EFFECTS OF MOUNTAIN GOATS ON SOILS, PLANT COMMUNITIES, AND SELECT SPECIES IN OLYMPIC NATIONAL PARK

W. Pfitsch; R.S. Reid; J. Harter; D.K. Pike; L.C. Bliss.

Department of Botany and College of
Forest Resources
University of Washington
Seattle, Washington 98195

Contract #CX 9000-0-E087

Final Report
July 1983

TABLE OF CONTENTS

Page

Appendices A-E

These appendices appear in a separate publication. If needed, contact the following office:

Office of Science and Technology
Olympic National Park
600 E. Park Avenue
Port Angeles, WA 98362

(206) 452-4501 ext. 223

EFFECTS OF MOUNTAIN GOATS ON SOILS, PLANT COMMUNITIES AND SELECT SPECIES IN OLYMPIC NATIONAL PARK

INTRODUCTION

Mountain goats (Oreamnos americanus) are a widely distributed ungulate in North America. However, they are not indigenous to the Olympic Mountains although they were introduced to the area in the late 1920's. The population grew and spread throughout the alpine and subalpine areas of the Olympic Peninsula (Moorhead 1977). In 1981 the population was estimated to number 500 to 700 animals, mostly within the Olympic National Park (Stevens 1983).

The highest density of mountain goats occurs on Klahhane Ridge, an east-west ridge in the north central part of the Park (47°59'30"N, 123°27'30"W). In 1980 the population was estimated to be about 180 animals within an area of 13km^2 (Stevens 1983). This concentration of 14 goats/km^2 compares with density estimates of 0.5 and 2.8 goats/km^2 for natural populations in Glacier National Park (Chadwick 1977, Singer 1975). The higher densities result from estimates in rocky terrain, an essential habitat for the species. The high densities on Klahhane Ridge result from availability of rocky terrain for escape, open meadows for forage, and north-facing slopes for thermoregulation in summer (Stevens 1979).

The Administration of the Park recognized the rapid increase in population size and thus initiated a removal program in June 1981. In the three summers, 156 animals have been removed from the Klahhane Ridge area. The effect of this removal program was not possible to estimate during our study.

This study was initiated in 1978 to investigate the impact of mountain goats upon soils and soil stability (See Harter Section), upon plant communities and their net annual production (see Pfitsch Section), upon three species

known to be selected in grazing (see Pike Section), and upon the establishment and maintenance of plant species relative to dusting sites (wallows) (see Reid section). Most of the research was conducted along Klahhane Ridge with additional work at Tyler Peak. Field work was completed September 1982.

This report summarized the four major studies conducted over the four-year period. Greater detail for three of the components can be found in the theses by Pike (1981), Pfitsch (1981) and Reid (1983).

We gratefully acknowledge the financial support of the National Park Service and the continued advice and support of James K. Agee, Bruce Moorhead, and Ed Schreiner. Mr. Roger Cantor, Superintendent, Olympic National Park was very supportive of this research and we gratefully acknowledge the advice of many other park personnel.

REFERENCES

Chadwick, D.H. 1977. Ecology of the Rocky Mountain goat in Glacier National Park and the Swan Mountains: Final Report. Glacier National Park, West Glacier, Montana. 54 pp.

Moorhead, B.B. 1977. Status and management of the mountain goat (*Oreamnos americanus*) in the Olympic Mountains. Prepared for status and management of the mountain goat in North America. R. Johnson (Ed.) unpub.

Pfitsch, W.A. 1981. The effects of mountain goats on the subalpine plant communities on Klahhane Ridge, Olympic National Park. M.S. thesis, Univ. Wash., Seattle, WA.

Pike, D.K. 1981. The effects of mountain goats on three plant species unique to the Olympic Mountains, Washington. M.S. thesis, Univ. Wash., Seattle, WA.

Reid, R.S. 1983. Patterns of juvenile mortality and plant life histories in response to mountain goat disturbance, Olympic National Park. M.S. thesis, Univ. Wash., Seattle, WA, 215 pp.

Singer, F.J. 1975. Behavior of mountain goats, elk and other wildlife in relation to U.S Highway 2, Glacier National Park. Federal Highway Administration, Denver.

Stevens, F.J. 1979. Mountain goat (Oreamnos americanus) habitat utilization in Olympic National Park. M.S. thesis, Univ. Wash., Seattle, WA.

____ 1983. Dynamics of dispersal in an introduced mountain goat population on the Olympic Peninsula, Washington. Ph.D. thesis, Univ. Wash., Seattle, WA.

The Effect of Mountain Goats on Soils and Soil Erosion, Klahhane Ridge, Olympic National Park

J.H. Harter

INTRODUCTION

Soil is an important component of the ecosystem that integrates biologic, climatic, edaphic, and topographic factors over time. Although soil is usually thought of as a living, dynamic system, the presence of a soil mantle is an indication of relative environmental stability. Any change in either the nature of the soil or the other components of the ecosystem will have reciprocal effects. One of the most important axioms of sound watershed management is that "stable soil is a prerequisite to satisfactory condition on any area where a soil mantle has been developed" (Ellison and Bailey 1951). This is especially true at high elevations where low temperatures and steep topography place stringent constraints on soil genesis (Retzer 1974). The introduction of mountain goats into the Olympic Mountains has resulted in adjustments within the environmental complex. The purpose of this research is to assess the nature of the changes to the soil system.

The mountain goats in Olympic National Park are largely confined to the subalpine and alpine zones where steep gradients result in a diverse mosaic of habitats and plant communities, and in great variability in soils and erosional characteristics. This is compounded by the complex geologic and glacial history of the Olympic Mountains (Tabor 1975, Tabor and Cody 1978) and the west to east gradient in precipitation in the range. Because of this variability, most of the research was conducted along Klahhane Ridge in the area of highest density of mountain goat. Between 1960 and 1980, the mountain goat population on Klahhane increased approximately threefold to <u>ca</u>. 180 animals (Stevens 1983) resulting in observable vegetation and soil disturbance (Olmsted 1976).

The steep topography in mountain goat habitat and the frequent freeze-thaw cycles and heavy winter precipitation at high elevations combine to produce rapid mass-wasting as evidenced by extensive areas of broken rock and scree along ridges. Soil development and surface stability in these areas are influenced by such physical parameters as slope, aspect, and the nature of the substrate as well as the physiognomy of the vegetation and plant cover. The habitats (landforms) utilized by goats on Klahhane Ridge are described by Olmsted (1976) and Stevens (1979) and plant community correlates provided by Pfitsch (1981, this report). These include: a) rock outcrops, b) scree, talus, or slide rock, and c) meadows.

Rock outcrops on Klahhane Ridge and in the northern and eastern Olympic Mountains are primarily of volcanic origin. These habitats are heavily utilized by goats although they contribute little to goat forage requirements due to low vascular plant cover. Rock surfaces are frequently bare or with a variable cover of saxicaulous lichens and mosses. Mineral soil material, when present, is largely confined to cracks or crevices on horizontal surfaces. Goat disturbance to rock outcrops on Klahhane Ridge and Tyler Peak are described by Pike (1981, this report). Goat usage results in a significant decrease in plant cover and increase in bare surfaces as indicated by remnant lichen lines.

Areas peripheral to rock outcrops and ridges consist largely of steep and extremely unstable scree or talus slopes on basaltic substrates. On Klahhane Ridge, these areas constitute >25% of the total non-forested goat range, have low productivity and species diversity, and have a high intensity and frequency of goat grazing (Pfitsch 1981, this report) which may reduce biomass of dominant vascular species (Pike 1981). These areas are very dynamic with little biological control. Erosive rates are naturally high and depend upon

particle size, slope angle, and the source of material (i.e. cliffs). Mineral soil material accumulates only in the more stable areas near the base of such slopes.

Subalpine meadow areas heavily utilized by mountain goats include unstable herb meadows on basaltic substrates and more stable Phlox-fescue meadows on sedimentary substrates. On Klahhane Ridge, these meadow types constitute nearly 60% of the total vegetated goat habitat (excluding rock outcrops and forested areas) and produce nearly 75% of the total available goat forage (Pfitsch 1981, this report). Fine particles have accumulated in many of these meadows and incipient soils have developed.

Mountain goat activities that result in habitat disturbance, ranked in order of decreasing damage, include trampling, wallowing, bedding, and feeding (Olmsted 1976). The effect of these activities on plant community composition selected endemic plant species, and plant regeneration are described by Pfitsch (1981), Pike (1981) and Reid (1983), respectively. These activities vary temporally and spatially, but when concentrated due to high goat population densities or habitat restrictions, result in destructive changes to the environment. In habitats of low resiliency, these activities destroy the intact vegetation cover resulting in soil displacement, accelerated loss through rilling and gullying or sheetwash erosion, and destruction of an important resource.

Most of this research on soil disturbance was conducted in an extensive, south-facing Phlox-fescue meadow on Klahhane Ridge where goat exclosures had previously been constructed and other studies were in progress. Research was concentrated in this area because: 1) the meadow is heavily utilized by goats and shows a large amount of disturbance that is unequivocally identifiable as goat induced; 2) the meadow soils are more stabilized and show greater

development (albeit incipient) than most other areas of high goat usage; 3) soil stability in the meadow is largely a function of biological controls (e.g. plant cover) and erosion can be more easily related to disurbance than in areas of greater surface instability; 4) the meadow is relatively homogeneous with a high degree of comparability with other non-goat areas; and 5) the meadow is an obvious area for initiation of revegetation and habitat stabilization studies. The objective of this research was to document the magnitude and rates of soil erosion in relation to goat utilization of this habitat.

Meadow Disturbance: Klahhane Ridge vs Tyler Peak

METHODS

The original (pre-goat) vegetation of Klahhane Ridge is unknown but an attempt was made to estimate the amount of disturbance that has resulted due to mountain goat activities by comparing the Klahhane site with an area of "similar" vegetation but low goat use. However, steep gradients in the Olympic Mountains complicate the selection of comparable sites. Tyler Peak, located just outside the northeast boundary of the Park, was chosen for comparison sampling in the habitat studies (see Pfitsch 1981, this report; Pike 1981, this report). Hurricane Hill was used by Reid (this report) as another comparison site of low goat density. South-facing, Phlox-fescue meadows on Tyler and Hurricane Hill are highly similar to Klahhane (Table 1).

A measure of the percentage of disturbed surfaces in the meadows was obtained using the line intercept technique (Canfield 1941, McDonald 1980). Vegetation (non-overlapping) and surface intercepts were recorded to 1 cm along meter tape transects oriented across the meadows parallel with the slopes (116° on Klahhane and 118° on Tyler); six transects (1025 m of line) were sampled on Klahhane and 2 transects (400 m of line) on Tyler. The

Table 1. Physical parameters of the Klahhane Ridge, Tyler Peak, and Hurricane Hill Phlox-fescue meadows.

Characteristics	Klahhane Meadow	Tyler Meadow	Hurricane Hill
Substrate	Sandstone	Sandstone and Basalt	Same as Tyler
	(Crescent Formation)	(Crescent Formation and Blue Mountain Unit)	
Elevation	ca. 1700 - 1750 mAMSL	1700-1750 mAMSL	1700-1730 aAMSL
Aspect	212°	190°	175-180°
Slope	30°	24°	28°

Klahhane transects began ca. 15 m above the northwest 10 x 10 exclosure and were spaced at 25 m intervals down slope with west and east boundaries determined by tree islands or basaltic outcrops (see Fig. 6). The Tyler transects were oriented to avoid changing slopes, substrates, or vegetation.

Disturbance on surface intercepts was accessed using a two-fold classification of a) nature of the surficial material, and b) disturbance process (Table 2). Surficial material was categorized according to particle size of the dominant fraction (>50% cover) ranging from organic matter or fine soil (<0.5 cm) to rock (>10 cm). Bare surfaces were subjectively categorized as to their disturbance including mountain goat trampling, trailing, and wallowing. However, these categories are not always mutually exclusive. Horizontal trailing was easy to assess but down slope trailing was often difficult to separate from water rilling (either "natural" or due to disturbance above) trampling, or outwash erosion from wallows. Many bare areas were indiscernible as to origin (either "natural" or old disturbance) and were unclassified. Wallows were considered as >1 m^2 with smaller areas designated as trampling.

Table 2. Meadow disturbance on Klahhane Ridge and Tyler Peak ( ) categorized as to particle size of surficial material and disturbance process.

MEADOW DISTURBANCE: KLAHHANE VS (TYLER)

	BARE AREAS		TRAILING		WALLOWS		TOTAL
	UNCLASSIFIED	OBVIOUS TRAMPLING	TRAVERSING	DOWNSLOPE & WATER RILLING	WALLOW PROPER	OUTWASH	
ORGANIC MATTER	4.1 (5.3)	1.9 (0)	0.1 (0)	tr. (tr.)	tr. (0)	0 (0)	6.1 (5.3)
FINE SOIL <0.5 cm	3.1 (0.4)	10.4 (0.3)	0.7 (0)	0.5 (1.2)	4.3 (0)	1.1 (0)	20.1 (1.9)
FINE SCREE 0.5 - 2.0 cm	0.6 (0.1)	2.2 (0)	0.4 (0)	1.3 (1.0)	0.2 (0)	1.4 (0)	6.1 (1.1)
MED. SCREE 2 - 5 cm	tr. (0.2)	0.3 (0)	tr. (0)	0.2 (tr.)	tr. (0)	0.2 (0)	0.7 (0.2)
COARSE SCREE 5 - 10 cm	0 (tr.)	0.1 (0)	tr. (0)	0.2 (tr.)	0 (0)	tr. (0)	0.3 (tr.)
ROCKS >10 cm	0.5 (0.5)	0.1 (0)	tr. (0)	tr. (tr.)	tr. (0)	tr. (0)	0.6 (0.5)
	8.3 (6.5)	15.0 (0.3)	1.2 (0)	2.2 (2.2)	4.5 (0)	2.7 (0)	33.9 (9.0)

TOTAL VEGETATED	66.1%	(91.0%)
TOTAL BARE	33.9%	(9.0%)
TOTAL OBVIOUSLY DISTURBED	25.6%	(2.5%)

designated as trampling. Some meadow disturbance may have derived from black-tailed deer, marmots or researchers (Klahhane). Sampling was conducted in early August, 1980, at the time of peak plant biomass and cover.

RESULTS

The Klahhane meadow has a greater proportion of disturbed surfaces of all particle sizes than the meadow of low goat use at Tyler Peak (Table 2). About 34% of the Klahhane meadow is bare and most of this is obviously derived from intensive utilization by mountain goats. In contrast, only about 9% of the Tyler meadow is bare with obvious disturbance accounting for <3%. These bare ground cover estimates agree closely with those of Pfitsch (this report) derived using quadrat sampling techniques.

Most of the disturbance on Klahhane is related to tramping or wallowing while at Tyler it is downslope trailing/water rilling which undoubtedly includes some "natural" erosion. Disturbance on Klahhane has resulted in a decrease in plant cover exposing a greater proportion of fine soil and fine scree. In contrast, the dominant bare surface material at Tyler is undisturbed organic matter. The most obvious between site difference noted while sampling was the almost complete cover of cryptogams and _Selaginella densa_ or _S. wallacei_ in microsites not covered by a vascular plant canopy at Tyler Peak. Pfitsch (1981) reports that mosses and lichens occurred in 86% of the Tyler plots for >11% cover but only in 33% of the Klahhane plots for <1% cover. These vegetation changes due to trampling, while more subtle than the dramatic effects of trailing or wallowing, are probably more serious relative to erosion and topsoil loss.

Microenvironments

METHODS

Microenvironments were monitored on the south and north-facing slopes of Klahhane Ridge during the summer months of 1980 - 1982 (south slope only in 1982). Besides quantifying environmental factors of importance relative to soil erosion, this information can be used to correlate goat behavior and habitat usage with microclimatic conditions, and to help interpret and extrapolate intensive sampling of Klahhane plots with regards to seasonal changes in community cover, production, and phenology of dominant species. Stations were established in the extensive, south-facing, Phlox-fescue meadow (1753 m above mean sea level) and in the north-facing cirque (1632 m AMSL).

Continuous records were made of air temperature and relative humidity with hygrothermographs (Belfort Instrument Co., Baltimore, Maryland) housed in louvered, white shelters placed on the ground surface. Sensor height was approximately 5 - 20 cm. Vapor pressure deficit (VPD) was calculated from the hygrothermograph data as follows:

$$\text{VPD} = \begin{matrix}\text{Saturation Vapor Pressure at} \\ \text{Air (Dry Bulb) Temperature}\end{matrix} \quad \text{X} \quad 1 - \frac{\text{Relative Humidity}}{100}$$

Global radiation was recorded with Belfort pyranometers placed on top of the shelters. The instruments were leveled and sensor height was approximately 70 cm. Precipitation was monitored at approximately weekly intervals with unshielded Tru-Check rain gauges, leveled at 1.4 m.

RESULTS AND DISCUSSION

The climate of the Olympic Mountains is moderated by the proximity of the Pacific Ocean which results in mild year-round temperatures, wet winters, and dry summers. The higher peaks in the center of the range intercept the pre-

vailing westerlies creating a dramatic rain shadow effect and a steep southeast to northwest gradient of precipitation which influences regional vegetation patterns and zonations. Most of the precipitation at high elevations falls as snow during the winter months and the duration and distribution of winter snow cover influences summer soil moisture patterns and the local distribution of plant communities (Pfitsch, this report).

The four years of habitat studies on Klahhane Ridge (1979 - 1982) differed in seasonal microclimates related primarily to the duration of winter snow cover. Snow accumulations in the subalpine meadows at the end of winter were ca. 60%, 40%, and 25% of the long-term record in 1979, 1980, and 1981, respectively (Table 3). Accumulations were slightly above "normal" in 1982. This resulted in year-to-year differences in the snow release of plant communities and the seasonal patterns of plant phenology, community production, and mountain goat habitat utilization.

Table 3. Snow depths and water equivalents at the end of April from the Hurricane Ridge Snow Course, Olympic National Park, 1372 m AMSL. (Source: Jack Hughes, ONP)

Period	Depth on Ground (cm)	Water Equivalent (mm)
$\bar{X}$ 1949-1982	169.9	711.2
1979	106.7	408.9
1980	71.1	256.4
1981	45.7	165.1
1982	193.0	729.0

Climatic data from Port Angeles (Table 4), the nearest reporting weather station located 13 km north of Klahhane Ridge at 110 m AMSL, must be used with caution to predict seasonal trends or the "normality" of climates at higher elevations. Winter (November through April) precipitation received at Port Angeles in 1980 and 1981 exceeded the long-term record although total snow accumulations in the mountains were much below normal. The above-normal winter temperatures in 1981 may indicate that a greater proportion of the precipitation at higher elevation occurred as rain rather than snow, but the other comparisons are unclear. Mean summer temperatures and precipitation at Port Angeles differed little between the years, a characteristic of the maritime climatic regime. The below-normal precipitation in August of 1979, 1980, and 1981, suggests that the habitat studies were conducted during a period of unusually dry mid-summer conditions.

Environmental data from the south-facing, Phlox-fescue meadow site for the 1980 - 1982 measurement periods are shown in Figs. 1-3 and summarized in Tables 5-7. Global radiation (horizontal surface) in the meadow averaged ca. 20 $MJ \cdot m^{-2} \cdot d^{-1}$ with maximum daily totals exceeding 30 $MJ \cdot m^{-2} \cdot d^{-1}$ during the June through August period; actual radiation received by the meadow (30° slope) would exceed these values. Clouds occur with a high frequency in the Olympic Mountains during the early and late summer, typically forming in valleys or on the leeward side of ridges and moving upslope to dissipate with the wind. This results in great variability in the radiation regime at high elevations. However, during mid-summer clear periods of 7 - 10 d or more are common.

The frequently high radiation loads and surface albedo resulted in high daytime shelter temperatures in the meadow. Mean daily temperatures during the warmest months (July and August) were near 10°C which is typical of many

Table 4. Climatic data for Port Angeles, WA., 48°07'N, 123°26'W, 110 m above mean sea level. Source: NOAA Tables.

	Winter			Summer				
	November - April inclusive)	May	June	July	Aug.	Sept.	Oct.	
"Normals": 78 yr record (temperature), 104 yr record (precipitation)								
mean temperature (°C)	5.8°	11.2°	13.5°	15.2°	15.0°	13.7°	10.1°	$\bar{X}$ = 13.
total precipitation (mm)	459.3	23.9	23.1	12.5	18.5	30.5	68.1	= 176.
1979								
mean temperature (°C)	5.3°	12.1° (+.9)	13.4°	16.2°	15.9°	15.7°	11.2°	$\bar{X}$ = 14.
total precipitation (mm)	378.0	13.2 (-10.7)	9.4	16.3	6.6	54.4	74.9	= 174.
1980								
mean temperature (°C) (Departure from normal)	5.7° (Apr. missing)	11.6°	13.0°	15.4°	14.8°	14.2°	11.2°	$\bar{X}$ = 13.
total precipitation (mm) (Departure from normal)	487.4	31.5	57.4	5.1	5.1	50.6	6.4	= 156.
1981								
mean temperature (°C) (Departure from normal)	7.5°	- -	12.9° (-0.6)	15.2° (0)	17.3° (+2.3)	13.9° (+0.2)	9.7° (-0.4)	$\bar{X}$ = 13. (May missing)
total precipitation (mm) (Departure from normal)	511.3	47.5 (+23.6)	35.6 (+12.5)	12.2 (-0.3)	3.3 (15.2)	54.9 (+24.4)	74.7 (+6.6)	= 228
1982								
mean temperature (°C)	6.4 (Jan. missing)	11.1	14.9	15.0	15.8 (+0.8)			
total precipitation (mm)	426.0 (Jan. missing)	4.8	16.3	18.3	11.6 (-6.9)			

Figure 1.

