Nooksack Cirque Natural History

Final Report

by

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Contract No. CX-9000-6-0148

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INTRODUCTION

This study was undertaken to gather resource data and assemble a natural history of the Nooksack Cirque area of the North Cascades National Park, Washington State. The area is at the headwaters of the North Fork of the Nooksack Rivers. The North Fork originates from the meltwaters of the East Nooksack Glacier on the northeast flank of Mt. Shuksan. East Nooksack Glacier occupies a cirque basin carved out between Jagged Ridge and Mt. Shuksan and is described by Beckey (1969) as "the finest Cascade example I have seen of a double cirque. The great semi-circle upper cirque curving from Cloudcap Peak to Nooksack Tower is a Valhalla of Ice; the lower cirque makes a tighter curve beneath incredibly polished slabs, and contains a remnant ice mass, snow chutes chocked with avalanche debris, and the terminal portion of the glacier -- usually cloaked with dirt and rock in late summer. The muddy torrent emerging from a mass of brown boulders is some distance from the white ice. Evidence of continued glacier recession is seen everywhere."

The northwest-southeast tending Nooksack valley comprises an accessible and vivid example of neoglacial activity and successional patterns.

The following report details the results of examining the soils geology, vegetation, and vertebrate population of the Nooksack Cirque area.

Setting

The Nooksack Cirque (121°34'W, 48°51'N) is within the North Cascades National Park near the northwestern border of Washington State. Figure 1 shows the general location of the cirque area.

The Nooksack Cirque and the Nooksack River valley are surrounded by prominent ridges and mountains. Nooksack Ridge is a northwest-southeast ridge (1800+ m) and rises above the valley floor to the north. Both Ruth Mt. (2166 m) and Icy Peak (2152 m) rise above the rest of Nooksack Ridge. Seapho Peak (Cloud Cap) (2264 m) and Jagged Ridge (2100+ m) overlook the cirque from the south. To the west of Jagged Ridge lies Nooksack Tower (2520 m). An unnamed ridge (1250-1500 m) forms the southern border of the valley. Price Lake lies south of this ridge at the western boundary of the study area. Mt. Shuksan, which cannot be seen from the valley, is southwest of the study area. The valley rises in elevation from 825 m at the park boundary sign to 1000 m at the ice edge. The East Nooksack Glacier has carved out the Nooksack Cirque.

Study Area

The study area was approximately 5 km long, ranging in width from 1 km near the cirque to 0.6 km at the park boundary sign. The total area studied is approximately 4.5 km^2 and includes areas in both North Cascades National Park and the adjacent Mt. Baker National Forest (Figure 1).

Figure 1: Location of upper Nooksack Valley and Nooksack Cirque in North Cascades National Park, Washington, U.S.A.

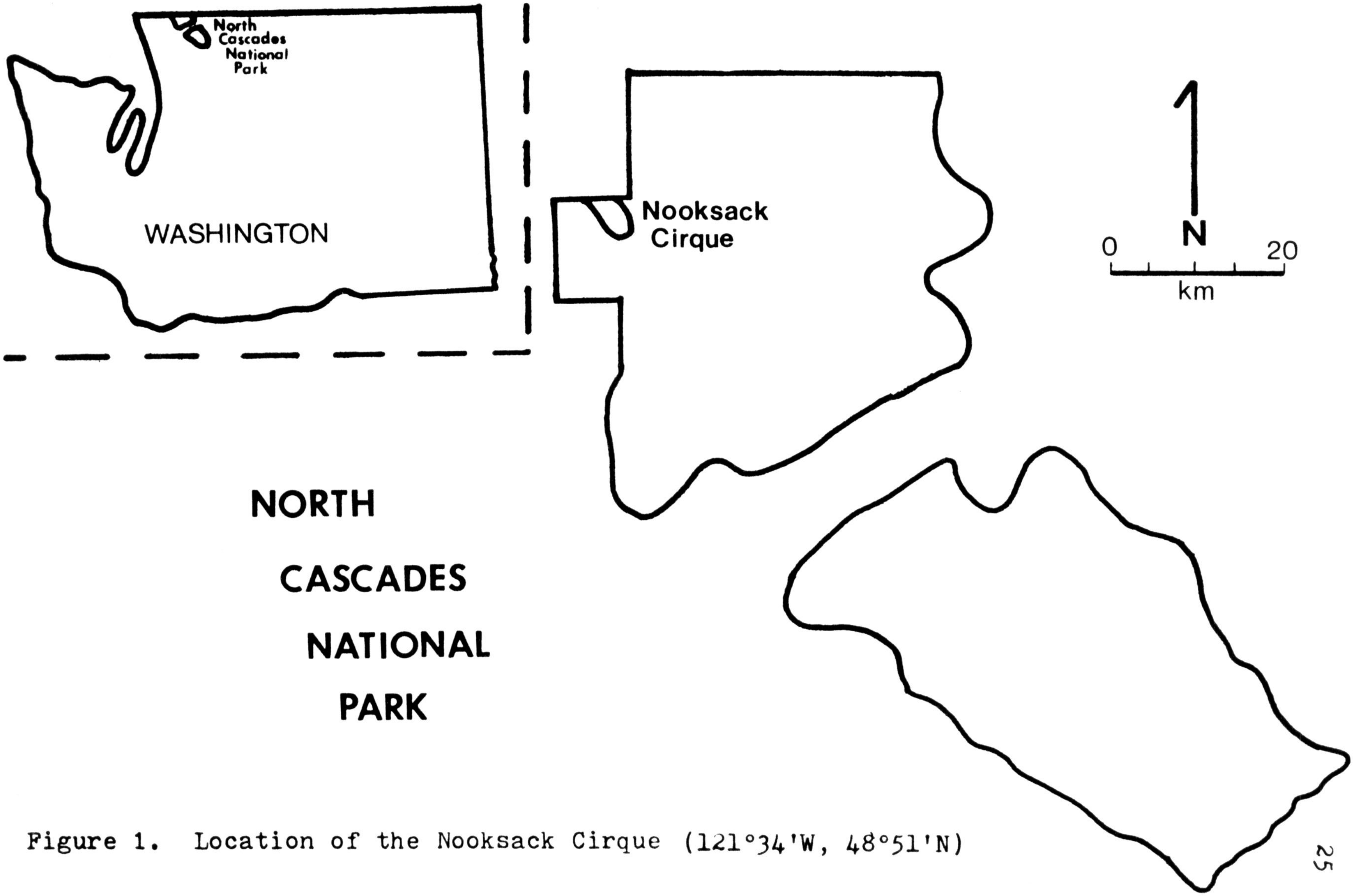


Figure 1. Location of the Nooksack Cirque (121°34'W, 48°51'N)

Macroclimate and Microclimate

A. Macroclimate

Two permanent weather stations are near the study area at Mt. Baker Lodge and Glacier Ranger Station. Climatic data for each site (Washington Climate 1966) is given below:

Glacier Ranger Station (elevation 285 m) 32 km west of cirque

mean annual temperature	8.3°C
mean annual precipitation	147 cm
mean annual snowfall	173 cm

Mt. Baker Lodge (elevation 1265 m) 8 km west of the cirque

mean annual temperature	4.4°C
mean annual precipitation	279 cm
mean annual snowfall	1311 cm

Based on topographic relationships between the permanent weather stations and the study area, estimated mean annual precipitation at the Nooksack Cirque (elevation 920 m) is 250 cm (Washington Climate, 1966). Mean annual snowfall is assumed to be less than that at Mt. Baker Lodge because of the lower elevation in the study area; however, snow avalanches off the valley walls cause deep accumulations in the valley bottom. Mean annual temperature is between 4.4°C and 8.3°C.

B. Microclimate

<u>Local Weather</u>.

Procedures. Local weather records were recorded at base camp from July 25 through August 30, 1979. Figure 2 shows location of base camp weather records. Records were taken each morning, noon, and evening. The following data were taken:

<u>Temperature</u>: Maximum/minimum thermometers located permanently in shade recorded temperatures at three places (as shown in Figure 2): at talus slope base; in the forested valley floor, and on the river bank. Because of the transport conditions into and out of the valley, thermometers were not standardized; therefore, recorded temperature differences between stations of 2 to 3 degrees F may not be significant.

<u>Barometric pressure</u>: Measured at base camp within the forest.

<u>Relative humidity</u>: Measured at base camp within the forest.

<u>Precipitation</u>: Measured from non-recording rain guage established in opening at base of talus slope.

<u>Cloud cover</u>: Estimated from river bank thermometer station three times daily.

Results. Figure 3 shows weather patterns for July 25 to August 30, 1977. There was a drought from July 30 to August 22, with heavy rains and cloud cover before and after this. Daily precipitation during rains was as high as 33 mm.

Figure 2: Location of microclimatic-related observations. (Observation results shown in Figures 3,4, and 5.)

A - C: Base camp local temperature stations

- A - Temperature station at talus slope base; precipitation guage
- B - Temperature station in forested valley floor; relative humidity and atmospheric pressure data
- C - Temperature station for river bank

D - K: Profiles of valley shown in Figure 5.

L - Q: Transect of local temperatures taken July 27, 1979.

- L and Q - Stations on talus slopes
- M - Station on East talus slope base
- N and O - Stations on valley floor
- P - Station on river bank

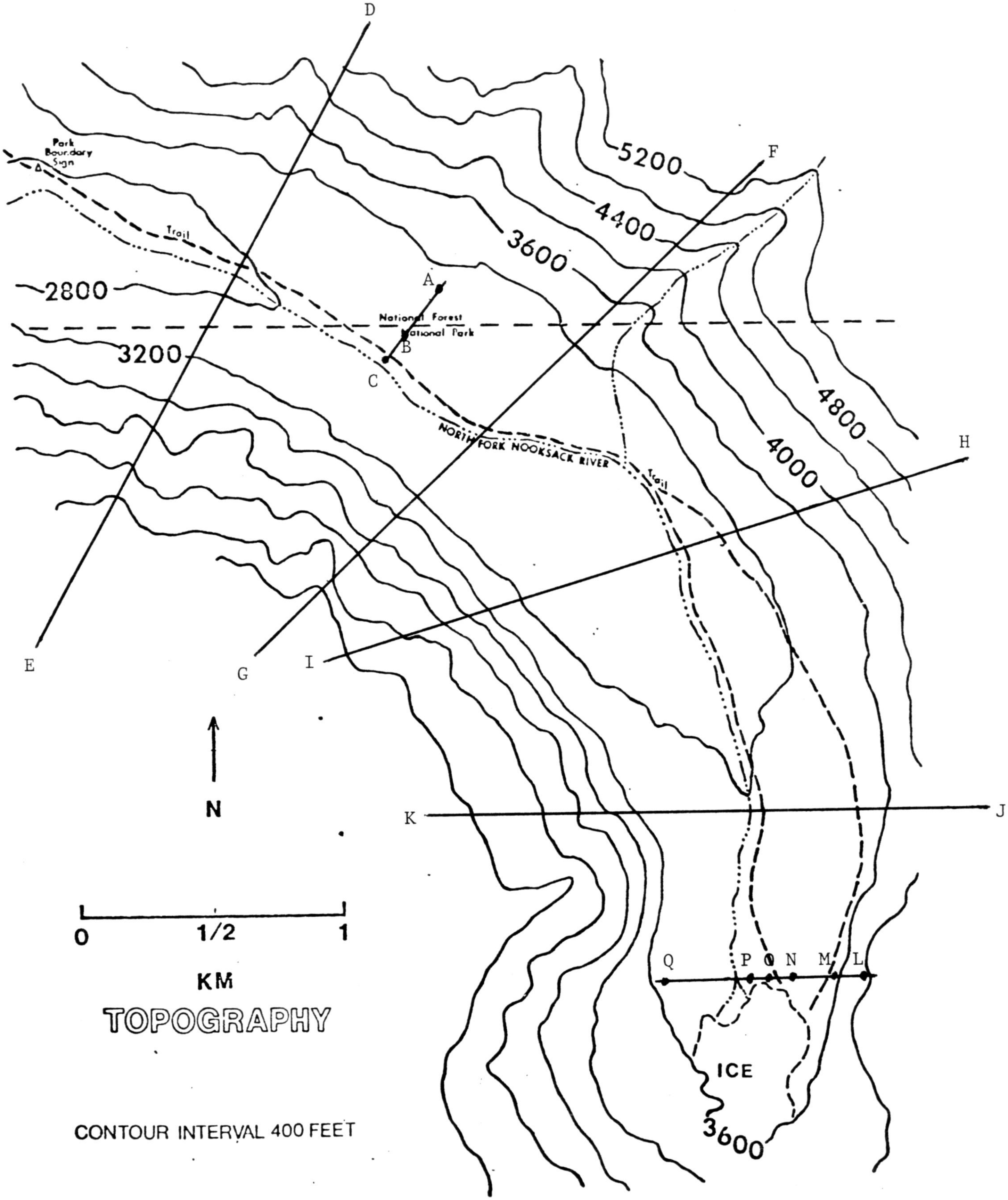
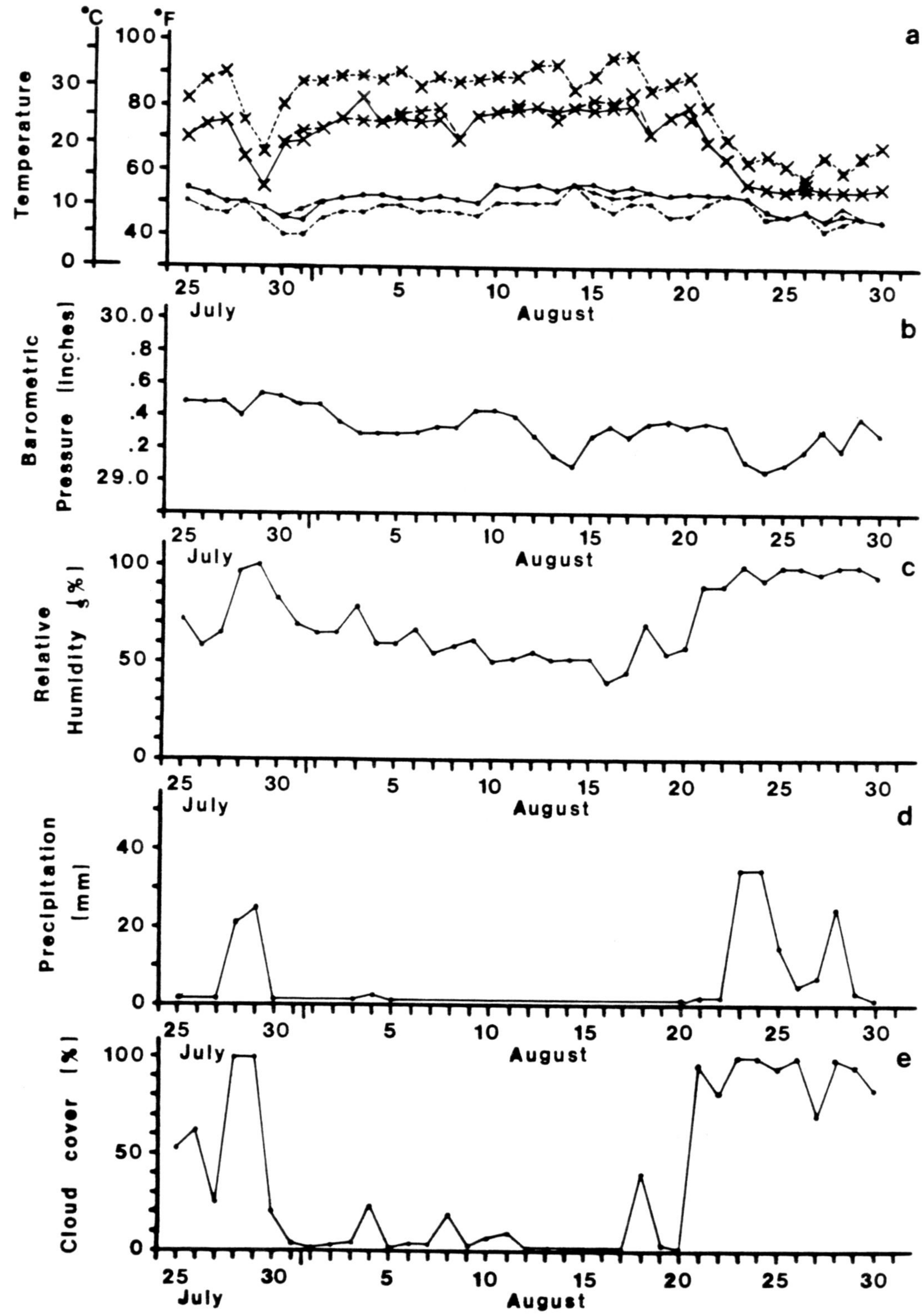

D
E
F
G
H
I
J
K
A
B
C
Q
P
O
N
M
L
Park Boundary Sign
Trail
2800
3200
3600
4000
4400
4800
5200
National Forest
National Park
NORTH FORK NOOKSACK RIVER
Trail
ICE
3600
N
0
1/2
1
KM
TOPOGRAPHY
CONTOUR INTERVAL 400 FEET

Figure 3: Weather records taken at base camp (A - C, Figure 2) from July 25 through August 30, 1979.

A. Daily local temperatures for three stations. (maxima = "X"; minima = "."; talus base temperatures = solid line; forested valley floor = long dashes; river bank = short dashes).
B. Barometric pressure
C. Relative humidity
D. Precipitation
E. Cloud cover


a
b
c
d
e
Temperature
°C
°F
Barometric Pressure (inches)
Relative Humidity (%)
Precipitation (mm)
Cloud cover (%)
July
August

During the clear, droughty weather, daily maximum temperatures were quite high, and minima were low. Rainy weather tended to depress the daily highs and hence the temperature fluctuations (Figure 3). Also, temperatures were more extreme on the open river bank than within the forest. Daily minima (usually at night) ranged between 3 and 13 degrees C (40-55°F) on the open river bank and between 7 and 13 degrees C (45-55°F) within the forest. Daily maxima were as high as 33 degrees C (97°F) (in the afternoon) on the open river bank and 29 degrees C (82°F) within the forest. Daily maximum temperatures in rainy weather were as high as 18 degrees C (65°F) on the riverbank and 13 degrees C (57°) within the forest.

Temperature transects at glacier's base.

A temperature transect was made across the valley approximately 150 meters from the (glacier's) permanent snowfield base (Figure 2) to determine if there was a noticeable "cold pocket" on the valley floor near the glacier's base compared either to the slopes on either side or to the base camp temperatures farther from the glacier. The transect was made during clear weather on July 26 and 27, 1979; maximum/minimum thermometers were placed in the shade and situated so that air would circulate freely around them. Again the thermometers were not standardized, so random temperature differences between stations of 1 - 2 degrees C may not be significant.

Other temperature transects were attempted throughout the valley during August, 1977, and August, 1978; however, injuries and rainy weather prevented reliable data from being obtained.

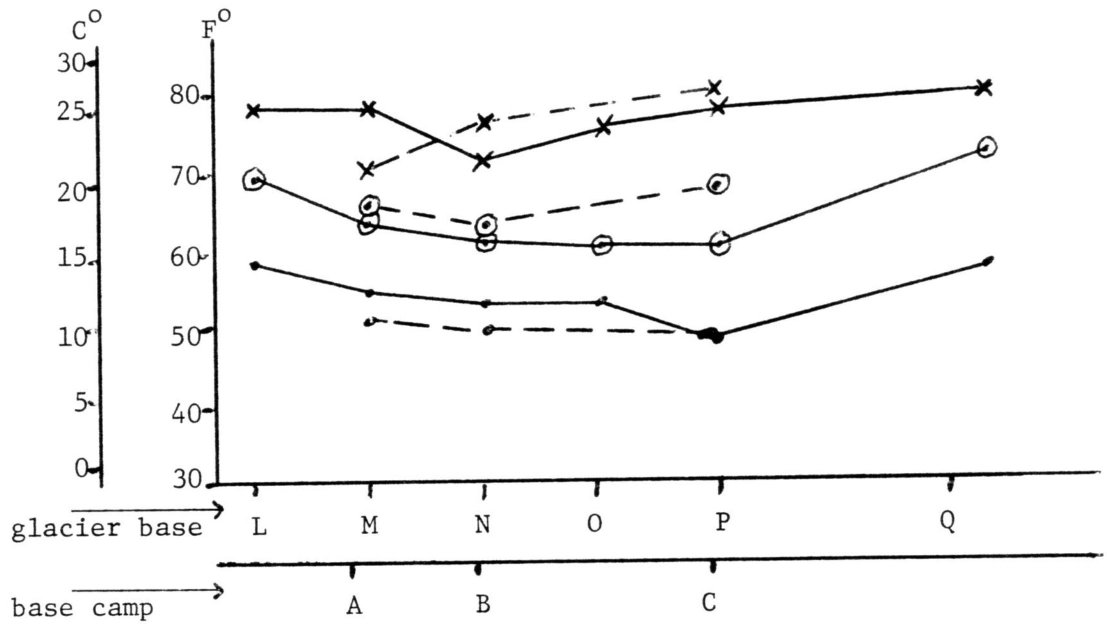
Figure 4 shows the results of these transects and a comparison with base camp temperatures during the same time. Unexpectedly, there were little temperature differences between base camp transects and those at the glacier's base. The slopes and valley floor near the glacier's base consisted of boulders and exposed rocks; these could have retained and then reradiated heat during the night. Night (minimum) temperatures were slightly warmer on the slopes than on the valley floor.

It must be remembered, however, that this was one day's transect during the warmest part of the year. It is possible that "frost pockets" could have occurred and been significant nearer the beginning or end of the growing season.

Sun angles and incident solar radiation

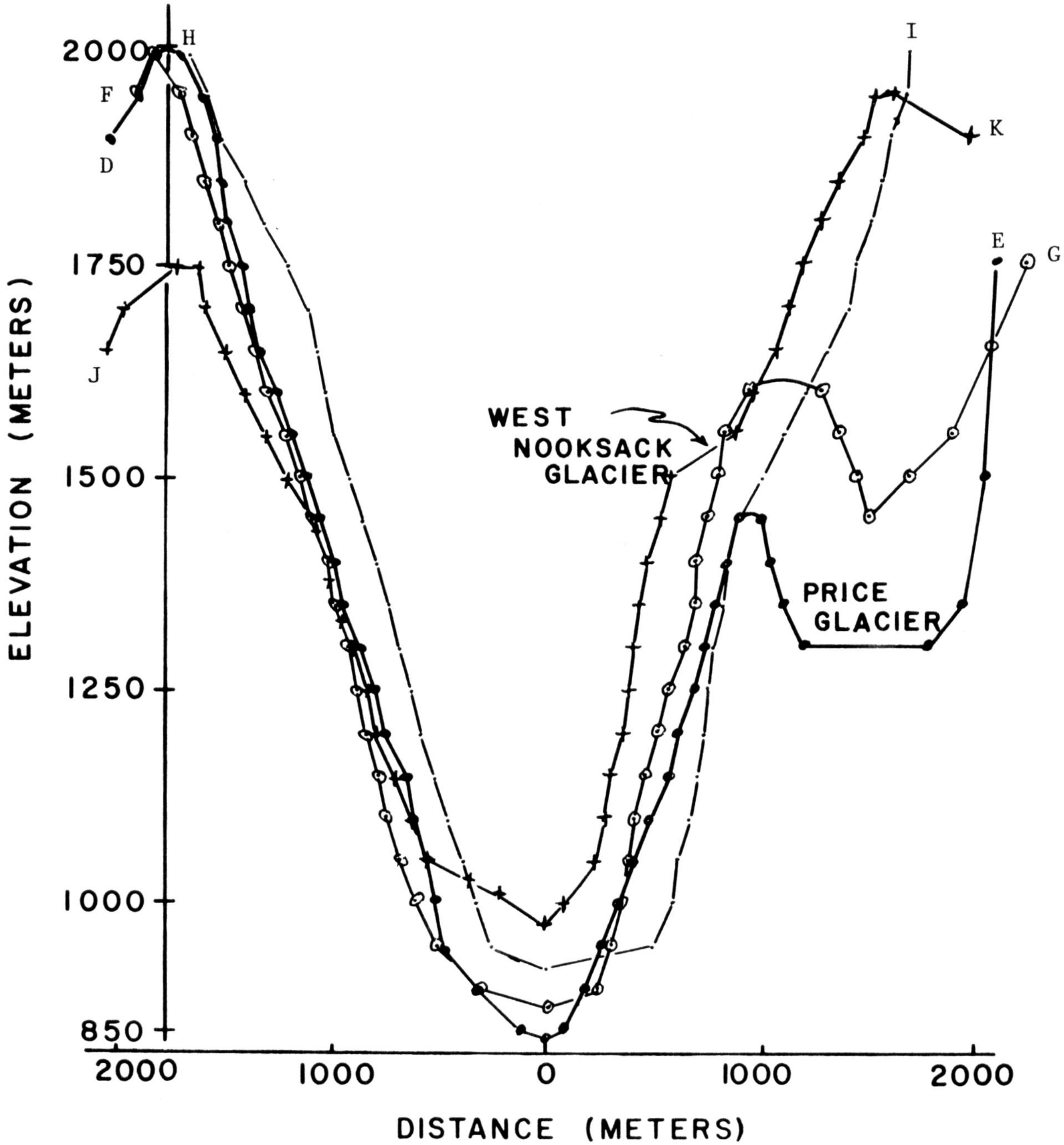
The study area is a Northwest-Southwest tending valley (Figure 1). Figure 5 is a cross section of the valley at 1 km intervals in the study area (vertical scale is four times horizontal scale). Because the valley shows such dramatic relief, there are periods of the year when direct sunlight does not reach parts of the valley floor. Where direct sunlight does reach the valley floor, the sun rays' angles (and hence the sunlight and heat received by the valley) varies greatly depending on slope and aspect.

Figure 4: Local temperature comparisons of glacier base (solid lines) and base camp (dashed lines) for period 7 P.M. July 26 through 7 P.M. July 27, 1977 (maxima = "X"; minima = "."; 7 P.M., July 27 7 P.M. temperature = ".") Letters refer to locations on Figure 2.



C°
F°
30
25
20
15
10
5
0
80
70
60
50
40
30
glacier base
L
M
N
O
P
Q
base camp
A
B
C

Figure 5: Cross section of Nooksack River valley in study area. Cross section locations shown on Figure 2. Vertical scale is four times horizontal scale.



2000
1750
1500
1250
1000
850
ELEVATION (METERS)
2000
1000
0
1000
2000
DISTANCE (METERS)
H
F
D
J
I
K
E
G
WEST
NOOKSACK
GLACIER
PRICE
GLACIER

Figures 6A-C show those parts of the valley in shade during selected hours on five representative days bracketing the growing season. During March 21 and September 23 (Figure 6A, the spring and fall equinoxes) the sun angles would be the same. During May 1 and August 12 (Figure 6C, approximately mid-spring and mid-summer) the sun angles would also be the same. On June 21 (Figure 6B, summer solstice) sun angles are at a maximum.

Figure 6D and Table 1 show incident direct-beam solar radiation on the valley floor (assuming no cloud cover) on selected days. The South-facing slopes (North side of the valley) receive the most solar radiation, and the North-facing slopes receive the least.

The Northwest-Southeast valley orientation and steep side walls cause quite varied microclimates within the valley. On the southern part (in the influence of the North-facing valley wall) there is less direct sunlight during the year; when there is direct sunlight, it is less intense than on the North half of the valley. This appears to have an effect on the vegetation distribution, as will be discussed later.

General discussion

Summer temperatures fluctuate widely during clear summer weather, ranging from daily highs in the 30's°C (90's°F) to daily lows below 5°C (41°F). Rainy weather depresses the daily highs to the 50's and lower 60's.

Vegetated areas (forests or talus slopes with brushy vegetation) mediate temperatures compared to the river bank, because of lower insolation received below the canopies.

Surprisingly, there was not a noticeable cold air "pocket" in the valley floor near the glacier's base. However, this is based on limited data; and temperature transects taken during more critical times of the year (early spring or late autumn) may give different results. It is possible that heat retained by exposed rocks near the glacier's base was reradiated during night and kept the temperatures high. Air drainage from the cirque down the river bottom did cause a noticeable "wind chill" near the glacier's base.

The South side of the valley is generally cooler, both because it is shaded more often and because the direct sunlight it receives is not as intense. Persistent snowfields were also numerous on this side of the valley.

General Geology

The North Cascades Range is partly composed of the Chilliwack Batholith, a large granitic intrusion. Other intrusions occur along with older metamorphics (gneiss, schist). The history of the range includes numerous periods of metamorphism, folding, and faulting.

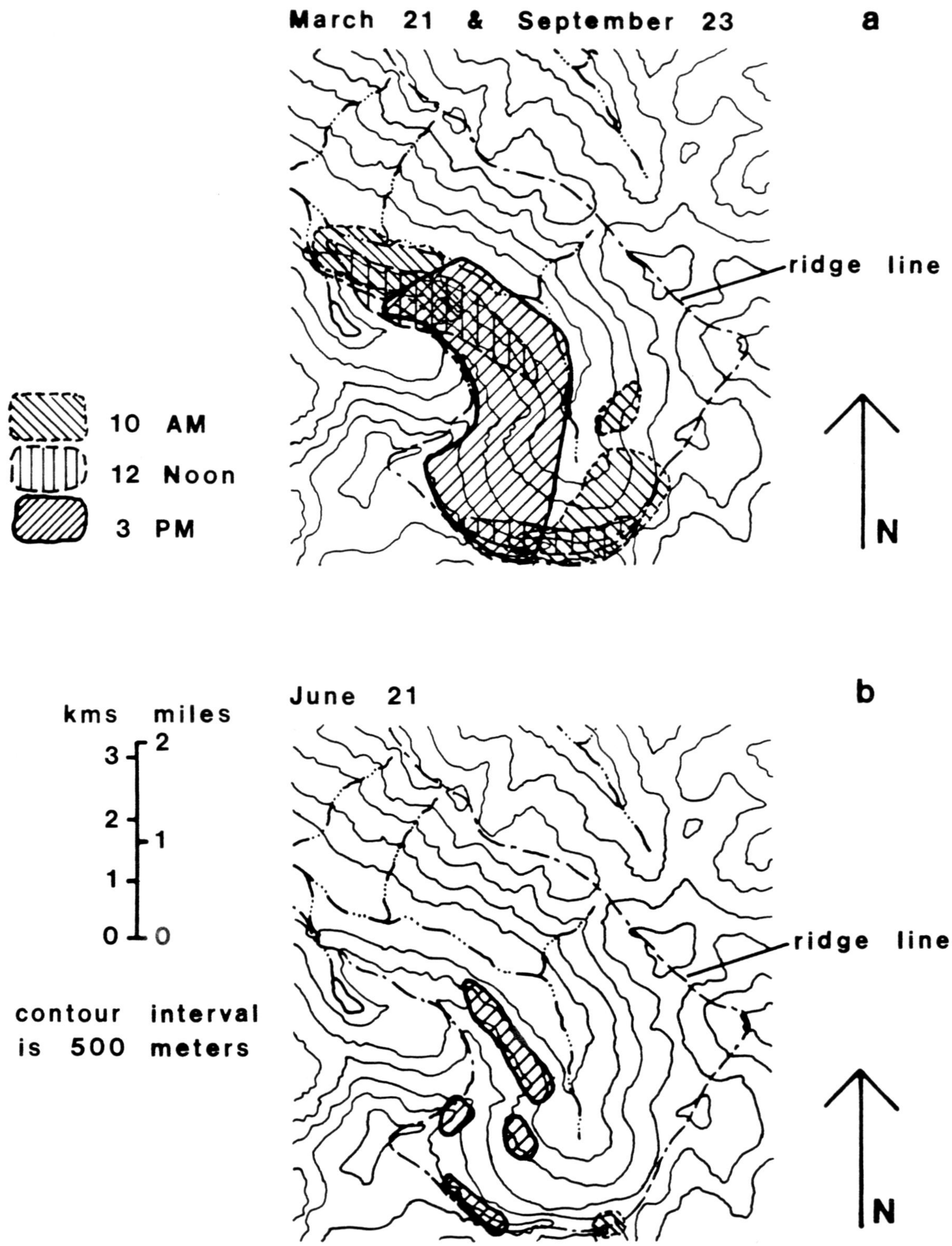
Misch (1966) has outlined the evolution of mountain building in the Cascades. During the Paleozoic period (≃400 million years B.P.), thick deposits of ocean sediments and volcanic material accumulated in a geosyncline (basin). These sediments were later metamorphosed into

Figure 6: Direct solar radiation on study area (from USGS Quandarngle map and Buffo et al. 1972).

Figures A - C: Portion of study area in shadow on selected days at 10 A.M., noon, and 3 P.M.

