Vegetation and Fuel Mapping of North Cascades National Park Service Complex

Final Report
National Park Service
Contract CX-9000-3-E029

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National Park Service
Cooperative Park Studies Unit
College of Forest Resources
University of Washington
Seattle, Washington

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by

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INTRODUCTION

The area within North Cascades National Park Service Complex in north-central Washington (Figure 1) contains a wide and in some respects unique variety of plant communities. The crest of the Cascade Mountains passes through the park, but the Cascades are so wide in this area that parts west of the crest are in the rain shadow of more massive mountains further to the west. The Skagit River valley passes through this area and provides a low elevation habitat more characteristic of dry interior forests than coastal forests. In the southern portion of the park complex, which is east of the Cascade crest, a similar, more typical Cascade rainshadow effect exists. The result is a vegetation mosaic that contains typical "westside" vegetation elements, typical "eastside" vegetation elements, and some hybrid mixtures of "eastside-westside" vegetation that are rarely found elsewhere in the Cascade Mountains.

A substantial body of literature on the vegetation of the the region and the park has been developed. Some reports are very generalized, while others are very specific to one watershed or one particular plant community. Fuel evaluations have never been done for the park. The only existing vegetation map covering the whole park is a 1936 commercial forest type map completed while the area was still under USDA Forest Service management. Much of the park is mapped as "non-commercial/rocky" or "subalpine". While the map has utility it is considerably out of date and not descriptive enough to meet current resources management needs.

Project Objectives

This project was designed to produce current vegetation and fuel type maps for the North Cascades National Park Service Complex using Landsat data, associated terrain and precipitation information available in digitized format, and ground information. The intended product was not only maps of vegetation and fuels, but a description of major communities in the park complex and a dynamic geographic information system. This system would include terrain information as well as vegetation and fuels information, and could accept new layers of information in the future. The objectives of the project were met; this report is a summary of the process and results.

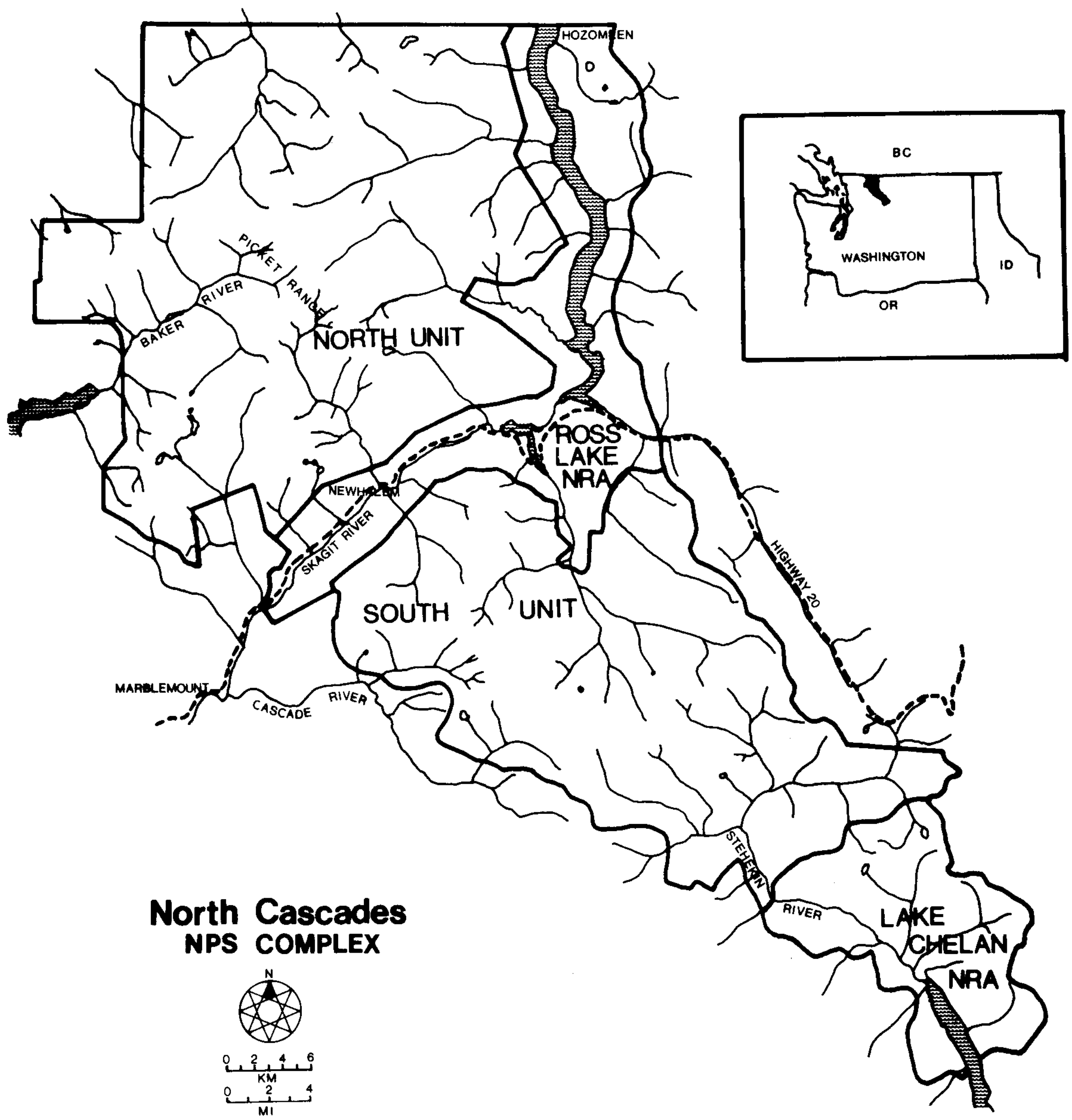


Figure 1. Location of the North Cascades National Park Service Complex in Washington.

Existing Vegetation and Fuel Information

This summary is intended to provide a capsulized look at the existing vegetation knowledge for the park complex. Reference can be made to individual publications to gain further insights into the scope of each project.

The flora of the park complex has been studied at several scales. Hitchcock and Cronquist (1973) provide a regional look at the flora, while Cooke (1962) limits his scope to the Cascades. The most complete flora for the park is by Naas and Naas (1974), and park-wide reconnaissances are also available (Kenady and Kenady 1969). More specific flora treatments are provided for the Silver Lake Research Natural Area (RNA) by Lesher (1984), the Pyramid Lake RNA by Zobel and Wasem (1979), and the Stetattle Creek RNA by Wagstaff and Taylor (1980).

The distribution of plant communities has been described at the regional level (Franklin and Dyrness 1973) as well as for the general North Cascades area (Franklin and Trappe 1963). When the park complex was created in 1968, additional park-wide surveys were done for plant communities, although little to no mapping was completed (Douglas 1971). Roughly equivalent treatment has been given to lowland/montane and subalpine plant communities. In the subalpine region, the most comprehensive study is by Douglas and Bliss (1977). Other studies of more limited application include Bjorklund (1980) in the Jasper Pass area off Goodell Creek, Douglas (1970) for the subalpine zone in general, Wiberg and McKee (1978) in the Boston Glacier area, Wagstaff and Taylor (1980) in Stetattle Creek, numerous lake surveys by Wasem and Bjorklund (unpublished), and some community mapping by Waggoner (unpublished) in the Stetattle Creek area. Montane to lowland vegetation studies have included Oliver et al. (1985) in the Nooksack Cirque area (which is at the subalpine border), Oliver and Larson (1981) in the Stehekin Valley (including some type mapping), Comulada (1981) in the Chilliwack Valley, Miller and Miller (1971) in the Big Beaver Valley, Scott et al. (1971) in the Ross Lake corridor, and Dueker and Glad (1979) in the Skagit River corridor. Different standards for measuring plant community characteristics have been used in each study.

Plant succession has been part of many of the studies cited above, but several studies have focused on community development and disturbance. Fire has been the most common process studied, although usually in rather brief, unpublished report form. The most complete study is Larson's (1972) on lodgepole pine in the Skagit-Ross Lake area. Oliver and Larson (1981) included fire history as part of their Stehekin fuelwood study. Miller and Miller (1974) conducted brief surveys of the Thunder Creek and Silver Creek fires; Tunison (1978, 1980) surveyed the Bear Mountain fire. Taylor (1977) and Allen (1983) have conducted brief surveys of fire history along the upper east side of Ross Lake, while Douglas and Ballard (1971) studied subalpine shrub community succession after wildfire in the Stetattle Creek area. Succession after glacial retreat was a focus of the Nooksack Cirque study (Oliver et al. 1985) and succession after disturbance by avalanche has been studied by Smith (1974).

The only fuels work done in the park was by Oliver and Larson (1981) who surveyed the Stehekin Valley for potential fuelwood supply for valley residents. Results were in cords of potential fuelwood and potential forest growth to supply firewood rather than any aspect of potential wildfire behavior.

METHODS

LANDSAT DATA COLLECTION AND DIGITAL ANALYSIS

The overall computer processing strategy employed in the North Cascades project closely paralleled that used in an earlier Olympic National Park project (Cibula and Nyquist (in press)). Landsat multispectral scanner (MSS) data were used in conjunction with other data sources (elevation, slope, aspect, and precipitation) in a geographic information system approach to derive vegetation/landcover and fuels classifications (Figure 2).

Two existing Landsat MSS data tapes (scene numbers: E-21640-18133-6, 20 July 1979 and E-30114-18141-5, 27 June 1978) were obtained from the University of Washington Remote Sensing Applications Laboratory (UW/RSAL), as prior work (Jim Eby, University of Washington, personal communication) suggested they were suitable for the North Cascades project. The 1978 scene covered most of the project area, while the 1979 scene was used to provide data for a small portion of the southeastern corner of the area not covered by the 1978 scene.

The 1978 data set was first processed through Earth Resources Laboratory Applications Software (ELAS) modules SRCH, an automated ("unsupervised") technique for deriving homogeneous training statistics, and MAXL, a maximum likelihood classifier. This operation yielded 38 spectral signatures that appeared valid when viewed with a false color infrared color table created by CIRT. These 38 multispectral classes were then lumped into nine broad cover type classes: dark conifer, light conifer, dark deciduous/mixed, light deciduous/mixed, herbaceous, bareground/rock, snow/ice, water, and shadow. These cover types correlated well with the

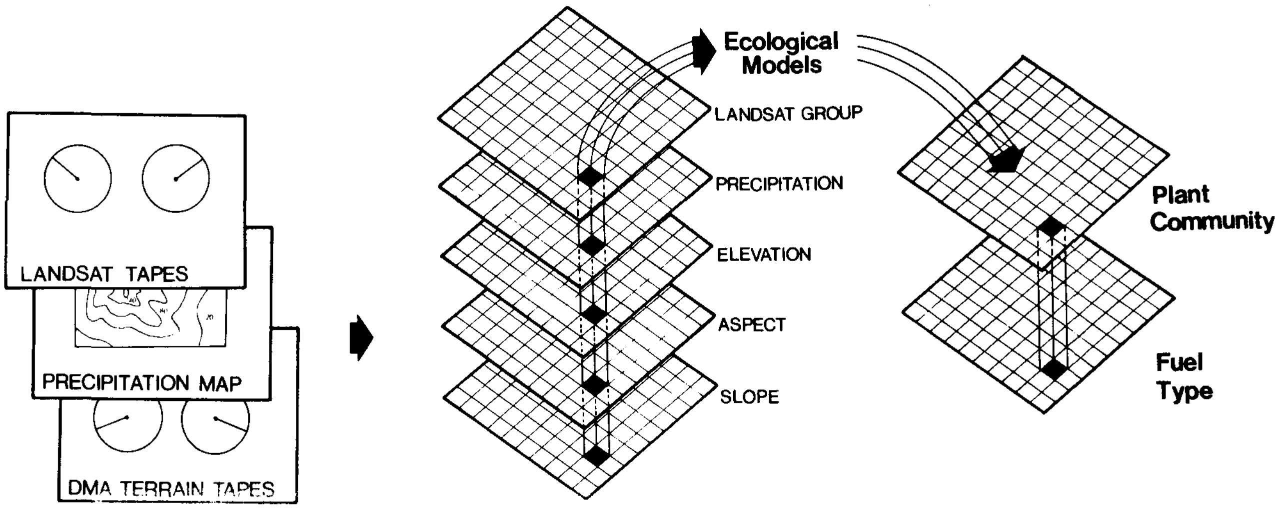


Figure 2. Conceptual scheme of a geographic information system.

work previously done by UW/RSAL and existing knowledge of landcover types in the North Cascades area.

Control points were then picked for this data set and ELAS modules PMGC and PMGE were used to resample the data to 50 meter cells and fit them to the Universal Transverse Mercator (UTM) grid projection. The resulting RMS error was +-59 meters (or one pixel). As described later, plots of these lumped, georeferenced Landsat groupings were used for initial field sampling.

Digital topographic information was obtained from the Defense Mapping Agency (1:250,000 scale DMA). The ELAS modules TOP1-TOP5 were used to reformat, rotate, compute mapping coefficients, and resample the data to the UTM grid. The ELAS module TOP6 was used to derive elevation (100 ft intervals), aspect (nine classes including flat), slope (15 intervals), and average slope length files, all of which were formatted in a 50 meter cell size.

Precipitation zone isohyets and park boundary lines were mapped. These data were manually digitized using modules in the Statistical Applications Group Information System (SAGIS) software package. The resulting vector files were converted to ELAS raster (cell) data files through ELAS module SAGE.

The geographic information system (GIS) data base was produced by using ELAS module OVLA which registers each of the various MSS, topographic, precipitation, and boundary files to the others and creates one new multi-channel data file. The multi-channel data file was eventually used for the 57 separate runs through ELAS module DBAS to perform the ecological modelling, which is described later in this report.

At this stage, the entire GIS data base had been created except for Landsat MSS classification of the southeastern corner of the park complex. Past experience had shown that a technique called "signature extension" might appropriately be used in this situation. Signature extension is where the set of training statistics from one scene is applied to an adjoining scene, and is usually applied between two Landsat scenes acquired in the same day on the same path. In this case, the June 1978 scene was from Landsat 3 while the July 1979 scene for the southeastern corner of the study area was from Landsat 2. Channel 7 in Landsat 2 has a dynamic range of 0-63 (as processed) compared to 0-127 for the same channel in Landsat 3. In an attempt to "normalize" the Landsat 2 data, a DBAS operation was used to double the values for channel 7 for the 1979 scene. Then the same SRCH statistics and MAXL parameters used in the June 1978 MSS data were applied to the altered July 1979 MSS data.

The false color infrared color table (CIRT) used for the June 1978 data was applied to the resulting July 1979 multispectral classes. Areas where the data sets overlapped were visually inspected for inconsistencies. The only detectable difference was the areal extent of snowpack. This indicated that the signature extension technique was valid and that the decision rules for the GIS ecological modelling could be applied to the entire GIS data set.

Control points for the July 1979 scene were picked. ELAS modules OCGN and OCEO were used to perform the georeferencing because of differences in data format (Goddard versus EROS). The RMS error was again +-59 meters, or one pixel.

The subset of the July 1979 MSS data set required to fill in the southeastern corner of the park complex was merged with the June 1978 set using ELAS module JCOP, producing one continuous data file of consistent multispectral signatures. The fit of the two data sets was excellent. For example, a major highway curves at one location where the two sets are joined, and there is no displacement at all in road alignment. The only discernible evidence of using two data sets is the differential extent of snowpack along the line joining the two sets. At this point the construction of input data files (or channels) for the GIS data base was completed.

VEGETATION METHODS

The ground sampling and analysis were designed to provide information with which to build predictive direct gradient models based on the layers of data in the geographic information system and to provide ground truth for the community maps produced.

FIRST YEAR FIELD PROCEDURES

The initial field sampling was designed to subjectively survey the entire park complex (approximately 700,000 acres (300,000 ha)) within one field season. Two 2-person crews conducted the field sampling, so a substantial amount of territory had to be covered by each crew. Information on physiography (elevation, aspect, and slope) and vegetation were collected to refine the initial Landsat spectral groupings and provide descriptive information on the variation within each mapped unit that would later be defined.

The sampling was done at a reconnaissance level. The park was divided up into sampling units, and each crew covered one sampling unit each trip. Team members alternated after each trip to minimize sampling bias due to team composition. Sampling was done along roads, trails, and cross-country traverses. Sampling points were subjectively established to sample a wide variety of the five broad Landsat groups (bareground/rock, snow/ice, water, and shadow were not sampled) and associated terrain conditions. A total of 425 plots were located in or immediately adjacent to the park complex (Figure 3).

Each ground plot was marked on an aerial photograph and on the appropriate USGS quadrangle. One ground level and one canopy oriented picture was taken at each plot. Information collected at each plot was recorded on waterproof data forms (Figure 4). Physical information included the plot number, team identification, aerial photo number, descriptive location, USGS quadrangle, UTM coordinates, elevation (by altimeter), aspect (by compass), and slope (by clinometer).

Vegetation information was gathered for two purposes: (1) to differentiate the five Landsat spectral groupings into a larger number of more specific vegetation cover types, and (2) to provide descriptive information on the variety of plant communities likely to be found in each identified cover type. Where possible, the habitat type (or potential vegetation) in the plot vicinity was recorded. If the stand was clearly multi-aged due to repeated disturbance, this was also recorded, as well as the general vegetation structure: grass, shrub, young growth, mature, old growth. The overall cover of vegetation was recorded in one of six classes: 1 (0-5%), 2 (5-25%), 3 (25-50%), 4 (50-75%), 5 (75-95%), 6 (95-100%). Specific measurements on trees were collected using dimensioned and non-dimensioned plots. A dimensioned plot of varying size was used to determine tree density of each species by height class (0-3m, 3-10m, and >10m). The plot size was small in dog-hair thicket stands (perhaps 25 sq m) and large in more widely spaced stands (100-400 sq m). The height of the dominant layer of each species was recorded, along with its cover class. Non-dimensional plots were used to record basal area by species, and cover of dominant shrubs and herbs. Comments were made on disturbance history if appropriate, community type, Landsat spectral groupings, and 35mm photo information.

Field notes were taken on general vegetation changes with terrain in each sampling unit to aid in the data analysis process; notes were referenced to map and aerial photo locations where appropriate. Binocular scans of surrounding terrain were often used to identify major tree species.

ORDINATION AND CLASSIFICATION PROCEDURES

The purpose of using multivariate analysis of vegetation at North Cascades NPS Complex was to (a) relate community

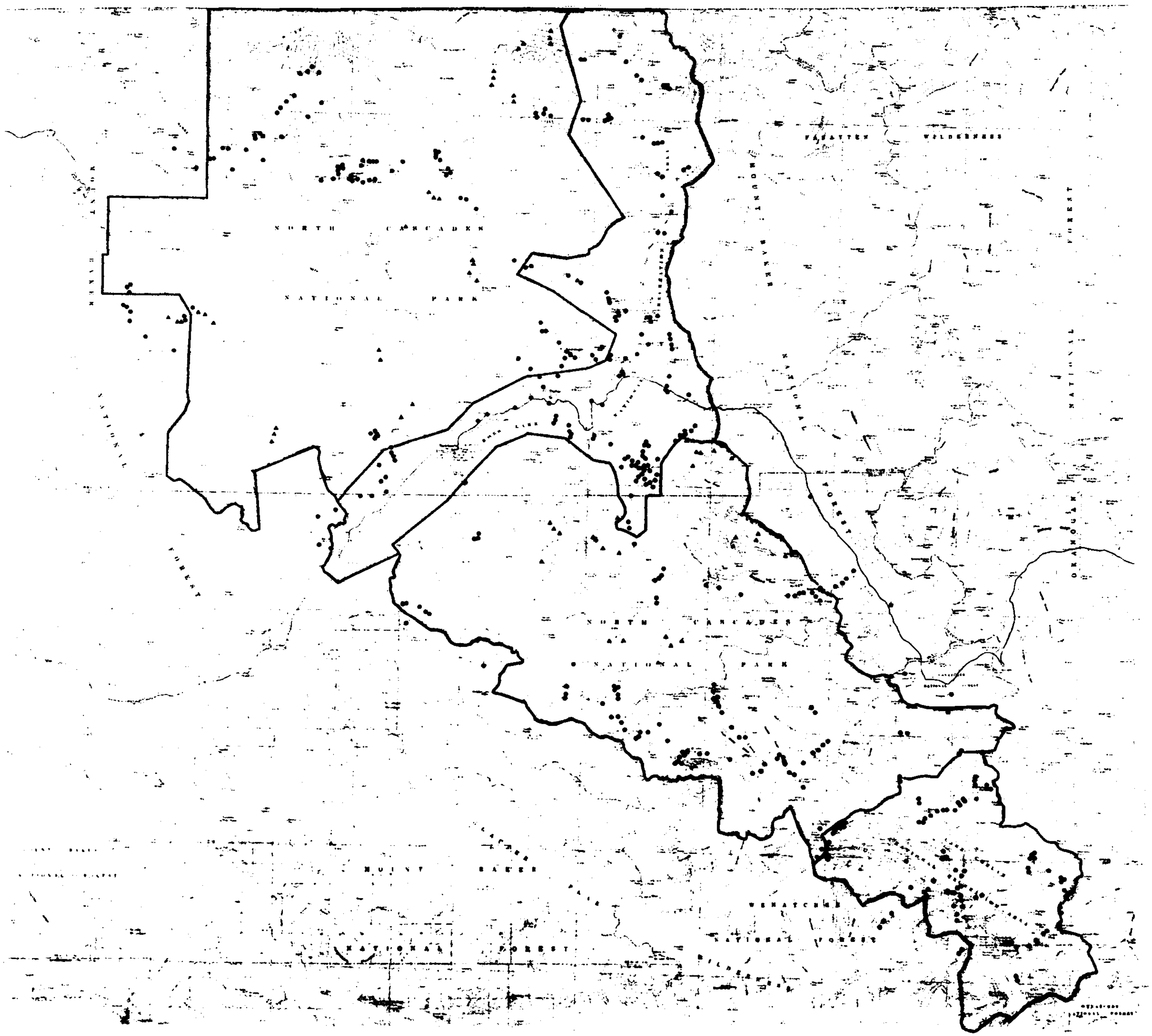
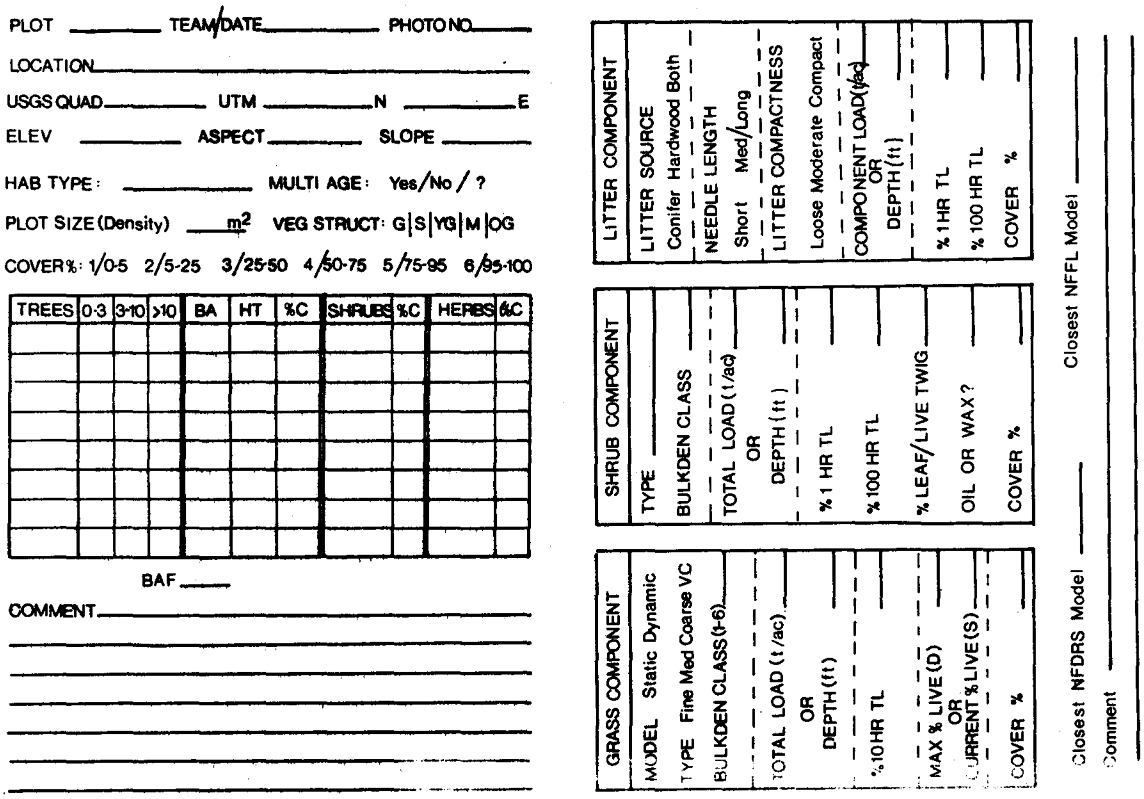


Figure 3. Field plots in 1983 ground sampling.


PLOT ______ TEAM/DATE ______ PHOTO NO. ______
LOCATION ______
USGS QUAD ______ UTM ______ N ______ E
ELEV ______ ASPECT ______ SLOPE ______
HAB TYPE: ______ MULTI AGE: Yes/No / ?
PLOT SIZE (Density) ___ m² VEG STRUCT: G|S|YG|M|OG
COVER%: 1/0-5 2/5-25 3/25-50 4/50-75 5/75-95 6/95-100

TREES	0-3	3-10	>10	BA	HT	%C	SHRUBS	%C	HERBS	%C

BAF ______
COMMENT ______

LITTER COMPONENT: LITTER SOURCE Conifer Hardwood Both; NEEDLE LENGTH Short Med/Long; LITTER COMPACTNESS Loose Moderate Compact; COMPONENT LOAD (t/ac) OR DEPTH (ft); % 1 HR TL; % 100 HR TL; COVER %

SHRUB COMPONENT: TYPE; BULKDEN CLASS; TOTAL LOAD (t/ac) OR DEPTH (ft); % 1 HR TL; % 100 HR TL; % LEAF/LIVE TWIG; OIL OR WAX?; COVER %

GRASS COMPONENT: MODEL Static Dynamic; TYPE Fine Med Coarse VC; BULKDEN CLASS (1-6); TOTAL LOAD (t/ac) OR DEPTH (ft); % 10 HR TL; MAX % LIVE (D) OR CURRENT % LIVE (S); COVER %

Closest NFDRS Model ______ Closest NFFL Model ______
Comment ______

Figure 4. The data form used in the 1983 sampling.

variation to environmental gradients that could be represented by layers of the geographic information system (e.g., elevation, aspect, etc.) and (b) to summarize and classify the 425 ground plots in a coherent manner. A wide variety of techniques is available. The most common ones are summarized below to help explain why the particular techniques used were chosen.

Techniques for Analyzing Vegetation by Multivariate Methods

This review is a summary of material contained in Gauch (1982) which is an excellent overview of available techniques. The main purposes of multivariate analyses are to summarize community data, relate community variation to environmental gradients, and to understand community structure. Relationships between community and environment are complex, often nonlinear, and numerous, making usual statistical techniques less satisfactory than multivariate ones, which allow examination of several variables simultaneously.

Direct gradient analysis is used to study the distribution of species along recognized predetermined environmental gradients. It is a subjective approach and is complemented and reinforced by more objective ordination techniques. The final North Cascades models were essentially direct gradient models. An example of a direct gradient analysis is one resulting in a plot of species abundances along a recognized environmental gradient such as elevation (which can also be interpreted as a temperature gradient). Variables measured can also be community types, or growth forms. Two dimensional direct gradient analysis can be plotted, using for example soil moisture on the abscissa and temperature along the ordinate. Groups of samples close to one another can be recognized as community types. Direct gradient analysis is primarily environment-centered; the environment is used as an independent variable and vegetation change is fitted to it in one or two dimensions.

Ordination and classification techniques, on the other hand, generally summarize and organize community data on species abundances only, leaving environmental interpretation to a later time. These were believed to be useful techniques for the North Cascades project because they would help define the most important environmental gradients in the park complex before the direct gradient models were constructed. The data of a samples-by-species matrix (with all species listed on one axis and all samples on the other) can be viewed from either a species or a sample perspective. A secondary matrix can be computed from the primary species-by-samples data matrix to produce dissimilarity values for each pair of species or samples. These four types of spaces represent the starting point for most ordination and classification techniques.

Ordination simplifies the original high dimension species or samples space to produce a two or three dimensional species or samples space, so that the distribution of points can be studied. The desired output of ordination is "ecological space", with easily recognized environmental gradients as axes. The most common ordination techniques are weighted averages, polar ordination, principal components analysis, reciprocal averaging, and detrended correspondence analysis.

Weighted averages is a subjective technique where the investigator assigns a relative weight to each species based on perceived placement on some environmental gradient (e.g., 1 for species found in moist environments, 5 for ones found in dry environments) and then a score is totalled for each sample based on the abundance of various species. It is a simple but very subjective ordination technique. Polar ordination arranges species or samples based on relative similarity or dissimilarity to the subjectively chosen species or samples complex serving as endpoints for each axis. Environmental interpretation of the results can be relatively straightforward.

Principal components analysis (PCA) assumes that the complexes of environmental factors determining plant distribution are measured indirectly through the plants themselves. Ordination placement is derived from the data alone; the investigator does not weight species or choose endpoints. Species and sample ordination scores are produced simultaneously. PCA efficiently projects points from multidimensional space into fewer dimensions with the least amount of distortion. The first PCA axis going through the points is in the direction that captures as much variance as possible along the ordination axis. A second axis perpendicular to the first accounts for much of the remaining variance, followed by a sequence of axes of diminishing importance. An eigenvalue is calculated for each PCA axis, showing its relative importance. The model assumes that the variables (species abundances) change linearly along the gradients, which is rarely true and causes distortion in interpreting the results.

Reciprocal averaging (RA) is related to weighted averages and PCA. It requires no weights or endpoint selection. Through a process of iteration, RA produces a sequence of axes of decreasing importance which can be related to environmental data. Typically, the samples on the ends of the first axis are compressed relative to those in the middle, so that scaling is difficult. The eigenvalue of the second axis often represents a distortion of the first axis, relegating secondary environmental gradients to the third or higher axes. RA results are generally superior to PCA results and the method is easily applied to large data sets.

Detrended correspondence analysis is based on RA but corrects its two major faults through detrending and rescaling. Detrending - a method of adjustment of scores of axis 2 against axis 1 - is applied to the iteration and removes the distortion or "arch" problem. Uniform axis rescaling allows better comparison with results from different data sets. Environmental interpretation, as with the other techniques, is a separate and subsequent task.

Classification involves grouping similar entities together in clusters. Community ecologists use three kinds of classification: tabular arrangement by the Braun-Blanquet approach, nonhierarchical classification, and hierarchical classification. Customary input is species abundance in a two-way samples-by-species data matrix. Classification can aid environmental interpretations of community variation, express relationships among samples, and identify outliers in the data sets.

The Braun-Blanquet table approach is a manual procedure that requires extensive subjective judgment and is not well standardized; it is a very slow process, too, so that other techniques are often preferred. Nonhierarchical classification assigns species or samples to clusters but does not arrange the clusters in relation to one another. It can identify redundant samples or outliers and is often used as a preliminary technique to edit very large data sets.

Hierarchical classification groups similar species or samples together and arranges them in a tree-like structure called a dendrogram. As a data set gets larger, the tree branches more, so that some branching cutoff is necessary. Of the three groups of hierarchical classification techniques, monothetic divisive techniques are rarely used anymore. Polythetic divisive techniques, more commonly used, split the entire data set into two branches, then each branch into two more branches, etc. The major advantage is that the entire data set is used for the critical topmost divisions, and it is a rapid (and thus inexpensive) procedure. Polythetic agglomerative techniques start with individual species or plots and group them into larger and larger entities, which is a more time-consuming process than the divisive techniques.

Choice of Multivariate Techniques

Detrended correspondence analysis was chosen as the ordination technique for the North Cascades data, as it seems to provide the most objective means of inferring important environmental gradients in the data set. A FORTRAN program called DECORANA (Hill 1979a) was used to analyze the data.

The input data was in the form of an importance value for each species in each sample. The importance value consisted of cover class alone (expressed on a scale of 1-6) for shrubs and herbs, and for trees was the average of relative density (expressed on a scale of 1-6) and cover class (on the 1-6 scale). Rare species were downweighted by the program using a predefined option.

Classification used the polythetic divisive method. TWINSPAN (Hill 1979b), a FORTRAN program designed for this analysis, was applied using default mode on all options. This limited the number of levels to be defined to reasonable numbers. The default options also include "pseudospecies" which are created by dividing species with high abundance values into two "species", so that a sample with high abundance can be separated from one with low abundance while still recognizing the basic similarity between the presence of the species in both samples.

The output was used to cluster groups of plots together into cover types, and to infer similarities between various cover types.

DEVELOPMENT OF INITIAL ECOLOGICAL MODELS

The DECORANA ordination technique provides a set of ordination axes that can be related to environmental gradients. However, these gradients are determined wholly on the basis of floristics rather than direct measurement of temperature or moisture or other gradient. Independent data or refined subjective judgment are necessary to translate the unlabelled axes into actual environmental gradients.

The ecological models necessary for the North Cascades project had to be based on indices of direct environmental gradients. While the indirect gradient ordination did not define the direct gradients, it was useful insofar as it provided direction for the choice of direct gradients. The indices to direct gradients in the geographic information system were elevation, as an index to temperature, and annual precipitation, slope, and aspect as indices to moisture availability. These indices were evaluated as reasonable predictors of the primary environmental gradients determining plant community distribution. Each combination of environmental variables, given Landsat group, had to be assigned to a unique cover type. While a less deterministic approach could have been used, the data necessary for a more probabilistic approach were not available.

Sample data were assigned into cover types based on the output from TWINSPAN. Each set of plots within a cover type was then described in terms of its range of precipitation, elevation, aspect, and slope. In some cases, the environmental data as summarized by plots assigned to two cover types overlapped to some degree. Other combinations of annual precipitation, aspect, slope, and elevation were not represented within the data set. If the vegetation of the park complex is viewed as a rumpled blanket on a bed, some areas had two blankets and others were not covered at all. Uncovered areas were assigned a plant cover type by stretching the nearest two cover types into the space. Areas that had overlap were assigned only one cover type by shrinking the extent of the two overlap cover types. These judgments were made based on field notes; where no field notes were applicable to the situation, a consensus from the field crew was reached. The final models were direct environmental models that predicted plant cover type from general Landsat type, annual precipitation, elevation, aspect, and slope.

There were five general Landsat vegetation types: "dark" conifer (generally mature forest), "light" conifer (generally open forest or very young forest), "light" and "dark" deciduous classes, and herbaceous. Annual precipitation ranged in 50 cm (20 in) classes from 50 cm (20 in) to >350 cm (>140 in). Elevation ranged in 30 m (100 ft) zones from 0 m (0 ft) to the highest elevation in the park. Slope ranged from 0 to >100 percent in 5 percent classes. Aspect was measured as one of the eight points around the compass (N, NE, E, SE, etc.) plus flat aspects.

These models were provided to the Denver Service Center Remote Sensing Group in the form of computer programs written in DBAS, a branching-type language developed from BASIC that is used in ELAS, the software package used to process and combine layers of the geographic information base. Each pixel was assigned one of 22 plant cover types based on the particular combination of the above data pertinent to that pixel.

Once the initial plant community classification was assigned within the geographic information base, maps were produced using both color line printer output at 1:100,000 and color polygon maps at 1:24,000 to aid field checking during the second field season. Reproductions of portions of both types of color maps (Figure 5) are shown with mylar overlays and are of significantly lower quality and readability than the actual maps.

FIELD REVIEW OF 1984 PLANT COMMUNITY MAPS

The objective of the field review was to check the accuracy of the cover type maps prepared.The goal of the classification was an 85 percent accuracy for the plant cover types as a whole. In order to adequately sample each type, 820 plots were sampled. Samples were chosen roughly proportional to area represented in the mapped cover type with relatively uniform sampling across the park complex (Table 1, Figure 6). The total sample number was based on financial criteria. Although some samples were taken outside of the park complex, conclusions about map accuracy should not be extended too far from the boundary of the park complex.

Each sample could be identified from the maps as a particular cover type. The sample on the ground was keyed to a particular cover type using the key shown in Table 2. This key was developed based on the overstory or cover characteristics of the ground plots previously sampled within each cover type. The cover of plants on each map check plot

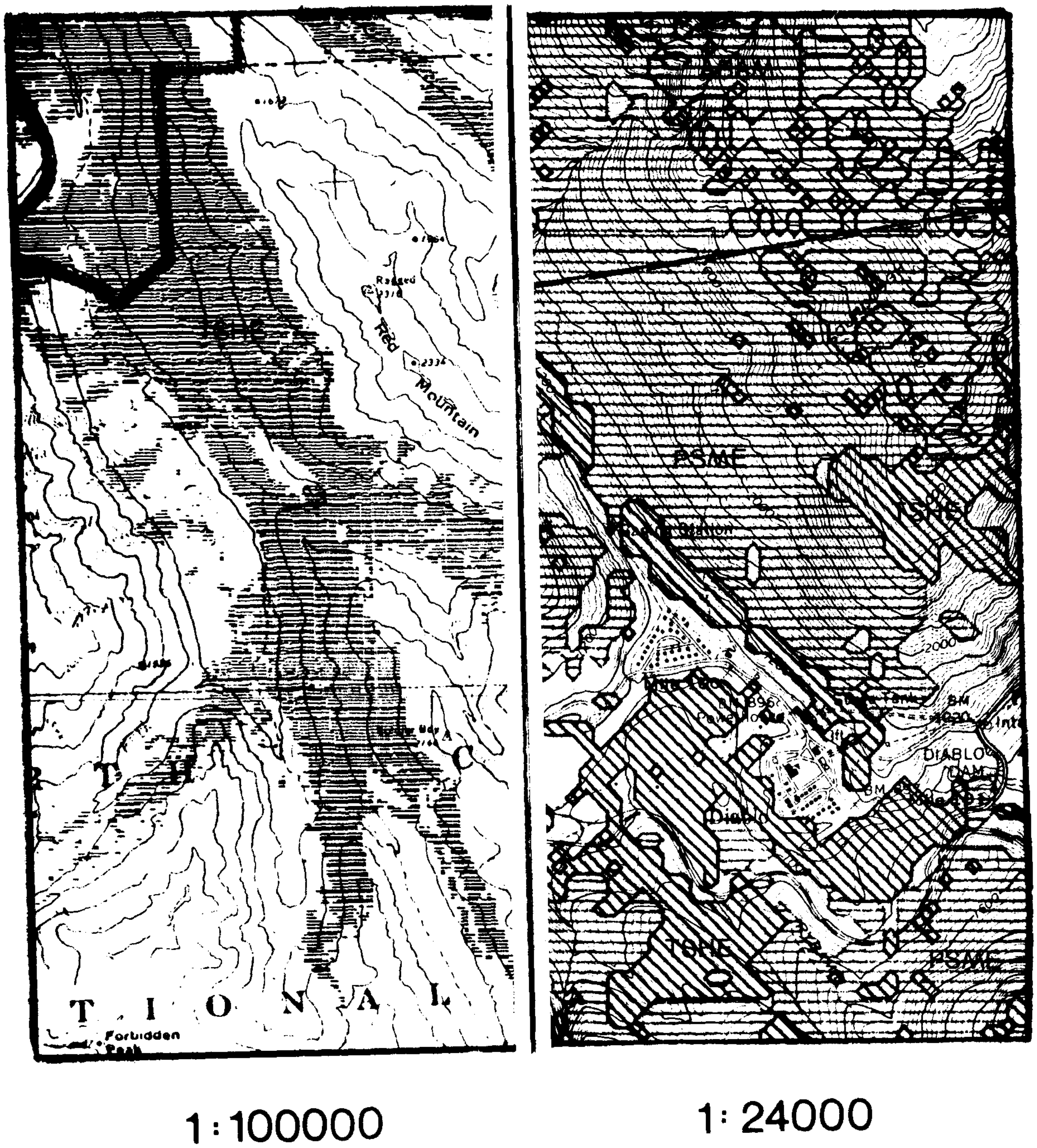


Figure 5. Examples of preliminary cover type maps at two scales.

Table 1. Distribution of 1984 field check samples by cover type.

Cover Type Number	Cover Type	Sample Dist. Prop. to Area		Actual Sample Distribution	
		No.	%	No.	%
1	Ponderosa pine-C*	1	.1	4	.5
2	Douglas-fir-C	106	12.9	102	12.4
3	Grand fir-C	1	.1	10	1.2
4	Subalpine fir-C	69	8.4	71	8.7
5	Whtbk. pine/Sub. larch-C	8	1.0	14	1.7
6	Mountain hemlock-C	46	5.6	30	3.7
7	Pacific silver fir-C	99	12.1	77	9.4
8	Western hemlock-C	97	11.8	71	8.7
9	Hardwood forest	4	.5	10	1.2
10	High shrub	54	6.6	54	6.6
11	Lowland grass	17	2.1	17	2.1
12	Fescue meadow	10	1.2	2	.2
13	Lush herb	93	11.3	89	10.8
14	Heather meadow	7	.9	14	1.7
15	Ponderosa pine-O*	2	.2	4	.5
16	Douglas-fir-O	50	6.1	69	8.4
17	Grand fir-O	1	.1	0	0
18	Subalpine fir-O	45	5.5	71	8.7
19	Whtbk. pine/Sub. larch-O	6	.7	26	3.2
20	Mountain hemlock-O	28	3.4	42	5.1
21	Pacific silver fir-O	37	4.5	17	2.1
22	Western hemlock-O	40	4.9	26	3.2
Totals		820	100	820	100

*C= closed canopy type
O= open canopy type

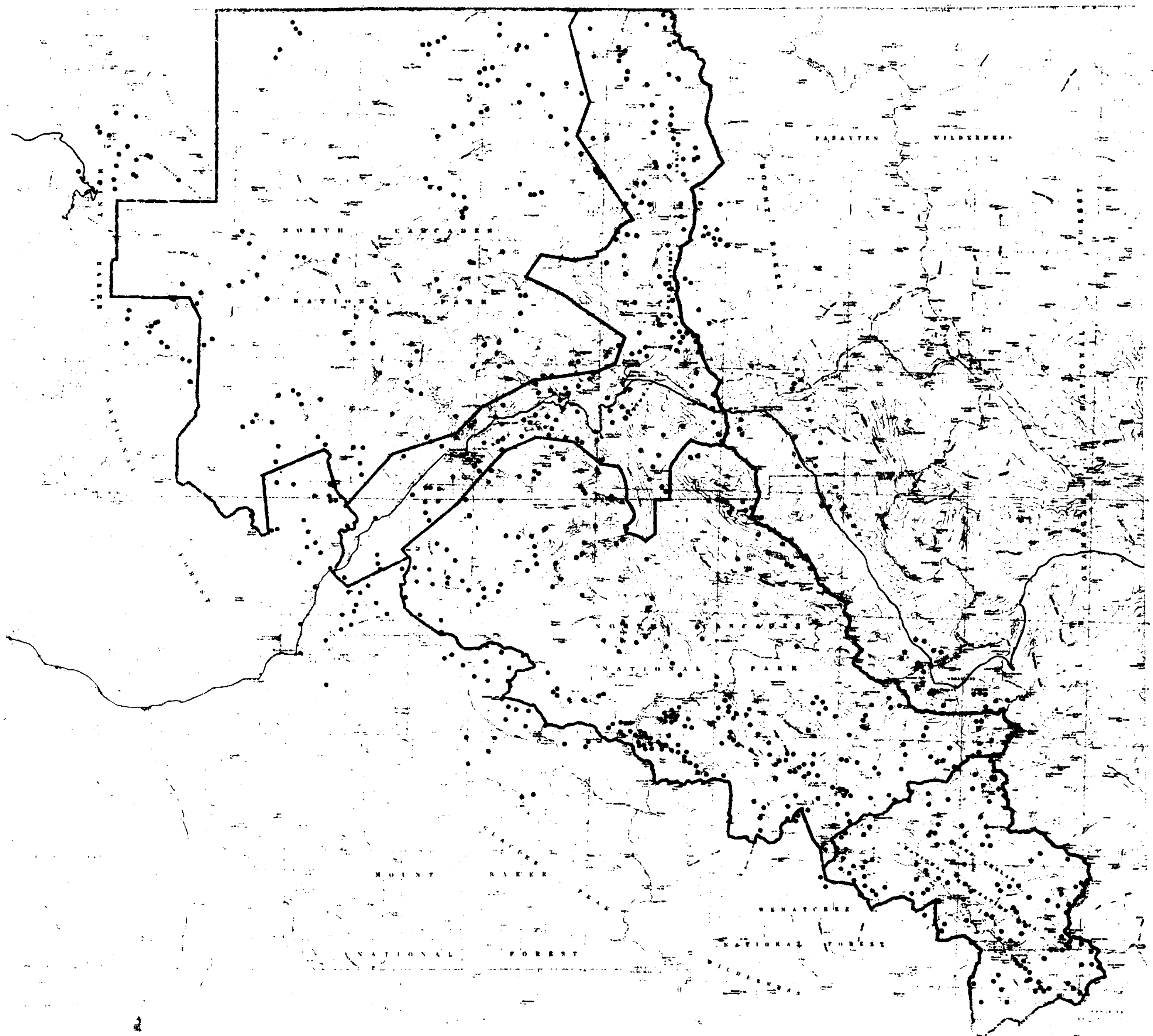


Figure 6. Plots sampled in the 1984 field check of cover type map.

Table 2. Key to Cover Type identification for 1984 field checking.

Key	Cover Type/No.
1. Coniferous cover dominant	
2. Abgr abs. cover >1	Abgr(3/17)
2. Abgr abs. cover <2	
3. Pipo rel. cover >50% and tot. cover <4	Pipo(1/15)
3. Pipo rel. cover <50% or tot. cover >3	
4. Abam>33% rel. cover or > rel.cover of (Tshe & Thpl)	
5. Tsme >50% rel. cover	Tsme(6/20)
5. Tsme <50% rel. cover	
6. Abla >50% rel. cover	
7. Pial/Laly >25% rel. cover	Pial/Laly(5/19)
7. Pial/Laly <25% rel. cover	Abla(4/18)
6. Abla <50% rel. cover	Abam(7/21)
4. Abam <33% rel. cover or <rel. cover of (Tshe & Thpl)	
8. Tshe/Thpl >10% abs. cover	Tshe(8/22)
8. Tshe/Thpl <10% abs. cover	
9. Tsme >50% rel. cover	Tsme(6/20)
9. Tsme <50% rel. cover	
10. Abla >50% rel cover	
11. Pial/Laly >25% rel. cover	Pial/Laly(5/19)
11. Pial/Laly <25% rel. cover	Abla(4/18)
10. Abla<50% rel. cover	
12. Psme/Pico >50% rel. cover	Psme(2/16)
12. Psme/Pico <50% rel. cover	Start over*
1. Non-coniferous vegetation	
13. Herbaceous or low shrub (<1.5m) dominant	
14. Below 3500 ft elevation	Lowland grass (11)
14. Above 3500 ft elevation	
15. Heather abs. cover >1	Heather meadow(14)
15. Heather abs. cover <2	
16. Fescue cover >1	Fescue meadow(12)
16. Fescue cover <2	
17. Varied herb cover w/ or w/o Vaccinium; grass cover <3	Lush herb(13)
17. Grass (non-fescue) dominant with abs. cover >2; below 4500 ft. elevation	Lowland grass (11)
13. Hardwood forest or high shrub	
18. Cover predom. shrub <10 m tall	High shrub(10)
18. Cover predom. taller than 10 m	Hardwood forest(9)

*If key does not work on first run through, rules may have to be slightly modified for that plot. Make note of any such changes.

Abam= Pacific silver fir, Abgr= grand fir, Abla= subalpine fir, Laly= subalpine larch, Pial= whitebark pine, Pico=lodgepole pine, Psme= Douglas-fir, Thpl= western redcedar, Tshe= western hemlock, Tsme= mountain hemlock.

were recorded in cover classes (1-6) by species. On forested plots, only overstory trees were recorded. On shrub or herb plots, major shrubs or herbs were recorded. One weak link in the key was the inability to differentiate between the relatively closed canopy portion and the relatively open canopy portion of forested cover types. The key to plant cover types (Table 2) did not differentiate between the open and closed canopy portions of each forested cover type, although generally stands with tree cover less than 50% (with rock or shrub or grass comprising the rest) were classed as "open". Field plots with cover classes 1 (0-5%) and 2 (5-25%) were classed as "open", and plots with tree cover of 4-6 (>50%) were classed as "closed". Plots with tree cover of 3 (25-50%) were put into one of the two classes based on the subjective judgment of the crew.

Because overstory or visible cover by species was the only community characteristic recorded in the field review of maps, considerably more flexibility was possible in the map review than in the previous year's intensive ground sampling. Samples were taken from helicopters, roads, trails, and boats on map blocks of cover types that were at least 5 pixels square (250 by 250 m) to avoid the possibility of improper map location in such rugged terrain. The data were returned to the lab and evaluated using a two-way matrix with the mapped cover type for each sample on one axis and the field keyed cover type on the other axis. A perfect fit would result in only the diagonal boxes of the matrix being filled in. Distance from the diagonal on an incorrectly identified plot has no ecological meaning past misidentification.

The proportion of correctly identified plots for each type was calculated as the sum of correctly identified plots (the diagonal box) divided by the total plots sampled within that mapped community type. The most common misclassifications were also identified using a similar approach.

Several cover types were eliminated after the field review. Some covered so little area that field checking was not possible, and their absorption into a more common type had an insignificant effect on the classification. One type was eliminated due to inadequate environmental definition of its boundaries. Revised ecological models were sent to the Denver Service Center Geographic Information Systems Field Unit, and final plant community maps were prepared.

FUELS METHODS

FIRST YEAR FUEL MODEL SAMPLING

Fuels data were collected using three related fire modelling or rating systems. At each of the first year ground plots where vegetation information was collected, fuels information was also collected. The closest National Fire-Danger Rating System (NFDRS) model and closest Northern Forest Fire Laboratory (NFFL) model were determined using existing keys (see appendix 1) provided by reference documents for each system (Deeming et al. 1977, Albini 1976). In addition, sufficient information was collected on each plot to generate parameters for new site-specific fuel models, using the BEHAVE program (Burgan and Rothermel 1984). Fuel data were collected for the three fuel components associated with the spread of fires: grass, shrub, and litter components (see Figure 4 for data form). The information collected was based on an early draft of the BEHAVE system, which underwent some changes before the final version was published, particularly in the photo keys for estimating load/depth relations in the shrub component.

FIELD SAMPLING OF FUEL WEIGHTS FOR SITE SPECIFIC REGRESSIONS

In order to verify the BEHAVE estimation procedures for grass and litter components, and to rectify the inconsistencies between our manner of collecting data and the final BEHAVE algorithms for calculating fuel parameters from the field data, actual fuel sampling was done for all three fuel components during the 1984 season.

Each of the fuel components was sampled separately, consistent with the manner in which they are treated in the Fuel Subsystem of BEHAVE. Grass and litter samples were collected from 0.1 sq m (20 X 50 cm) plots, while shrub samples were collected on 1.0 sq m (1 X 1 m) plots. Samples were wet weighed in the field and a composited subsample was sealed and returned to the lab for determination of moisture content. Grass fuel data was collected in fine, medium, and coarse type categories, with bulk density classes ranging from 1 (lowest) to 6 (highest). Altogether 120 samples were clipped and wet weighed in the field, and for each set of 6 samples a composited subsample was taken for dry weight determination. For shrubs, fine, medium, and coarse types were identified with the same bulk density classes. Samples were taken of shrub fuels below 1/4 in. diameter (including all leaves); 180 samples were taken to represent the range of depths in the data for different combinations of shrub type and bulk density. Composited subsamples for dry weight corrections were collected for shrubs in a similar manner to grass fuels.

Litter fuels were segregated into three types: medium/long needle (lodgepole or ponderosa pine), short needled (Douglas-fir or true fir), and hardwood.

For medium/long needle litter, 50 samples were collected; for short needled litter, 100 samples were collected; for hardwoods, 50 samples were collected. Composited subsamples were also collected for these samples.

All recorded wet weights were converted to dry weights by applying a sample set correction factor to each group of samples. Equations in English units were developed to produce load estimates from fuel component and type, bulk density, and depth.

DATA ANALYSIS WITH THE BEHAVE PROGRAM

The 425 plots on which site specific fuel information was collected were run through the NEWMDL section of BEHAVE to produce individual fuel models with the same types of parameters that exist for the existing 13 NFFL models. Once the NEWMDL runs were complete, each model was run through the TSTMDL portion of the fuel modeling subsystem of BEHAVE. This portion of BEHAVE produces fire behavior characteristics of the new fuel model under a variety of environmental conditions and allows one to vary model parameters to examine the effect on fire behavior. All operations were conducted on the University of Washington Cyber 180/850 computer.

The modeled fire behavior for each cover type was compared to the existing NFFL fuel models to determine if existing fuel models adequately predicted fire behavior. Fire behavior rather than fuel model parameters were analyzed because it integrates the various model parameters and is of most interest to fire managers. Flame length, rate of spread, and fireline intensity were the fire behavior characteristics chosen. For each model run, TSTMDL predicts a value for each of these variables for three sets of environmental conditions, which were set so as to produce low, medium, and high fire behavior conditions.

The model runs for each cover type produced a two way table of outputs for flame length, rate of spread, and fireline intensity: three sets of environmental conditions on one axis and the output value for each plot in each community type on the other axis. The environmental conditions that were fixed were those of the standard "medium" parameters: 1 hr timelag fuel moisture = 6%, 10 hr timelag fuel moisture = 7%, 100 hr timelag fuel moisture = 8%, live herb moisture = 120%, live woody fuel moisture = 120%, and slope = 30%. Windspeed was varied from 3 to 12 mph, and moisture of extinction was set for each run according to the field-keyed closest-fit NFFL models. For each set of environmental conditions, a mean and standard error was calculated for rate of spread, flame length, and fireline intensity. These sample statistics were then compared to the outputs from the field-keyed NFFL models under the same sets of environmental conditions to see which NFFL model best fit the predicted fire behavior of the cover type plots.

Each set of fire behavior outputs was compared to the two most commonly identified NFFL models from the ground data in each cover type. Where neither model fit well, suggestions for future fire behavior prediction and real time fire behavior data collection are made.