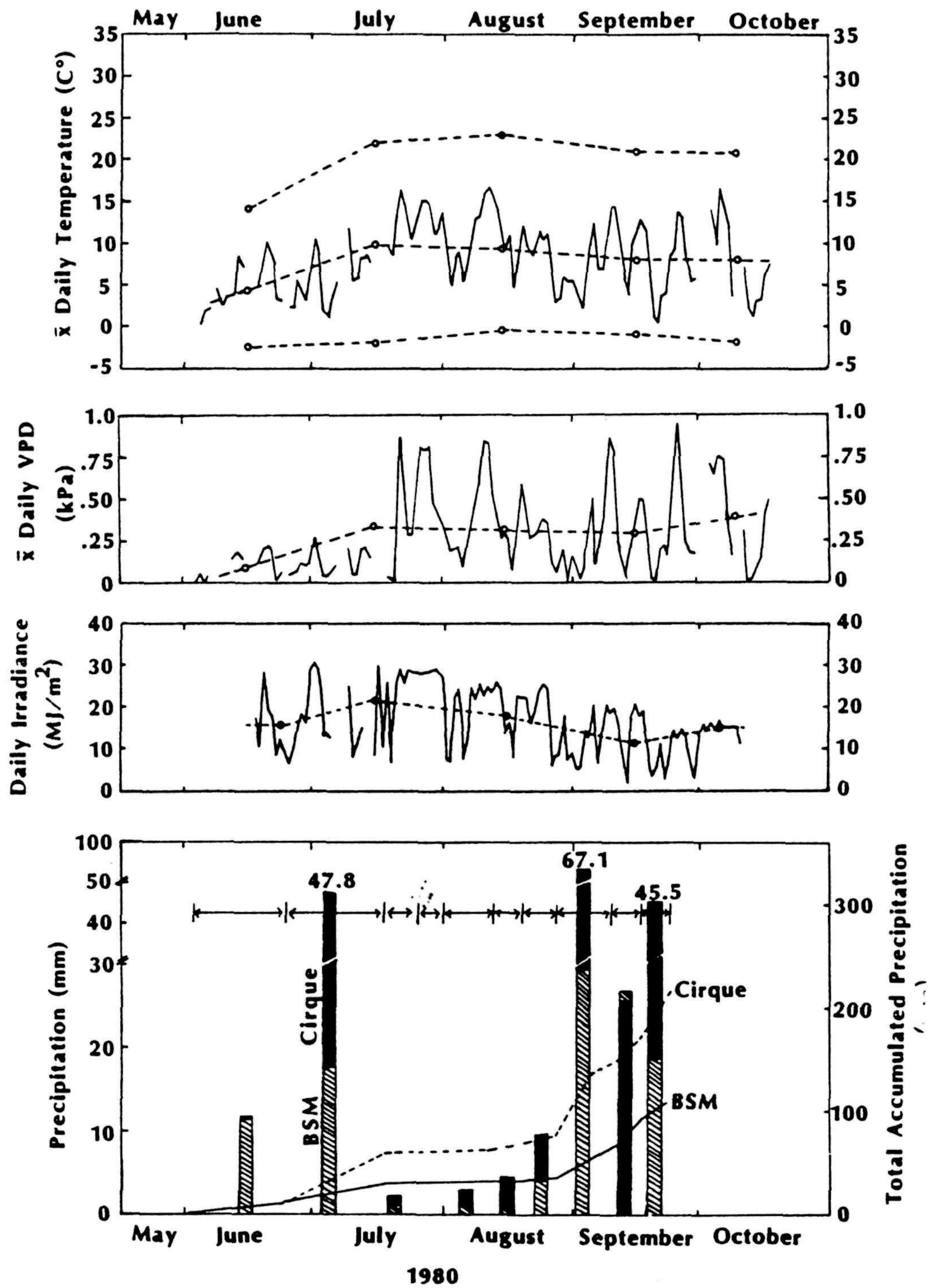

May
June
July
August
September
October
x̄ Daily Temperature (C°)
x̄ Daily VPD (kPa)
Daily Irradiance (MJ/m²)
Precipitation (mm)
Total Accumulated Precipitation
47.8
67.1
45.5
Cirque
BSM
1980

Figure 1 (continued). Data from the north-facing cirque.

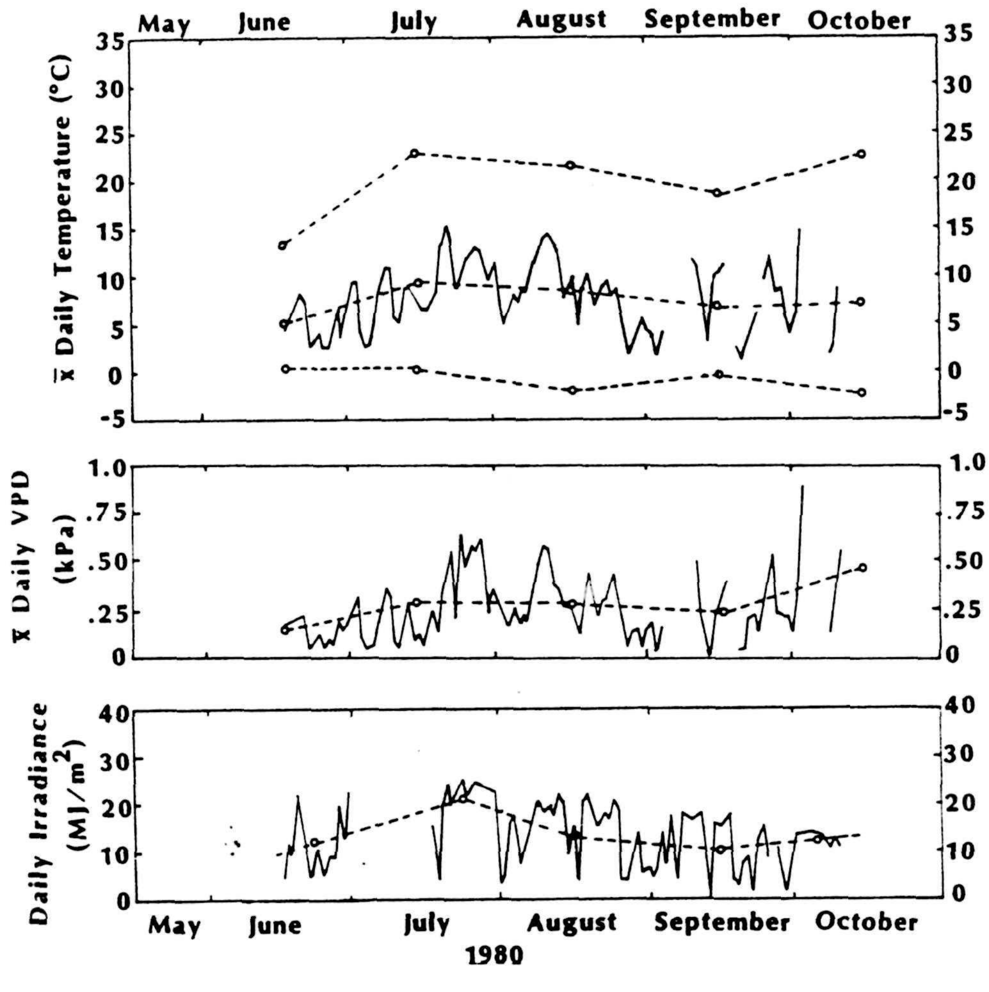


Figure 2. Microclimatic data for the south-facing meadow on Klahhane Ridge, 1753 AMSL; BSM=Big South Meadow, CIRQUE= north-facing slope.

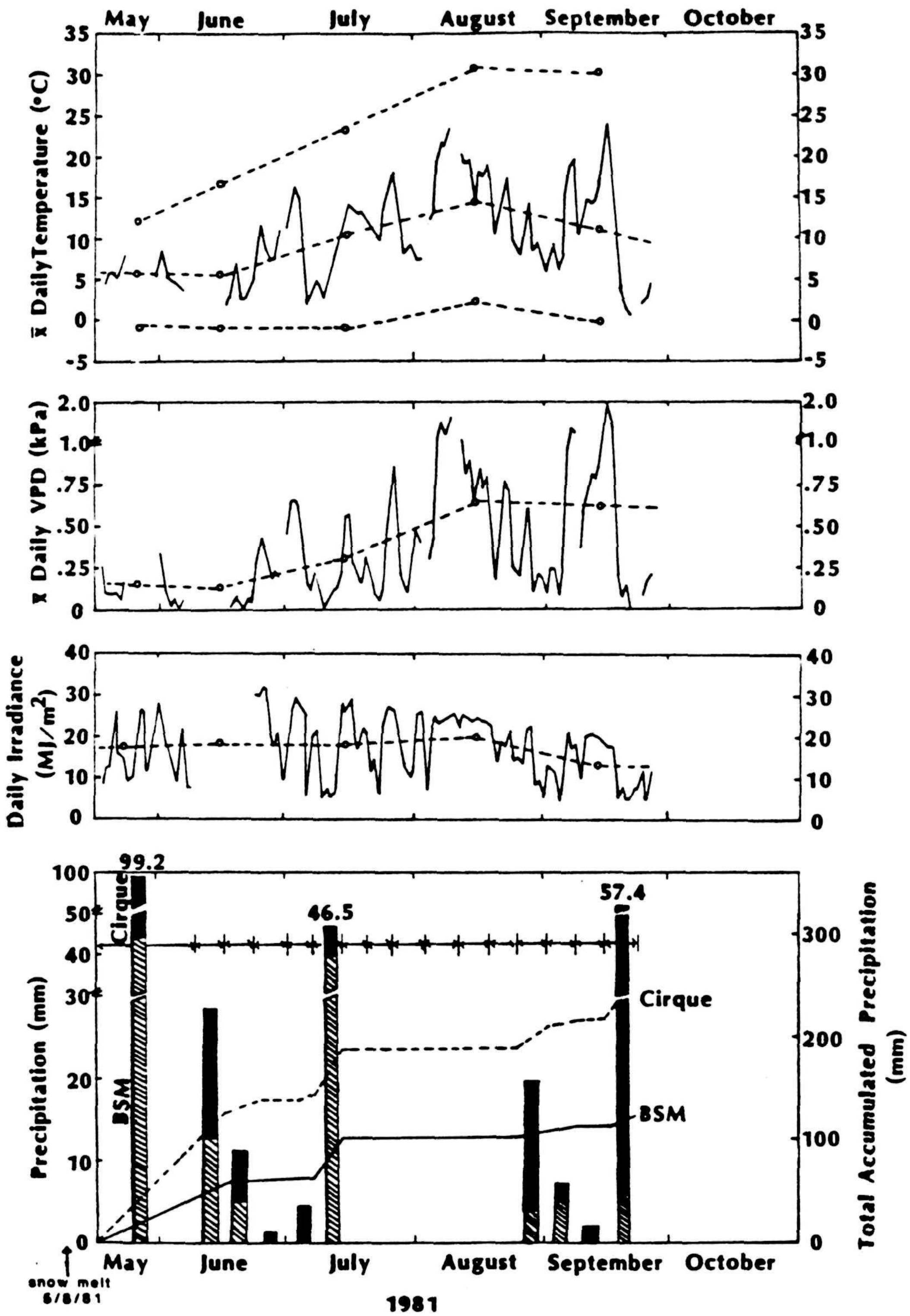


Figure 2. (continued) Data from the north-facing cirque.

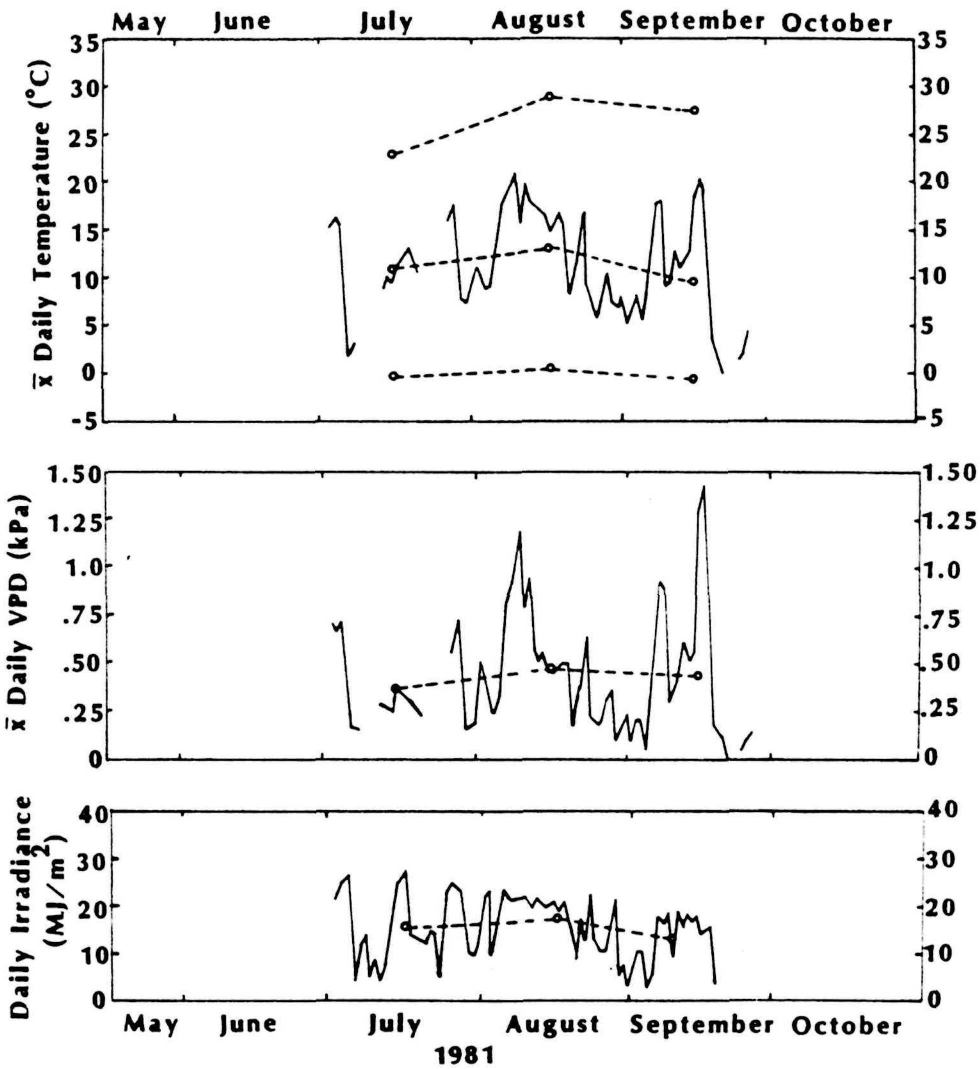


Figure 3. Microclimatic data for the south-facing meadow on Klahhane Ridge, 1753 AMSL. Temperature and precipitation values are from Port Angeles (see text).

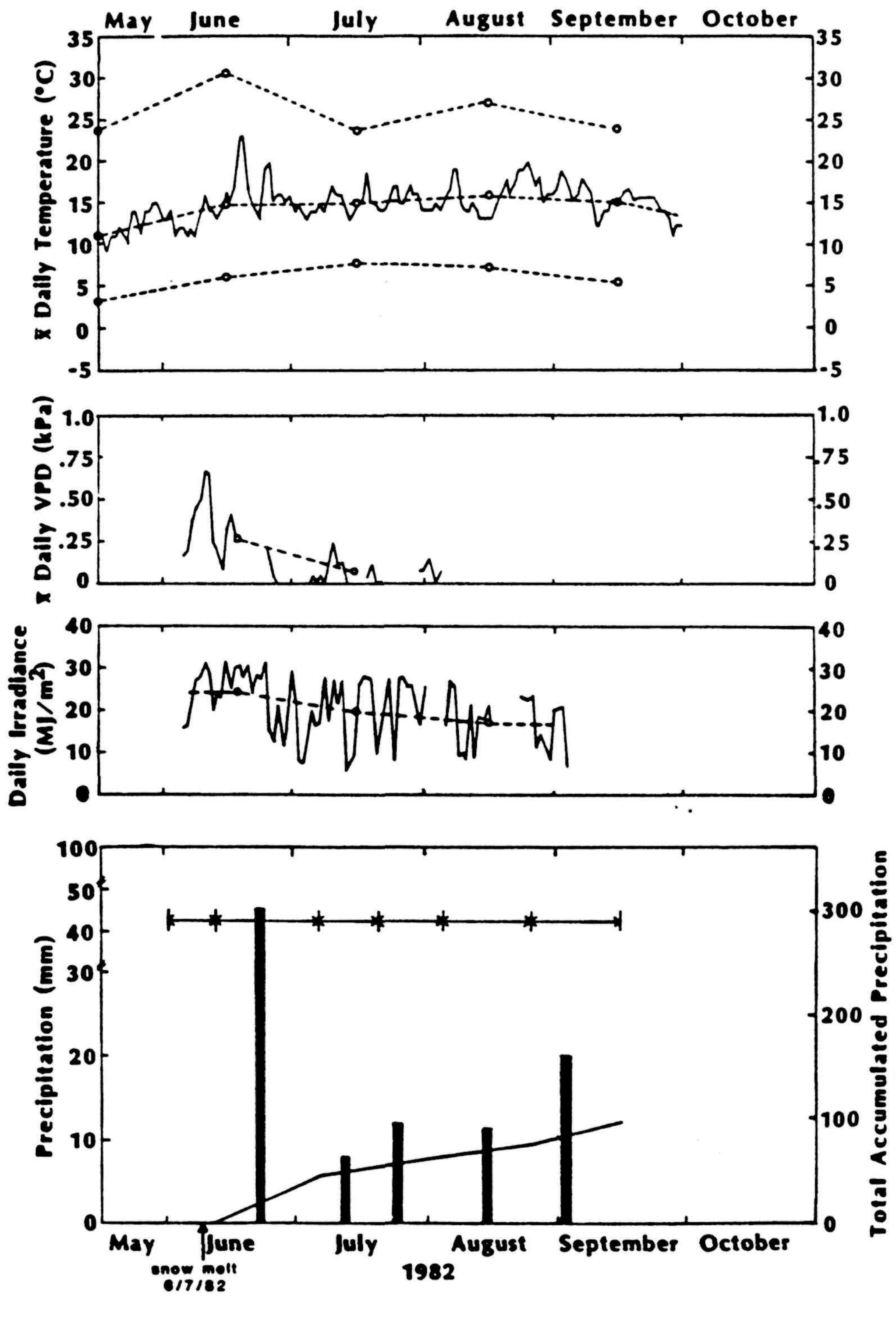


Table 5. Monthly summary of environmental data from the south-facing, Phlox-fescue meadow site, Klahhane Ridge, Olympic National Park (47°59'N, 123°27'W; 1753 m above mean sea level) for 1980.

Parameter	May	June	July	August	September	October
			1980			
Global Radiation (MJ m^{-2} d^{-1})						
Days of Record		14	25	31	30	10
Mean Daily Irradiance	N	15.6	21.8	17.5	11.1	15.0
Max. Mean Daily	O	28.5	30.9	25.7	21.8	16.9
Temperature (°C)						
Days of Record	R	23	26	31	29	13
Mean Daily	E	4.3 (+0.1)	9.9 (-0.5)	9.4 (-1.0)*	8.0 (-0.4)	8.1
Abs. Max.	C	14.0 (-0.5)	22.0 (+1.0)	23.0 (-1.5)	21.0 (-1.0)	21.0
Mean Daily Max.	O	7.6 (-0.2)	14.4 (-0.2)	14.3 (-0.9)*	12.1 (-0.4)	12.9
Mean Daily Min.	R	1.0 (+0.4)	5.3 (-0.8)*	4.4 (-1.2)*	3.8 (-0.2)	3.1
Abs. Min.	D	-2.5 (+0.5)	-2.0 (+1.5)	-0.5 (-1.5)	-1.0 (+0.5)	-2.0
Vapor Pressure Deficit (kPa)						
Days of Record		23	26	31	29	13
Mean Daily		0.09 (+0.03)*	0.33 (-0.03)	0.31 (-0.04)*	0.29 (-0.01)	0.39
Max. Daily		0.21 (0)	0.85 (-0.21)	0.85 (-0.26)	0.90 (-0.35)	0.88
Precipitation (mm)						
Total for Period 2 June - 23 September		111 (+106)*				

Table 6. Monthly summary of environmental data from the south-facing, Phlox-fescue meadow site, Klahhane Ridge, Olympic National Park (47°59'N, 123°27'W; 1753 m above mean sea level) for 1981.

Parameter	May	June	July	August	September	October
			1981			
Global Radiation (MJ m^{-2} d^{-1})						
Days of Record	14	15	31	31	26	
Mean Daily Irradiance	17.2	18.4	17.9	20.0	13.2	N
Max. Mean Daily	27.9	31.4	28.7	25.4	20.9	O
Temperature (°C)						
Days of Record	7	20	31	28	24	R
Mean Daily	5.6	5.5	10.1 (-0.3)	14.1 (-1.2)*	10.8 (-1.2)*	E
Abs. Max.	12.0	16.5	23.0 (0)	30.5 (-1.5)	30.0 (-2.5)	C
Mean Daily Max.	9.2	11.8	14.6 (-0.2)	20.9 (-1.7)*	16.1 (-1.3)*	O
Mean Daily Min.	1.7	2.0	5.7 (-0.5)	8.3 (-1.7)*	5.4 (-1.0)*	R
Abs. Min.	-0.5	-1.0	-1.0 (+0.5)	2.0 (-1.5)	-0.5 (0)	D
Vapor Pressure Deficit (kPa)						
Days of Record	7	20	31	28	24	
Mean Daily	0.14	0.12	0.30 (0)	0.63 (-0.18)*	0.62 (-0.19)	
Max. Daily	0.25	0.43	0.85 (-0.13)	1.64 (-0.45)	2.21 (-0.79)	
Precipitation (mm)						
Total for Period 16 May - 23 September		124 (+153)*				

Table 7. Monthly summary of environmental data from the south-facing, Phlox-fescue meadow site, Klahhane Ridge, Olympic National Park (47°59'N, 123°27'W; 1753 m above mean sea level) for 1982.

Parameter	May	June	July	August	September	October
			1982			
Global Radiation (MJ m^{-2} d^{-1})						
Days of Record		26	31	21		
Mean Daily Irradiance	N	24.2	19.8	17.0	N	N
Max. Mean Daily	O	31.4	28.0	26.9	O	O
Temperature (°C)						
Days of Record	R	19	22	N	R	R
Mean Daily	E	8.5	8.7	O	E	E
Abs. Max.	C	19.0	24.0		C	C
Mean Daily Max.	O	13.0	13.2	R	O	O
Mean Daily Min.	R	6.7	4.1	E	R	R
Abs. Min.	D	-1.0	-2.0	C	D	D
				O		
Vapor Pressure Deficit (kPa)				R		
Days of Record		19	17	D		
Mean Daily		0.27	0.07			
Max. Daily		0.67	0.25			
Precipitation (mm)	No Record					

treeline areas around the world. Mean daily maximum temperatures during this period were ca. 15°C with absolute maxima >25 to 30°C. Surface temperatures near 60°C were measured in this same community type by Kuramoto and Bliss (1970). Reradiation at night resulted in mean daily minimum temperatures ca. 5°C. Freezing temperatures can occur at any time during the summer months.

The frequent surface clouds and high humidities resulted in low average vapor pressure deficits (mean daily ca. 0.3 kPa). However, during the hot, dry periods of mid-summer, VPD's >1.0 kPa were common (maximum mean daily was 2.2 kPa), suggesting that many plants were exposed to atmospheric moisture stress.

The summer months were typically dry on Klahhane Ridge, and although ca. 120 mm precipitation was recorded at the south-facing meadow site during June through September, most of this occurred in early and late-summer. In 1980, only 6.8 mm precipitation (6% of season's total) was measured between 17 July and 27 August (36% of measurement period). The dry period was even more pronounced in 1981; only 4.1 mm precipitation (3% of season's total) was measured between 14 July and 1 September (37% of mesurement period). Total precipitation recorded at the cirque station was >200% that of the south-facing meadow. The "true" precipitation on the Ridge probably lies between these two extremes; the steep south-facing site is characterized by up-slope winds which tend to reduce the "catch" in a leveled rain gauge, whereas the cirque station is in a low-pressure area (wind shadow) that may tend to accentuate the "catch."