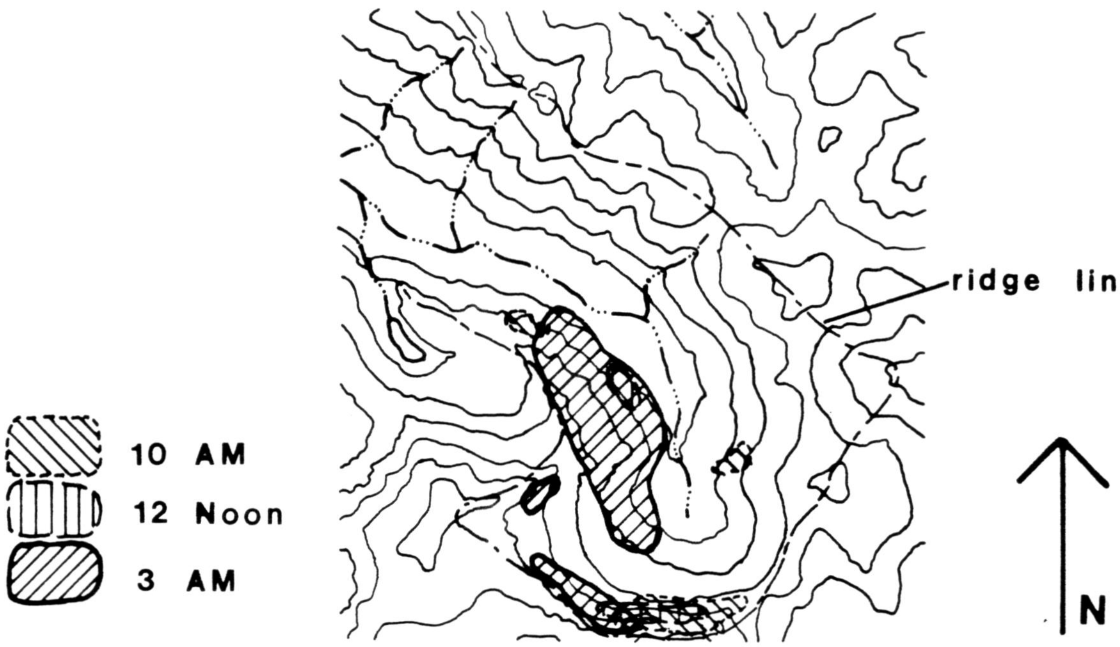
A. Parts in shadow during equinoxes (March 21 and September 22).
B. Parts in shadow during summer solstice (June 21).
C. Parts in shadow when sun angle is midway between equinoxes and summer solstice (May 1 and August 12).

Figure D: Areas from Table 1 showing potential direct solar radiation for parts of study area (from Buffo et al. 1972).

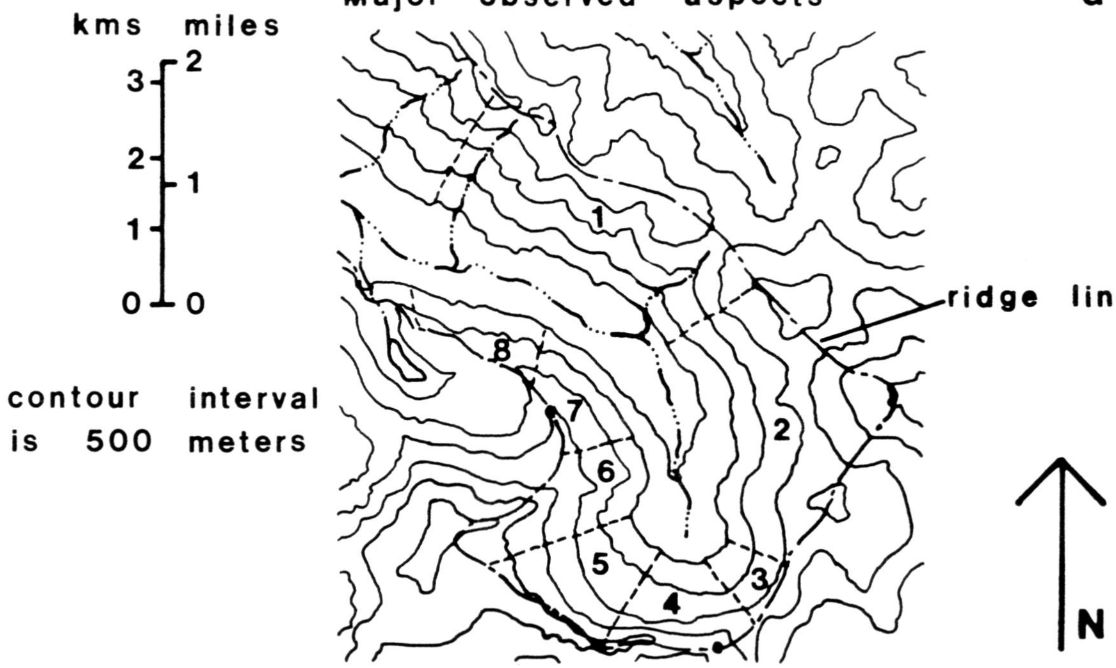


Seasonal direct sunlight and shade patterns

May 1 & August 12 c



Major observed aspects d



c Seasonal direct sunlight and shade patterns
d Major observed aspects

Table 1. Potential daily solar radiation on major observed aspects of valley and for given dates. Areas are shown in Figure 6D. (Radiation in Cal. $cm^{-2} day^{-1}$ calculated from Buffo et al., 1972.)

Table 1.

Area Number (See Fig. 6d)	Aspect	Slope (degrees)	*Potential daily direct solar radiation for given dates ($cal.cm^{-2} day^{-1}$)		
			June 22 (summer solstice)	May 1 and August 12	March 21 and September 23 (Equinoxes)
1	SW	40°	742	723	623
2	W	32°	758	649	435
3	NW	32°	666	498	238
4	N	45°	642	253	0
5	E	30°	758	603	435
6	NE	43°	773	614	344
7	NE	45°	536	387	167
8	N	40°	478	253	0
Valley Floor	NW	6°	830	700	456

*From Buffo et al. (1972).

phyllite and greenschist during the late Permian period (≃200 million years B.P.). The metamorphic suite was then thrust up during the mid-Cretaceous period (≃100 million years B.P.). Folding during the early Eocene period (≃50 million years ago) was caused by an intrusion known as the Chilliwack Composite Batholith. The intrusion occurred after the major mountain building period and consisted of diorite, quartz diorite, and granodiorite.

In the immediate study area, the last important event occurred during the Tertiary period (≃25-30 million years B.P.). Volcanic flows formed Ruth Mt. and Icy Peak and also intruded through fractures in the Chilliwack Batholith, forming dikes.

These various episodes of mountain development give the area a lithology consisting of granodiorite, phyllite, volcanics, and greenschist.

Mt. Shuksan is greenschist, while the ridges rising north and south of the valley are granodiorite with volcanic and quartz dikes. Volcanic material occurs on Icy Peak and Ruth Mt., but the valley walls at the base of these peaks are granodiorite. Ice eroding the cirque has exposed a phyllite strata that has apparently undergone contact metamorphism. The valley walls change from granodiorite to low grade metamorphics (greenschist, phyllite, slate) near the park boundary sign. At this contact zone, north of the river, there is a small gabbro intrusion. The lithologic boundary found here appears to explain the change in stream morphology from a braided stream channel to a channeled river with virtually no valley bottom.

Boulders in the river bed represent the composition of the local bedrock. These stones have accumulated on the valley floor through active erosional and colluvial processes transporting material from the valley walls and cirque. Granodiorite is, by far, the major rock material. Phyllite is found to a lesser extent, while volcanics and greenschist are minor lithic components.

Glacial History

Pleistocene glaciation has greatly affected northern Washington. There were three distinct glacial advances in the Puget Sound Lowland. The Fraser glaciation was the most recent. It advanced into the Puget Lowlands about 23,000 years ago and began retreating from its southern limit at Olympia about 14,000 years ago (Rosengreen 1965). Following continental glaciation, a warming period, called the Hypsithermal, began and reached a maximum about 6000 B.P. Maximum glacier shrinkage occurred from 8000-5000 B.P. In the periods following the Hypsithermal, three "little ice ages" or neoglaciations have been documented in North America, occurring 5500-4500 B.P., 2800-2600 B.P., and 700-∿70 B.P. The last period was the most extensive advance since continental glaciation (Denton and Porter 1970).

Several methods have been used to document neoglacial advances. Dendrochronology, lichenometry, and volcanic ash chronologies have all been used to determine age and positions of glacial features (Viereck 1967, Wilcox 1965).

Locally, Mazama ash (6600 B.P.) can be an important tool in determining glacial history. The presence of ash is useful for determining neoglacial boundaries (Wilcox 1965). However, the lack of ash does not, "a priori," indicate a glacial advance postdating the ashfall. Other erosional processes or atmospheric conditions may account for its absence.

Near the Nooksack cirque study area, Mazama ash was found exposed in a stream cut about 8 feet below the present soil surface. This stream is about one-half the distance between the clearcut area at the road end and the park boundary sign. Material deposited over the ash is colluvium and this suggests that glacial advances have not disturbed this area since the ash deposition (6600 B.P.). This ash is within 5.8 km of the cirque.

Glaciated valleys are typically U-shaped. Figure 5 shows a cross section of the valley and the U-shaped character. River valleys never glaciated or glaciated many thousands of years ago are typically V-shaped. The general appearance of any mountain valley will suggest whether glacial episodes have occurred in recent times; however, a U-shaped valley in itself is not sufficient evidence of glacial activity (Flint 1971). Hanging valleys and outwash material as well as glacial erattics down valley suggest a major role for pleistocene glacial activity in the Nooksack valley.

Approximately 5 km downvalley from the cirque, the typical glaciated U-shaped valley changes abruptly to a V-shaped valley. During Fraser glaciation (23,000 to $\sim$10,000 years B.P.), the Nooksack valley was ice filled. Therefore the V-shaped valley must have been established since the Fraser stade of continental glaciation. This change in valley profile may represent the terminus of a neoglacial advance; however, a mapped lithologic discontinuity occurs near the valley profile change. At this lithic boundary, tertiary granitics comprising the upper valley walls are replaced by low grade micaceous metamorphics such as greenschist and phyllite. There is also a small gabbro intrusion. Colluvium from the valley walls has been deposited downslope much faster west of the geological boundary. The granitics seem to be more coherent and are weathering more slowly than the metamorphics; therefore, debris has filled in the previously glaciated valley and the Nooksack River is cutting through the colluvium and forming a V-shaped river valley.

No evidence of neoglacial advances was found in this area.

Neoglaciation

Aerial photographs of the Nooksack Cirque dating back to 1947 indicate little fluctuation of the ice front within the past 30 years. For earlier periods before aerial photography, other means are needed for dating ice advances. End moraines can be used as time delineators of the landscape, since they denote the furthest extent for a particular glacial advance.

Three end moraines were found within 2 km of the East Nooksack glacier. Ages of these moraines were determined using dendrochronological methods (Lawrence, 1950). Lichenometry was also used but the literature concerning its use is contradictory (Beschel, 1973; Carrera & Andrews, 1973; Jochimsen, 1973; Lindsay, 1973; Webber & Andrews, 1973), and local dated rock structures necessary for construction of growth curves were absent.

The oldest trees on or behind the three moraines were ∿170, 130, and 63 years old, respectively (Figure 7). This would put the absolute minimum age of the three neoglacial advances at ∿1807, 1847, and 1914.

The age of trees on or behind a moraine will show the minimum age of that particular ice advance producing the moraine. However, several errors may be encountered (Lawrence, 1950). (1) The oldest tree may not be cored. (2) It is not always possible to obtain a core at the level at which the seed actually germinated. (3) The time between deglaciation and tree germination is unknown. All dates, therefore, are minimum ages, unless an arbitrary number of years is added to the tree age to compensate for errors.

Dendrochronology may also give deceptive dates in this valley because areas of frequent snow avalanches may have supported more than one generation of trees since deglaciation. However, we feel that the few older trees found within avalanche areas are first generation colonizers. Decomposed logs on or below the soil surface were not found.

Considering the number of trees cored and their sparseness in avalanche areas, the oldest trees were assumed to be located and aged.

Even though the trees were cored at the lowest point possible, the first few years of growth could not be included in the ring counts. To adjust for the time necessary for growth of the first foot, a few years should be added to the age of cored trees.

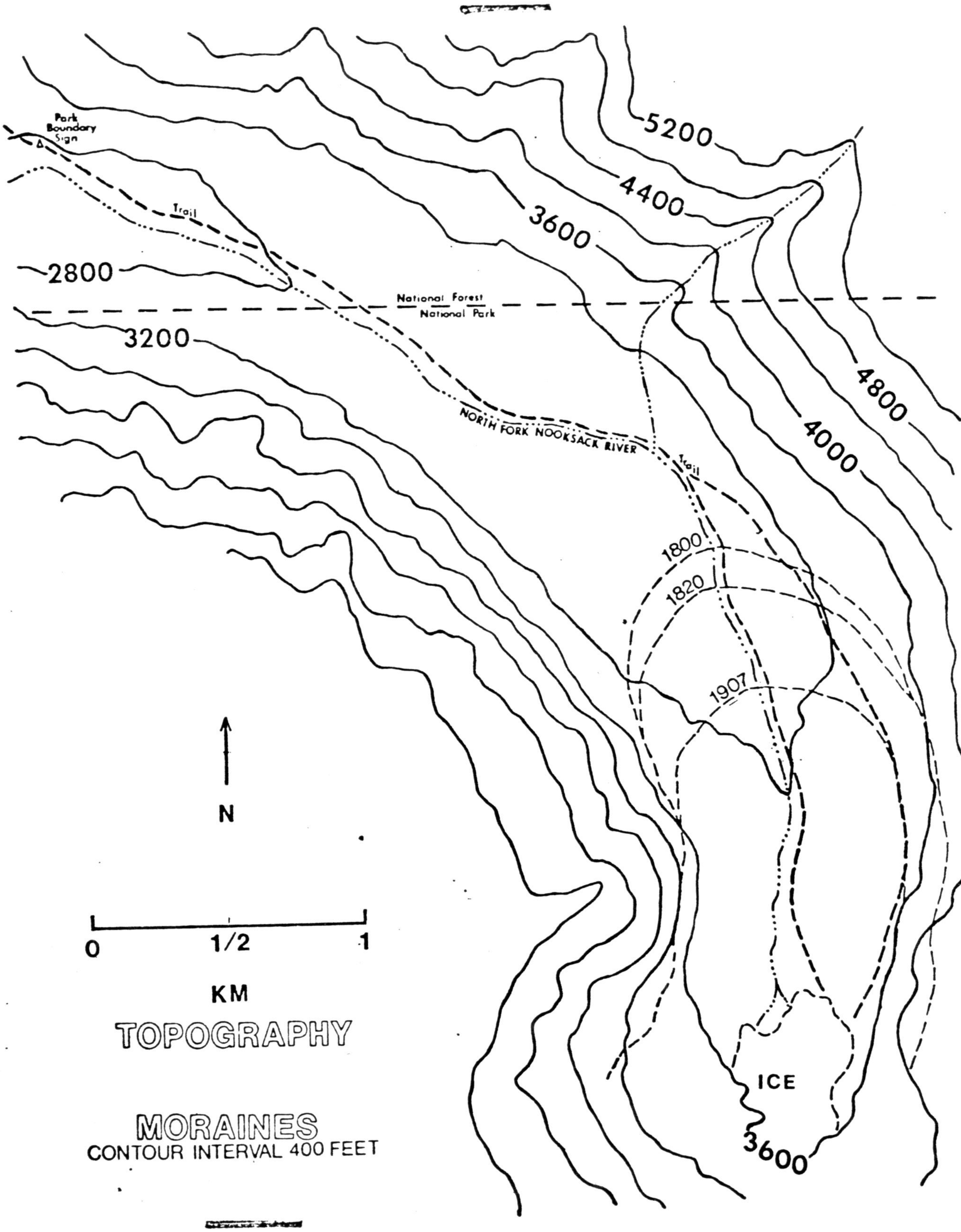
The time needed for seedling establishment on newly deglaciated terrain is unknown. The barren landscape near the current ice front suggests it may take several years for conifer establishment. However, this area is subjected to frequent snow avalanches and deep snow accumulations. Downvalley sites are less disturbed. Seed source is probably not a problem for tree establishment, but snow avalanches, rocky terrain, and lack of soil nitrogen appear to be limitations for rapid growth.

A few trees were found to be older than the average ages for each area. These unique trees may represent early colonizers.

Approximately seven years was added to the oldest tree ages to compensate for the seedling stage and time needed for seedling establishment. Adding 7 years to the tree ages results in general ice advance dates of 1800, 1840, and 1907 for each of the three moraines. These dates should be considered approximate minimum ages but correlate well with other ice advances in the Pacific Northwest (Porter & Denton, 1967; Viereck, 1967). The locations of moraines formed during the advances is presented in Figure 7.

Thallus size of the lichen species Rhizocarpon geographicum was also measured on each moraine as an aid in establishing ice advance dates. Growth curves exist for this lichen in the Mt. Rainier area. Whether these curves can be used in the North Cascades is questionable.

Figure 7: Topography and location of neoglacial moraines in the Nooksack Valley.



Park Boundary Sign
Trail
2800
3200
3600
4000
4400
4800
5200
National Forest
National Park
NORTH FORK NOOKSACK RIVER
Trail
1800
1820
1907
ICE
3600
N
0
1/2
1
KM
TOPOGRAPHY
MORAINES
CONTOUR INTERVAL 400 FEET

The largest thallus found on each moraine, from oldest to youngest, was 83, 74, and 52mm. Using Mt. Rainier growth curves, these thallus diameters represent 200, 175, and 120 years of growth for each respective lichen. Assuming that the lichen immediately colonizes each moraine when it is deposited, lichenometry suggests that the three ice advances occurred in 1777, 1802, and 1857. These dates are 20 to 50 years earlier than tree dates.

An error involving the time needed for seedling establishment can account for some of the discrepancy, but not all. It appears that the growth curve used from Mt. Rainier is not applicable to the Nooksack Cirque. A new growth curve needs to be established for this particular area, but lichens growing on materials of an absolute age are lacking. As of now, lichenometry in the Nooksack Cirque is not a useful indicator of absolute ages for moraines. However, it may be used for relative dating.

SOILS AND SURFICIAL GEOLOGY

Introduction

The use of any given area depends greatly on the soils and geologic materials present. This section of the report provides a summary of soil descriptions, surficial deposits, and slope classes encountered in the Nooksack Cirque.

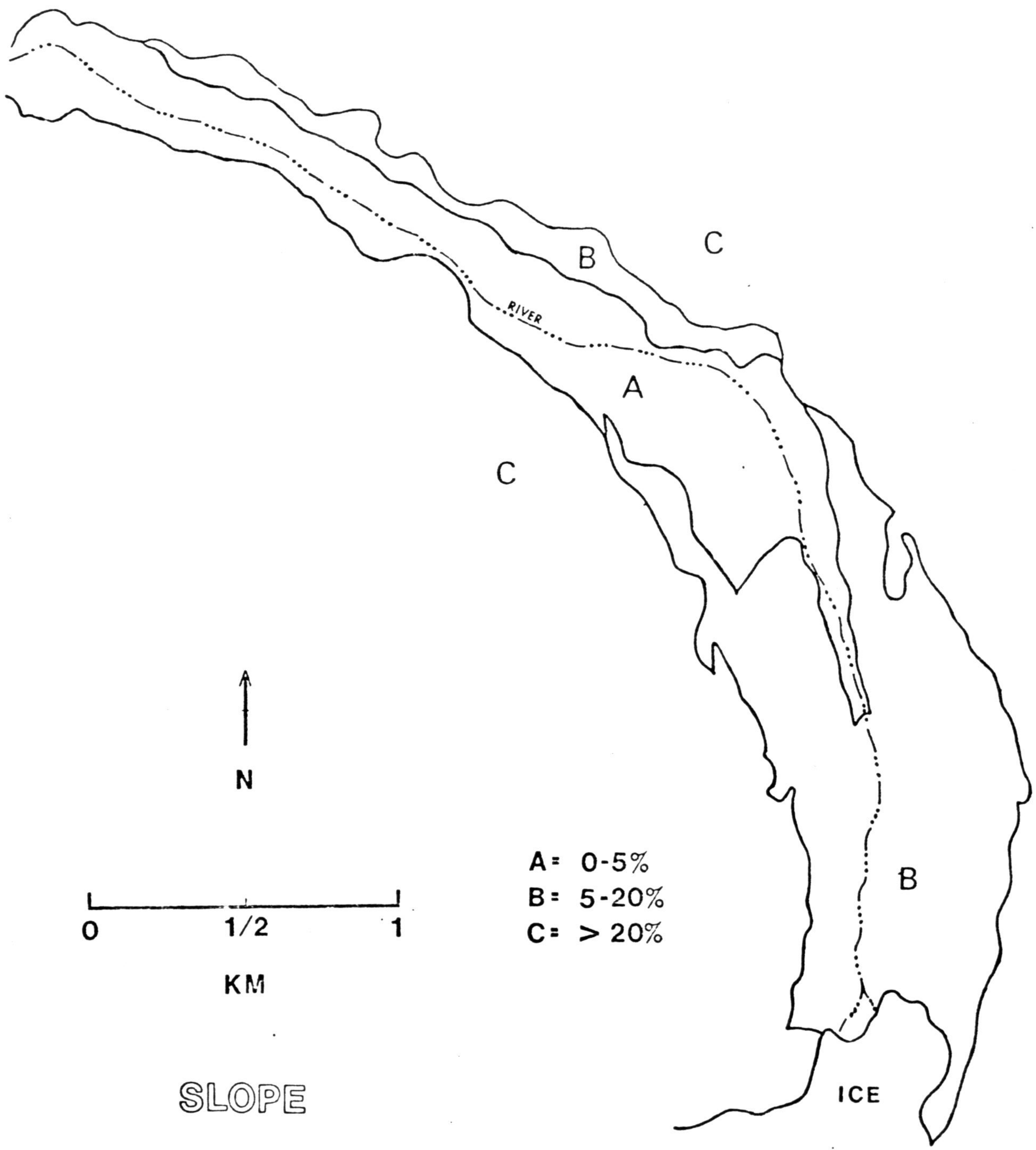
Methods

Soils and soil materials were delineated by careful inspection of aerial photographs and extensive on-the-ground observations. Several transects both perpendicular and parallel to the valley floor were established to determine the area geomorphology more clearly. Along these transects elevation changes and soil types were recorded and later transferred to graphs for better visual interpretations. Information gathered in these transects was combined with data from aerial photo interpretations to construct a soil map of the valley floor. Mapping units for this survey were based on slope and the mode of soil material deposition.

Results

Soils in the study area are young and show few distinct internal characteristics. The most useful categorization was one based on the slope and origin of the parent material. Figure 7 shows a topographic map of the study area used as a base map for the study and other maps in the soil and geology section. The contour intervals suggest that only the valley bottom provides an area suitable for visitor use and development. Figure 8 shows the valley divided into slope classes of 0%-5%, 5%-20%, and >20%; on the basis of this figure there is only a narrow band of area paralleling the river which is relatively level terrain. A major portion of the valley has a slope over 20% and many of the slopes on the valley sides are in excess of 50%.

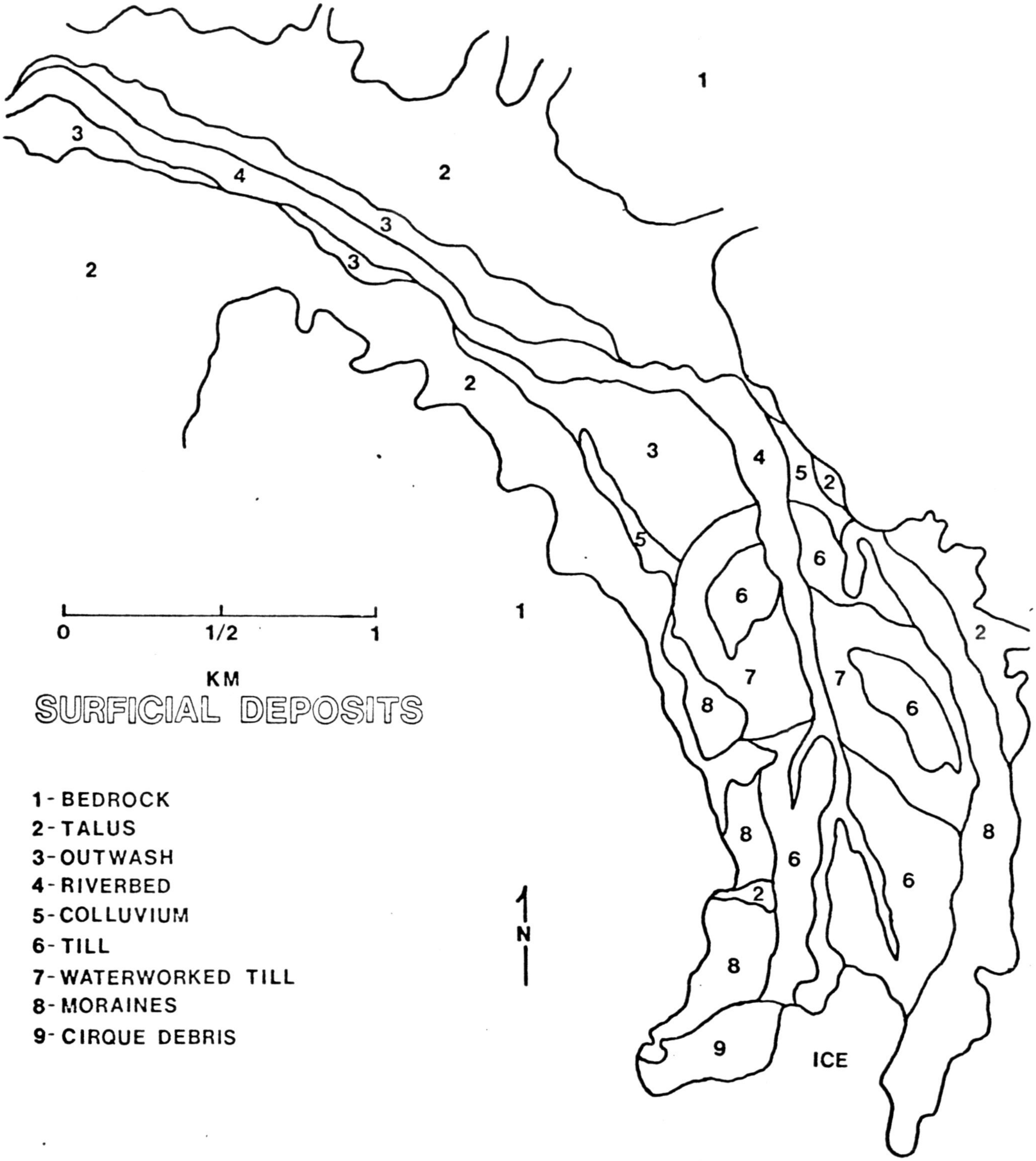
Figure 8: Slope classes in the study area.


C
B
RIVER
A
C
N
A= 0-5%
B= 5-20%
C= > 20%
B
0
1/2
1
KM
ICE
SLOPE

A combination of slope classes and surficial deposits (Figure 9) were used to compile the soils map presented in Figure 10 and Table 2. The surficial deposits are dominated by glacial materials (outwash and till) in the valley bottom and colluvium and talus slopes near the valley walls (Figure 9).

The mapping units shown in Figure 10 and Table 2 are presented in the following section:

Figure 9: Surficial deposits in the Nooksack Valley.



SURFICIAL DEPOSITS

Figure 10: Soil map of the study area; mapping unit key shown in Table 2.

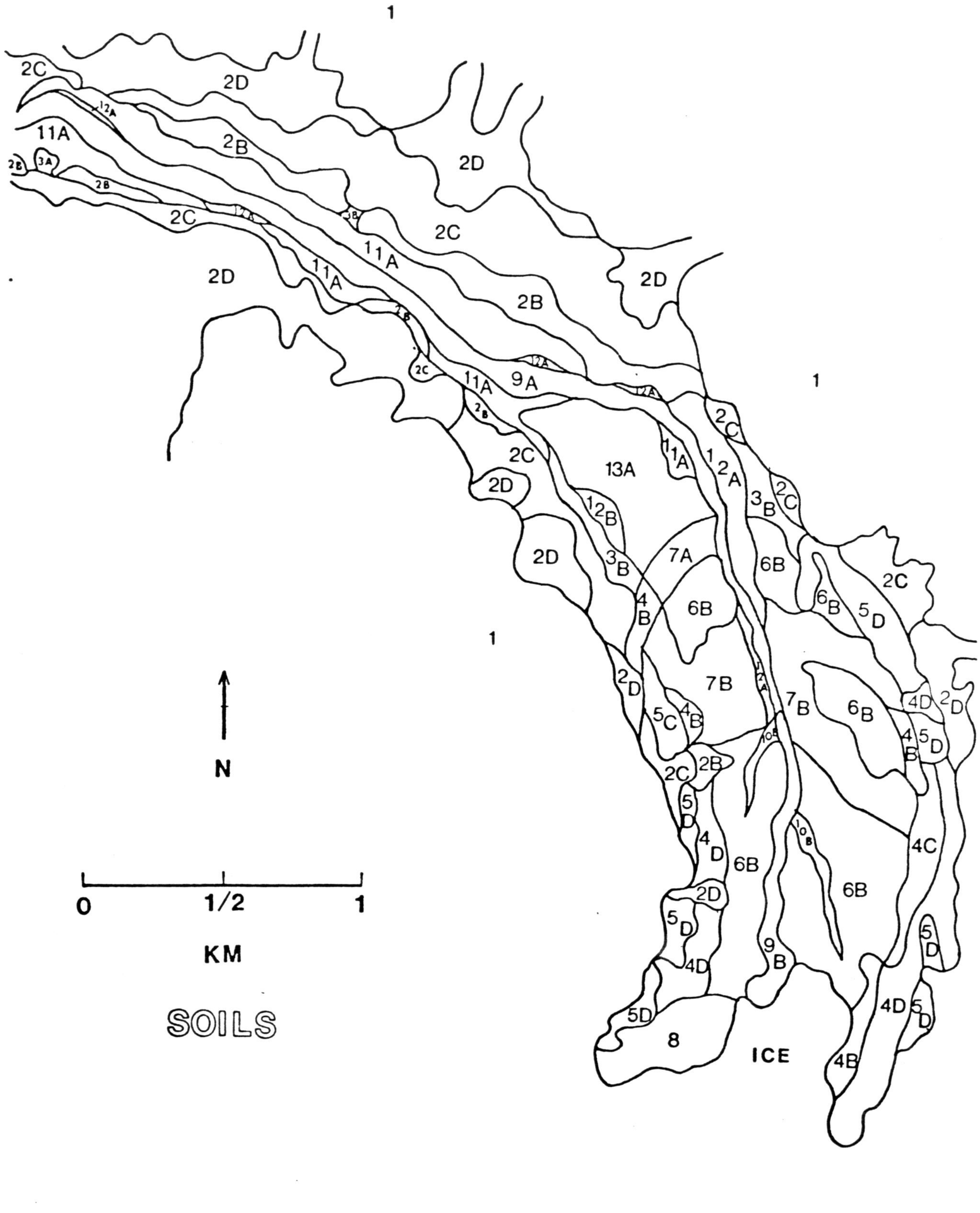

N
0
1/2
1
KM
SOILS
ICE

Table 2. Mapping Unit Key for soil units shown in Figure 11.

1	Bedrock and Talus, very steep valley walls
2B	Talus, 5%-20% slope
2C	Talus, 20%-50% slope
2D	Talus, >50% slope
3A	Colluvium, <5% slope
3B	Colluvium, 5%-20% slope
4B	Colluvium/Till, 5%-20% slope
4C	Colluvium/Till, 20%-50% slope
4D	Colluvium/Till, >50% slope
5C	Morainal Till (Lateral and Terminal), 20%-50% slope
5D	Morainal Till (Lateral and Terminal), >50% slope
6B	Morainal Till (Ground and Recessional), 5%-20% slope
7A	Waterworked Till, <5% slope
7B	Waterworked Till, 5%-20% slope
8	Cirque Debris, steep and unstable
9A	River Bed, <5% slope
9B	River Bed, 5%-20% slope
10B	Outwash Channel, 5%-20% slope
11A	Sandy Outwash, <5% slope
12A	Stony Outwash, <5% slope
12B	Stony Outwash, 5%-20% slope
13A	Stratified Outwash, <5% slope

Mapping Unit Descriptions

1. Valley Walls (very steep bedrock and thin soils). This mapping unit grades from bare rock near the cirque to thin forested soils at the western edge of the study area. It includes all of the landscape above the true talus (#2). Thin soils covering the bedrock may be residual or talus. They also may have Pleistocene glaciation origins.

The bare rock valley walls extend approximately 1.5 km downvalley from the cirque. Frequent rock and snow slides occur, along with sheet flow during rain storms. Further downstream, the valley walls become forested and more stable. Some thin soils also support dense vine maple and alder brush.

The walls are frequently dissected by talus chutes. Streams occur in these channels during spring melt and rains.

The excessively steep slopes of this unit make any development impractical.

2. Talus. This unit contains material varying in size from sands to boulders. It is predominantly granodiorite. The talus lobes develop below talus chutes (channels in the valley walls above). Talus development is more active near the cirque where vegetation is lacking.

During the study period, rocks were frequently heard and seen tumbling down. Sporadic boulders (10-30 ft. across) were found in an old-growth forest at the river bend. Their recent origins were evident from the destroyed trees.