DEVELOPMENT OF FUEL MAPS

Fuel maps similar in concept to the cover type maps were generated for both the NFDRS models and NFFL models (with cautions as appropriate from the BEHAVE output). The NFDRS map was constructed by assigning to each plant community the most common model type(s) recognized in the first year field work. The NFFL map was constructed by assigning to each cover type the most common field-keyed NFFL model(s) of the plots comprising the type. The legend of the NFFL fuel model map contains information concerning the fit of the assigned models to caution against incorrect reliance on the mapped types.

RESULTS

ECOLOGICAL MODELS FOR VEGETATION

The ecological models for vegetation were derived from combinations of direct gradients available in the geographic information base and the initial Landsat vegetation groups. Ordination and classification techniques were applied to help define plant cover types and to evaluate the importance of environmental gradients in the placement of these types over the landscape.

Ordination Results

The ordination was strengthened by the diverse geographic area covered and the "length" of associated environmental gradients over this area. The park is approximately 100 km long and 50 km wide; elevations range from less than 100 m to over 2700 m, and annual precipitation ranges from about 50 cm to over 350 cm.

All plots were entered into the DECORANA (DCA) ordination. Both species and sample ordinations are computed, with the sample scores being weighted means of the species scores within the sample. There is consequently more variation in species scores than in sample scores. The diverse environments encountered in the field gave rise to long DCA axes lengths for sample ordinations and high eigenvectors. The first axis length was 6.24 standard deviations (S.D.), with an eigenvalue of 0.691. The second axis was 5.94 S.D. long with an eigenvalue of 0.483. The third axis was 7.15 S.D. long with and eigenvalue of 0.388, and the fourth axis was 5.3 S.D. long with an eigenvalue of 0.251. The standard deviation can be interpreted as the length of a community gradient. A species usually appears, rises to its mode, and disappears within 4 S.D.; in the present case, there are samples at both ends of the gradients that contain no species in common, and given the breadth of environments at North Cascades, such long gradients are very reasonable.

Interpreting the axes was a difficult subjective task. Lower order axes are often more easily interpreted than higher order axes, so the interpretation began there. The best visual display of axes 1 and 2 is of the species ordination (Figure 7). Note that the axes have negative and positive values. This is because the sample ordination is scaled to begin at 0 and consist of positive real numbers; therefore, because the sample scores are weighted means of species scores, some species must be assigned negative numbers to achieve low sample numbers.

The common tree species are labelled in ecological space in Figure 7. It was apparent that species found at low elevations tended to be at the left of axis 1 while species found at high elevation were to the right. This elevational gradient was substantiated by regressing sample plot elevation onto sample scores for axis 1. The regression had a coefficient of determination (r-squared) of 0.71, indicating that elevation was strongly related to the axis 1 scores. Elevation is probably a dummy variable for temperature, the actual environmental gradient influencing axis 1. Because actual temperature data were not available, elevation is the most reasonable variable to use to explain the gradient. It is also available in the geographic information system for each pixel.

The second axis was more difficult to interpret. The shape of the distribution of the points is triangular, with much more spread in axis 2 on the left side than the right side of axis 1. The polarization for the lower elevational plots is due to the axis 2 gradient expressing itself more completely at lower elevation (Hill and Gauch 1980). Zobel et al. (1976) noted that temperature was the primary gradient differentiating major forest types in the Oregon Cascades, with moisture expressing itself as a differentiating factor within the lower elevation forest types. Temperature and moisture gradients have also been identified by del Moral and Watson (1978) as primary gradients for forest vegetation in the central Washington Cascades. This interpretation is consistent with the ordination in Figure 7. Axis 2 is interpreted as a moisture availability gradient which is more important at low than at high elevation. If the polarization decreases with elevation, then species within a given elevation belt should be ranked according to their tolerance to moisture.

The drought tolerances of northwestern tree species have been summarized by Minore (1979) and allow comparison of the axis 2 rankings within given axis 1 score ranges. Within the lowest axis 1 scores (low elevation) the low axis 2 scores are associated with species normally found in riparian situations or where moisture stress is low: bigleaf maple, red alder, black cottonwood, and grand fir. Ponderosa pine, a species well-adapted to droughty sites, is on the high end of axis 2. The next group along axis 1 includes western hemlock and western redcedar at the low axis 2 scores, and Douglas-fir and lodgepole pine on the high end. The next axis 1 group is a mid-montane set of species. On the low end of axis 2 is Pacific silver fir and Engelmann spruce, and on the high end is western white pine. The ordination position for Engelmann spruce is lower than might be expected in other parts of its range, but in the North Cascades it is commonly found in moist valley bottoms affected by cold air drainage. Next along axis 1 is a subalpine set of species, again ranked in order of relative drought tolerance: Alaska yellow-cedar on the low end, subalpine fir and mountain hemlock in the middle, and whitebark pine on the high end. Subalpine fir, like Engelmann spruce, shows up in a more mesic ordination position than would ordinarily be expected. At North Cascades, it is a sole climax dominant only in the driest eastern subalpine zone of the park, and over most of the park it is found in association with mountain hemlock. The highest axis 1 group is comprised of a single tree species, subalpine larch, which in the drier areas of the North Cascades is found growing at higher elevation than any other tree species.

The moisture gradient represented by axis 2 is a complex one. A regression of annual precipitation on axis 2 sample scores had a coefficient of determination of 0.10, showing it was related, but not strongly, to axis 2 scores. This is due to the distortion of scores at the low elevation end of axis 1, and also because moisture availability is not well characterized by total precipitation alone. Another set of regressions was developed using the technique of Stage (1976),

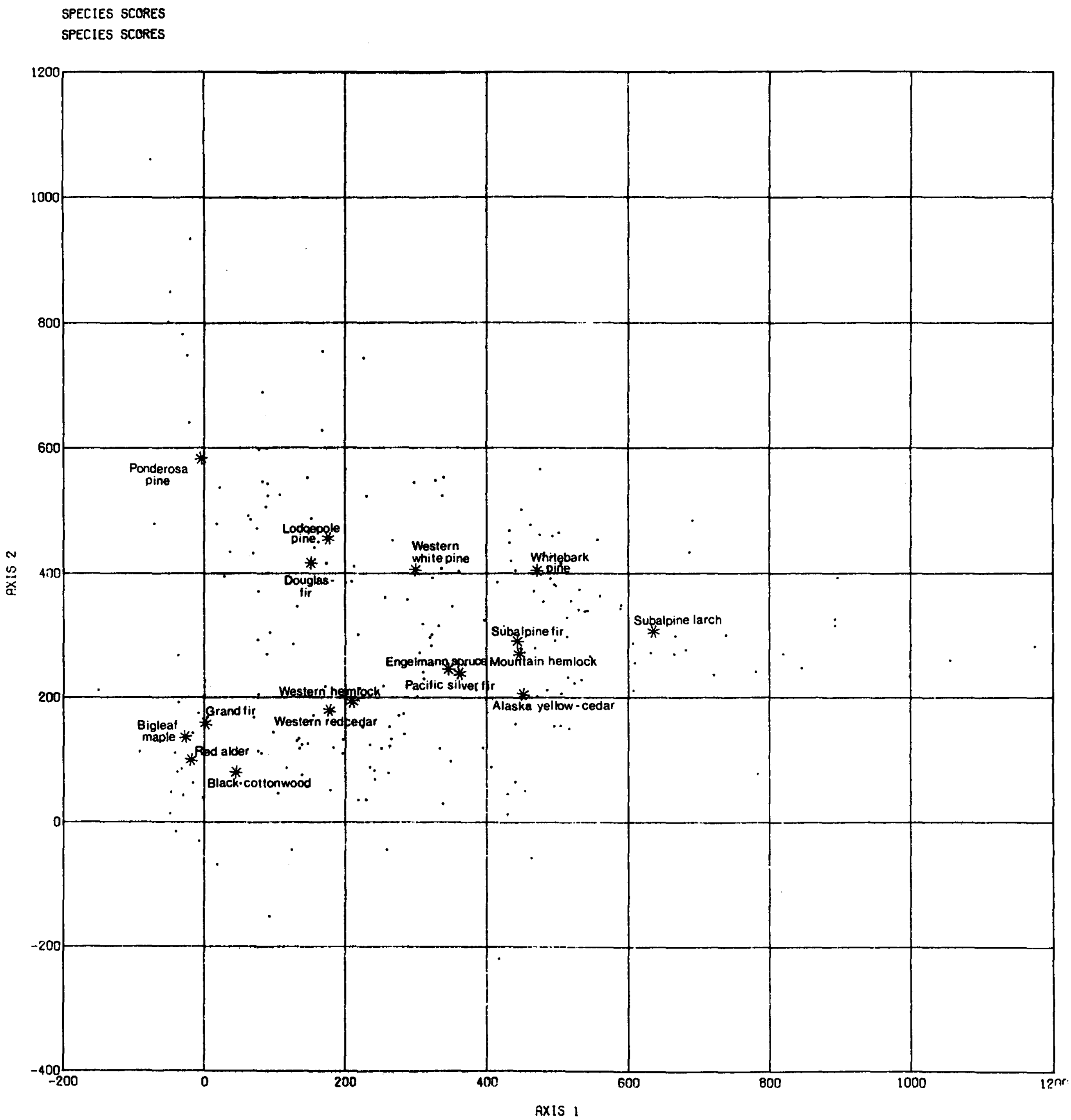


Figure 7. Ordination of common tree species on axis 1 (temperature) and axis 2 (moisture).

who used an index combining the effects of aspect and slope on tree growth. This method was adapted to the present situation by regressing onto axis 2 sample scores the variables precipitation class (nearest 50 cm), slope, slope times the sine of azimuth, and slope times the cosine of azimuth. The resulting equation had a multiple coefficient of determination of 17%, indicating a stronger relation when other environmental factors that influence moisture availability besides precipitation are taken into account. However, the distortion due to moisture being a more important floristic discriminator at low elevation was still present in the data. Three more regressions were done on data separated into three groups of axis 1 scores to reduce the distortion effect: axis 1 scores 0-200, 200-400, and >400. Using the same equation form as for the pooled data, the multiple coefficients of determination were 0.26, 0.15, and 0.15, respectively, suggesting a higher association of axis 2 scores with an index of moisture availability at lower elevations. This relationship is consistent with the assumption that moisture is a more important floristic discriminator at low elevations. Whether pooled or separated, the data analysis confirmed the existence of a significant relationship between axis 2 and moisture. These relationships substantiated the use of precipitation class, aspect, and slope as GIS predictor variables for the moisture gradient identified on axis 2.

Attempts to correlate the common tree species rankings on higher order axes with a variety of known relative tolerances (frost, heat, nutrients, etc.) failed, even though the eigenvalues for these axes were fairly high (0.39, 0.25). These higher order axes may be identifying more subtle gradients, those applicable to understory vegetation but not to the overstory, or may simply be statistical artifacts. No interpretation was attempted for axes 3 and 4.

Understory species were evaluated using a combination of temperature and moisture classes (Figure 8). Twelve combinations ranging from very warm/wet to very cold (where moisture is relatively unimportant) were defined, and common understory species were grouped according to their axis 1 and 2 ordination scores. The species comprising each group are listed in Table 3. Species groupings are reasonably consistent with environmental conditions in which the plants are usually found. Among the "very warm" species are "wet" species such as Spiraea douglasii (Douglas' spirea) and Viburnum edule (highbush cranberry), "mesic" species such as Berberis nervosa (Oregon grape) and Prunus emarginata (bitter cherry), and "dry" species such as Holodiscus dicolor (ocean spray), Ceanothus velutinus (snowbrush), and Bromus tectorum (cheatgrass). A gradient along the "warm" groups includes "wet" species such as Rubus spectabilis (salmonberry),

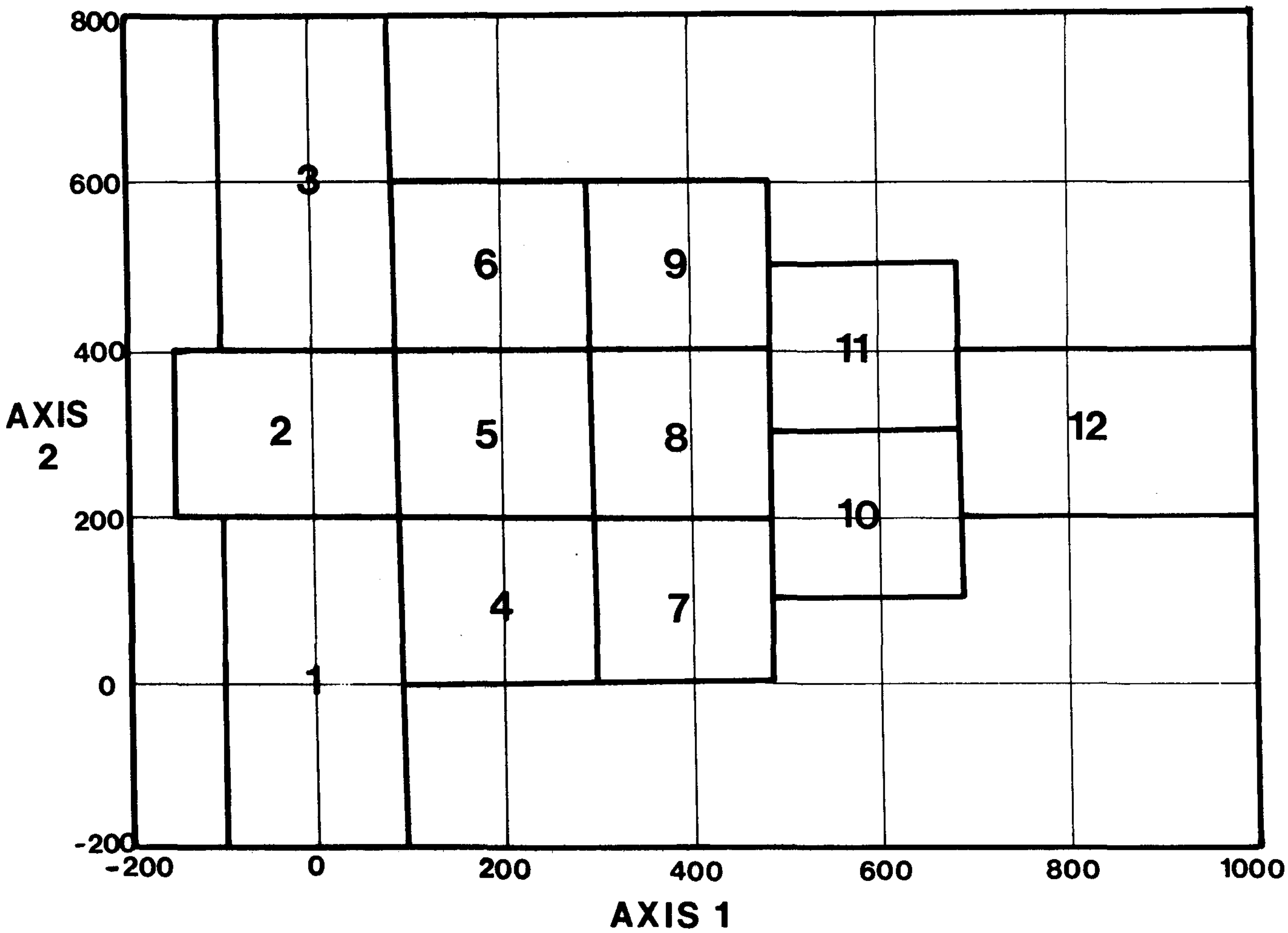


Figure 8. Groups of understory species in ordination space. Numbers refer to species listed in Table 3: 1=very warm/wet, 2= very warm/mesic, 3= very warm/dry, 4= warm/wet, 5=warm/mesic, 6= warm/dry, 7= cool/wet, 8=cool/mesic, 9= cool/dry, 10= cold/wet, 11= cold/dry, 12= very cold.

Table 3. Species characteristic of environments identified on the indirect ordination.

Very Warm/Wet	Very Warm/Mesic	Very Warm/Dry
Spiraea douglasii	Symphoricarpos alba	Berberis aquifolium
Viburnum edule	Corylus cornuta	Achillea millefolium
Solidago canadensis	Prunus emarginata	Spiraea betulifolia
Rubus parviflorus	Trientalis latifolia	Holodiscus discolor
Dicentra formosa	Betula occidentalis	Agropyron spicatum
Asarum caudatum	Montia parvifolia	Ceanothus velutinus
Cornus nuttallii	Berberis nervosa	Amelanchier alnifolia
Cornus stolonifera	Osmorhiza chilensis	Erigeron filifolius
Tolmei menziesii	Salix scouleriana	Cryptogramma stelleri
Dactylis glomerata	Festuca idahoensis	Balsamorhiza sagittata
Disporum hookeri	Trifolium repens	Lomatium nudicale
Rubus ursinus		Physocarpus malvaceae
Aruncus sylvester		Bromus tectorum

Warm/Wet	Warm/Mesic	Warm/Dry
Pteridium aquilinum	Gaultheria shallon	Calamagrostis rubescens
Polystichum munitum	Vaccinium parvifolium	Arctostaphylos uva-ursi
Acer glabrum	Chimaphila umbellata	Hieracium albiflorum
Smilacina racemosa	Linnaea borealis	Adenocaulon bicolor
Rubus spectabilis	Cornus canadensis	Pachistima myrsinites
Oplopanax horridum	Goodyera oblongifolia	
Galium aparine	Gaultheria ovalifolia	
Blechnum spicant		
Athyrium filix-femina		
Trillium ovatum		
Epilobium angustifolium		
Tiarella trifoliata		
Clintonia uniflora		
Lilium columbianum		
Aquilegia formosa		

Cool/Wet	Cool/Mesic	Cool/Dry
Thalictrum occidentale	Vaccinium alaskense	Anaphalis margaritacea
Lysichitum americanum	Listera caurina	Juniperus communis
Sorbus sitchensis	Vaccinium membranaceum	Lupinus latifolius
Heracleum lanatum	Rubus lasiococcus	Lupinus lyallii
	Menziesia ferruginea	
	Rubus pedatus	
	Rhododendron albiflorum	

Cold/Wet	Cold/Dry	Very Cold
Veratrum californicum	Festuca viridula	Phyllodoce glanduliflora
Valeriana sitchensis	Phlox diffusa	Arnica diverisfolia
Veratrum viride	Sibbaldia procumbens	Polygonum bistortoides
Vaccinium deliciosum	Vaccinium caespitosum	Veronica cusickii
Cassiope mertensiana	Claytonia lanceolata	
Phyllodoce empetriformis	Vaccinium myrtillus	
Luetkea pectinata	Erythronium grandiflorum	

Oplopanax horridum (Devil's club), and Polystichum munitum (sword fern), "mesic" species such as Gaultheria shallon (salal), Vaccinium parvifolium (red huckleberry) and Chimaphila umbellata (prince's pine), and "dry" species Pachistima myrsinites (Oregon boxwood), Arctostaphylos uva-ursi (kinnickinnick), and Adenocaulon bicolor (trail plant). "Cool" species include the "wet" members Lysichitum americanum (skunk cabbage), Sorbus sitchensis (mountain-ash), and Heracleum lanatum (cow parsnip),"mesic" species such as Rubus lasiococcus (dwarf bramble), Vaccinium alaskense (Alaska huckleberry), and Vaccinium membranaceum (bigleaf huckleberry), and "dry" species such as Juniperus communis (mountain juniper) and Anaphalis margaritacea (pearly everlasting). The "cold" species were divided into only two groups: "wet", including Vaccinium deliciosum (blue-leaf huckleberry), Valeriana sitchensis (Sitka valerian), and Veratrum californicum (false hellebore), and "dry", including Festuca viridula (green fescue), Phlox diffusa (spreading phlox), and Vaccinium myrtillus (dwarf bilberry). The "very cold" species included Polygonum bistortoides (American bistort), Phyllodoce glanduliflora (yellow heather) and Arnica diversifolia (sticky arnica). Among apparent inconsistencies in ordination placement in Table 3 are Sorbus sitchensis (mountain-ash), which has its centroid listed as cold/wet when in the field it appears to be a more mesic species; Veratrum californicum, listed as cold/wet, in fact spans a warm to cold gradient and may have been misidenitified with Veratrum viride, a more subalpine species, at times; and Festuca idahoensis, which is listed as a more mesic species than it may actually be in the field.

The ordination results supported the notion that groups of species could be identified occupying diffusely defined portions of the ecological space being considered. However, the data are defined in terms of gradients rather than in terms of boundaries between groups of species. Such boundaries are needed to define plant communities, and are most easily obtained through a cluster analysis such as TWINSPAN.

Classification Results

The community classification process using TWINSPAN was the first step in defining cover types, from which actual direct gradient information could be summarized for a given cover type. The integration of all cover type environmental boundaries could then be used to build the predictive ecological models.

The classification produced a large number of community types, limited by the number of divisions chosen as the cutoff level and the number of plots selected as a minimum beyond which further divisions would not be made. The dendrogram (Figure 9, Table 4) shows an early division into three major types, which are then further subdivided. The first group (left of Figure 9) is composed of the dry, lowland forest, shrub, and grass types plus the deciduous shrub and forest types. The second group (middle of Figure 9) includes the westside lowland and montane forests. The third group (right of Figure 9) contains the subalpine to alpine vegetation types. This suggests that floristically the subalpine types, whether dry or moist, are more closely related to one another than to their associated lowland types. This relation is consistent with the ordination results which indicated that moisture is a less important discriminating factor at high elevation.

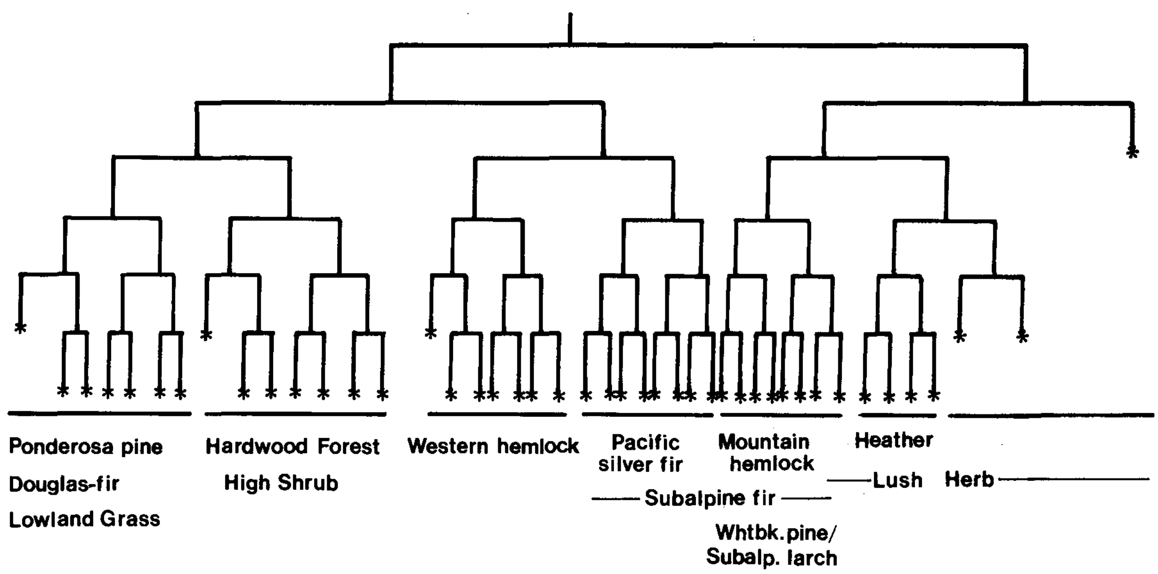


Figure 9. Clustering of vegetation plots with major cover types shown.

Table 4. Area covered by each cover type class within the North Cascades National Park Service Complex. PRELIMINARY CLASSES.

Cover Type	In Park Complex		
	Hectares	% of Veg.	%Land
Ponderosa pine	869	0.4	0.4
Closed canopy	376	0.2	0.1
Open canopy	493	0.2	0.2
Douglas-fir	38818	19.0	14.1
Closed canopy	26348	12.9	9.6
Open canopy	12470	6.1	4.5
Grand fir	127	0.1	0.1
Closed canopy	74	-	-
Open canopy	53	-	-
Subalpine fir	28177	13.8	10.2
Closed canopy	17105	8.4	6.2
Open canopy	11072	5.4	4.0
Whitebark pine/ Subalpine larch	3922	1.9	1.4
Closed canopy	2034	1.0	0.7
Open canopy	1888	0.9	0.7
Mountain hemlock	18444	9.1	6.7
Closed canopy	11381	5.6	4.1
Open canopy	7063	3.5	2.6
Pacific silver fir	33830	16.5	12.3
Closed canopy	24546	12.0	8.9
Open canopy	9284	4.5	3.4
Western hemlock	34031	16.7	12.4
Closed canopy	24128	11.8	8.8
Open canopy	9903	4.9	3.6
Hardwood forest	998	0.5	0.4
High shrub	13399	6.6	4.9
Lowland grass	4269	2.1	1.6
Fescue meadow	2448	1.2	0.9
Lush herb	23050	11.3	8.4
Heather meadow	1671	0.8	0.6
All other (rock, snow, ice, bare ground, water, shadow)	71086	--	25.8
Total	275139	100	100

Among the lower elevation types, the clustering of the dry forest and shrub types with the deciduous types seems unusual at first. The relative floristic similarities are probably due to the fact that both the drier forests and the deciduous types are more frequently disturbed than the wetter westside forest types. Fire in the dry forests and avalanches and floods in the deciduous communities have allowed at least some disturbance-oriented species to occupy both types (Pachistima mysinites and Amelanchier alnifolia were common to both groups).

The second group is composed of the westside lowland and montane types. There is a clear division between the lower elevation groups where Tsuga heterophylla (western hemlock) is a dominant and middle elevation groups where Abies amabilis (Pacific silver fir) is a dominant. Pseudotsuga menziesii (Douglas-fir), Tsuga heterophylla, and mosses were common to both groups. The placement of Tsuga heterophylla as a dominant in one group and also non-preferential between groups is due to (a) its lesser importance but presence at middle elevation where Abies amabilis is dominant, and (b) a fairly wide transition zone between the two types.

The third group is the subalpine and alpine types. The two initial divisions in the group are between non-forested and primarily forested groups. Subsequent forested divisions are between generally dry Abies lasiocarpa (subalpine fir) and generally moist Tsuga mertensiana (mountain hemlock) forest types.

Development of Initial Ecological Models

The ordination results indicated that temperature and moisture gradients were major environmental factors affecting plant distribution across the park complex. Cluster analysis defined a variety of possible community types within the same data set, but did not place environmental boundaries on any of the communities. To develop the models, a definitive set of cover types had to be defined and the environmental boundaries had to be established such that any combination of predictor variables in the geographic information system (GIS) would be assigned a plant cover type.

Since the Landsat data focus on reflected light, cover types were established on the basis of overstory or dominant vegetation cover. The TWINSPAN output was reviewed and a tentative set of cover types that were thought to be predictable on the ground from the available information were identified.

Among the "herbaceous" types, very generalized types were selected. The "lowland herbaceous" type was selected to represent lowland rocky sites, pastures, and the like. A subalpine complement to that type was the "lush herb" type, except that such herbaceous mixes were generally of natural origin. A dry variant of the "lush herb" type was the "fescue grassland". Near snowline and on moist flatter sites was the "heather" type. The deciduous shrub and forest types were divided into two broad types: a "high shrub" type typical of avalanche chutes and a "hardwood forest" type common in alluvial valleys. The coniferous types were broken into eight different cover types, each with an open canopy and closed canopy component. On the westside of the park, "western hemlock", "Pacific silver fir", and "mountain hemlock" cover types were prevalent. On the eastside, "ponderosa pine", "Douglas-fir", "grand fir", "subalpine fir", and a high elevation "whitebark pine/subalpine larch/subalpine fir" type were identified. One disappointing omission from the list is the lodgepole pine type, which was intertwined with Douglas-fir to the extent that it could not be separated from it based on the predictor variables we were using. More soils data (particularly soil depth) and fire history data would be needed to separate these types; more detailed spectral analysis within the Douglas-fir type might also be successful in delineating lodgepole pine stands as a separate type.

Each of the selected types (particularly the coniferous ones) appeared to be occupying well-defined space in the ordination and could be identified in the TWINSPAN output as one or several of the branches of the dendrogram. The 425 sample plots were then assigned to a cover type. The ranges of predictor variables (elevation, aspect, slope, precipitation, and Landsat type) were summarized for each cover type and then all cover types were integrated into one large model.

This model was sent to the Geographic Information Systems Field Unit in Denver, where it was applied to the existing database for the park complex. A cover type was assigned to each pixel in the database. The initial cover types and the proportion of area occupied by each within the park complex is presented in Table 4.

Field Accuracy of Initial Cover Types

Sampling of the 22 community types during 1984 was a stratified sample based on uniform coverage across the park complex and proportional coverage by area of the mapped type (Table 1, Figure 6). A contingency table was constructed to assess the accuracy of the initially defined plant cover types (Table 5). The values of intersections of rows and columns indicate the number of times the type in the column (mapped

Table 5. Contingency table for accuracy of PRELIMINARY vegetation classification at North Cascades NPS Complex.

Map indicates cover type is

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	3	2																				
2	1	75	8	3												4						
3			2																			
4		2		48												1		5				
O 5					11	1																
n 6		2		6	1	26	1											1		1		
7		1		11	1	2	69	3										3			2	1
G 8		5					4	63								1						2
r 9								1	9	2												
o 10										[illegible]			[illegible]								1	
u 11											16											
n 12												1	13									
d 13											1	1	70									
14													3	14								
i 15		1													4	2						
t 16		12					1	1					1			59						
17																						
i 18				2									1			1		46			3	1
s 19					1											1			25	1		
20				1		1												13		37		
21																		3	1		13	1
22		2					1	3														22
Tot.	4	102	10	71	14	30	77	71	10	54	17	2	89	14	4	69	0	71	26	42	17	26
%	75	74	20	68	79	87	90	89	90	96	94	50	79	100	100	86	-	65	96	88	76	85

Cover Type numbers in bold print along the edge of the table refer to:

- Ponderosa pine (1= closed canopy, 15= open canopy)
- Douglas-fir (2= closed canopy, 16= open canopy)
- Grand fir (3=closed canopy, 17=open canopy)
- Subalpine fir (4= closed canopy, 18= open canopy)
- Whitebark pine/Subalpine larch (5=closed, 19=open canopy)
- Mountain hemlock (6= closed canopy, 20= open canopy)
- Pacific silver fir (7= closed canopy, 21= open canopy)
- Western hemlock (8= closed canopy, 22= open canopy)
- Hardwood forest= 9
- High shrub= 10
- Lowland grass= 11
- Fescue meadow=12
- Lush herb= 13
- Heather meadow= 14

type) was classified as a type in the row (field identification). The diagonal indicates correct classification; any number off the diagonal indicates a misclassification, but the distance from the diagonal does not indicate the degree of misclassification.

The overall accuracy of the classification was 81%. In practical terms, this means if one was to go to 100 points in the park, 81 of them would be the type that the map shows. If misclassifications between open and closed portions of each plant community are ignored, the overall accuracy increases to 85.1%. The highest accuracy was for heather meadows and open ponderosa pine stands. Lowest accuracy was for grand fir; the open type could not be located in sufficently large clusters to sample, and the closed canopy type was usually Douglas-fir. The fescue meadow could not with any accuracy be differentiated from the generalized lush herb type. Among the remaining forested types, lowest accuracy was for the subalpine fir type, both open and closed canopy portions. The closed canopy type was most often confused with the Pacific silver fir type and the mountain hemlock type, while the open canopy portion was confused with mountain hemlock and closed canopy portions of the subalpine fir type.

The classification was relatively robust, with most classes above 75% accuracy. The lack of definition of some classes, however, prompted a revision of the initial cover classes.

Final Cover Type Classification

Four cover types were selected to be combined with the other 18 types in the final classification. The closed canopy ponderosa pine type was eliminated because it covered such a small area (0.18% of the vegetated area of the park), and even the correctly classed samples were borderline Douglas-fir types. If a site is productive enough to reach the closed canopy state in the park, it is rarely dry enough to be a ponderosa pine type. The closed canopy ponderosa pine type was absorbed into the closed canopy Douglas-fir type. The grand fir type (both open and closed canopy) was absorbed into the Douglas-fir type due to its limited coverage (0.06% of the vegetated area of the park complex) and the inability to correctly classify it. The fescue type (1.2% of the vegetated area of the park complex) was absorbed into the lush herb type because of the confusion of one for the other. The four types that were eliminated covered a total of 2951 ha or 1.4% of the area of the park complex, so the magnitude of the change in the classification was minor.

The final classification consists of the cover types shown in Table 6. A revised classification accuracy was constructed by

Table 6. Area covered by each cover type within the North Cascades National Park Service Complex and within the area covered by the Park Special Map (see Figure 3). FINAL CLASSIFICATION.

Cover Type	In Park Complex			In Special Map	
	Hectares	% of Veg.	% Land	Ha.	% Land
Ponderosa pine (Open Canopy only)	493	0.2	0.2	2772	0.3
Douglas-fir	39321	19.2	14.3	123430	14.5
Closed canopy	26798	13.1	9.7	86468	10.2
Open canopy	12523	6.1	4.6	36962	4.3
Subalpine fir	28177	13.8	10.2	122172	14.3
Closed canopy	17105	8.4	6.2	85401	10.0
Open canopy	11072	5.4	4.0	36771	4.3
Whitebark pine/ Subalpine larch	3922	1.9	1.4	30457	3.6
Closed canopy	2034	1.0	0.7	16998	2.0
Open canopy	1888	0.9	0.7	13459	1.6
Mountain hemlock	18444	9.1	6.7	43067	5.0
Closed canopy	11381	5.6	4.1	28424	3.3
Open canopy	7063	3.5	2.6	14643	1.7
Pacific silver fir	33830	16.5	12.3	81769	9.6
Closed canopy	24546	12.0	8.9	63343	7.4
Open canopy	9284	4.5	3.4	18426	2.2
Western hemlock	34031	16.7	12.4	116788	13.7
Closed canopy	24128	11.8	8.8	76779	9.0
Open canopy	9903	4.9	3.6	40009	4.7
Hardwood forest	998	0.5	0.4	10019	1.2
High shrub	13399	6.6	4.9	38830	4.5
Lowland grass	4269	2.1	1.6	13747	1.6
Lush herb	25498	12.5	9.3	69378	8.2
Heather meadow	1671	0.8	0.6	4259	0.5
All other (rock, snow, ice, bare ground, water, shadow)	71086	--	25.8	194345	22.8
Total	275139	100	100	851040	100

deleting those rows and columns associated with the eliminated types. The column data were then placed into the type within which the deleted type was being absorbed. The adjusted contingency table (Table 7) shows an adjusted overall accuracy of 84.3%, with 13 of the final 18 types above the mean. If misclasses between open and closed canopies of the same type are ignored, the accuracy increases to 88.2% overall. A pleasing characteristic of the final classification is that no class is below 64% accuracy. The open and closed subalpine fir types remain the least accurate for the reasons stated above. The non-coniferous vegetation types are all above 90% accuracy, in part because these types were defined very broadly.

There is considerable consistency between area of each cover type in the park complex and over the area in the "park special" map (see Figure 6 for area covered). The subalpine fir type shows the largest difference in percent area covered (about 4% higher outside the park). The higher coverage outside is likely due to past continental glaciation of the relatively dry uplands east of the park, resulting in more gentle terrain at high elevation which supports more forest. The whitebark pine/subalpine larch type, which includes a high component of subalpine fir, also has higher percent cover outside the park for the same reason. Pacific silver fir has lower percent cover as a type outside the park. It is restricted to the moist westside of the park, and to the west of the park complex where elevations are generally lower, resulting in less available habitat for this type but slightly more for the western hemlock type. Due to wider floodplains and timber harvesting west of the park, the hardwood type is better represented outside the park than inside. The heather type has very small coverage both inside and outside the park complex because of the date of the Landsat images (generally early summer) when some of the heather type may still be under snow. If the scenes had been late summer, the heather type would have shown up as a higher percentage cover. Generally, the remaining types are within 1% cover within and outside of the park complex.

The final plant cover types as identified were sent to the Geographic Information System Field Unit in Denver where they were placed permanently into the GIS for North Cascades National Park Service Complex. A map of the classification at the selected scale of 1:100,000 (the park special map scale) is enclosed at the back of this report.

Table 7. Contingency table for accuracy of FINAL cover type classification at North Cascades NPS Complex.

Map indicates cover type is

On Ground it is	2	4	5	6	7	8	9	10	11	13	14	15	16	18	19	20	21	22
2	91	3											4					
4	2	48											1	5				
5			11	1														
6	2	6	1	26	1									1		1		
7	1	11	1	2	69	3								3			2	1
8	5				4	63							1					2
9						1	9	2										
10					1		1	52		1							1	
11									16									
13									1	85								
14										3	14							
15	1											4	2					
16	12				1	1				1			59					
18		2								1			1	46		3	1	
19			1										1		25	1		
20		1		1										13		37		
21														3	1		13	1
22	2				1	3												22
Total	116	71	14	30	77	71	10	54	17	91	14	4	69	71	26	42	17	26
% OK	78	67	79	87	90	89	90	96	94	93	100	100	85	65	96	88	76	84

Cover type numbers in bold print along the edge of the table refer to:

Ponderosa pine (15= open canopy)
Douglas-fir (2= closed canopy, 16= open canopy)
Subalpine fir (4= closed canopy, 18= open canopy)
Whitebark pine/Subalpine larch (5=closed, 19=open canopy)
Mountain hemlock (6= closed canopy, 20= open canopy)
Pacific silver fir (7= closed canopy, 21= open canopy)
Western hemlock (8= closed canopy, 22= open canopy)
Hardwood forest= 9
High shrub= 10
Lowland grass= 11
Lush herb= 13
Heather meadow= 14

PLANT COVER TYPE DESCRIPTIONS

Descriptions of the 18 plant cover types identified in the North Cascades vegetation map (see foldout map at back of report) were developed based on the plots established on the ground during 1983. Information collected on each plot is described in METHODS; these data were used to develop the descriptions. The plots were biased towards those areas where access was possible. For example, many trails are oriented along south-facing slopes because they are free of snow earlier in the hiking season. While the descriptions are not based on randomly selected plots, they nevertheless encompass the range of conditions expected in a given type.

The coniferous forest type ordination (Figure 10) indicates the location of each type relative to the other coniferous types. The non-forest types were generally more scattered in ecological space because they were more generalized types.

Coniferous forest types have open and closed canopy components. In many cases the open canopy portion of the type is an early successional phase of the mature, closed canopy type. This is not always the case, however. The open canopy portion may consist of very old trees growing on rocky slopes; further succession to a closed type may not occur. If the open canopy is a result of disturbance, the successional implications might be either to set back or accelerate successional processes. Logging or fire will generally result in an open canopy situation that is early successional, but a mountain pine beetle epidemic may eliminate early successional lodgepole pine where it is co-dominant in a Douglas-fir stand and accelerate dominance of the later-successional Douglas-fir. With these cautions in mind, the ordination positions of open and closed canopy portions of each coniferous forest type (Figure 11) can but do not always contain ecological implications about the cover types.

Those cover types that are composed of relatively shade-tolerant species tend to increase their ordination space from the open canopy samples to the closed canopy samples in the ordination. The western hemlock and Pacific silver fir closed canopy types overlap with the open canopy types of their more shade-intolerant community neighbors, Douglas-fir and mountain hemlock/subalpine fir. The transition from Douglas-fir to western hemlock forest on sites where western hemlock will grow is well-documented (Munger, 1940). Similarly, subalpine fir and mountain hemlock are thought to be seral to Pacific silver fir where the latter will grow (Franklin, 1967). At North Cascades, these are places where each of the above species are considered "climax". Where they occur in a mix, the more tolerant species appear to gain dominance from the

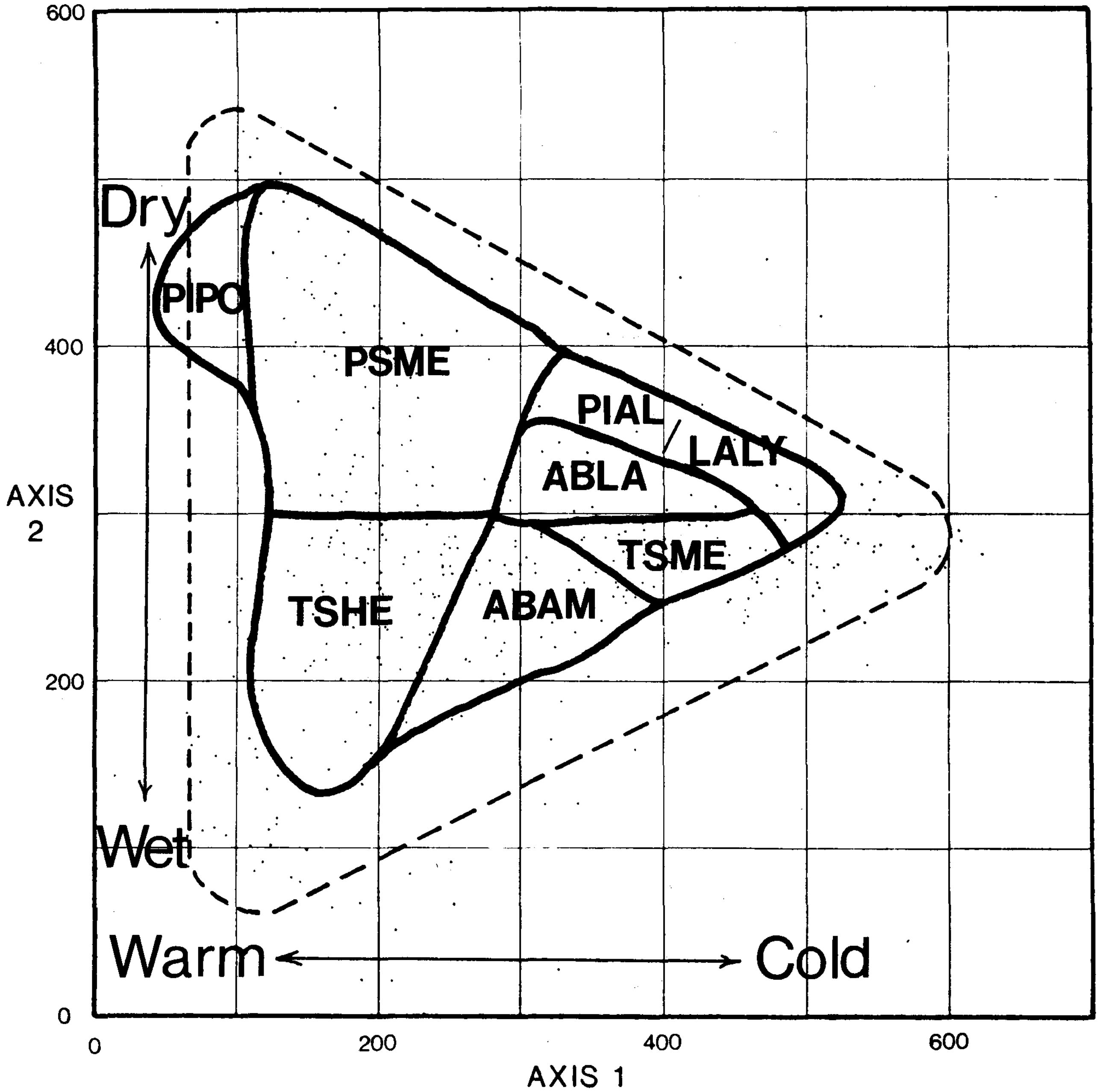


Figure 10. Ordination of major forest cover types on temperature and moisture axes.

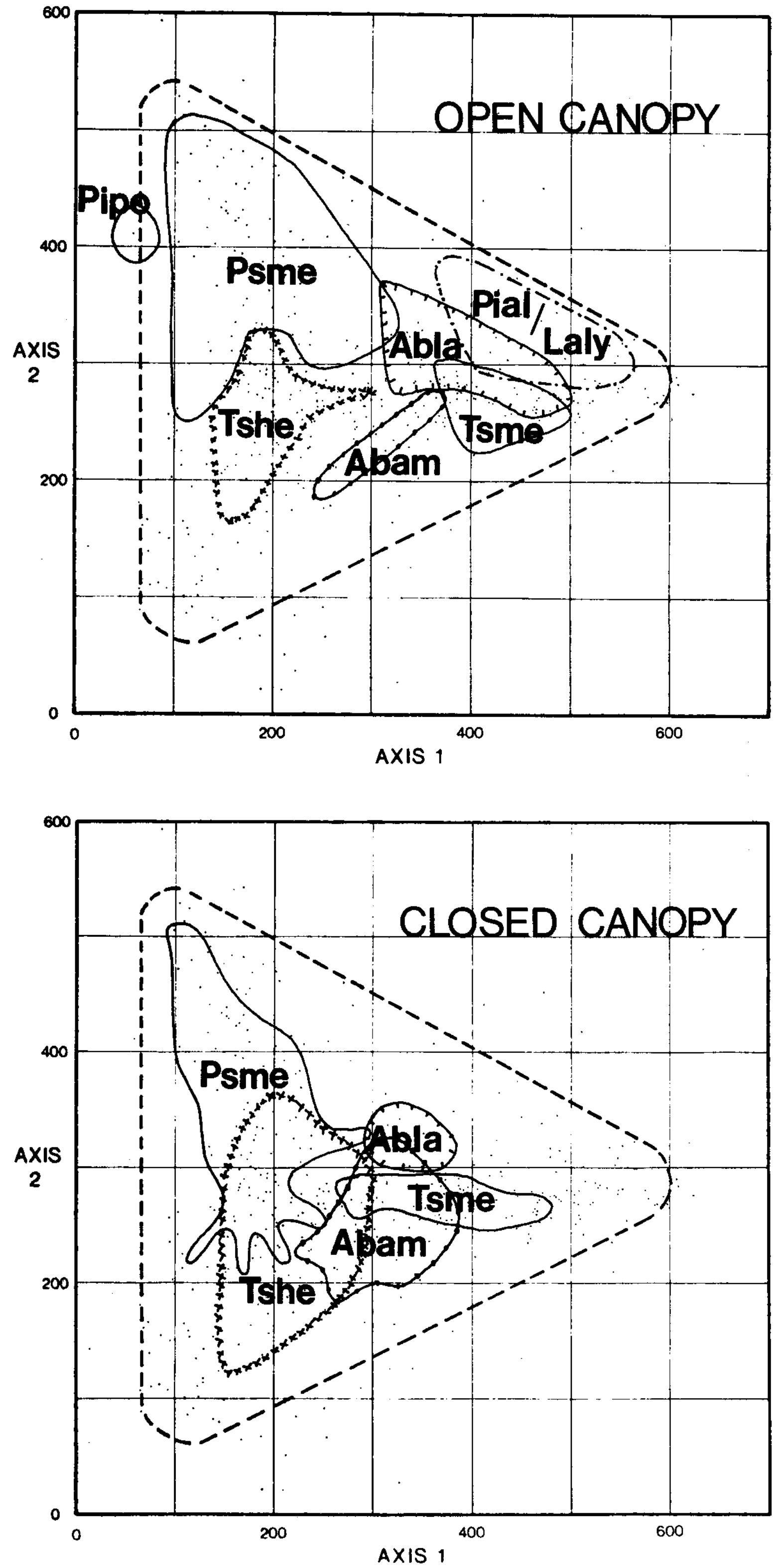
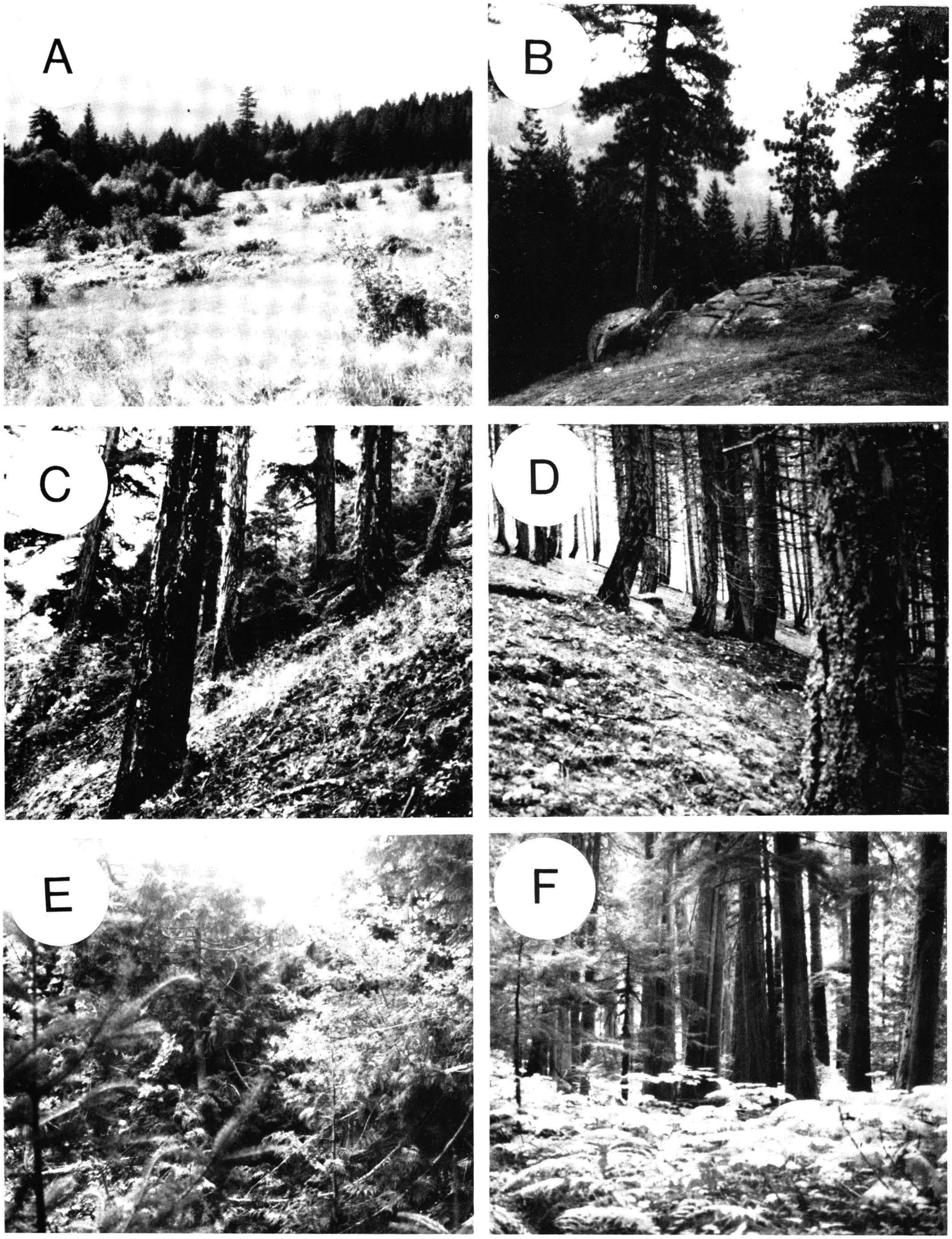
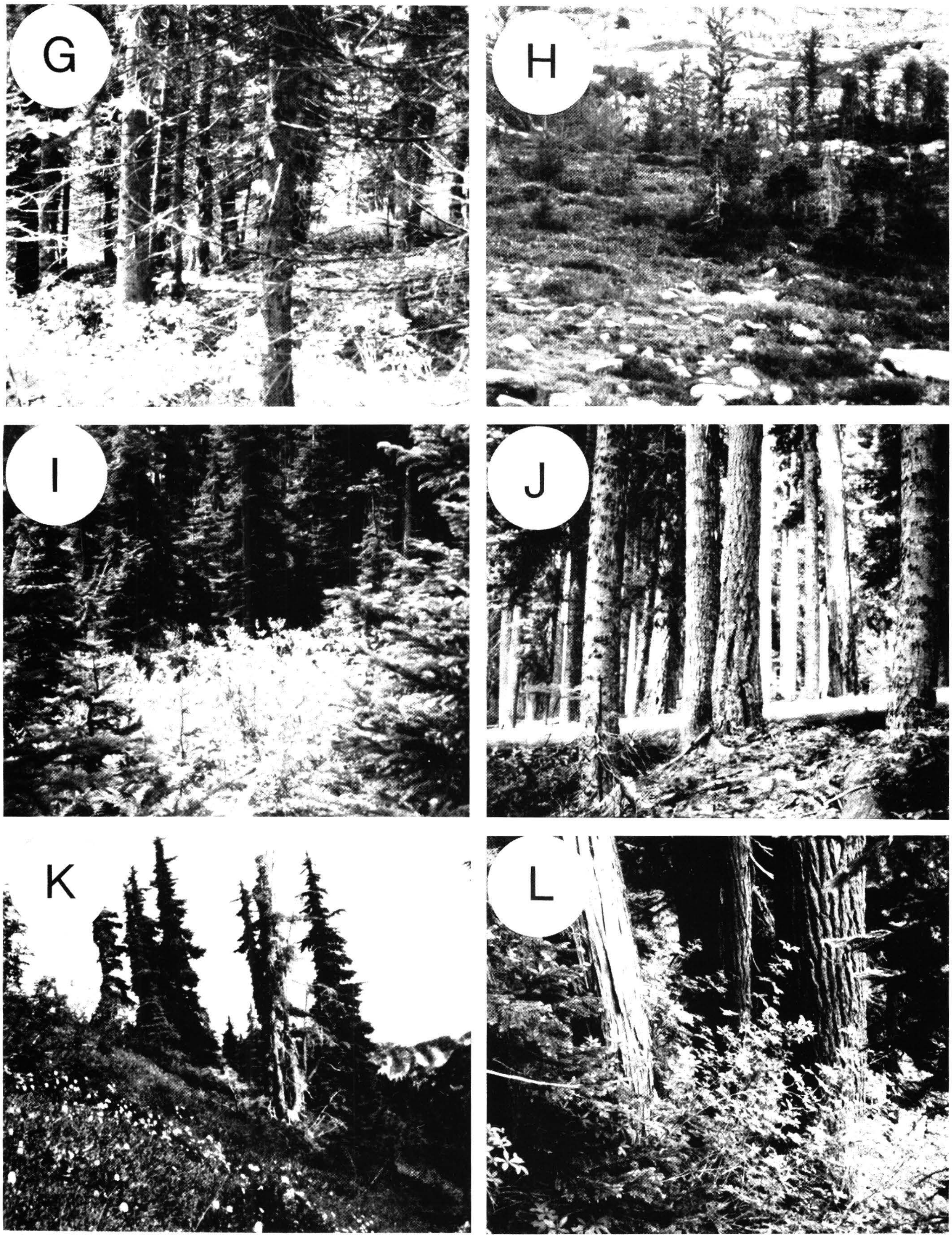


Figure 11. Ordination of closed canopy and open canopy forest types. Lines encompass the range of plots classified in a given cover type.

