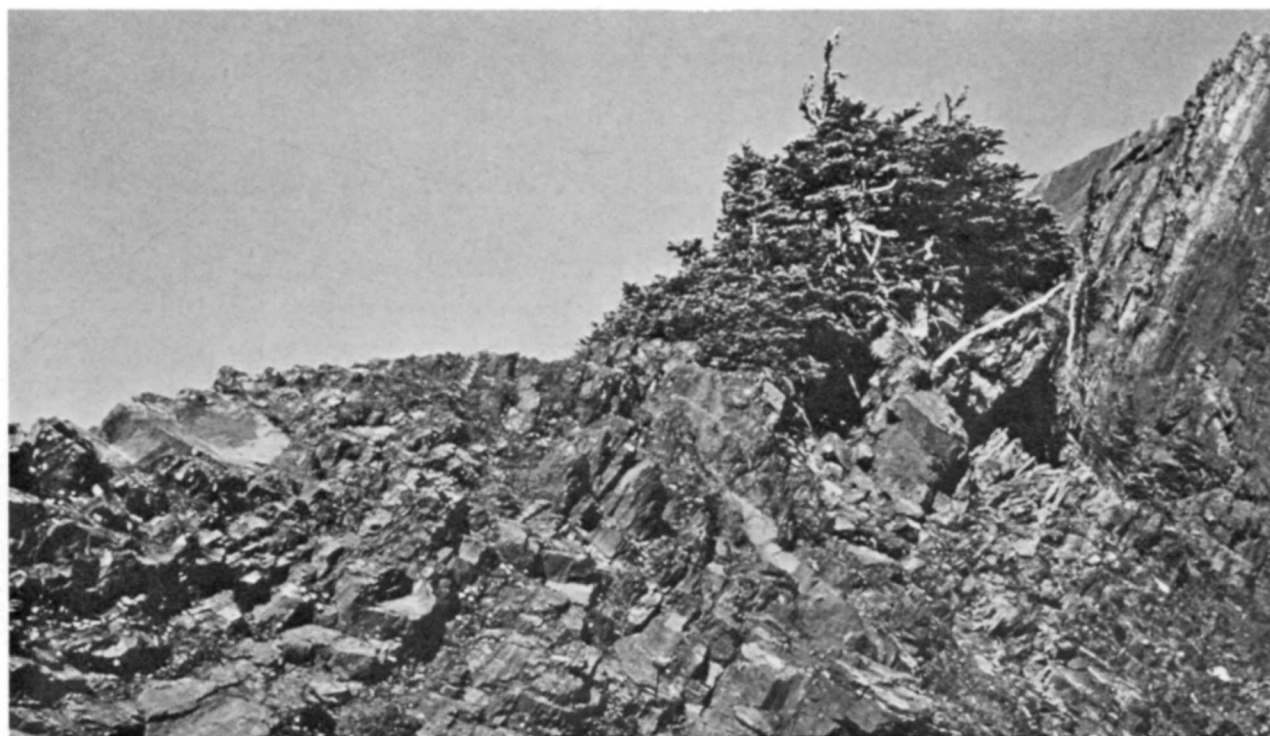


PLATE 6

Pair 38a

LOCATION: View of large "blowout" site on Klahhane Ridge, just east of where trail turns north to descend to Lake Angeles. View east from southeast of trail along the ridge crest (elev. 6000').

PHOTOGRAPHERS:

L. Lack (#2), June 1962 (from color)

D.B. Houston, August 21, 1981 (from color)

VEGETATIVE CHANGES:

Interval of 19 years.

This bare area may not have been started by goats, but heavy goat use exacerbated the damage by wallowing, removing plant cover and increasing the area's susceptibility to wind erosion. (See pairs 39 and 40 for details.)

Middleground and background - The middle and upper left of the "blowout" have eroded deeper and larger, with whole clumps of turf gone by 1981. The smaller bare areas to the left of the large one also eroded deeper. There are wallows visible in the center right slope in 1962, by 1981 this area appears to have less plant cover and some disturbed patches are still visible. The juniper clumps along the right edge are smaller and one is no longer visible.