The microclimate station in the cirque was significantly cooler (ca. 0.5 ± 2°C) than the south-facing meadow site during most of the summer period, although absolute minimum temperatures were frequently higher. These small differences recorded at a stationary shelter in an exposed and relatively

sunny location do not fully reflect the thermoregulatory gains incurred by the mountain goats as they follow the numerous shadows generated by the north aspect of the cirque. Because of the generally lower temperatures, the VPD's at the cirque station were also significantly lower than at the south-facing site.

Small year-to-year differences in microclimates were noted. The 1981 season was warmer and drier during mid-summer with higher maximum and mean daily temperatures, higher VPD's and a reduced frequency of precipitation. Combined with the shallow, late winter snow pack and early snow release of plant communities in 1981, this suggests that phenological patterns and production gains were accelerated and many plants may have experienced water stress in mid-season. The incomplete record from 1982 does not allow meaningful comparisons with the other years.

Soil Descriptions

METHODS

Soil pits were excavated in several areas of the Phlox-fescue meadows on Klahhane Ridge and Hurricane Hill and in other plant community and habitat types on Klahhane Ridge. Soils were described and classified according to the U.S. soil taxonomy (1975). Samples were collected from each described horizon or at fixed depths when horizons were indistinct. Soil pH was determined on the <2 mm fraction using a 1:1 soil-to-water paste. Soil color was determined under natural daylight using a Munsell color chart. Organic matter was removed from samples before determinations of particle size using a modified Bouyoucos hydrometer method (Bouyoucos 1951). The greater than 2 mm fraction was determined by sifting before particle size analyses. Soil nutrients, pH, and organic matter were determined by the Agriculture and Soil Analysis Lab,

University of Idaho, Moscow, Idaho. Their analyses included percent organic matter and percent organic carbon by the Walkley-Black wet digestion method, available (nitrate) nitrogen by an Auto Analyzer with a $CaSO_4$ wash, and total P and total K by the NaOAc colorimetric method.

RESULTS AND DISCUSSION

Soils at high elevations in the Olympic Mountains are generally young and poorly developed due to the rapid erosion on steep slopes, a short snow-free season, low annual temperatures, and frequent fires (Kuramoto and Bliss 1970). Soil development is more pronounced in forested areas and depressional or gently sloping sites of greater snow accumulation including heather, late-snow sedge, and Lupine-sedge meadows (Fonda and Bliss 1969, Kuramoto and Bliss 1970, Belsky 1979). However, such habitats are subject to slight goat usage or impact.

Soils of the extensive, south-facing Phlox-fescue meadow on Klahhane Ridge have developed on sandstones of the Crescent Formation, dated as Eocene in age. Volcanic basalt and breccia are the other dominant substrates on Klahhane, although recessive beds of shale and limestone occur locally. Soils of the Phlox-fescue meadow most closely resemble Haploborolls (Table 8) while soils of a more mesic phase of this community type were classified by Kuramoto and Bliss (1970) as Orthic Hapludolls. These soils are typical of semiarid, cool to cold steppes, and are characterized by a mollic epipedon with accumulated humus and a dominance of bivalent cations on the exchange complex, but few other diagnostic features. Soils nearer to the ridge crest of Klahhane are more shallow with lithic contacts closer to the surface, while down-slope areas have a thicker soil mantle. Horizons are poorly developed with only a slight change in color, pH, particle size and root abundance throughout the profile.

Table 8. Soil profile description from a mid-slope site of the extensive, Phlox-fescue meadow on Klahhane Ridge. The soil most closely resembles a Haploboroll.

Horizon	Depth (cm)	Description
A1	0-5	Dark reddish brown (5 YR 3/3d) gravelly, sandy loam; single grain; very friable; abundant, small and medium roots; abundant, angular gravel, 36% >2 mm; abrupt, smooth, indistinct boundary; medium acid, pH 5.7.
B1	5-25	Dark reddish brown (5 YR 3/3d) very gravelly, sandy loam; single grain; very friable; many, small and medium roots; very abundant, angular gravel, 51% >2 mm; clear, wavy, indistinct boundary; strongly acid, pH 5.3.
C	>25	Reddish brown (5 YR 4/4d) very gravelly, sandy loam; single grain; very friable; some, small and medium roots; very abundant, angular gravel, 51% >2 mm; strongly acid, pH 5.4.

Table 9. Soil profile characteristics from a mountain goat wallow (SW #5, IO #86) in which approximately 40 cm of the original surface (see Appendix B-3) eroded away exposing the C horizon.

Depth	Color	% 72 mm	pH
0-5	reddish brown (5 YR 4/3d)	48%	5.4
5-12	" " "	58%	5.3
12-25	" " (5 YR 4/4d)	62%	5.4
25-45	" " (5 YR 4/3d)	82%	5.5
45-55	" " "	77%	5.5

Goat-induced soil erosion results in the removal of surface horizons, particularly in wallows where disturbance is concentrated (Table 9). Erosion exposes material with a high gravel and scree content and these larger particles are readily displaced down slope. Table 10 shows that wallows in this same meadow had slightly higher sand contents, less organic matter, and a trend towards less aggregation of fines than adjacent, undisturbed meadow soils. Although many of these wallows have eroded down to very coarse-textured horizons, the surficial material in the wallows is finer grained. This is probably a result of the incorporation of meadow surface material derived either from the original site or transported down slope from the meadow above or the headward erosion of the wallow. The presence of this fine-textured surficial material in the wallows is a requisite to their use by goats for dusting, thermoregulation, and insect control. In areas with a shallow mantle, wallowing readily displaces all of the fines leaving a surface of scree which ceases to be used by the goats.

Soils of the unstable herb meadows show even less development than the soils of the Phlox-fescue meadow described above. The unstable herb meadow soils have developed on volcanic substrates and most closely fit the description of Typic or Lithic Ustorthents, depending on the depth to bedrock. These same soils were classified by Kuramoto and Bliss (1970) as Orthic Orthustents using the 7th Approximation Soil Classification System. These soils occur on recent geologic erosional surfaces such as steep, actively eroding slopes, and have an absence of diagnostic horizons. Due to the active erosion and poor horizon development in both of these soil types, profile characteristics can not be used to estimate topsoil loss, although soil remnants and plant pedestals can locally be used for this purpose. One major distinguishing characteristic of these soils was the percent soil organic matter and organic

Table 10. Chemical and physical properties of soils from Klahhane Ridge goat wallows and Klahhane and Hurricane Hill phlox-fescue meadows.

Site	Depth (cm)	>2 mm Fraction (%)	% of <2 mm Sand	Silt	Clay	pH	% Organic Carbon	% Organic Matter	Avail. N (NO)	Total P (ppm)	K (ppm)	Color
Klahhane Wallow	0-5	48	75.7	8.8	15.5	5.4	1.6	2.7	1.7	1.1	94	Reddish brown 5YR 4/3d
	5-25	60	79.6	6.3	14.1	5.5	1.3	2.3	0.6	0.5	52	Reddish brown 5YR 4/3d
	25	80	79.7	6.9	13.4	5.7	1.3	2.2	0.4	0.5	52	Reddish brown 5YR 4/3d
Klahhane Meadow	0-5	36	73.1	9.7	17.2	5.8	7.4	12.7	2.3	1.2	257	Dark red. brown 5YR 4/3d
	5-25	51	77.3	7.5	15.2	5.4	5.7	9.8	0.8	0.3	164	Dark red. brown 5YR 3/3d
	25	51	78.4	7.0	14.5	5.7	2.7	4.7	0.4	0.1	115	Reddish brown 5YR 4/4d
Hurricane Hill Meadow	0-5	50	71.4	12.8	15.8	5.4	15.4	26.5	5.4	10.7	355	Brownish black 7.5YR 3/2d
	5-20	57	72.8	8.6	18.6	5.3	3.3	5.8	0.9	0.2	34	Brown 7.5YR 4/3d
	20	61	74.8	11.2	14.0	5.4	1.4	2.4	0.5	0.4	26	Dull brown 7.5YR 5/3d

carbon. Organic matter decreased with depth, most dramatically in the Hurricane Hill soils. Surficial samples at Hurricane Hill had twice (27%) the organic matter content of those of Klahhane meadow soils (13%), while the latter had 4 times the content of the inorganic wallow soils (3%) (Table 10). All soils were similar in organic matter content of the lowest layer. Inceased organic matter/carbon distinctly influences soil properties by increasing water-holding capacity, holding more nutrients in forms available to plants, stabilizing the soil structure, and enhancing soil aeration and the amount of exchangeable bases (Broadbent 1965). Organic matter also darkens the soil which can increase surficial soil tempatures, particularly because organic matter is a poor conductor of heat (Geiger 1950).

Soil reaction showed very little variation among these soils at any depth (Table 10). These pH values are not so extreme to make essential micronutrients unavailable to root absorption (Brady 1974).

The other major distinguishing characteristic was soil nutrient content, which uniformly decreased with soil depth. Available nitrogen (nitrate) ranged from 5.4 ppm in Hurricane soils to 1.7 ppm in wallow soils. Total P and K followed the same pattern with greatest concentrations in the top layer of the Hurricane Hill soil. Soil nitrate content was highly and positively correlated with organic matter/carbon at $r^2=.92$. Total phosphorus and total potassium had similar high correlations with soil organic matter/carbon ($r^2=.83,.95$) (Table 10). The decrease in phosphorus with soil depth is contrary to those of Kuramoto and Bliss (1970) for available phosphorus in similar soils. Potassium decrease with depth concurs with the results of Nimlos and McConnell (1965) working with Montana alpine soils. Both P and K are probably held in forms largely unavailable to plant uptake. On the aver-

age, less than 0.5% of the total soil content of these two nutrients is available in humid, temperate soils (Brady 1974).

In summary, the principal differences in these soils are the result of goat activities and parent material differences. Goat activities remove plant cover which enhances soil erosion, causing the loss of the organic topsoil. The resulting soil has better drainage and aeration but is less able to hold nutrients and to stabilize the ground surface. The soil also provides less stability and nutrients needed for plant regeneration.

Parent material appears to be the distinguishing factor between soils of Hurricane Hill and Klahhane Ridge. Basaltic soils are high in iron and magnesium and are usually less acidic (Buol et al. 1973). Analyses of basaltic soils of similar plant communities showed that they were high in calcium and magnesium (Kuramoto and Bliss 1970). This initial increase in nutrients may explain the more dense plant cover on Hurricane Hill, while the more dense cover itself may explain the increased contents of organic matter, N, P, and K.

Mountain Goat Wallow Dynamics

METHODS

Surveys of Selected Wallows

Several of the wallows in the Phlox-fescue meadow on Klahhane Ridge were marked in 1976 (by Olmsted), measured in 1978 and 1979 (by Pike), and remeasured in 1979 (by Pike) and 1980 (by Pike and Harter) to detect changes in size. Measurements were taken with a meter tape of the length, width and depth of the wallows proper and the outwash scree below the wallows, and areas and volumes calculated (see Driver et al. 1979 for methodology). Measurements

(see Appendix B-1) appeared to be highly subjective necessitating a more detailed and consistent method of wallow survey.

Eight wallows were chosen for level-surveys at cross-sections from benchmarks to provide an accurate estimate of volumes of material removed which may be extrapolated to rates given repeated surveys or use of historic photographs. Active wallows with distinct boundaries were selected encompassing a range of sizes and including one small wallow totally excluded from current goat usage and the largest wallow identifiable on Klahhane (I.O.#86), also partially excluded.

Benchmark stakes (1.22 m X 0.95 cm dia. reinforcing rod driven approximately 1 m into the ground, spray painted red, and tagged SW#1- SW#8) were positioned several meters up slope from the center line of each wallow. A meter tape was stretched from the benchmark down slope along the center line and the compass heading determined for future orientation. Cross-section profiles were measured using a tripod-mounted level at various locations along the center line including at the benchmark, in the undisturbed meadow above and below the current wallow, and at a number of sites in the wallow proper or wallow outwash. Cross-sections were located wherever the dimensions of the wallow appeared to change appreciably. At each cross-section, a second tape was stretched out perpendicular to the center-line tape. Surface heights were measured at various distances along this tape extending from the center line of the wallow to the east and west into the meadow. Current wallow boundaries and vegetation within the wallows were noted. The cross-sections were graphed, areas determined by planimetry, and the average net change in area between adjacent cross-sections multiplied by the distance between them to determine net volume of erosion or deposition.

The eight wallows were originally surveyed in mid-summer 1980 (SW#6 and #7 were surveyed from one bench mark). Surveyed wallows #1 and #2 were resurveyed in 1981 at which time the down slope meadow cross-section (at the end of the center line) was also marked with a stake. Field-survey data and graph cross-sections are included in Appendix B-2.

Surficial Particle Movement in Wallows

Tracer material was used to monitor surficial particle movement in the wallows due to natural erosion and current mountain goat disturbance. The "tracer" consisted of several colors of aquarium gravel (3.7 $\pm$ 0.3 mm dia., X $\pm$CI.95) that approximated the average particle size in the wallows and did not appear to be attractive to the goats.

Lines of gravel approximately 1 cm in width and 1 m in length were placed across the width of the wallow proper or wallow outwash in six of the surveyed wallows (SW #1, #2, #5 - 8). Four lines were placed across each wallow (except in SW #5) including two in the wallow proper and two in the wallow outwash. Due to the large size of SW#5, five lines were utilized each consisting of two or three segments and covering both the sides and center zones of the wallow. In SW #5, one of the lines was located within the exclosure at the top of the wallow and was thus excluded from goat disturbance and another line was immediately above the exclosure where anchor wires to the exclosure's corner posts partially restricted goat movement. A line was also placed on the slope contour in the relatively undisturbed meadow adjacent to each marked wallow.

Gravel lines were marked with pins at each end such that a meter tape could be stretched along the line and disturbance measured to 1 cm intervals. Lines were initially marked in late-summer 1980 and were subsequently sampled

on two dates in the fall of 1980 and 11 dates during the snow-free season of 1981. Data recorded on each sampling date included line disturbance, maximum distance of down slope movement, and average distance of down slope movement. In addition, notes were taken concerning the apparent cause of disturbance including if the line was covered by wallow particles that moved down slope from above or if the colored gravel was actually displaced downslope, and if displacement appeared to be due to water, needle ice, or mountain goats.

Barriers were installed within wallows to collect material eroded down slope and to provide information on rates of wallow enlargement to supplement the more qualitative data from marked gravel ines or the long-term data from level surveys. Surficial material within wallows is probably moving at different rates and all is not moving uniformly down slope; accumulatioins along the edges of the wallow outwash indicate some lateral movement. However, the parallel sides of the outwash and the narrower width of the outwash compared to the wallow proper indicate that displacement is primarily down slope. A barrier across the outwash near the base should show the net movement of material downward and out of the wallow/outwash complex.

Barriers were installed near the base of the outwash in surveyed wallows #1, 2, 5, 7, and 8. Two other barriers were placed in SW #5 including one near the true left (east) side of the wallow proper and one in the center of the wallow outwash. A barrier was also placed in a disturbed meadow location; 0.5 m below the bottom rod pairs at rod placement site C-3 where ca. 45% of the surface was bare ground.

Installations were originally made in October 1980 but subsequent snow-creep damage over winter destroyed all the placements (except in SW# 2) and necessitated barrier redesign to reduce the exposed area. Barriers were functional as of late-summer 1982. Barriers consist of a "box" (constructed from 1 mm thick aluminum), open on the front and top and positioned level with the

slope (see accompanying 35 mm slides). Barriers are 1 m in width, 0.5 m in depth, 0.25 m in height along the sides and back, have a 15 cm lip on the front that projects downward into the slope, and are rigidly held in position by stakes along the sides and back. A number of small holes across the back allows water to drain without appreciable loss of sediment. They are designed for a minimum of maintenance or sampling difficulties. Sampling should be conducted in the spring and fall, and possibly at intervals during the snow-free season. Material within the 0.5 m^2 collection area is removed (up to the front edge of the barrier), air dried, sieved, weighed, and converted to volume (2.7 g/cm^3). Total displacement at the barrier location can be calculated from the ratio of wallow width to barrier width.

RESULTS

The most obvious example of mountain goat disturbance is the dusting wallow where the soil surface has been churned and surficial material displaced downslope. Although a large number of wallows in an area generally indicates a relatively high goat population density and/or frequent use of these sites, it is difficult to relate goat numbers and habitat usage to wallow numbers. Wallows can occur anywhere in prime goat habitat and have few environmental correlates other than the presence of a fine-grained soil mantle which implies a relatively stable surface. They are found in areas that goats utilize frequently and are thus more common at higher elevations, close to rock outcrops, and on relatively steep slopes. They appear to be more common on sedimentary substrates that weather to a fine-grained soil, but are also found where pockets of fines have accumulated on basaltic substrates. They are generally not found on steep scree slopes due to surface instability, but again there are exceptions related to microtopography and the accumulation of

fines. Although they can occur in any plant community type, they are most common in Phlox-fescue meadows because of surface material correlates, and least common in communities of low elevation or late snow release.

Wallows occur throughout the higher elevation areas of Klahhane Ridge. They are numerous in the Phlox-fescue meadows of the south-facing slopes, and are very conspicuous in this habitat because of the openness and homogeneity of the vegetation. They are also found on scree slopes of finer-grained material such as areas on the west side of Mt. Angeles, and at lower elevations in the north-facing cirque including a relatively lush meadow by the "waterfall." A number of very large wallows are found in a Phlox-fescue/ Lupine-sedge meadow of northeast aspect directly north of "First Divide." This area is heavily utilized by goats during the hot periods of mid-summer. Wallows are found at a number of relatively flat locations along the ridge top including at the "blowout" near Rocky Peak, a site of anthropogenic origin that is maintained by wind ablation, and in heather communities of north aspect at "Ingrid's Meadow." They are common on all slopes and benches of slide rock around Rocky Peak.

Wallows are abundant in the extensive south-facing, Phlox-fescue meadow on Klahhane Ridge due to intensive utilization by mountain goats and the fine-grained substrate. Over 70 wallows of >1 m^2 area occur in this meadow (Pfitsch 1981) encompassing ca. 7% of the surface area (Table 2). The wallows vary in size from small areas inseparable from intensively trampled microsites (thus the arbitrary 1 m^2 minimum area) to larger areas that are clearly distinguishable on satellite (E.R.T.S. or Landsat) photographs.

Wallows typically consist of an upper zone of erosion (the wallow proper) and a lower zone (the wallow outwash) disturbed by material eroded from above. The upper zone is an intensively disturbed depressional area of fine-grained

material where the surface soil horizons have been removed. The wallow proper usually has well defined top and side boundaries and is the site of most frequent mountain goat wallowing. The lower zone is usually an area of deposition of fine soil and scree. The outwash material may form a prominent, convex debris lobe on top of the original meadow surface or simply spread diffusely throughout the down-slope vegetation. The outwash zone may also be an area of net erosion depending on the slope and microtopography of the surface. Where appreciable accumulations of outwash material are present, they may also be utilized by goats for wallowing. Delineation of the boundaries of the lower zone and thus of the total wallow complex is often subjective.

Meter-tape surveys of thirty wallows in this Phlox-fescue meadow were conducted over three years (1978 - 1980) but failed to provide any meaningful data on rates of wallow change. Calculated areas and volumes of the wallows proper increased between 1978 and 1979 but decreased in 1980, while outwash areas increased in both years (see Appendix B-1). The calculated absolute change in size of individual wallows between years was as great as three orders of magnitude. Observations suggest this is highly improbable and simply a result of between-year inconsistencies in delineation of wallow boundaries. However, some of the measurement and observational data are of more value. The mean slope of the wallow outwash is _ca_. 31° which is essentially the same as the undisturbed meadow. The mean slope of the wallow proper is only _ca_. 22°, due in part to the frequent initial establishment of wallows in terraced sites as well as to the wallowing process itself. Outwash material may be eroded down slope many meters below the bottom of the wallow complex. Many larger wallows appear to derive from the coalescence of a number of smaller disturbed sites. Many of the wallows initially marked in 1976 and last measured in 1980 appear to have little use and to be revegetating. Goat

usage of individual small wallows may be less frequent than that of the larger wallow complexes.

The areas and volumes of the eight wallows surveyed from bench marks are presented in Table 11. The wallow complexes sampled range in size from ca. 3 m^2 to 230 m^2 active surface area. The total meadow area disturbed by the wallow complexes exceeds these reported values because some outwash margins show evidence of revegetation. There is no consistent relationship between the surface area of the wallow proper and that of the wallow outwash. The outwash may extend over a larger or smaller area than the wallow proper depending upon slope contour. The volume of wallow outwash generally does not account for the volume of material eroded from the wallow proper. This indicates that much of the eroded material is lost from the general proximity of the wallow either through ablation or widespread dispersal throughout the down-slope vegetation.

Two wallows (SW#1 and 2) were resurveyed in 1981 using a different survey crew than with the original to detect limitations of the technique. Observations suggested that the wallows had changed little in overall dimensions between the years. Relative heights of the center line points at each cross-section location varied by ca. $\pm$ 0.03 m between the surveys, with a maximum difference of 0.11 m (see Appendix B-2). A slight deviation from the center line compass heading could explain these differences. The survey points along the cross sections often deviated as much as 0.25 m indicating a skew from perpendicular of the cross section. Despite these apparently large differences, volumes calculated for either the wallow proper or wallow outwash differed by 0.05 m^3 between the surveys, suggesting that cross-sectional areas can be more accurately determined. These wallow volumes are based on subjective estimates of the position of the original meadow surface. Since

Table 11. Summary of surface areas and volumes of material displaced in surveyed wallows.[1]

Wallow Number	Surface Area (m^2)[2] Wallow Proper	Wallow Outwash	Wallow Complex	Volume of Material[3] Displaced (m^3) Wallow Proper	Wallow Outwash	Wallow Complex
SW#1 (I.O.#169)						
1980 Survey	8.07	4.20	12.27	-1.21	+0.01	-1.20
1981 ReSurvey	---	---	---	-1.17	+0.01	-1.16
SW#2 (I.O.#34)						
1980 Survey	3.63	6.34	9.97	-0.30	-0.04	-0.34
1981 ReSurvey	---	---	---	-0.29	+0.01	-0.28
SW#3 (I.O.#166)	2.47	4.61	7.08	-0.30	-0.26	-0.56
SW#4	1.91	1.50	3.41	-0.26	-0.10	-0.36
SW#5 (I.O.#86)	123.21	107.26	230.47	-34.48	+37.43	+2.95
SW#6 (I.O.#27)	5.03	6.18	11.21	-0.56	+0.26	-0.30
SW#7 (I.O.#26)	17.93	25.80	43.73	-3.38	+1.17	-2.21
SW#8	3.08	11.84	14.92	-0.84	+0.36	-0.48

1. See Appendix B-3 for cross-sections and B-4 and B-5 for calculations.
2. Based on current area (enclosed vegetation excluded) rather than subjective estimates of original boundaries.
3. Based on subjective estimates of original boundaries as suggested by cross-sectional topography.

this may vary with subsequent surveyors or erosion, it appears desirable to more clearly delineate the ends of the center and cross-section lines with additional benchmark stakes at the time of the next survey to allow more precise relocation of survey points.