Besides falling debris, the talus surface is typically unstable. Loose rocks give way when walked on. This makes travel dangerous. Some of the talus areas support dense alder brush. This makes travel nearly impossible. A few talus lobes of finer material (2B) support meadows. Travel is easy but the fragility of the vegetation should limit their use.

At the western edge of the study area, the lower talus slopes (2B, 2C) are forested and stable. These talus units near the end of the braided stream are within the National Forest. They are suitable for trails and lack limitations associated with the talus units upvalley. Their extent is minor.

Talus instability increases with slope. Typically, 2B is safer terrain than 2C or 2D. It is usually less bouldery also.

These areas rise above the valley floor and allow an excellent panorama of the valley. However, forethought is needed if trails are planned here. Fragile meadows should be avoided and trails should be kept on the lower slopes. Active talus slopes (unvegetated) should be avoided.

3. Colluvium. This unit occurs at the base of talus lobes and contains fine wash-deposited talus material.

3A is a soil consisting of silt and sand lenses. Drainage is poor and trees are few and stunted. Organic matter is accumulating and the water table is high. Excessive wetness limits its use for development.

The small 3B unit upvalley is a devastated area. Coarse sands and gravels have accumulated at the talus base below an intermittent stream. Deep deposits have killed the trees.

The long, narrow 3B strips in front of the end moraines support intermittent streams. They were major drains during glacial advances. Occasional talus stones litter the surface. Gentle slopes and a minimum of surface boulders makes this unit moderately suitable for trails. Fragile meadows, alder and wet spots are limitations.

Small, thin strips of this mapping unit also occur between units of 2B and 11A. The gravelly talus material overlies sandy outwash in some areas. The minor extent of these bands excludes them from being mapped.

4. Colluvium/Till. This unit contains water, snow, and gravity deposited rock material overlying lateral moraines. The transported rocks originate from the valley walls or from the moraine itself.

4B is greatly affected by streams originating from the valley walls. Colluvium has partly or completely buried remnant moraines. Small intermittent streams have also eroded the morainal rises. A few talus boulders cover the surface. Meadows are the predominant vegetation. Local wet spots have deep accumulations of organic material.

Gentle slopes and a minimum of surface boulders make this unit moderately suitable for trails. Fragile vegetation and wet spots are limitations.

4C and 4D occur on the lower parts of steep lateral moraines. Eroded material from the upper moraine and valley walls has been deposited over the till. The loose, unstable rocks on the steep surfaces makes climbing dangerous. Rock and snow slides occur frequently. They are not suited for any development.

5. Morainal Till (lateral and terminal). The major moraines in the valley are represented by this unit. They indicate the boundaries of neoglacial advances. Slopes are steep and often bouldery. The oldest moraine has areas of huge boulders ten to thirty feet across.

Rock slides, snow slides, and water are actively eroding this unit. Steep, unstable slopes and massive boulders are the major limitations for trails. However, the moraine peaks afford an excellent panorama of the valley.

6. Morainal Till (ground and recessional). Till in this unit was deposited during neoglacial retreat. The hummocky landscape is strewn with rocks. Most areas are unvegetated. The landscape is a sequence of barren, stony recessional moraines alternating with finer-textured ground moraines. Near the ice, some huge boulders from unit 5D have rolled down into this unit.

The uneven and bouldery topography somewhat limits trail development. The clearing of surface stones can produce a suitable trail.

7. Waterworked Till. These gently sloping units are comprised of small outwash channels and stony morainal ridges. Dense alder thickets cover the areas of finer outwash. The channels are fed intermittently by valley wall streams. These areas were also affected by proglacial streams during neoglaciation.

Unit 7A is suited for campsites. Damage to the site is minimal. The soil surface is smoother and less bouldery than unit 7B. Snow avalanches are a problem though. The young forest is frequently disturbed by snowslides. Clean-up operations in the spring may be necessary.

Unit 7B is moderately suited for trails. The terrain is often bouldery and hummocky. Dense alder patches would have to be cleared. It is also prone to snowslides but there are few trees to be disturbed. The alder seems to be suited to this type of natural disturbance.

8. Cirque Debris. This unit is a small, steep, unstable area occurring above the ice. The landscape is barren and bouldery. It is subjected to debris and snow slides. Snowfields or ice can cover it in any given year.

It is unsuited for any development because of the loose, unstable, bouldery surface.

9. Riverbed. This unit contains the braided channels of the north fork of the Nooksack River. The bed surface is bouldery. Fine sands interfill spaces between the stones. The river flow is dependent on weather conditions. Fluctuations were great during the summer. Warm rains can produce near flood conditions. Increased river flow changes the braided channel system. New channels are formed and old ones are abandoned. Crossing the river at most times is dangerous.

Neoglacial advances and cross-valley transects indicate that the main riverbed has meandered across the valley floor. It is currently eroding and undercutting neoglacial deposits.

The riverbed is one of the few areas where thick alder patches are lacking. However, the bouldery surface makes travel difficult. Numerous boulders would need to be cleared and bridges would have to be built for trail construction. Changing channels can easily destroy established trails.

10. Outwash Channel. This unit is represented by two small channels in recently deposited recessional and ground moraines. Water flow is intermittent. Fine sands and silts occur on the channel bottom. Alder occurs in patches but much of the terrain is bare.

These outwash channels are less bouldery than the riverbed but may support streams at any time. Water flow is dependent on the melting ice upvalley. Flow is probably greatest during spring thaw. This would have to be taken into account when building trails across the channels.

11. Sandy Outwash. This is one of the few areas that has escaped most of the frequent snow avalanches seen upvalley. The vegetation cover is old-growth western hemlock and silver fir along with some Douglas-fir. The soil is stratified deposits of sand and silts with underlying cobbles in some areas. Buried soils indicate up to five outwash periods.

The unit is dissected by numerous small streams. Wet spots, with accumulating organic matter, occur in local depressions. The boundaries of the unit are the riverbed and the talus base. A poorly drained backwater area butts up against the talus base. Beavers have created some ponds here. The backwater stream is on the same level or, in some cases, lower than the Nooksack River boulder bed. Coarse material (sands and cobbles) occurs near the river. Finer outwash (sands and silts) occurs near the backwater stream. The numerous buried soils here represent past landscapes. New deposition may correlate with flooding and/or neoglacial activity.

11A is one of the safer and more protected areas in the valley. Its gentle slope and sandy soil make it well suited for trails. There is a problem of a locally high water table. Higher ground along the river bed seems ideal for trails. Campsites should be concentrated on areas of high relief.

12. Stony Outwash. This unit mostly occurs as thin strips between the river bed (9A) and the sandy outwash plain (11A). These slightly elevated, bouldery benches support alder and are prone to flooding. They are minor in extent and can be bypassed for trails in favor of the adjacent sandy outwash unit (11A).

One large area of this unit occurs at the river bend in the middle of the study area. This is substantially higher than the smaller areas previously discussed. The terrain is cobbly. It is suited for trails and is much less prone to flooding.

12B is a stony outwash area with a mountain hemlock cover. It was probably deposited during one of the early 1800 glacial advances.

13. Stratified Outwash. This is a unique area that has undergone numerous depositional periods during the neoglaciation. Numerous strata of different sized outwash make up the profile.

This large, concentrated unit is well suited for trails and campsites. Flooding is infrequent. The varying stand ages indicate periodic disturbances. They can be associated with glacial meltwaters, windthrow, and/or snow slides. The eastern and western edges are prone to snow avalanches.

Areas of old growth mountain hemlock are probably best suited for campsites. Soil and site damage susceptiblity is moderate. Trails should detour snow slide areas and be located on high ground.

The management interpretation for the soil mapping units are in the most part derived from the Mt. Baker National Forest Soil Resource Inventory prepared by R. V. Snyder and J. M. Wade, and the application of these interpretations to the listed mapping units were prepared by the authors. These are presented in the following section and Table 3.

Definitions of Management Interpretations

1. EROSION INTERPRETATIONS

A. Surface Erosion Potential

This rating is based on expected losses of surface soil when all vegetative cover, including litter, is removed. Evaluations of climate, slope gradient and length, soil characteristics, hydrologic characteristics of the soil, and bedrock materials of each mapping unit are considered in making ratings.

Very Slight - Practically no loss of surface soil materials is expected.

Slight - Little loss of soil materials are expected. Some minor sheet and rill erosion may occur.

Moderate - Some loss of surface soil materials can be expected. Rill erosion and some small gullies or sheet erosion may be occurring. At this level of erosion there is a possible fertility loss.

Severe - Considerable loss of surface soil materials can be expected. Rill erosion, numerous small gullies or evidence that considerable loss from sheet erosion may occur. This is accompanied by a probable fertility loss.

Very Severe - Large loss of surface soil material can be expected in the form of many large gullies and/or numerous small gullies or large loss from sheet erosion. This is accompanied by fertility loss.

B. Natural Stability

This rating is based on the relative stability of the mapping units as they occur in the natural state. This includes any movement or loss other than surface erosion, by slumps, slides, and all kinds of deepseated features.

Very Stable - No evidence of failure.

Stable - Occasional failures are observed.

Moderately Stable - Several failures are observed.

Unstable - Many failures are observed.

Very Unstable - Entire area shows evidence of recent and past failures.

C. Nature of Mass Movement

This is an estimation of the kind and/or size of mass movement observed.

D. Expected Mass Movement AS A Result of Man's Activities

This rating indicates the expected mass movement resulting from man's activities as compared to stability under natural conditions. Ratings are based on soil and bedrock characteristics, slopes, revegetation potential, and effects of timber removal, road construction, and fire.

Unchanged - The expected mass movement is relatively unchanged from that of the natural state.

Increased - The expected mass movement is greater than that of the natural state.

Greatly Increased - The expected mass movement is much greater than that of the natural state.

II. RECREATION

A. Soil Suitability For Recreation Development

This rating is based on soil and bedrock characteristics and topographic features of each unit as related to recreation development. Factors important to this interpretation are soil depth, texture, structure, permeability, drainage, topography, and susceptibility to flooding.

Unsuited - This rating indicates that soils and/or topography are of a nature which would prohibit recreation development without extensive modification.

Low - These soil units have major limitations to recreation development but limited development is feasible.

Moderate - This rating indicates that the soil unit is generally suitable for recreation development but has minor limitations.

High - These soils are particularly well suited for recreation development. Generally, they have no limitations.

B. Soil Limitations For Recreation Development

This indicates the major limitations to recreation development.

C. Trail Suitability

This interpretation indicates the suitability of each soil for trails. Factors include soil and bedrock characteristics, drainage, climate, and slope.

Poor - These soils have properties which severely limit their use for trails. Extensive treatment measures are required.

Moderate - These soils have some limitations for trail development. Certain treatment measures may be required.

Well - These soils generally have no limitations for trail development.

Soil Development in the Cirque Area

(Data supporting the conclusions of this section are on file at the College of Forest Resources.)

PODZOLIZATION

Podzolization processes are expected to be occurring on till deposits at the Nooksack Cirque. Contributing to podzolization is the coarse acidic parent material, the cool moist climate, and the coniferous vegetation.

Podzolization involves the chemical translocation of free iron and aluminum oxides with or without organic matter. A small amount of phosphorus, manganese, and clay may also be translocated. Translocation of these compounds is influenced by hydrogen ions and by organic materials which can chelate the iron and aluminum. Intense weathering and chelation occurs in the eluvial A horizon and the compounds move down and accumulate in the illuvial B horizon. A deep, acid, dark black and matted (mor) organic layer accumulates on the soil surface becasue of a slow decomposition rate. Decomposition rates are reduced because of low temperatures and the resistant nature of the coniferous litter.

The source of iron and aluminum accumlating in the B horizon are ferromagnesian minerals and feldspars in the A horizon. Maximum concentration of aluminum is typically less than iron.

Spodosols are the end product of podzolization processes. They must have a diagnostic spodic (iron and aluminum enriched) B horizon which is indicative of iron and aluminum translocation. Where this process is not fully expressed, the soil may be an Inceptisol. Inceptisols have a cambic horizon (altered in color) instead of a spodic horizon. The cambic B horizon has not yet been affected by chemical additions from the A horizon.

Inceptisols occur on geomorphic surfaces that are too young for complete soil development. In time they may become Spodosols as they become equilibrated with the environment.

Chemical analysis of iron and aluminum shows that podzolization processes are becoming apparent on 70 year old sites. However, translocation of iron, aluminum, organic carbon, and phosphorus is not substantially expressed until approximately 130 years of time. For podzolization to be occurring, sites need to be vegetated by conifers or Sitka alder. The younger sites (1900+) may be classified as Inceptisols. The 1800 and 1840 areas may be, or are approaching Spodosols.

Visual observations of the soil profiles showed some A2 horizon development on the 1800 and 1840 areas. This albic (light colored) horizon is usually associated with podzol soils. Deep oxidized (reddish) B horizons were also apparent. The 1907 area also showed some A2 and B horizon development but not to the degree of the older sites. This also lends support to the conclusion that the 1800 and 1840 areas are becoming Spodosols while the 1900+ areas are still Inceptisols.

SOIL DEVELOPMENT

The neoglacial moraines in the Nooksack Cirque Area represent an excellent resource for the study of soil development. Soil development is modified by time, parent material, climate, topography and vegetation. In the Cirque area climate, topography, and parent material are constant so that the effects of time and vegetation can be examined.

In order to determine the effects of time and vegetation on soil development, 27 sample sites were chosen. Soil pits were dug and soils sampled in the following areas:

Approximate Year of Deglaciation	Vegetation	Number of Sites
1800	Mt. Hemlock	2
1840	Mt. Hemlcok	3
1840	Sitka Alder	3
1840	Barren	3
1907	Mt. Hemlock	2
1907	Sitka Alder	3
1907	Barren	3
1940	Mt. Hemlock	2
1940	Sitka Alder	2
1940	Barren	2
1950	Barren	2

Soil chemical properties determined were pH, total nitrogen, carbon content, total phosphorus, and free iron and aluminum oxides.

The organic layers and tree foliage at some sites were also analyzed for pH and percent nitrogen, phosphorus, potassium, calcium, magnesium, and Mn.

Soils:

pH - On each site, pH increases with depth because weathering and leaching are most intense near the soil surface. Reduction of pH at the surface is accelerated by plant litter which releases organic acids during decomposition.

The older vegetated sites have more acid surfaces caused by deep accumulations of organics. In the 1840 and 1907 areas, Sitka alder and Mt. Hemlock have caused decreases of 0.5 to 1.0 pH units compared to barren sites of the same age. The organic layers at these sites are very acidic and range in pH from 3.3 to 4.0.

Newly deposited albation till near the ice and till on the ice was found to be somewhat acid before it was colonized by vegetation. The typical pH ranged from 4.2 to 5.5. Comparing this to the pH of ground rock in the area (7.3 to 8.6), it is evident that chemical weathering and leaching of bases is occurring even before the till is being deposited. Granodiorite is low in bases and as the major fraction of the parent material, it will form a coarsely-textured, acidic soil that is low in clay.

Nitrogen - It was noted that conifers growing in recently deglaciated terrain (1940+) were chlorotic and stunted, while alders in the same area had deep green foliage and good growth. It is known that alders fix atmospheric nitrogen and act as important primary colonizers by building up soil nitrogen.

Soil nitrogen data obtained shows the importance of Sitka alder in the Nooksack Cirque. Initial nitrogen contents of newly deposited till are 0.01% or less. On sites supporting alder, there is a substantial increase of nitrogen in the soil surface. Nitrogen content decreases with depth. In the 1900+ areas, increases are confined to the upper few inches. On the 1800 and 1840 sites, there is a deeper accumulation of soil nitrogen which extends into the B horizons. It is assumed that soil nitrogen within mountain hemlock stands was initially added by Sitka alder which has long since died.

Barren sites show some nitrogen inputs in the surface inch of soil. This can be from lichens and mosses and also atmospheric pollution or fixation.

Carbon - Carbon increases with soil age and decreases with soil depth. On a few Mt. hemlock sites (1,2,4,5,22) carbon increases slightly at a depth from 14 to 22 cm, then decreases again. This may be evidence of a B2 horizon where humus, iron, and aluminum accumulate during podzolization. The organic acids, liberated during decomposition, chelate iron and aluminum, migrate down, and become immobilized in the B horizon. Iron and aluminum data tend to support this idea as they also increase at the same general depth. Further tests are being conducted using different extraction techniques.

C/N Ratios - Carbon/Nitrogen ratios on mountain hemlock sites are greater than those on alder sites, especially in the upper few inches of soil where roots proliferate. Values greater than 30 constitute net immobilization of nitrogen. Microbes are competing for available nitrogen in order to decompose litter. Values less than 20 constitute net mineralization and nitrogen is available for plant uptake.

Alder sites typically have C/N ratios less than 20 and hemlock sites have C/N ratios greater than 20. Nitrogen is much more available for plants on soils supporting alder rather than hemlock.

As time proceeds, mountain hemlock will occupy sites previously vegetated by Sitka alder. The soil and litter nitrogen added by alder will be used in the production of new hemlock foliage, which will act as a reservoir of nitrogen. As a result, soil nitrogen will be reduced and C/N ratios will increase. Microbes will compete for the available nitrogen during litter decomposition and it may become a limiting nutrient for mountain hemlock growth.

Phosphorus - Phosphorus is nearly constant as soils age which indicates similar parent materials on all sample sites. However, on the older vegetated soils (1800 and 1840), there is a depletion of phosphorus in the surface and a slight accumulation in the subsurface. Translocation of phosphorus on the older sites indicates podzolization.

Iron - If podzolization processes are occurring, iron would be expected to accumulate in the B horizon. Surface horizons typically show lower amounts than subsurface horizons. The amount and depth of iron accumlation varies between sites. The soil age and its vegetation cover greatly affect the degree of podzolization. Younger sites (1900+) and those that are unvegetated show less iron translocation. Older vegetated sites have greater and deeper translocation of iron.

Aluminum - Aluminum translocation, like that of iron, is indicative of podzolization. Aluminum translocation is readily apparent only on the 1800 and 1840 vegetated sites. The lack of aluminum accumulation in the subsurface horizons on the 1840 barren sites shows the importance of orgainc acids in chelating aluminum and making the ion mobile. The 1900 vegetated sites seem to show some aluminum translocation, but it is minor.

Organics:

pH - Organic layers were found to vary in pH from 3.3 to 4.0. Exceptions are 1907 alder sites which are less acidic (3.7 to 4.4). This acid litter layer causes intense weathering and leaching of the soil surface.

Nitrogen - Foliar nitrogen contents of Sitka Alder vary from 2.0 to 3.2% and 0.6 to 2.1% in Mountain hemlock. Mountain hemlock nitrogen contents are greater when it grows in association with alder.

Alder organic layers contain 2.4 to 3.3% nitrogen, appreciably more than hemlock sites (1.0 to 1.6%). Input of nitrogen on the hemlock sites is assumed to have come from initial alder colonization. The nitrogen fixed and stored by alder represents the current supply for hemlock. Much of the available nitrogen is tied up in hemlock foliage, so the quantities found in the litter are less than those of alder.

Other nutrients (P,K,Ca,Mg, and Mg) - It was initially postulated that nitrogen was a nutrient limiting conifer establishment. Newly established mountain hemlock seedlings not growing in association with Sitka Alder were chlorotic, which supports this contention.

Unlike nitrogen, these other nutrients become available from weathering of the soil parent material. Their contents were found not to increase on old or alder sites like nitrogen. No trends were found in their natural variability.

VEGETATION DYNAMICS OF THE NOOKSACK CIRQUE

Objectives

The objectives of the vegetation study of the Nooksack Cirque were:

1. To determine the species and plant communities present.
2. To study the factors which determine the composition, structure, and pattern of the plant communities. The major influencing factors were believed to be soil-site influences, micro- and macroclimate variations, and the influences of disturbances.
3. To examine the patterns of change over time in the various communities and their responses to various disturbances. This should allow prediction of future vegetation changes and the impact of various human manipulations on the natural vegetation. Such information would be of use to Park administrators, visitors, and scientists.
4. To suggest special vegetation features and areas of management considerations.

Methods

Procedures are divided into: (1) field procedures, (2) laboratory procedures, and (3) analytical procedures.

FIELD PROCEDURES

The field procedures were divided into two aspects: (a) vegetation studies, and (b) history of disturbances within the area.

Vegetation studies. The valley floor and lower sides (generally up to the steep cliffs) were studied first using aerial photographs. Homogeneously appearing areas indicating similar vegetation and soil types and physiognomies were delineated to stratify the field sampling process. Each area was examined in the field and further subdivided if previously unnoticed distinct vegetation boundaries became obvious.

Two general sampling techniques were performed within each homogeneous area: (i) sample points were distributed randomly on a systematic grid throughout each area and used as sample plot centers; and (ii) various forms of information which gave insight into the past history of each area were studied as they were opportunistically found.

Sample points and plots. Plot centers were established throughout the study area. At each point the following were recorded: 1) elevation, 2) slope and aspect, 3) topography, 4) rock sizes and relative soil textures, and 5) canopy cover of the overstory (when present), secondary layer, herbs, and mosses and lichens. A variety of plot sizes and measuring techniques were used because of the variations in plant sizes (from grasses to 61 meter [200-foot] trees) and because of the variety of information collected. Several concentric plots of different sizes were established around each center and each plot size was used to study a different component of the vegetation. The various plots used were as follows:

1. 0.1 m^2 (1.08 ft^2) plots. Three of these were spaced around each sample point. These were used to measure herbs, forbs, mosses, and lichens as well as trees less than 0.30 m (one ft) tall.

2. 9 m^2 (97 ft^2) circular plots. Shrubs and herbaceous vegetation and trees less than 1.5 m (5 ft) tall were analyzed in these plots. Plots of this size were measured at each sample point.

3. 0.0040 ha (0.01 acre) plots. Trees and taller woody shrubs (over 1.5 m [5 ft] tall) were recorded by height class. Plots of this size were taken at each sample point. Where prism plots (Bitterlich method; Kulow 1965, Wilson and Robbins 1969) were also taken, trees less than 13 cm (5.1 in) diameter at 1.5 m (4.5 ft) were recorded in the 0.0040 ha plot, and trees greater than 13 cm were recorded using the Bitterlich method.

4. 0.012 ha (0.029 acre) plots. These were taken to measure overstory trees (over 12.8 cm [5.1 in] diameter) if the overstory was regular and contained over 1,000 trees per hectare (400 per acre). These plots were used where trees were too small for accurate estimates from Bitterlich plots and too large for detailed estimates from 0.0040-ha (0.01-acre) plots.

5. Bitterlich (prism) point-samples. Plots in forests with large overstory trees were studied using the Bitterlich point-sampling method with a 20 B.A.F. prism to measure trees over 13 cm (5.1 in) diameter at breast height.

A variety of information was recorded on each plot:

1. A reconnaissance method modified from the *releve* approach (Mueller-Dombois and Ellenburg 1974) was used to determine percent cover by species. Species area curves showed the 0.0040-ha (0.01-acre) plots were most efficient for this.

2. On each plot of 0.0040 ha (0.01 acre) and smaller, record was made of the number of individuals within each species, the age of the oldest individual of each species (in some cases a field estimate based on bud break scars), the cover of each species, and the disturbance response and mode of reproduction of each species. Also, the maximum amount of primary growth during the current year was recorded for each species. Selected smaller woody vegetation was bored (with an increment borer) or sectioned (if very small) near the base for aging.

3. On the two largest plot types (0.012 ha [0.029 acre] radius and prism point-samples) the trees were recorded by species and diameter. Selected individuals representing each species and spaced throughout the diameter ranges were bored with an increment borer between 0.3 and 1.4 m (1 and 4.5 ft; depending on basal swell, rot, etc.) Heights were measured of the bored individuals.

History of disturbances in the area. Documentation of the disturbances was from a variety of sources and basically followed the historical development method (Stephens 1956, Henry and Swan 1974, Oliver and Stephens 1977).

As each relatively homogeneous area was traversed to reach sample points, evidence which might document past disturbances were studied. The evidence included such things as:

1. Observations of species composition and physiognomic characteristics of an area.

2. Studies of living and dead plant material and their pattern of growth and death.

3. Dating of scars on living trees, of stump sprouts, of the largest (and apparently among the oldest) stem ages, and of patterns of growth and release.

4. Observations of changes in snowfield sizes (comparing field observations with aerial photographs).

5. Observations of patterns of rocks, soil, and dead stems beneath and on top of vegetation.

6. Direct observation of falling rocks.

LABORATORY PROCEDURES

Plant specimens; Selected plant specimens were collected and prepared for herbarium specimens. These are presently at the University of Washington and will be turned over to the United States Park Service.

Stem aging: Collected tree sections and increment cores were mounted for stability and sanded for ease of counting annual rings.

Samples were aged by treating with petroleum jelly and counting rings with a dissecting scope. These samples are presently at the University of Washington and will be turned over to the United States Park Service.

Accuracy of aging varied with species, degree of suppression, and accuracy of coring to the pith. Accuracy was checked by independently counting rings on two discs cut contiguously from the same tree. In general, Alnus sinuata aging was inaccurate because of apparently missing (or extremely small) annual rings. Suppressed Abies amabilis in the understory of very old stands were inaccurately aged because of the very small rings. At the extreme of inaccuracy, estimates of the age of a single Abies amabilis tree 0.70 m (2.3 ft) tall ranged from 47 to 61 years.

Ages of very suppressed trees may have been underestimated because of the potential of such trees not to produce annual rings during certain years (Bormann 1965, Larson 1969). Complete ages could not be obtained from trees with rotten centers or trees of greater radius than the increment bore length (in most cases a 16-in. [40.6-cm] increment bore was used). Extreme detail in aging, such as finding abnormal growth years (Stubblefield and Oliver 1978) or tracing growth patterns down a tree (Oliver 1978), was not done here.

ANALYTICAL PROCEDURES

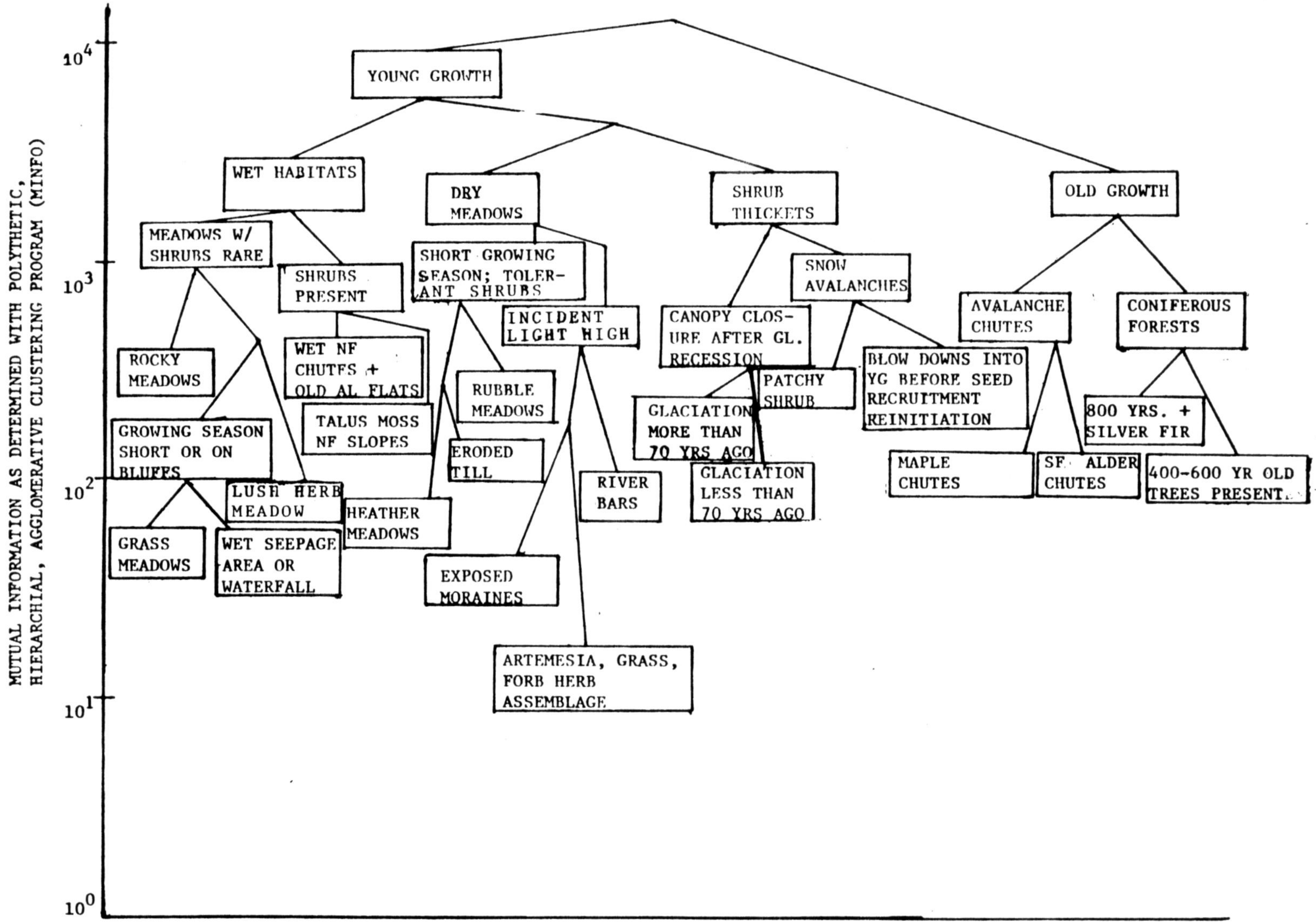
Age and diameter growth patterns: Problems of aging have already been mentioned. Cumulative diameter-age growth curves of trees generally over 60 years were graphed and studied for descriptive evaluation of past stand growth patterns. Because of the difficulties of accurately aging the trees and of extrapolating to the unbored centers of very large trees, age data is used primarily as a minimal estimate of a tree's age and to depict trends of stand development.

Height patterns: Height of each tree in the younger stands (where the trees were shorter) was estimated to the nearest 1.5 m (5-ft) class in the 0.0040-ha (0.01-acre) plots. The larger trees, sampled either in the 0.012-ha (0.029-acre) plots or Bitterlich point-sample plots, were subsampled for height. Regressions were run relating diameter at 1.4 m (4.5 ft) (as the independent variable) to height for each species. Heights were used to determine tree height profiles (similar to vertical foliage profiles) for structural analysis of each stand.

Community types: Relative vegetation similarities between previously grouped plots and parts of the valley were determined from the *releve* data of the 0.0040-ha (0.01-acre) plots. The data were analyzed for similarities of information. A computer model, MINFO, was used. It is an agglomerative clustering program using a mutual information method (Orloci 1969). The program and the formula used are presented by Goldstein and Grigal (1972). Figure 11 shows the results of the program analysis. Clusters of similar plots can be grouped as communities. The size of the cluster defined as a community would depend on the resolution of similarity desired.

Forest structure and overstory species composition: In addition to relative species composition, horizontal and vertical structure and overstory species composition are important in identifying homogeneous

Figure 11: Classification of communities based on agglomerative clustering. (See text for description.)


MUTUAL INFORMATION AS DETERMINED WITH POLYTHETIC, HIERARCHIAL, AGGLOMERATIVE CLUSTERING PROGRAM (MINFO)
10^4
10^3
10^2
10^1
10^0
YOUNG GROWTH
WET HABITATS
DRY MEADOWS
SHRUB THICKETS
OLD GROWTH
MEADOWS W/ SHRUBS RARE
SHRUBS PRESENT
SHORT GROWING SEASON; TOLERANT SHRUBS
INCIDENT LIGHT HIGH
CANOPY CLOSURE AFTER GL. RECESSION
SNOW AVALANCHES
AVALANCHE CHUTES
CONIFEROUS FORESTS
ROCKY MEADOWS
WET NF CHUTES + OLD AL FLATS
RUBBLE MEADOWS
PATCHY SHRUB
BLOW DOWNS INTO YG BEFORE SEED RECRUITMENT REINITIATION
GROWING SEASON SHORT OR ON BLUFFS
TALUS MOSS NF SLOPES
ERODED TILL
GLACIATION MORE THAN 70 YRS AGO
800 YRS. + SILVER FIR
LUSH HERB MEADOW
HEATHER MEADOWS
RIVER BARS
GLACIATION LESS THAN 70 YRS AGO
MAPLE CHUTES
SF. ALDER CHUTES
400-600 YR OLD TREES PRESENT.
GRASS MEADOWS
WET SEEPAGE AREA OR WATERFALL
EXPOSED MORAINES
ARTEMESIA, GRASS, FORB HERB ASSEMBLAGE

forested areas. Attempts were made to incorporate these structural and overstory species characteristics into a MINFO program; however, results to date did not fully delineate the structural similarities and differences. Therefore, graphs were made of tree height profiles (similar to vertical foliage profiles (Aber 1979) for each area. The areas were then assigned to a developmental stage (discussed later) based on visual association of these graphs and field notes for each area.

Scientific names: Authors of all vascular plant names in the text and Tables follow Hitchcock (1974). Mosses follow Lawton (1971); Lichens follow Hale (1967).

RESULTS AND DISCUSSION

Disturbance Types and Frequencies

Understanding the frequencies and types of disturbances incident to each area of the valley is basic to understanding the existing plant communities and their changes with time. A map of the noted major disturbances and their frequencies is shown in Figure 12. A brief description of each disturbance type follows.