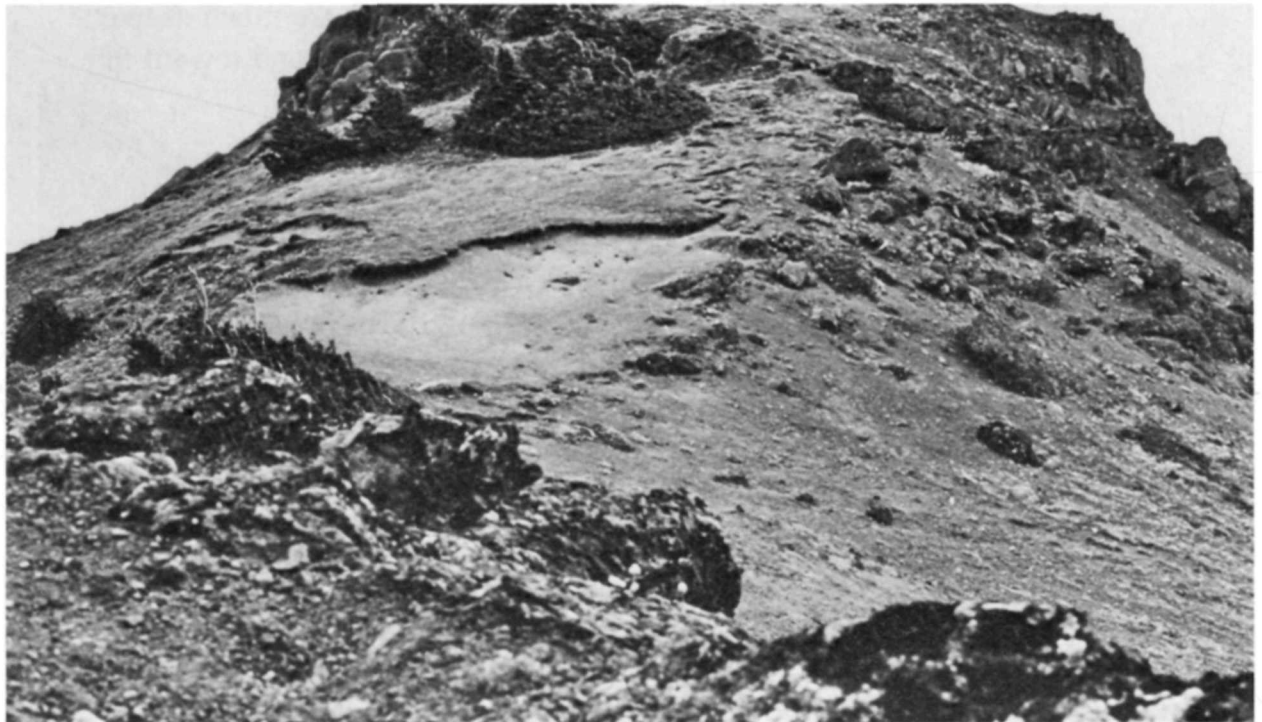


PLATE 7

Pair 41a

LOCATION: View of slope above (east of) large "blowout" site on Klahhane Ridge, just east of where trail turns north to descend to Lake Angeles (elev. 6000').

PHOTOGRAPHERS:

L. Lack (#4), August 31, 1964 (from color)

D.B. Houston, August 21, 1981 (from color)

VEGETATIVE CHANGES:

Interval of 17 years. (Also see pair 38 for overall view.)

Foreground and middleground - The whole area has less plant cover and much more churned up bare ground by 1981. The wallows on the left are much deeper and new wallows developed along the left edge and toward the center. There is an increase in *Achillea millefolium*.

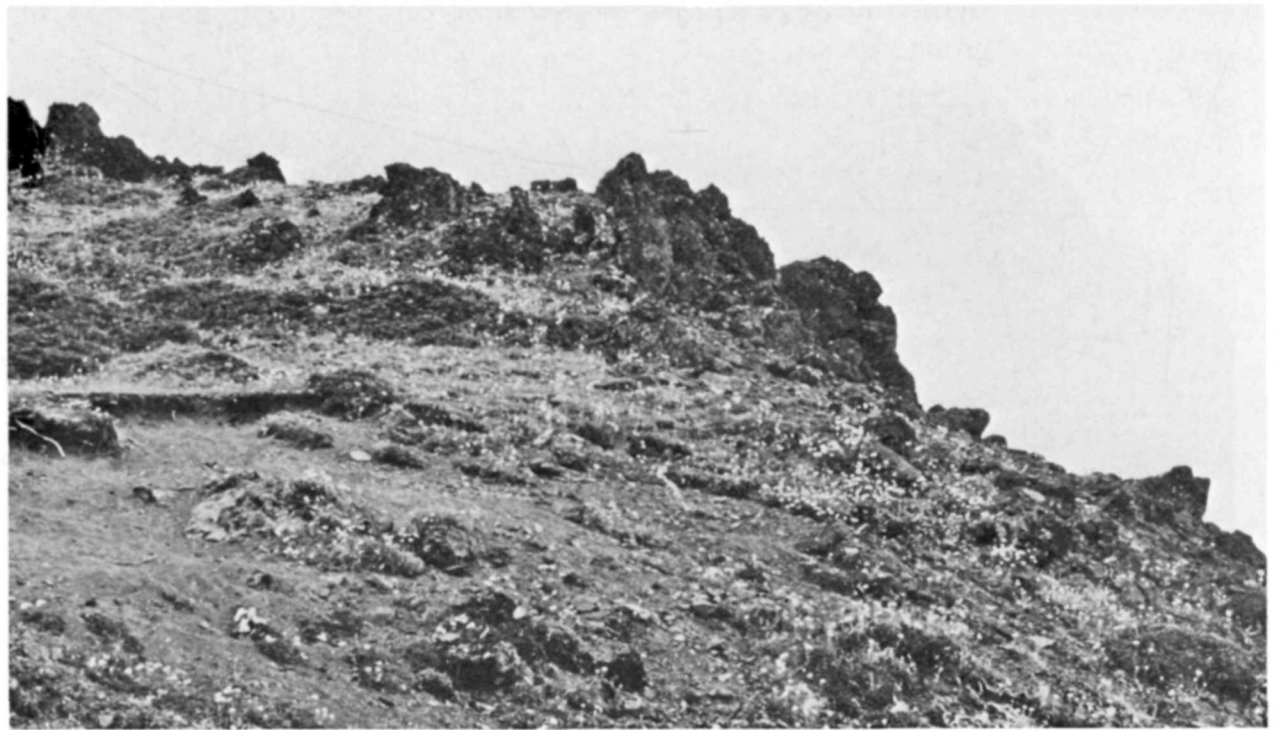


PLATE 8a

Pair 52a

LOCATION: Klahhane Ridge, view of the east-facing slopes of the cirque north of Klahhane Saddle, from just below the trail ca. 100 m before the trail begins switchbacks up to Second Divide (elev. 5500').

PHOTOGRAPHERS:

B. Moorhead (#1), August 27, 1970 (from color)

D.B. Houston, August 12, 1981 (from color)

VEGETATIVE CHANGES:

Interval of 11 years.

Foreground and middleground - As in Pair 51, there is a marked decrease in the plant cover, especially the light-colored *Artemisia ludoviciana*, on the middle and foreground slopes.

Background - There is also less plant cover on the far slope above and below the trail.



PLATE 8b

Pair 52b

LOCATION: Klahhane Ridge, view of the east-facing slopes of the cirque north of Klahhane Saddle, from just below the trail ca. 100 m before the trail begins switchbacks up to Second Divide (elev. 5500').

PHOTOGRAPHERS:

D.B. Houston, August 12, 1981 (from color)

J. Burger, August 6, 1985 (50mm lens, from color)

VEGETATIVE CHANGES:

Interval of four years during which the Klahhane Ridge goat population was drastically reduced.

Foreground and middleground - There appears to be a slight increase in plant cover on the middle and foreground slopes, though this may be caused by a difference in phenology making the plants appear more robust.

Background - There is no evident change.



PLATE 8c

Pair 52c

LOCATION: Klahhane Ridge, view of the east-facing slopes of the cirque north of Klahhane Saddle, from just below the trail ca. 100 m before the trail begins switchbacks up to Second Divide (elev. 5500').