The gravel-line transects provide a comparison of the magnitude and seasonality of erosion in the wallow complexes with that of adjacent vegetated meadow sites. Figure 4 summarizes the data from the six wallow and meadow locations, while Fig. 5 separates the various lines in one wallow complex (SW#5). Surface material is more readily displaced in the wallows than in the meadow at all times of the year. Erosion is slightly greater in the wallow outwash than in the wallow proper, probably due to the difference in slope of the two. Heavy precipitation, needle ice activity, and runoff from snow melt result in nearly 100% surface disturbance in the wallows during the spring and fall months. Although it was not possible to quantitatively separate the erosion due directly to mountain goats from these other causes, goats were implicated at all times during the snow-free season. Goat disturbance invariably resulted in considerable spatial displacement of surface particles while rain drop splash, surface flow, and needle ice tended to move particles only a small distance. The maximum distance that particles moved from the one exclosed line in SW#5 was <2 m. Continuous wallow disturbance by goats resulted, by the end of the study, in unexclosed tracer material being displaced up to 18 m down slope, i.e. to the bottom of the wallow complexes or even into the downslope vegetation.

The information collected from the barrier installations is limited due to their delayed functional operation, but trends are suggested. Data are presented for most wallows for a seven week period in late-summer, 1982, and for one wallow (SW#2) for a 11 month over-winter period (1981-1982) (Table

Figure 4. Mean (± 95% C.I.) percent line disturbance in six wallow and meadow locations between August, 1980, and October, 1981, on Klahhane Ridge.

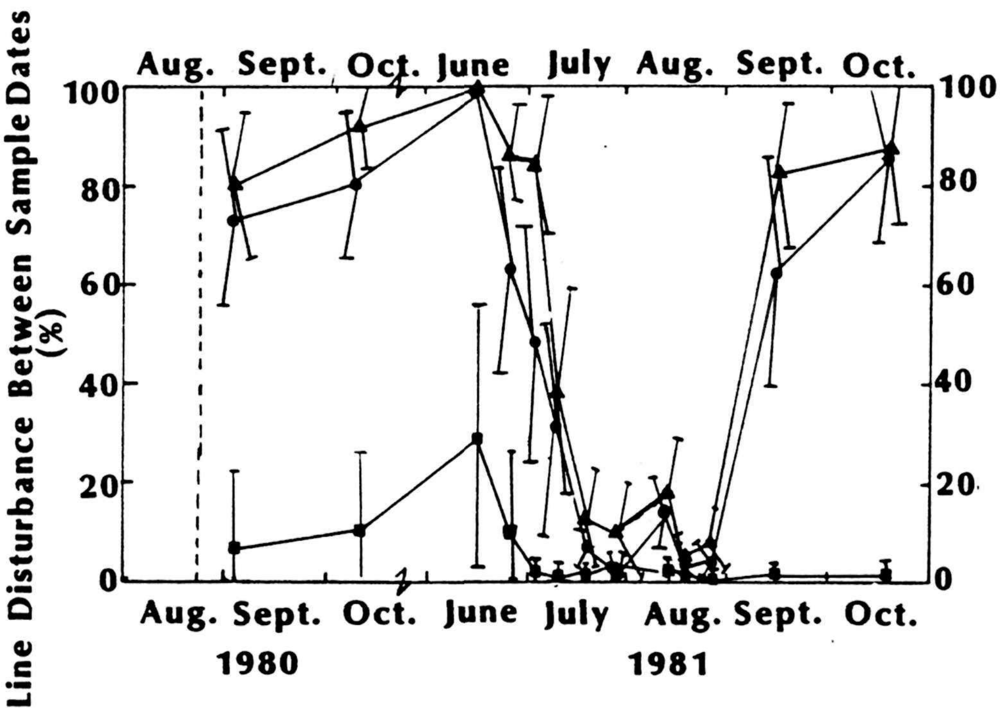
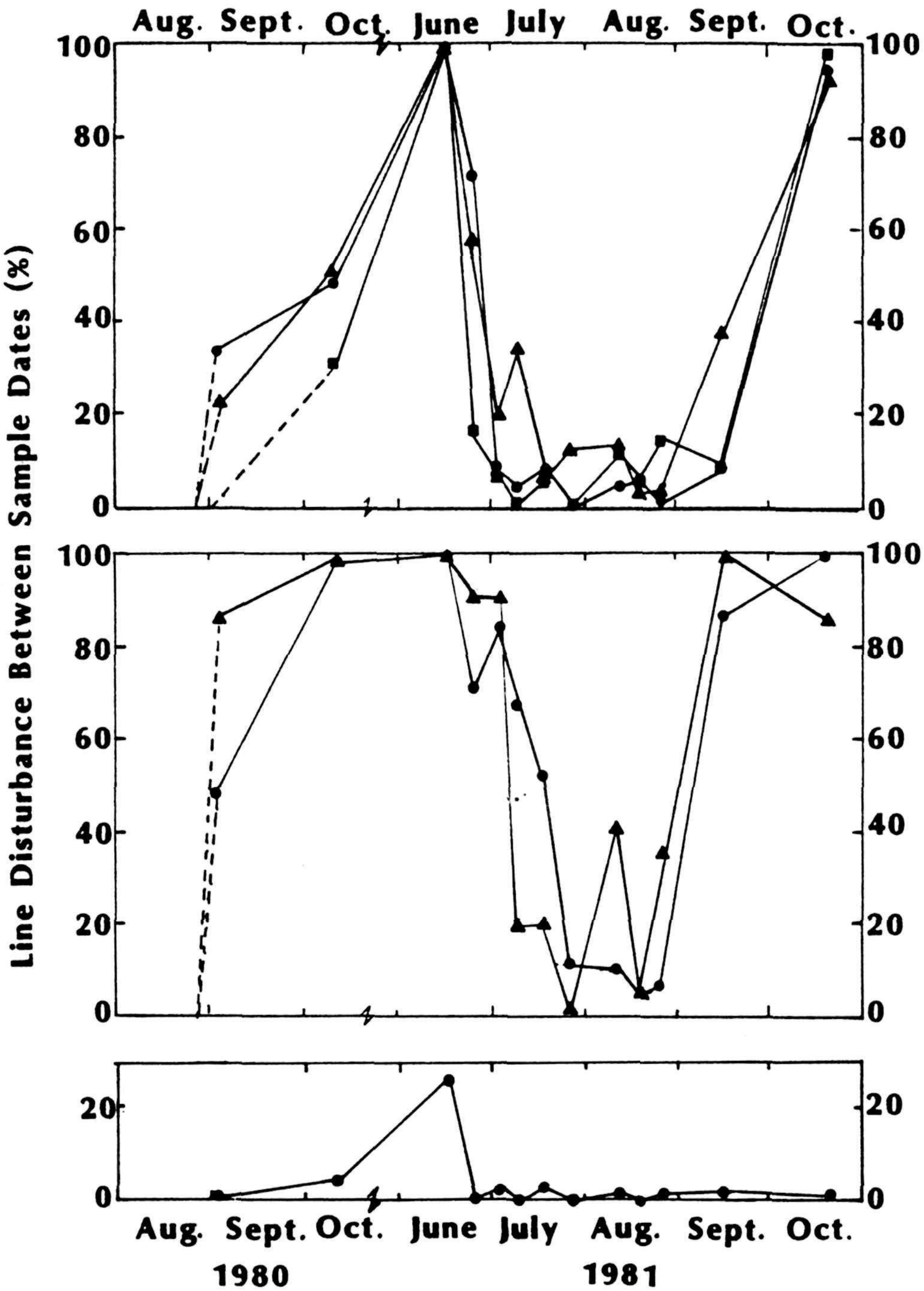


Figure 5. Line disturbance in one wallow (SW #5) between August, 1980, and October 1981, on Klahhane Ridge.



12). The actual mass of material collected in the wallow barriers (with one exception as noted below) was similar and not directly related to the area of the wallow complex above the barrier, although the values extrapolated to wallow width at the barrier locations obviously depend upon wallow dimensions. The small amount of material collected in the mid-barrier of SW#5 reflects the less-steep slope at this placement. Most of the material moving downslope in either the wallows or the disturbed meadow is of larger particle sizes (>2 mm). Relatively little material is moving in the meadow in comparison to the wallows, even when adjustments are made for differences in sampling periods and the bareness of the surface. The material displaced from SW#2 during the 11 month measurement period was 1.3 X 10^{-3} m^3 which would require ca. 240 years to remove the 0.34 m^3 from the wallow complex (1980 survey), assuming uniform erosion rates. This limited data grossly overestimates wallow age which is more likely in the range of 10 - 15 years. It is probable that erosion rates are not constant throughout the existence of a wallow. It must be stressed that the usefullness of these barriers was directed at and will depend upon a continuous monitoring program.

SUMMARY

The dramatic growth of the mountain goat population in Olympic National Park during the last 20 years has resulted in soil degradation in localized areas of high goat density. Current conditions on Klahhane Ridge indicate a trend towards increasing soil erosion and habitat destruction and provide a model of future conditions for other areas of the Park subject to increasing concentrations of goats. Soils of prime goat habitat show poor development and stability primarily due to steep slopes. Disturbance readily results in erosion of the finer textured and organic matter enriched surface horizons.

Table 12. Site characteristics of barrier installations and material collected over sampling intervals.

			Material Collected Between Dates					
			X/23/81 to IX/17/82		VIII/28/82 to IX/17/82		VIII/23/82 to IX/17/82	
Barrier Location	Area of Wallow Complex above barrier (m^2)	Wallow Width at barrier (m)	Actual / Adj. to Wallow Width (g)	% <2mm	Actual / Adj. to Wallow Width (g)	% <2mm	Actual / Adj. to Wallow Width (g)	% <2mm
SW #1	10.66	1.40	---	---	1277 / 1788	11.4	---	---
SW #2	9.56	1.40	2379 / 3331	17.2	---	---	---	---
SW #5(top)	59.47	7.10	---	---	1346 / 9558	11.7	---	---
(mid)	138.99	6.30	---	---	439 / 2764	16.7	---	---
(bottom)	228.50	2.80	---	---	1149 / 3216	10.5	---	---
SW #7	39.68	2.70	---	---	1330 / 3590	13.1	---	---
SW #8	10.44	1.60	---	---	1560 / 2496	3.6	---	---
Meadow below Rod Set C-3	(45% Bare)		---	---	---	---	92	16.3

Disturbed sites experience severe microenvironments and significant levels of soil drought during the summer months, which combined with needle ice activity in spring and fall restricts rapid revegetation.

An extensive Phlox-fescue meadow on Klahhane Ridge frequently utilized by mountain goats had reduced cover of vascular plants and cryptogams compared to a similar "control" meadow with little goat usage on Tyler Peak. Trampling was the dominant form of disturbance resulting in increased sheetwash erosion and large (>2 mm) particle displacement in direct proportion to the amount of bare mineral soil. Disturbance due to wallowing was more obvious and locally destructive resulting in rapid soil erosion and small gully formation. Permanent plots will allow monitoring of soil loss due to trampling and wallowing in this meadow.

Meadow Sheetwash Erosion

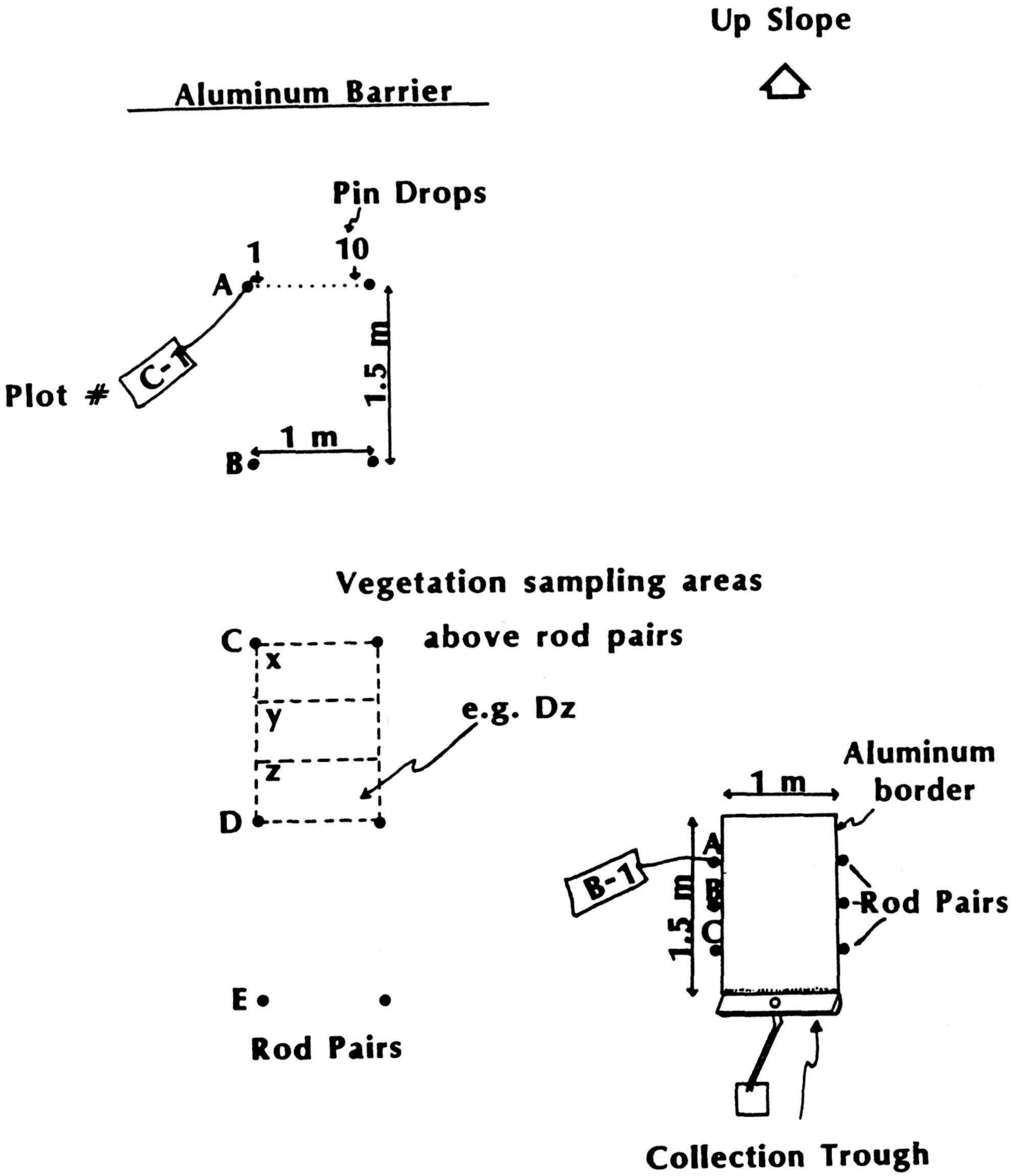
METHODS

Two approaches were used to measure sheetwash erosion in the extensive, Phlox-fescue meadow on Klahhane Ridge: permanent rod placements for use with a pin-drop sampling bar (Mueller-Dombois & Ellenberg 1974) and collection troughs for accumulating runoff and eroded soil from enclosed plots (Gerlach 1967, Dunne 1977).

Permanent Rod Placements

Rod placement plots were established at six locations in the meadow (Fig. 6 map) including one each in the 10 X 10 m northwest and northeast meadow exclosures. Each plot consists of a series of five pairs of rods (1.22 m long X 0.95 cm dia. reinforcing rod) driven approximately 1 m into the ground to avoid dislodgement and spaced at 1.5 m intervals downslope below a ca. 20 cm high aluminum barrier (Fig. 7 schematic). The barrier, 3 m in width and ex-

Figure 7. Schematic diagram of rod placement plots for soil erosion studies, Klahhane Ridge.



tending 1 m to each side of the rod placments, is used to standardize up slope "fetch" and overland flow since plots are located at varying distances down slope from the ridge crest. Paired rods are oriented on the slope contour such that a specially designed sampling bar (see accompanying 35 mm slides) can be repeatedly and solidly positioned on the rods. Rods are spray painted red or orange and plots identified by aluminum tags (C-1 through C-6) attached to the top left (facing up slope) or northwest corner rod.

The sampling bar has a series of ten holes drilled at 10 cm intervals through which a small pin (4.5 mm dia. brass brazing rod) is lowered to the ground surface to detect changes in relative ground surface height. Thus, each placement (plot) consists of a series of 50 pin "hits" on the surface. Placements were sampled in late August 1982 using a 25.00 cm pin and recording the vertical projections of the pin above the bar. Future lowering of the ground surface will reduce this vertical projection distance. Use of this particular length of pin is not critical but pin length must be accurately known and indicated with the sampling data. Sampling techniques are critical and outlined in more detail in Appendix A.

The surface material at the pin-drop point was classified using a combination letter/number designation primarily for ease in relocating point position and interpreting surface change. The vegetation was sampled at each plot location to allow future correlation of surface change to plant cover. One third of the area above each rod pair was sampled in a stratified random fashion using a 0.5 X 1.0m quadrant frame. Canopy projection cover of the different physiognomic categories of vegetation was estimated to the nearest 5% if >5%, to 1% if between 1 - 5%, or Tr. if <1%; summations of total cover estimates equal 100 ± 5%. Categories sampled include cushion plants and shrubs (including juniper), graminoids, forbs, cryptogams, and bare surface.

page missing

Similar sampling was conducted at each trough site as with the adjacent permanent rod placements. The vegetation cover within the entire enclosed plot was estimated and samples collected of surface material adjacent to the plot for particle size determinations. Three pairs of rods for use with the pin-drop sampling bar were installed at each enclosed plot, and the relative surface height and nature of surface material at the 30 pin "hits" within the plot recorded. The vegetation and pin-drop sampling data, dimensions of trough enclosures, and physical parameters at the placement sites are listed in Appendix A.

RESULTS

The permanent rod placements and collection trough plots are designed for a future monitoring program by the staff of Olympic National Park. Base-line data were collected from each installation (Appendix A) and erosion measured at the trough enclosures over a 24 d period. Observations on the effectiveness of these methods and some preliminary results will be discussed.

A number of factors influence sheetwash erosion and overland flow in the meadow on Klahhane Ridge including characteristics of the vegetation (physiognomy, cover, thickness of the root mat), soils (particle size and density of soil material at the surface and in surface horizons, percentage of fine organic matter, pre-existing soil moisture content, surface compaction, infiltration capacity), slope (degree, aspect, microtopography), and climate (periodicity, intensity, and form of precipitation, needle ice activity). The activity of mountain goats is but another factor in an already complex system. Moreover, goat disturbance itself is complex and modifies natural slope erosion indirectly through subtle changes to many of the above factors as well as directly through physical displacement of surface material. Predictions of

runoff and erosion even in a more simple system, involve rigorous statistical analyses with a large number of vegetation and soil parameters (Selby and Hoskins 1971). Although the six rod placements and enclosed plots include two from which goats are excluded, goat disturbance varies spatially and temporally, and this is a very small sample of a large and heterogenous meadow. Due to system complexity, it is probably not possible even if logistically feasible to separate the erosion due directly to mountain goats from that resulting due to natural processes. Therefore, the approach used here is to relate sheetwash erosion to factors that are presumed to have been modified by mountain goats rather than relate it directly to goat usage of the meadow. The underlying assumption is that goats have reduced the plant cover in the meadow (primarily through trampling) and if erosion can be shown to be correlated with the amount of bare surfaces, then it is also related to mountain goat disturbance (although not on a goat-use basis).

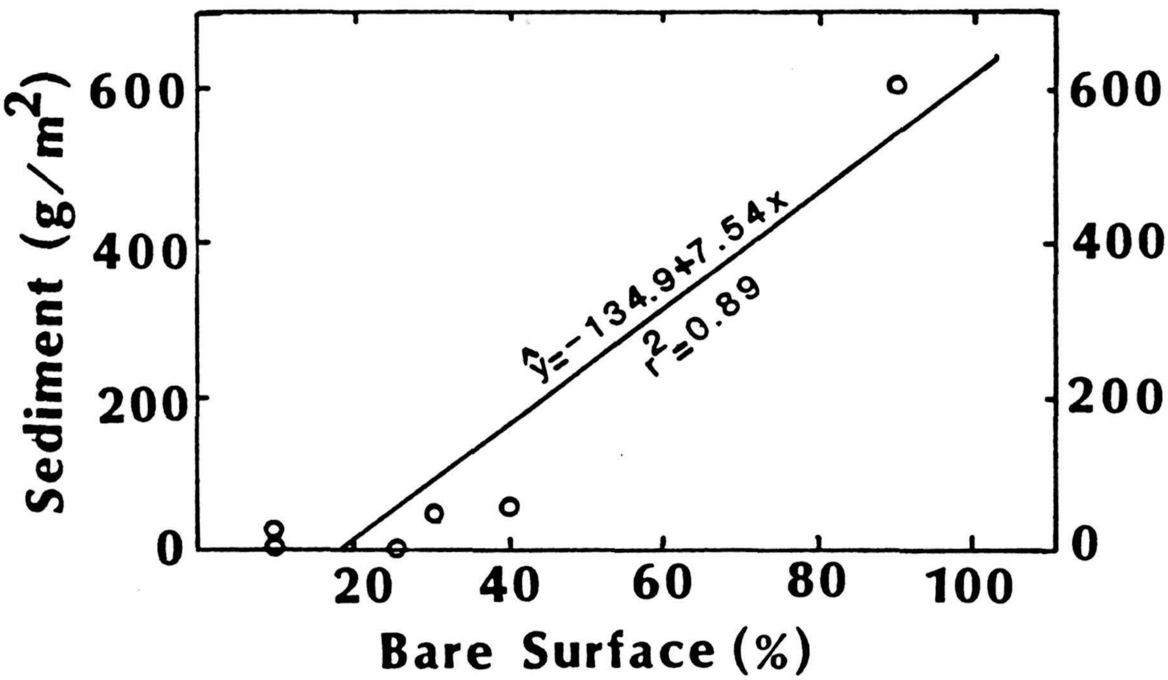
The rod placement plots provide a means of monitoring the relative height of 50 surface points at six different locations in the meadow. Only one set of measurement data are presented (Appendix A) against which future measurements will be referenced. Rates of surface change are unknown but it is conceivable that several years of monitoring may be necessary to detect differences. A limitation of the method is apparent; in the highly improbable instance of uniform mass movement downslope, each point would experience material movement but no net change in relative surface height. A more likely scenario is that some surface points will loose material, others will gain, and many will remain unchanged. Although the data from future samplings can be analyzed with respect to direction of change, it may be more meaningful just to consider the net change of the surface regardless of direction as an indication of the amount of material displaced downslope.