Morainal Area

Relatively little disturbance occurred in this area since the glacier last retreated, approximately 180 years B.P. This was detected by the absence of evidence of major disturbances (downed logs, extensive charcoal, etc.) and the growth forms and ages of trees growing on and still invading the areas. Plants in the area are subjected to droughts, possible mineral deficiencies, temperature extremes, and wind desiccation. Isolines showing maximum dates of woody vegetation following the glacial retreat are shown in Figure 7.

Intermittent Snowfields

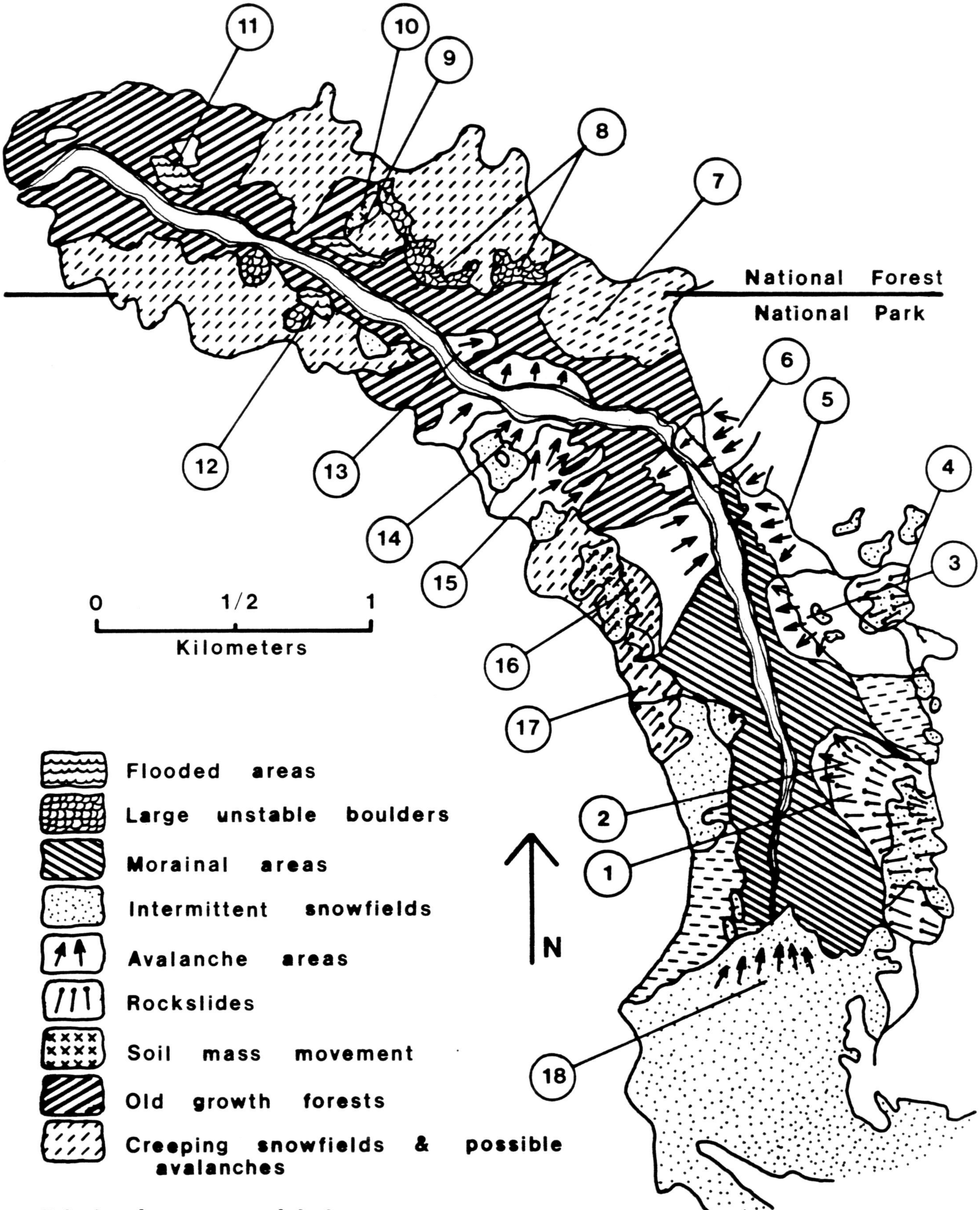
These areas were often under snow for much or all of cool growing seasons following winters of heavy snow, but were more free of snow and supported vegetation during warm summers following winters of little snow. The summer of the study (1977) was warm, contained little precipitation, and was preceded by a winter of relatively little snow. Therefore, there were fewer snowfields than usual. It was possible to infer where such snowfields would be from characteristic vegetation first noticed around rapidly melting snowfields in 1977. An alternate method of mapping intermittent snowfields was used; areas which appeared as snowfields on the aerial photographs of August 8, 1972, were more extensive than those observed in 1977. Figure 12 shows areas which were under snow when these photographs were taken. The snowfields were primarily at the bases of cliffs beneath glaciers and on the north-facing slope of the valley, where there is little direct sunlight much of the year.

Avalanche Areas

These were detected as large areas with standing trees "flagged" and leaning in a single direction, and by large areas with trees lying parallel and pointing away from the same direction. In all cases the avalanche paths could be traced up the mountains. Dates of some avalanches were documented by sectioning and aging scars on standing trees caused by avalanche-thrown trees, and by dating the release of "advance regeneration"

Figure 12: Map of major disturbances influencing vegetation. Mapping key:

1. Rockslides observed July 27, 1977 (chronic).
2. Avalanches (chronic).
3. Avalanches (chronic).
4. Rockslides (chronic).
5. Avalanches (1950±; 1960's;__).
6. Avalanches (1968; 1970,__).
7. Avalanches (1950±; 1960's;__).
8. Unstable rocks.
9. Soil mass movement (1830 - 1880).
10. Soil mass movement (chronic).
11. Flooded area.
12. Beaver pond flooding (current).
13. Avalanches (1875 - 1885).
14. Avalanches (1875 - 1885).
15. Avalanches (1950±; 1960's -).
16. Rockslides observed August 28, 1977 (chronic).
17. Rockslides observed July 29, 1977 (chronic).
18. Avalanches from glacier (chronic).



Disturbance history

seedlings (especially Abies amabilis) which assume rapid diameter and height growth after the overstory is removed. Some avalanches seemed to cover previous avalanche tracts, such as part of no. 7, Figure 12. Others swept through mature timber of over 350 years old. From scars and dates of release of residual standing trees, as well as from field observations, it appears that an avalanche does not necessarily create an entire "blow out" area in one year. Instead, it seems to create and expand an area over several years. Many of the avalanche areas had scars showing avalanches swept through between 1960 and 1967; however, aerial photographs of 1956 revealed the tracts were already present at this time. First avalanches in most of the areas had not occurred very many years prior to 1956, because the overturned trees had not decayed much; they had been large and old, and had grown as if they were not constantly subjected to previous avalanche impact. In certain areas the overturned trees were as much as 55 m (180 ft) tall and 375 years old. In Figure 12, "1950±" indicates a possible date for beginning of the avalanche tracts present in the 1956 photographs. These areas had no evidence of earlier disturbances, but had supported nonavalanched forests. Later avalanches apparently occurred also because of the later scars mentioned above. These disturbances are listed on Figure 12. The avalanches are not chronic, however, because the released understory trees do not appear to be constantly abraided. No immediately obvious reasons are apparent for the large number of recent avalanches within the past 30± years. It is possible that the general cooling trend in the northern hemisphere since the 1940's has created conditions more conducive to avalanches.

Rockslides

These were areas where large boulders (often several feet in diameter) became dislodged from the surrounding cliffs, fell free for several hundred feet, and bounced in the designated areas. One to three rockslides were observed on each of the three days during the summer of 1977 in the areas noted on Figure 12. Two of the observed days of rock slides were rainy days; the third day was clear and sunny. Also, in the designated rock slide areas, rocks (of one to three feet in diameter) were observed resting in or on trees, shrubs, and herbaceous vegetation. Where the shrubs were knocked over, the number of years of growth on the upturned shoots (determined from budbreak scars) showed that the rock slides were chronic and still occurring.

Soil Mass Movement

In some areas soil material had moved down a hill, covering the previously developed soil profile with several inches to several feet of soil material and often killing the pre-existing trees. The areas were determined by the presence of buried soil horizons, fresh material piled on an old soil, and standing dead trees or trees which had died standing. Ages of the soil mass movements were dated by the ages of the oldest trees or shrubs having invaded the area since the mass movement occurred. Some mass movement was occurring in area 10 (Figure 12). A young forest (110 to 140 years old; area 9, Figure 12) may also have been created by mass movement of soil. One area (#11, Figure 18) contained an unusually pure mountain hemlock (Tsuga mertensiana) stand of slightly younger age than the surrounding forest--300-390 years old, compared with 400-500 years for the surrounding forest. The mountain hemlock stand consisted of small, short trees, possibly indicating poor soil conditions. This forest may have originated in an old river channel.

Relatively Undisturbed Areas

These areas had been free of major disturbances for several hundred years. The dominant trees in one area (#13, Figure 18) were approximately 400-500 years old (#21, 26, & 27, Figure 18). In the other area they were up to 800 years old. The origins of the forests are perhaps from a previous glacial advance and retreat; this, however, is only speculative at present. Small disturbances such as individual tree windthrows occurred in this area.

Creeping Snow and Possible Avalanches

On steep slopes, extensive areas of thick *Alnus sinuata* and *Acer circinatum* shrubs were found growing with stems pointed downhill. The matted nature of this vegetation; the scars on the stems; and the bent, flagged appearances of occasional conifer trees indicated that heavy snows bent down and possibly tumbled over these areas chronically.

Other Disturbances

Besides the disturbances mentioned above, minor disturbances were also observed:

1. Fire. Charcoal evidence of a recent fire was found beside the river channel in area 21 of Figure 18. It was unclear if the fire was of natural (lightening) origin or human error. Natural fires do occur in the region. Because of the area's small size, it was not studied intensively.

2. Riverbank erosion. In two places in the morainal area, trees were being undermined by the river bank being cut away by the river.

3. Beaver ponds and other flooded areas. On both sides of the river in the old-growth area, dams as well as cut and gnawed trees witnessed previous beaver colonies. In addition to directly cutting many trees and shrubs, the ponds caused flooding and consequently the death of many trees. Herbaceous communities were often found in the old beaver pond areas. The herbaceous areas were being maintained by intensive browsing by other animals. Other areas also were ponded and contained old, dead trees apparently killed by the raised water table; the causes of the raised water tables were not always investigated.

4. Large, unstable boulders. Several talus slopes contained large boulders 10 to 30 ft (3 to 9 m) in diameter. These often had large trees growing around them and moss growing on them; however, personal experience found the weight of a person could in some instances unbalance them.

5. Mining activity. Records (Beckey 1969) indicate mining occurred on the Nooksack River about 1900; it is probable, however, that this occurred well below the study area.

Plant Species of the Area

Table 3 lists the species found in the area. The species generally were those found within the *Abies amabilis* zone of Franklin and Dyrness (1974); although elements of subalpine and alpine as well as lower vegetation were found.

In all, 194 species of vascular plants were found.

Significance of the various species will be discussed under a later section, "Special Vegetation Features."

In the older forests (400 and more years old), it was very difficult to distinguish western hemlock (*Tsuga heterophylla*) from mountain hemlock (*Tsuga mertensiana*) because the tall trees made foliage inaccessible and fallen cones could not always be traced to specific trees. In certain "old growth" areas (discussed later) the distinction may have been incorrect.

Vegetation Dynamics of the Upper Nooksack Valley

(Scientific papers, documenting the results of this section, are being prepared by C.D. Oliver and A.B. Adams.)

Microclimate, soil (or soil material), disturbance--type, frequency, and magnitude--interact with the species to determine the vegetation of each area of the cirque.

Large disturbances--glaciers, avalanches, rockslides, snowfields (which melt only on occasional years)--which knock back the cover vegetation of a large area allow many herbaceous, shrubby, and woody species to begin growing and competing for the soil and light "growing space" made available by the disturbance's removing previous vegetation. The vegetation on an area following the disturbance then appears to develop through a series of stages as the dominating species and the horizontal and vertical structure (or physiognomy) change. Often the structure is altered or set back by large or small disturbances.

Microclimate and soil material influence which species will dominate and the length of time needed to reach the different stages.

The general pattern of vegetation development will be discussed; after this, the specific plant communities will be identified and their development stages will be related to the general patterns of vegetation development.

General Successional Pattern Following Glacial Retreat

A schematic diagram showing the relation of succession and disturbances to the resultant vegetation is shown in Figure 13. The general stages of development following glacial retreat and, with slight modifications, similar large disturbances are described below:

Periglacial vegetation: Fugitive species and alpine and subalpine herbaceous and shrubby species are found. They are probably responding to the lack of competition from previously established vegetation and possibly to cooler microclimates around the glacier.

Table 3: List of Plant species found in the upper Nooksack Valley.

PLANT SPECIES LIST FOR THE NOOKSACK CIRQUE--NORTH CASCADES NATIONAL PARK

FERNS, FERN ALLIES

<u>Lycopodiaceae</u>
Lycopodium alpinum
L. sitchense
L. complenatum

<u>Selaginellaceae</u>
Selaginella densa

<u>Equisetaceae</u>
Equisetum telmateia var. braunii

<u>Polypodiaceae</u>
Adiantum pedatum
Asplenium trichomanes
Athyrium distentfolium var. americanum
A. Felix-femina
Blechnum spicant
Cryptogramma crispa var. acrostichoidea
Cystopteris fragilis var. fragilis
Gymnocarpium dryopteris
Polypodium hesperium
Polystichum andersonii
P. lochitis
P. munitum var. imbricans
P. munitum
Pteridium aquilinum var. pubescens
Thelypteris phegopteris
Dryopteris austriaca

<u>Taxaceae</u>
Taxus brevifolia

<u>Cupressaceae</u>
Chamaecyparis nootkatensis
Juniperus communis var. montana
Thuja plicata

(Table 3 - Cont'd)

<u>Pinaceae</u>
Abies amabilis
A. lasiocarpa
Pinus contorta var. latifolia
P. monticola
Pseudotsuga menziesii
Tsuga heterophylla
T. mertensiana

<u>Juncaceae</u>
Juncus drummondii var. subtriflorus
J. ensifolius var. ensifolius
J. mertensianus
Luzula campestris
L. parviflora
L. hitchcockii
L. spicata

<u>Cyperaceae</u>
Carex mertensii
C. pachystachya
C. spectabilis
Scirpus pallidus

<u>Poaceae</u> (<u>Granimeae</u>)
Agrostis tenuis
A. thurberiana
A. variabilis
Aira praecox
calamagrostic canadensis var. acuminata
Dactylis glomerata
Danthonia spicata
Deschampsia atropurpurea var. latifolia
D. elongata
Elymus glaucus var. breviaristatus
Glyceria elata
Holcus lanatus
Phleum alpinum
P. pratense
Poa sp.
Festuca uiridule
Trisetum spicatum

<u>Araceae</u>
Lysichitum americanum

<u>Liliaceae</u>
Clintonia uniflora
Lilium columbianum
Maianthemum dilatatum
Smilacina racemosa

(Table 3 - Cont'd)

Liliaceae (Continued)
S. Stellata
Stenanthium occidentale
Streptopus amplexifolius var. americanus
S. roseus var. curvipes
Tofieldia glutinosa var. brevistyla
Trillium ovatum
Veratrum viride

Orchidaceae
Corallorhiza striata
Goodyear oblongifolia
Habenaria dilatata
Listeria cordata
Spiranthes romanzoffiana

Salicaceae
Populus trichocarpa
Salix scouleriana

Betulaceae
Alnus sinuata

Urticaceae
Urtica dioica spp. gracilis var angustifolia

Polygonaceae
Oxyria digyna
Polygonum kelloggii
Rumex acetosella
Polygonum bistortoides

Portulaceae
Montia parvifolia
M. sibirica

Caryophyllaceae
Arenaria macrophylla
Sagina saginoides
Silene parryi

Ranunculaceae
Actaea rubra
Aquilegia formosa
Ranunculus eschscholtzii

Fumariaceae
Dicentra formosa

Brassicaceae (Cruciferae)
Cardamine oligosperma
Capsella bursa-pastoris

(Table 3 - Cont'd)

Crassulaceae
Sedum lanceolatum

Saxifragaceae
Heuchera glabra
H. micrantha var. diversifolia
Mitella breweri
Parnassia fimbriata
Saxifraga arguta
S. ferruginea var. macounii
S. Tolmiei
Tellima grandiflora
Tiarella trifoliata
Tolmiea menziesii

Grossulariaceae
Ribes bracteosum
R. howellii
R. lecustre

Rosaceae
Aruncus sylvester
Geum macrophyllum
Holodiscus discolor
Luetkea pectinata
Oemleria cerasiformis
Rubus leucodermis
R. parviflorus
R. pedatus
R. spectabilis
R. ursinus var. macropetalus
Sibbaldia procumbens
Sorbus sitchensis var. grayi
Spirea betulifolia var. lucida
S. douglasii

Fabaceae (Leguminosae)
Lupinus latifolius var. subalpinus

Celastraceae
Pachistima myrsinites

Aceraceae
Acer circinatum

Rhamnaceae
Rhamnus purshiana

Hypericaceae
Hypericum anagalloides

Violacieae
Viola adunca
V. glabella

(Table 3 - Cont'd)

Onagraceae
Circaea alpina
Epilobium alpinum var. alpinus
E. alpinium var. clavatum
E. angustifolium
E. glaberrimum
E. latifolium
E. luteum

Araliaceae
Oplopanax horridum

Apiaceae (Umbelliferae)
Heracleum lanatum
Lomatium utriculatum
Osmorhiza occidentalis
O. chilensis

Cornaceae
Cornus canadensis
C. stolonifera var. occidentalis

Ericaceae
Cassiope mertensiana
C. stelleriana
Chimaphila menziesii
Cladothamnus pyrolaeflorus
Menziesia ferruginea
Phyllodoce empetriformis
P. glanduliflora
P. xintermedia
Pyrola picta
P. secunda
Pterospora andromedea
Vaccinium deliciosum
V. membranaceum
V. ovalifolium

Primulaceae
Trientalis arctica

Polemoniaceae
Phlox diffusa var. longistylis

Hydrophyllaceae
Phacelia hastata var. leptosepala
Romanzoffia sitchensis

Lamiaceae (Labiatae)
Prunella vulgaris

(Table 3 - Cont'd)

Scrophulariaceae
C. hispida
Mimulus lewisii
M. moschatus
M. tilingii var. caespitosus
Pedicularis ornithorhyncha
Penstemon davidsonii
P. procerus var. tolmiei
Veronica cusickii

Rubiaceae
Galium aparine
G. triflorum

Caprifoliaceae
Linneae borealis var longiflora
Sambucus racemosa var. arborescens
Symphoricarpos albus var. laevigatus

Valerianaceae
Valeriana sitchensis

Campanulaceae
Campanula rotundifolia

Asteraceae (Compositae)
Achillea millefolium spp. lanulosa var alpicola
Adenocanlon bicolor
Anaphalis margaritacea
Antennaria umbrinella
Arnica amplexicaulis
A. cordifolia
A. diversifolia
Artemisia ludoviciana
Aster foliaceus
Cirsium edule
Erigeron peregrinus
Hieracium albiflorum
H. gracile
Lactuca muralis
Luina hypoleuca
Senecio trangularis

COMMON MOSSES OF THE NOOKSACK CIRQUE

Rhytodiopsis robusta
Hylocomium splenden
Rhytidiadelphus squarrosus
Dicranum fuscescens
Isothecium
Polytrichum piliferum
P. juniperum
Rhacomitrium canescens

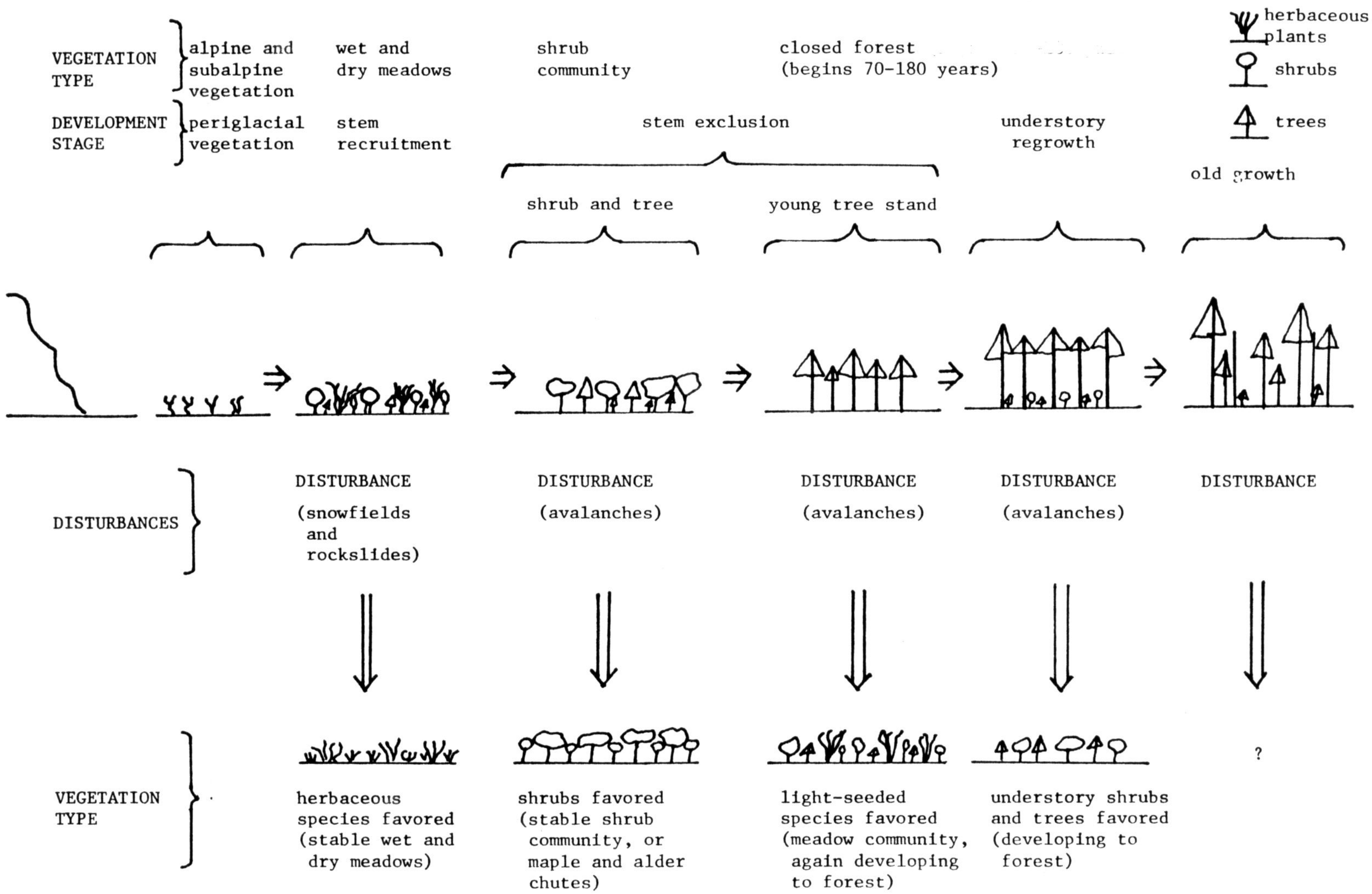
COMMON MOSSES (Cont'd)

R. lanuginosum
Eurhynchium oreganum
Leucolepis menziesii
Grimmia alpestris

COMMON LICHENS OF THE NOOKSACK
(Compiled by Mari Anne See and A.B. Adams)

Cladina rangiferira
Cladina mitis
Cladomia spp.
Stereocanlon alpinium
Alectoria samentosa
Nephroma respiratum
Cladonia chlorophaea
Sphaerophorus glolosus
Cladonia bellidflora
Cladonia coniocraea
Platiomatia herrei
Platiumatia glanco
Hypogymia physodes
Hypogymia enteromorpha
Nephioma respiratum
Lecanora
Rhizocarpinm geographium
Cladonia cristatella

Figure 13: Schematic of vegetation dynamics. (See text for description.)


herbaceous plants
shrubs
trees
VEGETATION TYPE
alpine and subalpine vegetation
wet and dry meadows
shrub community
closed forest (begins 70-180 years)
DEVELOPMENT STAGE
periglacial vegetation
stem recruitment
stem exclusion
understory regrowth
old growth
shrub and tree
young tree stand
DISTURBANCES
DISTURBANCE
(snowfields and rockslides)
DISTURBANCE
(avalanches)
DISTURBANCE
(avalanches)
DISTURBANCE
(avalanches)
DISTURBANCE
VEGETATION TYPE
herbaceous species favored (stable wet and dry meadows)
shrubs favored (stable shrub community, or maple and alder chutes)
light-seeded species favored (meadow community, again developing to forest)
understory shrubs and trees favored (developing to forest)
?

Stem recruitment stage: (meadow community type.) As the glacier retreated further from an area, a large variety of herbaceous, shrubby, and tree species invaded the area. There is a rich mixture of upper and lower elevation species here because of the microclimate and soil variations created by the shadows and depressions in the till and outwash, because of the availability of seeds from the high elevation forests and from lower in the valley, and because a few species have not yet begun to dominate the area and exclude others.

It has been assumed that other species (such as Alnus sinuata) must first invade the post-glacial soil material and develop the soil before coniferous species can grow there. Consequently, there is reported to be a stage where the recently exposed area is covered by a shrubby community before the conifers become established.

This was not found to be true following glacial recession in the upper Nooksack Valley. The conifers invaded very soon after glacial retreat in areas which had not been previously inhabited by other vegetation. Growing close to alders seemed to enhance the nitrogen uptake of conifers (see section on soils) and improve their growth potential, providing they were not severely shaded by the alders.

The area nearer the valley's south wall had less direct sunlight and hence was cooler (see section on Macro and microclimate) and had a shorter growing season. Here, fewer of the lower elevation plants (such as Douglas-fir [Pseudotsuga menziesii] and western hemlock [Tsuga heterophylla]) were found.

Stem exclusion stage: (shrub community type.) As a few species--generally trees and shrubs--begin to dominate the area, they exclude shorter, less competitive ones (most of the herbaceous species). This exclusion of new species can occur between 30 and 90 years after establishment of the first coniferous species. This stage probably lasts at least 150 more years, barring disturbances. On moist sites vegetation closure and exclusion occurs more rapidly than on drier sites.

The component trees, usually present since the stem recruitment stage, overtop the shrubs and form a closed overstory allowing relatively little, if any, understory to grow. The conifer species usually dominating the overstory here are mountain hemlock (Tsuga mertensiana), western hemlock (Tsuga heterophylla), Pacific silver fir (Abies amabilis), and Douglas-fir (Pseudotsuga menziesii).

Understory regrowth stage. Gradually the understory begins to redevelop beneath the forest, probably because the taller overstory trees can no longer dominate the site with an even, dense shade. This stage was noted in a forest with a 400 to 500-year-old overstory. (Where this was noted, the stand initiating disturbance had not been glacial retreat, since the oldest known stand initiating from glacial retreat was only 130 years old. Other unknown large disturbance(s) had created a forest stand with these characteristics.) Understory shrubs, herbs, and tolerant coniferous species begin to develop as advanced regeneration here. Pacific silver fir (Abies amabilis) is the most prevalent advanced regeneration species in the upper Nooksack Valley; it can be less than 1.2 m (four feet) tall and over 60 years old. Upon removal of the overstory such as by an avalanche, the tree can respond and grow as a vigorous tree with the competitive advantage of a preestablished root system and a slightly greater height than a germinating seedling would have.

Old-growth stage. Barring disturbances removing most of the standing trees, some of the overstory trees eventually die (or get blown over individually). This allows the advanced regeneration to respond to local releases from competition and grow; at this time the distinction between the overstory and the understory becomes less clear. The older forests were observed to be in various stages of upward growth of the understory when the oldest overstory trees were about 800 years old. The tolerant understory tree species here, too, was predominantly Pacific silver fir (*Abies amabilis*). Franklin and Dyrness (1974) and Scott et al. (1978) have stated that Pacific silver fir occupies this tolerant (often referred to as "climax") condition in this zone.

Vegetation Response to Secondary Large Disturbances

In many cases a vegetation community will go through the same general stages of forest development after other large disturbances. Other large disturbances to the developing stand cause deviations from the general successional pattern outlined above. These deviations often create relatively stable communities. Disturbances at different stages of the successional pattern described above favor different species. Also, each type of disturbance favors those plants able to respond to the disturbance.

Disturbances such as rock slides and avalanches, which occur (in the stem recruitment stage) before the overstory shrubs and tree species exclude the herbs, favor regrowth of the herbs from underground bulbs and rhizomes.

Disturbances such as rock slides or avalanches, which occur during the shrub stage (stem exclusion stage), often kill the trees or knock them beneath the shrubs (where they are shaded and die). The shrubs such as blueberry (*Vaccinium* species), Sitka alder (*Alnus sinuata*), and vine maple (*Acer circinata*) can sprout from a broken stem base and are resilient to being pushed over. These can endure the disturbance and dominate the area afterward. *Chamaecyparis nootkatensis* was able to withstand these disturbances more than most conifers; therefore, it was found on such areas occasionally.

Disturbances which remove the young closed stand favor light-seeded species which reinvade the site and grow similarly to the stem recruitment stage, except regrowth is on a better developed soil.

Disturbances such as avalanches which remove the overstory after understory regrowth favor the advanced regeneration and create Pacific silver fir forests, which then proceed through the different stages of development. Disturbances such as soil mass movement, which kill the understory as well as the overstory, favor light-seeded species and development patterns beginning with the stem recruitment stage.

Vegetation response to disturbances to the old-growth forests can vary, depending on the extent and type of disturbance.

Vegetation response to small disturbances

Small disturbances--those which knock over or kill individual trees or small groups of trees but allow other vegetation of similar size in the same area to continue growing--also occurred in the valley forests. Response to such disturbances was in two ways: 1) new vegetation became established where the disturbance made available light and soil moisture and nutrients; and/or 2) the surrounding stems which had not been killed by the disturbance expanded in response to the newly made available light and soil moisture and nutrients. One or both responses occurred, depending on how large the disturbance was and how readily the undisturbed trees could reoccupy the newly made available light and soil resources. Such small disturbances could create conditions which favor forests with the "understory reinitiation" and "old growth" physiognomies at a relatively young age by their allowing new stems to invade and grow where the older ones had been destroyed.

Influences of soils and microclimate on vegetation development

Soils and microclimate can affect the species composition and vegetation physiognomy both directly and indirectly.

Directly, the effect can be in several ways. The soils and microclimate can determine which species are able initially to become established; in very dry, very wet, very hot, or very cold microsites, certain species may be unable to germinate; hence, they are excluded from the resulting forest. The microsites can determine which species have the competitive advantage after initial establishment. Certain "site sensitive" species are able to outcompete others on non-extreme sites, while "site insensitive" species can outgrow others on sites with extremes of temperature or soil conditions. The soil, nutrient, and microclimate regimes determine the rates of growth of the plant species, and the growth rates determine how quickly the communities develop through the different phases. For example, on mesic (adequate moisture) sites growth rates are faster and the development to a phase of "stem exclusion" occurs more rapidly than on very dry (xeric) sites.

Indirectly, the soils and microsites may predispose certain areas to specific types of disturbances. For example, very wet (hydric) soils may not allow deep penetration of tree roots and therefore the trees are more vulnerable to windthrow. Soils with boulders may also not allow adequate anchorage of tree roots and therefore allow windthrow. Fine, sandy soils on slopes may be more susceptible to erosion and colluvial deposition than gravelly soils.

Specific areas which show the vegetation phases and their responses to disturbances, soils, and microclimates will be discussed in the following section.

Plant Communities and Forest Types of the Upper Nooksack Valley

As mentioned earlier, the upper Nooksack Valley is within the *Abies amabilis* zone defined by Franklin and Dyrness (1973). This is evident since the most recently invading stems in the "old growth" forests are predominantly *Abies amabilis*. Very often, external influences (disturbances, soils, and microsites) keep part of the area from achieving the pure *Abies amabilis* condition, as has been discussed in the previous section. Relatively stable communities can exist. Based on proportional representation (percent cover) by species, the areas can be subdivided into six habitats based on the agglomerative clustering method described under "analytical procedures." These habitats are shown in Figure 14 and are described as follows:

Wet Meadows: These areas include sites where moisture is available for most of the year, either from a stream (riparian), seepage from bluffs, or else from high humidity created by abundant waterfalls or shade. Near the glacier, wet rocky meadows approach low herbacous subalpine community types, whereas in meadows under north-facing bluffs, lush herbaceous meadows are found in areas of late snowmelt. Included here are north-facing talus slopes of granodiorite which have large masses of lichens intermixed with vascular species.