PHOTOGRAPHERS:

D.B. Houston, August 12, 1981 (from color)

J. Burger, August 1, 1990 (50mm lens on Pan-X)

VEGETATIVE CHANGES:

Interval of nine years during which the Klahhane Ridge goat population was virtually eliminated.

Foreground and middleground - There is an increase in plant cover on the middle and foreground slopes (primarily *Artemisia ludoviciana*, *Phacelia hastata*, and *Cirsium edule*).

Background - There is increased plant cover above and below the trail on the center right slope.



PLATE 9

Pair 10

LOCATION: View of the slope above the Klahhane switchback trail ca. 30 m before the saddle (elev. 5880').

PHOTOGRAPHERS:

D. Pike, June 30, 1978 (from color)

J. Burger, July 15, 1985 (50mm lens, from color)

VEGETATIVE CHANGES:

Interval of seven years during which goat population on Klahhane Ridge was reduced by about 80%.

Foreground - Areas below the rock along the right edge and along the left edge appear to have more plant cover by 1985, mostly *Achillea millefolium* and grasses. This may be partially due to phenologic differences.

Notice the large difference in proportion of fine soils between the two photographs. The bottom photograph shows rock (talus size) compared to finer fragments in the top image.



PLATE 10

Pair 22

LOCATION: Klahhane Ridge, about 1 km east of Klahhane Saddle. View east toward Rocky Peak (elev. 6,100').

PHOTOGRAPHERS:

G. Fagerlund, September 2, 1956 (from ONP 2 1/4 neg. #3433)

J. Burger, August 23, 1986 (28mm lens, on Technical Pan)

VEGETATIVE CHANGES:

Interval of 30 years.

Foreground and middleground - The trail is new, but the meadow vegetation of *Carex spp.* and *Antennaria lanata* seems unchanged. Some of the subalpine firs in the background have died. The dead ones are close to the trail (right clump) or near a way trail frequently used by goats (left clump).



PLATE 11

Pair 7a

LOCATION: From along the Klahhane Switchback trail four switchbacks above the junction with the Hurricane Ridge trail. View to the southwest (elev. 5500').

PHOTOGRAPHERS:

M. Hutchins, July 1980 (from color)

J. Burger, July 15, 1986 (50mm lens on Plus-X)

VEGETATIVE CHANGES:

Interval of five years during which the Klahhane goat population was reduced by ca. 80%.

Though the foregrounds match well, it was difficult to match the perspective; Hutchins probably used a short telephoto lens. Note: because people shortcut the trail switchback in front of the center rock, this area is not likely to recover completely, even in the absence of goats.

Foreground and middleground - The phenology is later, but there is an obvious increase in plant cover by 1985, mostly *Cirsium edule*, *Artemisia ludoviciana*, *Hydrophyllum fendleri*, *Phacelia hastata*, and grasses.

Background - Plant cover on the rocky outcrop increased.



CHAPTER 9:**SYNTHESIS**

Plants and herbivores are inescapably linked. The specific type and magnitude of the interaction between herbivores and plants depends on the food habits, behavior and abundance of the herbivore, the growth form and physiology of the plants, and the dynamics of ecosystem processes where the herbivores and plants occur (Harper 1977, Crawley 1983, Abrahamson 1989). Herbivore populations influence vegetation in a variety of ways ranging from direct effects on individual plants to indirect effects on individual plants, plant communities, and ecosystem processes such as nutrient cycling (Floate 1981, Begon et al. 1986).

The direct influence of herbivores on individual plants is relatively straight-forward. Plants either lose a portion of their biomass or sustain tissue injuries from being consumed or trampled (Caughley 1976, Harper 1977, Floate 1981, Crawley 1983). Wallowing, especially by large herbivores, may also damage plant tissue; death of the plant often results when it is directly under the herbivore (Polley and Wallace 1986, Begon et al. 1986). Burrowing tends to cause root injuries, burial of plant parts and, presumably death if the plant is directly in the path of the larger burrowing animals (Platt 1975, del Moral 1984, Kreuger 1986, Coffin and Lauenroth 1988, Whicker and Detling 1988).

Indirect effects of herbivores on individual plants, communities, and ecosystem processes are legion. Herbivores may alter plant growth form and reproductive output (Islam and Crawley 1983, Paige 1992), or cause individuals to produce tannins as secondary compounds to deter herbivory (Harper 1977, Rhodes 1985). Wallowing and burrowing expose bare mineral soil which alters community composition in favor of ruderal plant species (Platt 1975, del Moral 1984, Pfitsch 1981, Polley and Wallace 1986, Whicker and Detling 1988). Relative abundance of plant species in the community may be altered because herbivores consume some species in preference to others (Ellison 1960, Anderson and Loucks 1979, McNaughton 1979, Day and Detling 1990, McInnes et al. 1992). A subtle, but important effect of herbivores on ecosystem processes also results from redistribution of nitrogen in soils caused by urine and fecal deposition (Begon et al. 1986, Reuss and McNaughton 1987, Coffin and Lauenroth 1988, Day and Detling 1990, Seagle et al. 1992, Frank and McNaughton 1992). The deposition of nitrogen in feces may alter the rate nitrogen is cycled through the ecosystem which in turn may affect the productivity of plant communities (Cargill and Jeffries 1984).

In common with all other studies of ungulate grazing systems, our work demonstrates that introduced mountain goats have indirect and direct effects on the vegetation of the Olympic Mountains. We have no particular reason to believe that the overall biotic effects of goats on the vegetation of the Olympics differs appreciably from mountain goat grazing systems where the animals are native. Nonetheless, changes in the park's vegetation have been substantial and the status of rare plant populations is of concern.

Mountain goats modified the structure of subalpine plant communities of the Olympics. Ruderal species such as *Achillea millefolium* decreased while selected species such as *Festuca idahoensis* increased as mountain goat density declined at Klahhane Ridge. *Achillea* cover exceeded that of *Festuca* when goat density was high and was less than *Festuca* by the end of the study period after goat density had been substantially reduced. We believe mountain goats changed the nature of the competitive relationship between these two species, particularly since a laboratory study demonstrated that *Festuca* was the stronger competitor except when clipped (del Moral 1985). Similar results showing changes in plant cover of these two species were visible in comparative photographs and were reported from the exclosure studies of Pfitsch and Bliss (1985) and Schreiner (1987).