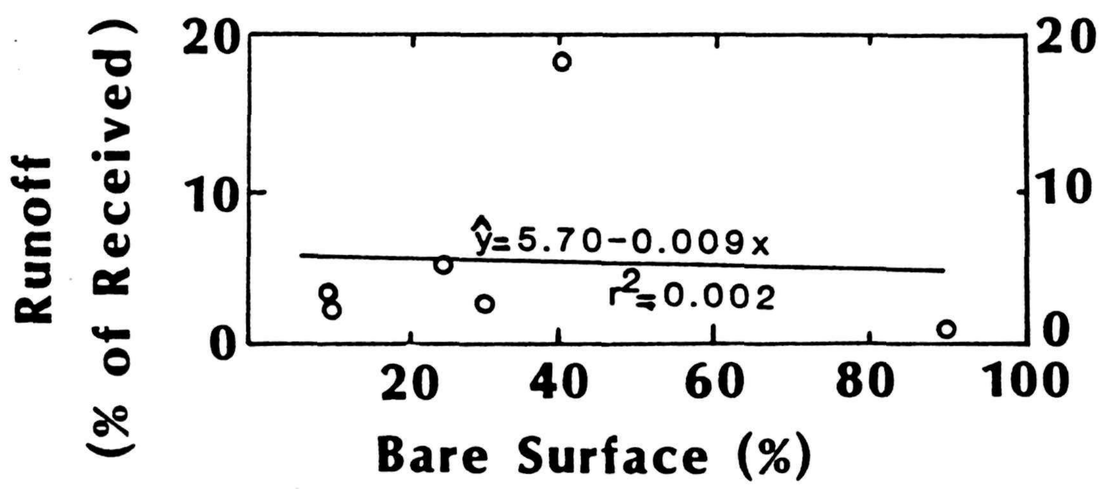
The rod placements and collection troughs were located at sites of varying slopes (27 - 33°), particle size of surface material (ca. 30 - 80% <2mm fraction), and percentage of bare ground at surface (5-90%). Sites were chosen to provide a wide range in the latter, from areas of relatively intact meadow to areas of heavy goat disturbance.

Sediment and runoff from the trough enclosures for a 24 day period in late summer 1982 (see Appendix A-7) suggest that slope erosion due to overland flow is inversely related to plant cover. The sediment collected in the troughs varied from <1 g/m^2 to >600 g/m^2 and was greatest at the site with the highest percentage of bare surface (Fig. 8). The linear regression line is the "best fit" for this limited data set but may not represent the true relationship. Runoff from the enclosed plots varied from <1% to >18% of the precipitation received and was not correlated with the percentage of bare surfaces or with sediment yield. The high proportion of coarse material in the sediment samples and the high sediment yield at the site with lowest runoff indicate that overland flow contributes to erosion by disloging if not actually transporting large sized material.

Slope erosion and overland flow has been intensively studied in laboratory simulations and with controlled experiments on agricultural plots or on water sheds subjected to various management regimes (Ellison 1945, Meyer and Monke 1965, Emmett 1970). Dingwall (1972) studied erosion on a 28° alpine debris slope using collection troughs similar to those used on Klahhane. He found that runoff, rainfall, and sediment yield were correlated but there was no relationship between runoff and rainfall intensity due to the high infiltration rates of the surface. Pre-existing soil moisture appeared to be the most important factor controlling runoff. The greatest sediment yields were measured in early-summer when the surface was saturated with melt waters and

Figure 8. Regression of both sediment and runoff collected in troughs and percent bare surface in soil erosion plots, Klahhane Ridge.





disturbed by freeze-thaw cycles. The eroded sediments had a greater proportion of finer grained material than the surficial debris indicating that finer fractions are selectively washed out. From his results it can be hypothesized that the Klahhane meadow is most susceptible to erosion in early and late-summer. Since this coincides with the period of most intensive utilization by mountain goats, it is suggested that goat activities play a major role in surface stability of this habitat.

Soil Moisture

METHODS

Soil moisture was determined gravimetrically at weekly or biweekly intervals during the summer of 1981 in the Phlox-fescue meadow. Samples were collected at 0-5 cm, 5-15 cm, and >15 cm depth in five replicates of six meadow microsites including vegetated meadow (dense vascular plant canopy and only slightly disturbed), disturbed meadow (bare), wallow proper center (bare), wallow proper margin (sparsely vegetated). The percent soil moisture was determined at -0.03 MPa (field capacity), -0.1 MPa, -0.3 MPa, and -1.5 MPa (permanent wilting point) soil matric potentials (Ψsoil) on the <2 mm fraction of bulk samples collected from each horizon and sample site using a ceramic pressure plate apparatus (Soil Moisture Equipment Co., Santa Barbara, California). The shape of the desorption curves allowed Ψsoil to be estimated to much lower values with reasonable reliability. The percent soil moisture available between -0.03 MPa and -1.5 MPa was calculated for each horizon as follows:

$$\frac{\%\ \text{Available } H_2O}{\text{in Horizon}} = \frac{\left(\frac{\%\ H_2O\ @\ -0.03\ \text{MPa}}{(2\ \text{mm fraction})} - \frac{\%\ H_2O\ @\ -1.5\ \text{MPa}}{(2\ \text{mm fraction})}\right) \times \frac{\%\ <2\ \text{mm}}{\text{in Horizon}}}{100}$$

This provides a standard means for comparing the water availability of microsites, although the soil moisture actually "available" to different plant taxa depends on their respective physiological tolerances and may differ from these conventional limits.

RESULTS AND DISCUSSION

Disturbance by mountain goats in the meadow did not appreciably change the moisture regime or water holding capabilities of the soil although trends are indicated. The primary effect of goat-induced disturbance is a loss of topsoil with its higher concentration of organic matter and fine-grained particles. The surface horizons (0-5 cm and 5-15 cm depth) of the vegetated meadow soil had a greater proportion of fines (<2 mm fraction), more water available between field capacity (-0.03 MPa) and permanent wilting point (-1.5 MPa), and thus a greater amount of "available" water than the disturbed microsites (Table 13). Also, the undisturbed meadow soils showed a decrease in these parameters with depth, whereas the disturbed microsites were more uniform. Although these differences were generally not significant due to microsite variability, the indicated trends may be of importance relative to plant establishment and growth in vegetated versus disturbed microsites.

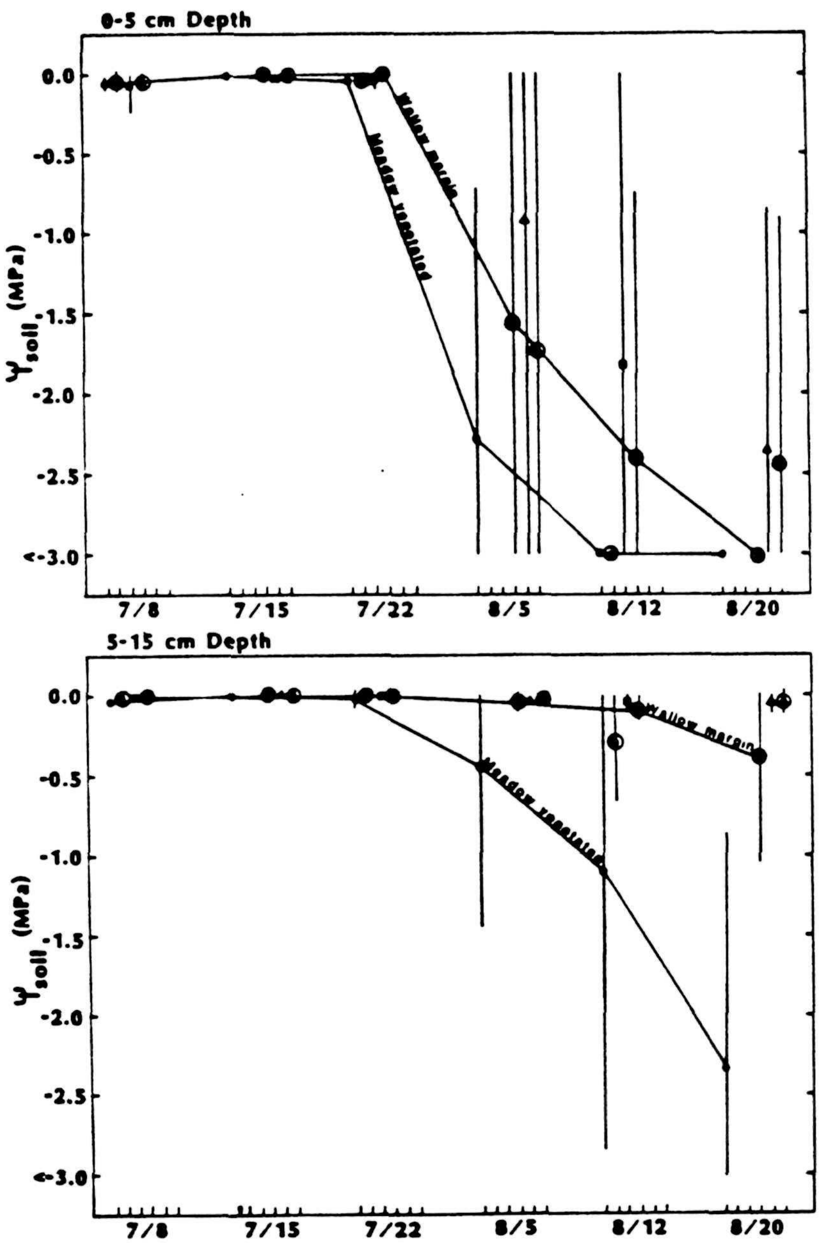
The maritime climate of the Olympic Mountains results in the deep accumulation of snow during winter at high elevations which, combined with frequent spring precipitation, tends to maintain high soil moisture contents in most subalpine and alpine sites until mid-summer which can result in soil moisture stress in exposed, well-drained sites.

During the summer of 1981, soil moisture in the Phlox-fescue meadow remained high until late-July (Fig. 9) and then declined during a period of >40 days without measurable precipitation (see Microclimate Section). Micro-

Table 13. Physical properties of soils from six microsites in the extensive phlox-fescue meadow on Klahhane Ridge. CI 95% are indicated.

Location	<2 mm Fraction (%)	Soil Moisture (%) 0.03 MPa	Soil Moisture (%) 1.50 MPa	Available in Horizon (%)
0 - 5 cm Depth				
Meadow				
Vegetated	57.0 ± 13.2	35.2 ± 5.6	21.5 ± 3.1	8.8 ± 3.7
Disturbed	54.7 + 14.1	27.7 ± 2.0	15.9 ± 1.9	6.6 ± 3.5
Wallow Proper				
Center	55.2 ± 4.9	22.7 ± 4.6	12.0 ± 1.7	5.9 ± 1.9
Margin	53.7 ± 15.7	23.5 ± 4.7	12.5 ± 2.8	5.9 ± 2.6
Wallow Outwash				
Center	50.6 ± 11.0	23.3 ± 4.9	11.8 ± 2.2	5.8 ± 1.9
Margin	54.2 ± 6.6	23.7 ± 4.8	11.8 ± 1.5	6.5 ± 2.5
5 - 15 cm Depth				
Meadow				
Vegetated	58.0 ± 6.0	28.9 ± 4.4	16.6 ± 2.6	7.2 ± 2.3
Disturbed	52.2 ± 8.7	27.4 ± 2.2	16.0 ± 1.0	6.0 ± 2.1
Wallow Proper				
Center	49.8 ± 12.4	23.7 ± 4.3	13.0 ± 2.4	5.2 ± 0.7
Margin	54.8 ± 4.8	24.1 ± 4.6	13.2 ± 3.0	6.0 ± 1.9
Wallow Outwash				
Center	47.7 ± 9.8	25.7 ± 2.6	13.6 ± 1.0	5.8 ± 2.1
Margin	41.6 ± 22.0	23.5 ± 4.8	14.6 ± 4.2	4.4 ± 3.2
> 15 cm Depth				
Meadow				
Vegetated	45.1 ± 17.3	26.5 ± 6.0	15.8 ± 2.3	4.7 ± 2.6
Disturbed	44.8 ± 11.7	25.0 ± 4.3	14.4 ± 1.1	4.8 ± 2.4
Wallow Proper				
Center	42.8 ± 23.6	23.6 ± 4.1	12.5 ± 2.6	4.7 ± 3.4
Margin	48.3 ± 9.5	24.1 ± 3.4	13.2 ± 2.7	5.2 ± 1.1
Wallow Outwash				
Center	47.3 ± 11.2	25.0 ± 1.6	13.4 ± 0.8	5.6 ± 2.0
Margin	45.5 ± 15.5	24.3 ± 4.5	13.4 ± 1.9	5.1 ± 2.7

Figure 9. Seasonal soil matric potential (soil) at six microsites in the extensive Phlox-fescue meadow on Klahhane Ridge during the summer of 1981. Lines connect the vegetated meadow and wallow margin microsites which were sampled on each date; other microsites were sampled only on alterate dates. C. I. 95 indicated by vertical bars.



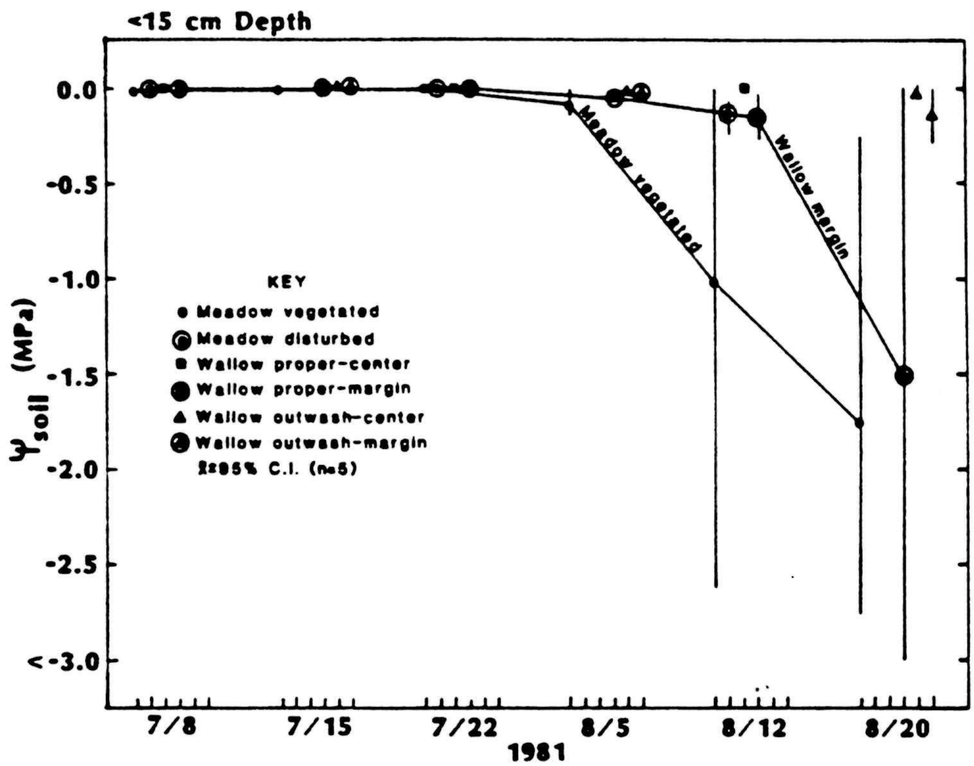


Figure 9 (continued).

site variability resulted in few significant differences but trends are indicated. The surface horizon (0-5 cm) of all microsites became very dry for a three week period in August prior to the fall rains, and mean Ψsoil was estimated at ca. -3.0 MPa with some individual samples estimated at <-10.0 MPa. Most plants do not have the physiological ability to extract water in this this range of Ψsoil values. Greater soil moisture was found in the subsurface horizons of all microsites. However, even at 15 cm depth Ψsoil in the vegetated meadow declined to <-1.5 MPa. Soil water at <5 cm depth was within the range of plant availability in the disturbed meadow, wallow proper center, wallow outwash center, and wallow outwash margin microsites throughout the summer. Although destruction of the plant canopy by goat disturbance might be expected to result in a lowered resistance to water loss from the soil surface and thus a drier soil, it appears this is compensated for by reduced transpirational losses from the profile. The driest microsites, particularly at <5 cm depth, were the vegetated meadow and the wallow margin, microsites where intact roots permeate the subsurface horizons resulting in depeletion of water reserves.

REFERENCES

Belsky, A.J. 1979. Determinants of ecological amplitude in Festuca idahoensis and Festuca ovina. Ph.d thesis, University Washington, Seattle, WA.

Bouyoucos, C.J. 1951. A recalibration of the hydrometer method for making mechanical analysis of soils. Angronomy Journal 43:434-438.

Brady, N.C. 1974. The Nature and Properties of Soils. 8th edition. MacMillian Publishing Co., Inc. New York, N.Y.

Broadbent, F.E. 1965. Organic matter. In: C.A. Black (ed.). Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. American Society of Agronomy, Inc. Madison, Wisc.

Boul, S.W., F.D. Hole, and R.J.McCracken. 1973. Soil Genesis and Classification. The Iowa State University Press, Ames, Iowa.

Canfield, R. 1941. Application of the line interception method in sampling range vegetation. Journal of Forestry 39: 388-394.

Climatological Data for Washington. 1978-1982. National Oceanic and Atmospheric Administration, Environmental Data and Information Service, National Climatic Center. Asheville, N.C.

Dingwall, P.R. 1972. Erosion by overland flow on an alpine debris slope. Pgs. 113-120, in H.O. Slaymaker and H.J. McPherson (Eds.), 1972, Mountain Geomorphology: Geomorphological Processes in the Canadian Cordillera. B.C. Geographical Series No. 14. Tantalus Press, Vancouver, B.C.

Driver, C.H., Bliss, L.C., Pike, D.K., & Pfitsch, W.A. 1979. Terrestrial baseline surveys, non-native mountain goats of the Olympic National Park. Annual report. Initial mountain goat habitat studies. Contract No. CX9000-9-0087. University Washington, Seattle, WA.

Dunne, T. 1977. Evaluation of erosion conditions and trends. Pg. 53-83, in Kunkle, S.H. and J.L. Thames, Eds., Guidelines for watershed management. Food and Agriculture Organization of the United Nations. Rome, Italy.

Ellison, W.D. 1945. Some effects of raindrops and surface flow on soil erosion and infiltration. Trans. Amer. Geophys. Union. 26: 415-429.

Ellison, L. & Croft, A. R. 1951. Indicators of condition and trend on high range-watersheds of the intermountain region. Agriculture Handbook No. 19, U.S. Dept. of Agriculture, Washington, D.C.

Emmett, W.W. 1970. The hydraulics of overland flow on hillslopes. U.S. Geol. Survey Prof. Paper 662-A, 68 pp.

Fonda, R.W. & Bliss, L.C. 1969. Forest vegetation of the montane and subalpine zones, Olympic Mountain, Washington. Ecological Monograph 39: 271-301.

Geiger, R. 1950. The Climate near the Ground. Harvard Univ. Press, Cambridge, Mass.

Gerlach, T. 1967. Hillslope trough for measuring sediment movement. Rev. Geomorph. Dyn. 17: 173.

Kuramoto, R.T. & Bliss, L.C. 1970. Ecology of subalpine meadows in the Olympic Mountains, Washington. Ecological Monographs 40: 317- 347.

McDonald, L.L. 1980. Line-intercept sampling for attributes other than coverage and density. Journal of Wildlife Management 44:530-533.

Meyer, L.D. & Monke E.J. 1965. Mechanics of soil erosion by rainfall and overland flow. Trans. Amer. Soc. Agric. Eng. 8: 572-577.

Mueller-Dombois, D. & Ellenberg, H. 1974. Aims and Methods of Vegetation Ecology. John Wiley and Sons, New York, NY.

Nimlos, T.J. and R.C.McConnell. 1965. Alpine soils in Montana. Soil Science 99: 310-321.

Olmsted, I.C. 1976. Alpine and subalpine vegetation under the influence of non-native mountain goats, Olympic National Park. Pp. 1143-1148, in Proceedings First Conference on Scientific Research in the National Parks. R.M. Linn (Ed.). Natl. Park Service Proceedings Series, No. 5.

Pfitsch, W.A. 1981. The effects of mountain goats on the subalpine plant communities of Klahhane Ridge, Olympic National Park. M.S thesis, University of Washington, Seattle, WA.

Pike, D.K. 1981. Effects of mountain goats on three plant species unique to the Olympic Mountains, Washington. M.S. thesis, University of Washington, Seattle, WA.

Retzer, J.L. 1974. Alpine Soils. Pg. 771-804 in J.D. Ives & R.G. Barry, Eds. Arctic and Alpine Environments. Methuen and Co., Ltd; London.

Selby, M.J. & Hosking, P.J. 1971. Causes of infiltration into yellow-brown pumice soils. Journal of Hydrology (N.J.) 10: 113-119.

Soil Survey Staff. 1975. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. Agriculture Handbook No. 436. U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C.

Stevens, 1983. Dynamics of dispersal in an introduced mountain goat population on the Olympic Peninsula, Washington. Ph.D. thesis, University of Washington, Seattle, WA.

Stevens, V. 1979. Mountain goat habitat utilization in Olympic National Park. M.S. Thesis, University of Washington, Seattle, WA.

Tabor, R.W. 1975. Guide to the geology of Olympic National Park. University of Washington Press, Seattle, WA.

Tabor, R.W. & Cody, W. M. 1978. Geologic map of the Olympic Peninsula, Washington. U.S. Geological Survey Map 1-994, Department of the Interior, Washington, D.C

THE IMPACT OF MOUNTAIN GOATS UPON SUBALPINE PLANT COMMUNITIES, KLAHHANE RIDGE

W.A. Pfitsch

Introduction

The introduction of ungulates to new habitats has characteristically resulted in an eruption of population levels followed by a decline attributed to the degradation of the food resource by overgrazing (Caughley 1970). Mountain goats (Oreamnos americanus) were introduced into the Olympic Mountains in the late 1920's. The introduced population has grown and spread throughout the alpine and subalpine areas of the Olympic Peninsula (Moorhead 1977). The current population of 500 to 700 animals is concentrated in the mountainous areas of Olympic National Park, where the goats have been protected from hunting since 1938 (Stevens 1983).