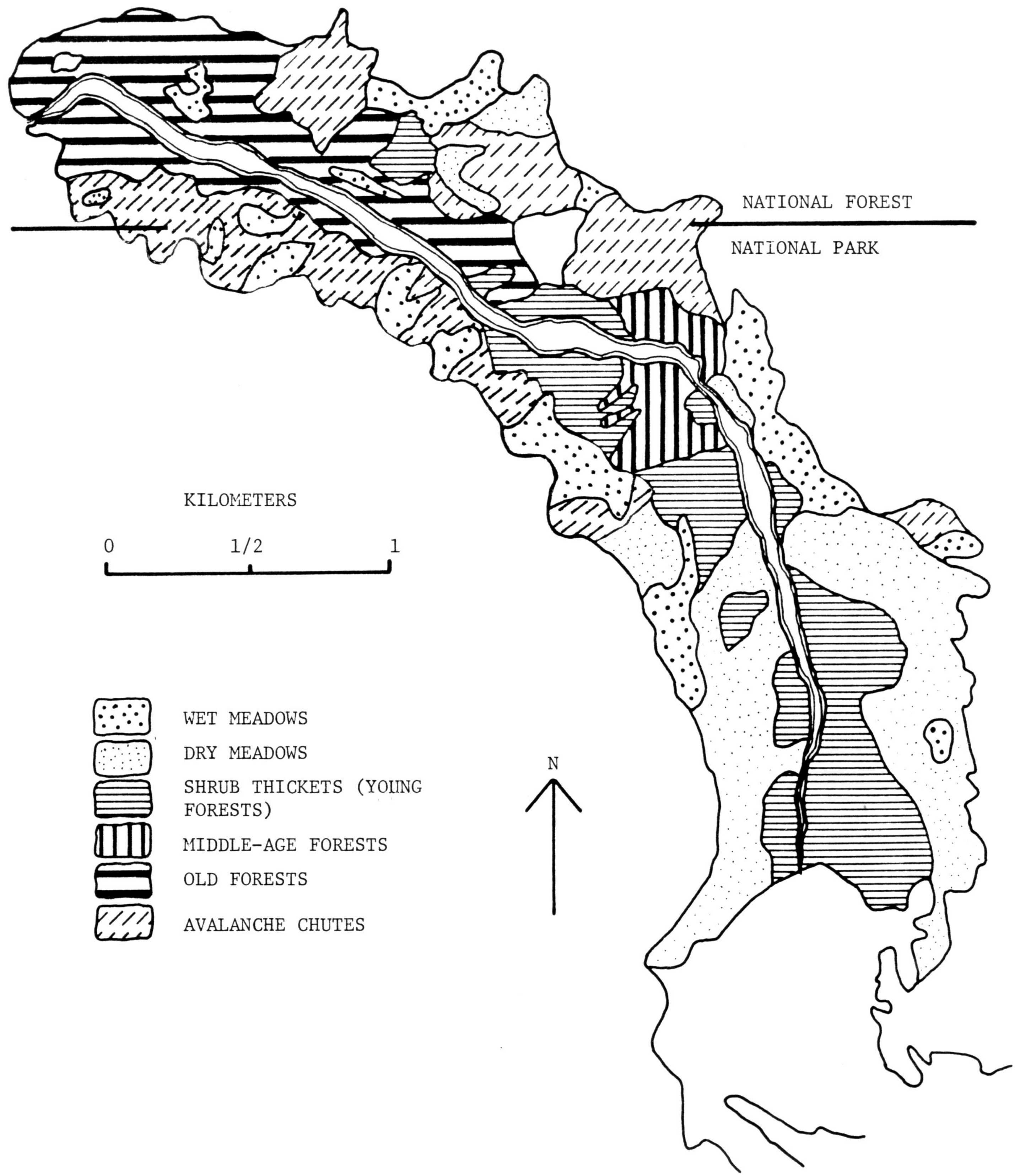
Dry Meadows: Here are included sites with sun exposure for much of the summer, heavy erosion, and/or a longer growing season. Productivity is limited by water availability and/or disturbance, so that conifers and shrubs cannot gain dominance. These communities are characterized by mosses, lichens, and slow-growing suffrutescent perennials. The number of vascular plant species found in these areas is higher than in other habitats. Found within this habitat type are communities of lateral and terminal moraines, glacial rubble, eroded till, and river bars.

Avalanche Chutes: These are dense thickets of Sitka alder and vine maple located on slopes greater than 8 degrees. Three communities are recognized: 1) North-facing alder chutes with species similar to those of the wet meadow habitat, with the exception of dominance by Alnus sinuata; 2) South-facing alder chutes with species composition of the herbaceous understory expressing similarity to that of old growth forests; 3) South-facing vine maple (*Acer circiunata*) chutes located on the convex ridges of these slopes. These vine maple chutes also have an understory layer similar to old growth forests in some respects.

Shrub Thickets: Within this habitat are found young growth coniferous forests and blow downs into areas glaciated within the last 200 years. Near the glacier these thickets are open portraying a topography of undulating morainal mounds with conifers and alders thicker in wetter depressions and conifers absent from poorly drained depressions. Further from the glacier, these areas become closed alder and conifer thickets with stem exclusion stages (see text) occurring in some sites. At the bottom of the runout zones of avalanche chutes a well-defined ecotone is found between the relatively undisturbed coniferous forest and the chutes or meadows. This patchy shrub community type is unique because it has many species of vascular plants (including up to 12 species of shrubs) and often dead conifers and alders are present.

Middle Age Forests: Here are found mountain hemlock, western hemlock, and silver fir stands where understory growth of conifers and shrubs has been initiated, yet the understory herbaceous layer has yet to develop well. Trees with DBH values greater than 50 inches are not present. Tree ages may reach 300 to 500 years.

Figure 14: Map of basic plant habitats. (See text for description.)


NATIONAL FOREST
NATIONAL PARK
KILOMETERS
0
1/2
1
WET MEADOWS
DRY MEADOWS
SHRUB THICKETS (YOUNG FORESTS)
MIDDLE-AGE FORESTS
OLD FORESTS
AVALANCHE CHUTES
N

Old Growth Forests: In this habitat understory growth is well established and light gaps are conspicuous within these forests. Pacific silver firs are always present and exhibit a spectrum of size and age classes. The shrub and herbaceous understory is well-established. Structural diversity of communities is at a maximum in these forests. Marshes are common within these forests because of beaver ponds and other causes of flooding.

More detailed plant communities (based on the MINFO analysis) are shown in Figure 15 and described in Table 4. A key to the plant communities is shown in the Appendix. The forested area can also be subdivided based on the present species composition and on the horizontal and vertical structure (physiognomy).

Subdivisions of the Forest Communities

The coniferous forest community subdivision is further refined. A forest contains more vertical development than herbaceous and shrub areas; therefore, this physiognomy can be considered in defining forest communities.

The forested areas are subdivided according to physiognomic stage (Figure 16) and predominant species composition of the overstory (Figure 17). The physiognomic stages shown are those described in the section "General Pattern of Vegetation Change" and shown in Figure 13.

As shown in Figure 17 and Table 5, there were three species which comprised more than 80 percent of the forest trees: mountain hemlock, Pacific silver fir, and western hemlock. The forested areas were delineated by physiognomic pattern and species composition of the overstory. The overstory was defined as all trees over 6.6 meters (20 feet) tall in stands of trees in the "understory reinitiation" and "old growth" phases, and all trees in the "stem recruitment" and "stem exclusion" phases. Each area was described as being predominated by one, two, or all three species. All species which accounted for 20 percent or more of the stems was included in defining an area.

Forest types

Figure 18 and Table 5 shows the individual forest types and their characteristics within the valley when areas are grouped by uniform time since disturbance, initiating disturbance type, soil microclimate, physiognomic stage, and overstory species composition. A description of each type is as follows:

Areas 1 through 5 all comprise the area being invaded by tree and shrub species following the glacial retreat. Generally, leaf canopies have not yet closed enough to exclude new stems from germinating; consequently, the area is described as being in the "stem recruitment" stage (Figures 13 and 16). Avalanches and rock slides from the east wall are knocking back tree species to the east side of this area and encouraging brushy species. Area 1 is generally more moist than areas 2 through 4; consequently, the stems grew larger (compared to others of the same age) and the species composition may reflect less dry soil conditions.

Figure 15: Map of detailed plant community types.

LEGEND FOR THE VEGETATION MAP OF COMMUNITY TYPES
AS DEFINED WITH CLUSTERING ANALYSIS AND COEFFICIENTS
OF VARIATION OF DIVERSITY INDICES

ROCKY MEADOWS

LUSH HERBACEOUS MEADOWS

DAMP MEADOWS AND BLUFFS (this includes grass meadows, seepage from bluffs, and waterfall communities)

WET (NF) AVALANCHE CHUTES AND ALDER FLATS

TALUS MOSS SLOPES

ERODED TILL

HEATHER MEADOWS

RUBBLE MEADOWS

EXPOSED LATERAL AND TERMINAL MORAINES

ARTEMESIA, GRASS, FORB, SHRUB MEADOW

RIVER BAR

SHRUB THICKETS FORMED AFTER GLACIAL RECESSION (70 yrs. and younger)

SHRUB THICKETS FORMED AFTER GLACIAL RECESSION (older than 70 yrs. with complete canopy closure)

BLOW DOWNS INTO YOUNG GROWTH FORESTS BEFORE REINITIATION OF SEED RECRUITMENT INTO THE UNDERSTORY

PATCHY SHRUB

MAPLE AVALANCHE CHUTES

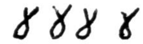
ALDER AVALANCHE CHUTES (SF for the most part)

OLD GROWTH CONIFEROUS FORESTS (800 yrs. + including blow downs that occurred after reinitiation of seed recruitment)

MIDDLE AGE FORESTS

The following communities were not used in the cluster analysis but were subsequently sampled and found to be distinct. Only the first represents a significant component of the total cover.

BEAVER PONDS 

GLYCERIA ELATA MEADOWS 

CALAMAGROSTIS CANADENSE MEADOWS 

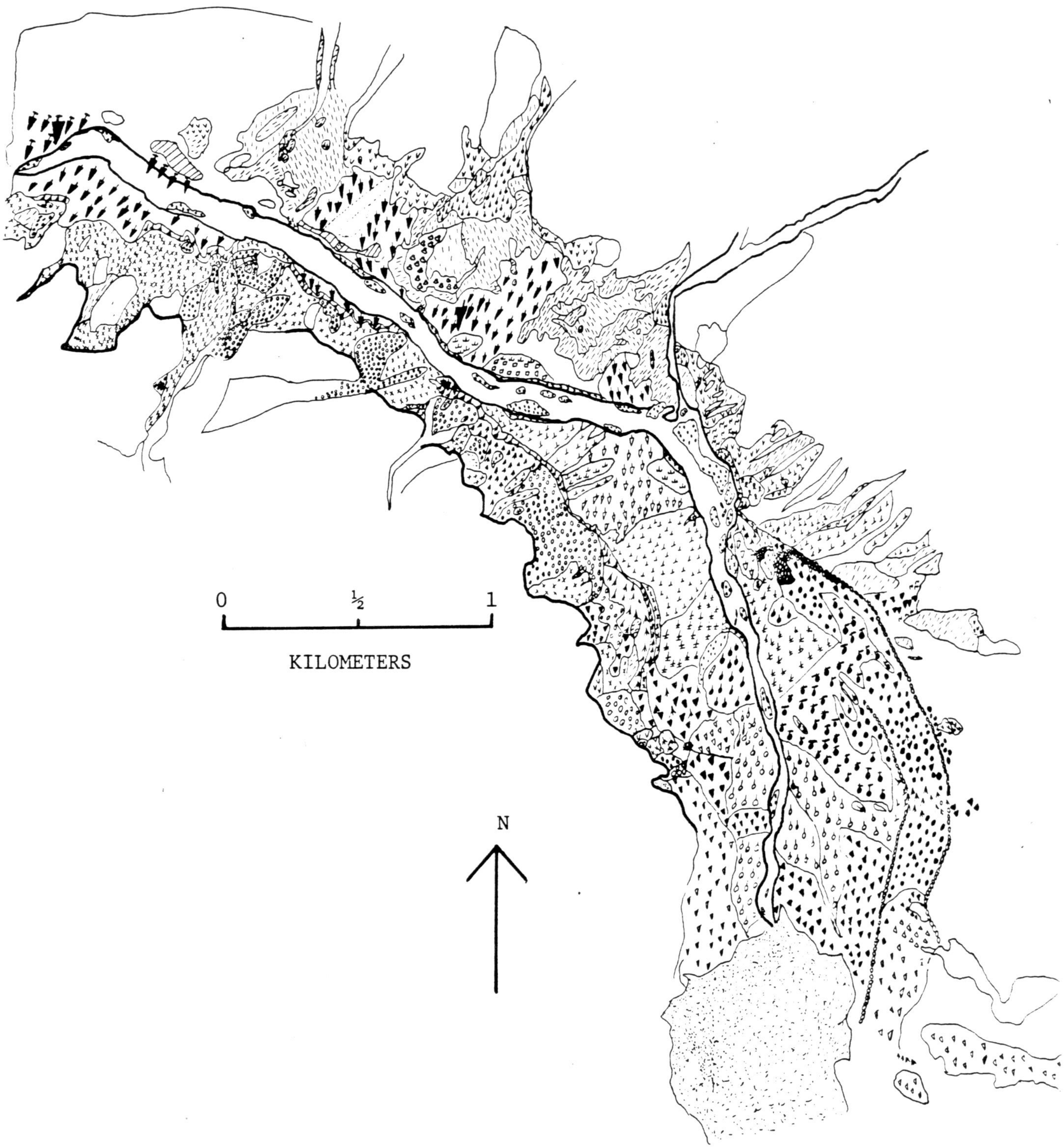

0
½
1
KILOMETERS
N

Table 4. Detailed plant communities of the Nooksack Cirque shown in Figure 15.

SUMMARY TABLE OF COMMUNITIES AS DEFINED BY MINFO CLUSTERING COMPUTER ANALYSIS

DENDROGRAM ASSOCIATION		COMMUNITY TITLE	# OF SAMPLES	EST. OF COVER OF COMM. W/IN STUDY AREA	AV. # OF SP. IN SAMPLES
A		ROCKY MEADOWS Ca sp, De at, Mi le, At di	11	1%	14.88
	A1	Riparian Mi le			
	A2	Rocky, eroded At di, Ox di			
	A3	North facing Ca sp			
B		LUSH HERBACEOUS MEADOWS Ve vi, El gl, Va si, Ca sp	7	1%	8.57
C		DAMP MEADOWS AND BLUFFS Ca sp, Sa fe, Ar sy	9	3%	16.55
	C1	High grass diversity; at least 3 spp. present			
	C2	Wet seepages; Ar sy			
D		WET AVALANCHE CHUTES AND ALDER FLATS Al si, El gl, Ru sp, Ru pa, Ri le, Ga tr, Ar ma, Ep an	7	10%	18.00
E		TALUS MOSS SLOPES Rh ca, Cr cr, Cl ra, Ca ca	7	6%	12.43

(Table 4 - Cont'd)

DENDROGRAM ASSOCIATION	COMMUNITY TITLE	# OF SAMPLES	EST. OF COVER OF COMM. W/IN STUDY AREA	AV. # OF SP. IN SAMPLES
F-1	ERODED TILL Ph em^{6}, Ca pa^{6}, Lu pe^{6}, Ca sp^{5}, An ma^{5}, De at^{6}, Lu hi^{5}, Rh ca^{6}	7	9%	12.43
F-2	HEATHER MEADOWS Lu pe, Ph em, Lu hi, Lu la, Carex sp., At di, Cr cr, Cl py, De at, Sp be, Al si, Higr., He gl	6	2%	20.83
G	RUBBLE MEADOWS Pe da, Cr cr, Ca sp, Rh ca, Ca ro, El gl, Cal can	8	6%	21.63
H-1	MORAINES Rh ge, Cr cr, Rh ca, Se wa, Bl mo	5	0.5%	12.00
H-2	ARTEMESIA GRASS FORB, SHRUB MEADOW At lu, Rh ca, Ph ha, Ac ci, Ru pa, Ep an, Cr cr, An ma, Ac mi, El gl	2	3%	20.50
I	RIVER BAR Ep la, Rh ca, Cr cr, Al si, Lu la, An marg Ab am, Psme, Sa fe, Tsme, Ts he, Clpy	8	3%	14.50
J-1	OPEN ALDER AND SMALL CONIFERS WITH UNDULATING MORAINAL MOUNDS Al si, Salix,	15	5%	7.87

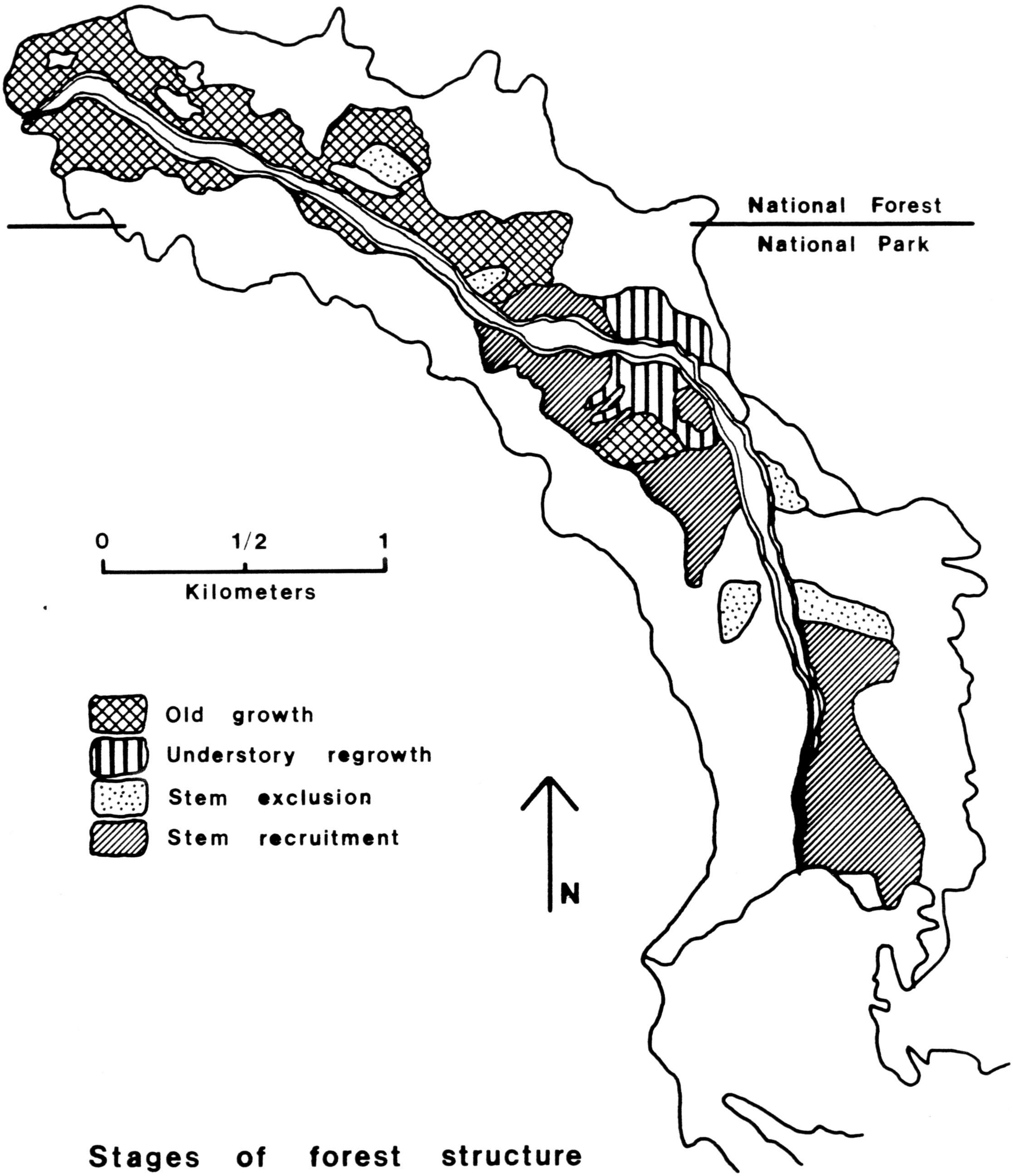
(Table 4 - Cont'd)

DENDROGRAM ASSOCIATION		COMMUNITY TITLE	# OF SAMPLES	EST. OF COVER OF COMM. W/IN STUDY AREA	AV. # OF SP. IN SAMPLES
		Cl py, Ts he, Ts me, Ab am, Ph em, Lu pe Mosses not identified			
J-2		CLOSED ALDER, SALIX, CONIFER, SHRUB THICKET Al si, Ts me, Ts he, Cl py, Salix, Moss	9	5%	8.11
K		YOUNG GROWTH CONIFEROUS FOREST AND BLOW DOWNS INTO FOREST LESS THAN 350 YEARS OLD Va ov, Al si, Ch no, Ab am, Ab la, Ts me	14	9%	10.36
	K1		8		7.7
	K2		6		13.0
L		PATCHY SHRUB Cl py, Me fe, Sa ra, Sp be, Sp do, Ru sp, Ru pa, Ch no, Al si, Lu pe, De at, Cr cr, Rh ca, Rh ge, El gl, Sc si, Ts me, Go lo, Moss	8	3%	22.38
M		MAPLE AVALANCHE CHUTES Ac ci, Ga tr, Sm st, Sm ra, Co st, Ri le	10	6%	7.00
	M1	Large conifers present--Ab la	2	1%	
	M2	No large conifers	8	5%	

(Table 4 - Cont'd)

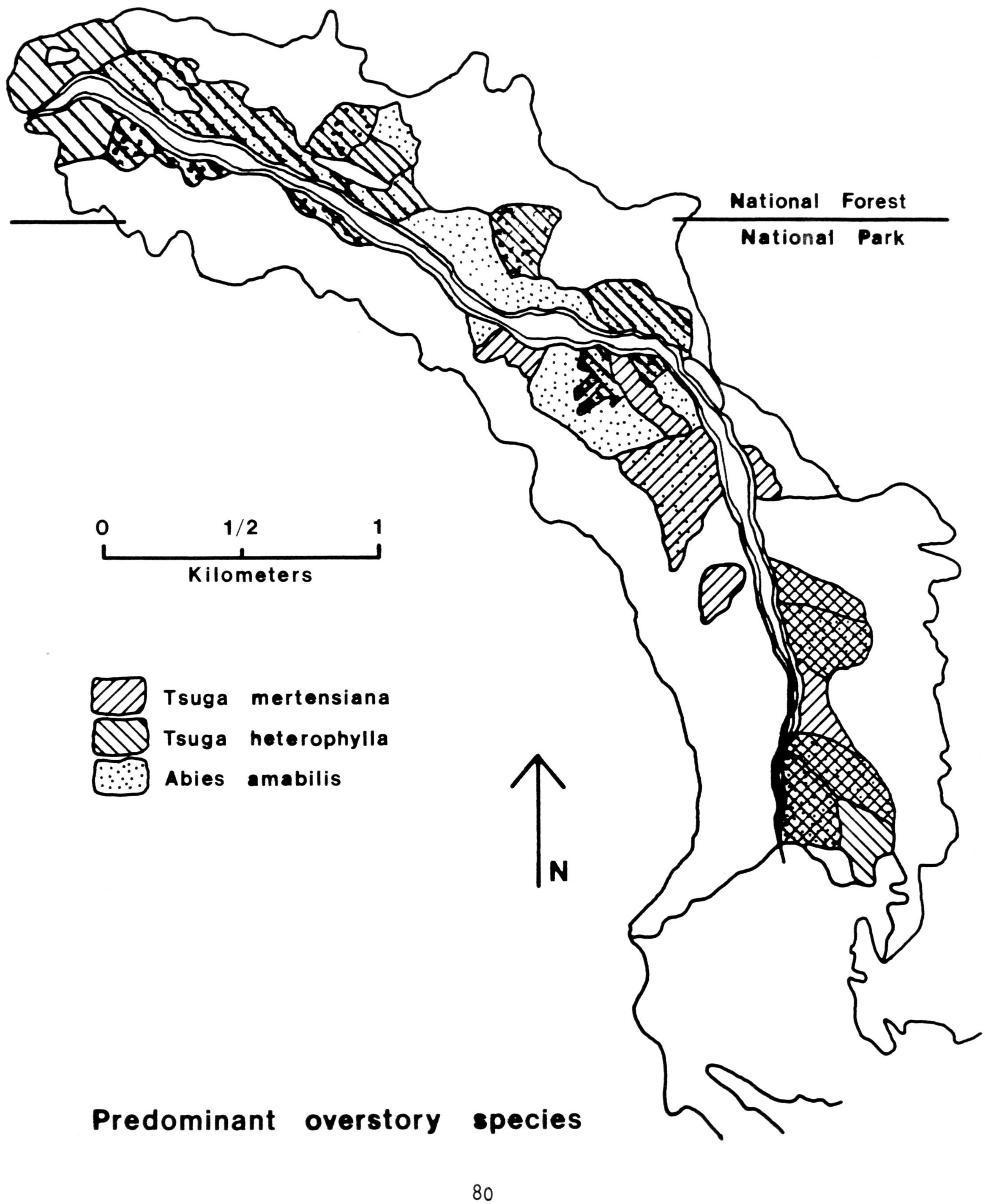
DENDROGRAM ASSOCIATION	COMMUNITY TITLE	# OF SAMPLES	EST. OF COVER OF COMM. W/IN STUDY AREA	AV. # OF SP. IN SAMPLES
N	ALDER AVALANCHE CHUTES Al si, Mo si, Di fo, At fe, Sm st, Sm ra, St ro, Ru sp, Pt ag, Ac ci	9	6%	8.00
O	OLD GROWTH CONI- FEROUS FOREST Ab am, Ts he, Ts me, Ru pe, Ti tr, Va ov, Rh ro, Sm st, Sm ra, Rn sp, At fe, Gy dr	15	9%	8.53
P	TSUGA MERTENSI- ANA FOREST AND BLOWDOWNS INTO YOUNG AND OLD GROWTH FOREST AND RIVER TERRA- CE FOREST	14	12.5%	6.21
P1	Blow downs into Ts me forest and young Ab am		.5%	
P2	Ab am blow downs		1%	
P3	Ts me forest		4%	
P4	Th pl, Ps me old growth forest		7%	
OTHER APPARENT COMMUNITY TYPES WHICH WERE NOT ANALYZED SO FAR INCLUDE THE FOLLOWING				
	BEAVER PONDS		1%	
	GLYCERIA ELATA MEADOWS		0.02%	
	CALAMAGROSTIS CANADENSE MEADOWS		0,02%	
	WATERFALL COMMUNITIES			

Figure 16: Map of stand structure (physiognomic) stages of forested areas. (See text for description.)



Stages of forest structure

Figure 17: Map of predominant overstory species of forested areas. (See text for description.)



Predominant overstory species

Table 5: Characteristics of stands when delineated by areas of uniform stand origin, soil material, age, developmental stage, and species composition. (Figure 19 shows locations of areas.) Footnotes: 1 = often determined as age of oldest tree or release of advance regeneration; 2 = excluding small advance regeneration; advance regeneration dated from time of release:

Stand number	Area (ha)	Time[1] of last major disturbance (yrs. B.P.)	Age[2] range of overstory trees (yrs.)	Number of overstory stems	Overstory Species Distribution (%)				Max. tree ht. (m)	Initiation disturbance type	Stand development stage
					Tsuga mert.	Abies amab.	Tsuga hetero.	Other			
1	5.1	37 yrs.	0 to 37	1,433	37	19	42	2	23	glacial retreat	stem recruitment
2	3.6	35 yrs.	0 to 35	699	19	19	62	0	9	glacial retreat	stem recruitment
3	5.2	54 yrs.	0 to 54	800	40	20	40	0	15	glacial retreat	stem recruitment
4	2.4	55 yrs.	0 to 55	1,100	91	9	0	0	33	glacial retreat	stem recruitment
5	5.4	63 yrs.	0 to 63	1,665	24	24	50	2	38	glacial retreat	stem recruitment
6	3.2	60 yrs.	41 to 60	1,000	50	0	40	10	55	glacial retreat	stem exclusion
7	1.2	130 yrs.	90 to 130	1,050	90	10	0	0	80	glacial retreat	stem exclusion
8	2.2	105 yrs.	61 to 105	2,000	88	10	2	0	82	glacial retreat	stem exclusion
9	9.4	20 - 35	14 to 35	3,200	39	58	2	1	60	avalanche	stem recruitment
10	3.6	530 yrs.	110 to 530	781	4	95	1	0	155	unknown	old growth

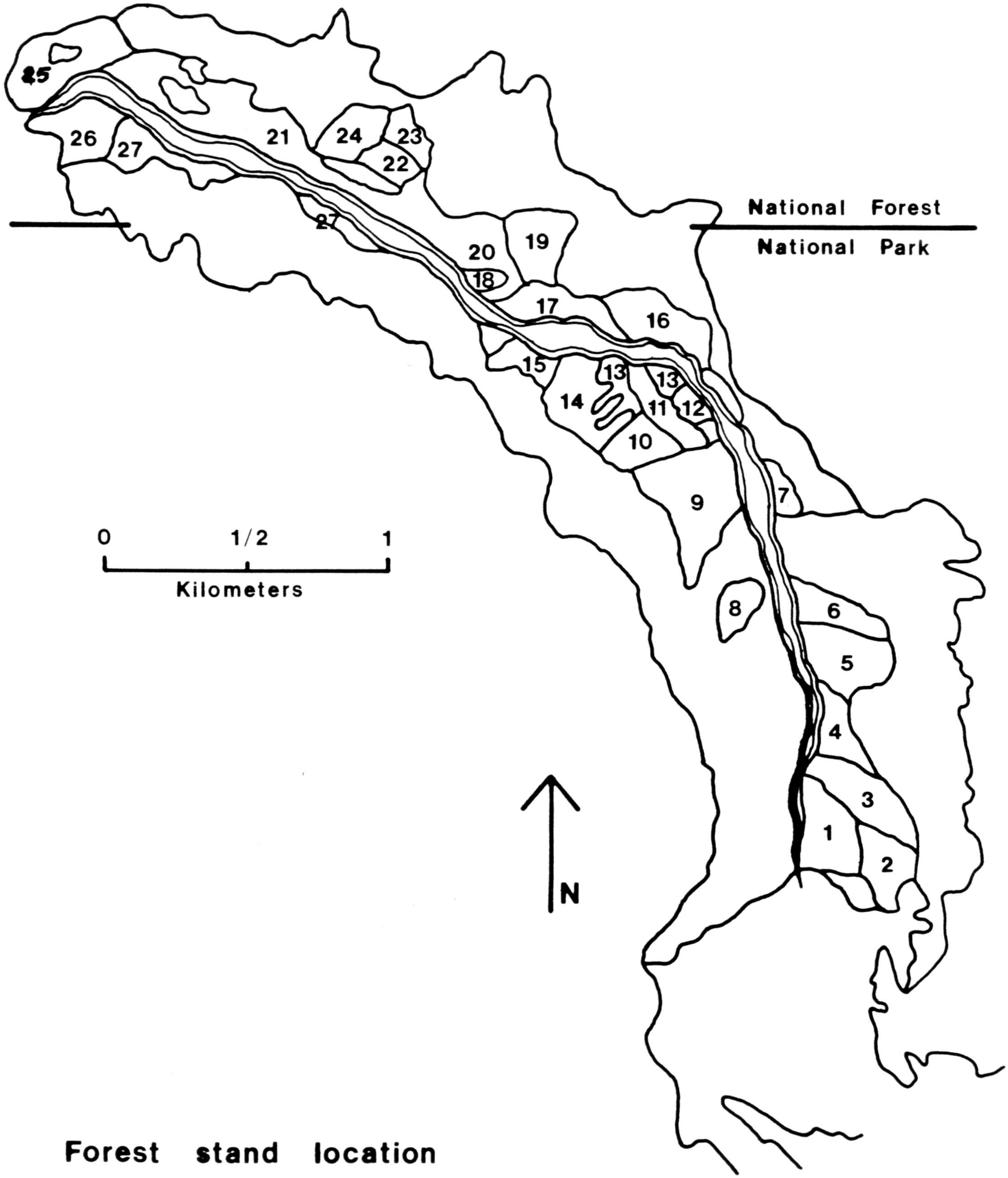
Table 5 (Cont'd)

Stand number	Area (ha)	Time[1] of last major disturbance (yrs. B.P.)	Age[2] range of overstory trees (yrs.)	Number of overstory stems	Overstory Species Distribution (%) Tsuga mert.	Abies amab.	Tsuga hetero.	Other	Max. tree ht. (m)	Initiation disturbance type	Stand development stage
11	2.8	390 yrs.	265 to 390	412	83	17	0	0	83	(abandoned channel?)	understory regrowth
12	1.1	7 yrs.	0 to 7	7,650	0	88	12	0	12	avalanche	stem re-cruitment
13	2.8	480 yrs.	295 to 480	79	5	71	24	0	198	unknown	understory regrowth
14	5.4	0 to 45	0 to 45	4,100	10	85	5	0	18	avalanche	stem re-cruitment
15	1.8	0 to 45	0 to 45	2,100	75	20	3	2	15	avalanche	stem re-cruitment
16	5.4	400 yrs.	250 to 400	102	2	57	41	0	234	unknown	understory regrowth
17	3.7	20 to 45	0 to 45	3,450	5	76	19	0	63	avalanche	stem re-cruitment
18	0.8	90 to 100	90 to 100	630	0	92	8	0	132	avalanche	stem ex-clusion
19	4.5	250 yrs.	90 to 250	287	0	40	60	0	210	unknown	old growth
20	5.3	over 750	210 to 750	238	1	95	4	0	202	unknown	old growth
21	14.4	over 800	152 to 800	219	3	67	29	1	174	unknown	old growth
22	1.8	165 yrs.	110 to 165	266	0	6	86	8	156	colluvial deposits	stem ex-clusion
23	1.8	151 yrs.	144 to 151	97	0	88	12	0	222	colluvial deposits	understory regrowth

Table 5 (Cont'd)

Stand number	Area (ha)	Time[1] of last major disturbance (yrs. B.P.)	Age[2] range of overstory trees (yrs.)	Number of overstory stems	Overstory Species Distribution (%)				Max. tree ht. (m)	Initiation disturbance type	Stand development stage
					Tsuga mert.	Abies amab.	Tsuga hetero.	Other			
24	3.2	660 yrs.	210 to 660	159	0	79	21	0	200	unknown	old growth
25	7.5	750	113 to 750	310	0	3	97	0	189	unknown	old growth
26	6.3	380	78 to 380	346	0	15	85	0	172	unknown	old growth
27	5.0	750	210 to 750	238	1	75	24	0	204	unknown	old growth

Figure 18: Map of individual stands when delineated by areas of uniform stand origin, soil conditions, age, developmental stage, and species composition. Table 5 gives characteristics of each stand. (See text for description.)