Modifications of plant communities also occurred without necessarily changing the competitive interactions between plant species. Mount Dana plots exhibited changes in the plant cover of selected and non-selected plant species but this did not result in a change in dominance. Percent cover of dominant, strongly competitive species such as *Carex spectabilis*, appeared not to respond to lower goat density. This does not necessarily mean that *C. spectabilis* was unaffected by goats. *Carex spectabilis* is highly productive (Kuramoto and Bliss 1970, del Moral 1983a, 1984, 1985) and may compensate for loss of grazed plant tissues. Graminoid species are well-known for their compensatory response to grazing (McNaughton 1979, Begon et al. 1986).

Additionally, mountain goats influenced the vegetation of Olympic National Park by wallowing. Wallows disturb soils and create mineral substrates for colonization by plants. Studies of Klahhane Ridge goat wallows (Pfitsch 1981, Reid 1983) and bison wallows (Polley and Wallace 1986) showed that ruderal plant species dominate wallow edges and that this differs from surrounding vegetation. We did not examine vegetation surrounding goat wallows, but did document their presence in all study areas. It is probable that ruderal species have invaded these wallow edges as they have on Klahhane Ridge. Such a result is to be expected since Olympic subalpine and alpine plant communities are particularly sensitive to soil disturbance (Bell and Bliss 1973, Schreiner 1974, Belsky

and del Moral 1982, del Moral 1984). Other investigators believe that physical disturbances associated with herbivory may be more important than grazing (Harper 1977, Floate 1981).

We infer from the studies of rare plants that the long-term persistence of these taxa may be at risk from mountain goats. Direct effects were observed as mortality and injuries to individual *Astragalus australis* var. *olympicus* plants and the loss of biomass from grazing on other plant taxa. It was also demonstrated that rare plant distribution, including seven of eight endemic taxa, overlaps goat summer range. We note that the *effects of goats on individual plant taxa may be severe* or potentially severe, especially for taxa with very restricted distributions (i.e. those that occur in less than 5 subpopulations). This occurs with generalist herbivores, such as the goat, because the rare plants (which are palatable) are quantitatively insignificant compared to the food base that supports the ungulate population. Moreover, the potential effects of goat-induced disturbance on rare plants may well be exacerbated in the Olympics because many occur primarily in "fragile" subalpine and alpine areas. Rare, endemic plants have been driven to extinction or near extinction elsewhere by introduced herbivores (e.g. goats in Hawaii, Galapagos Islands; Loope et al. 1988).

We believe that what has been reported here represents only a small part of the total picture of mountain goat/vegetation relationships. Recent studies demonstrate that ungulates alter nitrogen cycles and soil formation processes (Day and Detling 1990, Frank and McNaughton 1992, McInnes et al. 1992). Moreover, vegetative changes wrought by one herbivore may influence the feeding behavior of other herbivores (Kreuger 1986, Day and Detling 1990). Given the relationship between site productivity and the degree of interspecific plant competition in Olympic subalpine vegetation (del Moral 1983a, 1985), mountain goats are likely to have a far greater influence on individual plants, communities, and ecosystem processes than we have demonstrated here.

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Appendix A. Major subalpine and alpine plant communities above 1500 m in Olympic National Park. Mean cover and frequency (%) from 767 recon plots.

Scree and Talus										Phlox diffusa communities									
Astrag. Phacelia Delphin. Senecio										-- Phlox diffusa --- Juniper. Phlox/Pachistima									
(n)	(51)	(58)	(18)	(15)						Potent. Festuca Carex p. Phlox Sedum Phacelia									
SPECIES	C	F	C	F	C	F	C	F		(53)	(93)	(42)	(44)	(82)	(26)				
Ast Aus	2.5	90																	
Cre Nan	0.3	45																	
Cam Pip	0.2	31																	
Phl Dif	0.5	55	1.4	48			0.1	40		3.9	98	14.1	90	8.5	100	3.6	91	7.2	90
Ach Mil	0.3	35	1.2	50	0.3	33				1.6	83	2.7	88			0.7	75	0.5	46
Pot Fru										4.4	64					1.2	32		54
Eri Com	0.1	33								0.7	77					0.2	34		
Pha Ser	0.2	43			0.2	33				0.6	64								
Sit Hys	0.1	31								0.3	60					0.2	45		
Sme Cal										0.8	43								
Sol Mul										1.7	42								
Syn Pin										1.1	36								
Fes Ovi										0.4	60			0.2	40	0.3	59		
Luz Spi										0.4	42								
Fes Ida										1.0	47	11.0	85						
Ago spp.			0.4	66								1.3	69						
Sil Par												1.0	66			1.1	43	0.4	46
Are Cap												3.6	62	0.4	31				
Cam Rot												1.2	44						
Vio Adu												0.5	45			0.2	32		
Pol Bis												1.1	41						
Ali Cre												1.2	35						
Car Pha										1.2	55	0.5	31	3.8	79	0.2	48		
Tri Spi														1.0	57	0.3	45		
Car Spe														2.2	31				
Lup Lat			2.9	26										3.5	40	1.9	43		
Jun Com														15.4	84				
Sax Bro														1.1	64				
Pen Dav														1.4	66	0.9	51	0.1	19
Epi Ang														0.3	32				
Sed Div							0.2	47						0.5	50	1.2	71	2.6	73
Pac Myr																3.4	60	1.7	58
Dou Lee					0.2	33				0.7	38			0.5	40	0.6	59	1.6	66
Cry Cri																0.3	54	0.2	27
Lui Hyp																1.4	34	1.4	31
Pha Has		10.5	89	2.0	33											0.3	30	1.7	100
Epi Alp		1.1	74	1.4	61	0.7	80					0.1	36						
Hyd Fen		6.9	57																
Cir Edu		3.4	53																
Ast Pau		3.6	48													1.1	43	0.1	27
Art Lud		6.1	50															2.5	54
Bro Sit		0.4	48																
Del Gla				11.1	100	0.3	40												
Col Deb				0.6	39														
San Neo				1.6	33	1.8	93												
Elm Rac						0.7	53												
Oxy Dig						0.1	33												
Total Cover	7.0	54.7	25.7	8.7						32.9	67.3	31.3	39.4	34.8	32.0				