The highest density of mountain goats occurs on Klahhane Ridge, an east-west ridge in the Northwest part of Olympic National Park (47°59'30"N, 123° 27'30W). The ridge consists of steep rocky outcrops and unstable scree slopes and meadows generally underlain by basalt, and relatively stable meadows with sedimentary substrate. In 1980 approximately 180 goats shared a snow-free (May to November) range of about 13 km^2 (Stevens 1983). This concentration of 14 goats/km^2 compares with figures of 2.8 and 0.5 goats/km^2 (Chadwick 1977; Singer 1975) for natural mountain goat populations in Glacier National Park. Chadwick (1977) attributes the differences in goat density in Glacier to the relative abundance of rocky terrain with the more gentle areas studied by Singer (1975) supporting a lower density. Differential densities of mountain goats occur in the Olympic Mountain as well, the abundance of animals in an area is related to the availability of steep, rocky terrain for escape and cover, open subalpine or alpine meadows for forage, and thermoregulatory habitat, principally cool areas in which the goats can escape the summer heat (Stevens 1979).

Chadwick (1977) and Kuck (1977) propose that populations of mountain goats are limited primarily by extrinsic abiotic factors, climate and primary (geomorphic) succession. Biotic influences seem of secondary importance in native populations. In an area such as Klahhane Ridge with concentrated populations of mountain goats, their food resource may be expected to be more important for maintaining population levels. Indeed, the animals in this population exhibit several characteristics which are indicative of a population limited by its food resource. The Klahhane goats are smaller than those in other Olympic populations, they have a lower reproductive rate, the nannies bear young at an older age, and nannies rarely bear twins in recent years while twinning is quite common in other areas (Stevens 1982).

Despite this evidence that the overall health of the goats is possibly suffering from a lack of high quality forage, classical indictions of overgrazing, such as the prevalence of unpalatable species, are lacking. The most obvious effect of the goats on their habitat has been the creation of dust baths (wallows) which have subsequently become quite extensive. While wallows are common, and the plant community is changed in their immediate vicinity, they do not appreciably reduce the amount of forage available to the goats.

The goals of this study were the following: 1) to describe the plant communities important in mountain goat habitat on Klahhane Ridge; 2) to determine the relative foraging intensity in each community; and 3) to determine the annual net aboveground primary production of each community type, the areal extent and hence the total net annual production of each commuity as an estimate of the potential forage resource available to the goats during the snow-free period. These factors can be used to help understand how possible forage limitations during the snow-free period may contribute to the restriction of mountain goat population levels on Klahhane Ridge. Finally, evidence

will be presented as to how the mountain goat population pressure may be changing the plant communities of Klahhane Ridge.

METHODS

The plant communities of Klahhane Ridge were surveyed in 1979, and 20, 10 x 10 m plots were located for floristic analysis, grazing and production estimates. Areas were selected on the basis of uniform physiognomy and floristic pattern with an intent to express the range of plant communities important in mountain goat habitat. All measurements were made near the end of the growing season when plant biomass was greatest. One plant community and two habitat types important for the mountain goats on Klahhane Ridge were not sampled in this study, a Saussaurea-forb meadow at lower elevations, forested slops, and rocky outcrops. The latter two are presumed to contribute little to the forage requirements of the goats due to the fact that 87% of Klahhane Ridge mountain goat foraging time is spent on open meadows or scree slopes (Stevens 1979). Estimates of plant production of the lower elevation Saussaurea-forb meadow used in total ridge forage estimates are from Kuramoto and Bliss (1970).

A stratified random sampling procedure was employed in which one $1m^2$ quadrat was randomly located in each of 10, 2 x 5m subplots. Total cover of each species was visually estimated to the nearest 1%. Cluster analysis (Clifford and Williams 1977) and polar ordination (Bray and Curtis 1957) were used to help classify plots into community types and to interpret important environmental trends influencing community pattern.

An estimate of grazing intensity was made for each species in each quadrate: + indicating a tract of grazing; 1 that 1 to 25%; 2 that 26 to 50%; 3 that 51 to 75%; and 4 that 76 to 100% of the individuals of a species showed

evidence of grazing. Two plots located near marmot dens where grazing due to other large herbivores cannot be discounted as minimal have been excluded from the grazing analyses. Grazing evidence is retained by most species for the entire growing season, thus estimates made at the end of the season are assumed to integrate grazing for the entire period. Two grazing parameters were calcualted for each plot, the relative frequency of grazing and the average grazing intensity. The relative frequency of grazing is the number of quadrats in which a species showed evidence of grazing, relative to the number of quadrats in which the species occurred. The average grazing intensity is the grazing estimate averaged for those plots with grazing not equal to 0 for each species.

One $0.25m^2$ subquadrat was randomly selected in each $1m^2$ quadrat for production estimates. Herbaceous plants were clipped at ground level and the material sorted to include only plant material produced that year. Samples were dried at 54°C to constant weight and weighed to the nearest 0.1g. Cover estiamtes for Phlox diffusa, a mat species which was not harvested, were related to biomass by regression of biomass to area.

Exclosures (10 x 10m) paired with five vegetation plots sampled in 1979 were constructed as soon as possible after snowmelt in 1980. Production harvests were carried out within these exclosures at 3 or 4 times during the summer. Seven different stratified random $0.25m^2$ quadrats were harvested each time. All plants were clipped at ground level, dried to a constant weight at 65°C and weighed.

A map of the plant communities of Klahhane Ridge was constructed with reference to areal photos. The areal extent of communities was estimated by cutting them out of a map and weighing, using paper weights of standard areas as a reference.

RESULTS

Plant Communities of Klahhane Ridge

Time of snowmelt with its associated moisture relations, and substrate stability were found to be the most important environmental factors determining plant community distribution on Klahhane Ridge. Nine community types were identified ranging from a windswept ridgetop fellfield with mat and cushion plants that may be snow-free in March, to a variety of communities associated with snowbeds that are not free from snow until mid-July (Heather, Late snow sedge, Lupine-sedge). On a substrate stability gradient they range from completely stable sedge turf in late snow basins, through fairly steep (20° to 30°) but relatively stable south-facing meadows on sandstone substrate dominated by mat plants and bunch grass (Phlox-fescue), to steeper (30° to 35°) unstable herbaceous meadows, and very steep (35° to 40°) active scree slopes generally on basaltic substrate (Table 14).

The environmental factors important in determining community composition and distribution on Klahhane have been implicated as being important in other subalpine regions of the Olympic Mountains. Kuramoto and Bliss (1970) found air temperature and soil moisture to be the two most important environmental factors in their general study of the snowmelt gradient considered important on Klahhane. Belsky and del Moral (1982) and Sackett (1980) determined that soil moisutre and substrate stability were the most important environmental gradients at Deer Park. Canaday and Fonda (1974) found that plant community patterns were related to the distribution of snowbanks and time of snow-melt.

Net Aboveground Primary Production

The net annual production of herbs (aboveground) for 1979 ranged from 20 g/m to more than 200 g/m in the different plant community types of Klahhane

TABLE 14. General features of Klahhane Ridge plant communities.

Community type	Dominant Growth Forms	Dominant Species	Snow-free (Date)	Slope (°)
Phlox-fescue	mat plants bunch grass	Phlox diffusa Festuca idahoensis Arenaria capillaris	Early May to June	5 to 30
Unstable herb	large herbs	Eriophyllum lanatum Artemesia ludoviciana Phacelia hastada Cirsium edule Hydrophyllum fendleri	May to June	30 to 36
Scree	large herbs	Senecio neowebsteri Phacelia hastada Delphinium glareosum	June	35 to 40
Heather	shrubs	Cassiope mertensiana Phyllodoce empetriformis	June	10 to 15
Late snow-sedge	sedge mat	Carex nigricans Carex spectabilis	July	0
Lupine-sedge	large herbs and sedge	Lupinus latifolius Carex spectabilis	July	10 to 15
Luetkea drainage	mat plants graminoids	Luetkea pectinata Carex spectabilis	July	5 to 10
Tall grass-herb	graminoids large herbs	Carex spectabilis numerous grasses Cirsium edule Arnica spp.	late June	10 to 20
Ridge top fellfield	cushion and mat plants	Juniperus communis Phlox diffusa many "alpine" spp.	March to April	20 to 30

Ridge (Table 15). Communities with more abundant summer soil moisture (Lupine-sedge, Saussaurea-forb) have greater production than dry site communities (Phlox-fescue). Within the Phlox-fescue community type, production varied with time of snowmelt, with later melting areas having greater production. The extremely short growing season (40 to 50 d) in late snowmelt areas limited production (Late snow-sedge, Luetkea drainage, north-facing Scree) as does extreme instability of substrate (Scree).

The Phlox-fescue community type with its extensive range on the south side of Klahhane Ridge contributed nearly 60% of the total herbaceous production that was available for mountain goat forage (Table 15). Unstable herb communities occuring on both the north and south side of the ridge make up about 15% of the total production, as do the lower elevation Saussaurea-forb meadows. The remaining biomass is produced by meadows and scree slopes on the north side of the ridge. Scree slopes make up more than 25% of the total non-forested range, yet they contribute less than 10% of the total production.

Grazing Intensity by Area

The relative frequency of grazing calculated for each plot is an index of the proportion of species in a plot that showed evidence of grazing. It has been shown that as an area is subjected to more concentrated grazing pressure, more species are taken (Harper 1977). The average intensity of grazing for a plot is the proportion of the population of grazed species that had been grazed at the sampling time. This may be considered as an overall measure of grazing intensity if many species are grazed or as an indication of preference for certain species if few are grazed.

South side stable Phlox-fescue and ridgetop fellfield meadows have relatively low values for both grazing frequency and intensity (Table 16). Un-

TABLE 15. Aboveground net production, areal extent, and total production estimate for each plant community type on Klahhane Ridge.

Community Type	Production (g/m^2, $\pm$ S.E)	Areal Extent (m^2)	Total Production (kg)
Phlox-fescue	170 $\pm$ 60	532,000	90,440
Unstable herb	160 $\pm$ 70	151,000	24,192
Scree	40 $\pm$ 40	298,700	11,948
Heather*	20 $\pm$ 10	80,200	1,604
Late snow sedge	120 $\pm$ 70	17,300	2,076
Lupine-sedge	220 $\pm$ 50	8,700	1,914
Luetkea drainage	30 $\pm$ 30	13,700	411
Tall grass-herb	110 $\pm$ 40	8,500	935
Ridge top fellfield**	-	36,000	-
Saussaurea forb***	370 $\pm$ 110	57,000	21,090
		TOTAL	154,610

* Herbacous production only

** No production estimate

*** Kuramoto and Bliss (1970)

TABLE 16. Mean grazing intensity and relative frequency for plots of the north (N) and south (S) side of Klahhane Ridge. Summer (July to Aug.) Primary productivity for 5 enclosed plots in 1980.

Community type	Plot #	Side	Mean Intensity	Relative Frequency	Productivity ($g/m^2/d$)
Phlox-fescue	1	S	0.7	0.26	0.29
	2	S	0.6	0.17	0.91
	3	S	0.6	0.21	
	7	S	0.9	0.26	
	19	S	0.5	0.24	
Unstable herb	5	S	1.5	0.45	
	11	N	1.5	0.51	1.97
	12	N	1.3	0.53	
	20	S	1.6	0.60	1.77
Scree	8	N	1.8	0.33	
	9	N	1.5	0.46	
	10	N	1.9	0.48	
Heather	16	N	0.3	0.12	
Late snow sedge	17	N	1.0	0.44	
Lupine-sedge	18	N	1.2	0.41	
Luetkea drainage	15	N	2.4	0.18	
Tall grass-herb	14	N	1.2	0.52	1.23
Ridge top fellfield	4	S	0.5	0.21	

stable herb meadows with similar plant cover and species density located on the south and north side of the ridge received significantly higher (t-test prob L.T. 0.05) values of grazing frequency and intensity. The other meadows on the north side of the ridge all had high grazing frequency and intensity, with the exception of Heather which had very low grazing values, indicating low goat use of this community, and the Luetkea drainage which had very low relative frequency but high grazing intensity, indicating heavy grazing on one preferred species, *Carex spectabilis*.

There are no correlations between the net primary production of a site and its grazing indexes. This points up the fact that biomass does not equal forage utilization and that other factors play important roles in determining where animals forage. Production estimates do provide an absolute measure of the potential forage availability and will be used as such in this analysis.

DISCUSSION

The snow-free period (May to November) can be divided into three seasons with respect to the areas used by the goats for foraging. The first area to be snow-free on Klahhane is the windswept ridgetop from which snowmelt can be as early as March. Mountain goats have been seen foraging on the ridgetop at all tiems of the year (V. Stevens pers. comm.). Deep snow in other meadows prohibits grazing. The southerly slopes of Klahhane Ridge become snow-free from May to June. During this spring season, large numbers of goats return from winter range and forage in the stable Phlox-fescue and Unstable herb meadows on the south side. Deep snow continues to prevent access to areas on the north side of the ridge although some of the east-facing unstable herb meadows are snow-free by this time.

As average temperatures rise and most areas lose their snow cover, the goats spend more time on the northern side of the ridge. During the hot summer season (July to mid-August) little precipitation falls and the goats restrict their activities almost exclusively to the shelter of the north side of the ridge, apparently for thermoregulatory reasons. Some animals do forage at night on southerly slopes during the hot summer season, although this nocturnal activity is the exception rather than the rule.

With the onset of lower fall temperatures, generally accompanied by increased precipitation (mid-August to November), the range of the goats includes the entire ridge. Selection of foraging by thermoregulatory constraints continues with goats using the south side in cool weather and the north in hot (pers. obs).

The variability observed in grazing intensity may be explained by a combination of the followig factors: 1) the distribution of available and high quality forage in space and time; 2) preference for cooler exposures during mid-summer; and 3) the proximity of meadows to rock outcrops used by the goats for escape refuges. The highest grazing frequency and intensity occurs in the cooler meadows and scree slopes on the north side of Klahhane Ridge, which are generally close to rocky outcrops or cliffs. The fact that snow melts off many of these areas quite late in the summer ensures the presence of young, newly expanding plant tissue that may be of higher forage quality than the maturing plants in south-facing Phlox-fescue meadows. Plants on these northerly slopes make up only about 10% of the total biomass of the ridge (Table 15). This fact, coupled with the preference of the goats for these areas for a considerable period during the mid-summer, results in high values for grazing frequency and intensity.

Unstable herb meadows on the south side are the major exception to the rule that grazing is concentrated on northern exposures. These areas have grazing intensities and relative frequencies comparable to north side meadows (Table 16), despite the fact that goats are rarely observed in them during the mid-summer period. The higher grazing intensities in these meadows than in other south side meadows may be due to their relative proximity to rocky areas for escape. These areas also have mid-summer productivity (rate of dry matter production) values which are as high as productivity in north slope communities of the same type (Table 16). A combination of higher quality, rapidly growing forage and proximity to rock outcrops may result in the high grazing values observed for these south slope meadows.

The north slope and unstable south-side meadows that are preferred by the goats for foraging produce a relatively small proportion of the total potential forage on Klahhane Ridge. The thermoregulatory, escape, and forage constraints which restrict the mountain goats to these areas during the mid-summer limit the potential forage that is available to the goats. If the goats grazed only in north-side meadows during mid-summer, the total available forage on a per day basis would be less than 30% of that available at the beginning of the snow-free period and less than 25% of that available at the end of the season (Table 17). This represents the critical season for this mountain goat population in terms of forage availability. Even if unstable south slope herb meadows are included in the mid-summer forage calculation, a minimum of forage availability occurs at this time (Table 17).

It is possible to use these data to calculate a mountain goat carrying capacity. We assume that an average mountain goat weighs 42kg (weighted mean based on population proportion and weights of adult females and males, yearlings, and kids), and consumes 2.2% of its body weight (0.92kg) each day (dry

TABLE 17. Seasonal potential forage availability on Klahhane Ridge. These figures are calculated by partitioning the estimated total yearly production in each plant community into the number of days that each meadow is used intensively for goat foraging and summing for each season. E.G. meadow in Late snow sedge community type of areal extent 5000m2 available summer and fall only 45+80=125 days, total production of 119 g/m2 x 5000m2=595000g; summer forage availability = 595000 x 45/125=215 kg; fall forage availability = 595000 x 80/125=380 kg forage.

Season	# Days	Biomass(kg)	Biomass/Day(kg/d)
Spring (May to July)	55	46,620	820
Summer (July to mid-Aug.)	45	12,100	270
Fall (mid-Aug. to Nov.)	80	94,310	1,180
If south side unstable herb communities are used all year.			
Spring	55	44,680	810
Summer	45	16,730	370
Fall	80	93,530	1,170

weight of plants, live weight of goats - normal ungulate consumption rate) (Hudson pers. comm. 1982), and that the annual removal of 20 to 30% of the available forage does not cause a significant reduction in net plant production or species composition.

Assuming the removal of 20 to 30% of the annual aboveground production on Klahhane Ridge the sustainable carrying capacity, based upon spring to fall available forage would then be calcualted to be 190 to 280 goats [154, 610 kg total prod. x 0.2 (0.3)/0.92/180 = 190 (280)]. Clearly however, the summer season when the goats are concentrated on the north slope meadows is the most

limiting time in terms of the snow-free season. If we assume that the amount of grazing on these meadows is insignificant except for the 45d of the mid-summer season and that the goats eat 20 to 30% of the animal production, then the carrying capacity based on production available during this time would be 150 to 220 animals [30550 kg x 0.2 (0.3/0.92/45 = 150 (220)].

We have not considered the winter season, another time when forage availability may be at a limiting level. Little is known about the winter forage availabiltiy to the Klahhane goat population. Further investigations of winter forage are being conducted (pers. comm. Office of Science and Technology, Olympic National Park).

An animal population can be restricted by the availability of any of its necessary resources. Stevens (1979) has shown how important the availability of non-food resources, rock outcrops and thermoregulatory habitat can be in determining the mountain goat population that an area will support. On Klahhane Ridge the combination of abundant high quality early season forage in the form of south-facing Phlox-fescue meadows which melt out quite early, and a fairly substantial amount of cooler meadows with high mid-summer productivity, all with close proximity to escape habitat, has resulted in extremely high mountain goat densities. The same non-food resources that limit population densities in other areas of the Olympic Mountains play a role in determining the forage available to the goats during the summer season on Klahhane Ridge, and hence will ultimately determine the population levels which may be sustained. On Klahhane Ridge it is the abundance of forage that is available to the goats during the time when their activities are restricted by thermoregulatory demands which appears to play the most important role in limiting their population. It is particularly important to recognize that the limiting forage resource is the one which will suffer the most from overgrazing and

trampling damage. On Klahhane Ridge the limiting areas are largely unstable meadows and scree slopes. These same communities are potentially the most susceptable to damage from overgrazing pressure due to their substrate instability, and they also can be expected to have the slowest potential rate of recovery.

The question arises as to what evidence there is that mountain goat activities have changed the plant communities of Klahhane Ridge. This is extremely difficult to answer in light of the fact that there was no detailed plant community analysis done before the goats became abundant. Two areas, Constance Pass and Tyler Peak with south-facing Phlox-fescue meadows, similar to those on Klahhane Ridge, were sampled with the intent of addressing this question. Constance Pass and Tyler Peak both have low mountain goat population pressure. Since it is hazardous to attribute differences in geographically separate plant communities to differences in the intensity of animal use, sampling was restricted to a defined community type and only general factors such as species density and dominant species cover were compared.

Eleven plots were located in south-facing Phlox-fescue meadows on Klahhane Ridge. Six plots were sampled in similar south-facing meadows at Constance Pass and seven were sampled at Tyler Peak. A stratified random procedure was employed in which one $1m^2$ quadrat was randomly located in each of 5 (10 in 6 plots on Klahhane) regularly arranged 2 x 5m subplots. Three $1m^2$ quadrats were randomly sampled with 6, 5 x 5m exclosures constructed on Klahhane Ridge in 1976. Sampling was conducted in 1979 and 1981 for non-exclosed Klahhane plots, in 1981 for the rest of the plots. Total cover of each species was visually estimated to the nearest 1%. Mean values were calculated for each plot for the number of species/m^2 (species density).

Species density in Klahhane Ridge south-facing Phlox fescue meadows is significantly (t-test) probability; $p = 0.0266$) less than in comparable meadows at Constance Pass and Tyler Peak. The total plant cover of Klahhane meadows is less than in the areas of low goat use ($p = 0.021$). There is a greater cover of Phlox diffusa ($p = 0.0179$) and less cover of Festuca idahoensis ($p = 0.0009$) on Klahhane. Plots enclosed for 5 yr on Klahhane Ridge have similar values as unexclosed areas for everything except Festuca cover and species density which are significantly greater ($p = 0.0081$ and $p = 0.0766$ respectively) within exclosures (Table 18).

By grazing preferentially on a dominant species, a herbivore can release subordinate species from competitive inhibition. Trampling by a large grazer opens up patches in the plant community which creates colonization sites for opportunistic species and increases small-scale environmental heterogeneity, thus enabling species with slightly different germination or growth requirements to survive. In these ways, a grazing animal can increase the number of species which are able to coexist. Species density can be decreased by the activities of a large grazing animal if the activities are especially severe or if the environment is so extreme as to not allow rapid recolonization of open sites (Harper 1977).

It appears that concentrated mountain goat grazing and trampling have reduced the density of plant species in Klahhane Ridge Phlox-fescue meadows in spite of the fact that Festuca idahaensis is apparently reduced by preferential grazing. The fact that enclosed plots on Klahhane have Festuca cover and species density that are nearly as high as in low goat use areas suggests that the differences between unexclosed Klahhane Ridge meadows and low goat areas may be attributed to mountain goat activities.

If the stable meadows on Klahhane Ridge's south side have experienced a reduction in plant cover and a decline in species density as a result of moderate levels of grazing and trampling pressure, then it can be assumed that other areas which are subject to heavier goat pressure have experienced a similar fate. The decline in species density can be expected to be especially severe in areas of unstable soils where environmental limitations to plant growth and development are strong.

TABLE 18. Community characteristics (Mean ± S.D.) of south-facing *Phlox diffusa* and *Festuca idahoensis* dominated plant communities on Klahhane Ridge (KR) (high mountain goat densities), at Constance Pass (CP) Tyler Peak (TP) and Hurricane Hill (HH)(low mountain goat densities), and exclosures established on Klahhane Ridge (EX) in 1976.

	KR	CP	TP	CP+TP	EX	HH
Total plant cover	65.4 ±5.3	73.6 ±16.4	75.3 ±12.2	74.5** ±13.7	66.0 ±10.0	86.2
Festuca cover	11.0 ±5.8	17.3 ±2.8	19.8 ±4.9	18.7*** ±4.1	16.2** ±1.9	30.8
Phlox cover	25.0 ±9.8	14.6 ±4.5	19.2 ±7.8	17.1** ±6.7	22.7 ±6.3	25.2
Species per M2	15.1 ±2.6	17.2 ±2.1	16.9 ±1.3	17.0** ±1.6	16.7* ±1.7	11.6
Lichen/moss	0.9 ±		11.1 ± 6.8			9.2 ± 5.2
Bare ground cover	32.9 ± 6.9	27.6 ± 12.1	13.8 ± 5.1	20.2 ± 11.2	35.3 ± 9.4	4.6 ± 5.0
Number of plots	11	6	7	13	6	5

REFERENCES

Belsky, A.J. and R. del Moral. 1982. Ecology of an alpine-subalpine meadow complex in the Olympic Mountains, Washington. Canadian Journal of Botany 60: 779-788.