Figure 12. A. Lowland grassland. B. Open canopy ponderosa pine. C. Open canopy Douglas-fir. D. Closed canopy Douglas-fir. E. Open canopy western hemlock. F. Closed canopy western hemlock. G. Closed canopy subalpine fir. H. Open canopy whitebark pine/subalpine larch, here with larch and subalpine fir in krummholz form. I. Open canopy Pacific silver fir. J. Closed canopy Pacific silver fir. K. Open canopy mountain hemlock. L. Closed canopy mountain hemlock, with Alaska yellow-cedar to left. M. High shrub in an avalanche chute. N. Hardwood forest: bigleaf maple. O. Lush herbaceous meadow, here with American bistort. P. Heather meadow. Q. Typical dry slope vegetation: 1, hardwood forest; 2, closed canopy Douglas-fir; 3, high shrub; 4, open canopy Douglas-fir; 5, subalpine fir. R. typical moist westside slope vegetation: 1 and 2, open and closed canopy western hemlock; 3 and 4, open and closed canopy Pacific silver fir; 5, high shrub; 6, lush herbaceous; 7, closed canopy mountain hemlock.


A
B
C
D
E
F


G
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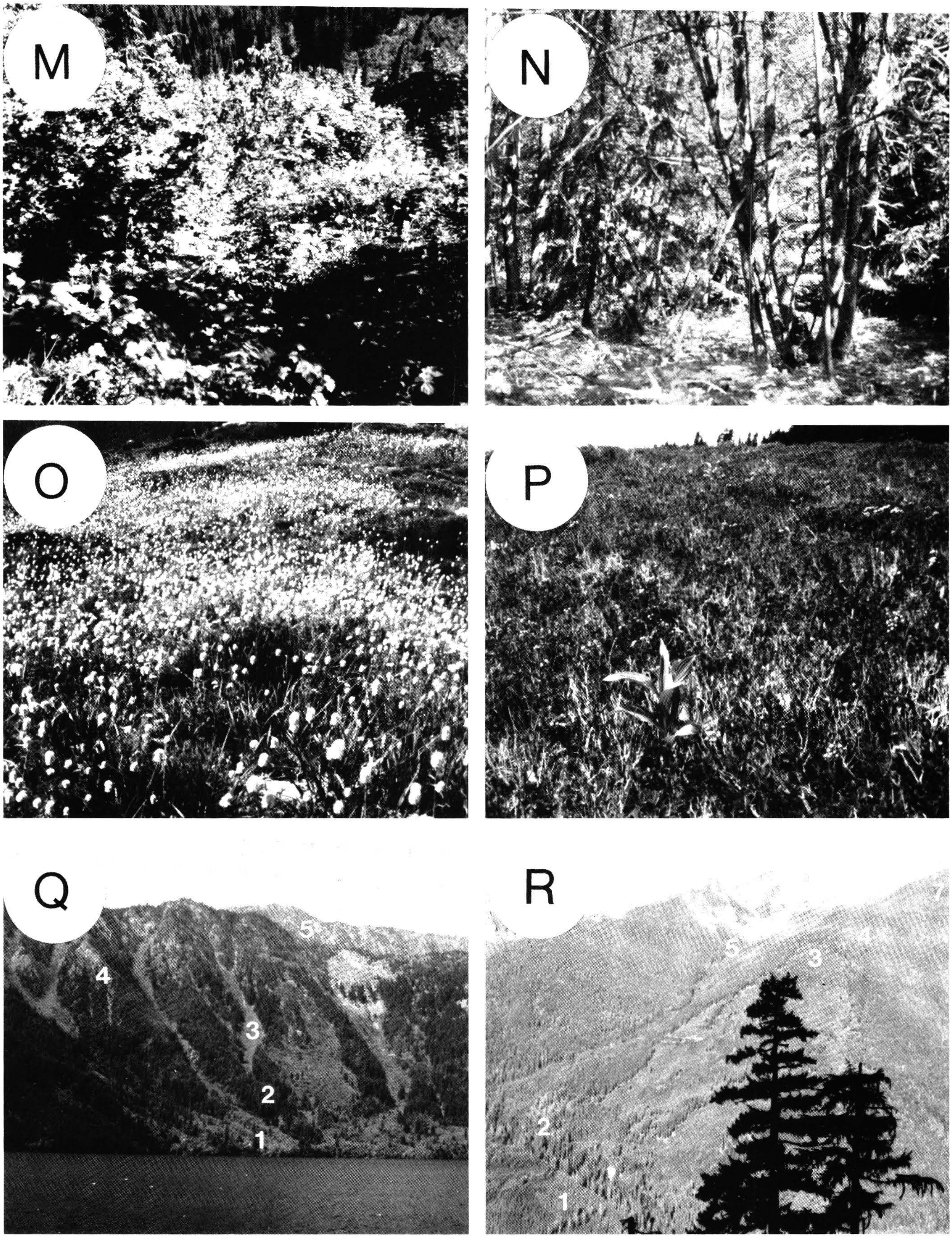
M
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O
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Q
5
4
3
2
1
R
7
5
4
3
2
1

open to closed canopy condition, and thus capture ecological space in the closed canopy delineation of the ordination.

There are a total of 18 plant cover types recognized in the classification, but when open and closed portions of the coniferous types are considered together there are 12 types. The photographs in Figure 12 illustrate commonly occurring characteristics of each of the 12 different vegetation cover types, with some additional photographs of open or closed canopy coniferous stands when both types commonly occur.

Ponderosa Pine Cover Type

The ponderosa pine cover type was initially defined with both closed and open canopy components. During the field checking, sites with productivity sufficient to create closed canopy stands were Douglas-fir, sometimes with a substantial but not dominant component of ponderosa pine. The closed canopy ponderosa pine was therefore integrated into the Douglas-fir closed canopy type. The open canopy ponderosa pine type remains. Within the park complex it covers only 0.2% of the land area, and for the classified area as a whole the type covers 0.3%. It was correctly mapped on all four map check plots, although the 100% sample accuracy probably overstates the actual accuracy.

The ponderosa pine open canopy cover type is found only at xeric low elevation sites, and on the forest ordination (Figure 10) is the driest and warmest of the coniferous types in the park complex. The single initial ground plot in this type shows up as almost an outlier on the ordination (Figure 13) supporting the extreme position on moisture and temperature gradients. Within the park complex the open ponderosa pine type is found primarily in the Stehekin area on rocky slopes above the Stehekin Valley. There is another scattered occurrence of the type in the Hozomeen area, the other dry low elevation area in the park complex.

The open canopy nature of these stands reflects the presence of mature trees growing in a widely spaced pattern. Because these areas often are quite rocky, canopy closure will probably never occur. The single plot in this type had an overstory dominated by ponderosa pine (100 stems/ha) with intermediate heights containing bigleaf maple and Douglas-fir. Maple and ponderosa pine dominated the regeneration. Total tree density in all layers was 600/ha, suggesting a rather open stand; basal area was 10 sq m/ha. Understory species included the shrubs serviceberry, ninebark, and ocean spray, while herbs included bluebunch wheatgrass and arrowleaf balsamroot.

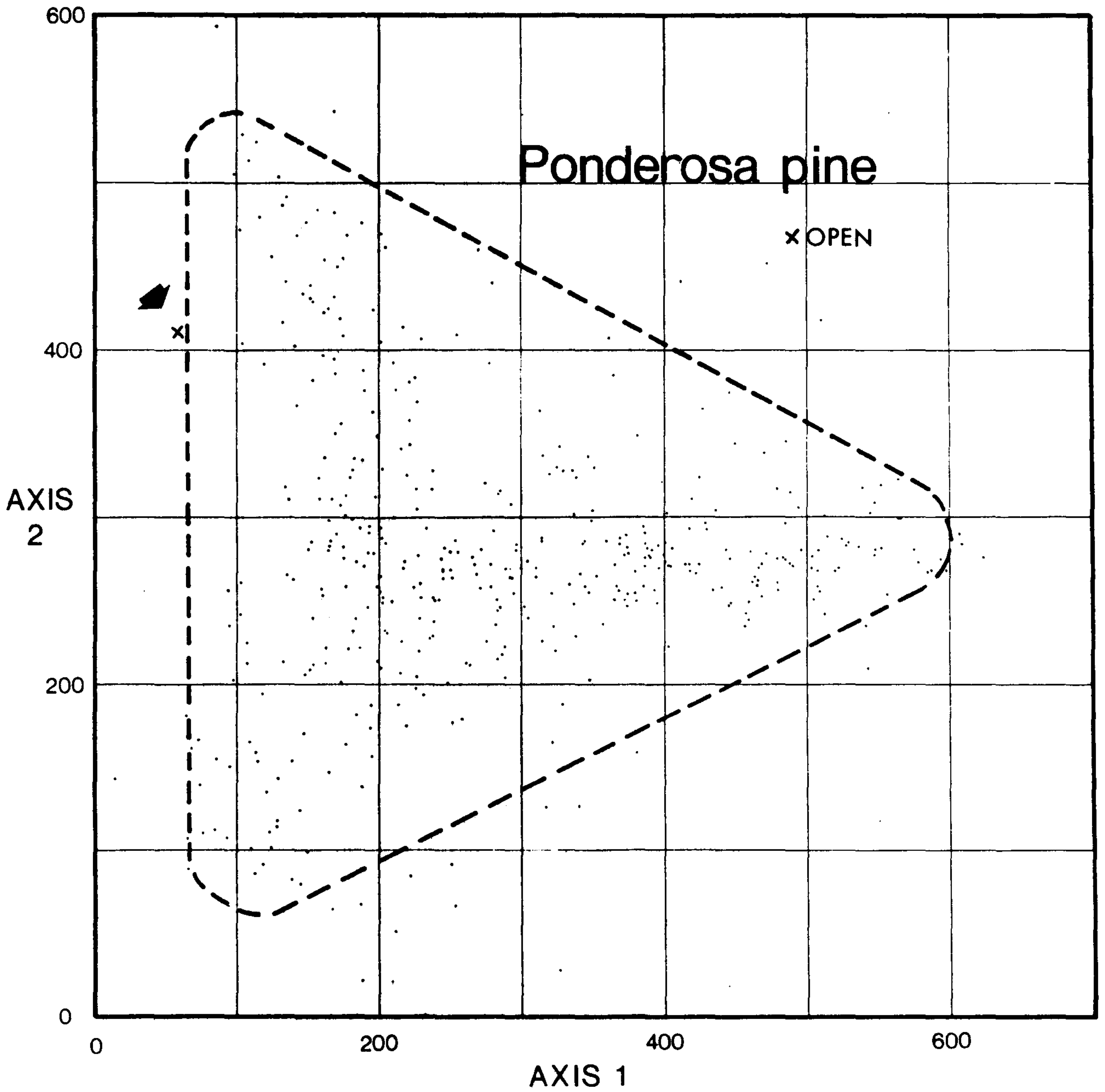


Figure 13. Ordination of the ponderosa pine cover type.

The open canopy ponderosa pine cover type is analogous to the Pinus ponderosa-Pseudotsuga menziesii/Agropyron spicatum var. inerme association on the Okanogan National Forest (Williams and Lillybridge, 1983). Recurrent fire probably kept Douglas-fir from attaining codominance with ponderosa pine, but the limited microsites for tree growth have kept Douglas-fir from rapidly replacing ponderosa pine in the absence of fire. As individual ponderosa pines die, some will likely be replaced by Douglas-fir, but ponderosa pine will continue to codominate such sites.

Douglas-fir Cover Type

The Douglas-fir cover type is the most widespread cover type within the park complex and over the area of the park special map. Within the park complex, the closed canopy portion of the type covers 9.7% of the land area and the open canopy type covers 4.6% of the land area, for a total land cover of 14.3% (Table 6). The coverage over the mapped area as a whole is similar. The largest concentrations of the Douglas-fir type are in the Ross Lake area, particularly on the east side of the lake. The type extends down the Skagit River corridor to the park complex boundary. The second concentrated area of the Douglas-fir type is the Stehekin River-Bridge Creek area in the southeastern part of the park complex. There are minor amounts of this type in the Chilliwack River drainage in the northwestern part of the park.

The Douglas-fir type occupies low to moderate elevation dry areas, as indicated by the ordinations in Figures 10 and 11. Average elevations for the sample plots were 2388 ft for the closed canopy and 2888 ft for the open canopy type. It appears to be found at higher elevations than its moist counterpart, the western hemlock type. At higher elevations it is replaced by the subalpine fir cover type. Average slopes were 36% for the closed canopy and 47% for the open canopy type.

The map accuracy of the closed and open canopy portions of the Douglas-fir type are 78% and 85% accuracy, respectively. For the closed canopy portion, the biggest source of error was the open canopy type, suggesting that the field check decision rules for open and closed canopy types were not well-defined (See "Field Review of 1984 Plant Community Maps"). Mapped Douglas-fir plots that turned out to be western hemlock were the second largest source of error, which is consistent with the amount of boundary the two types share in ordination space. Minor confusion occurred at high elevation with the subalpine fir and mountain hemlock types. For the open canopy portion, the largest source of classification error was the closed canopy portion of the type.

Closed Canopy Douglas-fir

The closed canopy Douglas-fir cover type is widely scattered in ordination space (Figure 14). Its occasional dominance towards low axis 2 scores is indicative of its long-lived seral role in western hemlock associations. The majority of plots are clustered along drier axis 2 scores where Douglas-fir is the climax species. Among the closed canopy plots (Table 8) basal area averages 43 sq m/ha; Douglas-fir comprises 60% of the total, lodgepole pine makes up 15%, and ponderosa pine comprises 12%. This reflects a codominance with ponderosa pine at the driest low elevation sites as well as the presence of lodgepole pine in other locations, sometimes in almost pure stands. Douglas-fir density is dominant in this type, with the highest density of any species in the >10m height class (348 stems/ha) and in the reproduction layer (0-3 m height) as well. Lodgepole pine is well represented in the top two layers of the canopy, even though it is present in only 25% of the plots. Ponderosa pine is also present about 25% of the time but consists of fewer stems than lodgepole pine.

Western hemlock, western redcedar, and subalpine fir are not important in this type; as the statistics for those species increase, a plot will likely be classified as the western hemlock or subalpine fir type. Grand fir was initially identified as a separate type in the classification but was present in such limited quantity and with so little predictability (Tables 4 and 5) that it was integrated into the Douglas-fir cover type.

Plant associations recognized in the data include several of the associations present on the adjacent Okanogan National Forest (Williams and Lillybridge, 1983): *Pseudotsuga menziesii/Carex rubescens*, *Pseudotsuga menziesii/ Arctostaphylos uva-ursi*, *Pseudotsuga menziesii/Pachistima myrsinites* (widely distributed), and *Pseudotsuga menziesii/Vaccinium* spp. The latter association tends to be a cooler type that often includes Engelmann spruce, subalpine fir, and lodgepole pine, which are all frost-tolerant species. An additional association is the *Pseudotsuga menziesii/ Berberis nervosa-Gaultheria shallon* association, which is a transitional type to the more moist western hemlock cover type. This type is particularly prevalent in the Skagit River corridor. The *Abies grandis/Pachistima myrsinites* association is also found in limited amounts in the Stehekin Valley and in

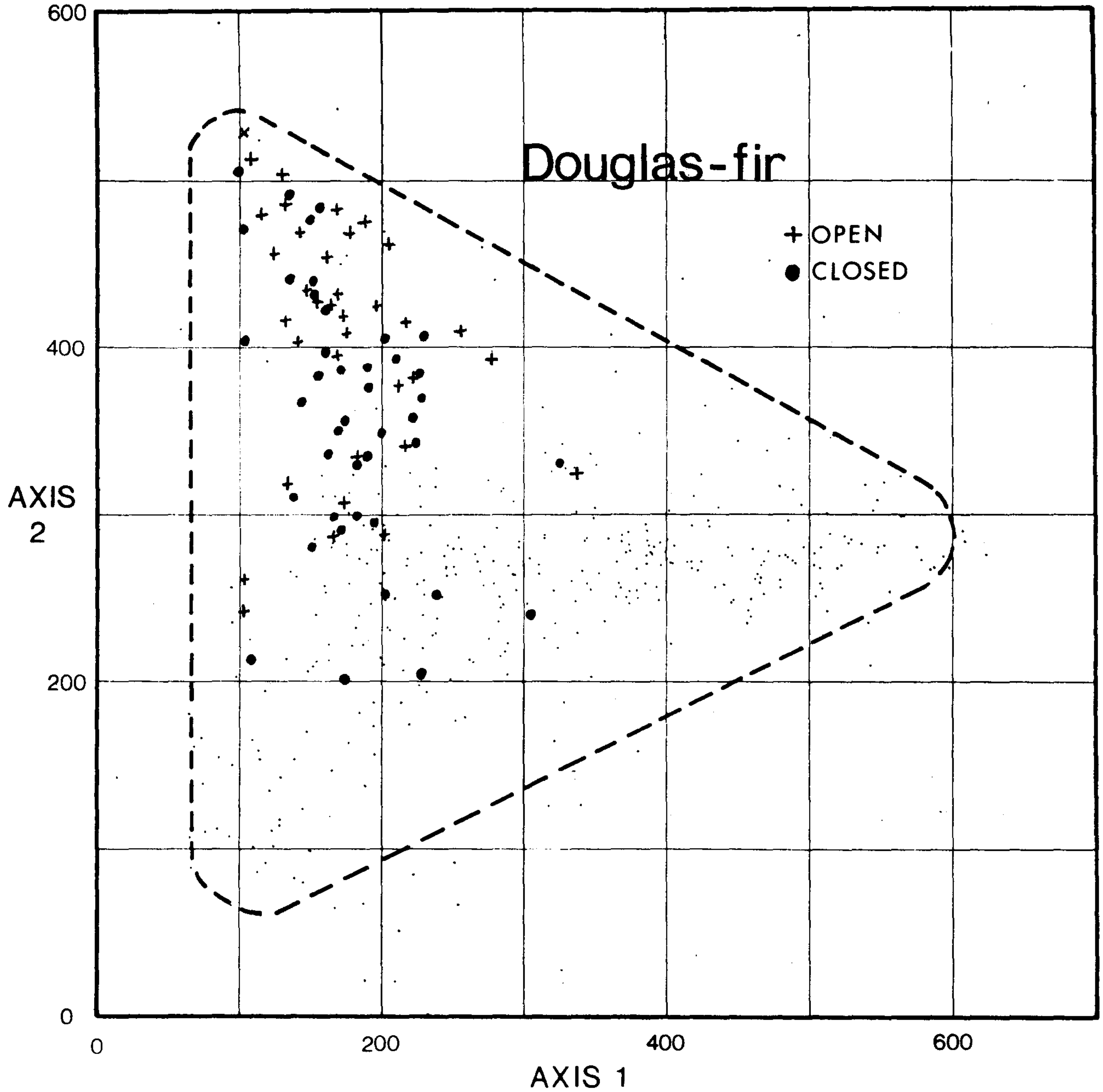


Figure 14. Ordination of the Douglas-fir cover type.

Table 8. Vegetation summary table for the Douglas-fir closed canopy cover type.

Tree species	Density/ha by height class 0-3m	3-10m	10+m	Basal Area sq.m/ha Mean	Max	Percent Average Cover	Relative Constancy (Percent)
Abies amabilis	50	10	0	T	10	T	5
Abies grandis	14	12	2	T	20	1	7
Abies lasiocarpa	31	10	39	1	20	1	12
Acer glabrum	0	7	0	0	0	T	2
Acer macrophyllum	0	12	2	T	10	1	7
Alnus rubra	0	0	2	0	0	T	2
Betula papyrifera	0	7	48	1	30	1	5
Picea engelmannii	0	0	69	3	110	1	10
Pinus contorta	14	251	221	6	50	4	26
Pinus monticola	74	0	10	T	10	1	7
Pinus ponderosa	15	20	38	5	70	3	24
Populus trichocarpa	0	0	0	0	0	T	2
Prunus emarginata	0	2	0	0	0	T	2
Pseudotsuga menziesii	543	207	348	26	75	38	100
Salix scouleriana	1	0	0	T	10	T	2
Salix spp.	5	13	3	T	10	1	12
Thuja plicata	57	33	7	1	25	2	26
Tsuga heterophylla	29	10	0	0	0	1	14

Most common shrub layer species with relative constancy: Pachistima myrsinites (66), Berberis nervosa (36), Arctostaphylos uva-ursi(33), Vaccinium membranaceum(26), Amelanchier alnifolia (29), Spiraea betulifolia (21), Ceanothus velutinus (19), Holodiscus discolor (19), Vaccinium spp. (19), and Gaultheria shallon (12).

Most common herb layer species with relative constancy: mosses (50), Chimaphila umbellata (36), Calamagrostis rubescens (33), Linnaea borealis (19), Pteridium aquilinum (19), Hieracium albiflorum (14), Goodyera oblongifolia (10), Poa spp. (10), Fragaria spp. (10).

thin belts, generally associated with springs along slopes in the Douglas-fir type.

Open Canopy Douglas-fir

The open canopy Douglas-fir type includes a very long list of associated tree species (Table 9). Douglas-fir makes up slightly more than half of the average 36 sq m/ha of basal area, with lodgepole pine and ponderosa pine again contributing the next highest amounts. Two fairly dense stands of grand fir enabled that species to rank as a fourth codominant, although like the other codominant species, it is more commonly found growing only with Douglas-fir than with the other codominants. Most of the other species are occasionals.

Large amounts of Douglas-fir and lodgepole pine in the understory (606 and 303 stems/ha) suggest that many of the open canopy Douglas-fir stands are early seral stands originating after disturbances, primarily fire. Little logging activity has occurred in the areas where this type is found, although some areas to the west of the park complex which have been logged are in the Douglas-fir open canopy type.

Plant associations in the open canopy type include those identified above for the closed canopy type. In addition, on rocky areas or areas burned in the past, the *Pseudotsuga mensiezii/Symphoricarpos albus* and *Pseudotsuga mensiezii/Holodiscus discolor* associations can be found in the open canopy Douglas-fir type.

Subalpine Fir Cover Type

The subalpine fir cover type covers about 10% of the land surface within the park complex, with a 3:2 ratio of closed to open canopy types. The type appears to cover a higher proportion of land outside of the park complex (Table 6) because of the relatively high proportion of gently-sloped high elevation dry habitats east of the park. Within the park complex, it is found on south-facing slopes in the wetter westside portion, and on more mesic aspects as well in the eastern portion (such as Panther and Bridge Creeks).

The subalpine fir type was the least accurate of all types defined in the classification, and Figure 10 illustrates why. Almost all of the other coniferous types border non-forest vegetation as well as other coniferous types, so that prediction of direct environmental gradients defining the type

Table 9. Vegetation summary table for the Douglas-fir open canopy cover type.

Tree species	Density/ha by height class			Basal Area sq.m/ha		Percent Average	Relative Constancy
	0-3m	3-10m	10+m	Mean	Max	Cover	(Percent)
Abies amabilis	6	3	0	0	0	T	3
Abies grandis	94	56	117	2	50	1	6
Abies lasiocarpa	56	0	17	1	30	1	11
Acer macrophyllum	3	6	11	1	20	1	8
Betula papyrifera	0	8	6	0	0	1	6
Cornus nuttallii	0	2	0	0	0	T	3
Picea engelmannii	0	3	0	0	0	1	6
Pinus albicaulis	28	11	11	0	0	1	8
Pinus contorta	303	524	240	9	100	4	31
Pinus monticola	167	11	11	T	10	1	8
Pinus ponderosa	28	14	23	4	30	3	42
Populus trichocarpa	0	0	3	0	0	T	3
Prunus emarginata	1	1	0	0	0	T	3
Pseudotsuga menziesii	664	266	244	19	80	13	94
Salix spp.	0	14	3	0	0	1	6
Thuja plicata	0	0	6	0	0	1	6
Tsuga heterophylla	0	0	0	0	0	T	3

Most common shrub layer species with relative constancy: Pachistima myrsinites (66), Ceanothus velutinus (42), Arctostaphylos uva-ursi (42), Amelanchier alnifolia (25), Spiraea betulifolia (19), Berberis nervosa (14), Vaccinium spp. (8), Holodiscus discolor (8), Vaccinium membranaceum (8).

Most common herb layer species with relative constancy: Calamagrostis rubescens (50), mosses (42), Hieracium cynoglossoides (19), Poa spp. (14), Lomatium spp. (14), Balsamorrhiza sagitata (11), Arnica cordifolia (8), Chimaphila umbellata (8), Pteridium aquilinum (8).

can in part rely on "greater than" or "less than" decision rules. The subalpine fir type is bordered completely by other forest types so that any gradient definition is a "between" decision rule. Because of this sandwich effect, accuracy was 67% for the closed canopy type and 65% for the open canopy type. The closed canopy type error was primarily generated by identifying Pacific silver fir and mountain hemlock forests as the subalpine fir type. Generally these types have subalpine fir as a common associate. The open canopy subalpine fir error was generated similarly, with some of the error due to confusion of the open canopy for the closed canopy portion of the type.

The subalpine fir type was identified by plot data down to 3700 ft elevation (closed canopy), with the highest stands occurring above 6200 ft elevation (open canopy); average elevations for the plots were 4381 and 5422 ft, respectively. Average slopes were 42% for the closed canopy and 53% for the open canopy type. The type was identified in most all precipitation zones occurring at subalpine elevations, with subalpine fir being restricted to more southerly and steeper slopes in the wetter precipitation zones; slopes ranged from 20 to 90%.

Closed Canopy Subalpine Fir

Subalpine fir is clearly the dominant tree in the closed canopy portion of the subalpine fir type. When it begins to share significant codominance with other tree species, then the forest is generally identified as another type. Basal area averages 29 sq m/ha with subalpine fir averaging 13 sq m/ha, or about half (Table 10). It is the most successful regenerating tree by an order of magnitude, and can be considered a "climax" type in the sense of being able to replace itself in the absence of disturbance. Where it is found in other cover types, it is usually a seral dominant. Because of its position in ordination space (Figure 15), it is found with a wide variety of associated tree species. Engelmann spruce is a basal area codominant, and Pacific silver fir and mountain hemlock are present, although neither reproduce well in the type.

Only two plant associations could be interpreted from the limited plot data. The Abies lasiocarpa/Pachistima myrsinites association is a lower elevation association that intergrades with the Pseudotsuga mensiezii/Pachistima myrsinites association; it appears similar to the association defined by Williams and Lillybridge (1983) on the adjacent Okanogan National Forest to the east. The other association is a higher elevation type also identified by Williams and Viccinium membranacem appears to be the dominant huckleberry in this type.

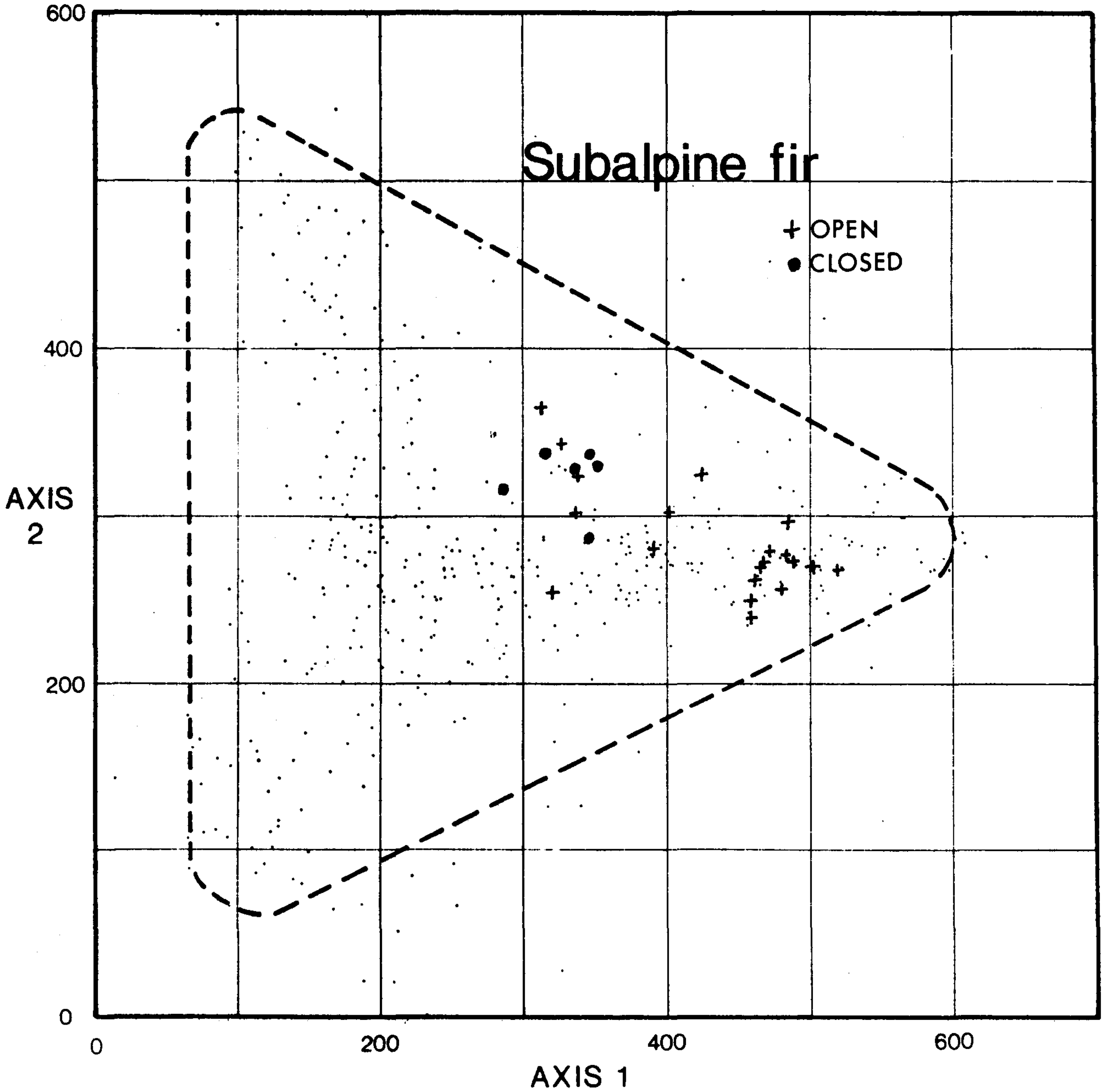


Figure 15. Ordination of the subalpine fir cover type.

Table 10. Vegetation summary table for the subalpine fir closed canopy cover type.

Tree species	Density/ha by height class 0-3m	3-10m	10+m	Basal Area sq.m/ha Mean	Max	Percent Average Cover	Relative Constancy (Percent)
Abies amabilis	17	83	33	3	10	2	66
Abies lasiocarpa	4553	283	300	13	30	22	100
Chamaecyparis nootkatensis	67	0	17	1	5	1	33
Picea engelmannii	100	250	133	7	20	8	50
Pinus contorta	417	33	0	1	5	1	50
Pinus monticola	283	0	0	0	0	2	83
Pseudotsuga menziesii	300	17	0	0	0	2	50
Tsuga heterophylla	133	0	0	0	0	T	17
Tsuga mertensiana	17	0	50	4	25	1	17

Common shrub layer species with relative constancy: Vaccinium membranaceum (83), Pachistima myrsinites (83), Sorbus sitchensis (34), Arctostaphylos uva-ursi (17), Spiraea betulifolia (17), Ribes spp. (17), Vaccinium spp. (17).

Common herb layer species with relative constancy: Mosses (83), Chimaphila umbellata (50), Lupinus spp. (34), Poa spp. (34), Rubus lasiococcus (34), Calamagrostis rubescens (17), Valeriana sitchensis (17), Anaphalis margaritacea (17), Goodyera oblongifolia (17).

Open Canopy Subalpine Fir

The open canopy portion of the subalpine fir type covers a wider range of elevation than the closed canopy portion (Figure 15). Basal area averages 21 sq m/ha, or about two-thirds that of the closed canopy type. Subalpine fir is again the dominant tree in both the understory and the overstory, comprising about half of the basal area and about half of the understory density (Table 11). At lower elevations, Douglas-fir is a common associate, while at higher elevations mountain hemlock is more common. Like the closed canopy type, a wide variety of associated species is found.

Earlier discussion concerning relative space covered by open and closed canopy portions of the coniferous forest types suggested that where the open canopy covered much more area than the closed canopy, the open canopy portions were likely a seral component of another forest association. Subalpine fir

Table 11. Vegetation summary table for the subalpine fir open canopy cover type.

Tree species	Density/ha by height class 0-3m	3-10m	10+m	Basal Area sq.m/ha Mean	Max	Percent Average Cover	Relative Constancy (Percent)
Abies amabilis	165	5	40	0	0	1	50
Abies lasiocarpa	1680	285	200	9	40	15	90
Chamaecyparis nootkatensis	510	5	5	1	10	2	50
Picea engelmannii	45	0	80	1	10	T	15
Pinus albicaulis	35	5	35	1	20	T	5
Pinus contorta	5	0	20	1	10	T	10
Pinus monticola	15	5	40	1	10	T	20
Pseudotsuga menziesii	10	0	90	4	40	T	20
Tsuga mertensiana	1115	205	85	3	20	12	75

Common shrub layer species with relative constancy: Phyllodoce empetriformis (55), Vaccinium deliciosum (45), Vaccinium membranaceum (40), Luetkea pectinata (40), Sorbus sitchensis (40), Pachistima myrsinites (35), Cassiope mertensiana (25), Menziesia ferruginea (10), Arctostaphylos uva-ursi (10).

Common herb layer species with relative constancy: Mosses (35), Lupinus spp. (30), Erigeron spp. (25), Arnica spp. (25), Valerina sitchensis (25), Veratrum californicum (25), Carex spp. (25), Luzula spp. (10).

as an open canopy type appears to cover much of the same ordination space as does the mountain hemlock closed canopy type (Figure 11). This occurs at higher elevations of the open canopy subalpine fir type and in relatively wetter locations. These are usually subalpine meadow areas that are being invaded by coniferous trees, primarily subalpine fir and mountain hemlock. Franklin et al. (1971) have suggested that this invasion is due to lower snowpack and drier conditions during the 1920-40 regional drought in the Pacific Northwest; these trees may be 1-2 m tall but 40-60 years old. Floristics of the sites at North Cascades suggests that such sites will eventually develop into mountain hemlock forests if major climatic shifts do not reverse the trend.

Plant associations in the open canopy portion of the subalpine fir type are difficult to define. Some of the sites are simply older forests on rocky sites, while others are in various stages of succession, not always to the subalpine fir closed canopy type. The two Abies lasiocarpa associations mentioned under the closed canopy type appear to exist in the open canopy type, too. The Abies lasiocarpa/Phyllodoce empetriformis type of Williams and Lillybridge (1983) also occurs but in the park complex it appears to be a seral type to a *Tsuga mertensiana* association.

Whitebark Pine/Subalpine Larch Cover Type

The whitebark pine/subalpine larch cover type is a high elevation variant of the subalpine fir cover type. Within the park complex, it covers 1.4% of the land surface. Roughly equal proportions are in the closed and open canopy portions of the type, which will be discussed together here. Mapped accuracy was 79% for the closed canopy type and 96% for the open canopy type (Table 7). The errors were relatively minor for both canopy types.

The elevation range of the type is from 5110 to 7320 ft; mean elevation of the sample plots was 6273 ft. While it is found as far west as the Baker River and Copper Ridge in the Chilliwack drainage, most of the whitebark pine/subalpine larch type is found in the eastern part of the park complex. It occurs over a wide range of precipitation zones; the plot ordination data (Figure 16) suggest that at its lower elevation range, the type dominates on drier sites; this is generally the whitebark pine portion of the type. At the highest forested elevations, subalpine larch is the dominant tree within the type. Slopes averaged 52%.

The common denominator in this type is the presence of subalpine fir (Table 12). Subalpine fir has a relative constancy of 95%, indicating is it almost always present; both subalpine larch and whitebark pine have lower relative constancies. About 35% of the plots had both of the latter species present, while 45% had no subalpine larch and 20% had no whitebark pine. The species ordination (Figure 7) also suggests that the two species overlap but occupy different niches: whitebark pine is generally on drier, slightly lower elevation sites while subalpine larch occupies the highest elevation, coldest treeline habitats in the park complex. Mountain hemlock is a common associate in this broadly-defined cover type, and Engelmann spruce, Pacific silver fir, and Douglas fir are occasionally present.

The plot statistics are biased towards open canopy plots, as all the ground plots were in the open canopy type. Closed canopy type statistics would parallel the subalpine fir type. Basal area averages 20 sq m/ha, and subalpine fir is usually the tallest tree in the stand. Krummholz stands are common along ridgetops and in rocky basins; the average height of both of the type species is below 7 m. Understory densities suggest that both whitebark pine and subalpine larch are

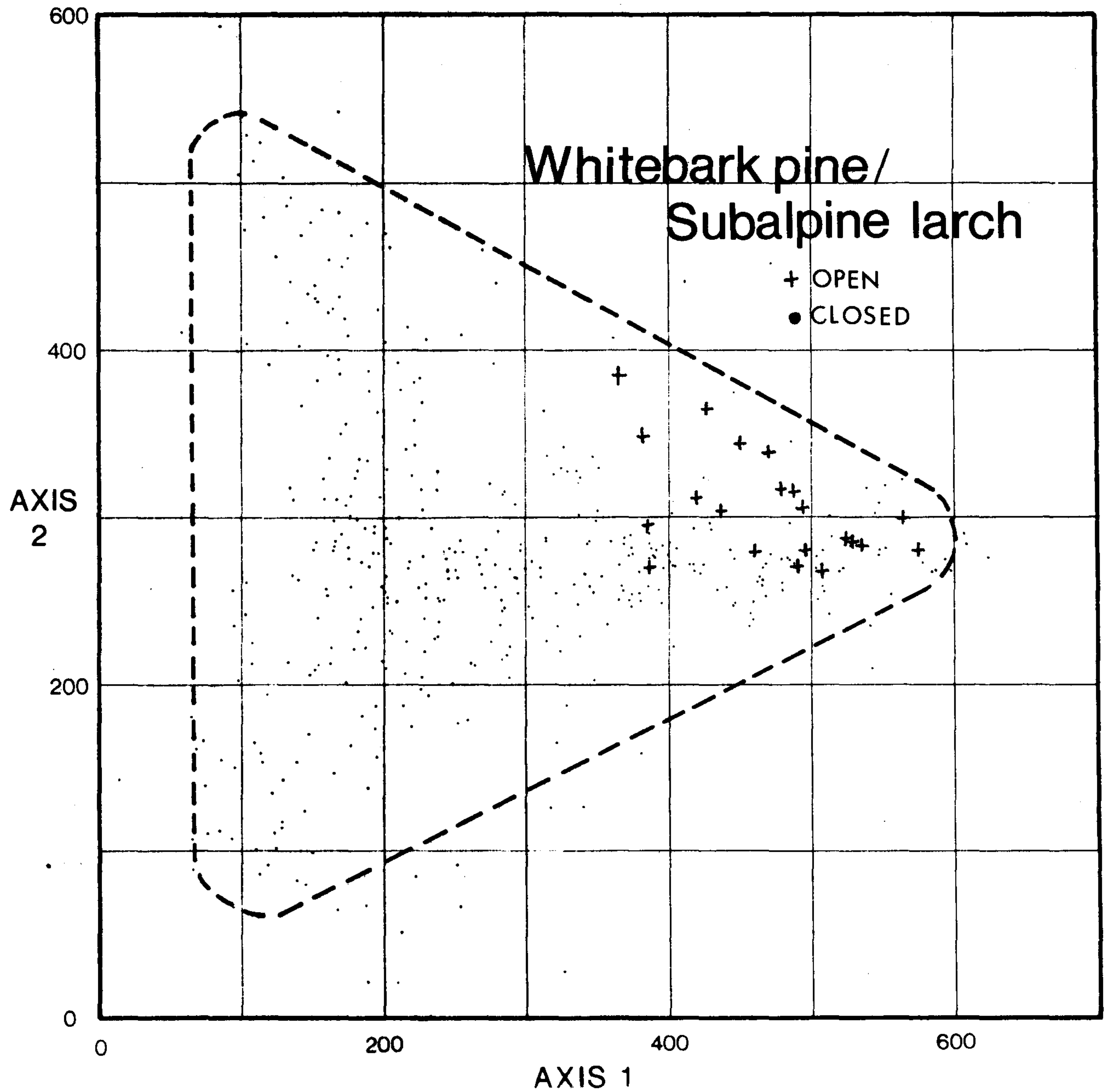


Figure 16. Ordination of the whitebark pine/subalpine larch cover type.

Table 12. Vegetation summary table for the whitebark pine/subalpine larch cover type (plots included open canopy type only).

Tree species	Density/ha by height class 0-3m	3-10m	10+m	Basal Area sq.m/ha Mean	Max	Percent Average Cover	Relative Constancy (Percent)
Abies amabilis	276	0	0	0	0	T	19
Abies lasiocarpa	2310	243	143	9	50	12	95
Larix lyallii	386	52	71	4	20	2	48
Picea engelmannii	62	38	43	2	30	1	29
Pinus albicaulis	305	238	52	4	30	5	81
Pseudotsuga menziesii	19	0	0	0	0	T	5
Tsuga mertensiana	410	95	38	1	20	2	52

Common shrub layer species with relative constancy: Phyllodoce empetriformis (71), Cassiope mertensiana (52), Luetkea pectinata (48) Vaccinium myrtillus (38), Pachistima myrsinites (33), Vaccinium deliciosum (24), Rhododendron albiflorum (19), Juniperus communis (19).

Common herb layer species with relative constancy: Poa spp. (52), mosses (38), Carex spp. (38), Erigeron spp. (38), Lupinus spp. (38), Valeriana sitchensis (19), Arenaria spp. (19), Phlox spp. (19)

pioneer species in these timberline environments and that subalpine fir might eventually dominate the sites. However, in these subalpine-alpine environments the success of trees depends as much on future climatic patterns as interspecific competition. Arno and Habeck (1972) suggest that whitebark pine is dominant on windy, warm exposed sites near the highest altitudes of forest growth, that it coexists with subalpine larch and subalpine fir on cooler exposures, and is less common on north-facing, coldest exposures. They suggest that the dissimilar habitat requirements of the two species results in a complementary rather than competitive relationship in these marginal forest environments.

The whitebark pine/subalpine larch type is transitional to non-forest environments, particularly the heather meadow type. Of the common understory species, Phyllodoce empetriformis and Cassiope mertensiana clearly have the highest cover values and highest relative constancy. Several Vaccinium species and Pachistima myrsinites are other associates, primarily where whitebark pine is the dominant tree species. Vaccinium deliciosum and Luetkea pectinata are common associates primarily where subalpine larch is the dominant tree species.

Mountain Hemlock Cover Type

The mountain hemlock cover type is found over 6.7% of the land area of the park complex; there is a 2:1 ratio of the closed canopy to the open canopy type (Table 6). This type is generally found above the Pacific silver fir type on the moist westside of the park, grading into open-canopied parkland and then into non-forested environments. Average elevations were 4714 ft for the closed canopy and 5158 ft for the open canopy type. The mountain hemlock type is widely distributed across the park, but is largely absent east of Ross Lake and east of Stehekin. In drier subalpine habitats, it tends to be found on benches and on northerly exposures; in the more moist westerly subalpine habitats it is commonly found on all aspects to timberline. Slopes averaged 43% for the closed canopy and 50% for the open canopy type.

Map accuracy for the mountain hemlock type was 87% for the closed canopy and 88% for the open canopy type (Table 7). Minor errors for the closed canopy portion included stands that were mapped as mountain hemlock but field-keyed to the Pacific silver fir cover type. Similar errors ocurred for the open canopy portion of the mountain hemlock type with the subalpine fir cover type.. There is a fair amount of similarity between floristic composition of all of these types.

Closed Canopy Mountain Hemlock

Basal area in the closed canopy mountain hemlock cover type is dominated by mountain hemlock (Table 13). Of the 57 sq m/ha, mountain hemlock comprises more than half, with Pacific silver fir contributing about one-third and very minor amounts by the other species. Average cover values follow the same trend, as does overstory density. Understory densities are more variable, with mountain hemlock dominating in the 3-10 m height class and Pacific silver fir dominating in the 0-3 m height class. Alaska yellow-cedar (Figure 12) may occur with mountain hemlock on moister microsites, while subalpine fir and Douglas-fir are occasional associates on drier microsites, particularly in the more easterly parts of the park complex.

Plant associations include several commonly found in other areas as well. The _Tsuga mertensiana/Vaccinium membranaceum_ association is common in the area, and recognized as a very common regional association by Franklin and Dyrness (1973). The _Tsuga mertensiana/Rhododendron albiflorum_ association on cooler sites and _Tsuga mertensiana/Vaccinium alaskense_ association on more mesic sites are also found in the park and to the west (Henderson and Peter, 1983). The _Tsuga mertensiana/Mensiesia ferruginea_ association is found in high

Table 13 . Vegetation summary table for the mountain hemlock closed canopy cover type.

Tree species	Density/ha by height class 0-3m	3-10m	10+m	Basal Area sq.m/ha Mean	Max	Percent Average Cover	Relative Constancy (Percent)
Abies amabilis	2144	176	228	18	60	22	92
Abies lasiocarpa	0	0	8	1	20	T	44
Chamaecyparis nootkatensis	284	8	44	1	10	1	28
Picea engelmannii	0	0	4	T	10	T	4
Pinus monticola	92	4	4	T	10	T	12
Pseudotsuga menziesii	4	8	28	3	20	1	20
Thuja plicata	288	32	16	2	40	1	20
Tsuga heterophylla	0	0	4	T	10	T	1
Tsuga mertensiana	1116	268	516	32	90	40	100

Common shrub layer species with relative constancy: Vaccinium membranaceum (56), Rhododendron albiflorum (52), Phyllodoce empetriformis (44), Vaccinium spp. (36) Luetkea pectinata (16), Menziesia ferruginea (12), Vaccinium deliciosum (8) Sorbus sitchensis(8), Cassiope mertensiana (8).

Common herb layer species with relative constancy: mosses (92), Rubus pedatus (32), Veratrum viride (16), Linnaea borealis (12) Carex spp. (8), Rubus lasiococcus (8), Pyrola spp. (8), Clintonia uniflora (4).

Table 14. Vegetation summary table for the mountain hemlock open canopy cover type.

Tree species	Density/ha by height class 0-3m	3-10m	10+m	Basal Area sq.m/ha Mean	Max	Percent Average Cover	Relative Constancy (Percent)
Abies amabilis	651	106	150	7	50	8	70
Abies lasiocarpa	60	45	35	3	20	1	20
Chamaecyparis nootkatensis	683	40	60	1	10	2	55
Pinus albicaulis	45	0	0	0	0	T	10
Pseudotsuga menziesii	5	3	15	1	10	T	5
Salix spp.	0	0	10	0	0	T	5
Tsuga mertensiana	855	573	315	25	70	31	95

Common shrub layer species with relative constancy: Phyllodoce empetriformis (65), Vaccinium membranaceum (55), Sorbus sitchensis (40), Vaccinium deliciosum (35), Rhododendron albiflorum (30) Cassiope mertensiana (25), Menziesia ferruginea (15) Luetkea pectinata (15).

Common herb layer species with relative constancy: mosses (75) Carex spp. (20), Veratrum californicum (15), Rubus lasiococcus (15), Arnica diversifolia (10), Valeriana sitchensis (5), Lupinus lepidus (5), Veratrum viride (5).

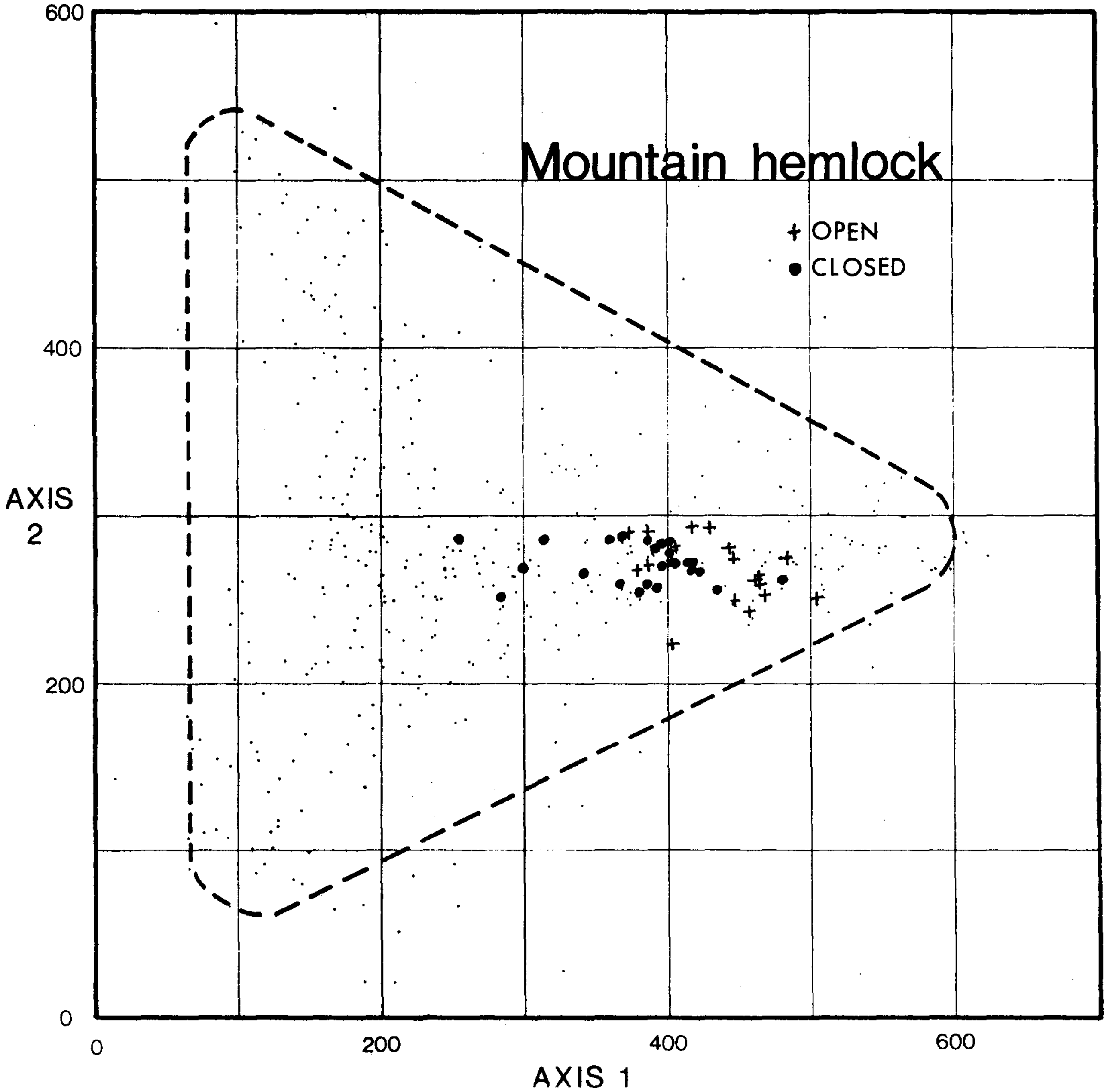


Figure 17. Ordination of the mountain hemlock cover type.

elevation, cool and moist sites in the eastern portion of the park complex, and has not been recognized elsewhere in the northwestern United States. Limited cover of the Tsuga mertensiana/Phyllodoce empetriformis-Vaccinium deliciosum association occurs in a closed canopy situation usually adjacent to more open parkland forest.

Open Canopy Mountain Hemlock

Open canopy mountain hemlock sites include mature tree clump parklands at high elevation and small-sized reproduction in subalpine meadows, recovering burns, or the upper ends of avalanche chutes. A variety of cover types may be adjacent: lush herb, high shrub, closed forests of mountain hemlock and Pacific silver fir, subalpine fir, or the whitebark pine/subalpine larch type. The open canopy type is not as widely distributed as the closed canopy portion; as the ordination (Figure 17) suggests, the open canopy type is more common in cooler, wetter environments than the closed canopy type. These are often westside timberline environments.

Mountain hemlock tends to be more dominant in the open canopy type than it is in the closed canopy type. While basal area estimates are somewhat questionable because of the often clumped nature of stands, two-thirds of the basal area is mountain hemlock; 80% of the cover is mountain hemlock, and it has the highest density in all canopy layers. Comparison of the open and closed canopy statistics suggests that in many instances, mountain hemlock is seral to Pacific silver fir. Alternatively, many of these timberline environments are not climatically stable and successional dynamics may not always be unidirectional.

The Tsuga mertensiana/Phyllodoce empetriformis-Vaccinium deliciosum association is the most common association in the open canopy mountain hemlock cover type. The other associations listed with the closed canopy mountain hemlock type also are found in limited quantities in sites similar to those described.

Pacific Silver Fir Cover Type

The Pacific silver fir cover type is a common mid-elevation forest type in western Washington, occurring between the western hemlock type at low elevation and the mountain hemlock type at high elevation (Figure 10). Mean elevation for the closed canopy type was 4001 ft; mean elevation for the open canopy type was 4318. The dividing line between the western hemlock and Pacific silver fir zone is usually the elevation at which perennial winter snowpack occurs. Within the park complex, Pacific silver fir is widely distributed, but is more prevalent towards the west. Optimum development for this cover type occurs where rainfall exceeds 100 in/yr. In the more easterly, dry portions of the park complex, the Pacific silver fir cover type is less common but is still found on gentle north facing slopes. Concentrations of this type in the park complex include the Cascade, Baker, and Chilliwack Rivers, and the upper reaches of Newhalem, Big Beaver, Little Beaver, and Thunder Creeks. Slopes averaged 36% for the closed canopy type and 47% for the open canopy type.

Pacific silver fir is the third most common forest cover type in the park complex behind the Douglas-fir type and the western hemlock type (Table 6). For the mapped area as a whole, it is also surpassed by the subalpine fir type due to large areas of the latter type to the east of the park complex, little or no Pacific silver fir to the east due to dry conditions, and generally lower elevations to the west which favor western hemlock. The ratio of closed to open canopy stands is about 3:1 for this type.