Appendix A. (continued)

Carex spectabilis communities

SPECIES	Carex - Valeriana (43)		Vaccinium (31)		Carex - Lupinus (101)		Phyllodoce (60)		Cassiope (38)		Luetkea - Saxifraga (9)	
	C	F	C	F	C	F	C	F	C	F	C	F
Car Spe	16.2	86	10.5	78	14.2	88	2.9	65	1.5	76	0.7	33
Val Sit	2.5	77	1.8	59								
Pte Aqu	2.0	2			1.0	11						
Epi Alp	0.8	77									0.1	33
Ver Vir	3.7	42										
Ast Pau	2.2	44										
Cir Edu	0.9	40										
Bro Sit	0.5	30										
Vac Del	4.5	23	25.7	75	1.0	15	13.7	63	1.1	22		
Lup Lat	4.2	51	13.1	88	8.7	63	2.2	42				
Pol Bis	1.5	70	3.7	94	2.1	63	1.5	65	0.6	35		
Eri Per	1.0	42	2.1	75	1.8	45	0.2	31				
Hie Gra			0.5	69	0.9	67	0.8	77	0.9	81	0.1	33
Luz Cam			0.5	63	0.4	50	0.3	49	0.2	41		
Poa Sec	0.5	35	0.3	44					0.2	32		
Lue Pec			3.6	41	6.1	61	5.6	78	12.2	86	4.6	78
Jun Par					2.5	52	1.6	34	2.4	49		
Lom Mar					0.4	46						
Phl Dif			0.6	38	4.0	57			0.4	41		
Phy Emp			2.6	41			26.9	89	1.1	43		
Ery Mon							0.6	32				
Cas Par							0.4	48	0.5	38		
Cas Mer							6.0	31	12.7	70	0.4	33
Abi Las									4.9	57	0.1	33
Luz Par	0.4	37	0.4	38					0.7	51	1.1	44
Ant Lan					1.3	28			5.4	43		
Rho Alb									1.1	5		
Sax Tol											3.2	78
Des Atr											1.9	67
Jun Dru											1.1	78
Sax Fer											0.4	44
Car Nig					1.3	16					9.0	33
Jun Mer											0.4	33
Ran Ver											0.1	33

Total Cover 61.7 105.5 61.9 74.9 55.0 26.5

Appendix B. Plants species classified as selected and non-selected at Klahhane Ridge and Mount Dana and as expected to recover or not recover at Avalanche Canyon. Species listed for Klahhane Ridge are from Pfitsch and Bliss (1985).

KLAHHANE RIDGE

Selected

Agoseris spp.
Artemisia ludoviciana
Aster paucicapitatus
Bromus sitchensis
Campanula rotundifolia
Carex spectabilis
Erigeron peregrinus
Festuca idahoensis
Hedysarum occidentale
Lomatium martindalei
Lomatium nudicaule
Poa secunda
Polygonum bistortoides
Silene parryi

Non-selected

Antennaria spp.
Arabis spp.
Arenaria rubella
Cassiope mertensiana
Cirsium edule
Delphinium glareosum
Deschampsia atropurpurea
Erysimum arenicola
Hieracium gracile
Juniperus communis
Lathyrus nevadensis
Luetkea pectinata
Orthocarpus imbricatus
Polygonum douglasii
Ranunculus eschscholtzii
Vicia americana

MOUNT DANA

Selected

Agoseris spp.
Carex rossii
Carex spectabilis
Deschampsia atropurpurea
Hieracium gracile
Juncus parryi
Pachistima myrsinites
Polygonum bistortoides
Silene parryi

Non-selected

Abies lasiocarpa
Antennaria lanata
Antennaria microphylla
Arenaria capillaris
Cheilanthes gracile
Claytonia lanceolata
Cryptogramma crista
Douglasia laevigata
Epilobium alpinum
Festuca ovina
Juniperus communis
Luetkea pectinata
Lupinus latifolius
Phlox diffusa
Sedum divergens

Appendix B. (continued)

AVALANCHE CANYON

	Recover	No Recover
P1	<i>Achillea millefolium</i> <i>Arabis</i> spp. <i>Hieracium gracile</i> <i>Juncus parryi</i> <i>Lomatium nudicaule</i> <i>Luzula spicata</i> <i>Pachistima myrsinites</i> <i>Poa cusickii</i> <i>Poa secunda</i> <i>Poa</i> spp. <i>Senecio flettii</i> <i>Solanum multiradiata</i>	<i>Agoseris</i> spp. <i>Arnica</i> spp. <i>Carex nigricans</i> <i>Carex phaeocephala</i> <i>Carex spectabilis</i> <i>Carex</i> spp. <i>Lomatium martindalei</i> <i>Penstemon procerus</i> <i>Polygonum bistortoides</i> <i>Silene parryi</i> <i>Veronica cusickii</i>
P2	<i>Bromus sitchensis</i> <i>Cirsium edule</i> <i>Hydrophyllum fendleri</i> <i>Polemonium pulcherrimum</i> <i>Lomatium martindalei</i>	<i>Agoseris</i> spp. <i>Castilleja miniata</i>
P3	<i>Cirsium edule</i> <i>Hydrophyllum fendleri</i> <i>Agoseris</i> spp. <i>Lomatium martindalei</i>	<i>Achillea millefolium</i> <i>Elmera racemosa</i> <i>Epilobium alpinum</i>
P4	<i>Aquilegia formosa</i> <i>Arabis</i> spp. <i>Arnica latifolia</i> <i>Arnica</i> spp. <i>Hydrophyllum fendleri</i> <i>Carex spectabilis</i> <i>Juncus</i> spp. <i>Phleum alpinum</i> <i>Viola adunca</i>	<i>Agoseris aurantiaca</i> <i>Agoseris</i> spp. <i>Campanula rotundifolia</i> <i>Carex nigricans</i> <i>Carex</i> spp. <i>Cirsium edule</i> <i>Epilobium alpinum</i> <i>Erigeron peregrinus</i> <i>Lomatium martindalei</i> <i>Penstemon procerus</i> <i>Poa cusickii</i> <i>Poa</i> spp. <i>Polygonum bistortoides</i> <i>Sibbaldia procumbens</i> <i>Silene parryi</i> <i>Trisetum spicatum</i> <i>Veronica cusickii</i>