Bray, J.R. and J.T. Curtis. 1957. An ordination of the upland forest communities of southern Wisconsin. Ecological Monographs 27:325-349.

Caughley, G. 1970. Eruption of ungulate populations with emphasis on Himalayan thar in New Zealand. Ecology 51:53-72.

Canaday, B.B. and R.W. Fonda. 1974. The influence of subalpine snowbanks on vegetation pattern, production and phenology. Bulletin Torrey Botanical Club 101:340-350.

Chadwick, D.H. 1977. Ecology of the Rocky Mountain goat in Glacier National Park and the Swan Mountains, Montana: Final Report. Glacier National Park, West Glacier, Montana, 54pp.

Clifford, H.T. and W.T. Williams. 1973. Classificatory dendrograms and their interpretation. Australian Journal of Botany 21:151-162.

Fox, J. 1983. Constraints on winter habitat selection by the mountain goat (Oreamnos americanus) in Alaska. Ph.D. Thesis, University of Washington, Seattle, WA.

Harper, J.L. 1977. Population Biology in Plants. Academic Press, London. 892pp.

Harter, J..1983. Mountain goat wallow dynamics. pp. 34-52. Ineffects of Mountain Goats on Soils, Plant Communities and Selected Species in Olympic National Park. W. Pfitsch, R.S. Reid, J. Harter, D.K. Pike, and L.C. Bliss. Final Report, Olympic National Park. Port Angeles, Washington.

Hitchcock, C.L. and Cronquist, A. 1978. Flora of the Pacific Northwest. Univ. Wash. Press, Seattle. 730pp.

Moorhead, B.B. 1977. Status and management of the mountain goat (Oreamnos americanus) in the Olympic Mountains, Washington. Prepared for Status and Management of the Mountain Goat in North America, ed. R. Johnson. unpub.

Pfitsch, W.A. 1981. The effect of mountain goats on the subalpine plant communities of Klahhane Ridge, Olympic National Park, Washington. M.S. Thesis, University of Washington, Seattle.

Reid, R. 1983. Patterns of juvenile mortality and plant life histories in response to mountain goat disturbance, Olympic National Park. M.S. Thesis, University of Washington, Seattle, WA.

Sackett, J. 1980. Adaptive strategy and gradient analysis of subalpine meadows. M.S. Thesis, U. of Washington, Seattle.

Singer, F.J. 1975. Behavior of mountain goats, elk and other wildlife in relation to U.S. Highway 2, Glacier National Park. Federal Highway Administration, Denver. 96pp.

Stevens, V. 1979. Mountain Goat (Oreamnos americanus) habitat utilization in Olympic National Park. M.S. thesis, U. of Washington, Seattle. 106pp.

Stevens, V. 1983. The dynamics of dispersal in an introduced mountain goat population on the Olympic Peninsula, Washington. Ph.D. thesis, University of Washington, Seattle. 194pp.

EFFECTS OF MOUNTAIN GOATS ON THREE PLANT SPECIES UNIQUE TO THE OLYMPIC MOUNTAINS

D.K.Pike

INTRODUCTION

The Olympic Mountains have been isolated from neighboring mountain ranges for a considerable time. This has resulted in the evolution of animal and plant taxa unique to these mountains. Thirteen plant taxa are endemic to the Olympic Peninsula with 68 additional taxa considered rare and/or endangered (Hitchcock and Cronquist 1973, Washington Natural Heritage Program 1980).

This study was directed toward the impact of mountain goats on three unique species, Campanula piperi and Senecio neowebsteri endemic to the Olympic Mountains and Asterpaucicapitatus restricted to these mountains and those of Vancouver Island.

Hypothese tested include:

1. Mountain goat habitat utilization and the distribution of the three species overlap.
2. Goat effects include grazing as well as trampling of the three species.
3. Goat use alters plant vigor as measured by plant production, sexual and asexual reproduction, seedling established, and longevity.
4. Goat use and simulated grazing alters the leaf area and the general morphology of clipped plants.

METHODS

The habitat of Campanula piperi on Klahhane Ridge is restricted to basaltic rock outcrops with a south exposure. The plants form small mats where small pockets of soil occur. Most plants are above 1600m.

Aster paucicaptatus is closely related to *Aster ledophyllus* which occurs in the Cascade ranges. This species occurs in open herbaceous meadows where it grows with 20-30 shoots (1-5dm tall) per clump. The species is quite common in mesic to dry subalpine meadows.

Senecio neowebsteri is restricted to steep scree slopes, generally in cirques where snow melt is in late July. The plants develop from a thick caudex and produce relatively large shoots with reddish-purple leaves that are conspicuous against a background of rock.

Exclosures were used to study the short term effect of eliminating grazing. Those build in 1977 were of two sizes, 1X1m and 4x4m. In 1979 exclosure frames (cones 1m in diameter 1.3m high were used. Adjacent paired plots were also used to measure cover of vascular plant species, bare soil, rock, mosses and lichens, and plant density. Litter classes (1=high, 2=moderate, 3=low, 4=none) erosion classes (1=no erosion, 2=surficial loss, 3=1cm loss, 4=1-10cm loss, 5=10cm loss, 6=erosion pavement), and plant phenological stages (leaf emergence, full leaf expansion, flower bud, anthesis, seed set, and leaf dieback) were measured on the plots. Within exclosures (n=5) the three species were subjected to clipping (simulated grazing): two week intervals, start of growth and at anthesis, and only at anthesis. The harvested material was oven dried at 70°C for 24 hr and weighted to the nearest 0.1 mg. Production was expressed on a per shoot (ramet) basis.

Root samples of *Aster* and *Senecio* were collected at each phenological stage, dried and used for analyses of crude protein (total N X 6.25), phosphorus, and calcuim. Seeds of *Aster* and *Senecio* were collected and tested for germination (100 seeds at 25°C within the greenhouse). *Aster* was also tested with tetrazolium salts.

In order to compare the responses of these species sampled under a regime with high grazing intensity with a "control site", plots were also established at Tyler Peak were grazing intensity is low. The bed rock at Tyler Peak is also basalt, the elevation is similar to Klahhane Ridge (1850m) as is slope aspect and slope angle (36° to 41° Tyler vs. 37 to 44° on Klahhane).

RESULTS

The comparative date in Table 19 show that, for each species and the community in which it occurs, there is a greater species richness and plant cover on Tyler Peak. In the communities where Camapanula piperi dominated, nearly all associated species had greater plant cover where goat grazing is minimal. The percentage of bare ground and amount of erosion were greater at Klahhane and the amount of moss and lichen cover were less than at Tyler Peak. Phenological development in Camapanula was not significantly different in the two sites, but the number of shoots and flower buds was greater on the Klahhane plants.

Plants of Camapanula piperi were enclosed in small wire exclosures to prevent grazing. Plants in five exclosures were clipped every two weeks and five plants were clipped only at anthesis, the control plants. Excluding (protecting) plants for only one growing season provided only limited data. However, plants clipped at two week intervals resulted in a shoot production only 20% of controls while plants normally grazed by goats had a shoot production averaging 62% of controls. Flowering was minor in all of the plants except the controls.

Aster paucicapitatus was one of the species with the greatest plant cover and highest frequencies per plot of the species sampled at the two sites. In the communities (Lupine-sedge, Tall grass-herb) where Aster predominates,

TABLE 19. Plant cover, number of species, and erosion and litter classes for plant communities in which Camapanula piperi, Aster Paucicapitatus and Senecio neowebsteri were sampled on Klahhane Ridge and Tyler Peak, Olympic Mountains/

Characteristics	Camapanula piperi		Aster paucicapitatus		Senecio neowebsteri	
	Klahhane	Tyler	Klahhane	Tyler	Klahhane	Tyler
Number of vascular plant species	27	43	30	31	10	13
Plant cover (%)						
vascular	8.5	27.0	54.4	27.7	3.2	6.4
moss	6.0	15.0**	T	0.2*	T	0.2*
crustose lichens	23.0	26.1	0.1	0.3	0.1	0.8*
fruticose lichens	0.8	3.7**	-	-	-	-
foliose lichens	0.1	0.4**	-	-	-	-
Bare ground (%)	31.0	16.9**	48.1	74.4**	79.3	81.5*
Rocks (>7.5cm) (%)	30.3	12.6**	0.3	4.0**	14.5	8.7*
Erosion class[1]	4.2	1.9**	3.9	3.4	5.1	4.7*
Litter class[2]	2.7	2.3**	2.6	2.6	3.5	3.1*

1. Erosion classes: 1 = no loss; 2 = surficial loss; 3 = up to 1cm loss, 4 = 1 to 10 cm loss; 5 = >10 cm loss; 6 = erosion pavement.

2. Litter classes: 1 = high litter load; 2 = moderate, 3 = low; 4 = none.

* P = <0.10
** P = <0.05

total plant cover was greatest at Klahhane but not the amount of bare ground. The number of stems per plant and the number of flowers per stem were significantly higher (P=0.05) at the lightly grazed Tyler Peak site.

At Klahhane Ridge, total shoot growth of control plants and those clipped only at the start of growth were not significally different, nor were those clipped every two weeks versus those grazed by goats. However, the two groups were significantly different from each other from late July to the end of the season. Total production per ramet of the plants clipped every two weeks and the exclosure plants was significantly lower from exclosure plants clipped once, the controls, and the Tyler Peak plants. This again illustrates the impact of grazing and artifical clipping on plant growth.

In general, plants enclosed for two years were taller and had larger leaves and fewer shoots per clump than plants normally grazed. The aboveground net production of exclosed (grazed) plants and plants clipped every two weeks was 40-45% that of the controls. Flowering and fruiting was also greater in the controls and even greater in the plants on Tyler Peak where grazing pressure is minor.

Senecio neowebsteri grows on scree slopes where few other species occur. Consequently, plant cover is minimal (3.2% Klahhane, 6.4% Tyler Peak) (Table 19). The plants grazed had significantly less cover and biomass compared with enclosure plants. Simulated clipping was also effective in reducing leaf length and leaf number compared with control plants.

The exclosure experiments for Senecio neowebsteri indicate visually that grazing removed 65% of aboveground net production of individual plants in 1979 and 1980. The simulated grazing (clipping) experiments of 1980 indicated that clipping resulted in a reduction of leaf size. There were not statistically significant differences in plant production between controls,

plants clipped once, plants clipped every two weeks and plants normally grazed. Observations indicate that flowers a preferred over mature leaf shoots. Newly emerged shoots are less frequently grazed.

Based upon the results of this study it is not evident that these species are seriously impacted by mountain goat grazing, except where soils are removed around rock masses, the favored habitat of Camapaula piperi. Plant cover of all three species was greater on Klahhane Ridge than at Tyler Peak, although plant frequency was lower on Klahhane for Camapanula and Senecio.

This is not to say that all three species receive little impact by goat grazing, only that there is no clear evidence of plant population reduction as a result of high goat density. There is clearcut evidence that repeated grazing during the season as with frequent clipping of shoots does significanty reduce flowering and the setting of viable seed.

REFERENCES

Hitchock, C.L. and A. Conquist, 1978. Flora of the Pacific Northwest. University of Washington Press. Seattle, WA.

PATTERNS OF JUVENILE MORTALITY AND PLANT LIFE HISTORIES IN RESPONSE TO MOUNTAIN GOAT DISTURBANCE, OLYMPIC NATIONAL PARK

R.S. Reid

INTRODUCTION

Dense populations of mountain goats have made several marked changes in the plant cover of the subalpine meadows of Olympic National Park. By grazing, trampling, and dust-bathing, goats remove plant parts, leave visible trails, and create large patches of bare ground (wallows). This considerably alters the microenvironment and creates a different balance of stresses for plants, allowing those species tolerant of disturbance to establish and flourish. It also changes the number and distribution of hospitable microsites for seed germination and seedling establishment.

One purpose of this study is to document and predict changes in plant populations caused by mountain goats. However, the population composition and distribution may be determined at a time and on a scale entirely different from that of the current mature plant population (Harper 1977). It depends on short-term fluctuations as well as long-term changes in flower and seed production, seed germination, seedling establishment, and survival to reproduction as an adult. It is necessary to observe and measure the seedling-scale environment as well as to monitor juvenile and adult plant survival and reproductive output to understand causes and possible trends.

From May to September, 1981 and 1982, the present study was focused on the south side of Klahhane Ridge, Olympic National Park, with the following objectives:

1) Describe the microenviroment and changes caused by goats in the number and distribution of microsites available for plant establishment.

2) Evaluate the ability of species to establish in these different microsites by monitoring plant survival of juveniles and adults.

3) Determine the effect of goats on plant survival in relation to other factors (e.g, frost heaving, climate).

4) Explore the importance of natural selection at the juvenile stage.

5) Compare the density, biomass, growth, phenology, reproductive output, survival, and water relations of four species able to grow in both wallows and the adjacent meadow.

6) Make predictions of future plant population changes under different goat-use intensities. Detailed methods, results, and discussion for this study are presented in Reid (1983). The following report is a brief summary of that thesis.

METHODS

Patterns of Juvenile Mortality

In 1981 and 1982, seedlings of six species (*Achillea millefolium, Erysimum arenicola, Viola adunca, Festuca idahoensis, Phacelia heterophylla, Silene parryi*) and first-year shoots (ramets) of *Achillea* were marked for survival and growth studies. Nomenclature follows Hitchcock and Cronquist (1978). Seven treatments were selected to reflect a scale of goat-use intensity from bare soil in active wallows to dense plant cover in exclosures. Survival and growth were followed using both a mapping table (photo, pg. 35, Reid 1983) relocated over fixed points and an individual flagging method (see Appendix C for methods). Maps of plant cover and shoot density were drawn to provide a baseline for future succession studies and to record the distribution of

microsites available for seedling and ramet establishment. Details of the mapping design are contained in Appendix A.

After marking, ten static parameters (Table 20) of the environment immediately (± 5cm) surrounding each marked seedling (i.e., microsite) were measured to provide correlations between seedling mortality and microenvironmental factors. Periodically throughout the season, dynamic microsite parameters were measured in the two extremes of available microsites :1) bare soil and 2) under dense Phlox diffusa cover. These included vapor pressure difficit (VPD), air and soil temperature profiles, wind speed profiles and soil moisture profiles. A distinction was made between static and dynamic parameters because the two groups require different methods of analysis.

The static microsite parameters (independent variables) were examined singly (bivariate) and in combination (multivariate) for their ability to predict the survival (the dependent variable) of a seedling to the end of its first growing season. Bivariate correlations were done with contingency tables, X^2 tests and Kendall's tau (SPSS, Nie et al. 1975). Logistic regression (BMDP, Dixon 1981) was chosen for multivariate analyses of seedling survival. Results were considered significant if $p < .05$. In depth explanation of these methods appears in Appendix A, pg. 212, Reid (1983).

Plant Life Histories

To investigate the population dynamics of plant species that flourish in areas of high mountain goat disturbance, four species were selected (Achillea millefolium, Artemisia ludoviciana, Phacelia heterophylla, and Eriophyllum lanatum). The variability of possible selective forces was examined in conjunction with the flexibility and endurance of the plants response at each

Table 20. List of safe-site descriptor variables and their ranges used as independent variables in seedling survival analyses (Ex.=Exclosure).

CATEGORICAL VARIABLES

VARIABLE NAME	DESCRIPTION	CLASS: LOW						HIGH
Microsite Type	Density of plant cover	Bare Soil	Tall Forbs		Grasses+ Sedges		Open Mat	Dense Mat
Grazing Treatment	Scale of goat-use intensity	Hurricane Hill	1976 Ex.	1980 Ex.	1981 Ex.	Trampled +Grazed	Wallow Edge	Wallow Center
Organic Matter	O.M. content of surficial soil	No O.M. 0%		Little O.M. 1-12%		Medium O.M. 12-25%		High O.M. >25%
Nearest Species	Species of nearest mature plant	Tall Forbs		*Achillea*		*Festuca*+ *Carex*		*Phlox*+ *Arenaria*
Upslope Species	Species of nearest upslope mature plt.	Tall Forbs		*Achillea*		*Festuca*+ *Carex*		*Phlox*+ *Arenaria*

CONTINUOUS VARIABLES

VARIABLE NAME	DESCRIPTION	RANGE: LOW	HIGH
Nearest	Distance to nearest mature plant	0	3000 cm
Upslope	Distance to nearest upslope mature plant	0	3000 cm
Percent Shade	Percentage of daylight hours site is without direct sunlight	0	100%
Soil	Size of a majority of the surficial soil particles	0	3.0 cm
Slope	Degrees deviation of site from horizontal	0	56°

stage of the life cycle. Experiments measured the comparative response of individuals of each species in disturbed (wallow) and relatively undisturbed (vegetated meadow) sites in the following characters: 1) seed germination, 2) seedling emergence, 3) seedling survival, 4) adult survival and growth, 5) speed of development (phenology), 6) flower and seed production, 7) seed dispersal and 8) water stress tolerance. In particular, adult survival was monitored using a reciprocal transplant experiment into wallow and meadow sites. Significance of data was tested with either a parametric analysis of variance or a non-parametric Kruskal-Wallis test (Tuccy 1978), both through SPSS subprograms (Nie et al. 1975).

RESULTS

Patterns of Juvenile Mortality

First season, overwinter, and second season survival values (Table 21) showed that the first season was the period of greatest mortality for seedlings, with mortality steadily decreasing as seedlings increased in age and size. In comparison, adult mortality over the same period was very low and steady (0-7%). Ramet (first-year shoot) mortality followed the same pattern, but was less than that of seedlings.

Logistic regression and contingency table analysis (Tables 12-16, pgs. 74-88, Reid 1983) revealed several distinct correlations of the ten static microsite parameters with seedling mortality patterns. First, the microsite parameters that most frequently predicted survival were: a) distance to the nearest mature plant, b) microsite type, and c) grazing treatment. Grazing treatment predicted survival well because it was a composite of several microsite variables. Variables that do not predict survival well were: a) soil particle size and b) degree slope. Second, mortality was different among

Table 21. Comparison of first season, overwinter and second season mortality in adults and seedlings of those species, studied for two seasons; NK=not known; *=significant at P<.05, G-test*. Percentages are calculated from those alive at the end of the previous period, so sample sizes are variable.

	FIRST SEASON SURVIVAL			OVERWINTER SURVIVAL			SECOND SEASON SURVIVAL	
SPECIES:	Bare		Veg.	Bare		Veg.	Bare	Veg.
Achillea								
Seedlings	100	*	54	NA		39	NA	7
Ramets	28		40	26		24	0	6
Adults	0		0	0		7	7	0
Eriophyllum								
Seedlings	*60		*50	NK		NK	NK	NK
Adults	*0		* 7	13		21	0	0
Erysimum								
Seedlings	70		67	50	*	25	14	4

different species of juveniles. As seen in Chapter IV (Reid 1983), mortality was also species-specific at the adult stage. Third, not only was mortality species-specific, but the definition of a species safe site was specific. A safe site is particular set of physical parameters of a microsite surrounding a seed or seedling which provides the necessary conditions for successful germination or establishment (Harper 1961). These safe sites were local and ephemeral, specific in both time and space.

The relative significance of the dynamic microsite parameters was less distinct, because the value of each parameter was strongly dependent on the value of several other parameters (e.g., soil temperature and soil moisture). However, it appears that differential soil surface temperature, erosion and soil moisture status had the greatest effect on seedling mortality. The role of competition was not investigated.

Directly, mountain goat activities had no discernible effect on seedlings growing under Phlox diffusa in open plots compared to fenced plots. However, they did cause substantial mortality in seedlings growing in bare soil, wallow sites compared to exclosed sites. Principally, their effect was indirect through changes in the microenvironment and shifts in the distribution of microsites available for establishment.

Plant Life Histories

Table 22 summarizes plant response at the life cycle stages of each species. Each species responded more favorably to the conditions in wallow (disturbed) sites than meadow (relatively undisturbed) sites. For example, in the meadow sites, Artemisia never flowered, Phacelia never survived to maturity, Archillea produced significantly less viable seed than in the wallow, and Eriophyllum transplants showed significantly greater mortality compared to

Table 22. Summary of responses of four colonizing species to existence in open (disturbed) and vegetated (undisturbed) microsites. Statistically significant responses show direction (e.g., ">W" means the response was significantly ($p<.05$) greater among individuals growing in wallow microsites). W=Wallow, T=Trampled, M=Meadow, NS=not significant, NA=not applicable.

SPECIES: CHARACTER	Achillea	Eriophyllum	Artemisia	Phacelia
1) Non-flowering shoot density	NS	>M	>W	No plants of this species grow in the meadow--no comparison possible.
2) Flowering shoot density	>W	NS	Only flowers in wallow	
3) Percent flowering	>W	NS	same	
4) No. leaves/ shoot	>W	>T	NS	
5) Shoot height	NS	>M	NS	
6) No. rhizome buds/shoot	>W	NS	NS	
7) Survival of transplants	NS	>W	>W	
8) Total season leaf RGR	NS	>T	>W	
9) Speed of development	>W	>W	NS	
10) Percent full embryos	>W	>M	Only flowers in wallow	
11) No. flowers/ stalk	>W	>W	same	
12) No. seeds/ flower	>W	NS	same	
13) % seedling survival	>M	NS	None emerged	

trampled sites. Increased water stress resulting from root depletion of soil water in meadow sites may partially explain the differential mortality, flower inhibition, seed abortion, and rhizome bud formation.

Comparing among species, Table 23 shows that each species exhibited a different degree of phenotypic plasticity. In all cases, *Achillea* showed the most plastic ability to respond to the different balance of stresses found in wallow and meadow sites. *Eriophyllum* and *Artemisia* were much less plastic, yet quite different in response. *Phacelia* could not be compared because it grew only in disturbed sites.

Like juvenile mortality, adult response to mountain goat disturbance was species-specific. However, unlike juveniles, stresses on adults usually resulted in changes in phenotypic expression rather than death. Differences of phenotypic expression were found in shoot density adult mortality after transplantation, water potentials, developmental timing, seed and flower production, seed dispersal, seed germination and seedling emergence. This increased plasticity in the adult stage further emphasized the vulnerability of the juvenile stage and the importance of natural selection in juveniles.

DISCUSSION

Factors Influencing Seedling Emergence and Survival

The factors that influence seedling emergence and survival fall into three categories: 1) abiotic; 2) biotic; and 3) intrinsic. Abiotic influences are static and dynamic features of the seedling-scale environment that determine the species-specific definition of a safe site. Biotic influences include herbivores and plant-plant interactions, the latter either between or within age groups. Intrinsic factors are features of the individual's morphology,

Table 23. Comparison of responses of four colonizing species to existence in the open (disturbed) and vegetated (undisturbed) microsites. Values are means with wallow/meadow. NA=not applicable, NT=Not taken.