Map accuracy of the Pacific silver fir type (Table 7) ranged from 90% for the closed canopy portion to 76% for the open canopy portion. For both canopy types, the most common error was misidentification of one canopy type for the other. Although the open canopy type was one of the lowest accuracy types, the sample size of 17 makes detailed error identification difficult.

Closed Canopy Pacific Silver Fir

Closed canopy stands of Pacific silver fir have the highest average basal area within the park complex (Table 15). Of the 67 sq m/ha, 48% is Pacific silver fir, while western hemlock and mountain hemlock each contribute 14%. Slightly lower average basal areas are found to the west on the Mt.Baker-Snoqualmie National Forest (Henderson and Peter, 1983). Canopy cover averages 60%, with most of the cover contributed by Pacific silver fir. Mountain hemlock is a major associate at high elevation, along with Alaska yellow-cedar. At the lower elevation boundary of this cover type, major associates are Douglas-fir, western hemlock, and western redcedar. Subalpine fir and Engelmann spruce are found as codominants in some stands, particularly in the drier eastern portion of the cover type range where the Pacific silver fir type is restricted to mid-elevation valley bottoms. Regeneration is primarily Pacific silver fir, as it is the most shade-tolerant of all its associated species in this cover type.

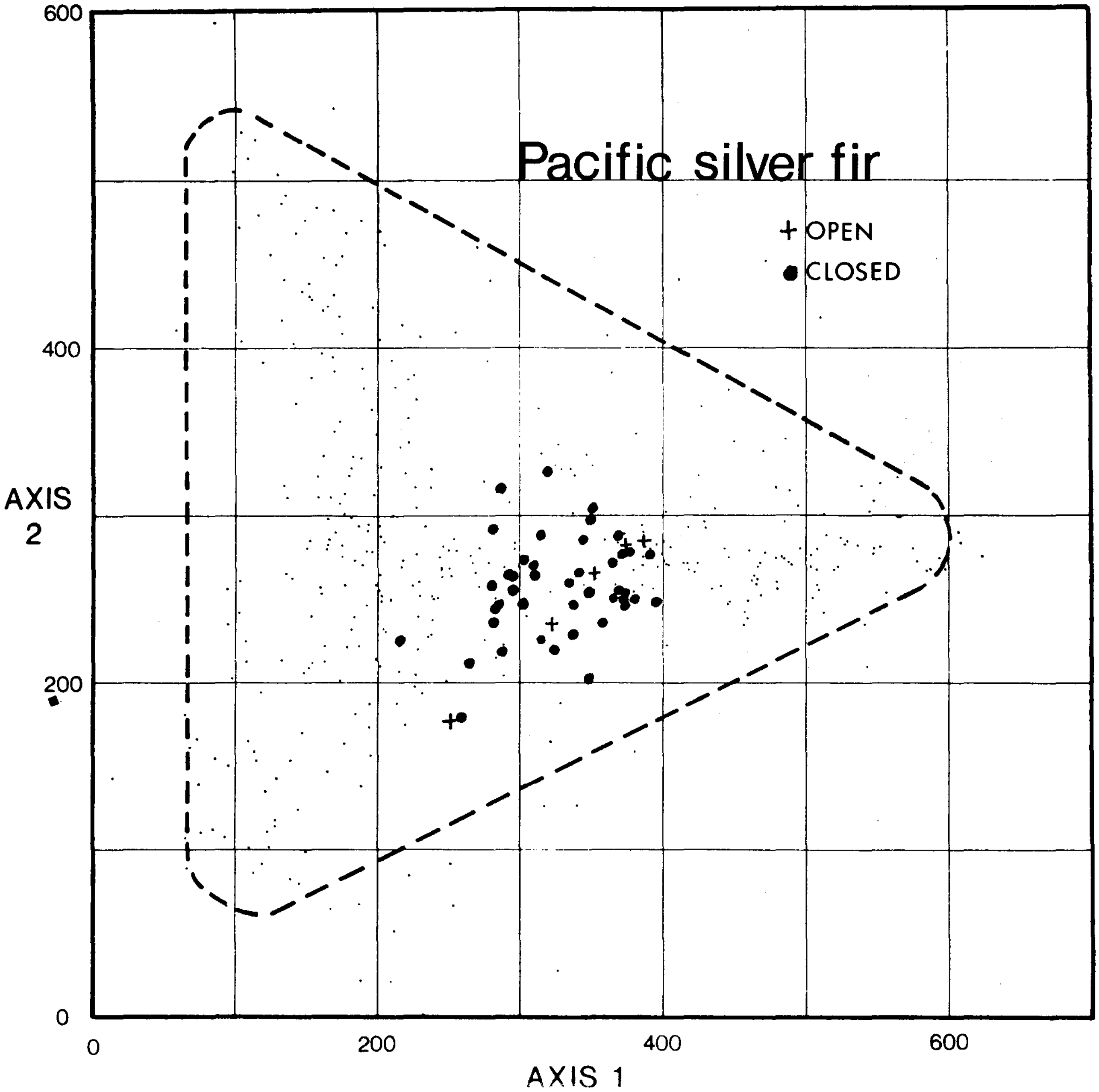


Figure 18. Ordination of the Pacific silver fir cover type.

Table 15. Vegetation summary table for the Pacific silver fir closed canopy cover type.

Tree species	Density/ha by height class 0-3m	3-10m	10+m	Basal Area sq.m/ha Mean	Max	Percent Average Cover	Relative Constancy (Percent)
Abies amabilis	2414	198	458	33	80	45	100
Abies lasiocarpa	2	5	56	2	40	1	16
Chamaecyparis nootkatensis	81	42	35	1	20	1	26
Picea engelmannii	0	2	59	6	70	1	21
Pinus contorta	0	0	2	0	0	T	2
Pinus monticola	3	0	0	0	0	T	9
Populus trichocarpa	0	0	2	T	10	T	2
Pseudotsuga menziesii	7	5	48	4	70	1	30
Taxus brevifolia	7	2	0	0	0	T	2
Thuja plicata	49	16	20	1	30	1	23
Tsuga heterophylla	63	49	105	10	60	2	30
Tsuga mertensiana	279	119	85	10	70	6	60

Common shrub layer species and relative constancy: Vaccinium membranaceum (65), Vaccinium spp. (23), Sorbus sitchensis (21) Pachistima myrsinites (19) Vaccinium alaskense (16), Menziesia ferruginea (12), Acer circinatum (12), Oplopanax horridum (12)

Common herb layer species and relative constancy: Mosses (78), Clintonia uniflora (49), Tiarella trifoliata (28), Gymnocarpium dryopteris (16) Rubus lasiococcus (16), Athyrium filix-femina (12), Pteridium aquilinum (9).

Several plant associations are found within the closed canopy Pacific silver fir cover type. On bottomland sites is the Abies amabilis/Oplopanax horridum association. Midslope types include the commonly sampled Abies amabilis/Vaccinium membranaceum association which occupies a relatively warm and dry portion of the ordination, and the Pachistima myrsinites phase of that type which is transitional in its eastern range to the Abies lasiocarpa/Pachistima myrsinites association. No beargrass is found in this type, while it is found nearby on the Mt. Baker/Snoqualmie National Forest (Henderson and Peter,

1983) and occupies its own association with Pacific silver fir at Mount Rainier National Park (Franklin et al., 1979).

The Abies amabilis/Vaccinium alaskense association, a common central Cascades plant association, also occurs at North Cascades, primarily on gentle, moist slopes at the lower elevation portion of its range. The Abies amabilis/Rhododendron albiflorum and Abies amabilis/Menziesia ferruginea associations occupy cool, mesic sites in the upper elevation range of the cover type. Another association with limited distribution at North Cascades is the Abies amabilis/Rubus lasiococcus association, which appears to be a more xeric type (Franklin et al., 1979).

Open Canopy Pacific Silver Fir

The open canopy Pacific silver fir cover type has the highest average stand basal area (44 sq m/ha) of all the open canopy cover types; over 50% of the basal area is accounted for by Pacific silver fir. Mountain hemlock and western hemlock also contribute some basal area at the low and high elevation ranges of the type. Regeneration is dominated by Pacific silver fir, and average canopy coverage of close to 65% is

Table 16. Vegetation summary table for the Pacific silver fir open canopy cover type.

Tree species	Density/ha by height class 0-3m	3-10m	10+m	Basal Area sq.m/ha Mean	Max	Percent Average Cover	Relative Constancy (Percent)
Abies amabilis	2355	680	370	24	60	52	100
Chamaecyparis nootkatensis	180	40	0	0	0	1	20
Picea engelmannii	0	0	20	2	10	T	20
Pinus monticola	0	0	0	0	0	T	20
Thuja plicata	0	0	10	4	20	1	20
Tsuga heterophylla	30	0	20	6	30	4	40
Tsuga mertensiana	480	240	80	8	30	10	80

Common shrub layer species and relative constancy: Vaccinium membranaceum (80), Sorbus sitchensis (40), Rhododendron albiflorum (20), Acer circinatum (20), Menziesia ferruginea (20), Rubus spectabilis (20), Alnus sinuata (20).

Common herb layer species and relative constancy: mosses (100), Carex spp. (40), Tiarella trifoliata (40), Rubus lasiococcus (40), Clintonia uniflora (20), Goodyera oblongifolia (20), Valeriana sitchensis (20), Pteridium aquilinum (20), Pyrola secunda (20).

high for an open canopy type. Limited sampling in this type may account for this unusually high value.

Plant associations are difficult to identify due to the early seral nature of some stands and the low number of samples. Most of the associations identified for the closed canopy portion of the cover type probably can be found in the open canopy type, too. The Abies amabilis/Vaccinium membranaceum and Abies amabilis/Rhododendron albiflorum associations were identified in the data; the Abies amabilis/Oplopanax horridum association is also found. This latter type is actually an old growth type but wide-spaced trees and sufficent openings for hardwoods or shrub/herbs cause it to be classified as an open canopy type.

Western Hemlock Cover Type

The western hemlock cover type occurs on 12.4% of the park complex and 13.7% of the entire mapped area (Table 6). There is a slightly higher proportion of the open canopy type outside the park complex due to regenerating logged areas, but the presence of some logged areas in the park (before its creation) and recent burns has kept the proportion of closed to open canopy western hemlock at about 2:1 for both areas.

The western hemlock cover type is the typical lowland westside forest type, but it occupies an atypical set of environmental conditions in the park complex. Average elevations of the closed and open canopy type plots were 2330 and 2356 ft, respectively. In most westside drainages, the park boundary runs rather high along the slope, such that the western hemlock type along the western edge of the park complex is cooler than average for the type and transitional to the Pacific silver fir type. It is best developed in the bottoms of the westside watersheds, such as the Baker River, Bacon Creek, and Newhalem Creek. Further to the east, the rainshadow effect on the valleys that are still west of the Cascade Crest restricts western hemlock to a valley bottom habitat; slope forests in these valleys are in the Douglas-fir cover type. These more easterly valley bottom forests often have an understory more typical of the Douglas-fir type. In general, the western hemlock cover type represents a warm, moist position on the forest ordination (Figure 19). Slopes averaged 34% for the closed canopy type and 52% for the open canopy type.

The accuracy of the western hemlock cover type was 89% and 84% for the closed and open canopy types. For the closed canopy type, the most common errors were mapped western hemlock types

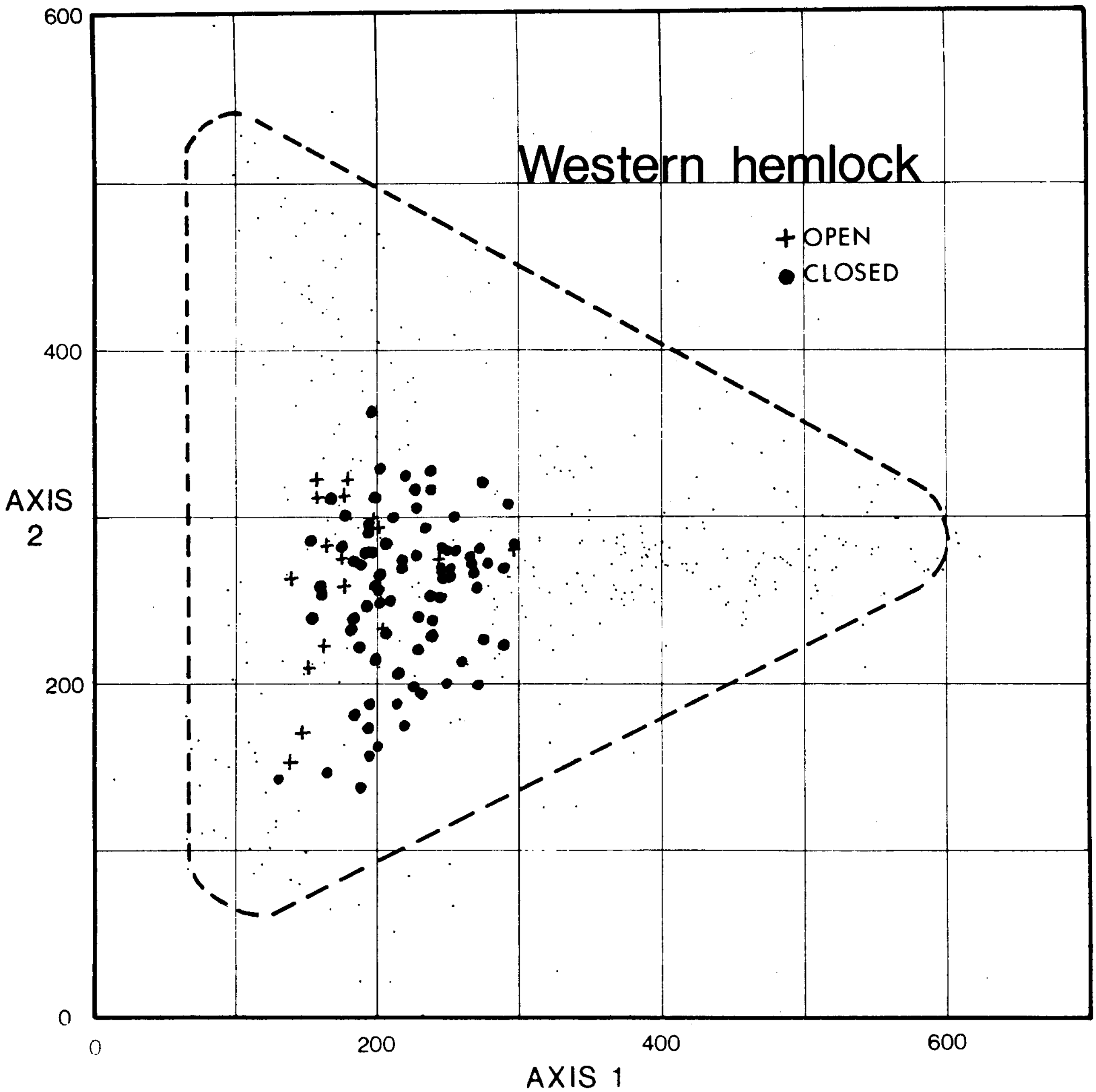


Figure 19. Ordination of the western hemlock cover type.

that field keyed to the Pacific silver fir closed canopy type or the open canopy western hemlock type. The open canopy error was primarily caused by field keying the type to the closed canopy western hemlock; minor problems with the Pacific silver fir type existed. The lack of error associated with the Douglas-fir type suggests that the moisture gradient was more accurately predicted than the temperature gradient.

Closed Canopy Western Hemlock

The closed canopy type averages 64 sq m/ha of basal area, second only to the Pacific silver fir type (Table 17). In other areas (Henderson and Peter, 1982, 1983, Franklin et al., 1979) the western hemlock type commonly but not always has

Table 17. Vegetation summary table for the western hemlock closed canopy cover type.

Tree species	Density/ha by height class 0-3m	3-10m	10+m	Basal Area sq.m/ha Mean	Max	Percent Average Cover	Relative Constancy (Percent)
Abies amabilis	349	51	65	3	70	2	43
Abies grandis	2	1	2	T	10	T	6
Abies lasiocarpa	2	1	2	T	10	T	4
Acer macrophyllum	0	0	6	T	10	T	2
Alnus rubra	0	6	8	T	30	T	7
Betula papyrifera	0	0	4	T	10	T	1
Chamaecyparis nootkatensis	0	0	0	0	0	T	1
Cornus nuttallii	1	2	0	0	0	T	1
Picea engelmannii	2	2	6	1	30	T	9
Pinus contorta	4	148	10	T	10	T	5
Pinus monticola	39	1	4	T	15	1	16
Populus trichocarpa	0	0	4	T	30	T	1
Pseudotsuga menziesii	155	59	242	21	90	15	74
Taxus brevifolia	35	2	0	0	0	T	6
Thuja plicata	349	60	127	16	140	15	90
Tsuga heterophylla	678	201	370	22	80	31	89
Tsuga mertensiana	54	22	21	1	40	1	11

Common shrub layer species and relative constancy: Acer circinatum (45), Berberis nervosa (41), Vaccinium spp. (39), Pachistima myrsinites (33), Oplopanax horridum (30), Vaccinium membranaceum (27), Gaultheria shallon (17), Rosa spp. (10), Vaccinium parvifolium (6), Rubus spectabilis (6).

Common herb layer species and relative constancy: mosses (78), Linnaea borealis (44), Chimaphila umbellata (36), Tiarella trifoliata (24), Clintonia uniflora (24), Polystichum munitum (20), Pteridium aquilinum (18), Cornus canadensis (14), Athyrium filix-femina, Gymnocarpium dryopteris.

higher basal area than the Pacific silver fir type. At North Cascades, the higher basal area for Pacific silver fir is due to the relatively dry set of western hemlock forest habitats available; the drier, lower productivity sites bring down the average basal area for the type as a whole. Some of the more moist sites on the western side of the park have 100 sq m/ha or more, particularly some of the western redcedar flats. Basal area is relatively evenly distributed between Douglas-fir, western hemlock, and western redcedar. Although Douglas-fir is on the average taller than the other species, western hemlock cover is on the average greater than any other tree species in this type. Regeneration density is highest for western hemlock, with lower amounts of western redcedar and Pacific silver fir; the fairly high fir numbers are due to the transitional nature of many of the mid-elevation westside stands of western hemlock. Most of the other tree species are occasionals in the western hemlock cover type. Western hemlock and western redcedar are the most constant species , but Douglas-fir as a major seral species is found almost as often.

A wide variety of plant communities are found in the western hemlock cover type. Among the mesic communities are Tsuga heterophylla/Gaultheria shallon, and Tsuga heterophylla/Berberis nervosa, both commonly found in other forest areas to the southwest (Henderson and Peter, 1982). Two communities intermediate to the Pseudotsuga menziesii group of associations are the Tsuga heterophylla/Pachistima myrsinites and Tsuga heterophylla-Thuja plicata/Pachistima myrsinites-Berberis nervosa associations. Both of these associations seem to be unique to the North Cascades area, and tend to be found in the more easterly valleys where slope forests are Pseudotsuga mensiezii associations. In cooler, moist areas the Tsuga heterophylla/Vaccinium spp. association is found; this type is often transitional to the Abies amabilis group of associations and often will have limited Abies regeneration. On well-drained slopes directly above valley bottoms the Tsuga heterophylla/Acer circinatum association is found; closer to the bottomlands on more moist sites the Tsuga heterophylla/Polystichum munitum and Tsuga heterophylla/Oplopanax horridum associations are found. The Tsuga heterophylla/depauperate association, a densely stocked, understory-free type (except for moss) is also occasionally found. Henderson and Peter (1982) recognized this type on the Soleduck District of Olympic National Forest, and questioned whether this type is truly an ecological site or simply an artifact of overstocking and low light levels in the understory.

Open Canopy Western Hemlock

The open canopy western hemlock cover type, like the other open canopy conifer types, can consist of scattered old trees on rocky sites or be a fairly dense stand of young growth forest. For the western hemlock type, the latter appears to be more commonly the case. Stands average over 700 stems/ha that are over 10 m tall, although basal area averages a fairly low 22 sq m/ha. Over 70% of the basal area is in Douglas-fir, and the cover of Douglas-fir exceeds that of any other tree species in this type. However, western hemlock and western

Table 18. Vegetation summary table for the western hemlock open canopy cover type.

Tree species	Density/ha by height class 0-3m	3-10m	10+m	Basal Area sq.m/ha Mean	Max	Percent Average Cover	Relative Constancy (Percent)
Abies amabilis	24	0	0	0	0	1	18
Abies grandis	71	0	0	0	0	T	6
Acer glabrum	0	0	18	0	0	T	6
Acer macrophyllum	0	12	24	1	10	1	6
Alnus rubra	0	29	47	1	10	1	22
Betula papyrifera	0	0	6	0	0	T	6
Cornus nuttallii	0	6	0	1	10	T	6
Pinus contorta	0	47	24	1	10	1	18
Pinus monticola	6	6	0	0	0	T	6
Pseudotsuga menziesii	541	1221	538	16	60	45	82
Salix scouleriana	0	6	0	0	0	T	6
Thuja plicata	1065	94	71	1	10	8	82
Tsuga heterophylla	1812	153	24	1	10	8	76

Common shrub layer species and relative constancy: Berberis nervosa (76), Pachistima myrsinites (47), Acer circinatum (35), Vaccinium spp. (23), Rubus parvifolius (29), Rosa spp. (29), Salix spp. (17), Vaccinium membranaceum (17), Oplopanax horridum (12).

Common herb layer species and relative constancy: mosses (70), Pteridium aquilinum (35), Epilobium angustifolium (23), Polystichum munitum (17), Cornus canadensis (17), Pyrola spp. (17), Clintonia uniflora (14), Linnaea borealis (12), Smilacina spp. (12).

redcedar are well represented in these stands, and their total density exceeds that of Douglas-fir. Douglas-fir is generally a significant component of the western hemlock type, and in most cases the dominance of Douglas-fir in the young growth condition (Table 18) will shift to a codominance in the mature, closed canopy position (Table 17), eventually disappearing in the absence of disturbance after 750 to 1000 years. Bigleaf maple and red alder are present in the mid and upper canopy levels of these generally young stands; some hardwood in the canopy was one the characteristics that caused a pixel to be classified in the open canopy component of a coniferous cover type.

The plant associations for the open canopy western hemlock are a subset of the closed canopy types. The *Tsuga heterophylla/Gaultheria shallon*, *Tsuga heterophylla/Berberis nervosa*, and *Tsuga heterophylla-Thuja plicata/Pachistima myrsinites-Berberis nervosa* associations were identified in drier locations. The *Tsuga heterophylla/Polystichum munitum* association was identified in more moist low elevation areas, and moist,higher elevation open canopy forests were generally the *Tsuga heterophylla/Vaccinium* spp. association.

Hardwood Forest Cover Type

Within the boundaries of the park complex, the hardwood forest cover type occupies 0.4% of the land surface (Table 6). It is found scattered throughout the western part of the park complex, mostly along flat river valley bottoms or at the base of avalanche chutes. It is found mostly below 3000 ft elevation, and never above 4000 ft. Precipitation may range from 20 to 100 inches per year. Except in rare cases it occupies terrain with slopes below 30%. It is primarily found in the Skagit River corridor. The ordination (Figure 20) suggests that the hardwood forest cover type is found in low elevation, generally moist areas.

This cover type is often found where some disturbance has occurred in areas previously dominated by conifers. Old clearcuts (especially at low elevation in flat terrain) and old fires have favored the temporary dominance of hardwood species such as bigleaf maple or red alder. In the case of avalanche chutes, hardwood forest is commonly found at the foot of the slope bordered on the upslope side by the high shrub cover type. Occasional conifers may be found mixed in with the hardwoods.

Hardwood forest stands are usually dominated by bigleaf maple (*Acer macrophyllum*) and black cottonwood (*Populus trichocarpa*), with cover values reaching 80% in lowland valley

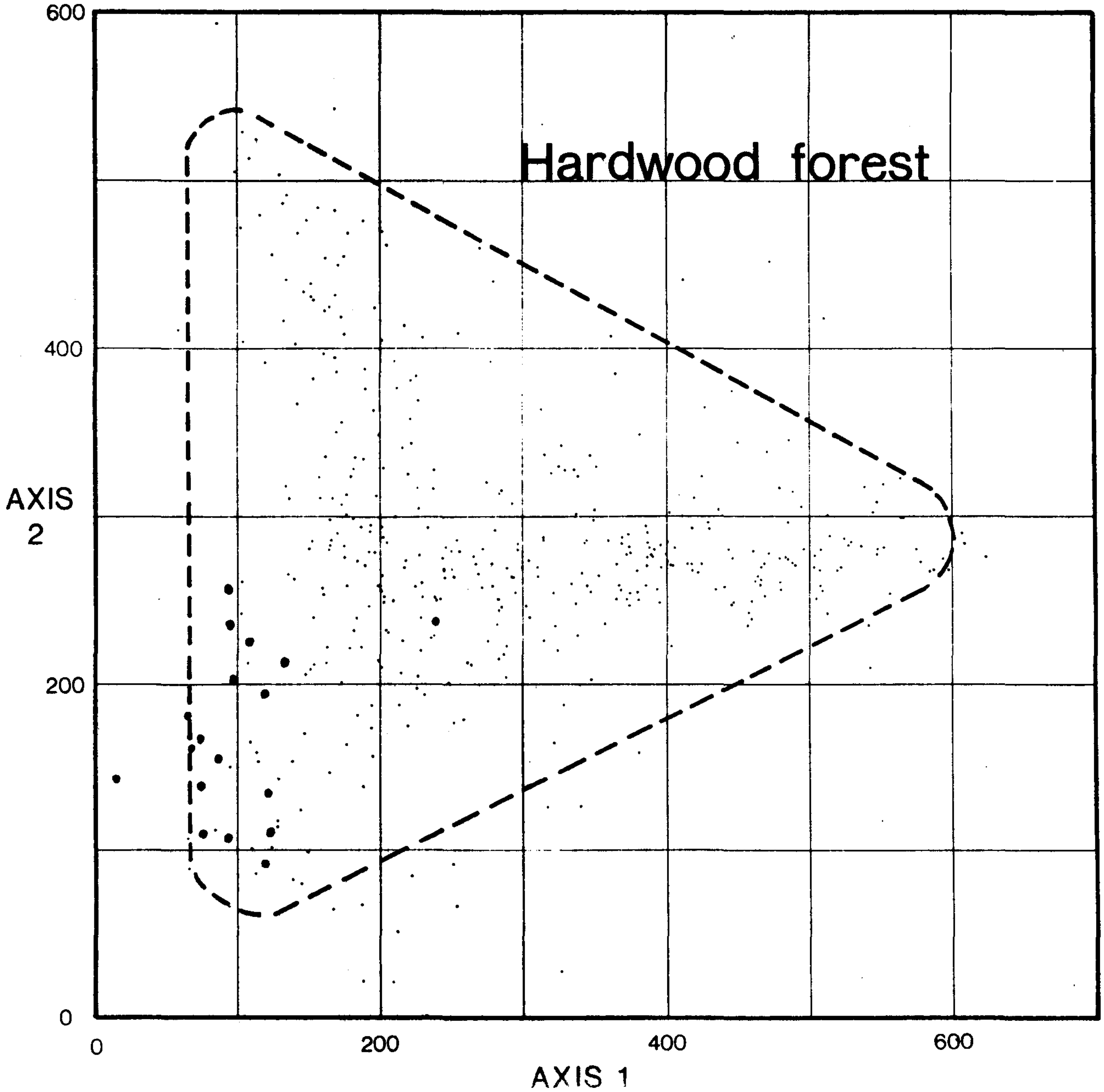


Figure 20. Ordination of the hardwood forest cover type.

Table 19. Vegetation summary table for the hardwood forest cover type.

Tree species	Density/ha by height class 0-3m	3-10m	10+m	Basal Area sq.m/ha Mean	Max	Percent Average Cover	Relative Constancy (Percent)
Abies amabilis	6	0	0	0	0	T	6
Abies grandis	0	0	0	0	0	T	6
Acer glabrum	0	6	0	0	0	T	6
Acer macrophyllum	450	217	83	6	30	11	83
Alnus rubra	22	0	39	2	20	3	50
Betula papyrifera	0	22	61	2	20	1	28
Cornus nuttallii	6	17	0	0	0	1	22
Pinus ponderosa	0	0	0	0	0	T	6
Populus trichocarpa	0	0	94	7	50	5	44
Prunus emarginata	0	0	0	1	10	1	11
Pseudotsuga menziesii	83	11	67	6	40	2	50
Salix spp.	0	333	0	3	40	1	17
Thuja plicata	22	11	6	1	10	1	28
Tsuga heterophylla	28	11	0	0	0	T	11

Common shrub layer species with relative constancy: *Rubus parvifolium* (50), *Pachistima myrsinites* (33), *Berberis nervosa* (22), *Rosa* spp. (22), *Vaccinium* spp. (22), *Cornus stolonifera* (11), *Symphoricarpos albus* (11), *Ribes* spp. (11), *Rubus spectabilis* (11), *Alnus sinuata* (5).

Common herb layer species with relative constancy: *Pteridium aquilinum* (44), *Smilacina racemosa* (22), *Trientalis latifolia* (11), mosses (11), *Cornus canadensis* (11), *Polystichum munitum* (5), *Aruncus sylvester* (5), *Clintonia uniflora* (5), *Athyrium filix-femina* (5), *Equisetum* spp. (5).

bottoms. In these moist sites, thimbleberry (Rubus parviflorus), blackberry (Rubus spp.), and bracken fern (Ptridium aquilinum) dominate the understory vegetation. Red alder is sometimes a codominant overstory species.

Moist valley bottom stands are likely to be fairly pure hardwood forests, while hardwood stands on slopes often contain conifers such as western redcedar, western hemlock, and particularly on drier slopes, Douglas-fir. Red alder and paper birch (Betula papyrifera) are more abundant on slopes than in valley bottom hardwood stands, and stands transitional with the high shrub type often contain vine maple (Acer circinatum) with up to 20% cover. The major overstory and understory species of the hardwood forest cover type, together with average basal areas and cover, are presented in Table 19. Because the hardwood type covers a broad spectrum of hardwood forest subtypes, the average values will rarely be achieved for all species at one location.

An overall 90% accuracy for this type in the classification reflects the distinct segregation of the hardwood stands from other vegetation types; the error present is primarily confusion with the high shrub type. Sizable areas occupied by hardwood forest can be found in the valleys of the Baker River, Big Beaver and Little Beaver Creeks, and McMillan Creek in the northern half of the park complex, and the Stehekin River and Cascade River in the southern half. Large areas of the Skagit River Valley west of the park complex are also covered with hardwood forest.

High Shrub Cover Type

The high shrub cover type is found over a wide range of elevations from 1600 to 5500 ft, and is clearly restricted to moist environments (Figure 21) according to the plot ordination. It predominately occupies avalanche chutes associated with steep secondary drainages that remain moist most of the year. Drainages of this type, with slopes of 25% or more and primarily on southern exposures, are most likely to support the high shrub cover type. Similar drainages with more northerly exposures are more likely to support coniferous forests.

This cover type is also found in creek drainages not subject to avalanches and in some flat wetlands. It may also occur in lowland clearcuts or burns not yet colonized by hardwood or conifer forests. Overall, this community covers 4.9% of the surface of the park complex and 4.5% of the total area covered by the classification (the park special map). Mapping accuracy of this type was found to be over 95% (Table 7),

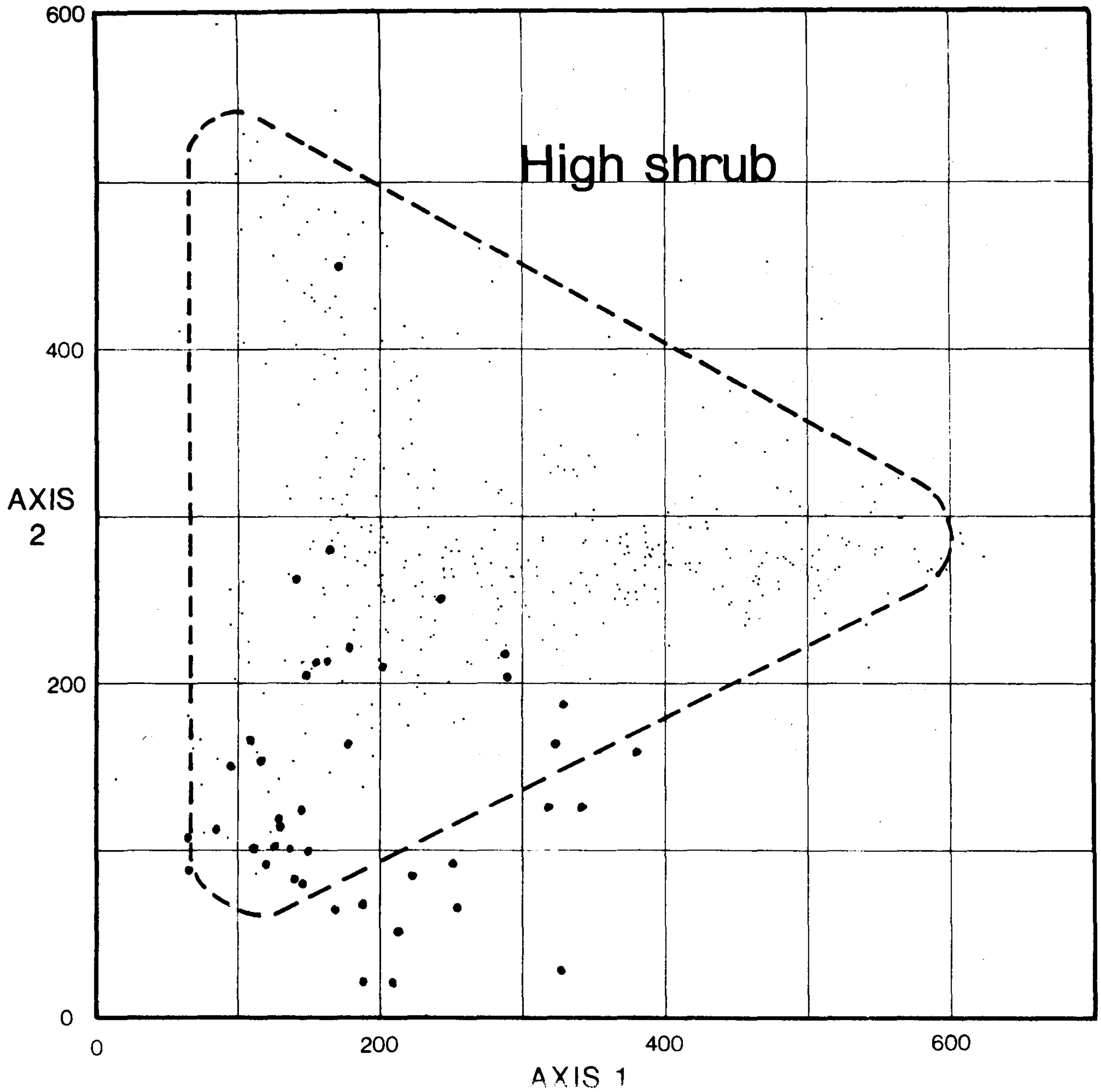


Figure 21. Ordination of the high shrub cover type.

Table 2Ø. **Vegetation summary table for the high shrub cover type.**

Tree species	Density/ha by height class Ø-3m	3-1Øm	1Ø+m	Basal Area sq.m/ha Mean	Max	Percent Average Cover	Relative Constancy (Percent)
Abies amabilis	Ø	Ø	Ø	Ø	Ø	T	2
Abies lasiocarpa	84	3Ø	2	Ø	Ø	T	19
Acer glabrum	1Ø2	37	Ø	T	1Ø	T	4
Acer macrophyllum	Ø	56	19	Ø	2Ø	T	4
Alnus rubra	Ø	Ø	Ø	Ø	Ø	T	2
Chamaecyparis nootkatensis	1Ø2	19	Ø	Ø	Ø	T	7
Picea engelmannii	Ø	Ø	Ø	Ø	Ø	T	4
Populus trichocarpa	Ø	Ø	9	1	3Ø	T	4
Pseudotsuga menziesii	12	2	5	Ø	Ø	T	12
Salix spp.	47	344	9	2	5Ø	1	12
Thuja plicata	9	Ø	Ø	Ø	Ø	T	4
Tsuga heterophylla	28	9	Ø	Ø	Ø	T	2
Tsuga mertensiana	9	5	Ø	Ø	Ø	T	2

The shrub layer is ususally dominant in the high shrub type. Common shrub layer species and relative constancy: Alnus sinuata (51), Rubus parviflorus (51), Acer circinatum (4Ø), Pachistima myrsinites (4Ø), Amelanchier alnifolia (26), Sorbus sitchensis (26), Cornus stolonifera (21), Rubus spectabilis (13), Vaccinium membranaceum (7).

Common herb layer species and relative constancy: Pteridium aquilinum (37), Epilobium angustifolium (23), Athyrium filix-femina (16), Veratrum spp. (15), Smilacina spp. (13), Dicentra formosa (1Ø), Achillea millefolium (1Ø), Aquilegia formosa (8), Heracleum lanatum (8).

because the type is easily differentiated by spectral signatures. The error was due to confusion with the hardwood forest type, which often intergrades with the high shrub type at lower ends of avalanche chutes.

The avalanche chute communities are dominated by sitka alder (Alnus sinuata), willows (Salix spp.), and vine maple. Associate species found on some sites include thimbleberry, bracken fern, dogwood (Cornus stolonifera), and boxwood (Pachistimia myrsinites). Occasionally this cover type supports low densities of conifers such as subalpine fir at higher elevations and western hemlock or western redcedar at lower elevations, with Douglas-fir in drier locales. Hardwood trees such as black cottonwood, bigleaf maple and red alder may also be present but usually as occasionals with cover less than 25%.

When growing in wetland areas, the high shrub cover type is mostly made up of willows in association with dogwood or sedges. In the plot data, these occurrences were mainly at low elevation.

Lowland Grass Cover Type

The lowland grass cover type is a very broadly defined group of low to mid-elevation herbaceous communities, with a mean elevation of 2432 ft. It occupies only 1.6% of the land area in the park, and the same proportion for the mapped area as a whole. Mapping accuracy was 94%, with minor confusion of this type with the lush herbaceous type, a higher elevation herbaceous cover type.

The major species found in the lowland grass cover type are shown in Table 21. The ordination of lowland grass plots (Figure 22) suggests a tendency for such areas to be warm and dry, but there are representative plots in moist areas (low axis 2 scores) and two outlier plots that floristically appear more similar to high elevation areas (high axis 1 scores).

The types of communities include:

(1) Herbaceous communities growing on steep, rocky slopes above 2000 ft elevation. Most of these are found at the upper end of southerly exposed avalanche chutes adjacent to high shrub communities. Exposed rock covers from 20-40% of the ground and slopes are usually in the 40-70% range. Annual precipitation is usually below 80 in/yr. Major species are bearberry (Arctostaphylos uva-ursi), wheatgrass (Agropyron spicatum), and sage (Artemisia tridentata).

Table 21. Vegetation summary table for the lowland grass cover type.

Tree species	Density/ha by height class 0-3m	3-10m	10+m	Basal Area sq.m/ha Mean	Max	Percent Average Cover	Relative Constancy (Percent)
Alnus rubra	0	0	0	0	0	1	18
Pinus contorta	0	0	0	0	0	T	9
Pinus ponderosa	2	0	0	0	0	T	9
Pseudotsuga menziesii	0	0	0	0	0	T	9
Salix scouleriana	0	0	0	0	0	T	9

The shrub layer is usually codominant with the herb layer in the lowland grass type. Co on shrub layer species with relative constancy are: Arctostaphylos uva-ursi (64), Ceanothus velutinus (27), Pachistima myrsinites (27), Spirea betulifolia (10), Juniperus communis (10), Holodiscus discolor (10).

The herb layer is usually codominant with the shrub layer in this type. Common herb layer species with relative constancy are: Aspidotis densa (45), Agropyron spicatum (36), Penstemon spp. (36), mosses (36), Achillea millefolium (27) Carex spp. (27), Cryptogramma crispa (27), Erigeron filifolius (18), Dactylis glomerata (18), Poa spp. (18), Anaphalis margaritacea (10), Balsamorhiza sagittata (10), Pteridium aquilinum (10).

(2) Disturbed grasslands at low elevation. These communities are usually associated with human activities, including road cuts, towns, transmission line corridors, pastures, and recent clearcuts. Most of these areas are in valley bottoms. Idaho fescue (Festuca idahoensis), yarrow (Achillea millefolium), pearly everlasting (Anaphalis margaritacea), chrysanthemum, and aster are among the common species found.

(3) Wet meadows. These low to mid-elevation bogs contain horsetail (Equisetum arvense), sedges, rushes, and skunk cabbage (Lysichitum americanum).

(4) Moss-covered rock. In many areas obvious rock and cliff areas were being identified from reflectance values as herbaceous communities. This was primarily where there was moss and lichen growth.

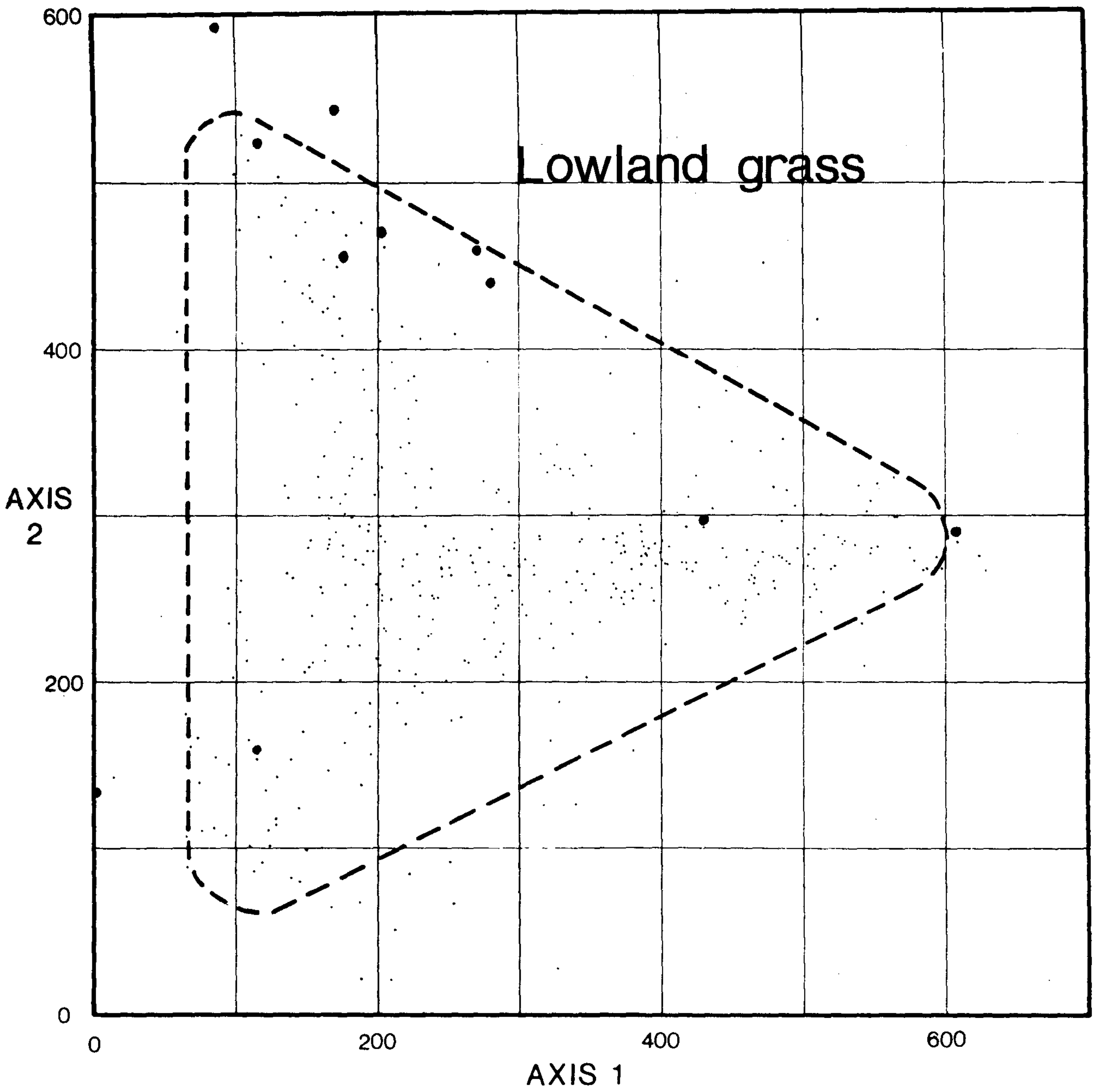


Figure 22. Ordination of the lowland grass cover type.

Lush Herbaceous (Subalpine Herb) Cover Type

The lush herbaceous cover type is essentially a subalpine herb cover type, with a mean elevation from sample plots of 5512 ft. It is found at high elevation, both in moist and dry situations. The ordination (Figure 23) indicates that with one exception the type is floristically associated with other high elevation plots, and spans a moisture range larger than any other subalpine to alpine cover type. The lush herb type covers more area (9.3%) in the park complex than any other non-forest vegetation cover type (Table 6). Lowland grass or open coniferous cover types may be contiguous at lower elevation, while the upper edges of the lush herb type may be heather meadows. Plot slopes averaged 42%.

Mapping accuracy was 93%, indicative of the high accuracy with which the Landsat group clustering was able to identify herbaceous dominated communities. The largest sources of error were heather meadows, high shrub, and open canopy forest types, each of which may at times have a substantial herbaceous component.

The type is so broadly defined that it includes all of the subalpine herbaceous communities covered by Douglas and Bliss (1977). Along with many herbs, common low shrub associates include partridge-foot (Luetkea pectinata), red heather (Phyllodoce empetriformis), and huckleberry (Vaccinium spp.); sparse tree cover of mountain hemlock, Engelmann spruce, or subalpine fir may be present (Table 22). However, if the meadow has substantial tree invasion it will be classified as the open canopy component of one of the forest types. Some of these meadows may be the result of past disturbance (avalanche or fire) and may be an early successional stage of a coniferous forest type.

Among the common herbaceous species are American bistort (Polygonum bistortoides), subalpine daisy (Erigeron spp.), sedges, false-hellebore (Veratrum spp.), and fescue.

Heather Meadow Cover Type

The heather meadow cover type is associated with the coldest environments in the park (Figure 24). It is found only at high elevation (average elevation = 5869 ft), usually in areas that are snow-free only in mid to late summer. The heather type covers only 0.6% of the land surface within the park complex, but this is an underestimate of its true cover. At the time the Landsat scenes were recorded (early to mid-summer) some of the heather meadows were just emerging from snow cover. That which was still under snow or in a mosaic of

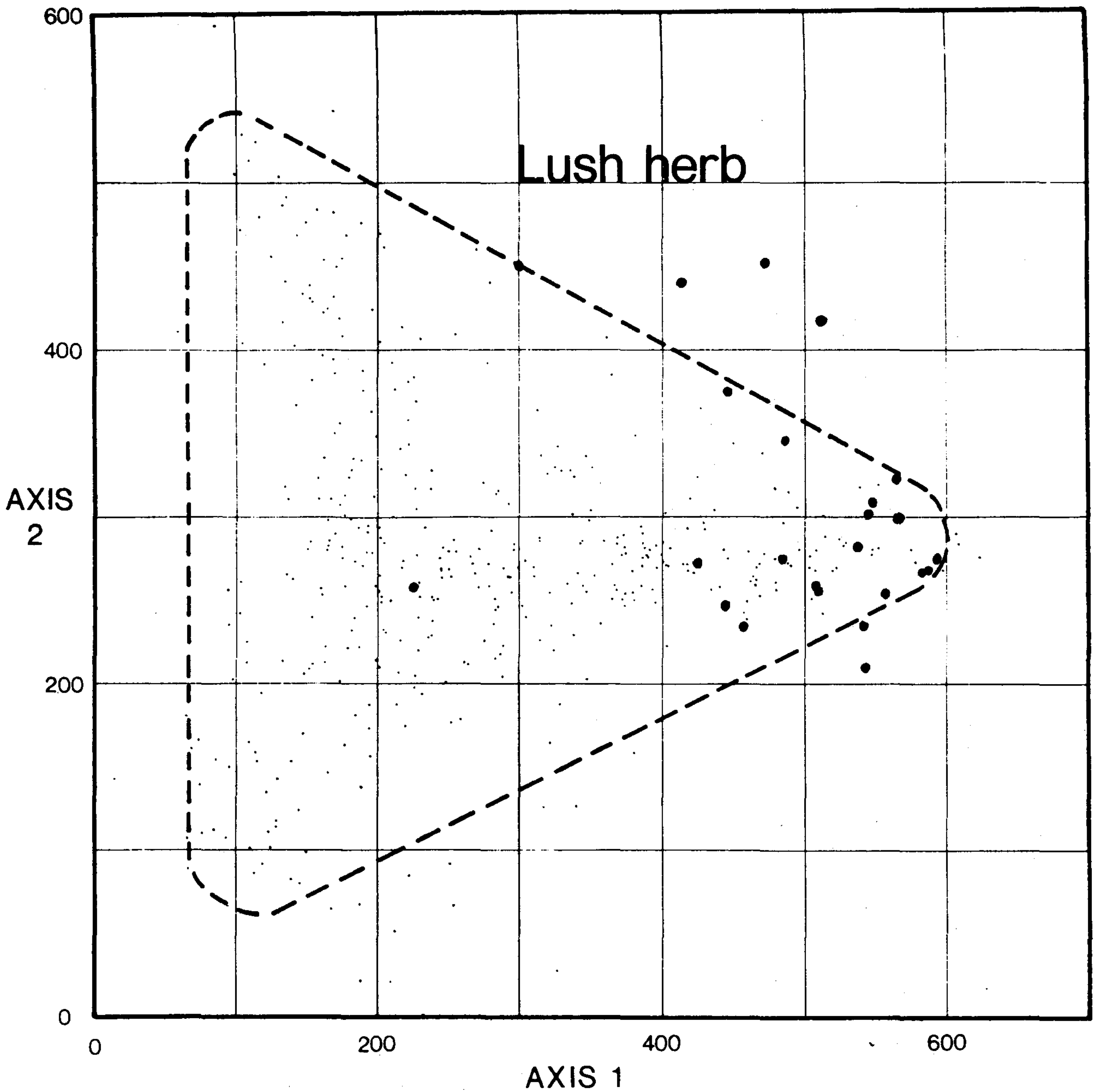


Figure 23. Ordination of the lush herbaceous (subalpine herb) cover type.

Table 22. Vegetation summary table for the lush herbaceous cover type.

Tree species	Density/ha by height class 0-3m	3-10m	10+m	Basal Area sq.m/ha Mean	Max	Percent Average Cover	Relative Constancy (Percent)
Abies lasiocarpa	0	0	0	0	0	T	8
Tsuga mertensiana	0	0	0	0	0	T	8

The lush herbaceous type has a codominant shrub-herb layer with very little tree cover.

Common shrub species with relative constancy include: Vaccinium deliciosum (24), Phyllodoce empetriformis (24), Luetkea pectinata (20), Sorbus sitchensis (20), Vaccinium spp. (12), Cassiope mertensiana (8).

Common herbaceous species include: Carex spp. (64), Valeriana sitchensis (44), Erigeron spp. (36), Veratrum californicum (32), Poa spp. (32), Lupinus spp. (28), Epilobium angustifolium (20), Thalictrum spp. (20), Heracleum lanatum (16), Claytonia lanceolata (16), Polygonum bistortoides (16), Arnica spp. (16), Lomatium spp. (16), Arnica diversifolia (16), Festuca viridula (12), Senecio spp. (12), Castilleja spp. (12).

heather dominated by snow would likely be identified as snow rather than heather. The typical basin-like physiography often associated with heather meadows is indicated by the average slope of 15%, far below the average slope of the other cover types in the classification.

The heather type was correctly identified in all 14 samples for 100% accuracy. While the mapped areas very accurately predict that heather is present, the snow effect mentioned above and the lush herb cover type results suggest that heather is likely to be found in areas other than those mapped as well. In fact, the subalpine non-forest communities are often present in a mosaic with patch sizes much smaller than the 50 m square pixel size used in the classification process.

Common species within the heather cover type (Table 23) include red heather, white heather (Cassiope mertensiana), huckleberry, partridge-foot, and sedges. Scattered tree cover of subalpine fir, mountain hemlock, whitebark pine, subalpine larch, and Alaska yellow-cedar may be present but will not exceed 20-25% without being classified as an open canopy forest type.

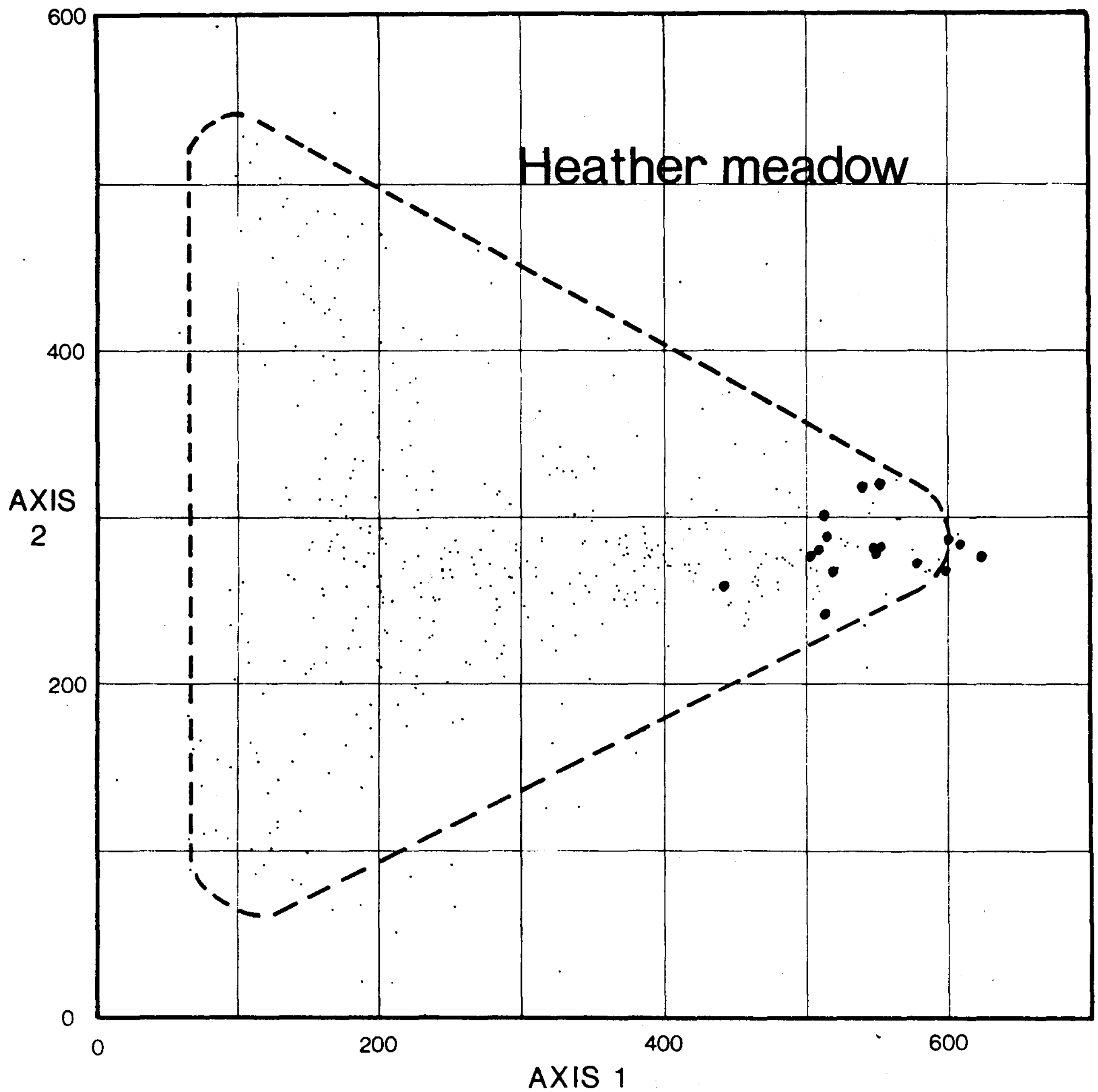


Figure 24. Ordination of the heather meadow cover type.