Appendix B. (continued)

AVALANCHE CANYON

	Recover	No Recover
P5	<i>Arabis hirsuta</i> <i>Delphinium glareosum</i> <i>Poa secunda</i> <i>Sedum divergens</i> <i>Viola adunca</i>	<i>Bromus sitchensis</i> <i>Campanula rotundifolia</i> <i>Epilobium alpinum</i> <i>Epilobium spp.</i> <i>Hydrophyllum fendleri</i> <i>Poa spp.</i> <i>Sitanion hystrix</i>
P6	<i>Phacelia hastata</i> <i>Phleum alpinum</i>	<i>Delphinium glareosum</i> <i>Epilobium alpinum</i> <i>Luzula parviflora</i> <i>Poa spp.</i> <i>Senecio flettii</i> <i>Valeriana sitchensis</i>

Appendix C. Individuals or organizations which kindly shared their historic photographs for use in repeat photography studies.

British Columbia Provincial Archives
Howard Cameron
Paul Cameron
Clallam County Historical Society
Russ Dalton
Marion Harthill
Michael Hutchins
Glenn Kelsey
Klahhane Club
Larry Lack, Sr.
The Mountaineers
John and June Nelson
Richard Olson
Olympic National Forest
Oregon Historical Society
Bill Pfitsch
Harold Pinch
Douglas Pike
Dawn Ronlund
Konrad Schwencke
Rosemary Taylor
J.W. Thompson Co.
Dr. Keith Thompson
University of Washington
Washington State Historical Society
Esther Webster
Mark Welch

Appendix D. Plant codes and scientific names.

CODE	GENUS	SPECIES	VARIETY OR SSP
Abi Ama	Abies	amabilis	
Abi Las	Abies	lasiocarpa	
Ach Mil	Achillea	millefolium	
Ago Aur	Agoseris	aurantiaca	
Ago Gla	Agoseris	glauca	
Ago spp.	Agoseris	spp.	
Agr Can	Agropyron	caninum	subsp. majus
Agr Exa	Agrostis	exarata	
Agr Sca	Agrostis	scabrella	
Agr Thi	Agrostis	thurberiana	
Agr Var	Agrostis	variabilis	
Ali Cre	Allium	crenulatum	
All Cer	Allium	cernuum	
Ame Aln	Amelanchier	alnifolia	
Ana Mar	Anaphalis	margaritacea	
Ane Dru	Anemone	drummondii	drummondii
Ane Dru	Anemone	drummondii	
Ane Lya	Anemone	lyalii	
Ane Mul	Anemone	multifida	
Ane Occ	Anemone	occidenalis	
Ant Alp	Antennaria	alpina	media
Ant Lan	Antennaria	lanata	
Ant Mic	Antennaria	microphylla	
Ant Rac	Antennaria	racemosa	
Ant Umb	Antennaria	umbrinella	
Aqu For	Aquilegia	formosa	
Ara Hir	Arabis	hirsuta	
Ara Spp	Arabis	unknown	
Arc Uva	Arctostaphylos	uva-ursi	
Are Cap	Arenaria	capillaris	
Are Mac	Arenaria	macrophylla	
Are Obt	Arenaria	obtusiloba	
Are Ros	Arenaria	rossii	
Are Rub	Arenaria	rubella	
Arn Div	Arnica	diversifolia	
Arn Lat	Arnica	latifolia	
Arn Par	Arnica	parryi	parryi
Arn Ryd	Arnica	rydbergii	
Art Lud	Artemisia	ludoviciana	
Art Nor	Artemisia	norvegica	
Ast Alp	Aster	alpigenus	alpigenus
Ast Aus	Astragalus	australis	olympicus
Ast Fol	Aster	foliaceus	foliaceus
Ast Pau	Aster	paucicapitatus	
Ath Dis	Athyrium	distentifolium	americanum
Ath Fil	Athyrium	filix-femina	
Ble Spi	Blechnum	spicant	
Bot Lan	Botrychium	lanceolatum	
Bot Mul	Botrychium	multifidum	
Bro Car	Bromus	carinatus	
Bro Sit	Bromus	sitchensis	
Cal Bif	Caltha	biflora	biflora
Cal Ine	Calamagrostis	inexpansa	barbulata
Cal Pur	Calamagrostis	purpurascens	

Appendix D. Plant codes and scientific names.

CODE	GENUS	SPECIES	VARIETY OR SSP
Cal Ses	Calamagrostis	sesquiflora	
Cam Pip	Campanula	piperi	
Cam Rot	Campanula	rotundifolia	
Car Alb	Carex	albonigra	
Car Aur	Carex	aurea	
Car Cal	Carex	californica	
Car Hoo	Carex	hoodii	
Car Ill	Carex	illota	
Car Nig	Carex	nigricans	
Car Obt	Carex	obtusata	
Car Oed	Carex	oederi	viridula
Car Oli	Cardamine	oligosperma	kamschatica
Car Pha	Carex	phaeocephala	
Car Plu	Carex	pluriflora	
Car Pyr	Carex	pyrenaica	
Car Ray	Carex	raynoldsii	
Car Ros	Carex	rossii	
Car Spe	Carex	spectabilis	
Car Spp	Carex	spp.	
Car mer	Carex	mertensia	
Cas His	Castilleja	hispida	
Cas Mer	Cassiope	mertensiana	
Cas Min	Castilleja	miniata	
Cas Par	Castilleja	parviflora	
Cer Arv	Cerastium	arvense	
Cha Noo	Chamaecyparis	nootkatensis	
Che Gra	Cheilanthes	gracillima	
Cir Edu	Cirsium	edule	
Cla Lan	Claytonia	lanceolata	
Col Deb	Collomia	debilis	larsenii
Col Par	Collinsia	parviflora	
Cre Nan	Crepis	nana	subsp. nana
Cre Occ	Crepis	occidentalis	
Cry Cri	Cryptogamma	crispa	acrostichoides
Cry Int	Cryptantha	intermedia	
Cys Fra	Cystopteris	fragilis	
Dan Int	Danthonia	intermedia	
Del Gla	Delphinium	glareosum	
Del Men	Delphinium	menziesii	
Del Nut	Delphinium	nuttallii	
Des Atr	Deschampsia	atropurpurea	
Des Cae	Deschampsia	caespitosa	
Dod Jef	Dodecatheon	jeffreyi	
Dou Lae	Douglasia	laevigata	
Dra Ind	Draba	incerta	
Dra Lon	Draba	loncharpa	
Dra Pay	Draba	paysonis	
Dra Spp	Draba	spp.	
Dro Rot	Drosera	rotundifolia	
Elm Rac	Elmera	racemosa	
Ely Gla	Elymus	glaucus	?
Ely Hir	Elymus	hirsutus	
Emp Nig	Empetrum	nigrum	
Epi Alp	Epilobium	alpinum	
Epi Ang	Epilobium	angustifolium	