SPECIES: CHARACTER	Achillea	Eriophyllum	Artemisia	Phacelia
1) Non-flowering shoot density	43/32	2/18	8/1	111/0
2) Percent flowering	49/13	13/11	4/0	69/NA
3) Root morphology	Robust rt.+rhz.	Spindly rt.+rhz.	Woody caudex	Deep Taproot
4) Development speed	Fast	Fast	Slow	NT
5) Survival of transplants	Most	Least	Intermed. (low)	NT
6) Growth response	Least	Intermed.	Most	NT
7) No. seed/m^2	21,149/ 1043	110/273	2797/0	4725/NA
8) No. full embryos/m^2	9456/282	11/32	322/035	43/NA
9) % germination (10/20°) strat.	63	19	1.4	2.0
10) % seedling emergence	0.6/5.3	4.4/7.7	0/0	NT
11) % seedling survival	0/46	40/50	None emerged	36/14

physiology, and size that influence its response to extrinsic abiotic and biotic factors.

In combination, these abiotic, biotic, and intrinsic influences appear to explain seedling survival patterns. Needle ice, goat activities, erosion, soil temperatures, wind speed, and potential VPD differentially affect seedlings growing in bare ground compared to those under plant cover. In contrast, competition with adult plants for light, water, and nutrients favors seedling existence of some species in bare ground (Osburn 1961).

The magnitude and predictability of each of these influences change as the growing season progresses. Needle ice, goat activities, and erosion are particularly damaging early and late in the season. VPD, competitive effects, and soil moisture stress are most severe during the mid-summer drought. Fitness is maximized in those individuals that either avoid, tolerate, or escape these stresses more effectively than other individuals.

Finally, each species appears to have particular traits that allow differential survival in different microsites. Phacelia can endure the stresses of bare ground with a long tap-root, fast growth, and pubescent leaves. In contrast, Festuca has traits suited for growth under vegetation: vertical growth, early germination, and fibrous roots. Even more important may be that these species lack the characters to enable them to exist in other microsites.

Juvenile and Adult Tolerances

Comparison of the abilities of juveniles and adults to endure stress, disturbance and competition shows that tolerances can change as the individual develops (see Table 23). These patterns suggest that the adult and juvenile stages of the same plant can have quite different niches. This conclusion supports the conceptual model developed by Grubb (1977). Niches would be expected to shift or broaden/narrow gradually through ontogenetic development.

Table 24. Tolerances of the juvenile and mature stages to stress, disturbance, and competition of plant species on Klahhane Ridge. S=stress, D=disturbance, and C=competition.

SPECIES	JUVENILE TOLERANCE	MATURE TOLERANCE
Achillea seedling	"Competition"	S,D,C, (es.D)
Achillea ramets	Stress	same
Erysimum	S,D,CComp., Dist.	
Festuca	Str., Comp.	Competition
Phacelia	Str., Dist.	Str. Dist.
Silene	Str., Comp.	Competition
Viola	"Competition"	Dist.(Sackett 1980)

The coupling of these two stages of tolerance explains much of the species pattern. The ability of Achillea to invade different kinds of microsites with either seedlings or ramets explains its ubiquitous occurrence in the Olympics and perhaps worldwide. At the other extreme, tolerances of Phacelia explain its restriction to growth in stressful, disturbed sites. Again, it is not surprising that Erysimum appears to be recently widespread on Klahhane Ridge (Pike 1981). It is easy to see from this list why certain species (Achillea, Phacelia, Erysimum) persist around wallows and other highly disturbed sites while other species are prominent in the closed, relatively undisturbed meadow.

Predictions of Plant Community Change

To accurately predict the future behavior of an association of species, it would be necessary to understand the differentiation of tolerances and safe-site requirements for each species at each life cycle stage. Not only that, it would be essential to understand how the response of each species changes with environmental fluctuations and biotic interference. However, from the viewpoint of a two year study, there are some predictions of plant community change that can be made with reasonable certainty.

The following predictions are made assuming mountain goat use is maintained or increased. Predictions in the absence of goats will follow.

1) Goat presence will maintain or increase the occurrence of the following: erosion, needle ice formation, soil compaction, inorganic soil with large particle size, and bare ground.

2) With the increase in bare ground, there will be more area covered by extremes of temperature, wind, and irradiance, and less area affected by later-season soil water depletion by plant roots.

3) For colonizing species, goat disturbance will increase the number of safe-sites available for seed and ramet establishment. Thus, species able to establish in bare ground (*Phacelia*, *Erysimum*, *Achillea* ramets) will increase in cover and density. In particular, *Erysimum*, with its ability to establish in a wide range of safe-sites, will increase. This implies an increase in colonizing species density.

4) For non-colonizing species, goat disturbance will decrease the diversity of safe-sites available for seedling establishment. Thus, species that are represented by a few seedlings per season will decrease in numbers or perhaps disappear entirely from the meadow. This implies a decrease in non-colonizing species density.

5) Overall, species density should decrease because there are fewer species able to colonize goat disturbed areas than there are species able to exist in closed vegetation.

6) Vegetation patches will become smaller and more discrete. Within these patches, competitive interactions may increase.

7) Festuca, a present community dominant, will occasionally become established in bare mineral soil, but primarily will be restricted to establishment under existing plant cover. Subsequently, its distribution will become more patchy and disjunct. Even so, it is likely that it will maintain its dominance in these discrete patches.

8) The other community dominants (Phlox and Arenaria) will probably continue to persist for a long period of time because of their hardy growth forms. In places where they become physically removed, it is unlikely that their small, fragile seedlings will reestablish until other species are established. Apparently, these species regenerate infrequently, probably only in years of unusually good conditions.

9) The three community dominants will probably maintain dominance within stable vegetation patches. In other areas, colonizing species will be dominant and eventually may set up a dominance hierarchy.

10) Species that regenerate by both seed and ramet will increase in density. For example, establishment of Achillea will be principally by seed in vegetated areas and solely by ramets in bare areas. This may lead to differences in genetic plasticity of Achillea populations growing in areas of different ground cover.

11) The ratio of ramet to seedling regeneration will increase. In particular, species like Eriophyllum and Artemisia will maintain populations principally by vegetative propagation.

12) Because of these changes, there should be patches of adjacent vegetation that have very different successional ages.

If mountain goats are absent, these opposite patterns will be seen:

1) Plant cover, soil stability, and organic matter will increase.

2) Colonizers will decrease and non-colonizers will increase, principally because of a shift in the diversity of species-specific safe sites available for establishment.

3) Species density will increase because there appear to be a larger percentage of non-colonizing species than colonizing species among those in the meadow.

4) Cryptogamic cover will probably increase. Cryptogamic cover increases soil stability, organic matter, soil water-holding capacity (Kleiner and Harper 1977), and nitrogen levels (Shields 1957).

5) Patches in the meadow will continue to revegetate and eventually, the succesional age of the meadow will increase.

Revegetation Options

The options for revegetation include seeding, transplantation of seedlings and adults, and vegetative spread from surrounding rhizomatous species. The following recommendations are made from personal observation and the data in this study:

1) Revegetation would be most successful through a combination of these options. Stabilization of the soil through transplantation of young adults is essential before successful establishment by seed will take place. Transplantation of seedlings will not likely succeed.

2) Certain species are better able to tolerate disturbance than others. In this study, greatest transplantation survival was in Achillea (93%), followed by Artemisia (67%), then Eriophyllum (47%). After two years in the middle of a large, actively used wallow, the Achillea individuals were large and robust while those of the other two species had grown little since transplantation (Reid, pers. obs. June 1983). Achillea is further ideal because it appears to spread more rapidly by rhizome than others and is very plastic.

3) For seeding, Erysimum and Phacelia would be the most successful of those in this study. These two species grow rapidly and can establish in actively eroding soil. Achillea and Viola would be poor choices because no seedlings of either species survived in bare soil microsites throughout this study. Festuca, even though its survival rate was not as high as the first two species, may be a good choice because it germinates very rapidly, grows quickly and, once established, holds the soil well.

4) There is ample seed and ability to revegetate within the species native to Olympic National Park. Coupling this fact, Park Service philosophy, and ecological common sense leaves absolutely no reason for any revegetation to be carried out with non-native species.

REFERENCES

Dixon, W.J. (ed.). 1981. Biomedical Computer Programs. Health Sciences Computing Facility, Univ. of California, Los Angeles, CA. USA.

Grubb, P.J. 1977. The maintenance of species richness in plant communities: The importance of the regeneration niche. Biological Reviews 52:107-145.

Harper, J.L. 1961. Approaches to the study of plant competition. In: F.L. Milthorpe (ed.). Mechanisms in Biological Competition. Symposium of the Society for Experimental Biology 15:1-39.

_______ 1977. Population Biology of Plants. Academic Press. New York, N.Y. USA.

Hitchcock, C.L. and A. Cronquist. 1978. Flora of the Pacific Northwest. University of Washington Press. Seattle, WA. USA.

Kleiner, E.F. and Harper, K.T. 1977. Soil properties in relation to cryptogamic ground cover in Canyonlands National Park. Journal of Range Management 30(3):202-205.

Nie, H.H., C.H. Hull, J.G. Jenkins, K. Steinbrenner, and D.H. Bent. 1975. Statistical Packages for the Social Sciences. McGraw-Hill Book Company. New York, N.Y. USA.

Osburn, W.S. 1961. Successional potential resulting from differential seedling establishment in alpine tundra stands. Bulletin of the Ecological Society of America 42:146-147.

Pike, D.K. 1981. The effects of mountain goats on three plant species unique to the Olympic Mountains, Washington. M.S. Thesis, U. of Washington, Seattle, USA.

Reid, R.S. 1983. Patterns of juvenile mortality and plant life histories in response to mountain goat disturbance, Olympic National Park. M.S. Thesis, U. of Washington, Seattle, USA.

Sackett, J.C. 1980. Adaptive strategy and gradient analysis of a subalpine meadow. M.S. Thesis, U. of Washington, Seattle, USA.

Shields, L.M. 1957. Algal and lichen floras in relation to N content of certain volcanic and arid range soils. Ecology 38:661-663.

Tuccy, J. 1978. SPSS subprogram NPAR TESTS: nonparametric statistical tests. Vogelback Computing Center Manual No. 324, Northwestern University, Evanston, Illinois, USA.

INTEGRATION

Within the Olympic National Park, mountain goats are largely confined to subalpine and alpine areas where there are rock outcrops for protection, meadows for foraging, and cirque basins for thermoregulation (Stevens 1979, 1983, this study). Our research was confined to the Klahhane Ridge because of the high goat density and its ease of access for both research and public viewing of the animals. The field research was initated in 1979 and concluded in 1982.

Soils

The most conspicuous aspect of heavy goat utilization of these high mountain landscapes is the presence of dusting wallows, trails and denuded ridgetops where salt licks were established. Soils within the Klahhane meadow are poorly developed and are subject to severe erosion due to steep slopes. Sheet erosion is accelerated by trampling, the most important disturbance factor within the meadow. The major objective of this portion of the study was to initiate research on the magnitude and rates of soil erosion. The south-facing Klahhane meadow has 34% of its area bare, the result of trampling (15%), trailing (6.7%), wallows and outwash (7.2%) and other bare soil and organic mat surfaces (8%) (Harter this report). Nearly all of this is attributed to goats and the surfaces are nearly devoid of cryptogams and organic mat surfaces. In contrast, the comparable Tyler Peak site showed 9% bare areas, about 33% of this is obvious disturbance; cryptogams are a conspicuous component of all sites.

The measurements of sheet erosion confirm that erosion is inversely related to plant cover, ranging from 1 $g.m^{-2}$ in a closed plant community to >600 $g.m^{-2}$ in a bare soil site for a 24 h period in late summer. Run-

off from the enclosed plots was 1 to 18% of precipitation received and was not correlated with percentage of bare surface or sediment load. High sediment yield at the site with lowest runoff indicates overland flow contributes significantly to erosion.

Through the use of cross-section profiles and the placement of painted stones in wallows, it was possible to estimate rates of wallow erosion. Most material moving within wallows was >2 mm in size. During an 11 month period, wallow SW #2 showed a displacement of 1.3 x 10^{-3} m^3 of material. Both sheet erosion and gully formation were evident within wallows. Only through annual monitoring of these wallows can rates of erosion be determined (Harter this report).

Microenvironments

Through the use of weather instruments, the microenvironments of the Klahhane meadow (south-facing) and the cirque basin (north-facing) were monitored 1980-1982. From 1979-81 snow accumulations were below normal (25 to 60% of normal), while 1982 was near normal. This coupled with below normal summer precipitation in August 1979-81 resulted in unusually dry mid-summer conditions. In general global radiation was high (average 20 $MJ.m^{-2}.d^{-}$, mean daily temperatures were near 10°C with few freezing nights, and vapor pressure deficits averaged 0.3 K Pa, but exceeded 1.0 K Pa during hot, dry periods. Although plant production data are not available from more typical summers, plant production would no doubt be 10-25% greater.

At the cirque station temperatures were lower (0.5 to 2°C), precipitation was greater, and VPD was lower, especially in mid-summer.

Soil moisture was measured in 1981, a relatively hot and dry summer. Disturbance by goats did not appreciably alter the soil water regime or water-

holding capacity except as surface organic matter is removed. Surfce soils frequently had soil water potentials of -1.0 to -1.5 MPa and during the three week dry period in August, soil water potentials averaged -3.0 MPa. Implications of this will be discussed later.

Plant Communities and Plant Production

Nine plant community types were identified through sampling of 23 stands and cluster analysis. They range from mat and cushion plant dominated communities on ridgetops usually snow free in March to various communities in mesic sites covered by snow until mid July. On a substrate gradient they range from stable soils in cirque basins dominated by sedges and herbs to slopes of 20-30° dominated by bunch grasses (Phlox - fescue) to steep scree slopes (35-40°) with few vascular pants. Time of snowmelt and summer soil water conditions appear most important in determining the mosaic pattern of communities. Plant production (aboveground) ranged from 20 $g.m^{-2}$ in the heather community and 170 $g.m^{-2}$ in the large Phlox-fescue meadow, to 220 $g.m^{-2}$ in the late snow release Lupine-gedge community. Of the estimated 154,600 kg production in all meadows in 1979, 74% occurred in the Phlox-fescue and the unstable herb meadows, mostly on the south-facing slope. Scree slopes make up 25% of the total range, yet contribute 8% of total production (Pfitsch this report).

Data analyses show that grazing frequency (percentage grazing among plots) and grazing intensity (magnitude of plant consumption) are unusually high for Festuca idahoensis and Carex spectabilis. The highest grazing frequency and intensity occurs in the cooler meadows and scree slopes in the cirque basin (Pfitsch this report).

The snow-free season (May-November) can be divided into three seasons with respect to goat foraging. In May and June goats concentrate in the Phlox-fescue and unstable herb meadows of the south slopes where production is high. During the July and mid-August period, goats concentrate their feeding on the north slopes, returning to the ridges and south meadows only at night or on foggy days. The limited extent of these north-facing meadows results in high values for grazing frequency and intensity. From mid-August to November goats again concentrate their foraging in the south meadows. The unstable herb meadows on the south slope do have high grazing intensity and frequency in mid-summer which is the product of higher rates of plant growth and proximity to rocky areas for escape. The mid-summer concentration of goats in the cirque basins and the unstable herb communities near the ridge crest appears to be the limiting component. The north slope meadows comprise only 30% of the available forage on a daily basis compared with the south meadows in spring.

The calculation of mountain goat carrying capacity resulted in an estimated 190-280 goats based upon the utilization of the total range May-November. These estimates were reduced to 150-220 animals if the north-slope meadows are assumed to be used primarily during the 45 d mid-season period (Pfitsch this report).

We have not considered the winter season and its very limited availability of herbaceous plants. No doubt conifers play a more significant role in the winter diet of these animals as they do in the mountain goat populations in southern Alaska (Fox 1983).

Comparing data from Klahhane Ridge, Constance Pass and Tyler Peak, it is evident that species diversity, total plant cover and cover of Festuca idahoensis are significantly less on Klahhane where goat populations are high.

These findings coupled with the greater abundance of bare ground and reduced cryptogam plant cover directly address the question, "What is the total impact of mountain goats?"

Goat Impact Upon Three Species

Studies were conducted upon Campanula piperi, Aster paucicapitatus, and Senecio neowebsteri, species believed to be directly impacted by goat grazing and trampling. Where possible comparative studies were conducted on Klahhane Ridge and on Tyler Peak. The data show that species richness, plant cover, including cryptogams, and amount of bare soil were significantly different in the two areas. These findings parallel those of Harter (this report). Campanula piperi, a species common to rock outcrops, was significantly reduced in total production by clipping at two week intervals (20% of controls) and by goat grazing (62% of controls). Flowering was minor in all plants except controls. These results show Campanula has little ability for compensatory growth with excessive grazing pressure (Pike this report).

Aster paucicapitatus grows in meadows, especially the Lupine-sedge and tall grass-herb communities. Both artificial clipping and goat grazing resulted in significant reductions in plant production when compared with plants clipped once, controls, and plants at Tyler Peak. Flowering and fruiting were also reduced in grazed and clipped plants (Pike this report).

The data for Senecio neowebsteri were less pronounced, in that grazing and simulated grazing resulted in only reduced net production and leaf size. In general the findings show that there is relatively little compensatory ability in these three species, they all are reduced in vigor by grazing or simulated grazing. However, there is no clear evidence of population reduction from the grazing pressures of the past several years, although frequent clipping resulted in a significant reduction in flowering and seed set.

Seedling Emergence and Survival

The previous studies speak to the role of the environment as it influences plants in general and to the role of adult plants in established communities. This component deals with the complex interactions of abiotic, biotic and intrinsic factors that influence seedling emergence and survival in a relatively stressful environment, compounded by goats. Only if we understand the actions and interactions of these factors as they influence plant establishment, can we hope to understand the present changes in species composition and to learn how to rehabilitate moderately to highly disturbed soils in the future. This series of studies was undertaken in the Klahhane meadow within a Phlox-fescue community and its complex of wallows. In general, needle ice formation, goat activities, and soil erosion are particularly damaging early and late in the season. This results from climatic conditions and the predominance of goats. During the mid-summer drought, VPD, soil moisture stress and plant competition for light, water and nutrients are most severe. Species fitness is maximized in those individuals that either avoid, tolerate, or escape this stress (Reid this report).

In addition to understanding the seasonality of environmental stress, there is a need to determine juvenile vs. adult plant tolerances. *Achillea millifolium* seedlings survive best in vegetated areas where juvenile tolerance is mainly for competition with other species. *Achillea* raments, in contrast, grow well in open sites where they are tolerant of stressful conditions. *Phacelia heterophylla* seedlings and adults are tolerant of stressful, disturbed soils and seldom occur in closed plant communities. *Festuca idahoensis* juveniles and adults grow best in closed plant communities and are seldom found in bare soil of disturbed sites.

Based upon these kinds of data (Reid this report) has predicted the plant community changes that will accrue as the result of maintaining or eliminating goat populations. Some of these points are discussed in the next section.

Alternative Recommendations for Mountain Goat Management

Our research of the past four years provides at least partial answers to a number of questions regarding the short term and long term impact of mountain goats on the soils and vegetation of steep terrain at high elevations. Only with long term monitoring of the sites established for measurement of soil erosion, plant recovery, and plant production can these predictions be confirmed or refuted.

1. Mountain Goat Populations Maintained

Continued goat pressure in numbers greater than 1-2 animals per square kilometer will:

a. Maintain or increase surface erosion and stimulate limited gulley erosion in wallows and possibly along steeper-angled trails through erosive substrates. Overland flow of soil and rock particles will increase on the steep slopes.

b. Maintain needle ice formation, soil compaction, soil with large particle size and bare soil.

c. Bare soil will maintain microenvironmental extremes of temperature, wind, and irradiance.

d. Bare soil will provide more "safe sites" for the colonizing species Phacelia, Erysimum and ramets of Achillea.

e. Maintain pressure on the limited extent of plant communities in the cirque basins with higher biomass of graminoids, especially Carex.

f. Further reduce the still abundant but decreasing biomass of <u>Festuca idahoensis</u>, the preferred species on the south-facing meadows. Because of its inability to establish in disturbed sites, its distribution will become more patchy. Overall plant cover and species richness will continue to decline because fewer species are able to colonize goat disturbed areas vs. closed plant communities.

g. A shift to greater cover of the less palatable species such as <u>Hydrophyllum</u>, <u>Cirsium</u> and <u>Delphinium</u> and the maintenance of the already abundant <u>Phlox</u> and <u>Arenaria</u> would further reduce the carrying capacity for goats.

h. Wallows will increse in their total area and will be difficult to revegetate as long as goats have direct access to them each year.

2. Mountain Goat Populations Reduced 50 to 75% and Maintained at Lower Levels.

The previously described scenario will be slowed and some bare soil sites may recover, especially if fenced for a number of years. The most sensitive areas (<u>Carex</u> and <u>Festuca</u> dominated meadows, wallows, steep slopes) will continue to receive the greatest impact.

3. Mountain Goat Removal or Near Removal

Should goats be totally removed, or more logically held at low densities the following scenario is predicted:

a. Plant cover, species richness, and soil organic matter will increase. This will reduce surface erosion from terraces in the steep meadows.

b. The colonizer species will be reduced and the stable plant community species including the graminoids will increase.

c. Bare patches in meadows will revegetate, primarily by the more agressive colonizing species. The lower slope and smaller wallows will

probably revegetate in 10-15 years though floristic differences will be evident for at least 30-50 years. The selection of species for revegetation should be based upon the research by Robin Reid (see thesis and this report).

4. Restoration of Soils and Vegetation

Those severely eroded sites at the ridge tops with salt licks can be vegetated only at considerable expense through the addition of soil pockets, mulching and the establishment of rhizomatous species such as *Achillea*, *Artemisia* and *Eriophyllum* via plugs not seed. These sites will take 25-50 years for any significant recovery.

Fencing, limited mulching, transplants of rhizomatous species and seeding with native species (*Erysimum*, *Phacelia*) would speed recovery of the larger wallows. The addition of *Festuca* seed, provided there are some "nurse plants" and surface mulch, would be effective.

5. The monitoring of recovery should be based upon the establishment of erosion plots by John Harter, the recovery of vegetation based upon the sampling procedures of Bill Pfitsch, and mapping of the wallow sites by Robin Reid. Recovery of species needs to be monitored in the different communities utilizing a range of species but including *Festuca*, *Carex*, *Aster* and *Achillea*.

REFERENCES

Fox, J. 1983. Constraints on winter habitat selection by the mountain goat (*Oreamnos americanus*) in Alaskan. Ph.D. Thesis. University of Washington, Seattle, WA.

Stevens, V. 1979. Mountain goat habitat utilization in Olympic National Park. M.S. Thesis, University of Washington, Seattle, WA. 106 pp.

Stevens, V. 1983. The dynamics of dispersal in an introduced mountain goat population on the Olympic Peninsula, Washington. Ph.D. Thesis, University of Washington, Seattle, WA. 194 pp.