Forest stand location

Area 6 is similar to areas 1 through 5 except the glacial retreat was long enough ago so that trees are apparently outgrowing and beginning to kill the brush. A closed tree canopy is forming ("stem exclusion" stage). Just north of area 6, avalanches from the east wall knocked down much of the forest when in the "stem exclusion" stage. Consequently, (see Figure 13) the responding vegetation are: herbaceous species which invaded after the avalanche; shrubs which had not yet been excluded from the previous forest; and the residual trees.

Areas 7 and 8 are also in the "stem exclusion" stage, although places within these may be in different stages where either disturbances such as falling rocks or avalanches occurred or soil conditions made growth so slow that the tree canopy had not yet dominated the area. Areas 7 and 8 are probably the result of periglacial activity similar to that which created area 6.

Areas 10 through 16 and part of 17 seem to have been originally a relatively uniform area on which a forest began approximately 550 years ago. Residual forests which have not been disturbed significantly since then can be found in areas 13 and 16 and are in the "understory regrowth" stage, with primarily Pacific silver fir advanced regeneration and brushy species in the understory beneath a mixed Pacific silver fir and Western hemlock overstory.

Area 11 is also in the "understory reinitiation" phase, although here the overstory is almost entirely mountain hemlock and the understory is advance regeneration Pacific silver fir and brushy species. The location of this stand, its age, and the ditch on either side of it indicate it may have been an abandoned water channel.

Area 10 does not appear very much older than area 13; however, it has an "old growth" phase appearance, probably because the rock falls and colluvium from the southwest have killed many of the original trees in the stand.

Area 14 is apparently created by snow avalanches from the southwest. These avalanches are knocking over the original Pacific silver fir and hemlock overstory and releasing the Pacific silver fir advance regeneration, creating a young stand of Pacific silver fir. The avalanches began about 30 to 40 years ago. Overstory trees on the interface between stands 14 and 13 are still being knocked over each year (as of 1977), expanding the size of stand 14 and decreasing stand 13.

Area 12 was created by an avalanche from across the river to the northwest. This avalanche occurred about 9 years ago and knocked over most of the overstory Pacific silver fir and mountain hemlock originally continuous with stand 13. Advanced regeneration Pacific silver fir was released and is growing with brush in the "stand initiation" phase.

Area 15 was subjected to the same avalanche that removed the overstory in area 14 30 to 40 years ago; however, there appears to have been a previous disturbance (possibly an avalanche) from the same direction about 100 years previously. There is less advance regeneration showing response in the area, and it is quite brushy.

Area 17 was in the "stand initiation" stage after avalanches from the cliffs to the southwest (across the river and probably the same disturbances which knocked over the overstories of stands 14 and 15) knocked over the overstory and released Pacific silver fir advance regeneration and brush species. The eastern half of area 17 originally was similar to area 16 before the overstory was blown over. Overstory trees on the western edge of area 16 are still being overthrown, probably by winds. The western half of area 17 was probably similar to area 20 before the overstory fell down.

Areas 19, 20, 21, 24, 25, 26, and 27 all appear in the "old growth" phase. Here there are "small" disturbances which knock over or kill individual trees, causing local invasions and release of other stems. Local species variation may reflect slight differences in site and disturbance type. Areas 20, 21, 25, 26, and 27 are generally on the flat areas surrounding the river. Areas 19 and 24 are on steeper slopes.

Area 18 was apparently created by an avalanche or a series of avalanches from the cliff across the river to the west about 100 years ago. The overstory (previously similar to area 20) was knocked over, releasing advance regeneration *Abies amabilis*. The stand is now predominantly in the "stem exclusion" phase, with relatively little understory (Figures 13 and 16).

Areas 22 and 23 are on a slope and contain forests which began 150 to 165 years ago, apparently after colluvial deposits had killed the previous vegetation. Area 22 is in the "stem exclusion" phase, with a dense overstory and relatively little understory. Area 22 has a more developed understory of advance regeneration and brush ("understory reinitiation" phase), probably because disturbances from the slope above (to the north) have knocked over some of the overstory trees.

Trends in Forest Development

Distribution of forested areas by time since major disturbances and by physiognomic stage are shown in Figure 19. Distribution by physiognomic phase and dominant overstory species are shown in Figure 20. Much of the valley consists of very old, "old growth" forests and young "stem recruitment" forests. The "understory regrowth" forests are being knocked down by avalanches. Most of the "old growth" forests occur on the National Forest land; most of the other phases are within the National Park ownership.

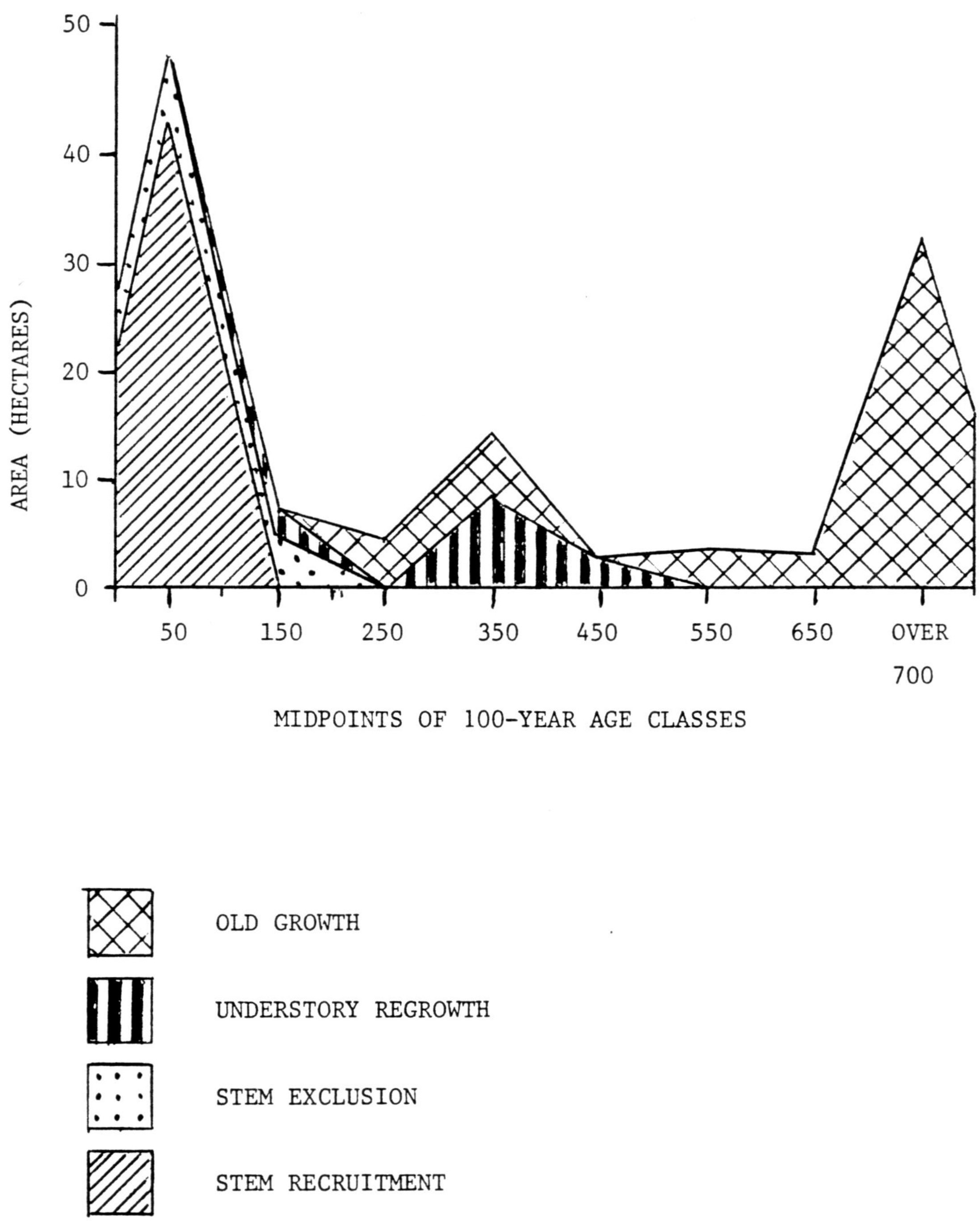
External disturbances are frequent in certain areas; therefore, any predictions of forest changes should be regarded as tentative. In the summers of 1978 and 1979 the glacier receded greatly. If this continues, the future vegetation may appear as follows:

50-year projection

The rock fall and avalanche areas (Figure 12) will continue to exclude forested vegetation beneath them. These will stay as brushy and herbaceous communities.

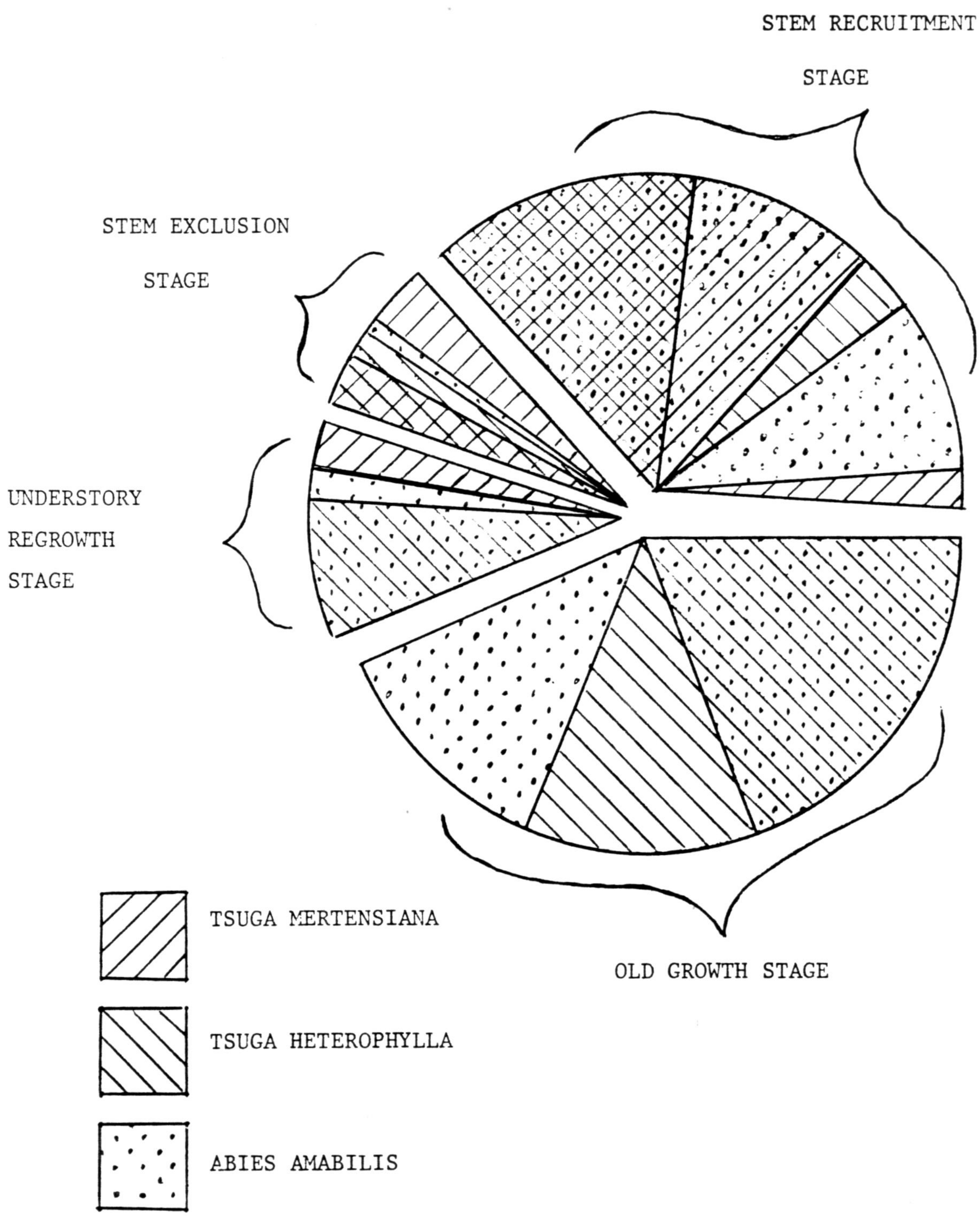
Areas 1 through 5 (Figure 18) will develop more into the "stem exclusion" phase, with a closed forest canopy covering all but the driest site areas of poorest growth.

Figure 19: Histogram showing distribution of stands by time since origin and by developmental stage. (Area 25 was beyond Park Boundary sign and therefore not included in this chart.)



50
40
30
20
10
0
AREA (HECTARES)
50
150
250
350
450
550
650
OVER 700
MIDPOINTS OF 100-YEAR AGE CLASSES
OLD GROWTH
UNDERSTORY REGROWTH
STEM EXCLUSION
STEM RECRUITMENT

Figure 20: Pie-chart distribution of forested area by developmental stage and overstory species composition.


STEM RECRUITMENT STAGE
STEM EXCLUSION STAGE
UNDERSTORY REGROWTH STAGE
OLD GROWTH STAGE
TSUGA MERTENSIANA
TSUGA HETEROPHYLLA
ABIES AMABILIS

Areas 6,7, and 8 will stay in the "stem exclusion" phase, since these stands will not be very old.

Areas 9, 12, 14, and 17 will probably develop into the "stem exclusion" phase during the next 50 years with closed canopies of predominantly *Abies amabilis*. Area 13 (both parts) and the western part of 16 will probably have their overstories knocked over by wind and avalanches, since previous disturbances have created openings in the stand edges. The advance regeneration of predominantly *Abies amabilis* will respond in these areas, creating first the "stand initiation" and then the "stem exclusion" phases.

Area 15 will probably develop into a relatively brushy area.

The physiognomies of areas 10, 16, and 18 through 27 will probably change relatively little. Areas 18 and 22 will probably not develop enough understory to be characterized as in the "understory reinitiation" phase during the next 50 years. The "old growth" areas will probably maintain their structure as small disturbances kill individual trees.

In general there will be much more and continuous forested area with little understory (stem exclusion phase) in the upper parts of the valley. These will be surrounded by shrub and herbaceous communities.

500-year projection

If the glacier did not readvance during the next 500 years, rockfall and avalanche areas (Figure 12) would probably develop more into talus slopes with *Alnus sinuata* and *Acer circinatum*, similar to avalanche chutes shown on Figure 14. The forests of areas 1 through 17 will probably be predominantly in the "understory reinitiation" phase where disturbances did not intervene. The species composition would be approximately that shown in Figure 17 for each area. There will probably be secondary large disturbances such as avalanches and small disturbances such as rockfalls. These will create a mosaic of stands such as shown in the non-"old growth" areas of Figure 18.

Special Vegetation Features of the Upper Nooksack Valley

This information was sorted with the contributions of Mr. Ralph and Mrs. Dorothy Naas, U.S. Park Service "V.I.P.'s"

1. Two hundred and twenty-four plant species were found in the study area. Table 3 is a species list of the area (including 12 mosses and 18 lichens).

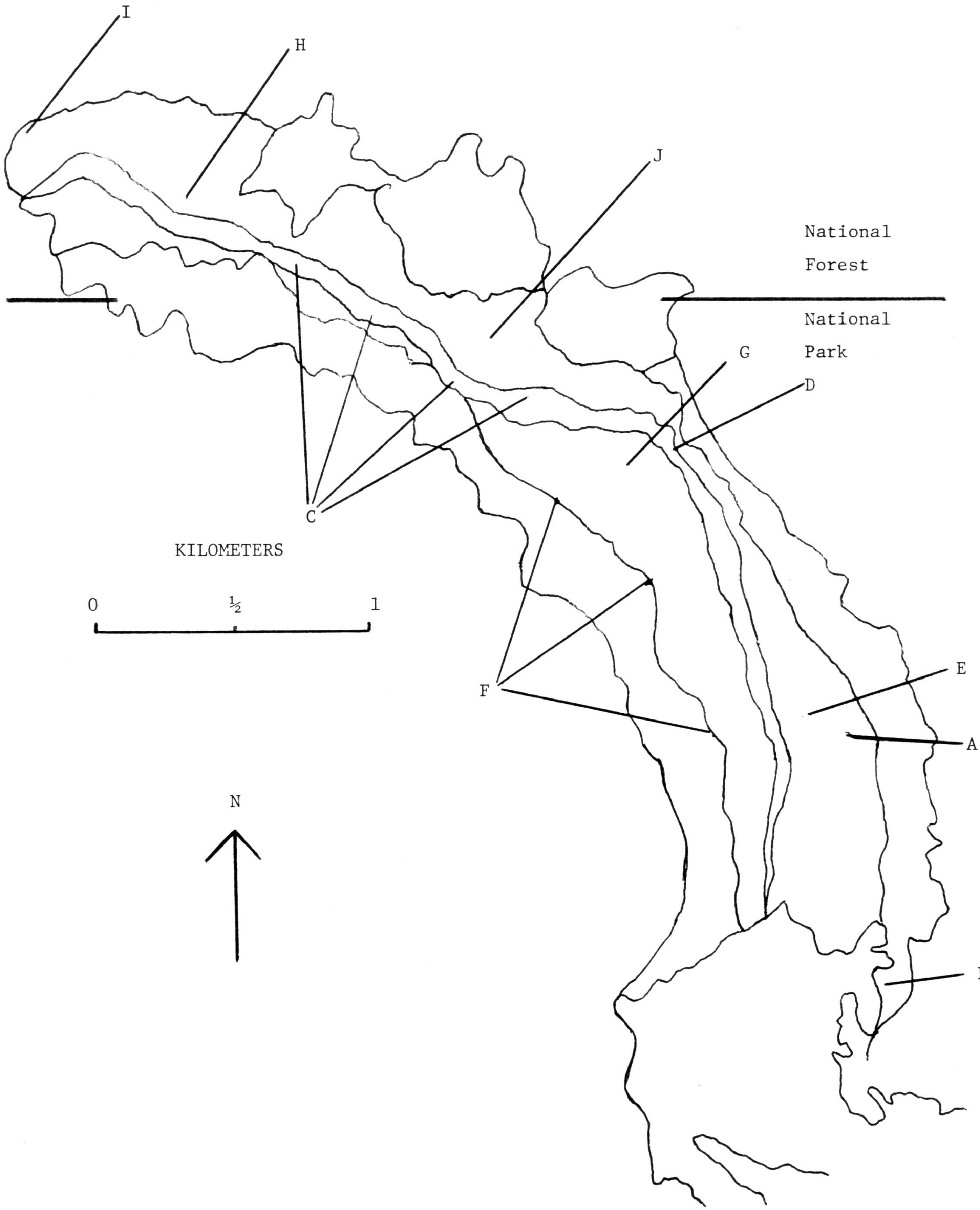
2. Two plants on the Rare, Endangered, or Threatened Plant Species List of August, 1977, were found. Fig. 21 shows the location of these individuals. The species are:

    Polystichum onchitis (Pt. A, Fig. 21) Mountain holly
    Cassiope stelleriana (Pt. B, Fig. 21) Alaska cassiope

3. Two plants were found which are not presently on the Check List of Vascular Plants of the North Cascades:

    Aira praecox an introduced grass
    Urtica dioica spp. *gracilis* var. *angustifolia* a nettle

Figure 21: Map of Special Vegetation Features. (See text for description).


I
H
J
National
Forest
National
Park
G
D
C
KILOMETERS
0
½
1
F
E
A
N
B

4. Two plants which seem quite rare in Washington were found there:

   Lycopodium alpinum

   Cladothamnus pyrolaeflorus

5. Seven introduced species were found in the area. These were found primarily along the lower river bar (Pt. C, Fig. 21), where constant floods and disturbances do not allow vegetation to become well enough established to dominate the site and exclude newly germinating individuals. The species are:

Agrostis tenuis	Colonial bentgrass
Dactylis lanatus	Orchard grass
Holcus lanatus	Velvet grass
Phleum pratense	Timothy
Rumex acetosella	Red sorrel
Capsella bursa-pastoris	Shepherd's-purse
Lactuca muralis	Wild lettuce

   Only one specimen of _Lactuca muralis_ (wild lettuce), an aggressive, nonnatural species, was found. Contrary to the usual practice of not collecting infrequent specimens, this plant was collected for taxonomic examination.

6. The five-needled pine trees found on the river bar (Pt. D, Fig. 21) were western white pine, _Pinus monticola_. Contrary to previous suggestions, no white-barked pine (_Pinus albacaulis_) was found in the area.

7. Two areas had a very rich variety of coniferous trees. This is probably because of two factors: (1) the proximity of seed sources of high elevation species from the above cliffs, and low elevation species from the valley floor; and (2) because no few species could grow large enough on the area to outcompete and exclude the other trees. The two areas are:

   (a) Along the river bar at Pt. D (Fig. 21), nine conifer tree species were found together. They are:

Pseudotsuga menziesii	Douglas-fir
Pinus monticola	Western white pine
Pinus contorta	Lodgepole pine
Thuja plicata	Western redcedar
Chamaecyparus nootkatensis	Alaska-cedar
Tsuga heterophylla	Western hemlock
Tsuga mertensiana	Mountain hemlock
Abies amabilis	Pacific silver fir
Abies lasiocarpa	Subalpine fir

   (b) At Pt. E (Fig. 21), on a very well-drained (dry) area of the recently glaciated region, eight tree species were found together. They are:

Pseudotsuga menziesii	Douglas-fir
Pinus monticola	Western white pine

Pinus contorta	Lodgepole pine
Chamaecyparus nootkatensis	Alaska-cedar
Tsuga heterophylla	Western hemlock
Tsuga mertensiana	Mountain hemlock
Abies amabilis	Pacific silver fir
Abies lasiocarpa	Subalpine fir

8. The greatest variety of all species was found along the ecotone (transition) between the meadows maintained by rock falls and avalanches and the forests. These ecotones (Pt. F, Fig. 21) consisted of herbaceous species, shrubs, and trees, but the frequency of disturbances did not allow a few species to gain dominance and exclude the others.

9. A very low elevation mauntain hemlock (Tsuga mertensiana) stand was found at Pt. G (Fig. 21) at approximately 1000 m elevation. This is probably attributable to the northern latitude and the northern exposure creating cool soil conditions here at the time the stand was established.

10. Very large trees found were as follows and listed on Figure 21:

Species	Diameter	Map location
Douglas-fir (Pseudotsuga menziesii)	159.3 cm (62.7 in.)	H
Western hemlock (Tsuga heterophylla)	192.8 cm (75.9 in.)	I
Western hemlock (Tsuga heterophylla)	197.4 cm (77.7 in.)	K

MAMMALS AND BIRDS OF THE NOOKSACK CIRQUE

Introduction

Any plan calling for management of National Parks must consider the impacts of that activity on the resident mammals and birds. To that end this study was carried out from 19 July through 2 September 1977 in the Nooksack Cirque of the North Cascades National Park. The purpose of the field work was to provide information about the presence and distribution of mammals and birds which would aid in determining management activities of that area.

Methods and Materials

Mammals were sampled using standard Calhoun traplines, which consist of two parallel rows of trap stations (Manville 1949, Brant 1962). Traplines were rotated to new habitats every fourth day or, alternatively, when the net addition to trapping success approached zero, i.e., no new species and very few, if any, individuals added. Observations (sightings, signs, etc.) by all members of the field party yielded additional information.

Differences among traplines were analyzed by the students and Wilcoxan ranked sum tests (Sokal and Rolfe 1969). Comparisons were made between the means of total length, tail length, right hind foot length, weight, and the ratio of weight to right hind foot for each species, species by trapline, and species by sex. Such analysis compares characteristics of populations found in differing habitats.

An attempt was made to sample as many habitats and/or plant communities as possible. Habitats were chosen by map and foot reconnaissance in conjunction with the plant ecology and soils/geology teams (Figure 22), with great effort taken to ensure coincidence in site selections whenever practical. It was designed to integrate all information gathered in the course of the study which would allow for a more thorough evaluation of management plans.

All mammal specimens were prepared as study specimens in the field and were later deposited in the National Park Service Collections at the Washington State Museum of Natural History on the University of Washington campus, Seattle, Washington. Skeletal material was prepared at the museum and joined with appropriate study skins in the museum collections.

Bird data was collected by observation only and species list prepared (Table 6). All nesting activities in the area were apparently completed by the onset of the study, and the concomitant decline in the visibility of birds made accurate censusing impossible.

Results and Discussion

Thirty-one mammal species (Table 7) were either captured or observed in the study area. The species trapped, except for *Peromyscus maniculatus* and *Sorex* spp., were restricted to very few traplines with only *Peromyscus*, *Sorex* spp., and *Zapus trinotatus* occurring in at least half of the traplines (Table 8). In the case of *Z. trinotatus* only one trapline (77-10) had more than one individual captured.

There is evidence to suggest that faunal distributions follow the patterns of floral distributions. By looking at a sequence of traplines based on an index of faunal resemblance (Long 1963), and then comparing the corresponding sequence of plant communities, certain observations can be made. Faunal resemblance indices indicate the degree to which the number of species and individuals of an area overlap, and assumes that similar fauna probably are living under similar environmental conditions.

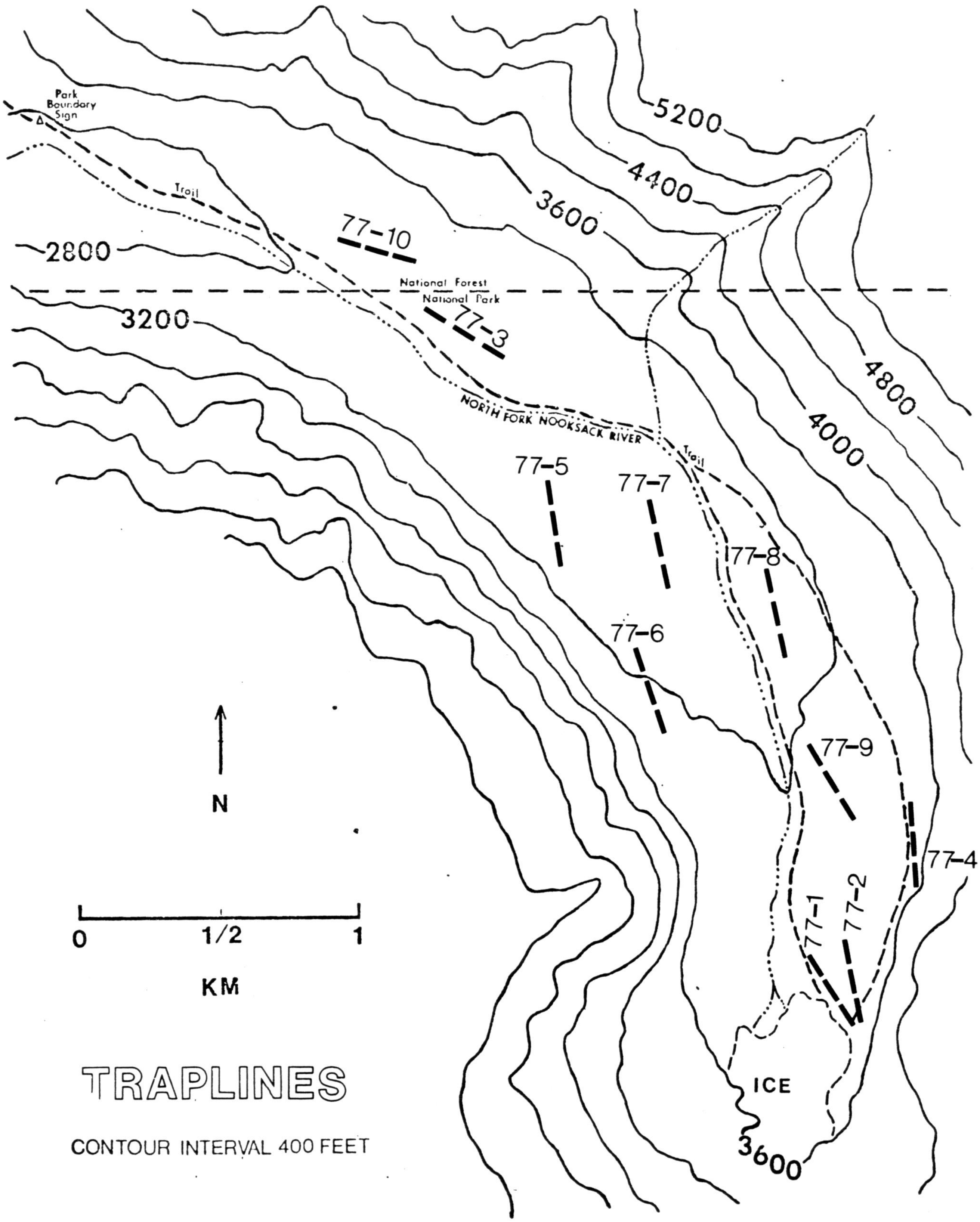
Faunal resemblance (R) is calculated as:

$$R = \frac{2w}{a + b}$$

where: *a* = number of species from plot *a*
b = number of species from plot *b*
c = number of species common to plots *a* and *b*

Pairwise comparisons of all traplines were made and tabulated in a matrix (Table 9). Then, each column was summed to find which trapline

Figure 22: Map of trapline locations.



TRAPLINES

CONTOUR INTERVAL 400 FEET

Table 6. Bird species observed, Nooksack Cirque, July-September 1977.

FALCONIFORMES		
Accipitridae		
	Accipiterstriatus	Sharp-shinned Hawk
	Buteo jamaicensis	Red-tailed Hawk
	Circus cyaneus	Marsh Hawk
GALLIFORMES		
Phasianidea		
	Lagopus leucures	White-tailed Ptagmigan
CHARADRIIFORMES		
Scolopacidae		
	Actitus macularia	Spotted Sandpiper
STRIGIFORMES		
Strigidae		
	Bubo virginianus	Great Horned Owl
APODIFORMES		
Trochilidae		
	Selasphorus rufus	Rufus Hummingbird
PICIFORMES		
Picidae		
	Colaptes auratus	Flicker
	Dryocopus pileatus	Pileated Woodpecker
	Sphyrapicus various	Yellow-bellied Sapsucker
	Dendrocopos villosus	Hairy Woodpecker
PASSERIFORMES		
Tyrannidae		
	Empidonax difficilis	Western Flycatcher
	Nuttalornis borealis	Olive-sided Flycatcher
Bombycillidae		
	Bombycilla cedrorum	Cedar Waxwing
Cinclidae		
	Cinclus maxicanus	Dipper
Troglodytidae		
	Troglodytes troglodytes	Winter wren
Musicapidae		
	Turdus migratorius	Robin
	Catharus guttata	Hermit Thrush
	Catharus ustulata	Swainson's Thrush
	Regulus satrapa	Golden-crowned Kinglet

Table 6 (Cont'd)

Certhiidae	
Certhia Familiaris	Brown Creeper
Paridae	
Parus rufescens	Chestnut-backed Chickadee
Corvidae	
Cyanocitta stelleri	Stellar's Jay
Corvus brachyrhynochos	Common Crow
Fringilidae	
Hesperiphona vespertina	Evening Grossbeak
Leucosticte tephrocotis	Gray-crowned Rosy Finch
Spinus pinus	Pine Siskin
Losia curvirostra	Red Crossbill
Emberizidae	
Junco hyemalis	Oregon Junco
Melospiza melodia	Song sparrow
Parulidae	
Vermivora celata	Orange-crowned Warbler
Dendroica patechia	Yellow Warbler
Wilsonia pusilla	Wilson's Warbler

Table 7. Mammals of the Nooksack Cirque.