Appendix D. Plant codes and scientific names.

CODE	GENUS	SPECIES	VARIETY OR SSP
Epi Glab	Epilobium	glaberrimum	
Epi Glan	Epilobium	glandulosum or glaberr	
Epi Lat	Epilobium	latifolium	
Epi Lut	Epilobium	luteum	
Epi Min	Epilobium	minutum	
Epi Mir	Epilobium	mirabile	
Epi Pan	Epilobium	paniculatum	paniculatum
Epi Spp	Epilobium	spp.	
Eri Cha	Eriophorum	chamissonis	
Eri Com	Erigeron	compositus	
Eri Fle	Erigeron	flettii	
Eri Lan	Eriophyllum	lanatum	
Eri Ova	Eriogonum	ovalifolium	
Eri Per	Erigeron	peregrinus	
Eri Spp	Erigeron	spp.	
Eri Sub	Erigeron	subtrinervis	conspicuus
Ery Are	Erysimum	arenicola	torulosum
Ery Gra	Erythronium	grandiflorum	grandiflorum
Ery Mon	Erythronium	montanum	
Fes Ida	Festuca	idahoensis	
Fes Ovi	Festuca	ovina	
Fes Sub	Festuca	subulata	
Fra Ves	Fragaria	vesca	
Fra Vir	Fragaria	virginiana	
Gal Bif	Galium	bifolium	
Gal Spl	Galium	unknown species #1	
Gal Tri	Galium	Trifidum or triflorum	
Gal Tri	Galium	trifidum or triflorum	
Gau Ova	Gaultheria	ovatifolia	
Gen Ama	Gentiana	amarella	
Gen Cal	Gentiana	calycosa	
Gen Dou	Gentiana	douglasiana	
Gen Sce	Gentiana	sceptrum	
Geu Tri	Geum	triflorum	campanulatum
Hab Una	Habenaria	unalascensis	
Hap Lya	Haplopappus	lyallii	
Hed Occ	Hedysarum	occidentale	
Heu Gla	Heuchera	glabra	
Heu Mic	Heuchera	micrantha	diversifolia
Hie Alb	Hieracium	albiflorum	
Hie Gra	Hieracium	gracile	
Hyd Fen	Hydrophyllum	fendleri	albifrons
Hyp Ana	Hypericum	anagalloides	
Jun Bal	Juncus	balticus	balticus
Jun Com	Juniperus	communis	montana
Jun Cov	Juncus	covillei	covillei
Jun Dru	Juncus	drummondii	subtriflorus
Jun Mer	Juncus	mertensianus	
Jun Par	Juncus	parryi	
Jun Sp	Juncus	sp.	
Kal Occ	Kalmia	occidentalis	
Koe Cri	Koeleria	cristata	
Lat Nev	Lathyrus	nevadensis	ssp lanceolatus var pilos
Led Gro	Ledum	groenlandicum	

Appendix D. Plant codes and scientific names.

CODE	GENUS	SPECIES	VARIETY OR SSP
Lep Pyr	Leptarrhena	pyrolifolia	
Lew Col	Lewisia	columbiana	rupicola
Lil Col	Lillium	colmbianum	
Lin Bor	Linnaea	borealis	
Lit Bul	Lithophragma	bulbifera	
Lom Mar	Lomatium	martindalei	flavum
Lom Nud	Lomatium	nudicaule	
Lom Utr	Lomatium	utriculatum	
Lue Pec	Luetkia	pectinata	
Lui Hyp	Luina	hypoleuca	
Lup Lat	Lupinus	latifolius	
Lup Lep	Lupinus	lepidus	lobbii
Lux Pip	Luzula	piperi	
Luz Cam	Luzula	campestris	
Luz Hit	Luzula	hitchcockii	
Luz Par	Luzula	parviflora	
Luz Spi	Luzula	spicata	
Luz Spp	Luzula	spp.	
Lyc Inu	Lycopodium	inundatum	
Lyc Sit	Lycopodium	sitchense	
Lyc Uni	Lycopus	uniflorus	
Lys Ame	Lysichitum	americanum	
Mel Sub	Melica	subulata	subulata
Mer Pan	Mertensia	paniculata	borealis
Mic Gra	Microsteris	gracilis	
Mim Gut	Mimulus	guttatus	
Mim Lew	Mimulus	lewisii	
Mim Til	Mimulus	tilingii	
Mit Bre	Mitella	breweri	
Mit Pen	Mitella	pentandra	
Mit Tri	Mitella	trifida	
Mon Cor	Montia	cordifolia	
Mon Par	Montia	parvifolia	
Myr Gal	Myrica	gale	
Not Nem	Nothochechone	nemorosa	
Oro Fas	Orobanche	fasciculata	
Oro Uni	Orobanche	uniflora	purpurea
Ort Inb	Orthocarpus	imbricatus	
Osm Spp	Osmorrhiza	spp	
Oxy Cam	Oxytropus	campestris	gracilis
Oxy Dig	Oxyria	digyna	
Oxy Vis	Oxytropus	viscida	
Pac Myr	Pachistima	myrsinites	
Par Fim	Parnassia	fimbriata	fimbriata
Ped Bra	Pedicularis	bracteosa	atrosanguinea
Ped Rac	Pedicularis	racemosa	racemosa
Pen Dav	Penstemon	davidsonii	
Pen Pro	Penstemon	procerus	tolmiei
Pen Ser	Penstemon	serrulatus	
Pet Fri	Petasites	frigidus	nivalis
Pet Hen	Petrophytum	hendersonii	
Pha Has	Phacelia	heterophylla	
Pha Ser	Phacelia	sericea	sericea
Phl Alp	Phleum	alpinum	
Phl Dif	Phlox	diffusa	longistyla

Appendix D. Plant codes and scientific names.