Table 23. Vegetation summary table for the heather meadow cover type.

Tree species	Density/ha by height class 0-3m	3-10m	10+m	Basal Area sq.m/ha Mean	Max	Percent Average Cover	Relative Constancy (Percent)
Abies lasiocarpa	118	0	0	0	0	T	6
Chamaecyparis nootkatensis	59	0	0	0	0	T	12
Pinus albicaulis	6	0	0	0	0	T	12
Tsuga mertensiana	118	18	0	0	0	T	6

The heather meadow type is typically dominated by shrubs and herbs.

Common shrub species and relative constancy are: *Phyllodoce empetriformis* (82), *Cassiope mertensiana* (71), *Luetkea pectinata* (71), *Vaccinium deliciosum* (59), *Vaccinium caespitosum* (12), *Vaccinium* spp. (6), *Sorbus sitchensis* (6), *Phyllodoce glanduliflora* (6).

Common herbaceous species and relative constancy are: *Carex* spp. (71), mosses (59), *Antennaria* spp. (24), *Potentilla* spp. (24), *Polygonum bistortoides* (18), *Castilleja* spp. (18), *Arnica diversifolia* (12), *Lupinus* spp. (12), *Juncus* spp. (12).

FUEL TYPES AND MODELING

Development of Fuel Maps

Because the ecological modeling developed a set of plant cover types from the layers of the geographic information system, the fuel types were derived by first segregating the data into vegetation cover types. At each of the 1983 ground plots, NFDRS (National Fire-Danger Rating System) and NFFL (Northern Forest Fire Laboratory) models were keyed out, so that when ground plots were sorted by cover type, fuels information was also sorted.

Considerable variation existed when the sorting was completed. The fuel models keyed out at each plot were applicable to the limited area surrounding the vegetation plot so variation within the cover types was expected. The most common NFDRS and NFFL models within each cover type were selected as the best fit models (Table 24). Where two models within either

Table 24. National Fire-Danger Rating System and Northern Forest Fire Laboratory Models for North Cascades, based on field classification of plots later grouped into cover types.

Cover Type	N	NFDRS MODELS	NFFL MODELS
Douglas-fir (C)	44	H	8
Subalpine fir (C)	6	H	8
Whtbk. pine/Sub.Larch (C)	0*	H	8
Mountain hemlock (C)	25	H/G	8
Pacific silver fir (C)	43	H/G	8
Western hemlock (C)	83	H/G	8
Hardwood forest	17	R	9
High shrub	42	O	4/5
Lowland herb	11	L	1
Subalpine herb	26	L	1
Heather shrub	16	S/L	1/5
Ponderosa pine (O)	0*	C	8/1
Douglas-fir (O)	36	H/G	8/5
Subalpine fir (O)	20	F/Q	8/5
Whtbk. pine/Sub. Larch (O)	21	H/Q	8/1
Mountain hemlock (O)	20	H/F	8/5
Pacific silver fir (O)	5	H	8/5
Western hemlock (O)	17	H/Q	8/5

C= closed canopy type
O= open canopy type

*No field plots were established in 1983 in these types, so nearest fit models were subjectively assigned to these types.

the NDFRS or NFFL system had about equal coverage within a type, both of them were listed to best represent the variation in the cover type.

The most common models across the park complex were NFDRS Model H and NFFL Model 8. Over 70% of the park vegetation keys out to one of these models or to a two fuel model where one of these models is the dominant type. NFDRS Model H is for short-leaved coniferous forest with moderate to little debris and an understory of low flammability. NFFL Model 8 also fits short-needled conifer litter with scattered large fuel and understory vegetation.

The closed canopy coniferous forests were most commonly keyed to NFDRS Model H and NFFL Model 8. The second choice NFDRS Model for closed canopy conifer stands was Model G, which includes more large debris and branchwood on the ground.

The open canopy coniferous stands fit the two-fuel model concept (see last page of Appendix 1 for explanation). Within a given area, one fuel model may represent the dominant vegetation and another fuel model may represent fuel conditions that are interspersed within the first model. In the open canopy stands, the dominant model was generally the same as for the cover type's closed canopy portion. The subordinate model was generally a shrub-dominated or grass-dominated model occurring in openings between the conifer clumps. The hardwood, shrub, and herbaceous cover types generally keyed out as expected.

The fuel model maps for the park complex were developed using the NFDRS and NFFL models identified in Table 24. Each pixel was assigned the closest fit NFDRS and NFFL model(s) to create two new layers in the geographic information system. In the NFDRS layer, the following fuel models are recognized: C, H, L, O, R, H/G, H/F, H/Q, F/Q, and S/L. The NFFL layer is composed the following models: 1, 8, 9, 1/5, 4/5, 8/1, and 8/5.

The NFFL best-fit models are useful in predicting surface fire behavior produced by fine fuels at the perimeter or front of the fire. However, keying out the best-fit model does not guarantee that fires burning under the above assumptions will actually behave as predicted. The standard 13 models can be useful to predict fire behavior when there are no other fuel models for the area, but the specific fuel complex may not be accurately modeled by any of the standard models. Calibration of observed fire behavior to modeled fire behavior is the most rational way to choose or develop an appropriate fuel model. For this reason, site specific fuels information was collected on each ground plot, and this information was used to create site-specific fire behavior predictions that could be compared to the standard 13 NFFL models.

Fuel Modeling With BEHAVE

The fuels data collection was completed using an early version of the BEHAVE manual that differed somewhat from the final version in the way the photo keys identified shrub types. Because of this variation, and the lack of site-specific information to verify that the photo keys applied to the study area, site-specific regressions were developed to predict fuel loads from bulk density/fuel height relationships.

Litter loads were defined as those occurring between the top of the F layer and the surface of the L layer. The following relationships were derived:

Short-needled conifer	Y(tons/ac)	= 84.1X	(Depth,ft)
Long-needled conifer	Y "	= 75.1X	"
Hardwood/Avalanche	Y "	= 17.ØX	"
Hardwood Forest	Y "	= 24.2X	"

These bulk density relationships are consistent with others for short and long-needled conifers (Agee 1973). Using the litter depth recorded for each plot, litter loads were calculated for input into the litter component of BEHAVE.

Grass and shrub fuel loads were determined using similar regression techniques. A separate equation was developed for leaf and live twig loads less than 1/4 inch diameter for the bulk density types represented in each shrub and grass type (Figure 25). Higher bulk density numbers within each graph are associated with higher bulk densities. The fine grass type included grasses such as fescues, and the medium grass type included grasses such as orchardgrass. The fine shrub was primarily heather, which because of its dense, low growth habit appears to have very high fuel loads; depth is rarely more than 20-30 cm, however. The medium shrubs were the most commonly occurring type, including *Menziesia*, *Holodiscus*, and *Vaccinium*. The coarse shrub type included *Arctostaphylos*. From these regressions and other fuel data collected at each site, information sufficient to develop fire behavior predictions in the NEWMDL portion of BEHAVE was present. Within each cover type, such predictions were developed for each sample plot in the type.

All fuel models were then run through the TSTMDL portion of BEHAVE to produce fire behavior outputs over a range of environmental conditions. The outputs within each cover type were summarized by averaging values for rate of spread, flame length, and fireline intensity (Table 25, Figure 26). For each cover type, the most common NFFL model outputs are shown along with the averages for the BEHAVE output for windspeeds between 4 and 12 miles per hour. Standard errors around each mean are shown by vertical lines extending from each mean value identified by a dot. Although not all conceivable ranges of environmental conditions were tested, the output did enable some rough comparisons to be made between the field data and the standardized NFFL models.

The Douglas-fir cover type, both closed and open canopy, fit NFFL Model 8 quite closely for all three variables: rate of speread, flame length, and fireline intensity. The subalpine fir and mountain hemlock cover types also fit NFFL Model 8 reasonably well for both open and closed canopy portions of both types.

The whitebark pine/subalpine larch cover type fire behavior was overestimated by both of the closest-fit NFFL models: 8 and 1. Model 1 is actually inappropriate because it assumes complete curing of the grass loads, while the dynamic model used in BEHAVE could account for the high proportion of green

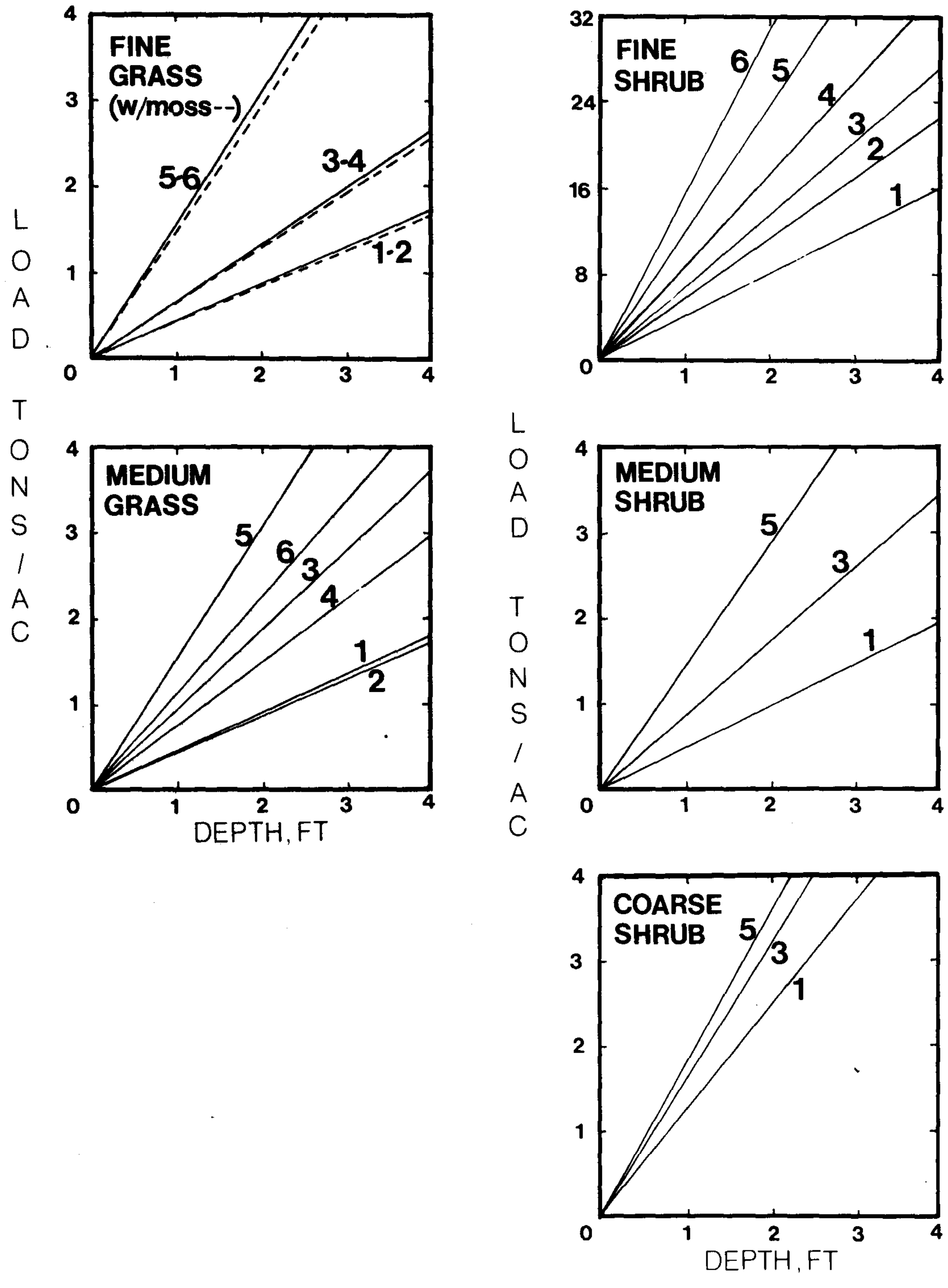


Figure 25. Relations of mass to depth for bulk density classes of common groups of shrubs and grasses.

Table 25. Summary of BEHAVE outputs by cover type.

Cover Type	Sample Size	Rate of Spread (ft/min) with winds of			Flame Length (ft) with winds of			Fireline Intensity (BTU/ft/sec) with winds of		
		4	8	12	4	8	12	4	8	12
DF-Closed*	43	1.97	4.02	6.35	1.00	1.42	1.72	24.9	55.2	92.8
DF-Close	42	1.73	3.50	5.45	0.83	1.17	1.40	11.9	26.5	44.5
DF-Open*	36	1.22	2.31	3.53	0.72	0.97	1.17	24.2	52.8	88.5
DF-Open	35	0.80	1.31	1.80	0.49	0.63	0.71	5.7	10.7	16.0
SAF-Closed	6	1.83	4.00	6.83	1.00	1.67	2.00	17.3	38.9	65.8
SAF-Open	20	1.50	3.05	4.60	1.10	1.40	1.70	10.4	22.9	37.4
WP/SL Open	20	0.80	1.10	1.50	0.40	0.60	0.65	2.2	4.1	6.3
MH-Closed	25	1.40	3.12	5.20	0.96	1.28	1.60	19.1	42.6	72.1
MH-Open	20	1.80	3.85	5.95	1.10	1.50	1.80	13.3	29.8	49.2
PSF-Closed*	43	1.26	2.67	4.30	0.70	1.02	1.26	23.0	51.6	87.2
PSF-Closed	42	0.98	2.02	3.19	0.52	0.79	0.95	11.8	26.5	44.7
PSF-Open	5	2.00	4.60	7.60	1.80	2.40	3.00	36.6	80.0	133.4
WH-Closed	82	2.02	4.35	7.05	1.26	1.84	2.26	38.1	83.8	141.0
WH-Open	17	5.65	12.53	21.12	2.76	4.12	5.24	163.0	371.6	634.9
Hardwd. F.#	17	7.00	16.41	29.29	3.35	5.06	6.65	154.1	366.3	650.4
High Shrub#	42	18.98	44.21	78.43	9.10	13.2	17.1	1114.2	2604.7	4534.8
Low Grass*	11	5.72	17.00	35.64	0.64	1.00	1.36	22.8	72.9	156.3
Low Grass	10	0.80	0.80	0.80	0.10	0.10	0.10	0.5	0.5	0.5
Lush Herb*	26	2.31	6.31	5.35	0.46	0.58	0.62	2.8	6.1	8.9
Lush Herb	25	2.08	3.08	3.32	0.40	0.48	0.48	2.1	3.6	3.6
Heather	16	0.75	1.50	2.13	0.50	0.75	0.88	5.6	12.1	19.5

*In each of these cover types, a single outlier significantly raised the average, so the values are shown with and then without the unusually high value.

#The high output values for these types reflect the standard "medium" environmental conditions: 1, 10, 100, hr timelag fuel moistures of 6, 7, and 8%, live fuel moisture of 120%, slope= 30%. These are exceptionally low values for these primarily riparian types and outputs suggest more intense fire behavior than is likely.

DF= Douglas-fir, SAF= subalpine fir, WP/SL= whitebark pine/subalpine larch, MH= mountain hemlock, PSF= Pacific silver fir, WH= western hemlock.

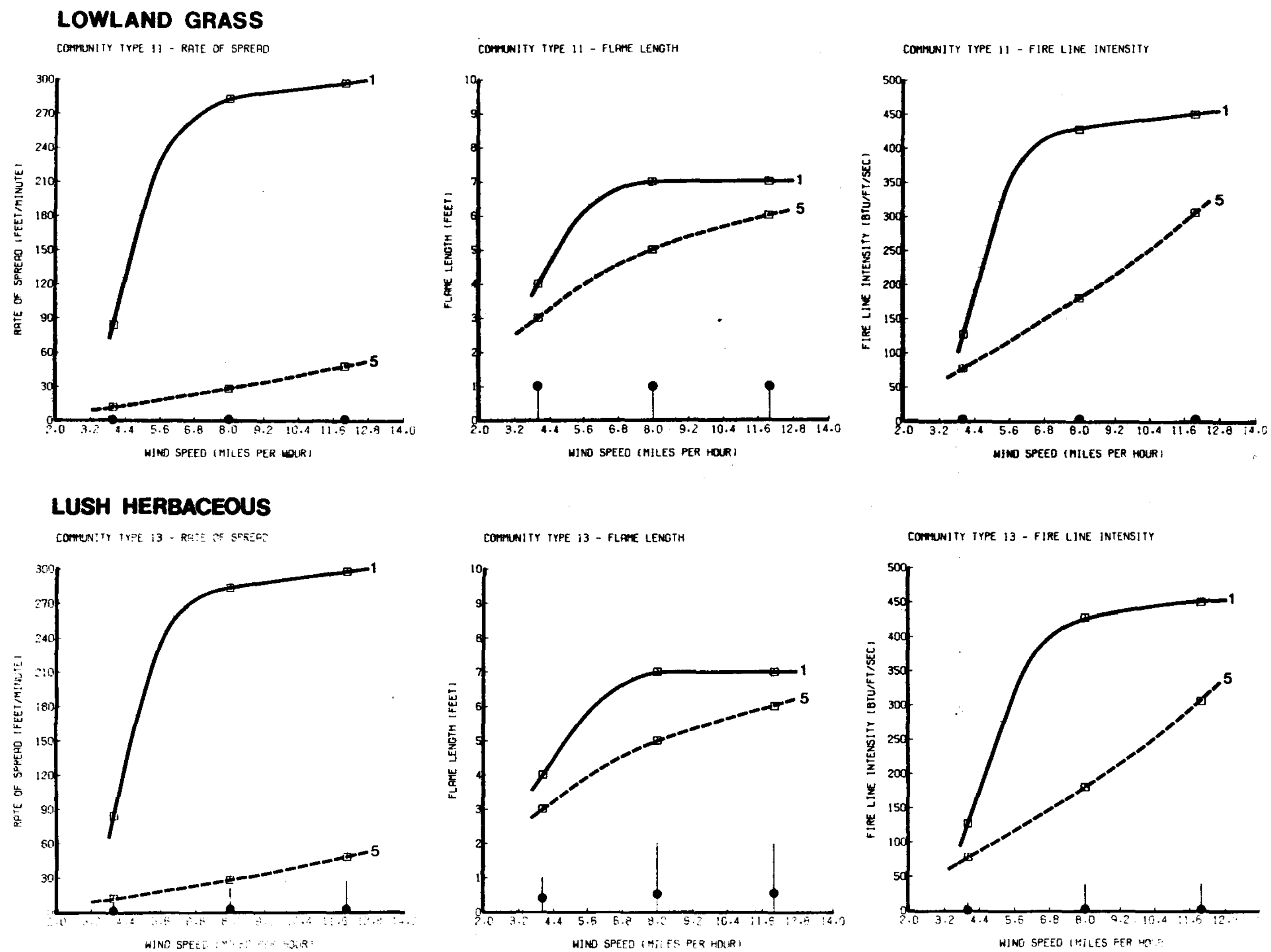
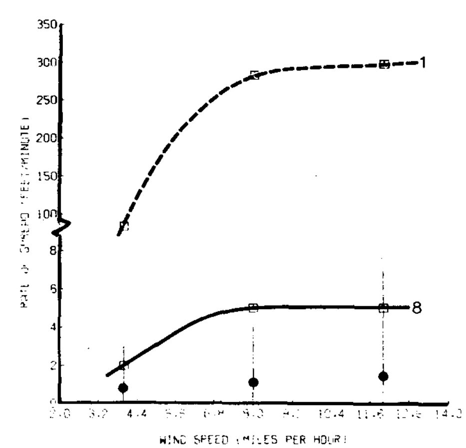


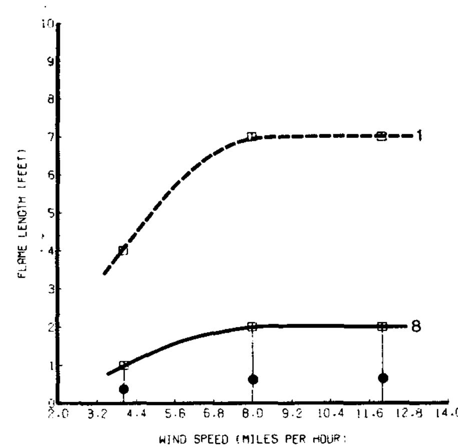
Figure 26. Rate of spread (ft/min), flame length (ft), and fireline intensity (BTU/sec/ft) for each cover type compared to best-fit NFFL models. The output averages for all plots within a cover type are shown by the dots; best-fit NFFL models are shown by solid or dashed lines. Standard errors are plotted as vertical lines surrounding each dot.

WHITEBARK PINE - SUBALPINE LARCH

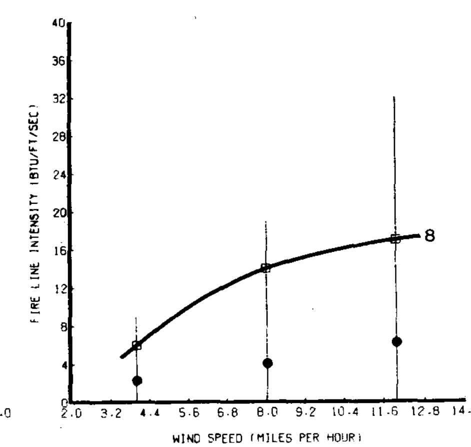
COMMUNITY TYPE 19 - RATE OF SPREAD



COMMUNITY TYPE 19 - FLAME LENGTH

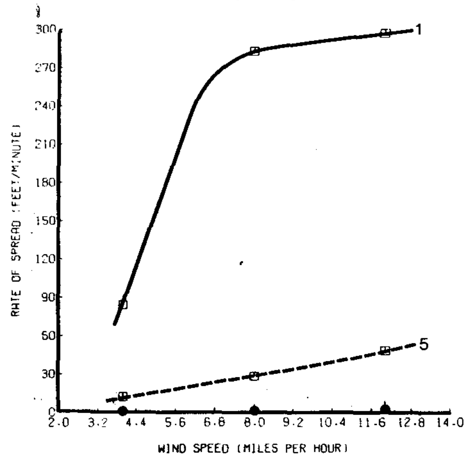


COMMUNITY TYPE 19 - FIRE LINE INTENSITY

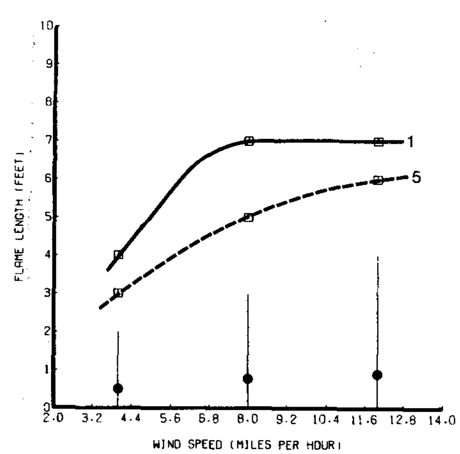


HEATHER MEADOW

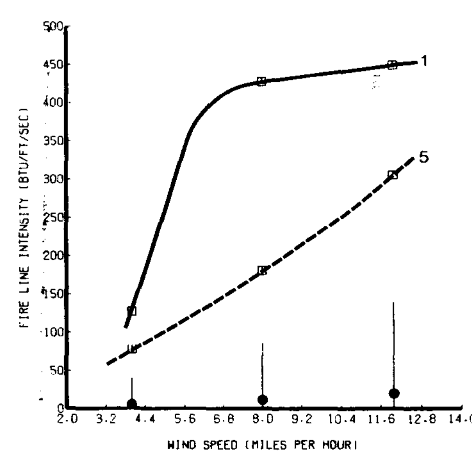
COMMUNITY TYPE 14 - RATE OF SPREAD



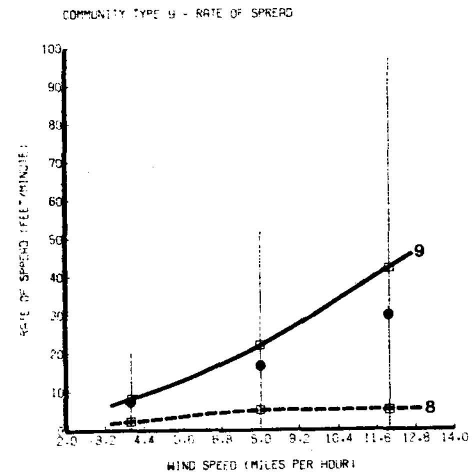
COMMUNITY TYPE 14 - FLAME LENGTH

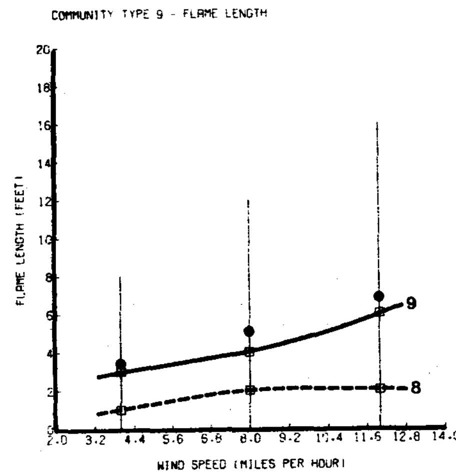


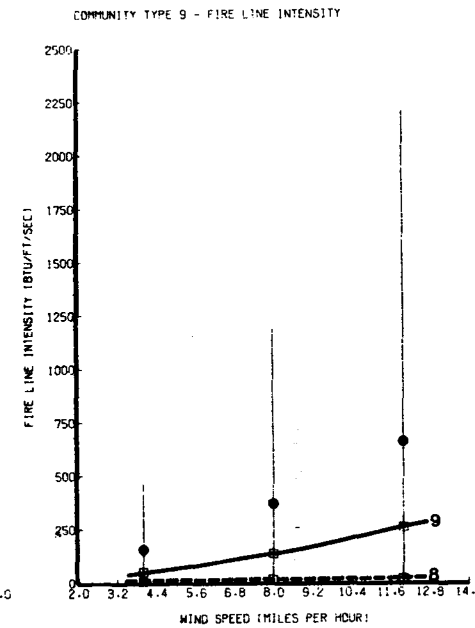
COMMUNITY TYPE 14 - FIRE LINE INTENSITY



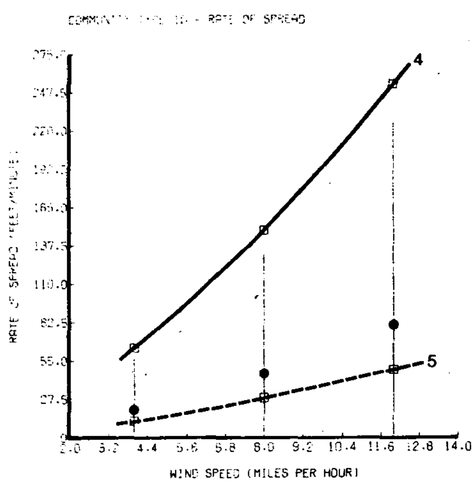
HARDWOOD FOREST

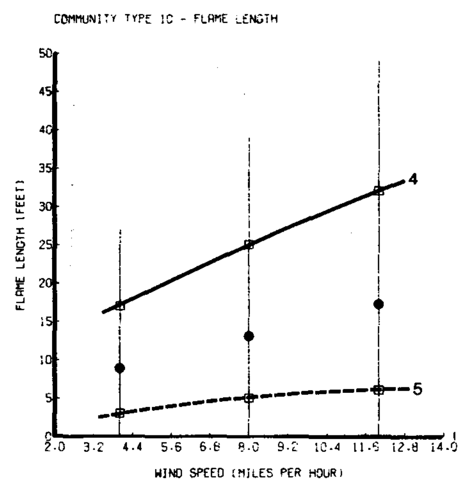


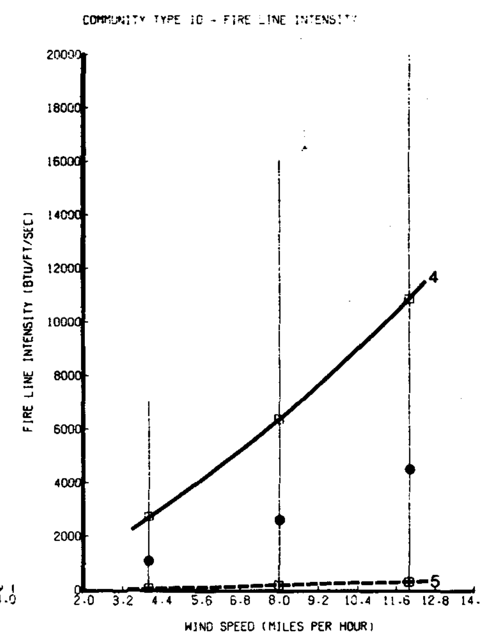




HIGH SHRUB

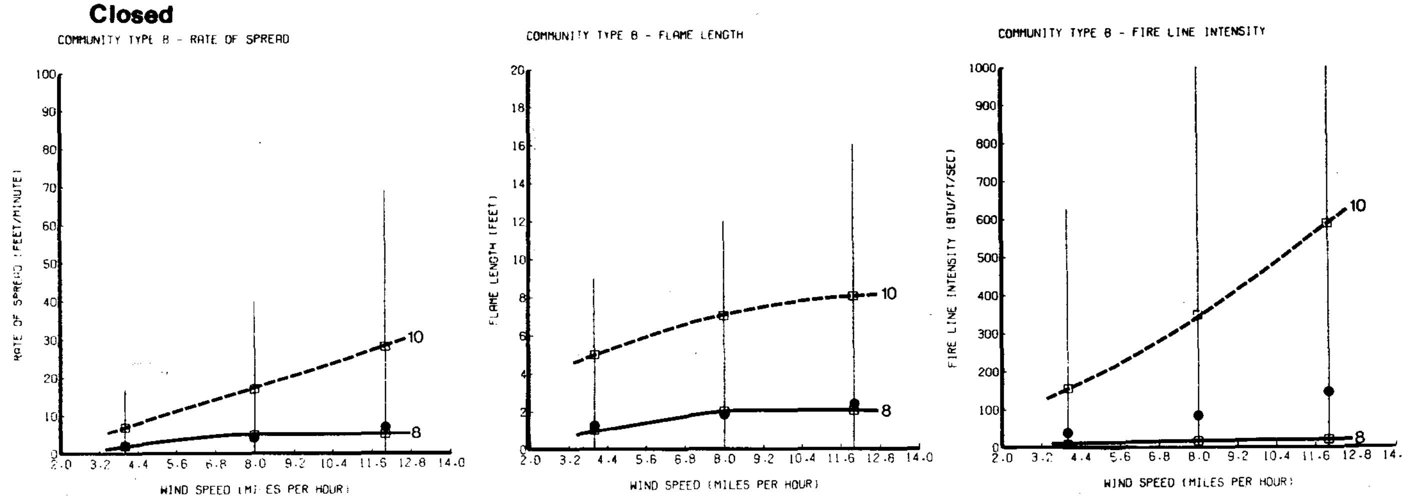






WESTERN HEMLOCK

Closed



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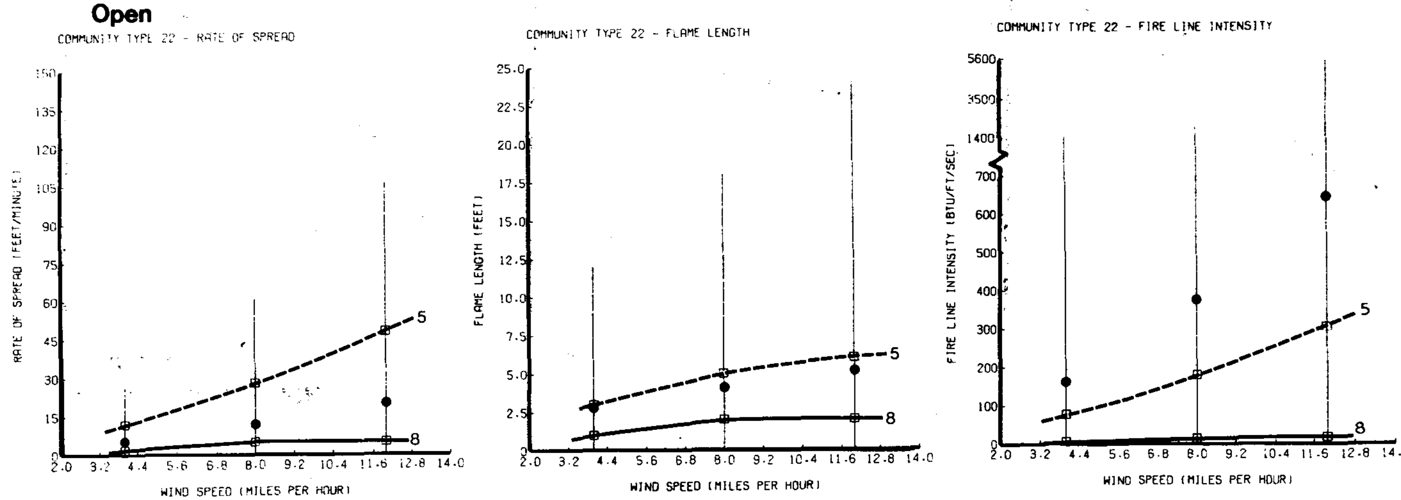
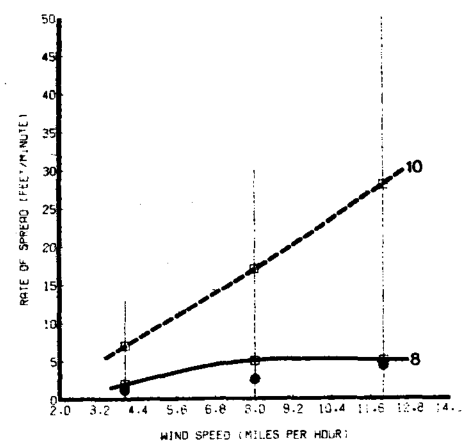


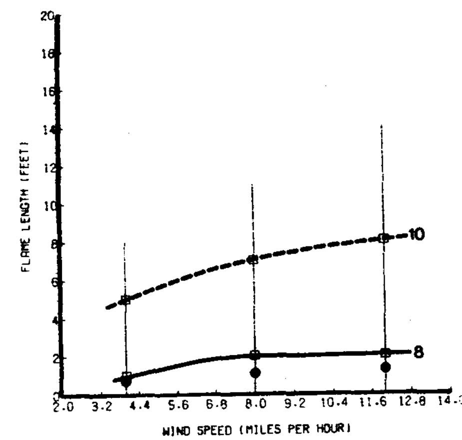
PACIFIC SILVER FIR

Closed

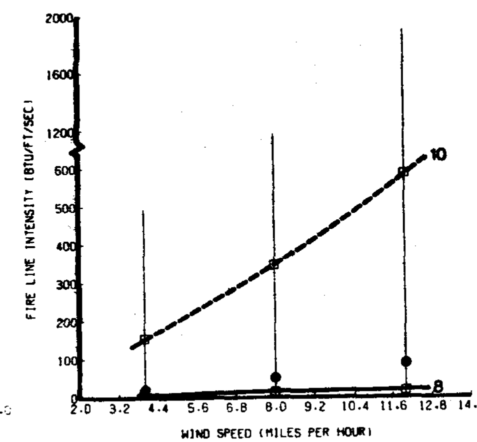
COMMUNITY TYPE 7 - RATE OF SPREAD



COMMUNITY TYPE 7 - FLAME LENGTH

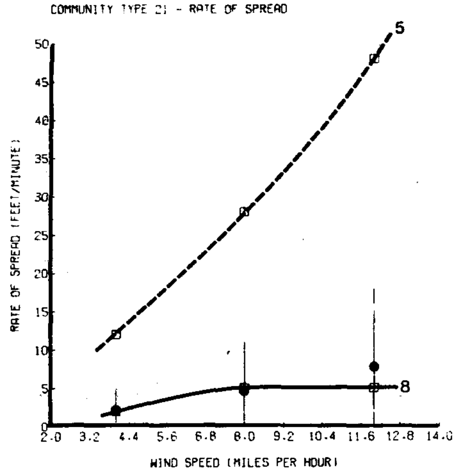


COMMUNITY TYPE 7 - FIRE LINE INTENSITY

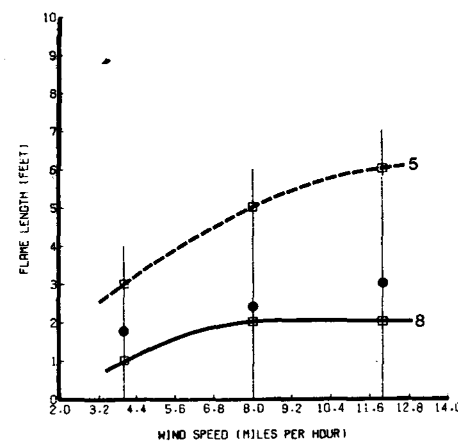


Open

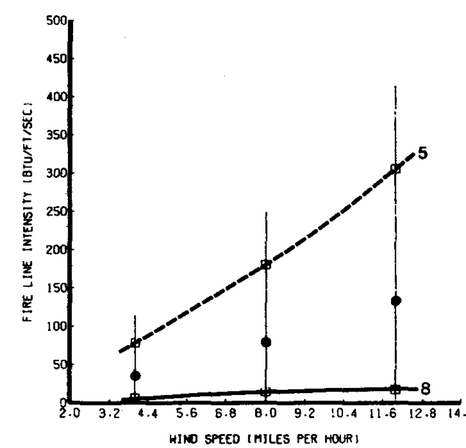
COMMUNITY TYPE 21 - RATE OF SPREAD



COMMUNITY TYPE 21 - FLAME LENGTH

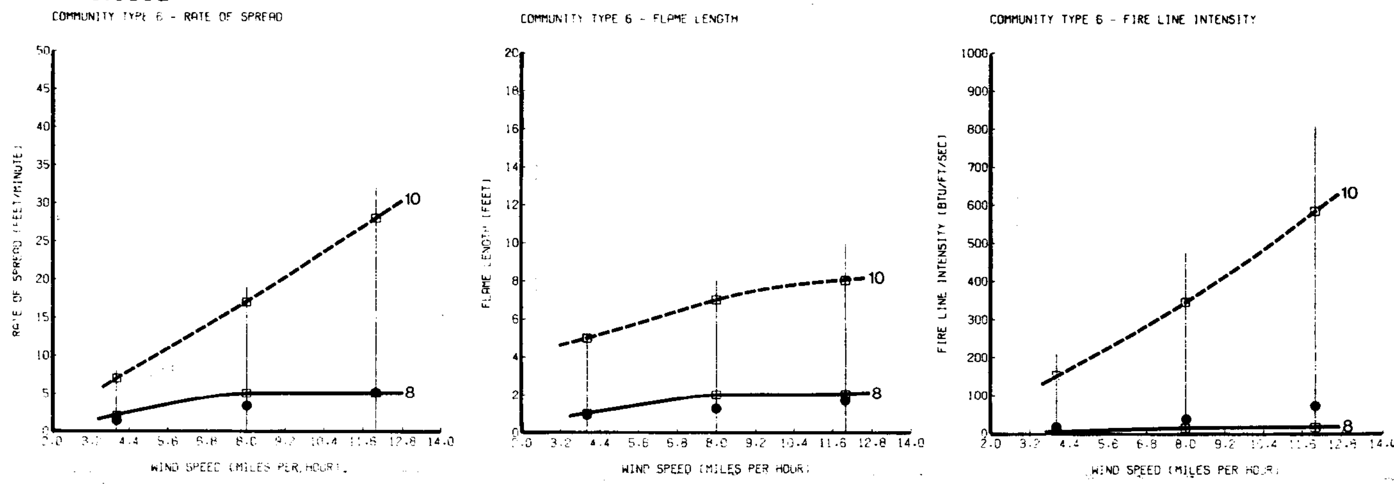


COMMUNITY TYPE 21 - FIRE LINE INTENSITY



MOUNTAIN HEMLOCK

Closed



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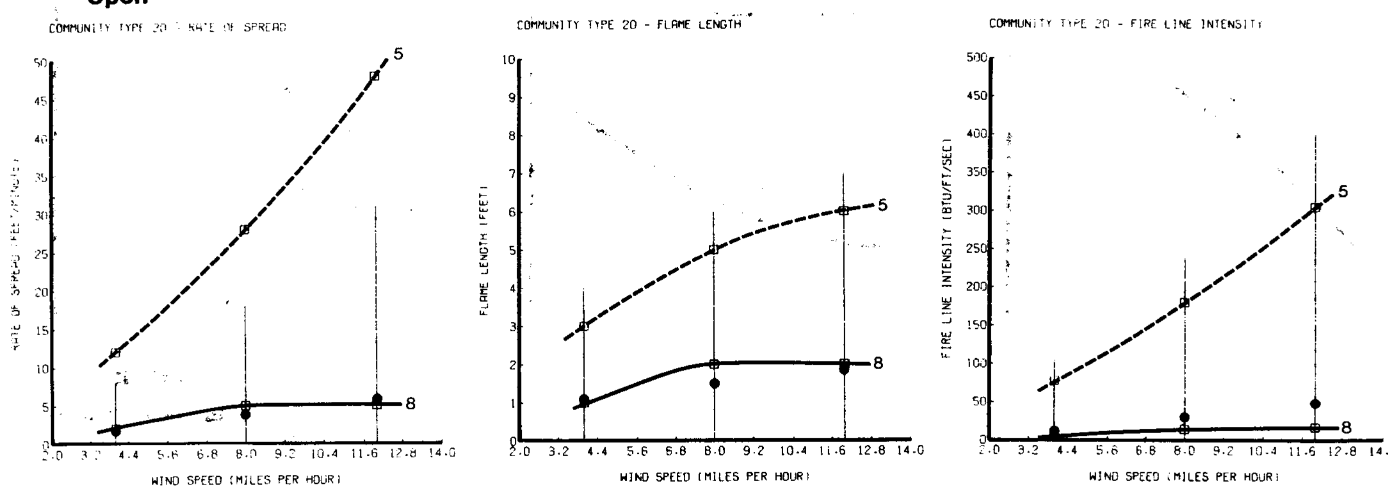
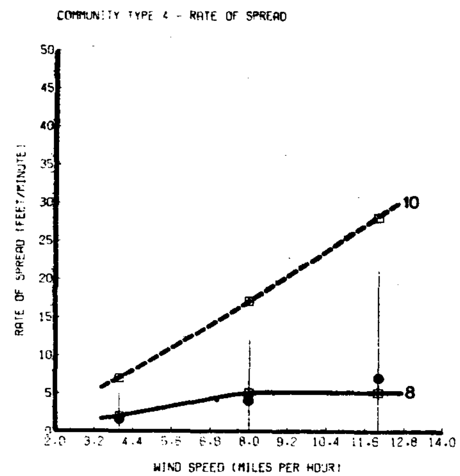
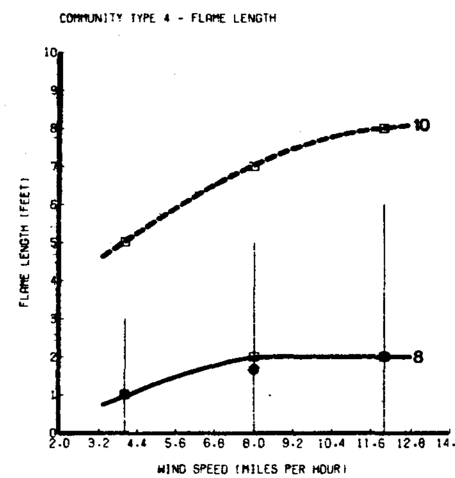
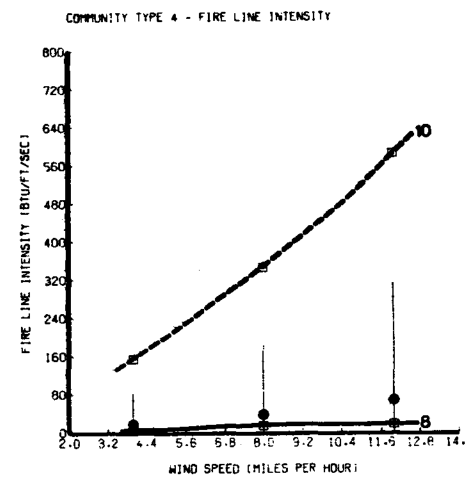


SUBALPINE FIR

Closed







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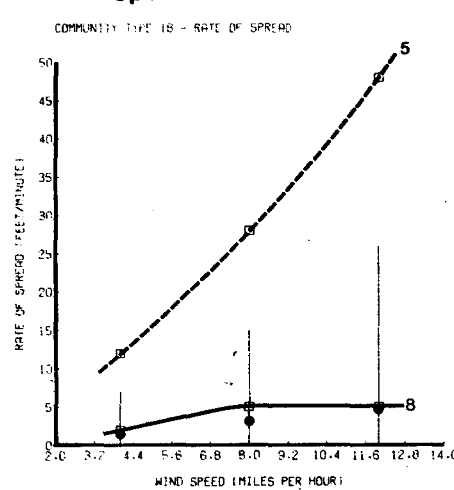

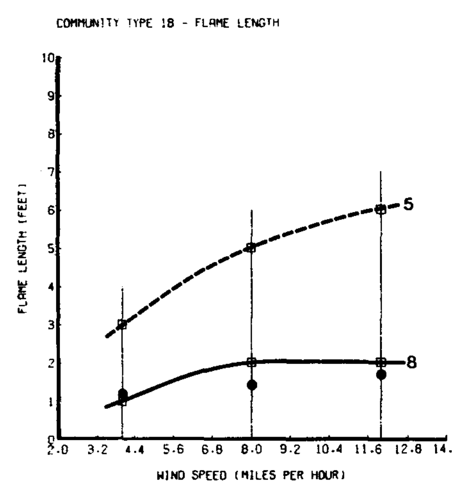

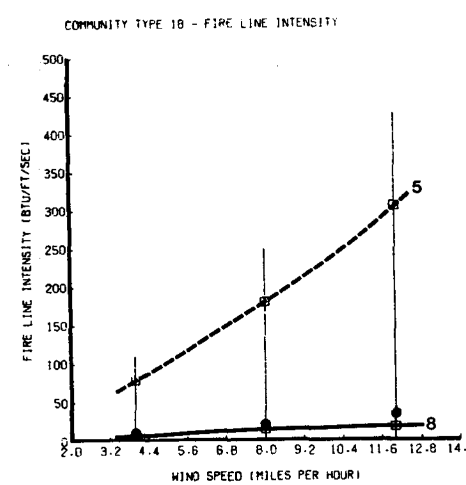

DOUGLAS-FIR

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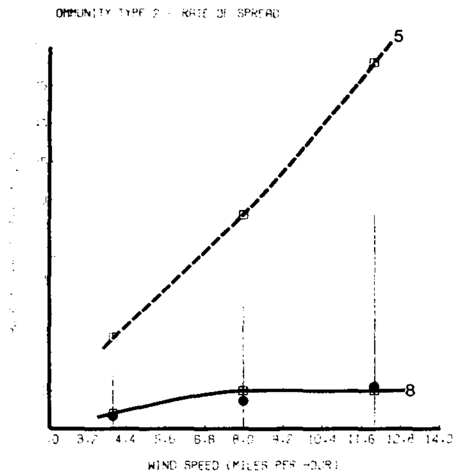

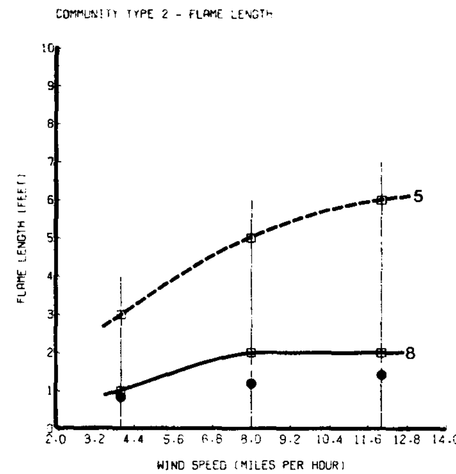

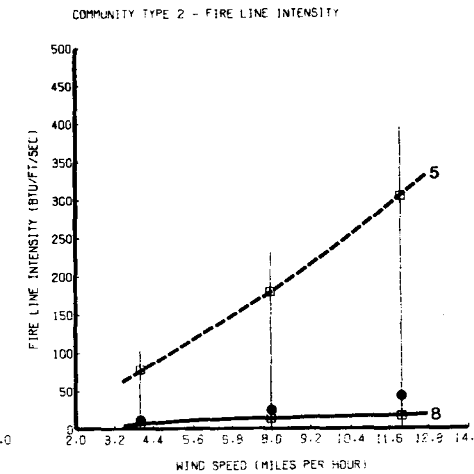

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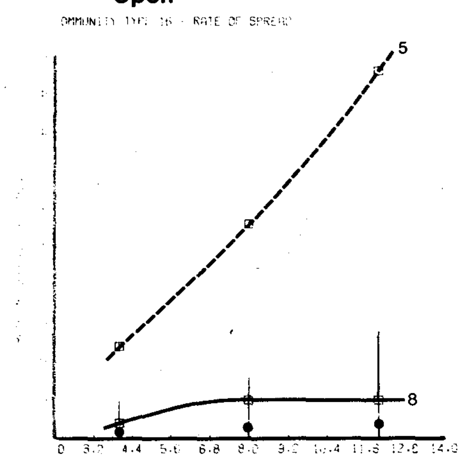

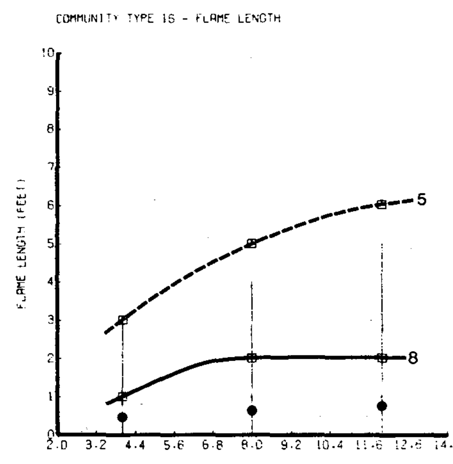

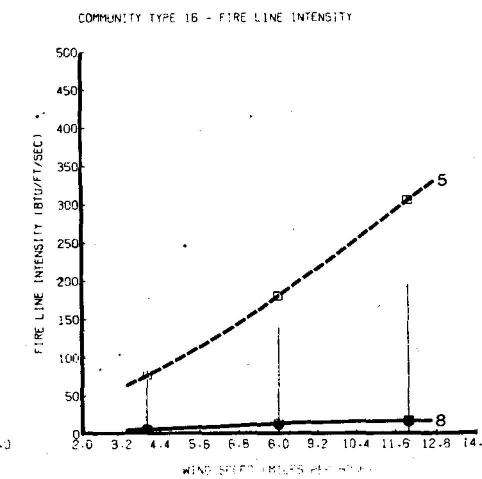

fuel actually present in these high elevation, shrubby/grassy, open conifer stands. The results suggest that the whitebark pine/subalpine larch type is generally not very flammable. Sparse vegetation and rocky slopes usually cause fires burning from lower elevations to be extinguished, but fires can burn in this type. Typical behavior includes low-to moderate intensity fire burning in the undergrowth with occasional torching of trees where shrubs or krummholz is near the lower crown of larger trees.

Fire behavior output for the heather meadow cover type suggests that it burns less easily than the two best-fit NFFL models: 1 and 8. Again, the high proportion of live fuel in the field dampens the spread of fire. In most Pacific Northwest areas where fire has been observed in subalpine areas, heather meadows have acted as good fuelbreaks (Agee and Smith, 1984). Under severe burning conditions, with drought, low relative humidity, and high winds, heather meadows will carry a fast-moving fire. At the Chimney Peak fire at Olympic National Park in 1981, low live fuel moisture contributed to several instances of heather meadows burning. The low fire behavior outputs from the field data must be interpreted with this in mind. Heather meadows will usually, but not always, act as a good natural firebreak.

The western hemlock and Pacific silver fir cover types have similar best-fit NFFL models for closed and open canopy types: models 8 and 10 for closed canopy and models 8 and 5 for the brushier open canopy portions of each cover type. BEHAVE outputs for the closed canopy portions of each type are close to NFFL model 8 for rate of spread and flame length and are intermediate between models 8 and 10 for fireline intensity, with values closest in both cases to those of NFFL Model 8. Fire behavior outputs for the open canopy portions of each type show more variability. For western hemlock, the rate of spread is closer to model 8, while flame length is closer to model 5 and fireline intensity is considerably higher than predicted for either NFFL model. This was apparently due to heavy loads of fuel with adequate fuel depths; many plots had total fuel loads exceeding 6 tons/acre with fuel depths exceeding 1 ft. For Pacific silver fir, the open canopy plots had rates of spread close to model 8, and flame lengths and fireline intensities intermediate between models 5 and 8.