INSECTIVORA	
Soricidae	
Sorex bendirii	Marsh shrew
Sorex palustris	Water Shrew
Sorex cinereus	Masked Shrew
Sorex vagrans	Vagrant Shrew
Sorex monticolus	Dusky Shrew
Talpidae	
Neurotrichus gibsii	Shrew-mole
CHIROPTERA	
Vespertilionidae spp.*	
LAGOMORPHA	
Ochotonidae	
Ochotona princeps	Pika
Leporidae	
Lepus americanua	Snowshoe Hare
RODENTA	
Sciuridae	
Eutamias townsendii	Townsend Chipmunk
Eutamias amoenus	Yellow Pine Chipmunk
Marmota caligata	Hoary Marmot
Tamiasciurus douglasii	Douglas Squirrel
Castoridae	
Castor canadensis*	Beaver
Cricetidae	
Peromyscus maniculatus	Deer Mouse
Neotoma cinerea	Busy-tailed Meadow Mouse
Microtus longicaudus	Long-tailed Meadow Mouse
Microtus townsendii	Townsend Meadow Mouse
Microtus oregoni	Oregon Meadow Mouse
Clethrionomys gapperi	Gapper Red-backed Mouse
Phenacomys intermedius	Heather Vole
Zapodidae	
Zapus trinotatus	Pacific Jumping Mouse

Table 7 (Cont'd)

CARNIVORA	
Canidae	
Canis latrans*	Coyote
Vulpes fulva*	Red Fox
Ursidae	
Ursus americanus*	Black Bear
Mustelidae	
Mustela vison*	Mink
Mustela erminea	Short-tailed Weasel
Martes americana*	Pine Marten
ARTIODACTYLA	
Cervidae	
Odocoileus hemionus coloumbianus*	Black-tailed Deer
Bovidae	
Oreamnos americanus*	Mountain Goat

*Presence known only be observation, scat, tracks, bits of hair or fur, etc.

Table 8. Species distribution by trapline, Nooksack cirque, 2 July - 2 September, 1977.

Trapline	Clga*	Euam*	Euto*	Maca*	Mior*	Milo*	Muer*	Neci*	Negi*	Ocpr*	Pema*	Phin*	Sorex spp.	Tado*	Zatr*	Totals Indiv.	Spp.
77-1		1									15		6			22	3
77-3	3										21					24	2
77-4		1				2				6	4		3			16	5
77-5				2		1					24	1	13		1	42	6
77-6			1			4				1	14		3		1	25	7
77-7	8										1		2	1		14	5
77-8		1					2		1		13		10		1	28	6
77-9	1										13		12		1	28	5
77-10	18		1		2	2		1	1	2	40		13		8	88	10
TOTAL	30	4	4	2	3	9	2	1	2	9	145	1	62**	1	12	287	15

*Species symbols are: Clga, Clethrionomys gapperi; Euam, Eutamias amoenus; Euto, Eutamias townsendii; Maca, Marmota calligata; Mior, Microtus origoni; Milo, Microtus longicaudus; Muer, Mustella erminea; Neci, Neotoma cinera; Negi, Neurotrichus gibsii; Ocpr, Ochotona princeps; Pema, Peromyscus maniculatus; Phin, Phenacomys intermedius; Tado, Tamiasciurus douglasii; Zatr, Zapus trinotatus.
**All Sorex species were lumped for this table.

Table 9. Faunal resemblance matrix.

Trapline	77-1	77-3	77-4	77-5	77-6	77-7	77-8	77-9	77-10
77-1		33.3	66.7	36.4	36.4	44.4	50.0	55.5	25.0
77-3	33.3		28.6	22.2	22.2	57.1	20.0	44.4	28.6
77-4	66.7	28.6		50.0	50.0	20.0	30.8	33.3	47.1
77-5	36.4	22.2	50.0		57.1	33.3	40.0	57.1	42.1
77-6	36.4	22.2	50.0	57.1		50.0	40.0	42.9	73.7
77-7	44.4	57.1	20.0	33.3	50.0		46.2	30.0	47.1
77-8	50.0	20.0	30.8	40.0	40.0	46.2		66.7	40.0
77-9	55.5	44.4	33.3	57.1	42.9	50.0	66.7		42.1
77-10	25.0	28.6	47.1	42.1	73.7	47.1	40.0	42.1	
Σ	347.7	256.4	326.5	338.2	373.3	348.1	333.7	392.0	245.7

	Line	R	Community
77-3 vs	77-8	20.0	Meadow
	77-5	22.2	Meadow
	77-6	22.2	Meadow
	77-4	28.6	Meadow
	77-10	28.6	Beaver Pond
	77-1	33.3	Meadow
	77-9	44.4	Alder
	77-7	57.1	Hemlock
	77-3	---	Hemlock

had the least overall resemblance to the others. This trapline (77-3) was chosen as a reference point, and all other traplines were ordered by their degree of resemblance to the reference line. In this case, the order is from least resemblance to most alike. The results suggest a sequence of increasing faunal resemblance from the various meadow communities through the heavily canopied hemlock communities. The finding is consistent with the observed patchiness of mammal distributions. That is, most species are confined to a few places, perhaps related to structural components of the vegetation.

Distribution of mammals seems to be related to the presence or absence of canopy cover. For example, Microtus spp. are found either in the wetter portions of the subalpine or grammanoid meadows, or around disturbed sites (beaver pond) within hemlock (Tsuga heterophylla) stands. By comparison, Clethrionomys gapperi is found predominantly in the drier mountain hemlock (Tsuga mertensiana) forests.

Canopy cover may simply be a reflection of the effect of disturbance on community development. Oliver and Adams (in this report) have shown that the incidence of disturbance at particular seral stages influences final community composition. In conjunction with this, we found that mammals of the Nooksack cirque were generally restricted to only one or two community types (Figures 23, 24, 25) and the presence of mammals is probably predicated on the maintenance of these community types.

Few traplines had large numbers of individuals, and only Peromyscus maniculatus (50.5% of total captures), Sorex spp. (21.6%), and Clethrionomys gapperi (10.4%) occurred in any abundance (Figure 26). Trapping success per trapline is given in Table 10. (10% trapping success was used as an expected rate of return.) Only 5 of 10 traplines exceeded expectations when those traplines showing less than 10% success were well below that standard. Success rates were not necessarily matched by high or low numbers of species present on any given trapline. Rather, high success rates tended to reflect great numbers of one or two species present at a given line. Thus, success rates are consistent with the uneven distribution of mammals over the landscape, with pockets of high numbers of species and/or individuals occurring in different localities. Individual species accounts may serve to illustrate this.

Clethrionomys gapperi. All individuals of this species were taken from four sites located in closed canopy silver fir, hemlock (Tsuga heterophylla and T. mertensiana) forests; 90% were found at the two sites of this kind with the most diverse understories. C. gapperi is known to be a forest dwelling seed and leaf eater. A well-developed shrub and herb layer may be a prerequisite to maintaining a reproducing population.

Microtus oregoni. Only three individuals were captured. All were near water, either at a forest edge or within a disturbed site within the forest, i.e., a beaver pond.

Microtus longicaudus. Those were restricted to the graminoid meadows which occur either in pockets behind the recent lateral moraines left by the Nooksack Glacier, or in subalpine meadows maintained by periodic rock and/or snowslides.

Figure 23: Animal community locations.

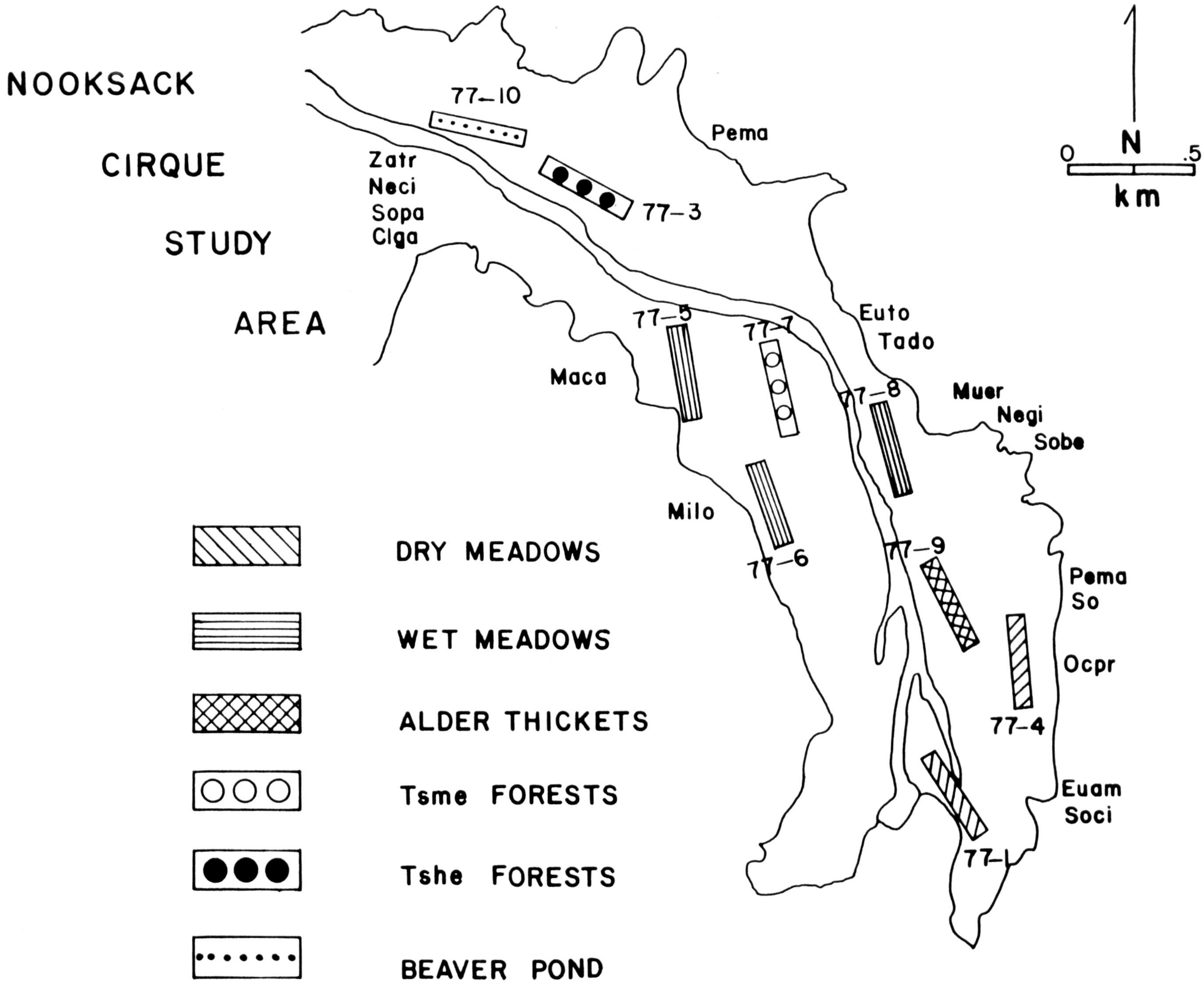

NOOKSACK
CIRQUE
STUDY
AREA
77-10
77-3
Zatr
Neci
Sopa
Clga
Pema
N
0
.5
km
77-5
77-7
Euto
Tado
Maca
77-8
Muer
Negi
Sobe
Milo
77-6
77-9
Pema
So
Ocpr
77-4
Euam
Soci
77-1
DRY MEADOWS
WET MEADOWS
ALDER THICKETS
Tsme FORESTS
Tshe FORESTS
BEAVER POND

Figure 24: Distribution of animal species and individuals by habitat.

DISTRIBUTION OF SPECIES AND INDIVIDUALS BY HABITAT

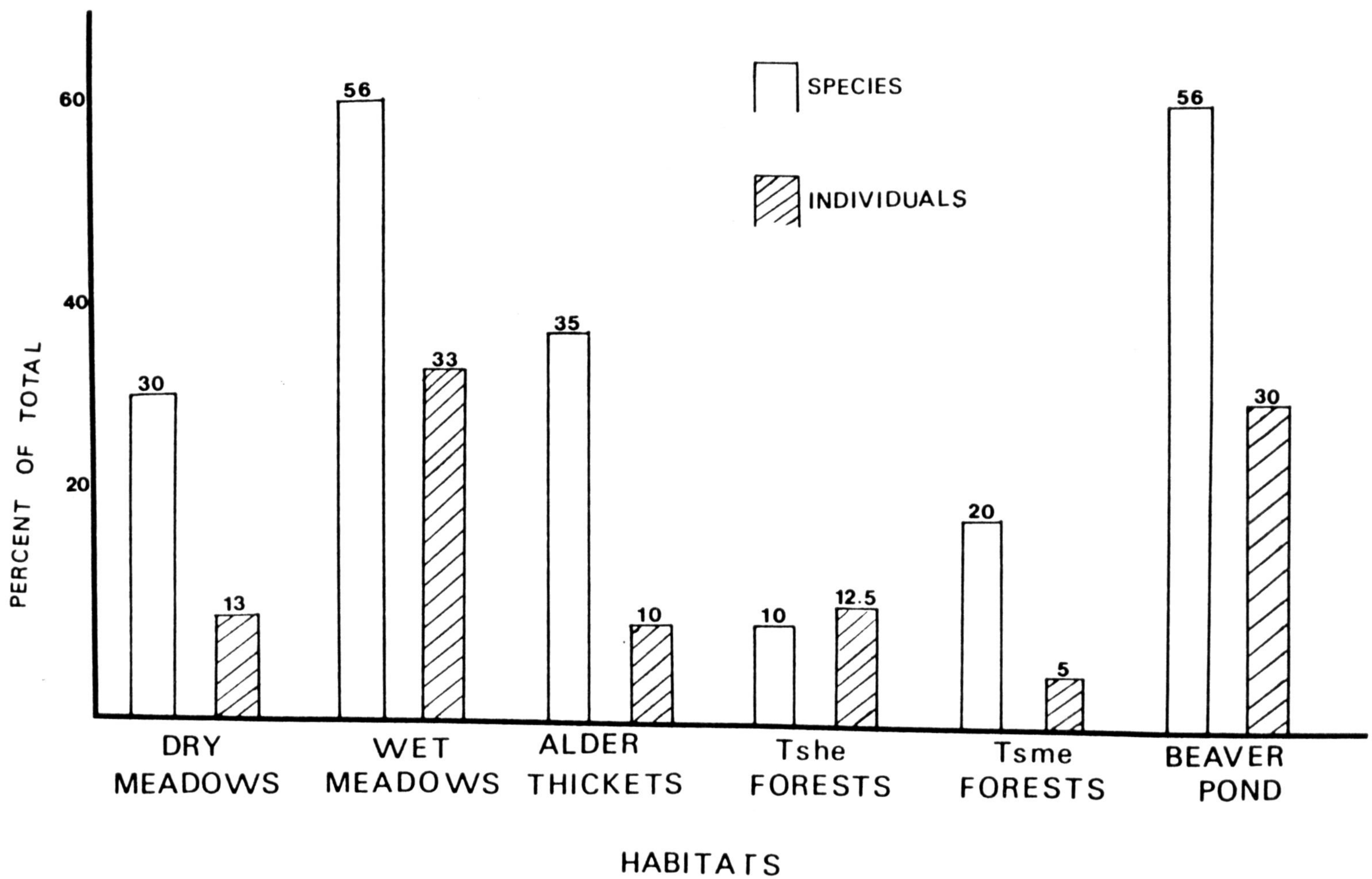


Figure 25: Distribution of animal species by habitat.

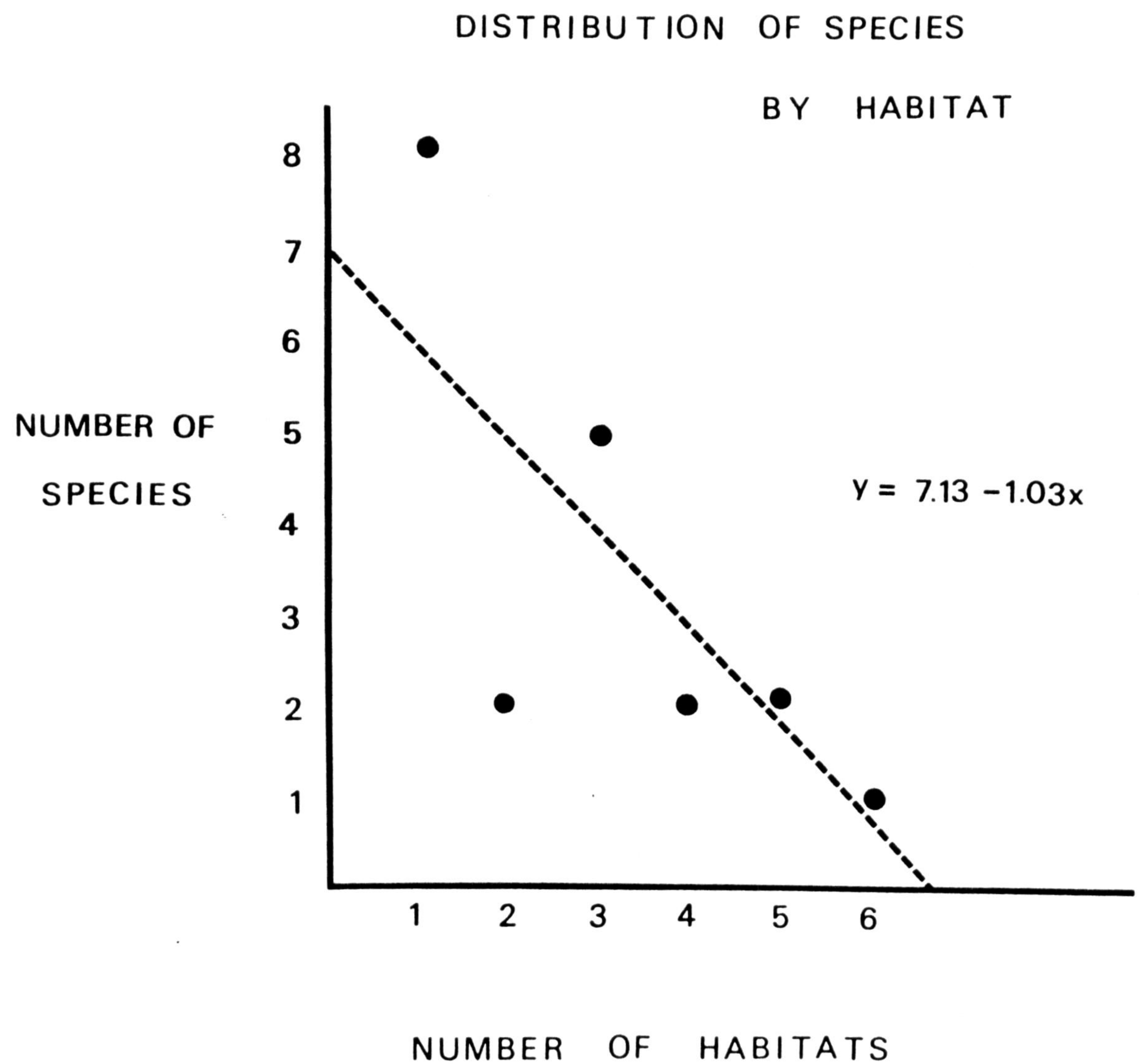
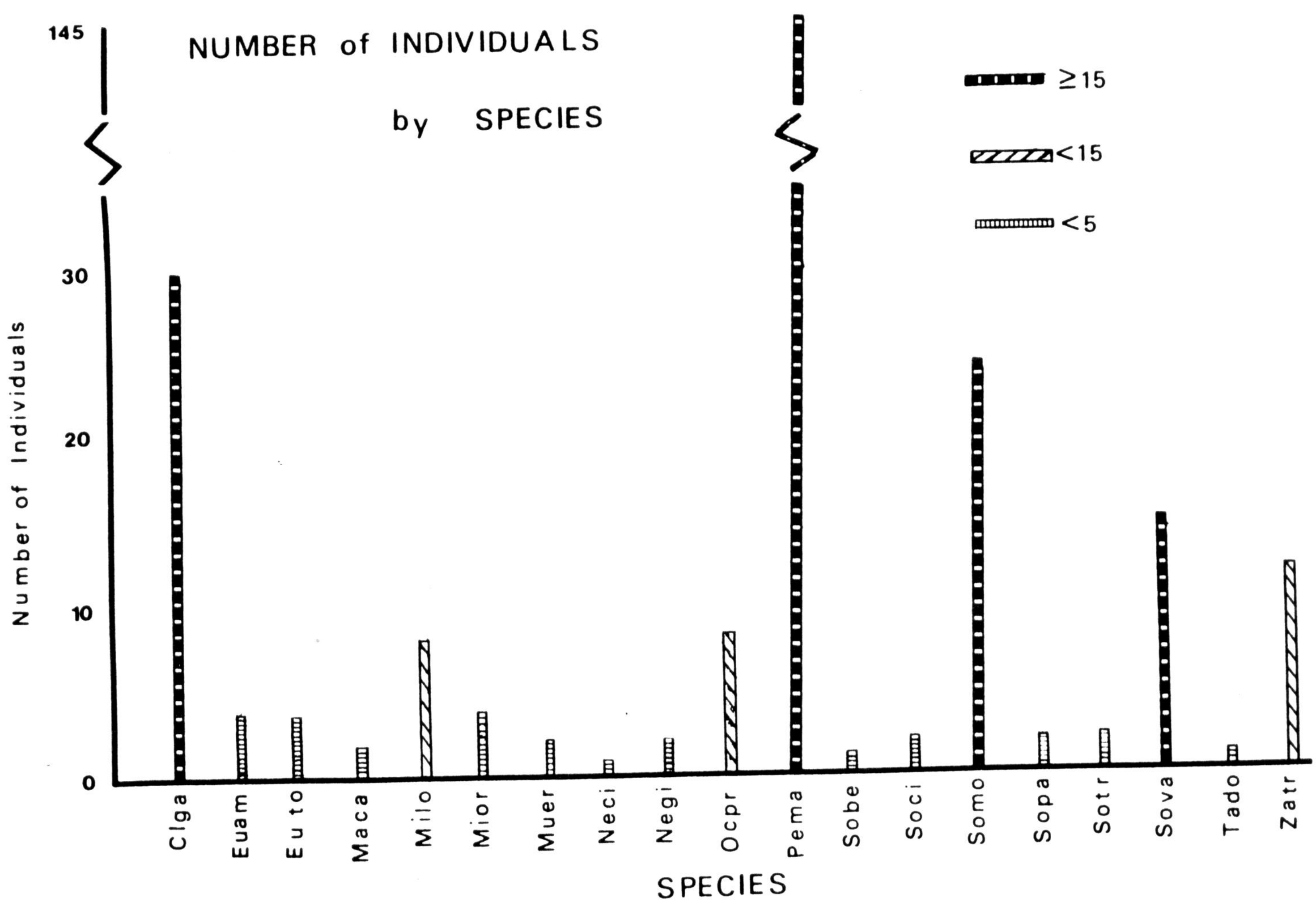

DISTRIBUTION OF SPECIES
BY HABITAT
NUMBER OF SPECIES
8
7
6
5
4
3
2
1
y = 7.13 -1.03x
1
2
3
4
5
6
NUMBER OF HABITATS

Figure 26: Number of animals by species.



NUMBER of INDIVIDUALS
by SPECIES
≥15
<15
<5
Number of Individuals
0
10
20
30
145
Clga
Euam
Eu to
Maca
Milo
Mior
Muer
Neci
Negi
Ocpr
Pema
Sobe
Soci
Somo
Sopa
Sotr
Sova
Tado
Zatr
SPECIES

Table 10. Catch per unit effort (Success Rate) by trapline.

Trapline	C.E.
77-1	5.60
77-3	15.43
77-4	4.52
77-5	17.78
77-6	8.93
77-7	4.59
77-8	9.24
77-9	10.21
77-10	19.47

where $CE = A \frac{100}{TU - \frac{IS}{2}}$

A = Number of captures

TU = Total trap nights. Number of trapping intervals x number of traps per interval.

IS = Number of traps sprung.

Phenacomys intermedius. One individual was captureed in a cirque meadow.

Peromyscus maniculatus. In keeping with its generalist nature, Peromyscus was found in almost all localities in relatively great abundance. The exceptions were sites 77-4 and 77-7. Site 77-4 was in a graminoid meadow abutting a talus slope (both Microtus longicaudus and Ochotona princeps were taken from this same site). Site 77-7 was in an almost pure stand of Tsuga mertensiana which exhibited an extremely poor understory. The diet of P. maniculatus consists largely of seeds and arthropods; thus, it is likely that P. maniculatus would be at a competitive disadvantage with strict herbivores, and may be food limited in an understory dominated by mosses.

Neotoma cinerea. A single specimen was found in a rock pile in a hemlock (T. heterophylla) forest. From the amount of feces and number of middens seen, there are indications that N. cinerea may be more prevalent than indicated by trap results.

Zapus trinotatus. Eight of the 12 jumping mice captured were from trapline 77-10 which wound an abandoned beaver pond through a wet, dense understory. This was expected since Z. trinotatus has been associated with boggy or wet areas that have a lush herb cover. It is known that Z. trinotatus is an excellent swimmer.

Eutamias amoenus. Four individuals were found, all at the edges of meadows near talus slopes, typical habitat for the species.

Eutamias townsendii. Four individuals were collected from typical E. townsendii locales. Three were found wholly within a hemlock stand, and one was captured along the stand's edge.

Marmota caligata. Two specimens were captured from a typical marmot site, i.e., a boulder pile in a side slope meadow. Numerous marmots were seen in similar places throughout the canyon. The striking characteristic of marmot sightings was the apparently low elevation (less than 800 m) of nesting sites for some of the families.

Ochotona princeps. Pikas were captured from meadows abutting talus or from within the talus itself. An apparent exception was found on trapline 77-10 which generally lies within a mixed Pacific silver fir/western hemlock (T. heterophylla) community. Such a community description is tentative since rock slides intrude into almost all vegetation types. It was in just such a disturbed site that these two pikas were taken. Again, the low elevational distribution of breeding individuals is unusual.

Sorex Supp.

Sorex cinereus. The masked shrew has been identified from site 77-10. This trapline was near a beaver pond in a western hemlock forest. Sorex cinereus is considered to be rare in western Washington, although it may be the most common mammal in other states.

Sorex bendirii. The Marsh Shrew is usually found near or in standing or slow moving water. A single specimen was collected from a boggy area near a Carex sp. meadow.

Sorex palustris. Northern Water Shrews are usually found near fairly swift moving water. The two found in the Nooksack were taken from clear streams feeding into a beaver pond.

Sorex trowbridgii. One specimen was found in the wet litter of an *Alnus sinuata* (Sitka alder) thicket.

Sorex vagrans and S. monticolus (obscurus). These two closely related species were temporarily lumped for convenience. These insectivores were the only species other than *P. maniculatus* found in almost all habitats. *S. vagrans/monticolus* tend to inhabit somewhat open forests and forest edges out into shrubby meadows. Few were found in graminoid meadows or closed mountain hemlock (*T. mertensiana*) stands.

Neurotrichus gibbsi. One specimen was taken from a wet site with a reasonably well-developed organic layer. This mammal burrows fairly extensively as it forages and may be restricted by the distribution of sites with abundant organic material.

Mustela erminea. Two were collected near a meadow area which was coincidentaly devoid of all microtine rodents. Only a few *P. maniculatus* were found in addition to a high number of shrews.

Other mammals (bats, Snowshoe hares, Black bears, Black-tailed deer, etc.) whose presence was noted by observation, scat, fur, or tracks, are noted on the species list, but are not further discussed here.

Data on productivity (reproduction) seem to concur with the patchiness suggested above. Traplines alternately show breeding adults with juveniles, adults with no juveniles, or few adults with many juveniles. Since the sample size per species is usually small, it is difficult to generalize concerning population dynamics of individual species. Only *Peromyscus maniculatus* has enough individuals from which to perceive patterns. Reproductive data from *P. maniculatus* indicate probable locales of population expansions as well as probable locales of marginal habitat. Two patterns are discernable. First, productivity in *P. maniculatus* seems to vary with habitat suitability and disturbance frequency. The stable wet hemlock forest with well-developed herb and shrub layers shows a large percentage of adults in breeding condition, and well-defined subadult and juvenile groups (Figure 27). The other extreme is a relatively dry, chronically disturbed, graminoid meadow found well within the cirque. Here, only adult males were found, suggesting dispersal of newly adult males into perhaps a marginal area with the likelihood of annual extinction.

Second, productivity in *P. maniculatus* seems to be related to size (Figure 28). Comparison of mean total lengths, tail lengths, and weights of total populations, males, and females by trapline indicate a discrete size difference among populations of *P. maniculatus* (Table 11). Those from sites in the lower and/or wooded canyon areas are much smaller than those in the upper, open areas for all these measurements. Conversely, productivity (based on presence of uterine scars, embryos, mammae, enlarged testes, juveniles) is much higher in the smaller groups. A

Figure 27: *P. maniculatus* size and reproduction distribution.

P. maniculatus Size & Reproduction Distribution

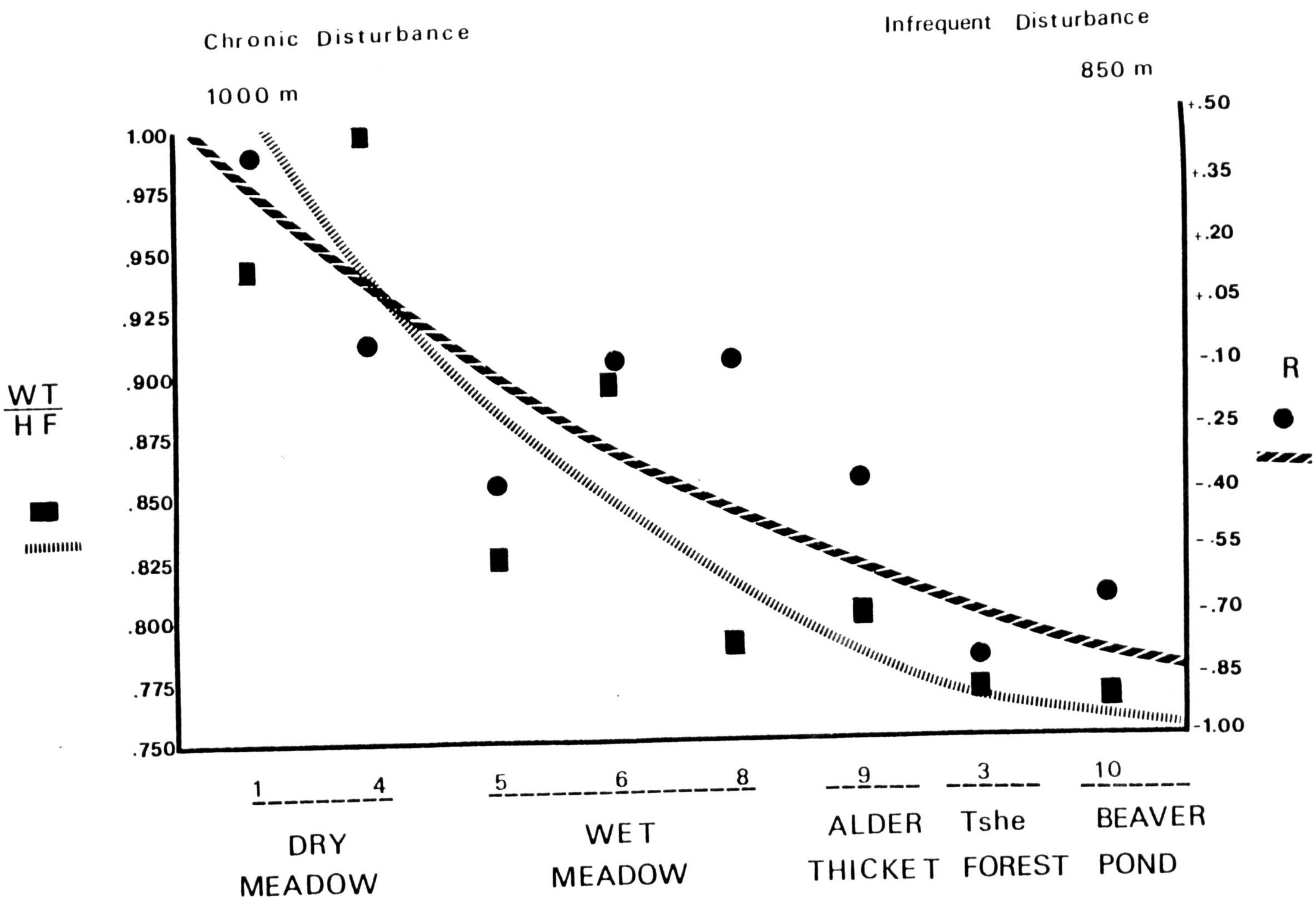
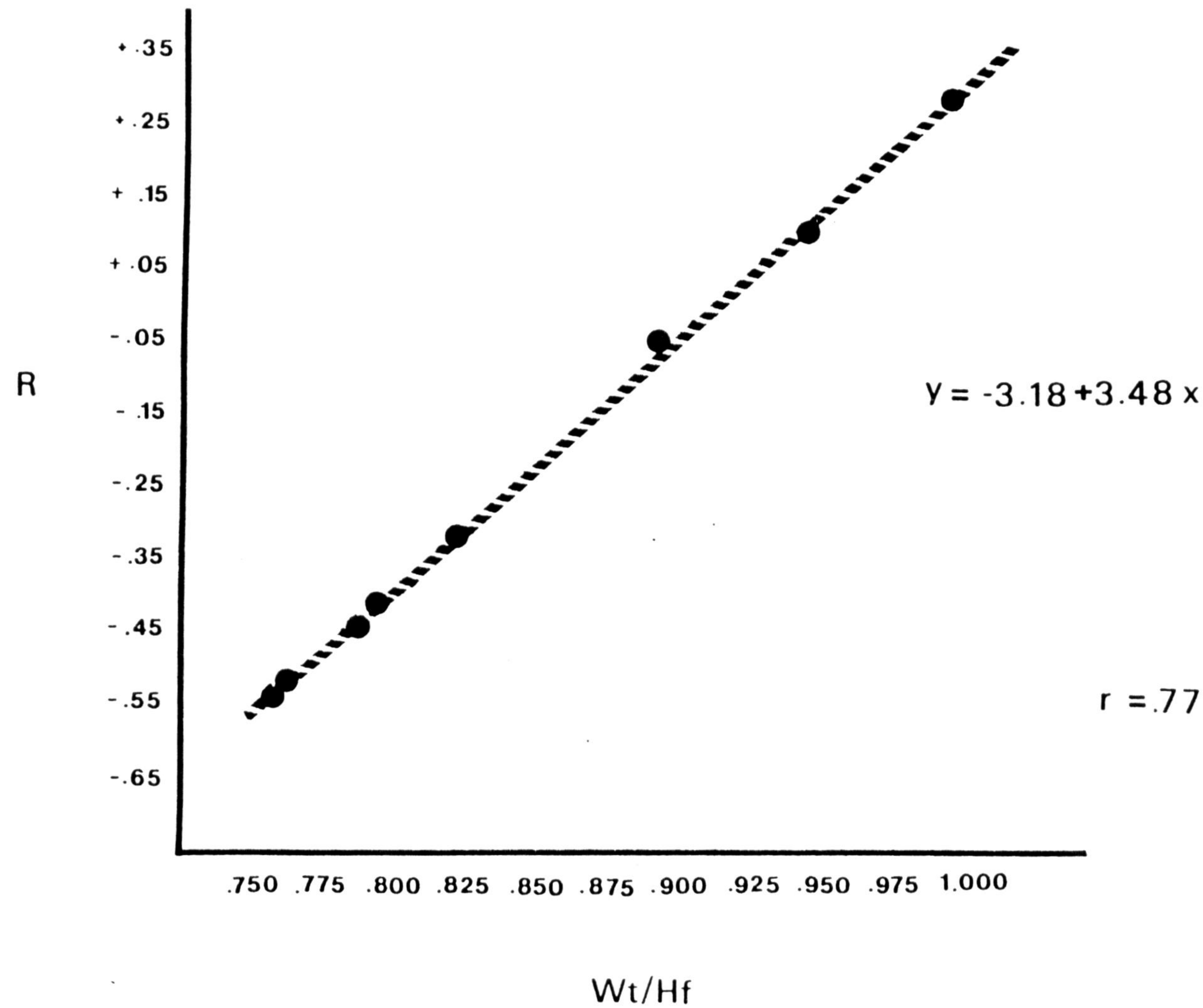


Figure 28: Regression of R. on Wt/Ht for P. ma.