CODE	GENUS	SPECIES	VARIETY OR SSP
Phl Hen	Phlox	hendersonii	
Phy Emp	Phyllodoce	empetriformis	
Phy Gla	Phyllodoce	glanduliflora	
Phy Int	Phyllodoce	x intermedia	
Pin Alb	Pinus	albicaulus	
Pin Mon	Pinus	monticola	
Pla Mac	Plantago	macrocarpa	
Poa Cus	Poa	cusickii	
Poa Lep	Poa	leptocoma	
Poa Pra	Poa	pratensis	
Poa Sec	Poa	secunda	
Poa Sp	Poa	sp.	
Pol Bis	Polygonum	bistortoides	
Pol Dou	Polygonum	douglasii	
Pol Hes	Polypodium	hesperium	
Pol Lon	Polystichum	lonchitus	
Pol Min	Polygonum	minimum	
Pol Mun	Polystichum	munitum	
Pol New	Polygonum	newberri	glaucum
Pol Pul	Polemonium	pulcherrimum	
Pot Div	Potentilla	diversifolia	diversifolia
Pot Dru	Potentilla	drummondii	
Pot Fla	Potentilla	flabellifolia	
Pot Fru	Potentilla	fruticosa	
Pot Gla	Potentilla	glandulosa	glandulosa
Pot Vil	Potentilla	villosa	
Pre Ala	Prenanthes	alata	
Pru Ema	Prunus	emarginata	
Pse Men	Pseudotsuga	menziesii	
Pte Aqu	Pteridium	aquilinum	
Pyr Sec	Pyrola	secunda	
Ran Esc	Ranunculus	eschschooltzii	
Ran Ver	Ranunculus	verecundus	
Rho Alb	Rhododendron	albiflorum	
Rib How	Ribes	howellii	
Rib Lac	Ribes	lacustre	
Ror Cur	Rorripa	curvisiliqua	
Ros Gym	Rosa	gymnocarpa	
Ros Nut	Rosa	nutkana	nutkana
Rub Las	Rubus	lasiococcus	
Rub Par	Rubus	parviflorus	
Rub Ped	Rubus	pedatus	
Sag Sag	Sagina	saginoides	
San Gra	Sanicula	graveolens	
San Off	Sanguisorba	officinalis	
Sau Ame	Sauseria	americana	
Sax Arg	Saxifraga	arguta	
Sax Bro	Saxifraga	bronchialis	
Sax Cae	Saxifraga	caespitosa	emmarginat
Sax Fer	Saxifraga	ferruginea	macounii (?)
Sax Occ	Saxifraga	occidentalis	rufidula
Sax Pun	Saxifraga	punctata	cascadensis
Sax Tol	Saxifraga	tolmiei	tolmiei
Sed Div	Sedum	divergens	

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CODE	GENUS	SPECIES	VARIETY OR SSP
Sed Lan	Sedum	lanceolatum	
Sed Spp	Sedum	unknown	
Sed Ste	Sedum	stenopetalum	
Sel Den	Selaginella	densa	scopulorum
Sel Wal	Selaginella	wallacei	
Sen Fle	Senecio	fletti	
Sen Neo	Senecio	neowebsteri	
Sen Tri	Senecio	triangularis	?
Sib Pro	Sibbaldia	procumbens	
Sil Aca	Silene	acaulis	exscapa
Sil Dou	Silene	douglasii	douglasii
Sil Par	Silene	parryi	
Sis Ang	Sisyrinchium	angustifolium	
Sis Dou	Sisyrinchium	douglasii	
Sit Hys	Sitanion	hystrix	hystrix
Sme Cal	Smelowskia	calycina	americana
Smi Ste	Smilacina	stellata	
Sol Mul	Solidaga	multiradiata	scopulorum
Sor sit	Sorbus	sitchensis	
Spi Den	Spiraea	densiflora	
Spi Rom	Spiranthes	romanzoffiana	romanzoffiana
Ste Cal	Stellaria	calycantha	?
Sti Occ	Stipa	occidentalis	minor
Sym Alb	Symphoricarpos	albus	
Syn Pin	Synthyris	pinnatifida	lanuginosa
Tar Off	Taraxacum	officinale	
Tax Bre	Taxus	brevifolia	
Tha occ	Thalictrum	occidentale	
Thl Fen	Thlaspi	fendleri	glaucum
Thu Pli	Thuja	plicata	
Tof Glu	Tofieldia	glutinosa	brevistyla
Tra Car	Trautvetteria	caroliniensis	occidentalis
Tri Spi	Trisetum	spicatum	
Tsu Mer	Tsuga	mertensiana	
Vac Cae	Vaccinium	caespitosum	
Vac Del	Vaccinium	deliciosum	
Vac Mem	Vaccinium	membranaceum	
Vac Oxy	Vaccinium	oxycoccos	
Val Sco	Valeriana	scouleri	
Val Sit	Valeriana	sitchensis	
Ver Cus	Veronica	cusickii	
Ver Sp	Veronica	sp.	
Ver Vir	Veratrum	viride	
Ver Wor	Veronica	wormskjoldii	
Vic Ame	Vicia	americana	truncata
Vio Adu	Viola	adunca	?
Vio Fle	Viola	fletti	
Vio Gla	Viola	glabella	
Woo Sco	Woodsia	scopulina	
Xer Ten	Xerophyllum	tenax	