The hardwood forest cover type is usually represented by NFFL model 9. This model closely approximated the BEHAVE output from field data for rate of spread and flame length; fireline intensity was greater than predicted from NFFL model 9 by a factor of two. Heavy fuel loading is the most likely factor influencing the high fireline intensities.

The high shrub cover type fire behavior is between closest-fit NFFL models 4 and 5 for all three fire behavior variables. In fact, the fire behavior from field-collected BEHAVE plots fits NFFL model 6 much better than NFFL model 4, although model 6 also overestimates fire behavior. In general, the fire behavior represented is higher than would actually occur in the field, because the high shrub type is often an avalanche chute community that remains seasonally moist. Fuel moistures, both live and dead, will be much higher than the average found on adjacent mid-slope areas. In practice, these avalanche chutes can often act as natural fire barriers.

The lowland grass cover type appears to have very low fire behavior in comparison to the closest-fit NFFL models 1 and 5. In most cases, the live herbaceous load was equal or greater than the dead fuel load, which made the community too moist to burn. Although the models were not rerun with all fuel cured, the behavior would very likely mimic NFFL model 1 were total curing to occur. Total curing would be characteristic of the lowest elevation areas of the park on dry slopes in late summer. At the higher elevation lowland grass areas, in moist areas like bogs, or in early season, the low fire behavior shown is probably quite reasonable.

The lush herbaceous, or subalpine herb type, has fire behavior well below that of the best-fit NFFL models 1 and 5, again due to a high proportion of live fuel. This community, like the heather meadow, usually acts as a natural firebreak because of the typical high fuel moisture and low proportion of dead fuel.

No fire behavior averages could be made for the ponderosa pine open canopy type or for the closed canopy portion of the whitebark pine/subalpine larch type due to lack of plot data. Together these areas cover less than 1% of the land area of the park complex.

In summary, the BEHAVE output suggests that the field identification of closest-fit NFFL models was accurate, and that the existing NFFL models, either singly or in the two-model concept, are sufficient to predict fire behavior in the fuel types at North Cascades National Park Service Complex. The fire behavior for the ranges of environmental variable tested (using the "medium" environmental parameters and windspeeds up to 12 mph) for each cover type followed an existing model or was intermediate between two existing models. Field observation of the areas where the intermediate behavior was predicted suggests that rather than a uniform intermediate fuel complex there is a mosaic of two fuel complexes that can be described by using two NFFL fuel models.

In addition, the variation around each mean was fairly large, and a 95% confidence interval around the mean usually encompassed the values of both best-fit NFFL models. The histograms of outputs for each output variable within each cover type (Appendix 2) suggest that the variables are not normally distributed and therefore that confidence limits as calculated are not reliable. However, regardless of the actual distribution there is considerable variation about the mean and associated caution about the uniformity of fuel complexes within any of the cover types.

The results of the BEHAVE modeling are largely theoretical in that little monitoring of actual fire behavior has been done for the park complex. On future prescribed natural fires, fire behavior observations should be made for a range of burning conditions over as wide a set of cover types as possible, using the procedures in Rothermel and Rinehart (1983). This will enable validation of the conclusions reached by the present analysis or provide a data set from which a potential new site-specific fuel model can be developed. At this time, such fuel model development is premature: in none of the fuel types is fire behavior so unusual that existing models cannot approximate behavior and no actual field fire behavior data is available to justify new fuel model development and adjustment.

CONCLUSIONS

The geographic information base for the North Cascades National Park Service Complex is a working tool for management. The research and application have resulted in a current GIS framework that is immediately useful. In the future, new layers of information can be added to increase the power of the GIS; existing layers, such as fuels or vegetation, can be updated.

The accuracy of any vegetation map diminishes over time. The current classification used Landsat scenes that were several years old, so that this vegetation map is already 5-6 years old. Several fires have occurred in this timeframe, and other disturbances in and around the park have and will continue to occur. Future updates will require either manually outlining these changes and placing them in the existing files, or obtaining a more recent Landsat scene and redoing the Landsat clustering; the existing models for vegetation cover types should remain valid so that little to no field work would be necessary in the new update. The terrain information, barring catastrophe, should remain current and require no updating for significant periods into the future. Updates of the fuels information can be done concurrently with the vegetation update, and new information from fire monitoring may result in some altered fire behavior models.

While this report contains a significant addition to the knowledge base of the park and is a potentially very powerful resources management tool, its potential will only be realized if the GIS can be used by the park staff in a timely manner. The most critical need now is to arrange for an easily accessed database management system so that the GIS can be manipulated from the park or from elsewhere on a very short turnaround. The technology exists now to do this, but the mechanism to achieve this has not yet been defined in early 1985. Several options are available: provide more staff to GISFU in Denver, develop satellite database stations at universities (such as is now occurring at Oregon State University), or provide sufficient hardware to each park so that each park is self-sufficient. No option is but each or all can be effectively implemented once a decision is made.

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APPENDIX 1

NATIONAL FIRE-DANGER RATING SYSTEM (NFDRS) FUEL MODEL KEY

NORTHERN FOREST FIRE LABORATORY (NFFL) FUEL MODEL KEY

SIMILARITY OF NFDRS AND FBO (NFFL) FUEL MODELS

NFDRS FUEL MODEL KEY

I. Mosses, lichens, and low shrubs predominate ground fuels.

- A. An overstory of conifers occupies more than one-third of the site.. MODEL Q
- B. There is no overstory, or it occupies less than one-third of the site (tundra).. MODEL S

II. Marsh grasses and/or reeds predominate................................ MODEL N

III. Grasses and/or forbs predominate.

- A. There is an open overstory of conifer and/or hardwood trees........ MODEL C
- B. There is no overstory.
  - 1. Woody shrubs occupy more than one-third, but less than two-thirds of the site.. MODEL T
  - 2. Woody shrubs occupy less than one-third of the site.
    - a. The grasses and forbs are primarily annuals................ MODEL A
    - b. The grasses and forbs are primarily perennials............. MODEL L

IV. Brush, shrubs, tree reproduction or dwarf tree species predominate.

- A. Average height of woody plants is 6 ft or greater.
  - 1. Woody plants occupy two-thirds or more of the site.
    - a. One-fourth or more of the woody foliage is dead.
      - (1) Mixed California chaparral............................ MODEL B
      - (2) Other types of brush.................................. MODEL F
    - b. Up to one-fourth of the woody foliage is dead............. MODEL Q
    - c. Little dead foliage....................................... MODEL O
  - 2. Woody plants occupy less than two-thirds of the site.......... MODEL F
- B. Average height of woody plants is less than 6 ft.
  - 1. Woody plants occupy two-thirds or more of the site.
    - a. Western United States..................................... MODEL F
    - b. Eastern United States..................................... MODEL O
  - 2. Woody plants occupy less than two-thirds but greater than one-third of the site.
    - a. Western United States..................................... MODEL T
    - b. Eastern United States..................................... MODEL D
  - 3. Woody plants occupy less than one-third of the site.
    - a. The grasses and forbs are primarily annuals................ MODEL A
    - b. The grasses and forbs are primarily perennial.............. MODEL L

V. Trees predominate.

- A. Deciduous broadleaf species predominate.

1. The area has been thinned or partially cut, leaving slash as the major fuel component.................................. MODEL K

2. The area has not been thinned or partially cut.

   a. The overstory is dormant; the leaves have fallen........... MODEL E
   b. The overstory is in full leaf.............................. MODEL R

B. Conifer species predominate.

1. Lichens, mosses, and low shrubs dominate as understory fuels... MODEL Q
2. Grasses and forbs are the primary ground fuels................. MODEL C
3. Woody shrubs and/or reproduction dominate as understory fuels.

   a. The understory burns readily.

      (1) Western United States.................................. MODEL T
      (2) Eastern United States.

         (a) The understory is more than 6 ft tall............. MODEL O
         (b) The understory is less than 6 ft tall............. MODEL D

   b. The understory seldom burns................................ MODEL H

4. Duff and litter, branchwood, and tree boles are the primary ground fuels.

   a. The overstory is overmature and decadent; there is a heavy accumulation of dead tree debris........................... MODEL G
   b. The overstory is not decadent; there is only a nominal accumulation of debris.

      (1) The needles are 2 inches or more in length (most pines).

         (a) Eastern United States............................ MODEL P
         (b) Western United States............................ MODEL U

      (2) The needles are less than 2 inches long............... MODEL H

VI. Slash is the predominant fuel.

A. The foliage is still attached; there has been little settling.

1. The loading is 25 tons/acre or greater......................... MODEL I
2. The loading is less than 25 tons/acre but more than 15 tons/acre.. MODEL J
3. The loading is less than 15 tons/acre.......................... MODEL K

B. Settling is evident; the foliage is falling off; grasses, forbs, and shrubs are invading the areas.

1. The loading is 25 tons/acre or greater......................... MODEL J
2. The loading is less than 25 tons/acre.......................... MODEL K

PHYSICAL DESCRIPTION SIMILARITY CHART OF NFDRS AND FBO FUEL MODELS

NFDRS MODELS REALINED TO FUELS CONTROLLING SPREAD UNDER SEVERE BURNING CONDITIONS

NFDRS FUEL MODELS	FIRE BEHAVIOR FUEL MODELS													
	1	2	3	4	5	6	7	8	9	10	11	12	13	
A W. ANNUALS	X													GRASS
L W. PERENNIAL	X													GRASS
S TUNDRA	X					3rd			2nd					GRASS
C OPEN PINE W/GRASS		X							2nd					GRASS
T SAGEBRUSH W/GRASS		X			3rd	2nd								GRASS
N SAWGRASS			X											GRASS
B MATURE BRUSH (6FT)				X										SHRUB
O HIGH POCOSIN				X										SHRUB
F INTER. BRUSH					2nd	X								SHRUB
Q ALASKA BLACK SPRUCE						X	2nd							SHRUB
D SOUTHERN ROUGH						2nd	X							SHRUB
H SRT-NDL CLSD. NORMAL DEAD								X						TIMBER
R HRWD. LITTER (SUMMER)								X						TIMBER
U W. LONG-NDL PINE									X					TIMBER
P SOUTH, LONG-NDL PINE									X					TIMBER
E HRWD. LITTER (FALL)									X					TIMBER
G SRT-NDL CLSD. HEAVY DEAD										X				TIMBER
K LIGHT SLASH											X			SLASH
J MED. SLASH												X		SLASH
I HEAVY SLASH													X	SLASH
	GRASS			SHRUB				TIMBER			SLASH			

Figure 3.—Similarity chart to aline physical descriptions of fire danger rating fuel models with fire behavior fuel models.

The availability of only 13 fuel models to describe all the fuels in the United States may seem very limiting. The two-fuel-model concept, however, expands this number considerably. The two-fuel-model concept depends upon the proportional coverage of an area by two fuels. (The method is fully described in this section.)

Fire behavior estimates will be simpler if a single fuel model can be found to describe the fuels. In fact, as experience is gained from observing fires and estimating behavior, it is possible to select a fuel model, not only from a description of the physical properties of the vegetation, but also by the fire behavior characteristics it is known to produce. Experienced fire behavior officers, working in one or two fuel types, have learned to calibrate or tune the answers to more closely match fire behavior (Norum 1982). Methods for calibrating a fuel to match the behavior in a specific fuel type are provided by Rothermel and Rinehart (1983).

Considerations in Selecting a Fuel Model

1. Determine the general vegetation type, i.e., grass, brush, timber litter, or slash.
2. Estimate which stratum of surface fuel is most likely to carry the spreading fire. For instance, the fire may be in a timbered area, but the timber is relatively open and dead grass, not needle litter, is the stratum carrying the fire. In this case, fuel model 2, which is not listed as a timber model, should be considered. In the same area if the grass is sparse and there is no wind or slope, the needle litter would be the stratum carrying the fire and fuel model 9 would be a better choice.
3. Note the general depth and compactness of the fuel. This information will be needed when using the fuel model key. These are very important considerations when matching fuels, particularly in the grass and timber types.
4. Determine which fuel classes are present and estimate their influence on fire behavior. For instance, green fuel may be present, but will it play a significant role in fire behavior? Large fuels may be present, but are they sound or decaying and breaking up? Do they have limbs and twigs attached or are they bare cylinders? You must look for the fine fuels and choose a model that represents their depth, compactness, and to some extent, the amount of live fuel and its contribution to fire. Do not be restricted by what the model name is or what its original application was intended to be.
5. Using these observations, proceed through the fuel model key and the descriptions provided by Anderson (1982) to select a fuel model.
6. Record the selected fuel model on line 3 of the fire behavior worksheet.

NFFL Fuel Model Key[3]

I. PRIMARY CARRIER OF THE FIRE IS GRASS. Expected rate of spread is moderate-to-high, with low-to-moderate fireline intensity (flame length).

A. Grass is fine structured, generally below knee level, and cured or primarily dead. Grass is essentially continuous.
SEE THE DESCRIPTION OF MODEL 1.

B. Grass is coarse structured, above knee level (averaging about 3 ft) and is difficult to walk through.
SEE THE DESCRIPTION OF MODEL 3.

C. Grass is **usually** under an open timber, or brush, overstory. Litter from the overstory is involved, but grass carries the fire. Expected spread rate is slower than fuel model 1 and intensity is less than fuel model 3.
SEE THE DESCRIPTION OF MODEL 2.

II. PRIMARY CARRIER OF THE FIRE IS BRUSH OR LITTER BENEATH BRUSH. Expected rates of spread and fireline intensities (flame length) are moderate-to-high.

A. Vegetative type is southern rough or low pocosin. Brush is generally 2 to 4 ft high.
SEE THE DESCRIPTION OF MODEL 7.

B. Live fuels are absent or sparse. Brush averages 2 to 4 ft in height. Brush requires moderate winds to carry fire.
SEE THE DESCRIPTION OF MODEL 6.

C. Live fuel moisture **can** have a significant effect on fire behavior.

1. Brush is about 2 ft high, with light loading of brush litter underneath. Litter may carry the fire, especially at low windspeeds.
SEE THE DESCRIPTION OF MODEL 5.
2. Brush is head-high (6 ft), with heavy loadings of dead (woody) fuel. Very intense fire with high spread rates expected.
SEE THE DESCRIPTION OF MODEL 4.
3. Vegetative type is high pocosin.
SEE THE DESCRIPTION OF MODEL 4.

III. PRIMARY CARRIER OF THE FIRE IS LITTER BENEATH A TIMBER STAND. Spread rates are low-to-moderate; fireline intensity (flame length) may be low-to-high.

A. Surface fuels are mostly foliage litter. Large fuels are scattered and lie on the foliage litter; that is, large fuels are not supported above the litter by their branches. Green fuels are scattered enough to be insignificant to fire behavior.

1. Dead foliage is **tightly compacted**, short needle (2 inches or less) conifer litter or hardwood litter.
SEE THE DESCRIPTION OF MODEL 8.
2. Dead foliage litter is **loosely compacted** long needle pine or hardwoods.
SEE THE DESCRIPTION OF MODEL 9.

B. There is a significant amount of larger fuel. Larger fuel has attached branches and twigs, or has rotted enough that it is splintered and broken. The larger fuels are fairly well distributed over the area. Some green fuel may be present. The overall depth of the fuel is probably below the knees, but some fuel may be higher.
SEE THE DESCRIPTION OF MODEL 10.

C. Fuels are nonuniform, the area is mostly covered with litter interspersed with accumulations of dead and downed material (jackpots).
SEE THE TWO-FUEL-MODEL CONCEPT.

[3]Gordie Schmidt (of R-6 and the PNW Station) has been especially helpful in reviewing and suggesting changes in the fuel model key.

IV. PRIMARY CARRIER OF THE FIRE IS LOGGING SLASH. Spread rates are low-to-high, fireline intensities (flame lengths) are low-to-very high.
   A. Slash is aged and overgrown.
      1. Slash is from hardwood trees. Leaves have fallen and cured. Considerable vegetation (tall weeds) has grown in amid the slash and has cured or dried out.
         SEE THE DESCRIPTION OF MODEL 6.
      2. Slash is from conifers. Needles have fallen and considerable vegetation (tall weeds and some shrubs) has overgrown the slash.
         SEE THE DESCRIPTION OF MODEL 10.
   B. Slash is fresh (0–3 years or so) and not overly compacted.
      1. Slash is not continuous. Needle litter or small amounts of grass or shrubs must be present to help carry the fire, but primary carrier is still slash. Live fuels are absent or do not play a significant role in fire behavior. The slash depth is about 1 ft.
         SEE THE DESCRIPTION OF MODEL 11.
      2. Slash generally covers the ground (heavier loadings than Model 11), though there may be some bare spots or areas of light coverage. Average slash depth is about 2 ft. Slash is not excessively compacted. Approximately one-half of the needles may still be on the branches but are not red. Live fuels are absent, or are not expected to affect fire behavior.
         SEE THE DESCRIPTION OF MODEL 12.
      3. Slash is continuous or nearly so (heavier loadings than Model 12). Slash is not excessively compacted and has an average depth of 3 ft. Approximately one-half of the needles are still on the branches and are red, OR all the needles are on the branches but they are green. Live fuels are not expected to influence fire behavior.
         SEE THE DESCRIPTION OF MODEL 13.
      4. Same as 3, EXCEPT all the needles are attached and are red.
         SEE THE DESCRIPTION OF MODEL 4.

NFFL Fuel Model Descriptions

These descriptions are taken from Anderson's book (1982) and should be used in conjunction with the fuel model key.

Grass Group

Fire behavior fuel model 1.—Fire spread is governed by the fine herbaceous fuels that have cured or are nearly cured. Fires move rapidly through cured grass and associated material. Very little shrub or timber is present, generally less than one-third of the area.

Grasslands and savanna are represented along with stubble, grass tundra, and grass-shrub combinations that meet the above area constraint. Annual and perennial grasses are included in this fuel model.

Fire behavior fuel model 2.—Fire spread is primarily through the fine herbaceous fuels, either curing or dead. These are surface fires where the herbaceous material, besides litter and dead-down stemwood from the open shrub or timber overstory, contribute to the fire intensity. Open shrub lands and pine stands or scrub oak stands that cover one-third or two-thirds of the area may generally fit this model, but may include clumps of fuels that generate higher intensities and may produce firebrands. Some pinyon-juniper may be in this model.

Fire behavior fuel model 3.—Fires in this fuel are the most intense of the grass group and display high rates of spread under the influence of wind. The fire may be driven into the upper heights of the grass stand by the wind and cross standing water. Stands are tall, averaging about 3 ft, but may vary considerably. Approximately one-third or more of the stand is considered dead or cured and maintains the fire. Wild or cultivated grains that have not been harvested can be considered similar to tall prairie and marshland grasses.

Shrub Group

Fire behavior fuel model 4.—Fire intensity and fast-spreading fires involve the foliage and live and dead fine woody material in the crowns of a nearly continuous secondary overstory. Stands of mature shrub, 6 or more feet tall, such as California mixed chaparral, the high pocosins along the east coast, the pine barren of New Jersey, or the closed jack pine stands of the North Central States are typical candidates. Besides flammable foliage, there is dead woody material in the stand that significantly contributes to the fire intensity. Height of stands qualifying for this model depends on local conditions. There may be also a deep litter layer that confounds suppression efforts.

Fire behavior fuel model 5.—Fire is generally carried in the surface fuels that are made up of litter cast by the shrubs, and the grasses or forbs in the understory. The fires are generally not very intense because surface fuel loads are light, the shrubs are young with little dead material, and the foliage contains little volatile material. Shrubs are generally not tall, but have nearly total coverage of the area. Young, green stands such as laurel,[4] vine maple, alder, or even chaparral, manzanita, or chamise with no deadwood would qualify.

Fire behavior fuel model 6.—Fire carries through the shrub layer where the foliage is more flammable than fuel model 5, but requires moderate winds, greater than 8 mi/h at midflame height. Fire will drop to the ground at low windspeeds or openings in the stand. The shrubs are older, but not as tall as shrub types of model 4, nor do they contain as much fuel as model 4. A broad range of shrub conditions is covered by this model. Fuel situations to consider include intermediate-aged stands of chamise, chaparral, oak brush, and low pocosin. Even hardwood slash that has cured out can be considered. Pinyon-juniper shrublands may be represented, but the rate of spread may be overpredicted at windspeeds less than 20 mi/h.

Fire behavior fuel model 7.—Fires burn through the surface and shrub strata with equal ease and can occur at higher dead fuel moisture contents because of the flammable nature of live foliage and other live material. Stands of shrubs are generally between 2 and 6 ft high. Palmetto-gallberry understory within pine overstory sites are typical and low pocosins may be represented. Black spruce-shrub combinations in Alaska may also be represented.

Timber Group

Fire behavior fuel model 8.—Slow-burning ground fires with low flame heights are the rule, although the fire may encounter an occasional "jackpot" or heavy fuel concentration that can flare up. Only under severe weather conditions involving high temperatures, low humidities, and high winds do the fuels pose

[4]Recent information indicates that laurel may be more flammable than model 5 indicates.

fire hazards. Closed canopy stands of short-needle conifers or hardwoods that have leafed out support fire in the compact litter layer. This layer is mainly needles, leaves, and some twigs since little undergrowth is present in the stand. Representative conifer types are white pines, lodgepole pine, spruce, fir, and larch.

Fire behavior fuel model 9.—Fires run through the surface litter faster than model 8 and have higher flame height. Both long-needle conifer and hardwood stands, especially the oak-hickory types, are typical. Fall fires in hardwoods are representative, but high winds will actually cause higher rates of spread than predicted. This is due to spotting caused by rolling and blowing leaves. Closed stands of long-needled pine like ponderosa, Jeffrey, and red pines or southern pine plantations are grouped in this model. Concentrations of dead-down woody material will contribute to possible torching out of trees, spotting, and crowning.

Fire behavior fuel model 10.—The fires burn in the surface and ground fuels with greater fire intensity than the other timber litter models. Dead down fuels include greater quantities of 3-inch or larger limbwood resulting from overmaturity or natural events that create a large load of dead material on the forest floor. Crowning out, spotting, and torching of individual trees is more frequent in this fuel situation, leading to potential fire control difficulties. Any forest type may be considered if heavy down material is present; for example, insect- or disease-ridden stands, wind-thrown stands, overmature stands with deadfall, and aged slash from light thinning or partial cutting.

Logging Slash Group

Fire behavior fuel model 11.—Fires are fairly active in the slash and herbaceous material intermixed with the slash. The spacing of the rather light fuel load, shading from overstory, or the aging of the fine fuels can contribute to limiting the fire potential. Light partial cuts or thinning operations in mixed conifer stands, hardwood stands, and southern pine harvests are considered. Clearcut operations generally produce more slash than represented here. The less-than-3-inch material load is less than 12 tons per acre. The greater-than-3-inch material is represented by not more than 10 pieces, 4 inches in diameter, along a 50-ft transect.

Fire behavior fuel model 12.—Rapidly spreading fires with high intensities capable of generating firebrands can occur. When fire starts, it is generally sustained until a fuel break or change in fuels is encountered. The visual impression is dominated by slash, much of it less than 3 inches in diameter. These fuels total less than 35 tons per acre and seem well distributed. Heavily thinned conifer stands, clearcuts, and medium or heavy partial cuts are represented. The greater-than-3-inch material is represented by encountering 11 pieces, 6 inches in diameter, along a 50-ft transect.

Fire behavior fuel model 13.—Fire is generally carried across the area by a continuous layer of slash. Large quantities of greater-than-3-inch material are present. Fires spread quickly through the fine fuels and intensity builds up more slowly as the large fuels start burning. Active flaming is sustained for long periods and firebrands of various sizes may be generated. These contribute to spotting problems as the weather conditions become more severe. Clearcuts and heavy partial cuts in mature and overmature stands are depicted where the slash load is dominated by the greater-than-3-inch material. The total load may exceed 200 tons per acre, but the less-than-3-inch fuel is generally only 10 percent of the total load. Situations where the slash still has "red" needles attached but the total load is lighter, more like model 12, can be represented because of the earlier high intensity and quicker area involvement.

The Two-Fuel-Model Concept

If nonuniformity of the fuel makes it impossible to select a fuel model from part 1, then the two-fuel-model concept may be useful.

The two-fuel-model concept is designed to account for changes in fuels in the horizontal direction, i.e., as the fire spreads, it will encounter significantly different fuels. The concept depends upon the size of the fire being large with respect to the size of the fuel arrangements causing the discontinuity. By this it is meant that the length of the fireline is long enough so that at any one time the fireline extends through both fuel types in several locations and that as the fire spreads it will encounter both fuel types repeatedly during the length of the prediction period. If this is not the case, it is likely that you will have two distinct burning conditions and the averaging process used for estimating spread rate will be meaningless. The larger the fire and the farther it travels, the larger the fuel patches can be when applying this concept.

Another consideration is that if one fuel does not make up at least 20 percent of the area, fire spread will be dominated by the other fuel and it is not worth attempting to apportion the spread rate between two fuels.

The concept assumes that horizontally nonuniform fuels can be described by two fuel models in which one represents the dominant vegetative cover over the area, and the second represents fuel concentrations that interrupt the first. For example, in a forest stand the dominant fuel strata over most of the area may be short-needle litter (fuel model 8), with concentrations of dead and down limbwood and treetops. Depending on the nature of these jackpots, they could be described by model 10 or one of the slash models, 12 or 13. An important feature of the concept is that it is not necessary to try to integrate the effect of both the needle litter and limbwood accumulation into one model. Two distinct choices can be made.

The two-fuel-model concept may also be applied to rangeland, where grass may dominate the area, along with patches of brush. Of course, the system will work vice versa, where brush is dominant, with occasional patches of grass.

The process is begun with four steps:

1. Select a fuel model from the key that represents the dominant cover—50 percent or more of the area.
2. From the key, select a fuel model that represents fuel concentrations within the area that interrupt the dominant cover.
3. Estimate the percentage of cover for the two fuels. The sum of the two should equal 100 percent.
4. Record the selected fuel models on line 3 of the fire behavior worksheet in two separate columns. Record the estimated proportional coverage of each model on line 2. This completes the information needed as inputs to the two-fuel-model concept. Calculating spread rate and interpreting intensity are explained in chapter III.

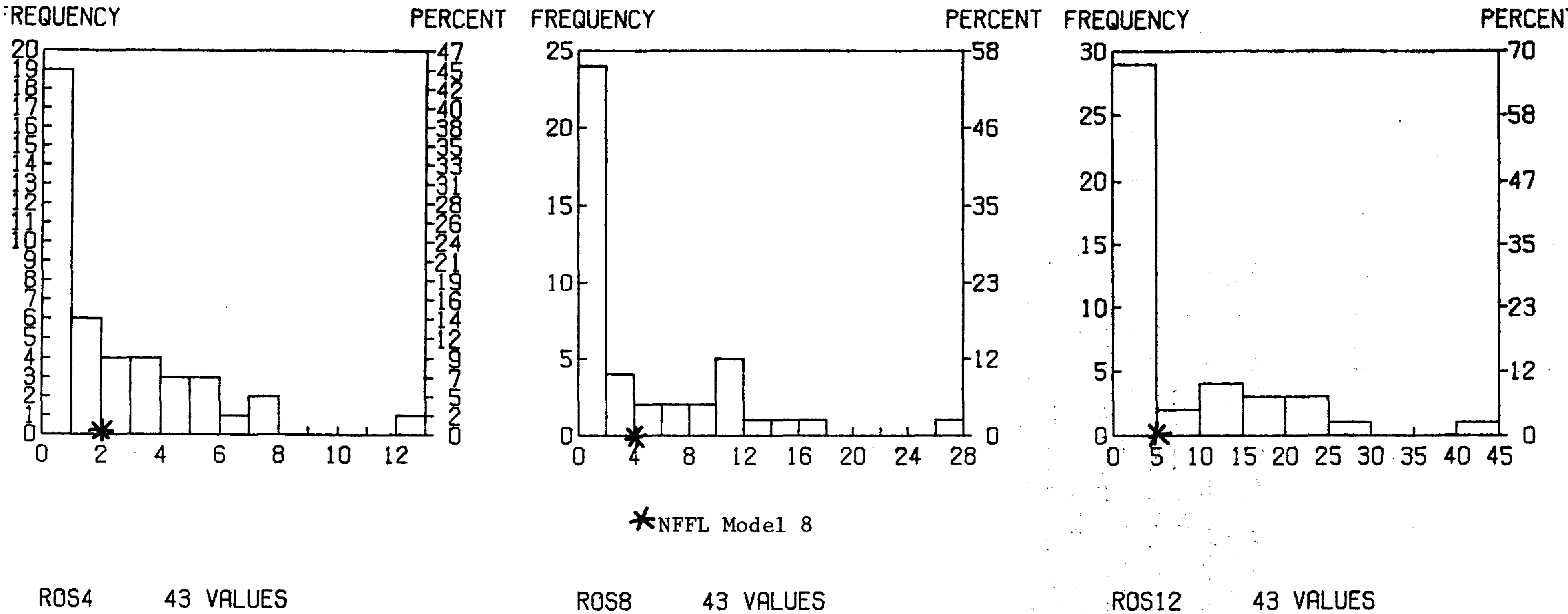
APPENDIX 2

HISTOGRAMS OF BEHAVE OUTPUT

The text discusses BEHAVE output for average values of rate of spread, flame length, and fireline intensity for each cover type. This appendix contains histograms of output for each cover type, showing the distribution of values for each cover type. Each cover type is represented by three pages of the appendix: one page for rate of spread (ft/min), one page for flame length (ft), and one page for fireline intensity (BTU/ft/sec). On each page are three graphs representing outputs for windspeeds of 4, 8, and 12 miles per hour. Where appropriate, outputs for field-identified NFFL models are plotted along the x-axis.