REGRESSION OF R ON Wt/Hf FOR Pema



tentative explanation of this observation is that the two size groups represent two subspecies of P. maniculatus; P. m. austerus, and the larger p. m. oreas, although some authors suggest that the larger race be elevated to specific status, i.e., Peromyscus oreas. In either case, it is well known that the larger form favors more open habitat, reproduces at an older age, and has fewer offspring per litter.

Summary

A study was initiated to describe the presence of mammals and birds in the Nooksack cirque. Thirty-one mammals and thirty-three bird species were observed in the study area. Most of the mammals were relatively rare and limited in distribution. Only Peromyscus maniculatus, Sorex spp., and Clethrionomys gapperi were found in any abundance (these three species accounted for over 80% of all observations) and only P. maniculatus, Sorex spp., and Zapus trinotatus were found on half of the traplines.

Distributions tend to coreespond to vegetation patterns, especially to elements of community structure. Canopy cover was suggested as an approximation indicator of mammal species presence and was related to disturbance patterns. It was shown that faunal resemblance followed a trend from meadow communities through mixed Pacific silver fir/hemlock forests and that races of Peromyscus maniculatus were distributed along a canopy gradient as well. P. maniculatus races were discriminated by size, and size and reproduction gradients in P. maniculatus also followed structural patterns.

Most mammals are relatively rare and apparently tightly associated with specific vegetation. Any alteration of vegetation structure could drastically alter species presence and/or distribution.

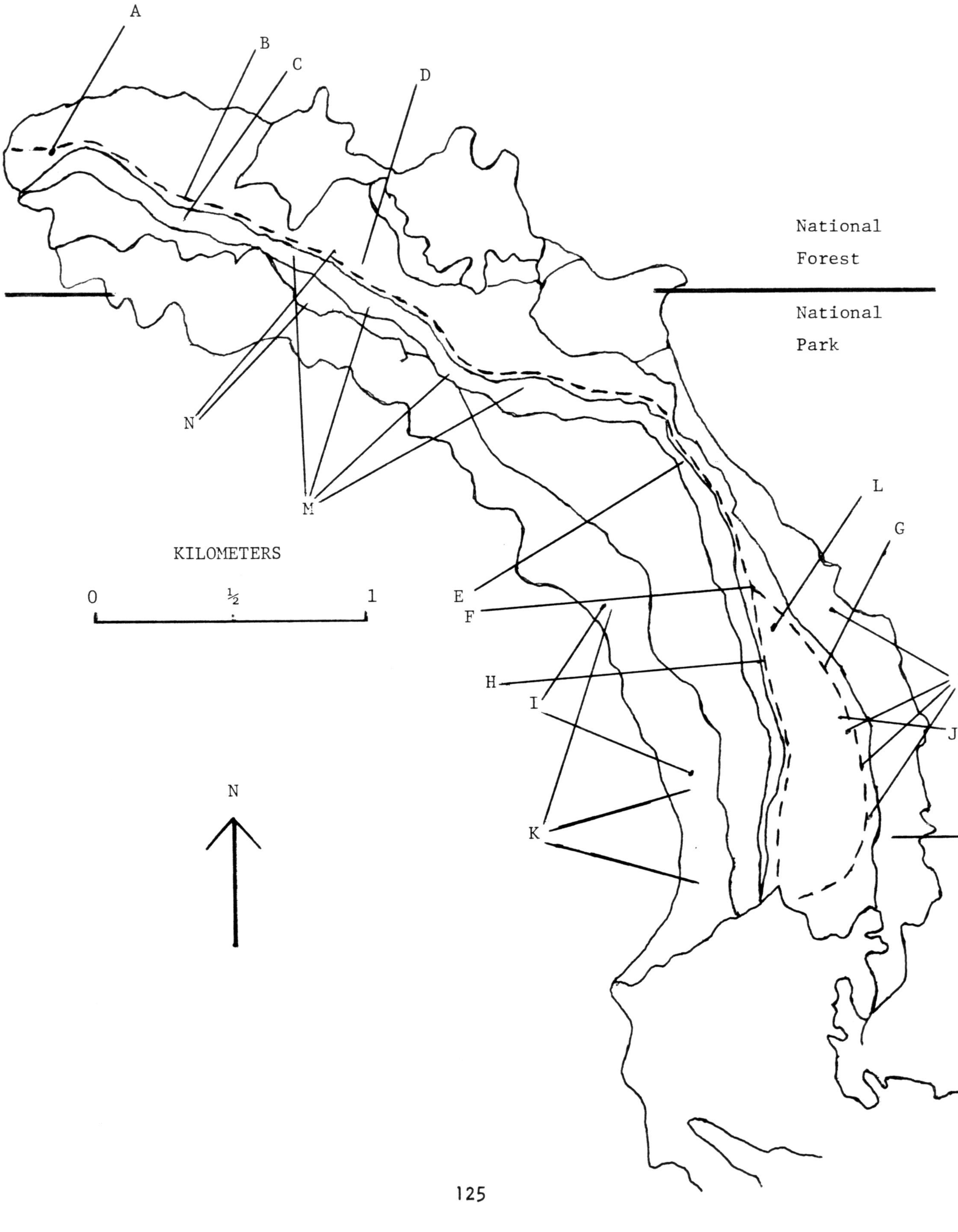
CONSIDERATIONS FOR MANAGEMENT

Suggestions for various alternative management plans were beyond the scope of this study; however, there are certain features concerning safety, rare species, encroachment of exotic species, and various development (and lack of development) impacts which should be noted. These features will be discussed in two sections: Access and development; and Aesthetic, natural, and scientific value and maintenance. Figures 16 and 29 show the areas discussed below.

Access and Development

At this time access to the trail head is over several kilometers of single-lane gravel road. The route is not well marked and this may limit visitor use. At road end the distance to the cirque is 8 km. The next section of fairly well maintained trail continues for 2 km through an old-growth stand of silver fir, Douglas-fir, and western hemlock, ending at the Park Boundary sign (A, Figure 29) approximately 4.4 km from the cirque. From this point progress is made either by bushwacking on an unmaintained trail (B, Figure 29) through the "old-growth" forest parallel to the river or by traveling on the river bar (C, Figure 29). During low flows the river bed is the easier choice, although several stream crossings (which can be hazardous) may be necessary.

Figure 29: Map of areas for management considerations. (See text for description.)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The old-growth forest trees are quite resistant to damage by hiking on trails. Extreme activity off the trails could compact the soil and hurt the tree roots, but moderate activity should not be serious. The understory trees, primarily Pacific silver fir (Abies amabilis) are small but usually quite old. They generally range up to 6 m (20 ft) tall; at 0.6 m (2 ft) tall they can be over 100 years old. These trees are quite tough and resiliant to physical pushing (they are adapted to withstand wet, heavy snow accumulation); however, during the spring (at bud break and shortly thereafter) their new growth and stems can be damaged quite easily. If these understory trees are eliminated from an area, it will take a long time and conditions of no disturbances for them to be naturally replaced. If trails are constructed through the forests, thick Vaccinium shrub (blueberry) growth (which is compatible to hiking) may discourage excess movement from the trails.

For motorized access to the upper area a road system would have to be built on the flat flood plain of the river (D), since the talus slopes are unstable and subject to snow avalanches in the winter. A 90-ft right-of-way on the flood plain would remove much of the existing old-growth forest.

The old-growth forests (Figure 16) consist of "stand-grown" trees whose windfirmness depends on the mutual wind protection. Trees adjacent to the river banks or uphill shrubby vegetation are "open grown" on the exposed side. These are more resistant to being overturned by the wind. Under most natural conditions trees blow over individually and in small patches; and the surrounding trees gradually become more windfirm. Large areas where all trees blow over occur, but are infrequent within the study area (except where avalanches occur) and not very probable for a given area. Even a more narrow road created through the forest on either side of the river would greatly increase the probability of the forest blowing down. There are three reasons for this: (a) The road would create a funnel for wind to be channeled into the stand. Since the road would run east and west and most windstorms here blow from the southwest, this could be especially serious; (b) The trees along the road would lose the protection previously provided by trees which were cut down to create the road; (c) The windward roots of a tree are generally the supportive roots against windthrow. If a road eliminates these, the trees close to the road are more likely to fall. A road through the forest on either side of the river would not be expected to alter the forest on the other side of the valley.

At the river bend (E, Figure 30), avalanches have occurred for the past 100 years. Since about 1950 avalanches have occurred in previously unavalanched areas. These avalanches are quite destructive (blowing over trees 55 m [180 ft] tall and 86 cm [34 in] in diameter); they originate from either side of the valley and often run across the river to the other side of the valley. Future management plans may consider cautioning or limiting winter visitors during avalanche danger periods. Future access facilities (roads, trails, or other) may need to be constructed to withstand frequent, severe avalanches.

About one km from the ice front (F, Figure 20) two routes to the cirque appear to be used. One route (G, Figure 30) moves upslope to the talus and lateral moraines and runs along the cliff base to the glacier, while a second alternative (H, Figure 30) follows the river up to the immediate cirque area. Portions of the river route (H) pass through dense alder stands and ford several small streams (3-5 m wide). The moraine route (G) may pass through some meadow communities which are more fragile than the alder communities.

Dangerously large rocks fall down the cliffs at unpredictable times during the summer (and probably at other times of the year). Pt. I (Figure 29) designates areas of known rockfalls based on direct or indirect observations. It is possible that rocks can fall elsewhere as well. The rockfalls occurred during all weather conditions, but they were most frequent during rains. Future management plans may consider directing visitors away from these areas, as will be discussed later.

Mountain holly (Polystichum lonchitis), a rare and endangered species, as well as other herbaceous plants are found along the cliff bottoms within the cirque area. These plants are relatively incompatible with hiking and camping activities. The areas are shown at J, Figure 29, (where, incidentally, the rock falls are frequent).

The distribution of two field mice (Microtus longicaudus and M. oregoni) and one chipmunk (Eutamias amoenus) were restricted only to these kinds of meadows, while marmots (Marmota caligata) and pikas (Ochotona princips) forage heavily there.

At present, most frequent and convenient travel to the glacier base is through this area (along trail G, Figure 29). The area is also used for camping. Construction of a trail or improvement of trail H (Figure 29) through areas with vegetation more compatible with hiking and camping (but currently difficult to travel through) would help keep this area from being altered by visitor activity.

In addition to the rockfall areas described above, the talus slopes (K, Figure 29) are quite unstable. These contain rocks of over 10 m (30 ft) in diameter. Whether the rocks are freshly fallen or are covered with moss and surrounded by trees, personal experience indicates they are unstable for human climbing. It may be desirable for visitors to be cautioned or for trails to be routed to avoid such areas.

Each species and vegetation type within the study area is adapted to particular types of disturbances. Human activity such as hiking is similar to certain types of disturbances, but not to other types. To preserve areas incompatible to hiking but presently being used, visitor use should be encouraged in vegetation types responding to appropriate disturbances. Sitka alder (Alnus sinuata) and blueberry (Vaccinium species) areas are especially compatible with human activity (such as hiking). To preserve the more sensitive herbaceous areas, it may be desirable to locate a trail through the dense alder shrub community to the base of the glacier such as trail H (Figure 29). A high moraine, relatively flat on top, and covered with alder (L, Figure 29) could be developed as a vista point with relatively little disturbance to the area. This point also provides a spectacular view of the whole cirque area. The suggested trail from here to the base of the glacier would channel people to a place with possible drinking water, but discourage travel in the dangerous areas and areas of sensitive vegetation.

The studied area is interesting both from an aesthetic and a scientific aspect. If trails are constructed on one side of the river, an absence of trails on the other side would discourage use and maintain it in a relatively unaltered condition. (If visitor use continued on the undeveloped side, trails could then be constructed to channel people away from sensitive and dangerous areas).

Aesthetic, Natural, and Scientific Value and Maintenance

Exotic species have been obvserved on the river bank (M, Figure 30). As mentioned earlier, this area provides open areas where such species can migrate far into the cirque. Some of the exotic species are quite aggressive. If the natural condition of the cirque is to be preserved, annual "removal" of the exotic plants from the river bar areas may be incorporated into a management program.

The Nooksack Cirque is an excellent outdoor laboratory. Natural succession following glacial retreat is easily visible. Secondary succession following numerous disturbances is also available for study. The glacial materials deposited by the present ice front are acidic; this is unique since many previously studied glacial materials are initially alkaline. Opportunities to study ecosystem development in initially acid materials is a distinct possibility. Vegetation and succession studies can be done within a small area here. The physiological response of mammal populations to stress can be studied, as well as the taxonomy and natural history of Peromyocus maniculatus and the relationship of small mammals to elements of vegetation communities may be expanded.

There are many interesting vegetation features to the valley, as was discussed in the previous section on "Special Vegetation Features" and is shown in Figure 21.

It may be desirable to keep part of the Nooksack Valley forest in each stage of stand development (Figure 16) for several reasons:

a. Aesthetics: It is aesthetically pleasing to travel in all forest types--from large trees and varied canopies of the "old growth" stage through the "understory regrowth" and "stem exclusion" stages to the young "stand initiation" stage.

b. Wildlife: Specific wildlife species live within each of the forest types for all or part of their life cycle. Exclusion of a physiognomic stage would discourage certain animal species from the valley.

c. Scientific interest: Presently the area gives an excellent example of all forest development stages within a relatively small area. This is a very valuable natural research laboratory.

Several small mammals, such as water shrews (Sorex palustris), Douglas squirrels (Tamiasciurus douglasii), Townsend chipmunks (Eutamias townsendii), Pacific jumping mice (Zapus princips), and red-backed voles (Clethrionomys gapperi) are essentially found only in "old-growth" (and possibly "understory regrowth") forests. The presence of Sorex cinereus may indicate an especially sensitive area around beaver ponds in the "old-growth" area (N, Figure 30). Sorex cinereus is considered to be rare in western Washington. Any alteration of these conditions could lead to permanent local extinctions. Most of the "younger" physiognomic stages of forest development (Figure 16) are within the National Park Boundary. The "old growth" forests are within National Forest Lands. It will be very long (probably several hundred years) before much of the forested area within the National Park develops naturally into the "old growth" stage.

It may be desirable to incorporate the "old growth" stage into the upper Nooksack Valley Park-like area in two ways, with varying degrees of success:

a. By selectively cutting or killing certain overstory trees in areas which are in the "stem exclusion" or "understory regrowth" stages. These would mimic the natural disturbances which cause the natural all-aged condition of the "old growth" stage. Area 10 is an example of one area in which the "old growth" stage is achieved at a relatively young age through such natural small disturbances which the cuttings would mimic. The killed or cut trees should be left to create downed, dead materials. This alternative would not be completely satisfactory since the very large trees would not be present.

b. By incorporating the lower area studied but officially in the National Forest into National Park-like management so that these trees are not commercially harvested. This area should be down to the end of the present study area (the U.S. Park Service sign; A, Figure 29) and possibly farther to a natural wind-break location. Further pursuit of this was beyond the scope of the present study.

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APPENDIX 1. A KEY TO THE MAJOR PLANT COMMUNITIES OF THE NOOKSACK CIRQUE.

1a.) Vegetation dominated by conifer species greater than 20 feet tall. Although dead conifer stems may be on the ground, they do not lie parallel to one another as would occur in an avalanche blow-down.

2a.) Tsuga mertensiana dominant (composing more than 50% of the larger stems) with Abies amabilis, Pinus monticola, and Pseudotsuga menziesii occurring as rare components of the canopy. Understory regrowth dominated by the conifer Abies amabilis and the shrub Vaccinium ovalifolium. The mosses Rhytidiopsis robusta and Dicranum spp. are common on the forest floor. Area of low taxonomic richness.

TSUGA MERTENSIANA FOREST

2b.) A conifer other than Tsuga mertensiana dominant or at least codominant with T. mertensiana.

3a.) Abies amabilis either dominant or codominant with T. heterophylla or T. mertensiana. Herbaceous plants conspicuous and include Rubus pedatus, Tiarella trifoliata, Smilacina stellata, S. racemosa and often the moss Rhytidiopsis robusta is present. The shrubs Oplopanax horridum and Vaccinium ovalifolium should be easily found and possibly Sambucus racemosa. Oldest trees should range from 400 to 800 years old and may reach up to 60 inches in DBH.

OLD GROWTH SILVER FIR FOREST

3b.) Understory herbaceous layer not well-developed or else Abies amabilis is not dominant.

4a.) Herbaceous layer well-developed with Tsuga heterophylla dominant. Located on south-facing slope well above river.

TSUGA HETEROPHYLLA OLD GROWTH FOREST

4b.) Herbaceous layer not well-developed although understory regrowth of conifers may be well initiated.

5a.) Forest located on steep slopes and surrounded by avalanche chutes or bluffs. Chamaecyparis nootkatensis or Thuja plicata may be codominant with Abies amabilis and A. lasiocarpa sometimes present. Understory similar to 2a above except that Taxus brevifolia might be present.

CHAMAECYPARIS-THUJA FORESTS

5b.) Abies amabilis dominant but trees less than 550 years old. Understory regrowth of silver fir and western hemlock present.

ABIES AMABILIS UNDERSTORY REGROWTH

1b.) Vegetation not dominated by conifer species greater than 20 feet tall. Either small conifers; deciduous alders, maples, or willows; shrubs; and/or suffrutescent perennials dominant.

6a.) Athyrium distensifolium and Oxyria digyna concurring with one being dominant. Small patches of these two species are found just in rocky meadows just below the glacier or on north-facing slopes which are shaded most of the day and heavily eroded.

ATHYRIUM-OXYRIA ASSOCIATION
A SUBCOMPONENT OF ROCKY MEADOWS COMMUNITY TYPE

6b.) Athyrium and Oxyria not co-occurring with one being dominant.

7a.) Area dominated by Alnus sinuata or Acer circinata with either species or the two together composing more than 80% of the overstory (absolute cover). The understory herbs might be reminescent of old growth coniferous forests (see lead 1B) and found on slopes greater than 10 degrees. Avalanche Chutes.

8a.) Alnus sinuata dominant with an understory of Dicentra formosa, Montia siberica, Smilacina spp., plus others. Other shrubs present include Ribes bracteosum, Rubus spectabilis, and Sambucus racemosa. On lower slopes (near the valley floor) Pteridium aquilinium is sometimes present and may occupy up to 80% of the cover.

ALNUS SINUATA AVALANCHE CHUTE

8b.) Acer circinata dominant with an understory of Smilacina spp., Galium trifolium, and sometimes the shrub Pachistima myrsinitites. This community is found on south-facing slopes which are convex and more xeric than areas with alders.

ACER CIRCINATA AVALANCHE CHUTE

7b.) Canopy cover of alder and maple less than 70% (not counting layering) or shrubs other than alder and maple occupying more than 20% of the absolute cover, and/or not located on a substrate with a slope greater than 10 degrees.

10a.) Shrubs (including alder, maple, and willows) present and conspicuous, possibly intermixed with conifers. If alders or willows occupy more than 80% of the cover, then they are found on areas with slopes less than 10 degrees.

11a.) Absolute cover of vascular plants less than 35% except for areas with clumps of Lupinus latifolius. Located on rocky areas or fine eroded till. Phyllodoce and Luetkea are often both present.

12a.) On eroded glacial till with Phyllodoce and Luetkea present and one of these taxa occupies more than 20% of the area. Anaphalis, Luzula, Juncus, and Lupinus might be present and codominant.

HEATHER MEADOWS

12b.) Glacial rubble conspicuous and large boulders are ubiquitous; alders are present or else the area is in an outwash channel or fine till.

13a.) Area highly eroded and steep with Anaphalis margaritacea and Alnus sinuata present with Luzula hitchcockii being less common. Slope greater than 15 degrees and total cover less than 15%.

ERODED TILL COMMUNITY

13b.) Other than above

14a.) Large boulders prominent in areas of recent glacial activity (within the last 80 years). Alnus sinuata, Cladothamnus pyrolaeflorus, and Menziesia ferriguinea present. Grasses never dominant. Subcomponents include Lycopodium alpinum, Phyllodoce spp. and Juncus might be present.

RUBBLE MEADOWS

14b.) Meadows with glacial rubble conspicuous also or else an area of outwash channels. Cryptogramma crispa, Penstemon davidsonii, Calamagrostis canadensis, Carex spectabilis and Elymus glaucus are indicative of this community of high taxonomic richness. Phleum alpinum is often dominant.

GRAMINOID MEADOWS

11b.) Absolute cover of vascular plants greater than 30%, or communities dominated by the moss Rhacomitrium canescens, or on alluvium or rocky moraine tops.

15a.) An abundance of large to intermediate sized conifers on the ground, apparently downed by snow slides or beavers, or an area of patchy shrubs and conifers of small stature. This includes young growth forests near the glacier and less than 80 years old.

16a.) Young growth conifer forest and shrub thickets in areas of undulating moraines. Mixtures of Abies amabilis, A. lasiocarpa, Chamaecyparis nootkatensis, Thuja plicata, Pseudotsuga menziesii, Pinus contorta, and Tsuga mertensiana accompany the shrubs Cladothamnus pyralaeflorus, Menziesia ferruginea, and Vaccinium spp.

17a.) Alnus sinuata present but not occupying more than 40% of the cover in areas that were glaciated 22 to 78 years before present. This is an area of active stem recruitment of Abies amabilis, Tsuga mertensiana, and Tsuga heterophylla (the latter in areas receiving direct sunlight for most of the growing season) with Abies lasiocarpa and Chamaecyparis nootkatensis recruitment noted in cooler, shaded areas with shorter growing seasons. Undulating moraines noted and Salix Scouleriana may be present in wetter areas.

OPEN ALDER, CLOSED CONIFER COMMUNITIES

17b.) Conifers and/or alders dominant agnd growing in dense thickets which make foot travel extremely difficult. Canopy closed and this area represents a stage of stem exclusion with sparse (if any) understory development.

CLOSED CONIFER, ALDER YOUNG GROWTH COMMUNITIES

16b.) A high density of large, felled conifers present or else an ecotonal area located between meadows or avalanche chutes and middle aged and old growth forests. Many small, rapidly growing Abies amabilis may be present (advanced regeneration) or else dead, standing trees in water may be present. Forest slides.

18a.) A distinct band of vegetation located between meadows or avalanche chutes and middle aged or old growth forest with 6 or more species of shrubs easily found, and possibly as many as 11 species of shrubs found within a $40m^2$ area.

PATCHY SHRUB COMMUNITY

18b.) Similar in structure to 18a above but not a distinct narrow band of vegetation located between 2 structurally different vegetation types.

19a.) Standing stumps 1 to 2 meters above ground level and the downed conifers are usually lying parallel to one another. The large downed trees were apparently broken by wind and/or snow slides. The grass Glyceria elata and species of Equisetum are noticeably absent.

FOREST BLOW DOWNS

19b.) Old stumps less than 1 meter above ground level and cone shaped at the tips (undoubtedly the work of beavers). Glyceria elata, Lyschitichum americanum, and species of Equisetum present. Marshy area with standing water or a running creek nearby.

BEAVER POND COMMUNITIES

15b.) Downed conifers absent (at least not common enough to make walking through the area difficult), or not an open, young growth coniferous forest.

20a.) Located on convex ridges or slopes of intact glacial moraines (most conspicuous on lateral moraines) with the lichen genera Rhizocarpium and Lecanora, the moss Rhacomitrium canescens, the lycopod Selaginella wallacei, the fern Cryptogramma crispa, and the angiosperm Saxifraga ferriguinea, Penstemon davidsonii, and Luzula spicata present.

20b.) Not as above.

21a.) Community located at the top of south-facing avalanche chutes (start zone) with Phacelia hastata and Artemesia ludoviciana present and perhaps dominant. Scherophyllous, evergreen shrubs (e.g., Pachistima myrsenites) might be present but do not occupy more than 20% of the absolute cover. Area of high taxonomic richness.

ARTEMESIA, GRASS, FORB
SHRUB COMMUNITIES

21b.) Vegetation found on sandy river bars with a mixture of conifers (up to 9 species), shrubs (alders and willows), and many mosses (particularly Rhacomitrium). The herbs Lupinus latifolius subalpinus and Epilobium latifolium are usually present (and sometimes dominant) and often co-occur.

RIVER BAR COMMUNITIES

10b.) Wet or shaded meadows (i.e., shaded by north-facing bluffs and cliffs) and/or avalanche chutes dominated by herbs other than Phacelis or Artemesia; or talus slopes with extremely late snowmelts; or waterfall communities.

22a.) Riparian habitat dominated by Mimulus lewisii.

MIMULUS LEWISII ASSOCIATION
A SUBCOMPONENT OF ROCKY
MEADOW COMMUNITIES

22b.) Mimulus lewisii not dominant.

23a.) Shrubs common although overall the physiognomy is open and patchy.

24a.) Shrubs covering 10 to 35% of the area; on slopes of 15 to 30 degrees with Sorbus, Rubus spp. and Sambucus racemosa co-occurring. Veratrum viride, Valeriana sitchensis and Elymus glaucus are usually present.

LUSH HERB AND SHRUB
MEADOW COMMUNITIES

24b.) Shrubs more dense than in 21a above, but in areas still characterized by patchiness and open canopy. Alnus sinuata codominant with Rubus spectabilis or R. parvifolius, or the latter 2 shrubs dominant. Generally found on slopes less than 15 degrees or wet, cool flat areas. Run out zone.

RUBUS AVALANCHE CHUTE

23b.) Physiognomy of low stature and/or rocky and located on granodiorite bluffs or talus slopes. Shrubs and conifers absent or else representing a very minor element of these communities.

25a.) Grass meadows with signs of heavy grazing. Three or more species of grasses present and abundant.

GRASS MEADOW COMMUNITIES

25b.) Vegetation on granodiorite bluffs or bouldery talus slopes or rarely flat talus at the base of slopes.

26a.) Heavy moss and lichen cover with shrub and herb cover less that 15%. The lichens Cladina rangiferina, Cladina mitis, Stereocaulon alpinum, Cladonia chlorophaea, Cladonia cristatella, Cladonia coniocraea, Cladonia bellidiflora, plus others are present and perhaps dominant. The mosses Polytrichium piliferum and Rhacomitrium spp. and the vascular plants Crytogramma crispa and Saxifraga ferriguinea are present as well; this community type is often found on slopes facing north and having very short growing seasons due to late snow melt. Small shrubby patches dominated by *Oplopanax horridum*, *Ribes bracteosum*, or even *Acer circinatum* are found here. As many as 3 species of *Lycopodium* may also be found here.

TALUS MOSS COMMUNITIES

26b.) Moisture present and conspicuous (wet seepage area or waterfall areas) and creating habitats with unique vegetation types.

27a.) Wet seepage areas on bluffs or at the tops of slopes with Aruncus sylvester always present and often the relative dominant. One to 3 species of *Arnica* are present.

ARNUCUS SYLVESTER COMMUNITIES

27b.) Waterfall community with *Mimulus tilingii*, *Tolfieldia glutinosa brevistyla*, *Penguiculia sp.*, and possibly *Pedicularis groenlandica* possibly present.

WATERFALL COMMUNITIES

APPENDIX 2. VISITORS TO NOOKSACK CIRQUE AREA:

20 July - 29 August 1977

VISITORS TO NOOKSACK CIRQUE AREA
20 July - 29 August 1977

Date	Visitors Male No.	∿Age	Female No.	∿Age	National Forest	National Park	Origin	Remarks
20 July	1	25-30	1	23-25	X			2 adults with 6 children
	2	6-10	2	6-10				
	2	<5						
22 July	1	20-25				X		Going over Icy Peak
23 July	1	30-35				X		1 adult with 1 child
	1	11-15				X		
	1	25-30	1	25-30		X		2 adults with 2 children
	1	6-10	1	6-10				
	3	20-25				X		
	2	25-30	2	25-30		X		
24 July			1	20-25		X		Day hike
28 July	1	25-30			X			Day hike
30 July	1	20-25				X		Overnight
	1	25-30				X		Day hike
	1	20-25	1	20-25	X			Camp visitors
			1	20-25	X			Camp visitor

VISITORS TO NOOKACK CIRQUE AREA
20 July - 29 August 1977

Date	Visitors Male No.	Male ∿Age	Female No.	Female ∿Age	National Forest	National Park	Origin	Remarks
31 July	2	15-20			X			Overnight
	2	25-30	2	25-30	X			4 adults, 4 dogs
1 Aug	2	20-25				X		Climbers
5 Aug	1	20-25			X			Frequent visitor
10 Aug	1	25-30	1	25-30		X		Frequent visitors
11 Aug	1	25-30	1	25-30		X		Overnight
12 Aug	1	20-25			X			Overnight
	1	20-25	1	20-25	X			
13 Aug	1	25-30	1	25-30		X		Overnight
14 Aug	2	20-25				X	Bellingham	Overnight
15 Aug	2	20-25				X		Day hike
	1	25-30				X		Weekend stay
16 Aug	2	20-25				X	Bellingham & Texas	Overnight
			1	20-25		X	Santa Barbara	Back-country Ranger
17 Aug	1	30				X	Maple Falls	Frequent visitor
	1	66				X		

VISITORS TO NOOKSACK CIRQUE AREA (Continued)

Date	Visitors: Male No.	~Age	Visitors: Female No.	~Age	National Forest	National Park	Origin	Remarks
19 Aug	2	45	1	40		X	Mt. Vernon	Family, overnight
	1	10	1	10				
	1	12						
20 Aug	2	20				X	Seattle	Overnight
	1	28	1	28		X	Seattle	Overnight
	1	45				X	New Haven, CT	
	1	25	1	25		X	Custard	Overnight
	6	25-30	3	25-30		X	Seattle	Mountaineers-Ruth Mt.
	3	?	2	?		X		Day hikers
23 Aug	4	15-30				X	Bellingham	Overnight
29 Aug	1	25-30	1	25-30		X	Seattle	Visitors
	1	50	1	50				
30 Aug	2	20-25	2	20-25	X		Sedro Woolley	Overnight