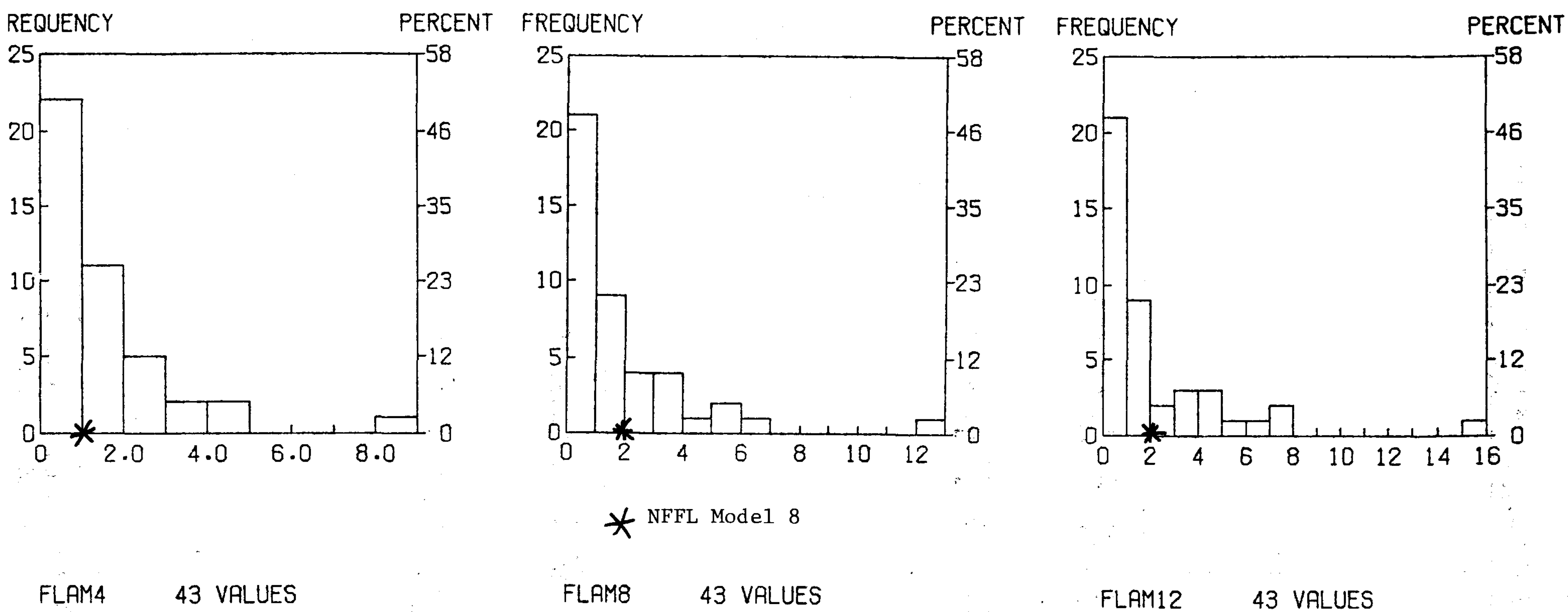
DOUGLAS-FIR CLOSED CANOPY

COMMUNITY TYPE 2 - RATE OF SPREAD



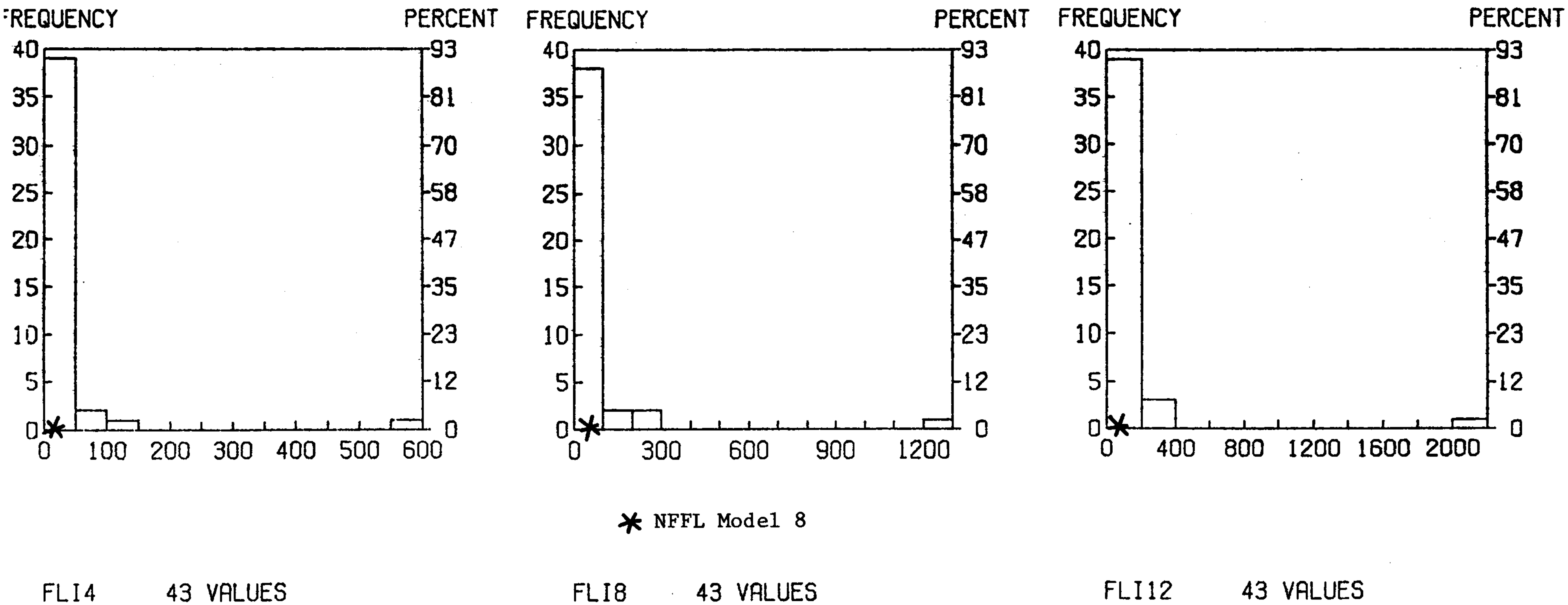
DOUGLAS-FIR CLOSED CANOPY

COMMUNITY TYPE 2 - FLAME LENGTH

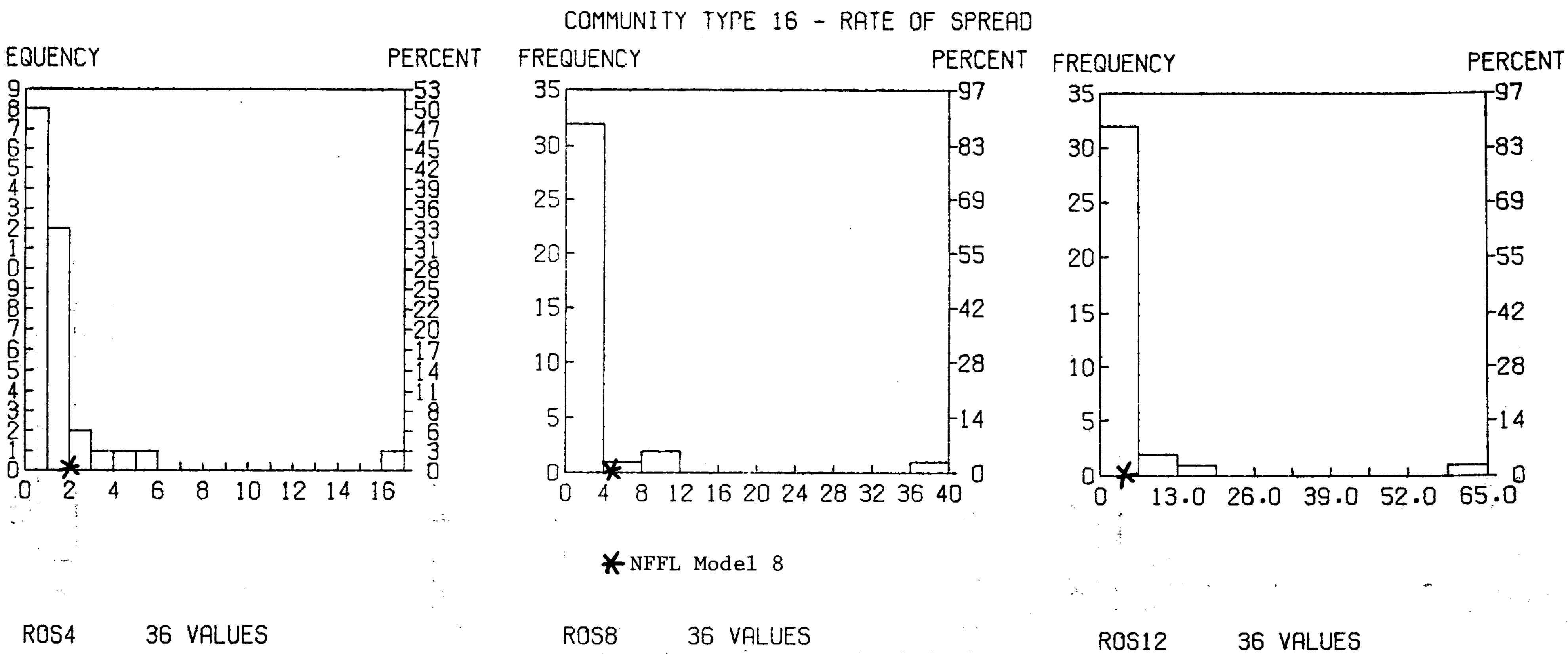


DOUGLAS-FIR CLOSED CANOPY

COMMUNITY TYPE 2 - FIRE LINE INTENSITY

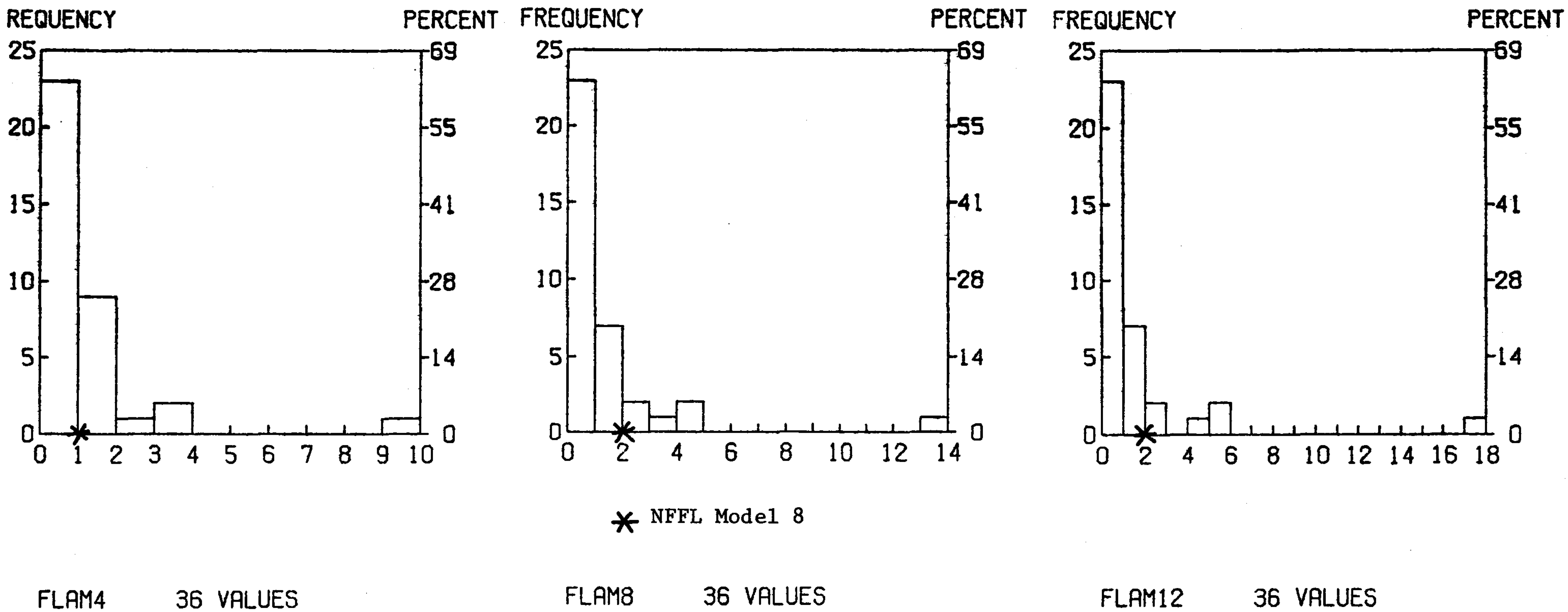


DOUGLAS-FIR OPEN CANOPY



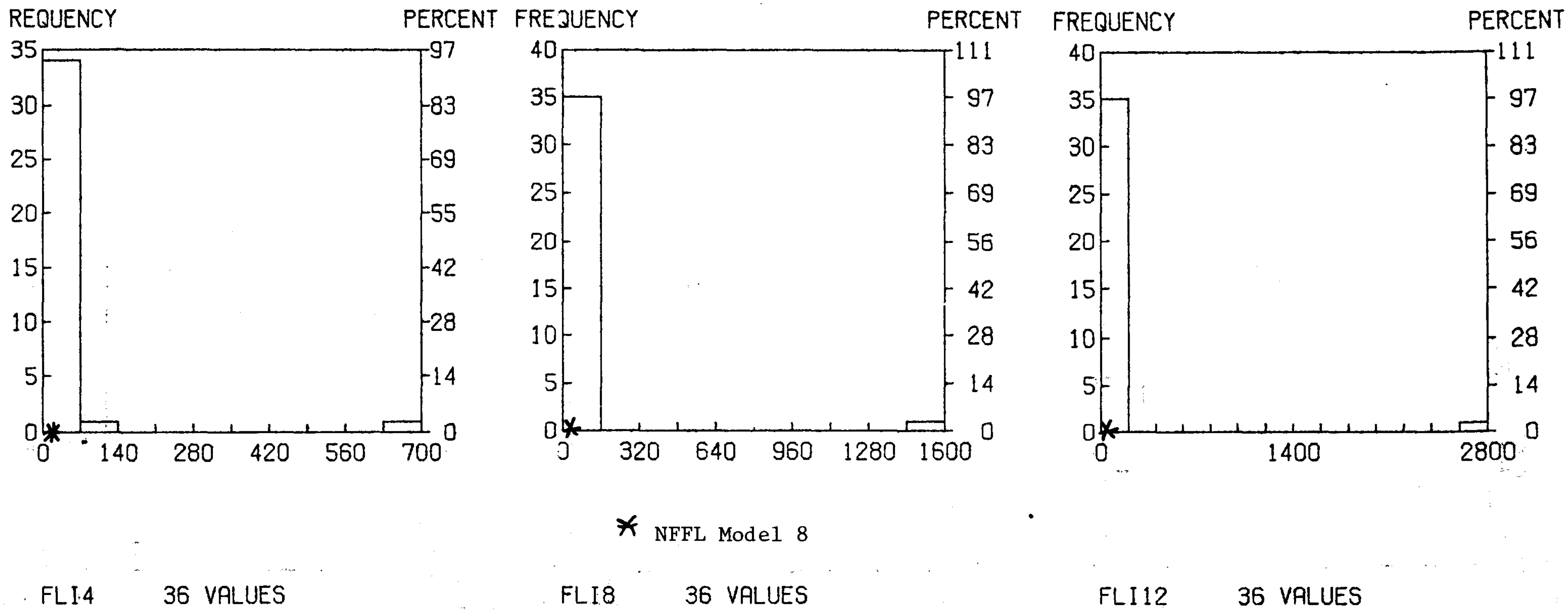
DOUGLAS-FIR OPEN CANOPY

COMMUNITY TYPE 16 - FLAME LENGTH



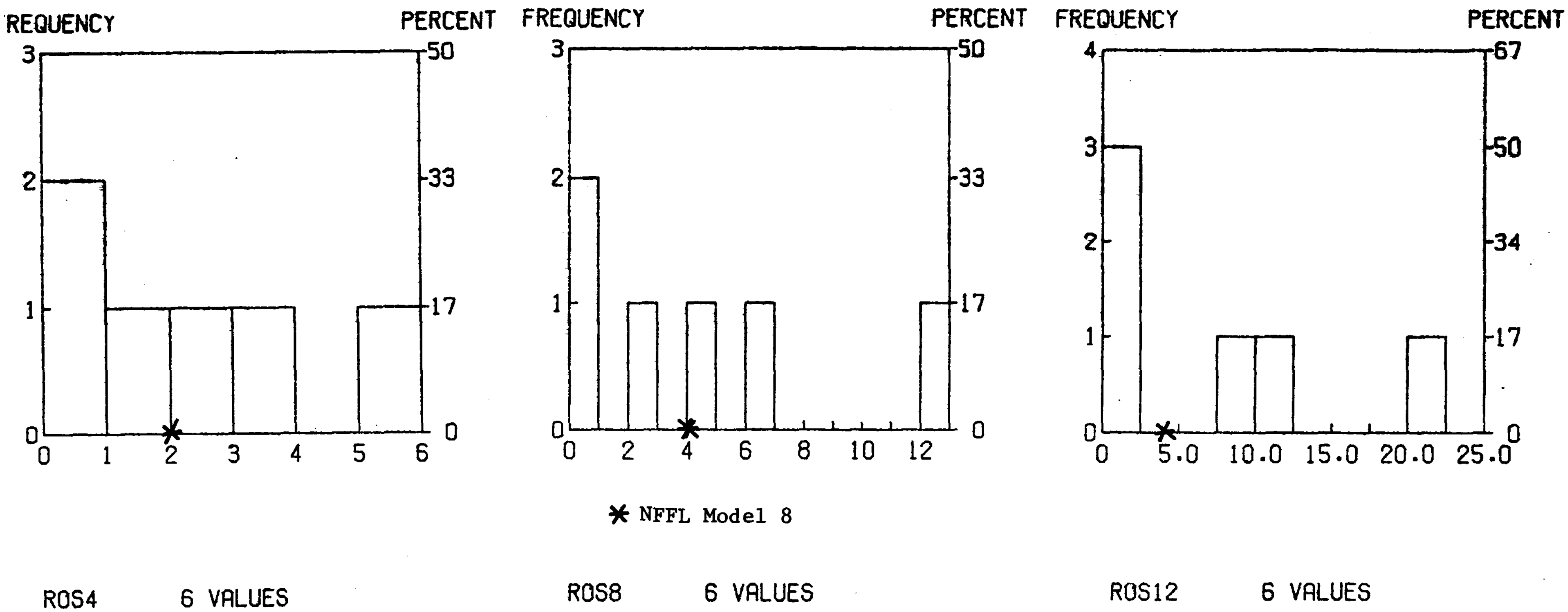
DOUGLAS-FIR OPEN CANOPY

COMMUNITY TYPE 16 - FIRE LINE INTENSITY



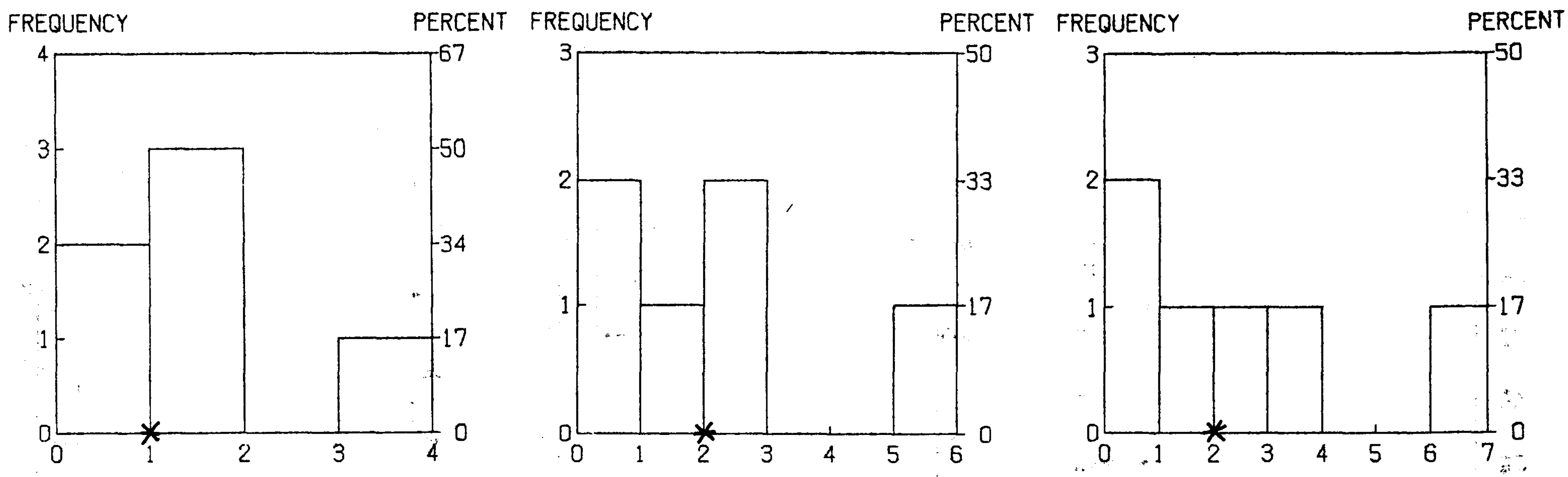
SUBALPINE FIR CLOSED CANOPY

COMMUNITY TYPE 4 - RATE OF SPREAD



SUBALPINE FIR CLOSED CANOPY

COMMUNITY TYPE 4 - FLAME LENGTH



✱NFFL Model 8

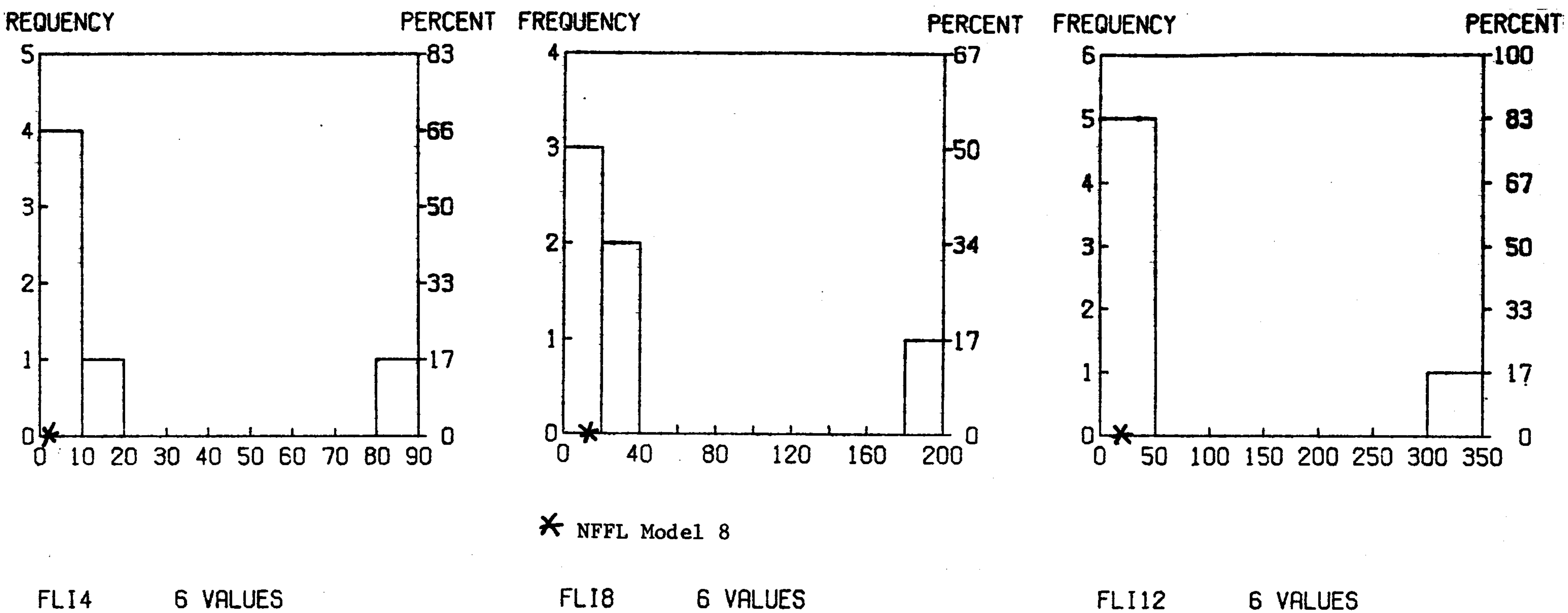
FLAM4 6 VALUES

FLAM8 6 VALUES

FLAM12 6 VALUES

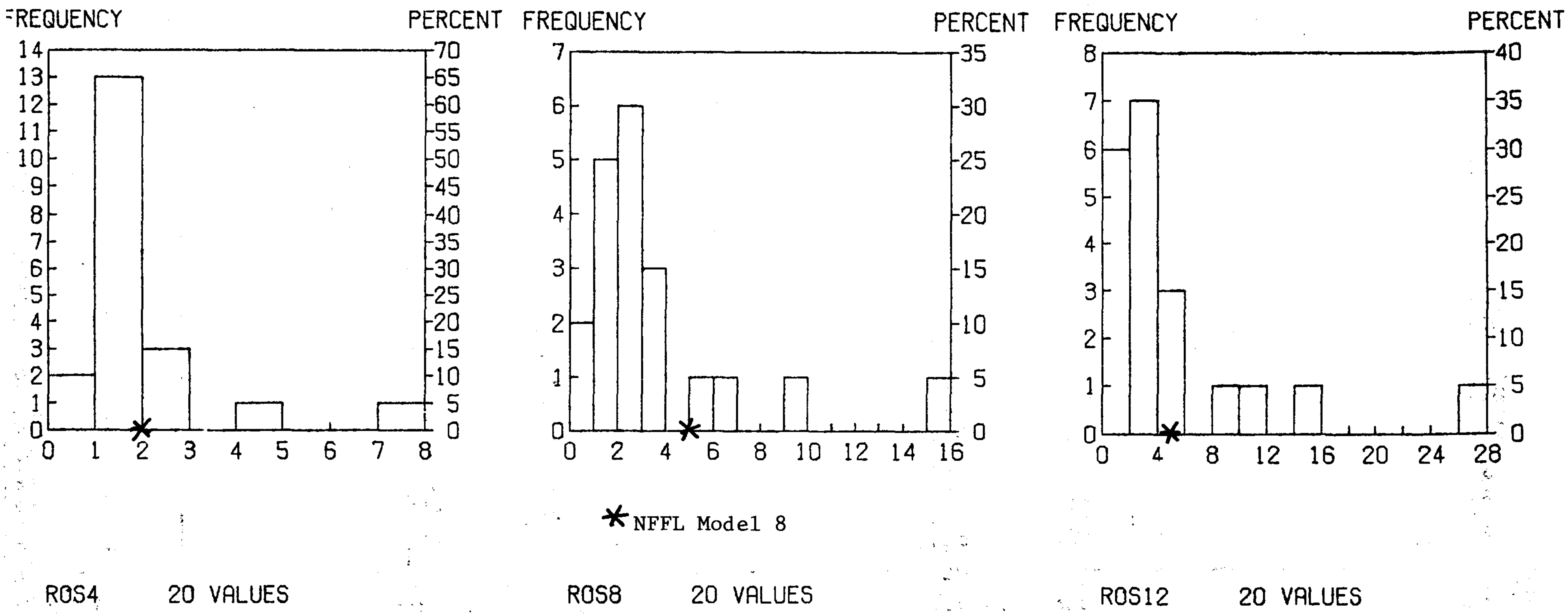
SUBALPINE FIR CLOSED CANOPY

COMMUNITY TYPE 4 - FIRE LINE INTENSITY



SUBALPINE FIR OPEN CANOPY

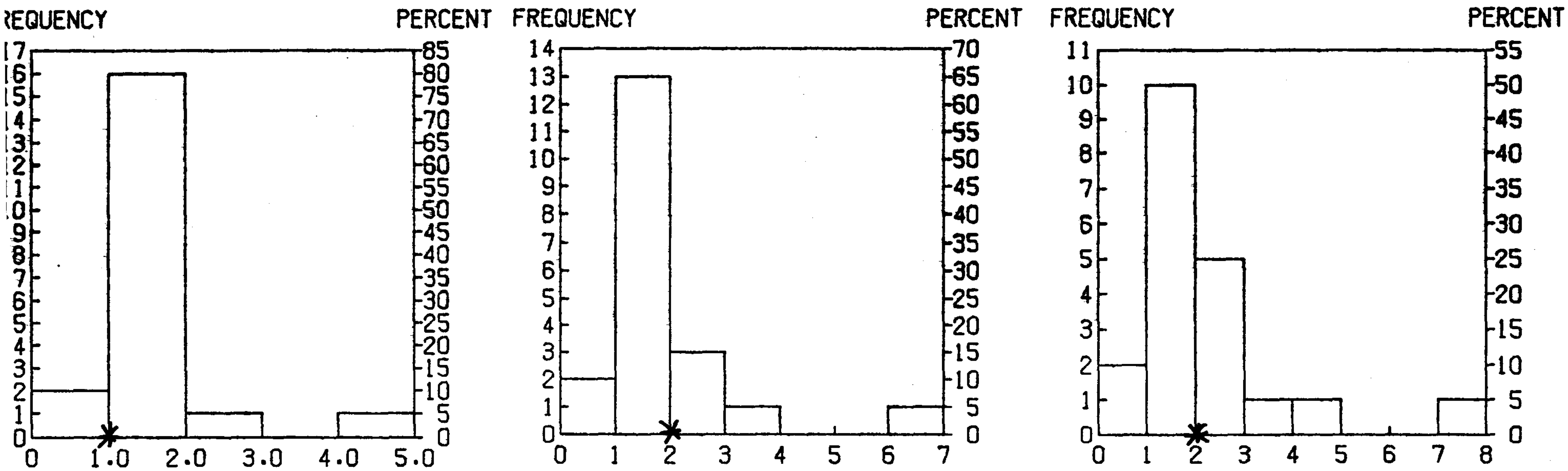
COMMUNITY TYPE 18 - RATE OF SPREAD



* NFFL Model 8

SUBALPINE FIR OPEN CANOPY

COMMUNITY TYPE 18 - FLAME LENGTH



✱ NFFL Model 8

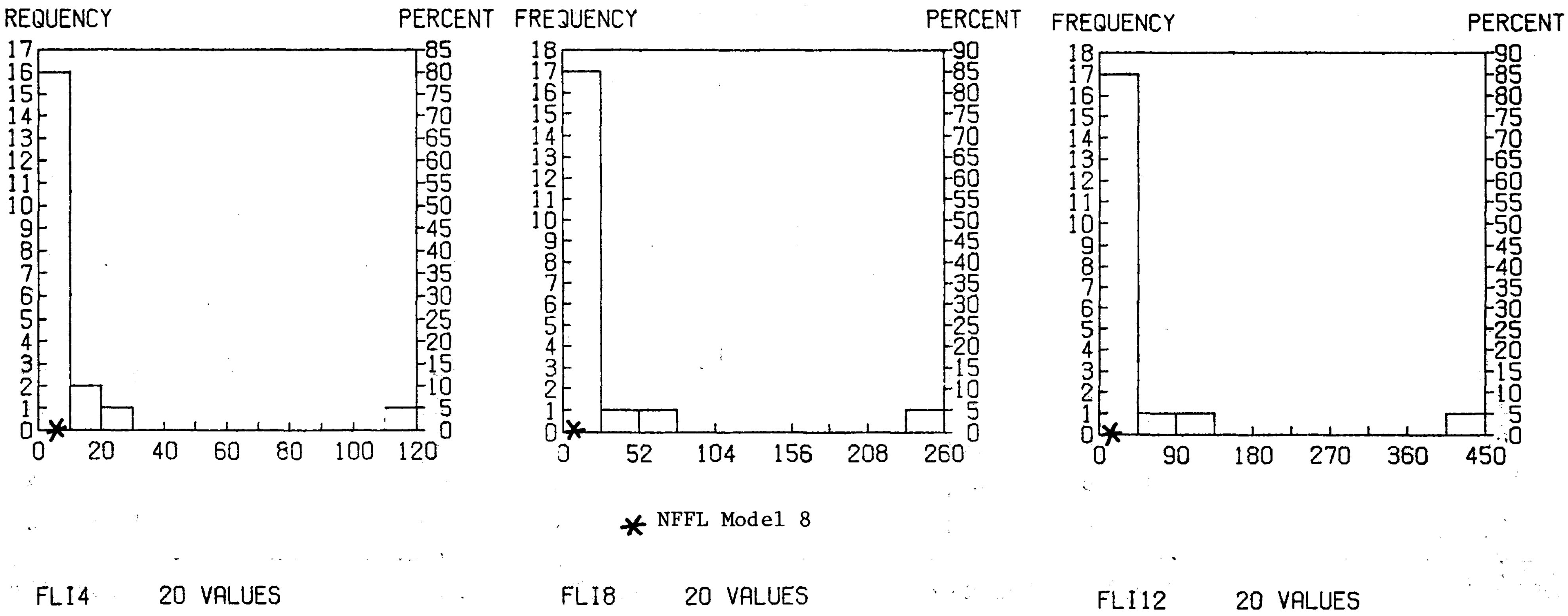
FLAM4 20 VALUES

FLAM8 20 VALUES

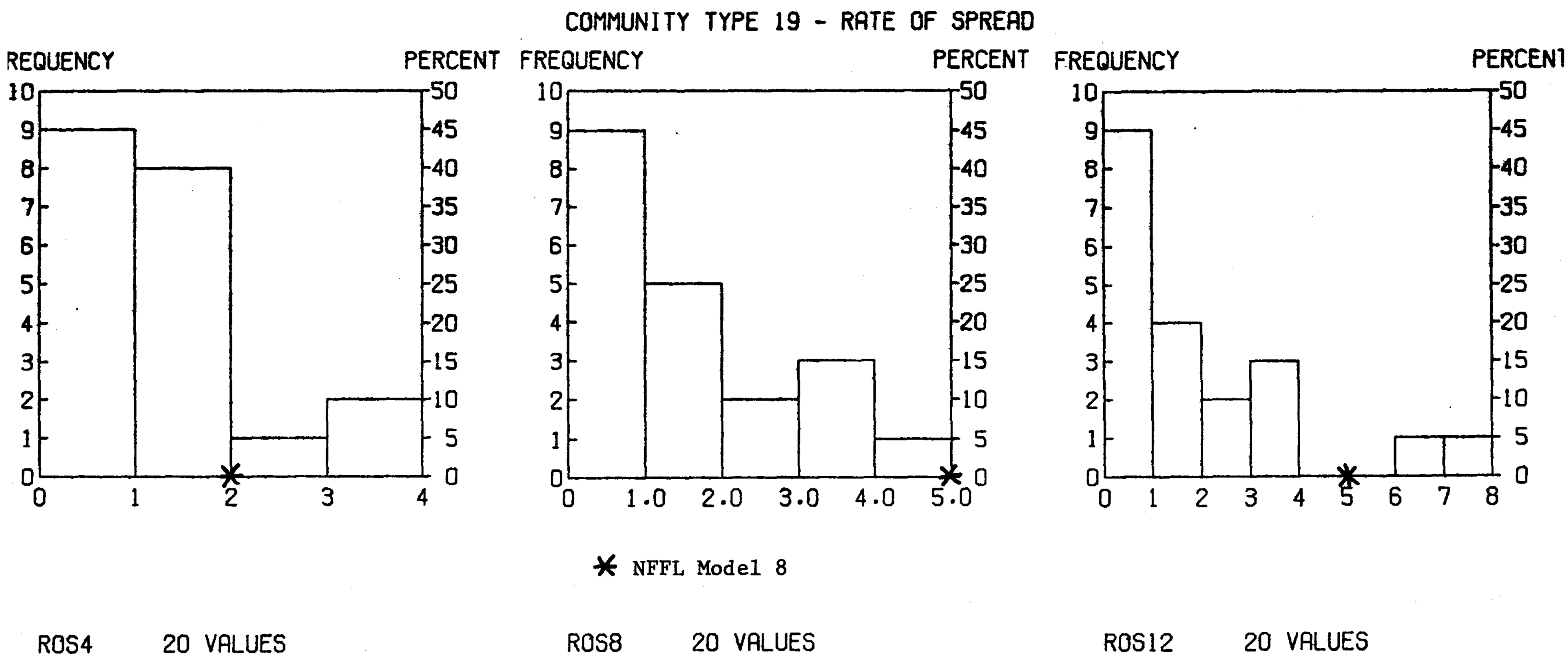
FLAM12 20 VALUES

SUBALPINE FIR OPEN CANOPY

COMMUNITY TYPE 18 - FIRE LINE INTENSITY

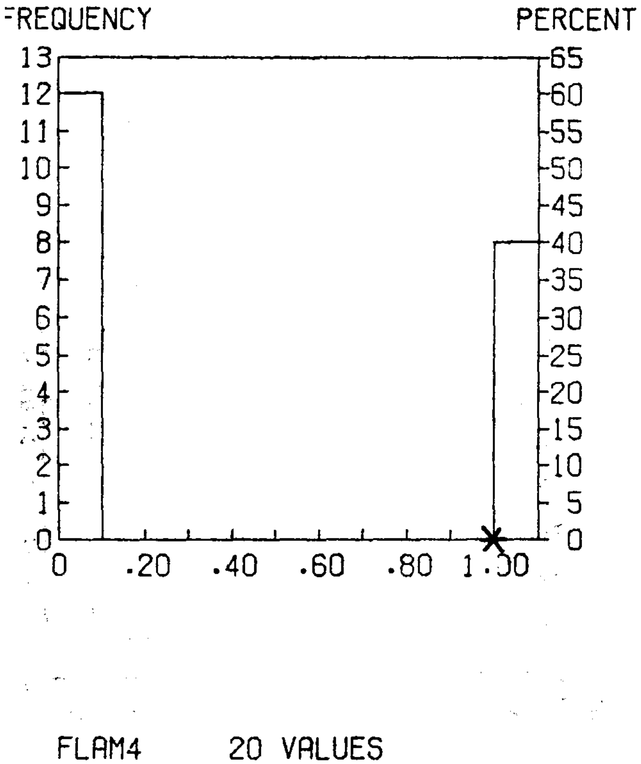


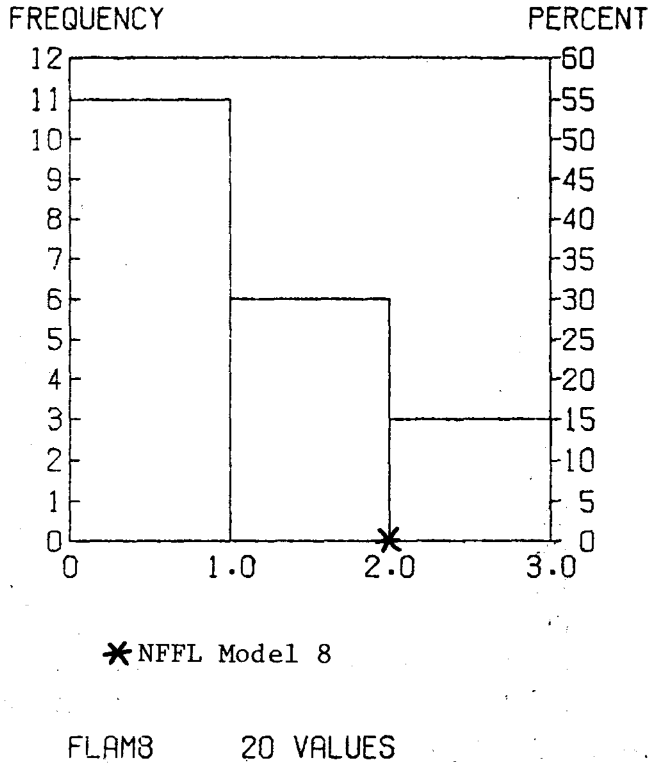
WHITEBARK PINE/SUBALPINE LARCH OPEN CANOPY

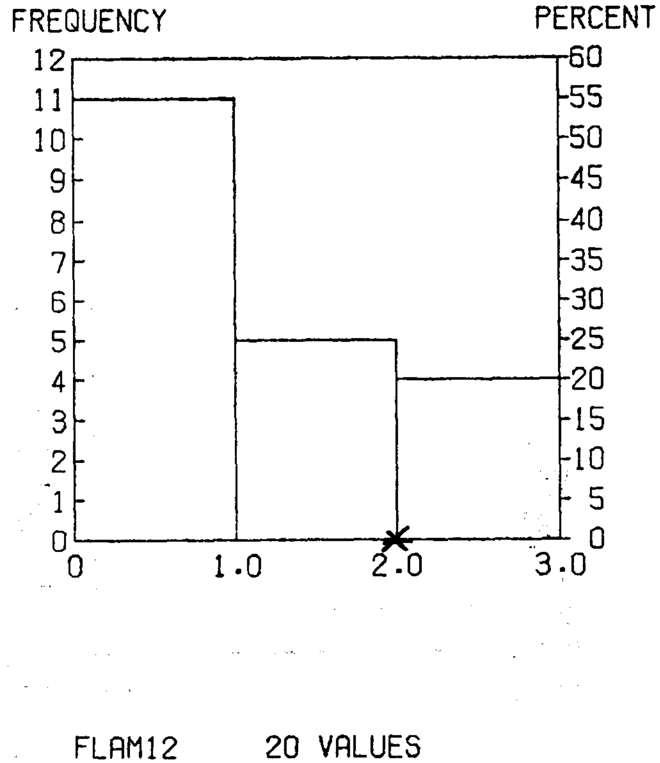


WHITEBARK PINE/SUBALPINE LARCH OPEN CANOPY

COMMUNITY TYPE 19 - FLAME LENGTH



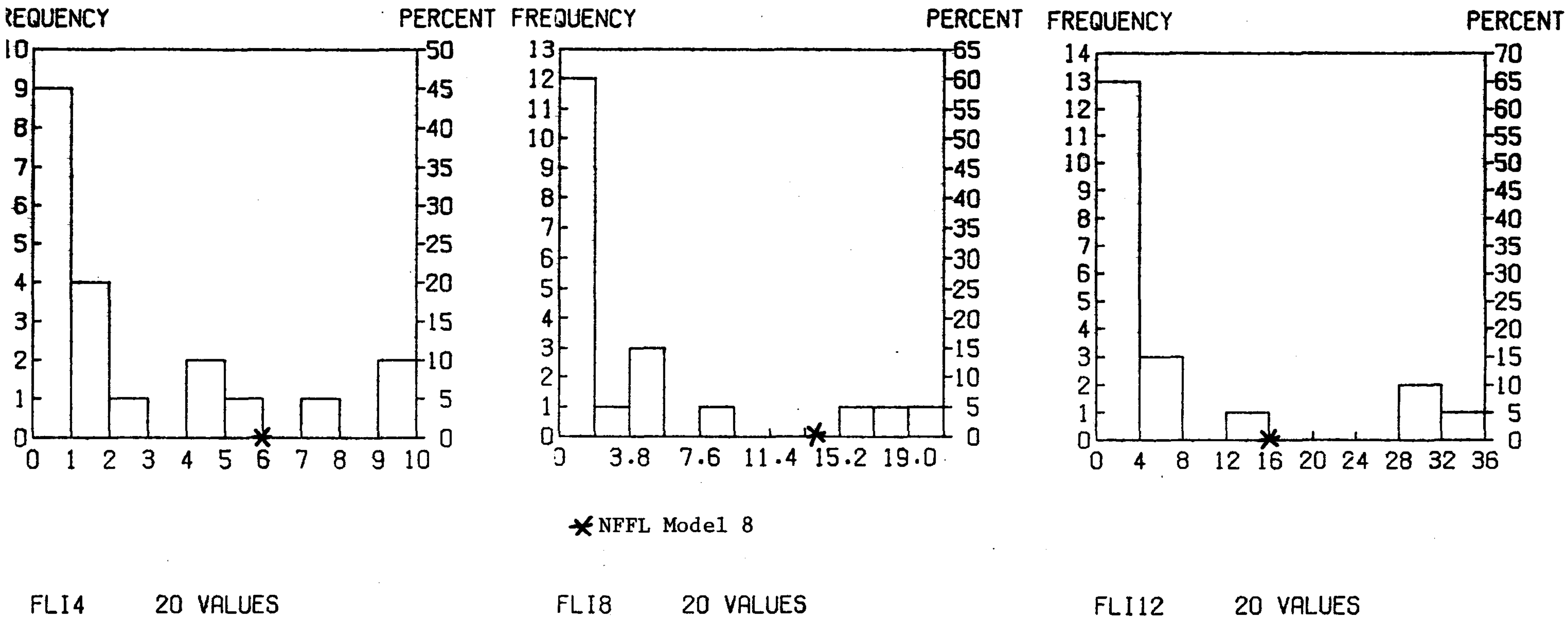




✱NFFL Model 8

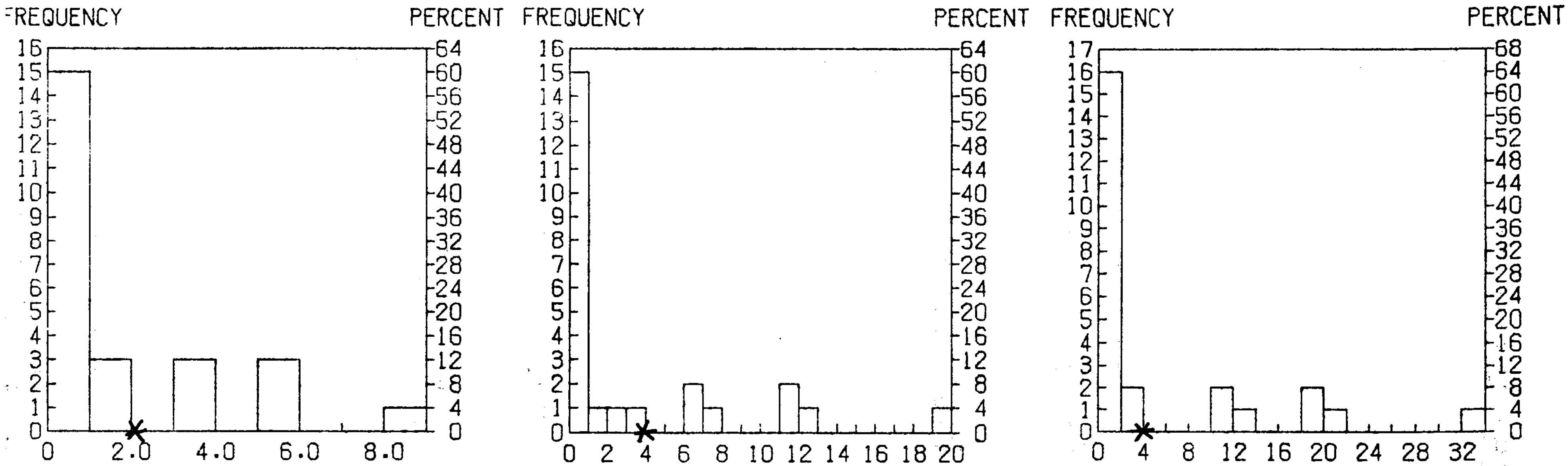
WHITEBARK PINE/SUBALPINE LARCH OPEN CANOPY

COMMUNITY TYPE 19 - FIRE LINE INTENSITY



MOUNTAIN HEMLOCK CLOSED CANOPY

COMMUNITY TYPE 6 - RATE OF SPREAD



✱ NFFL Model 8

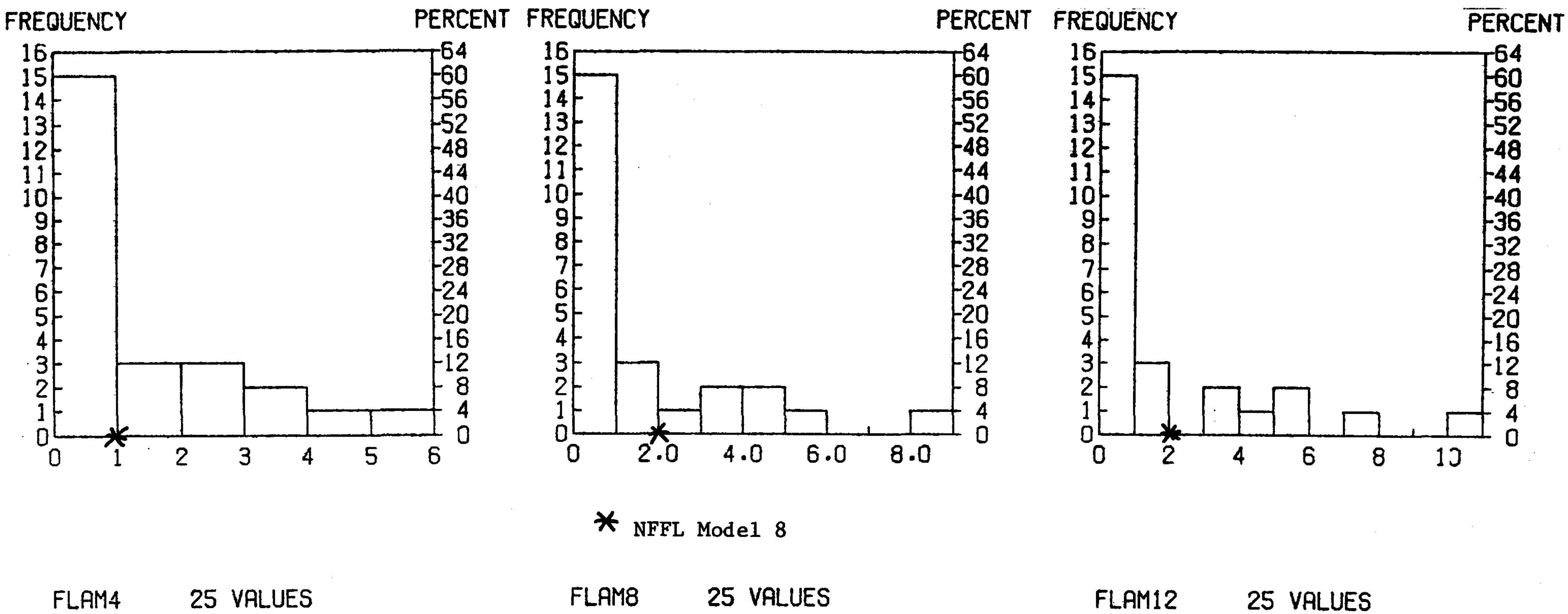
ROS4 25 VALUES

ROS8 25 VALUES

ROS12 25 VALUES

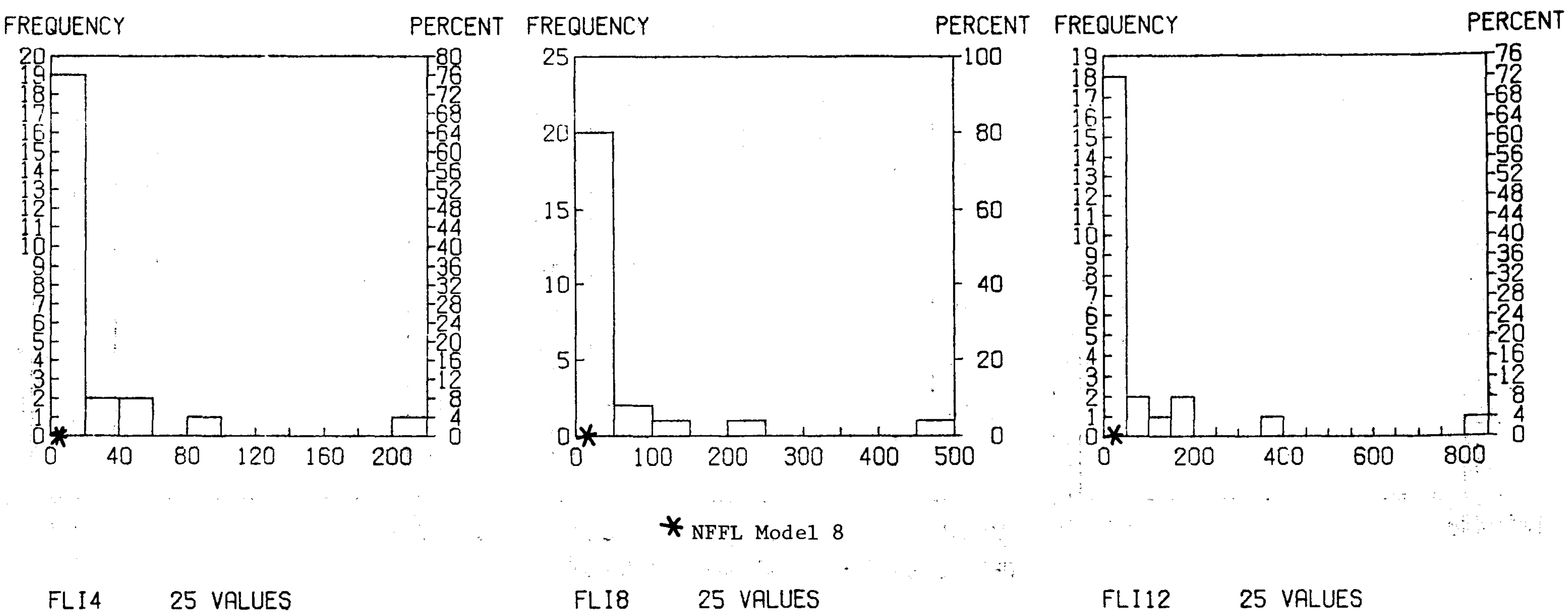
MOUNTAIN HEMLOCK CLOSED CANOPY

COMMUNITY TYPE 6 - FLAME LENGTH



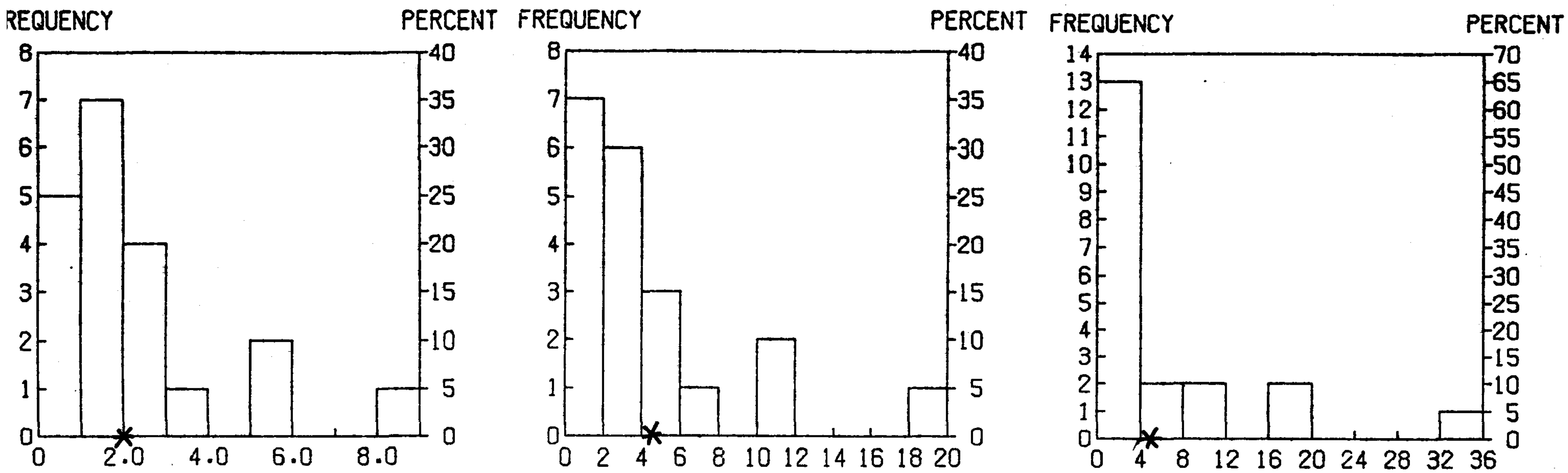
MOUNTAIN HEMLOCK CLOSED CANOPY

COMMUNITY TYPE 6 - FIRE LINE INTENSITY



MOUNTAIN HEMLOCK OPEN CANOPY

COMMUNITY TYPE 20 - RATE OF SPREAD



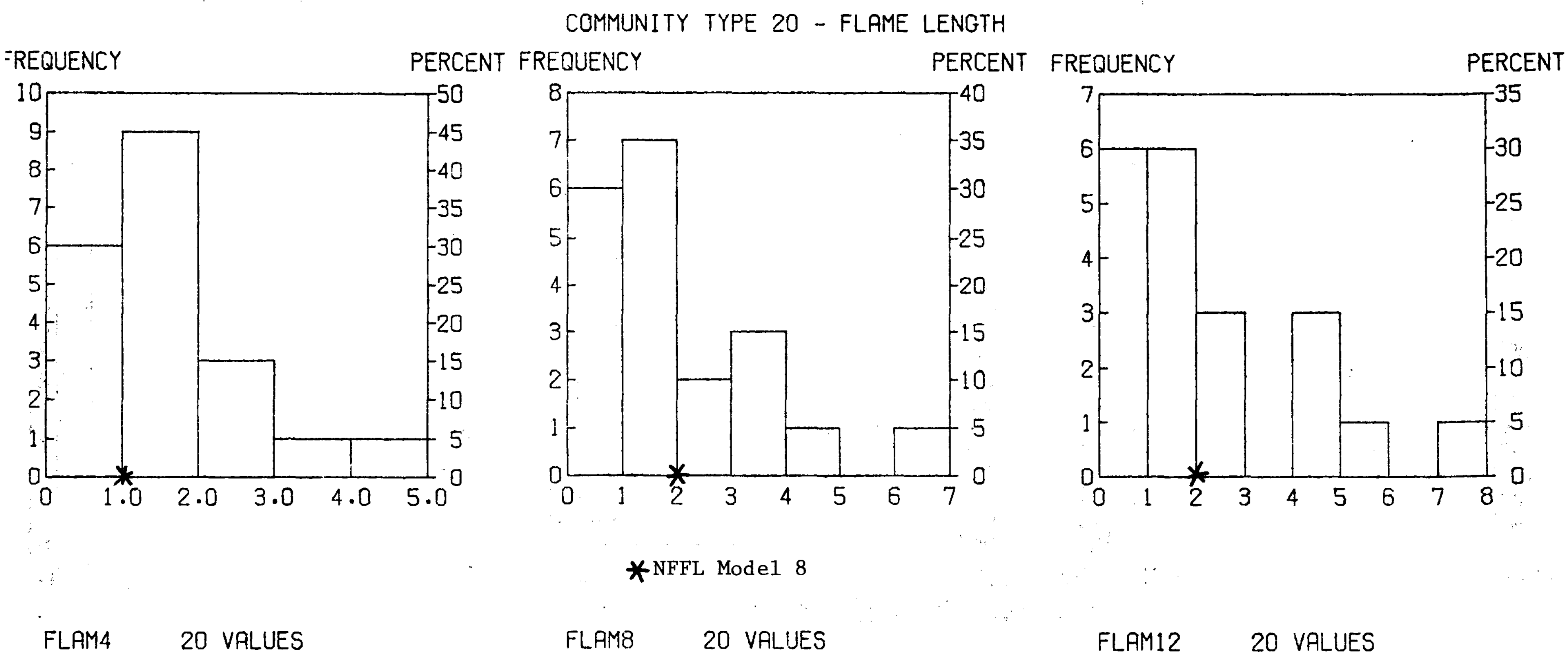
* NFFL Model 8

ROS4 20 VALUES

ROS8 20 VALUES

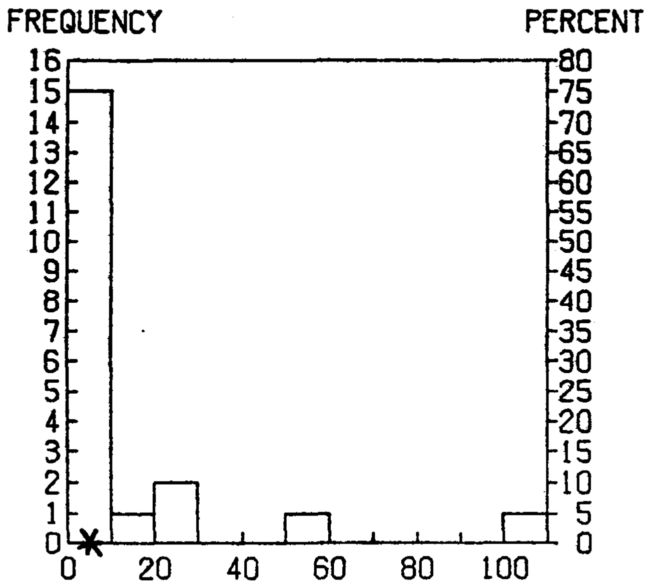
ROS12 20 VALUES

MOUNTAIN HEMLOCK OPEN CANOPY

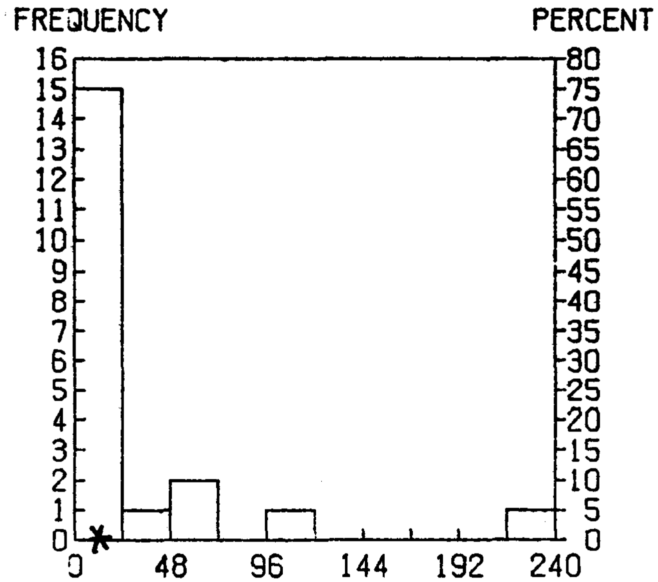


MOUNTAIN HEMLOCK OPEN CANOPY

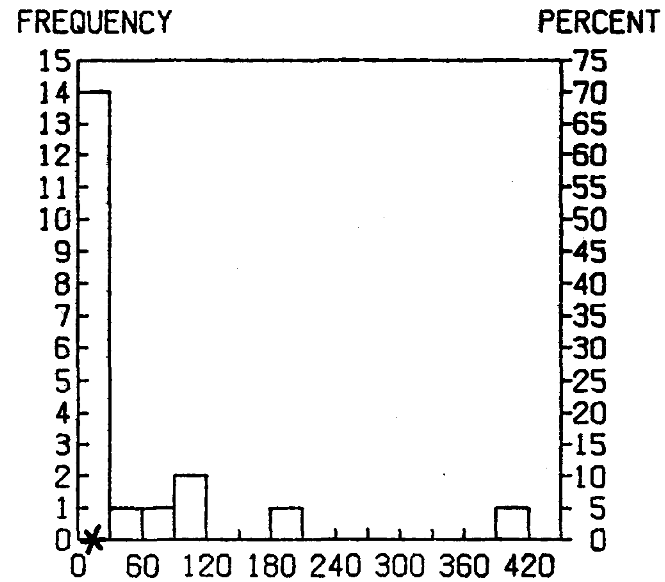
COMMUNITY TYPE 20 - FIRE LINE INTENSITY



FLI4 20 VALUES



FLI8 20 VALUES

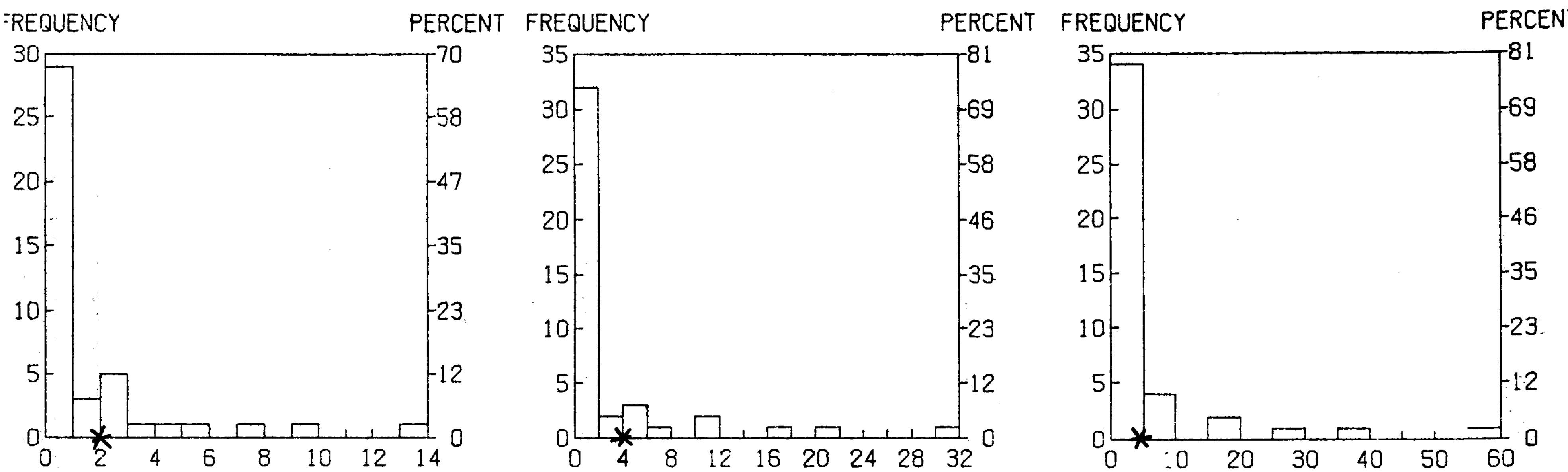


FLI12 20 VALUES

* NFFL Model 8

PACIFIC SILVER FIR CLOSED CANOPY

COMMUNITY TYPE 7 - RATE OF SPREAD



✱ NFFL Model 8

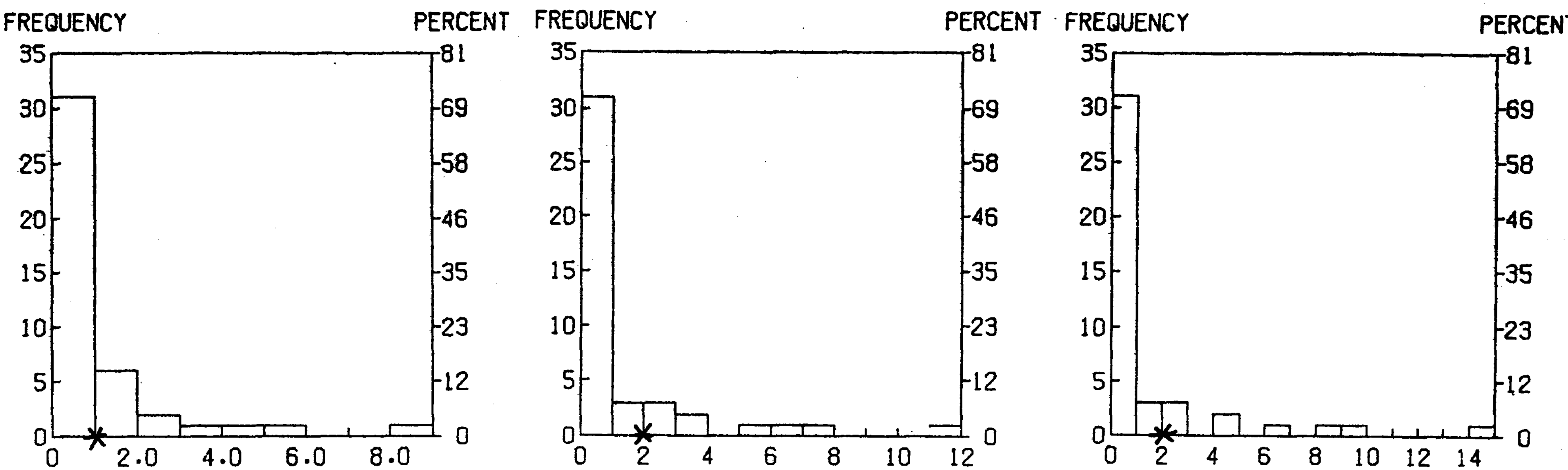
ROS4 43 VALUES

ROS8 43 VALUES

ROS12 43 VALUES

PACIFIC SILVER FIR CLOSED CANOPY

COMMUNITY TYPE 7 - FLAME LENGTH



* NFFL Model 8

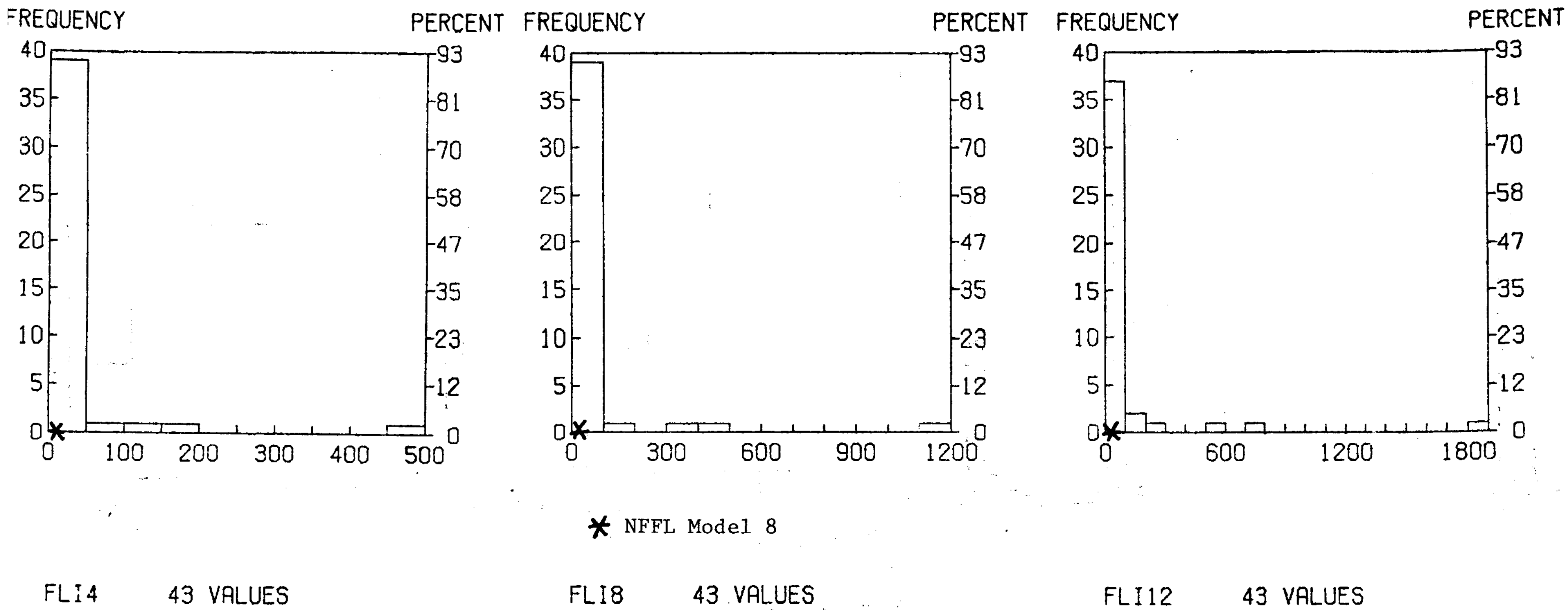
FLAM4 43 VALUES

FLAM8 43 VALUES

FLAM12 43 VALUES

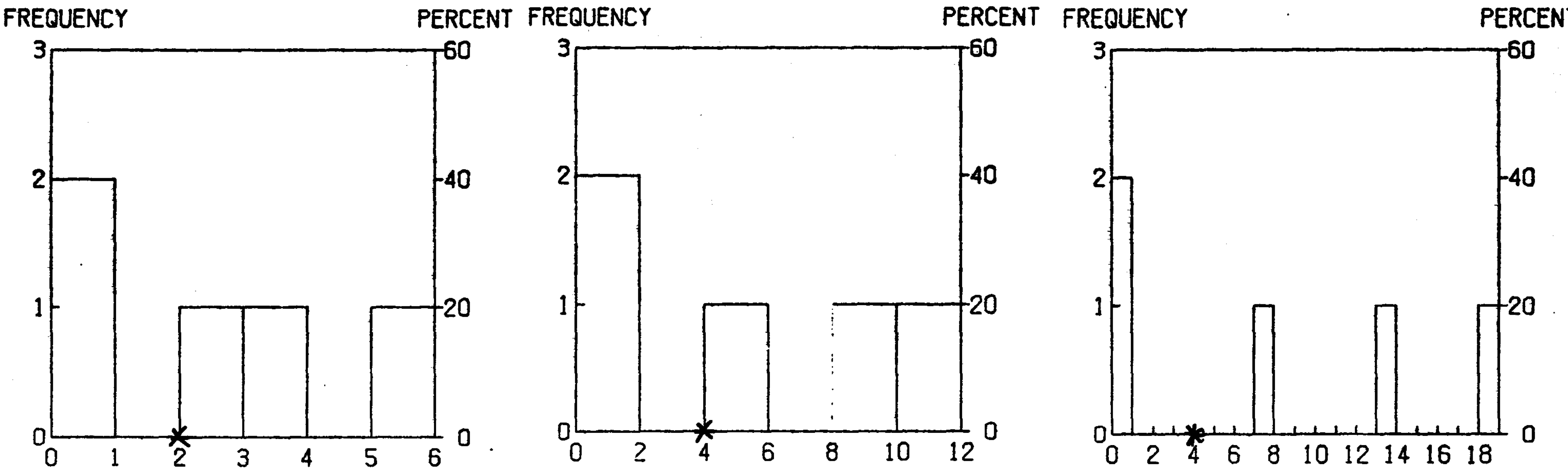
PACIFIC SILVER FIR CLOSED CANOPY

COMMUNITY TYPE 7 - FIRE LINE INTENSITY



PACIFIC SILVER FIR OPEN CANOPY

COMMUNITY TYPE 21 - RATE OF SPREAD



* NFFL Model 8

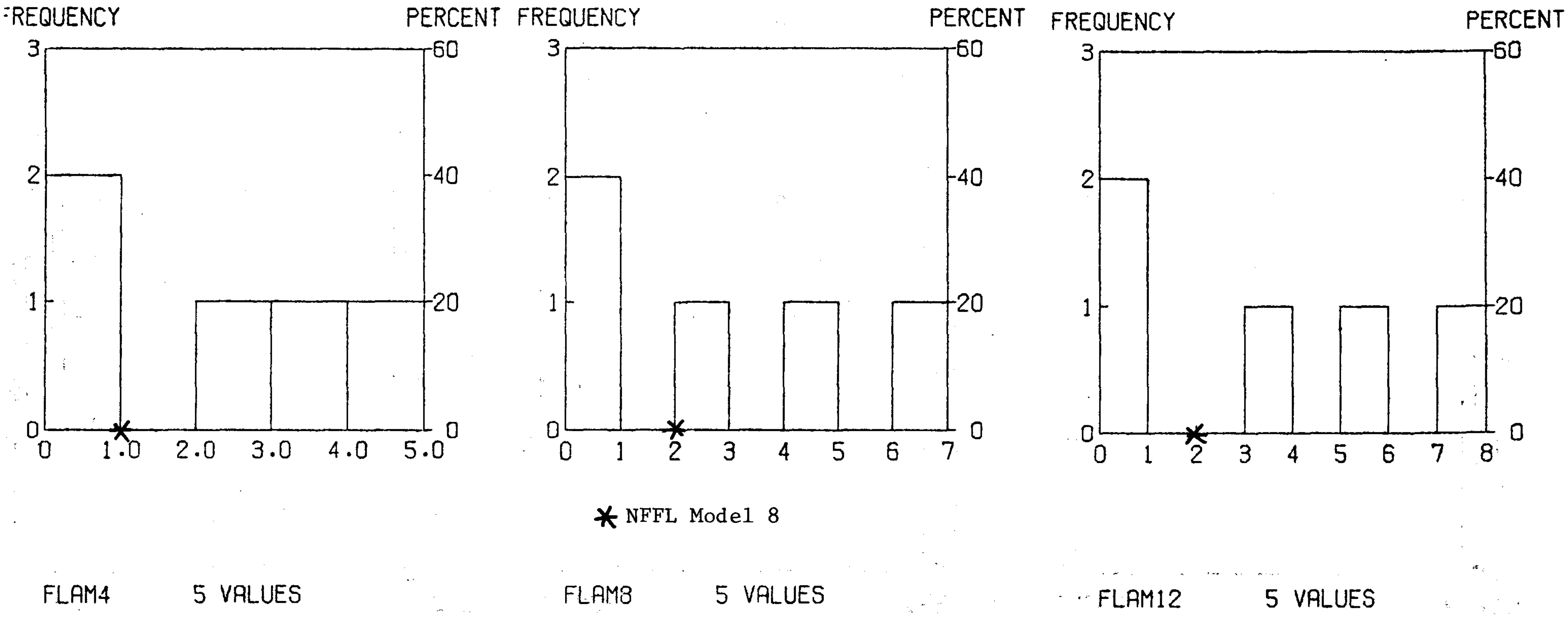
ROS4 5 VALUES

ROS8 5 VALUES

ROS12 5 VALUES

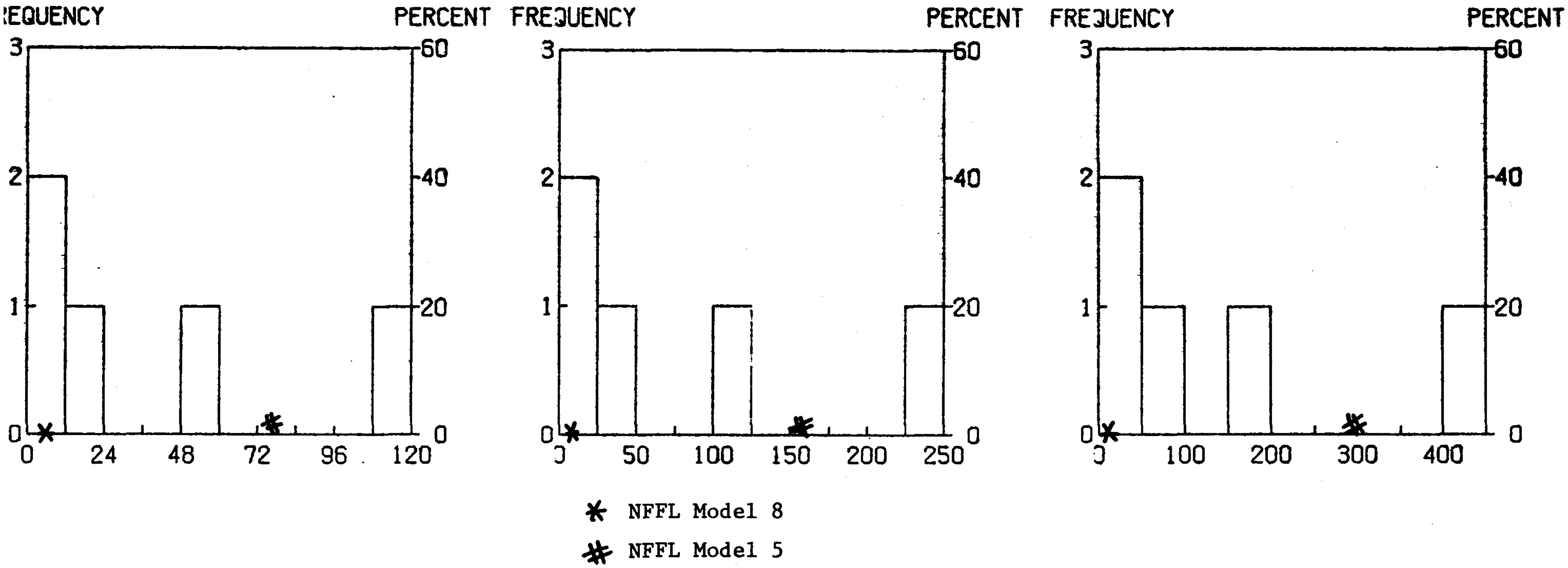
PACIFIC SILVER FIR OPEN CANOPY

COMMUNITY TYPE 21 - FLAME LENGTH



PACIFIC SILVER FIR OPEN CANOPY

COMMUNITY TYPE 21 - FIRE LINE INTENSITY



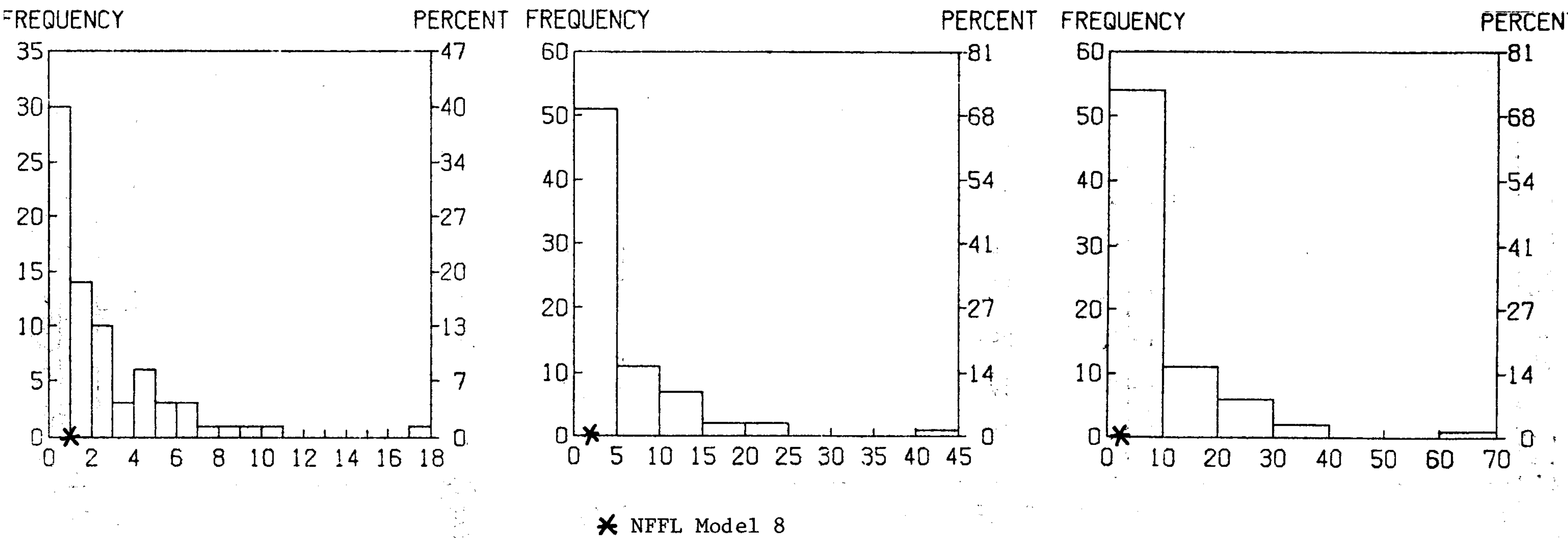
FLI4 5 VALUES

FLI8 5 VALUES

FLI12 5 VALUES

WESTERN HEMLOCK CLOSED CANOPY

COMMUNITY TYPE 8 - RATE OF SPREAD



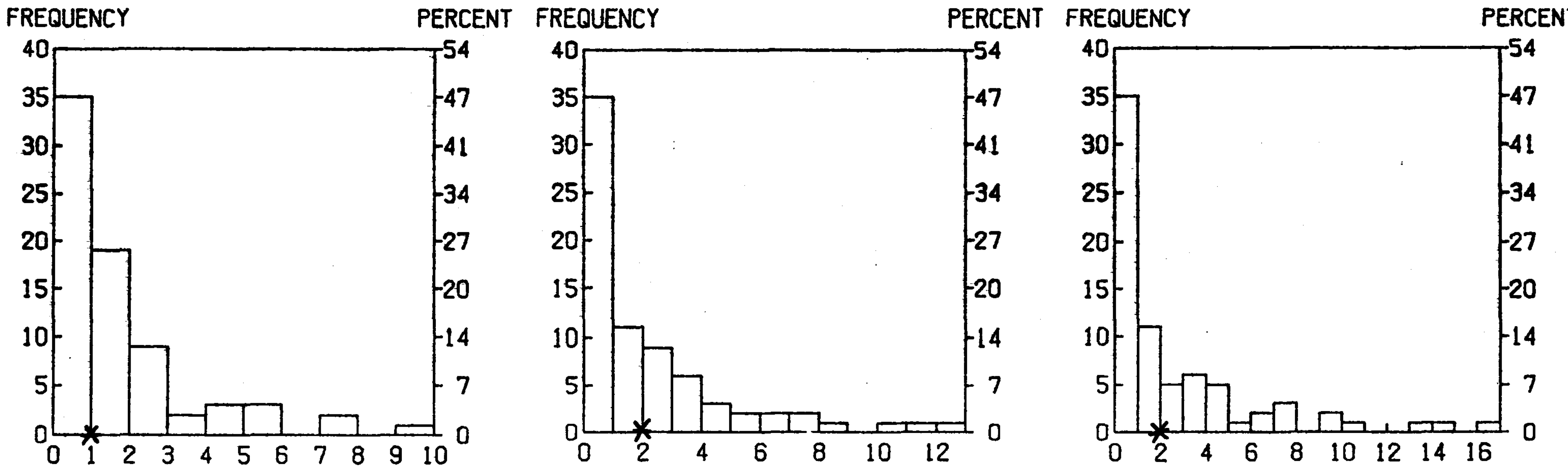
ROS4 74 VALUES

ROS8 74 VALUES

ROS12 74 VALUES

WESTERN HEMLOCK CLOSED CANOPY

COMMUNITY TYPE 8 - FLAME LENGTH



* NFFL Model 8

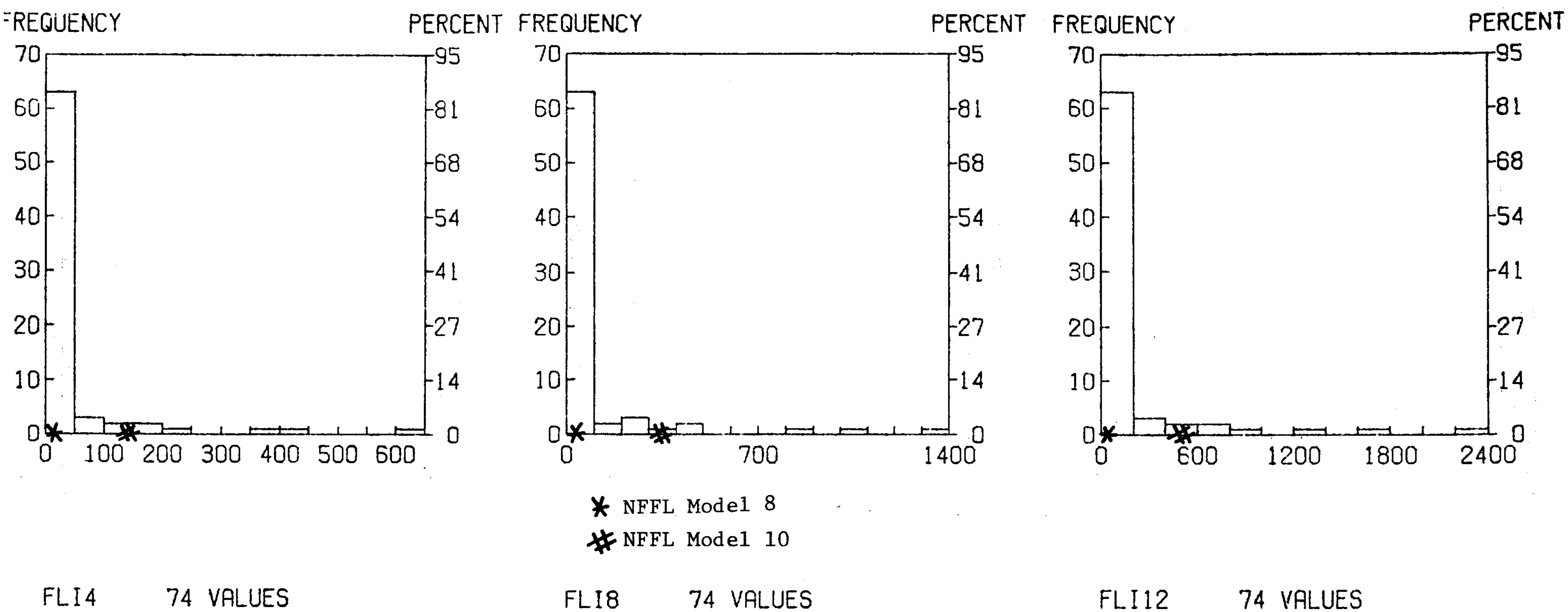
FLAM4 74 VALUES

FLAM8 74 VALUES

FLAM12 74 VALUES

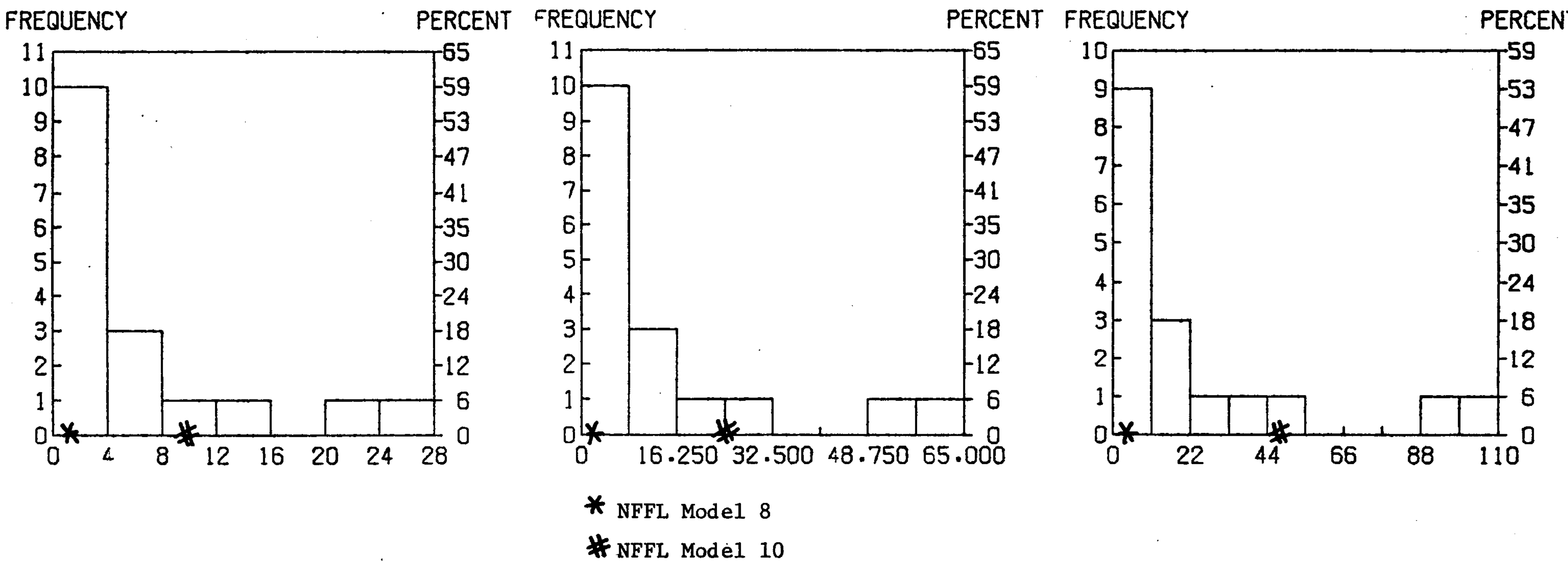
WESTERN HEMLOCK CLOSED CANOPY

COMMUNITY TYPE 8 - FIRE LINE INTENSITY



WESTERN HEMLOCK OPEN CANOPY

COMMUNITY TYPE 22 - RATE OF SPREAD



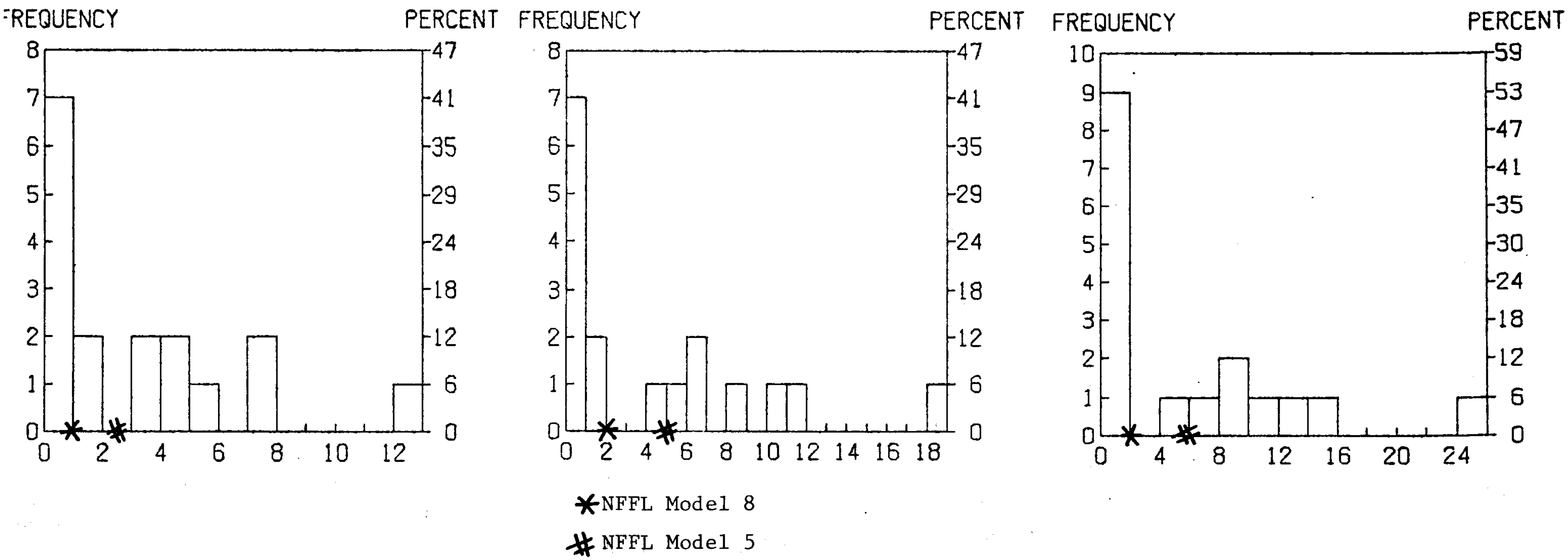
ROS4 17 VALUES

ROS8 17 VALUES

ROS12 17 VALUES

WESTERN HEMLOCK OPEN CANOPY

COMMUNITY TYPE 22 - FLAME LENGTH



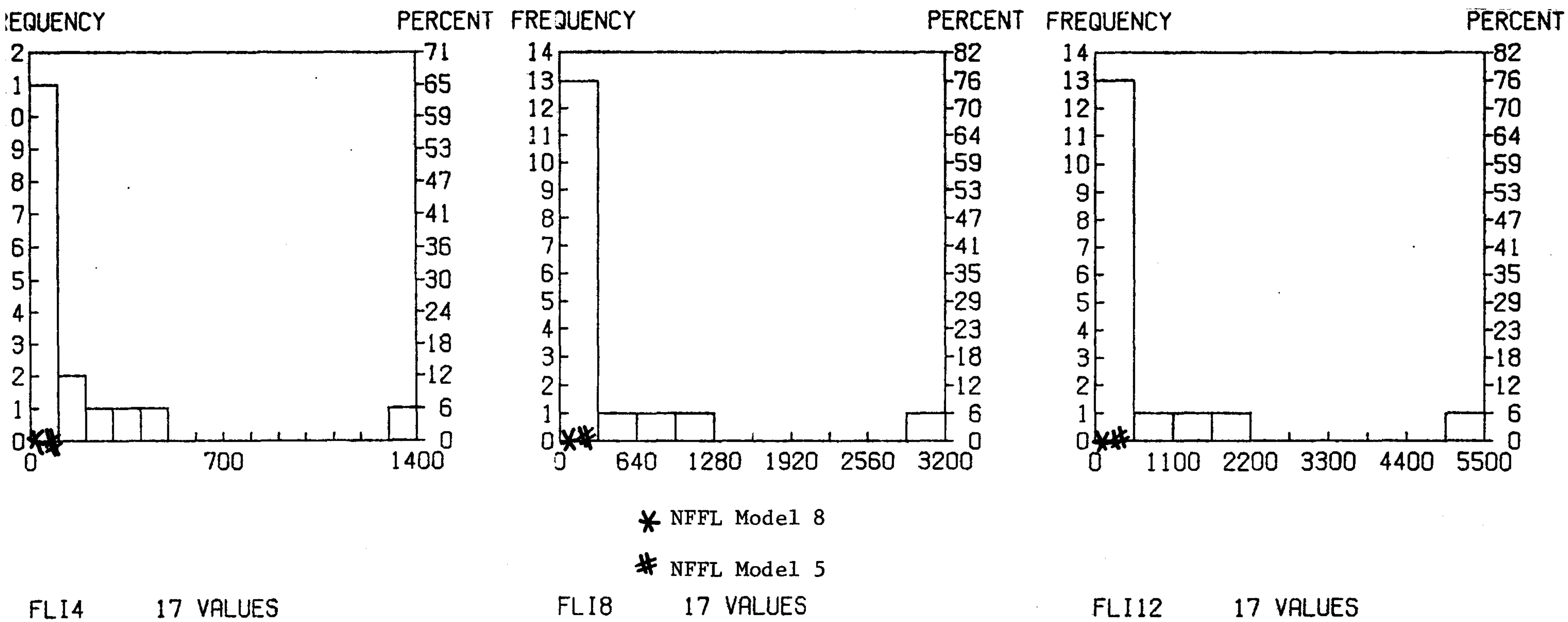
FLAM4 17 VALUES

FLAM8 17 VALUES

FLAM12 17 VALUES

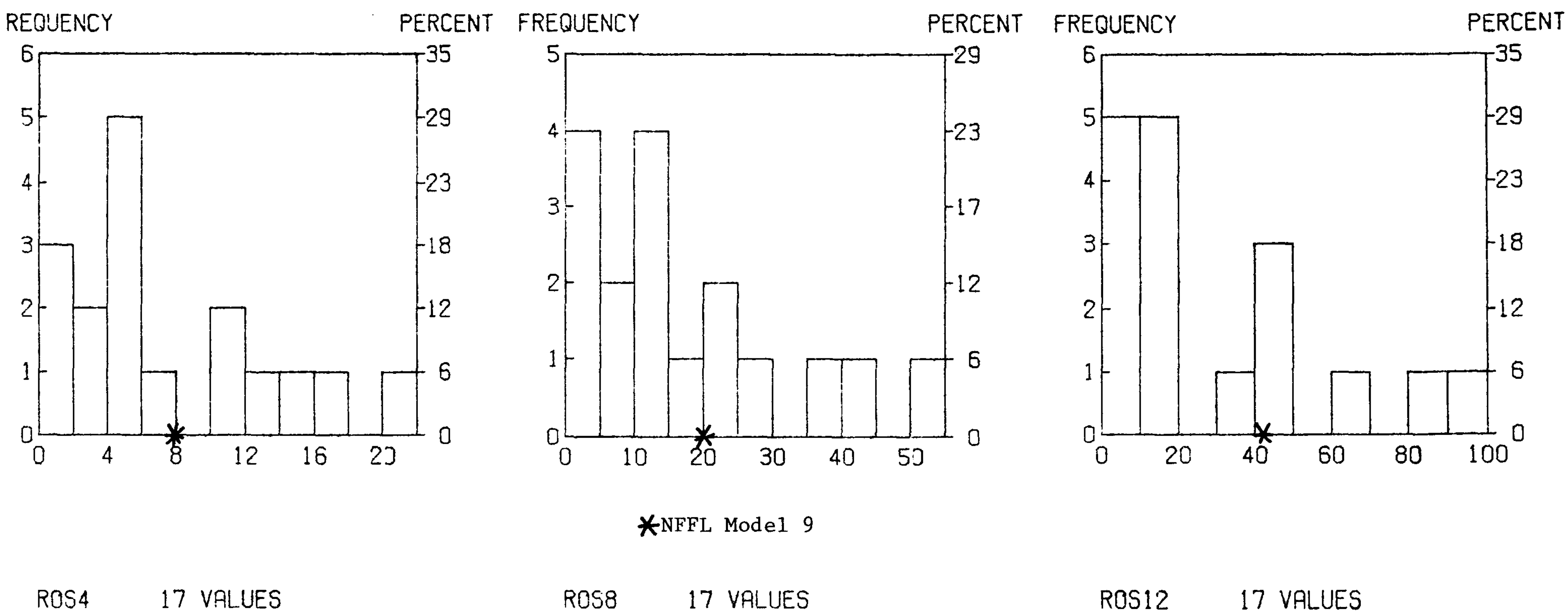
WESTERN HEMLOCK OPEN CANOPY

COMMUNITY TYPE 22 - FIRE LINE INTENSITY



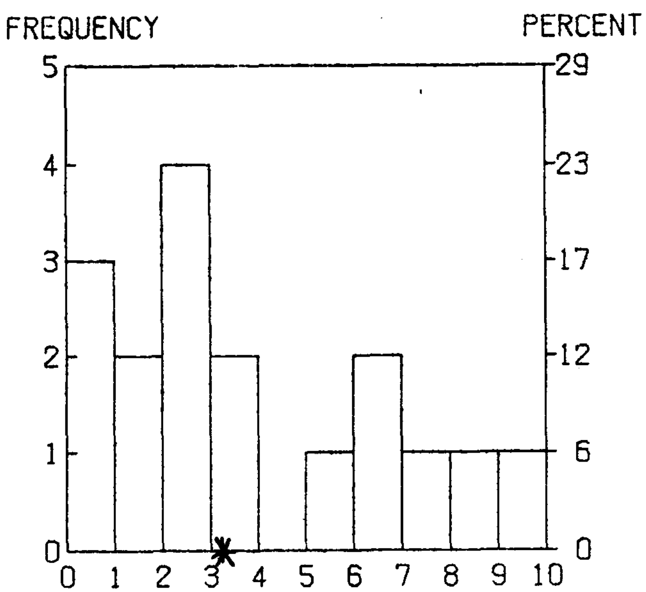
HARDWOOD FOREST

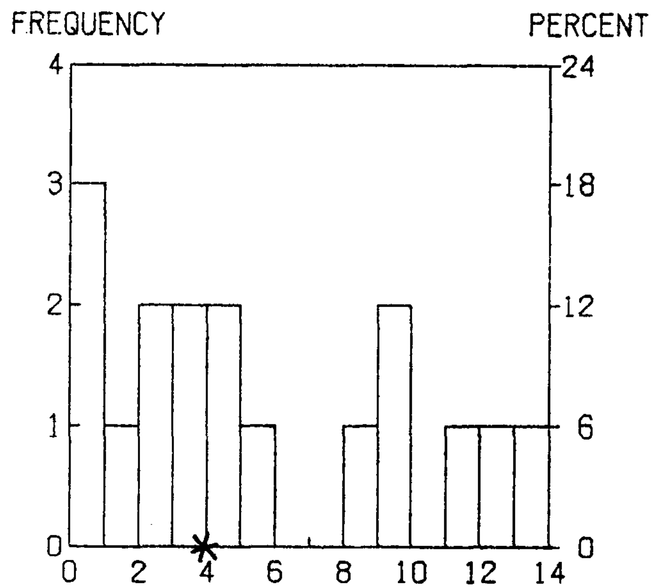
COMMUNITY TYPE 9 - RATE OF SPREAD

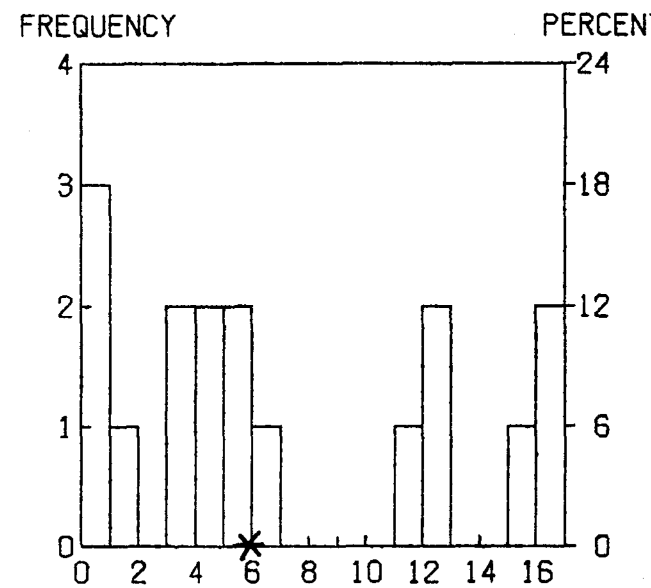


HARDWOOD FOREST

COMMUNITY TYPE 9 - FLAME LENGTH







* NFFL Model 9

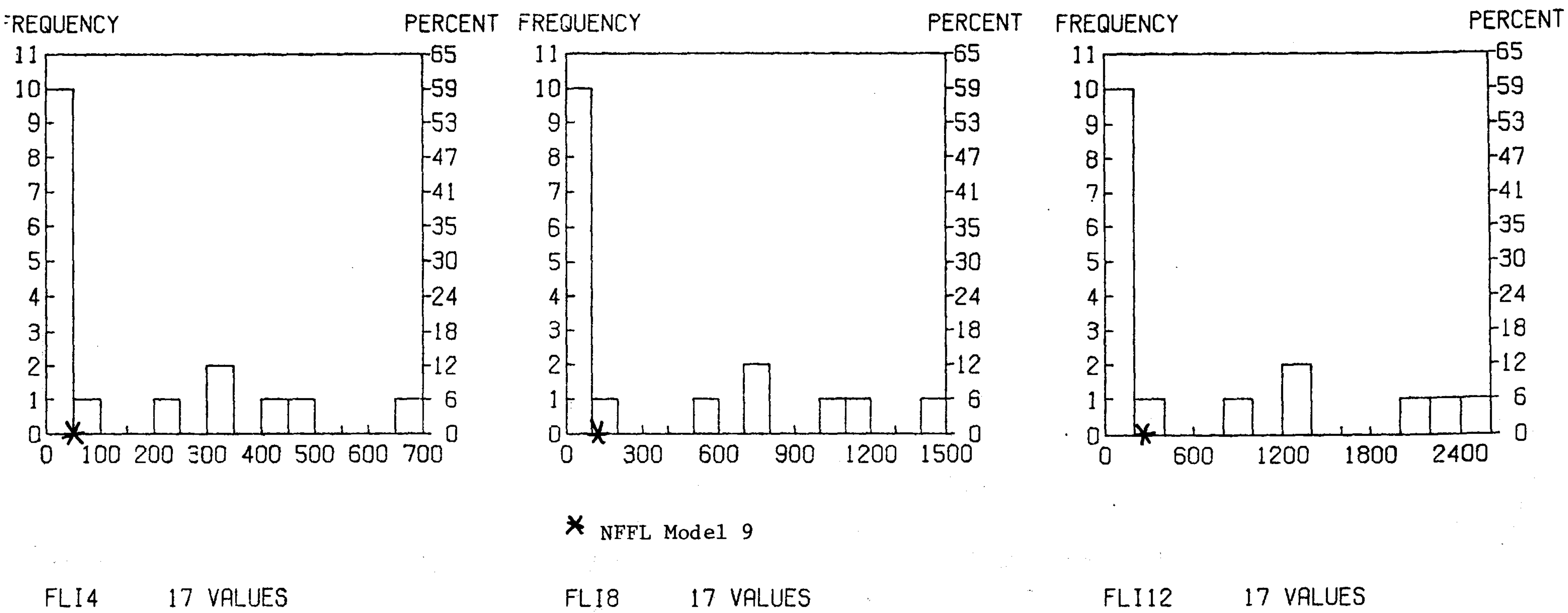
FLAM4 17 VALUES

FLAM8 17 VALUES

FLAM12 17 VALUES

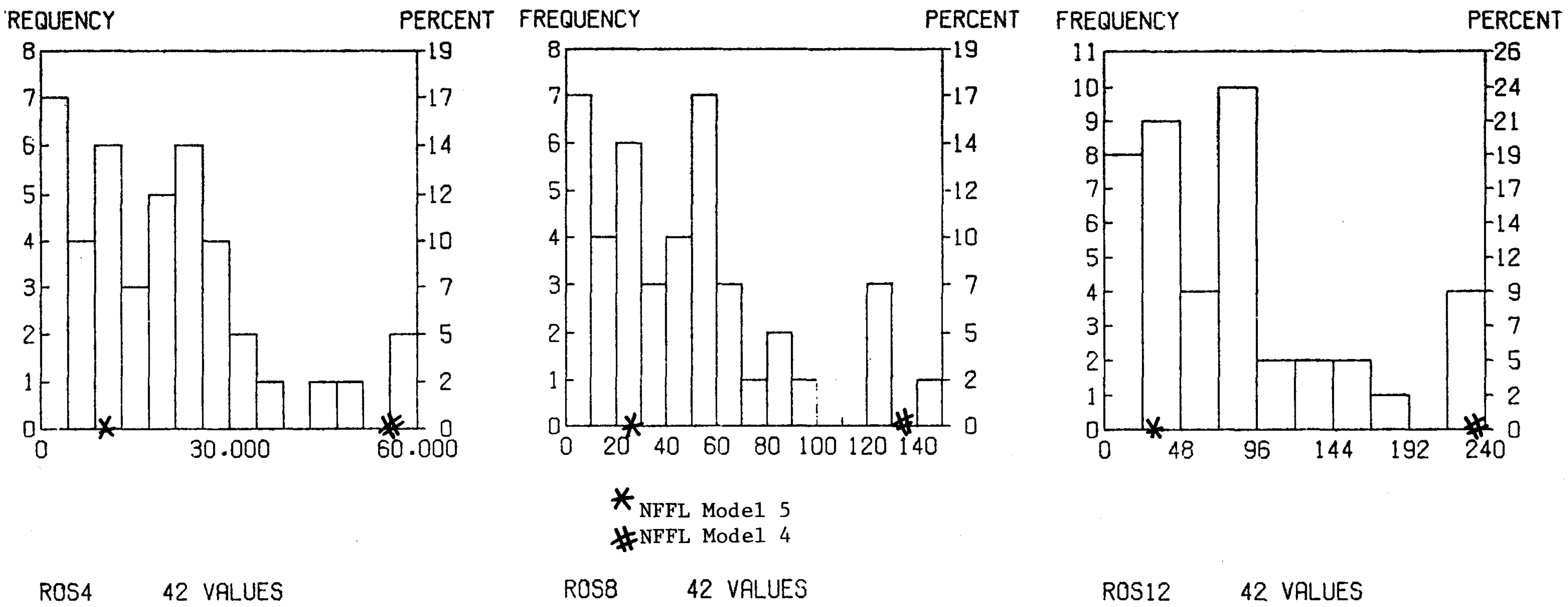
HARDWOOD FOREST

COMMUNITY TYPE 9 - FIRE LINE INTENSITY



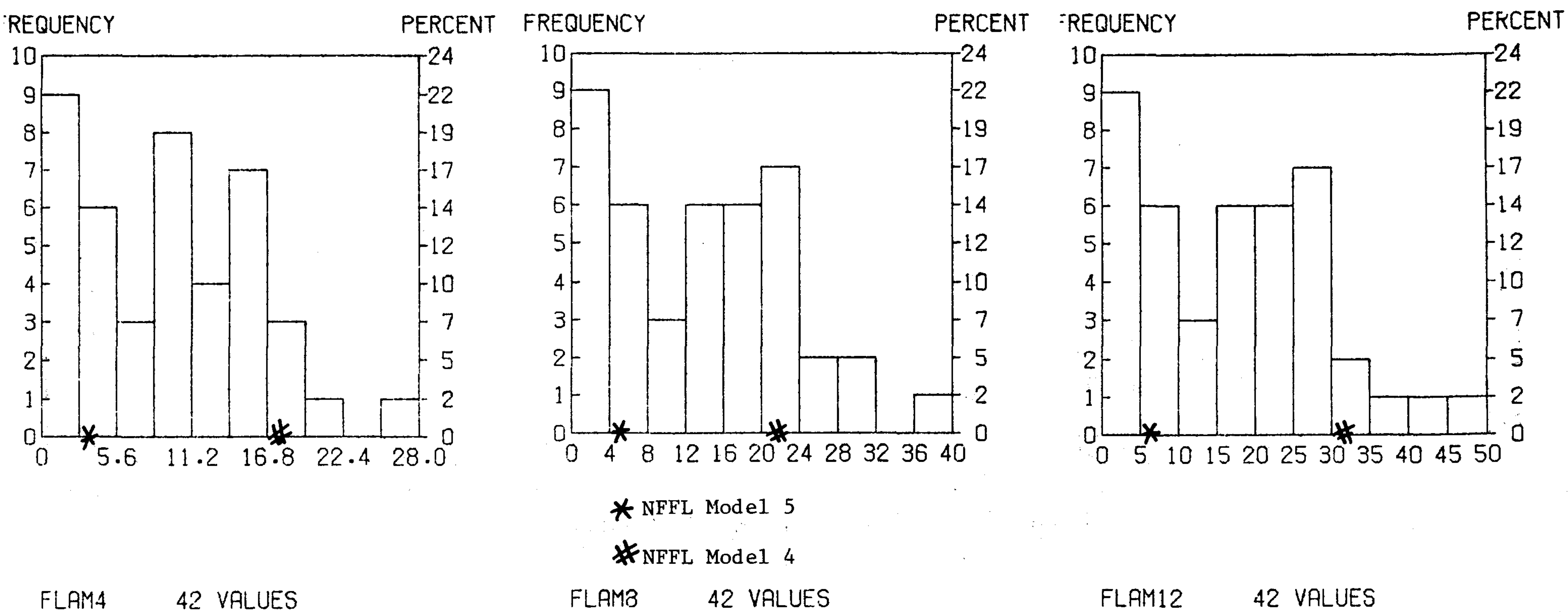
HIGH SHRUB

COMMUNITY TYPE 10 - RATE OF SPREAD



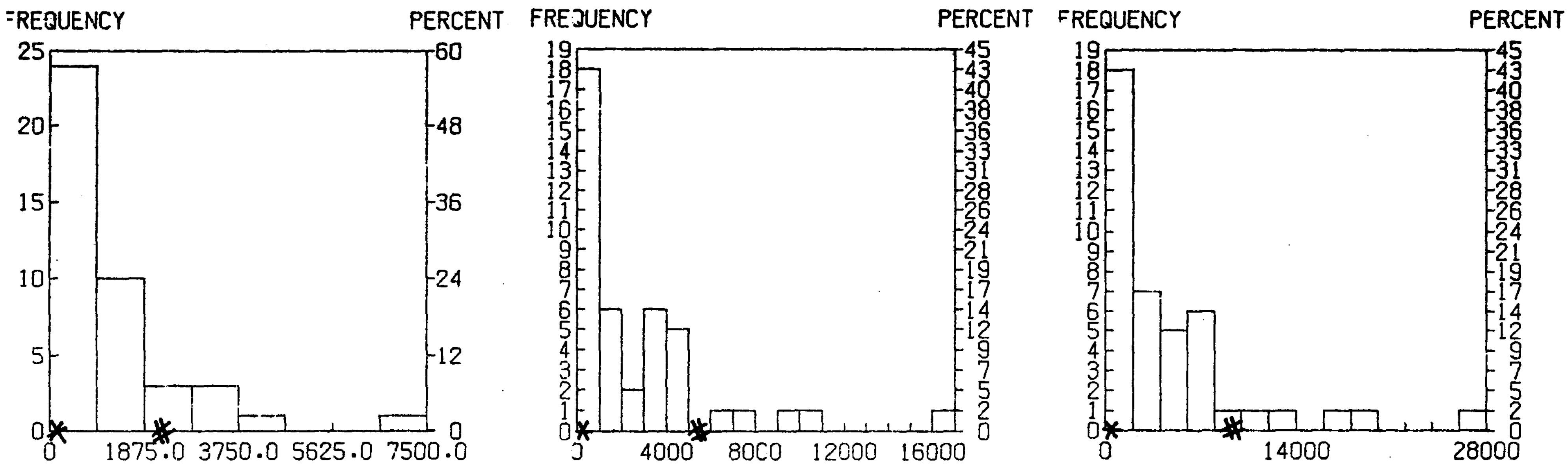
HIGH SHRUB

COMMUNITY TYPE 10 - FLAME LENGTH



HIGH SHRUB

COMMUNITY TYPE 10 - FIRE LINE INTENSITY



*NFFL Model 5

#NFFL Model 4

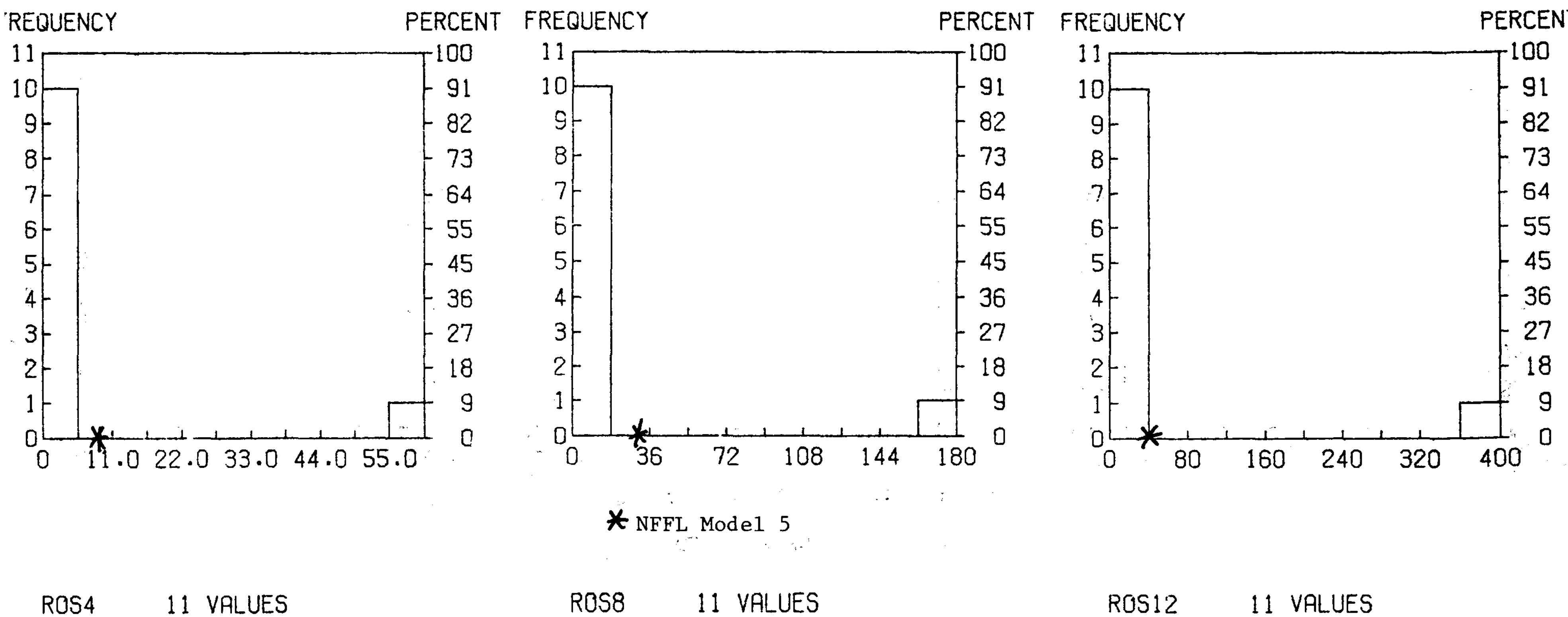
FLI4 42 VALUES

FLI8 42 VALUES

FLI12 42 VALUES

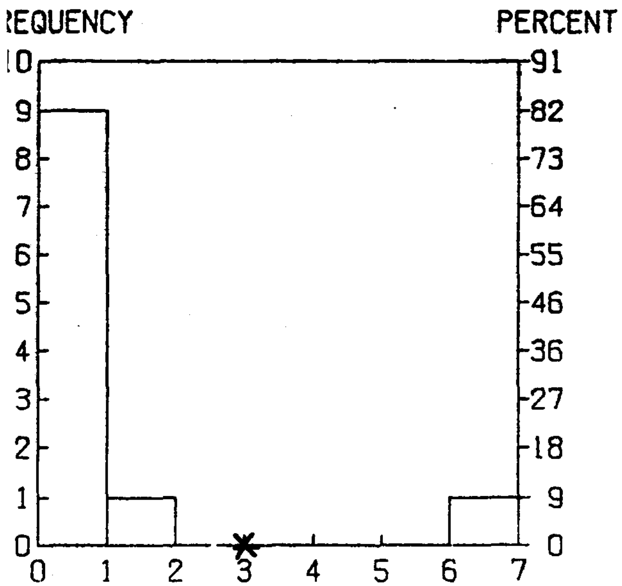
LOWLAND GRASS

COMMUNITY TYPE 11 - RATE OF SPREAD

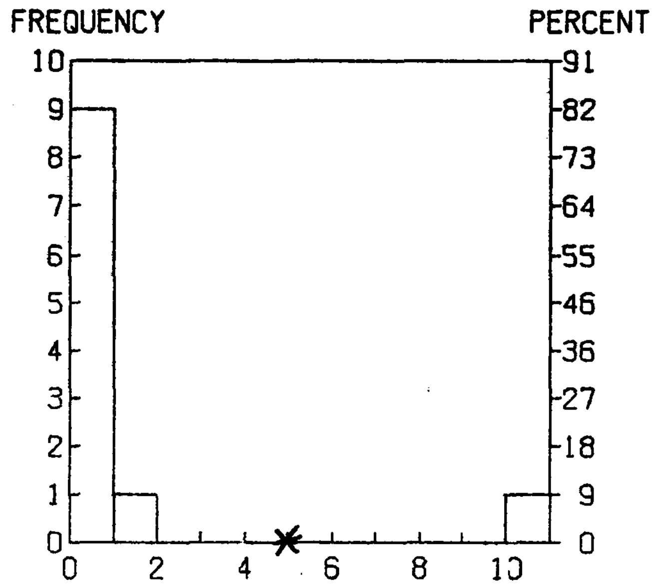


LOWLAND GRASS

COMMUNITY TYPE 11 - FLAME LENGTH

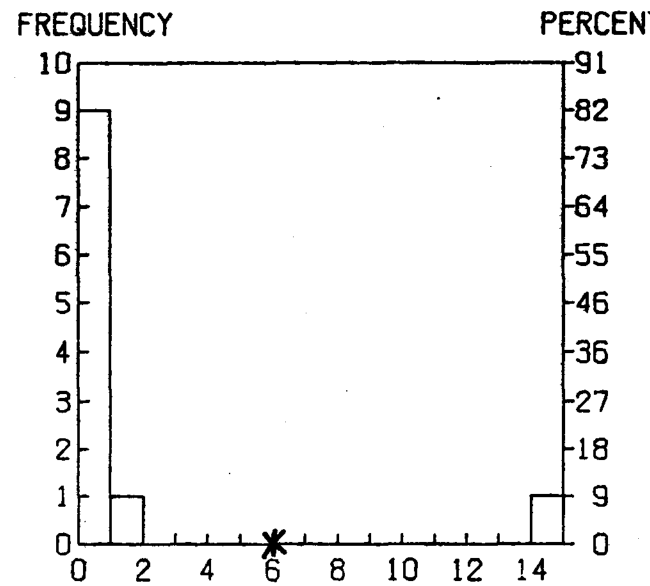


FLAM4 11 VALUES



✱ NFFL Model 5

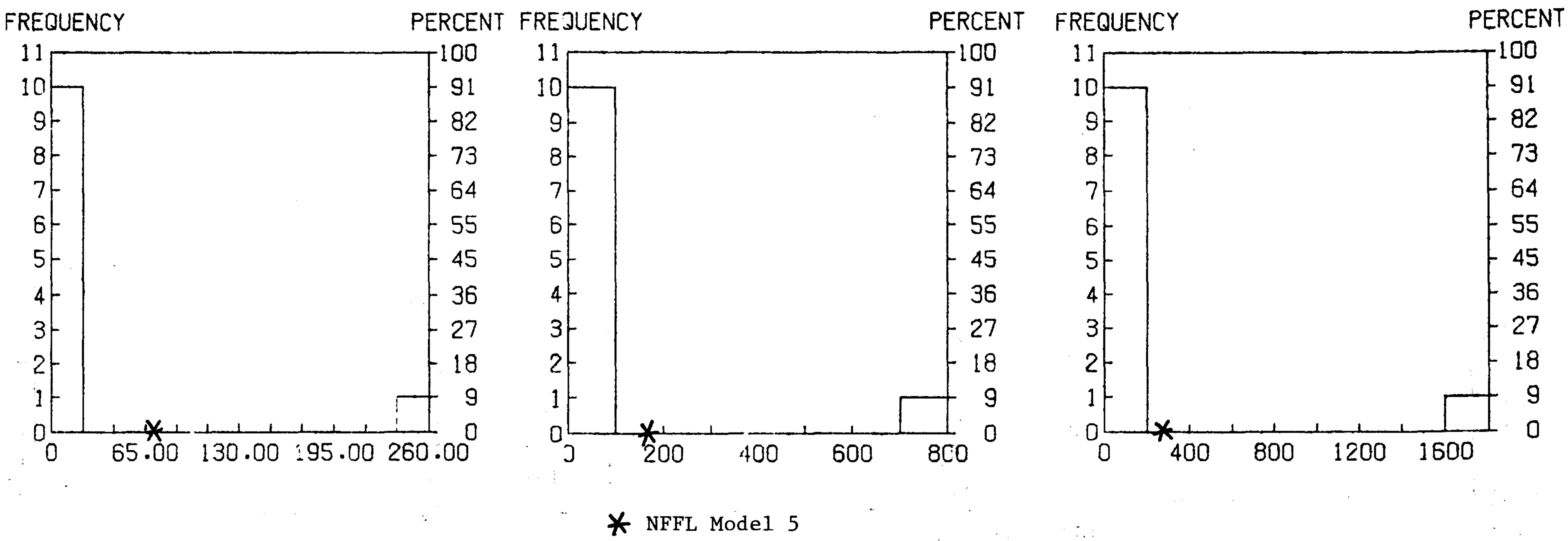
FLAM8 11 VALUES



FLAM12 11 VALUES

LOWLAND GRASS

COMMUNITY TYPE 11 - FIRE LINE INTENSITY



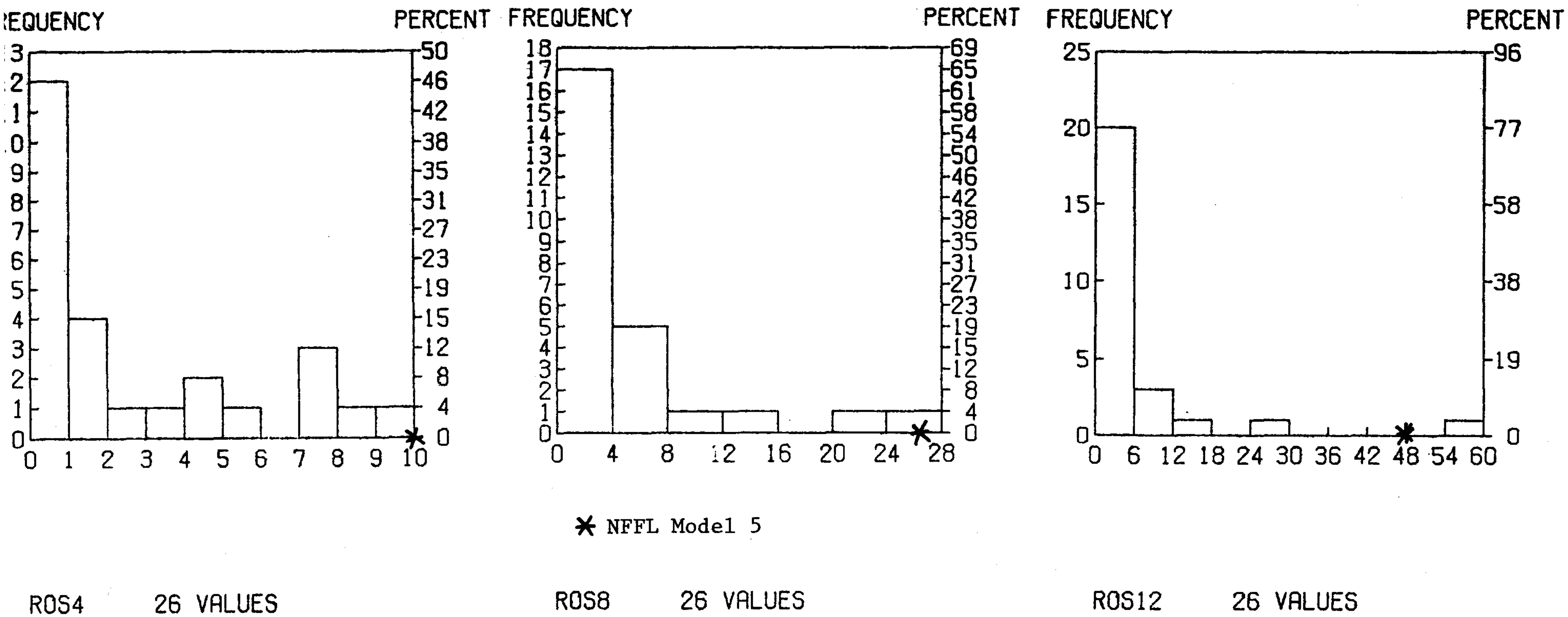
FLI4 11 VALUES

FLI8 11 VALUES

FLI12 11 VALUES

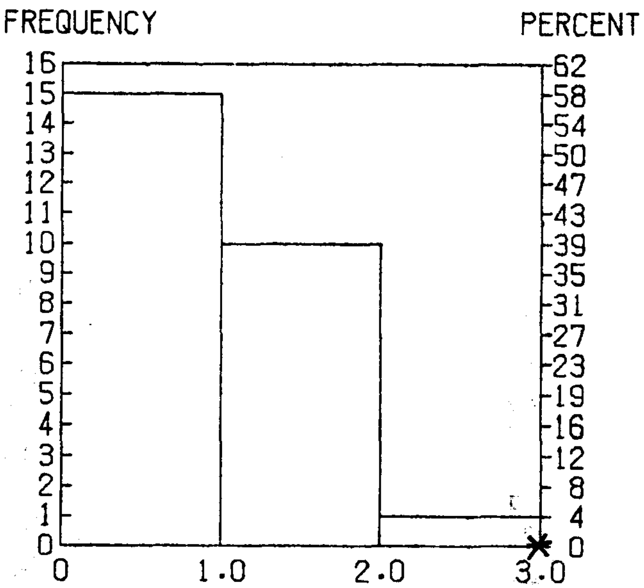
LUSH HERB -----SUBALPINE HERB

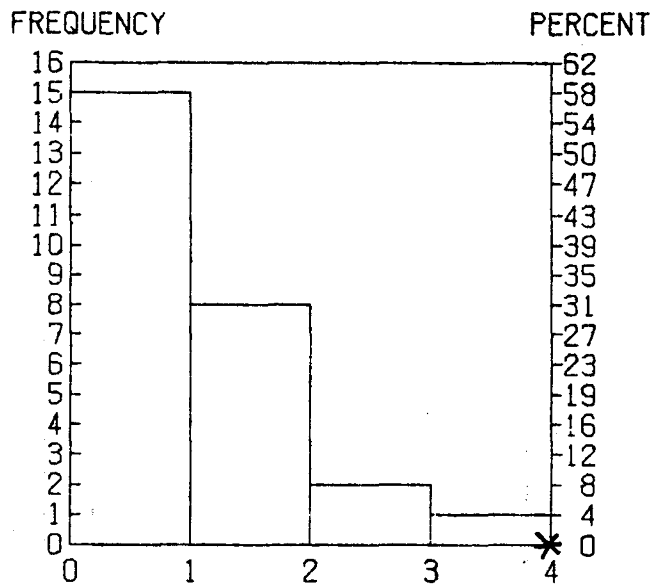
COMMUNITY TYPE 13 - RATE OF SPREAD

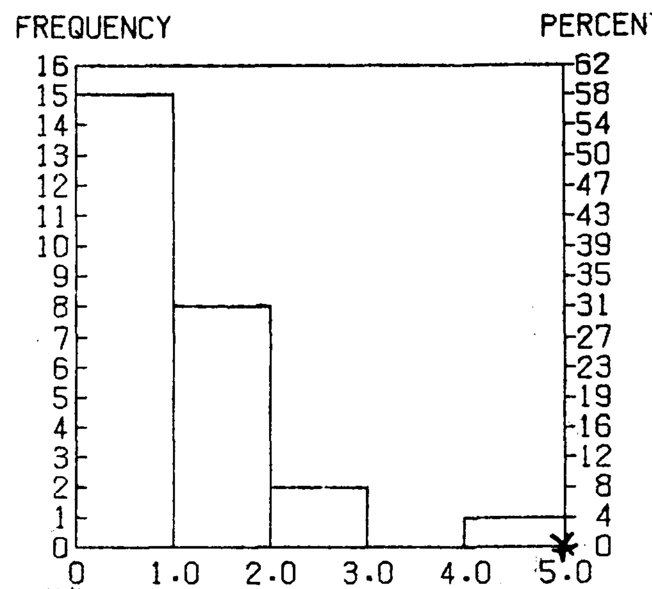


LUSH HERB --- SUBALPINE HERB

COMMUNITY TYPE 13 - FLAME LENGTH







*NFFL Model 5

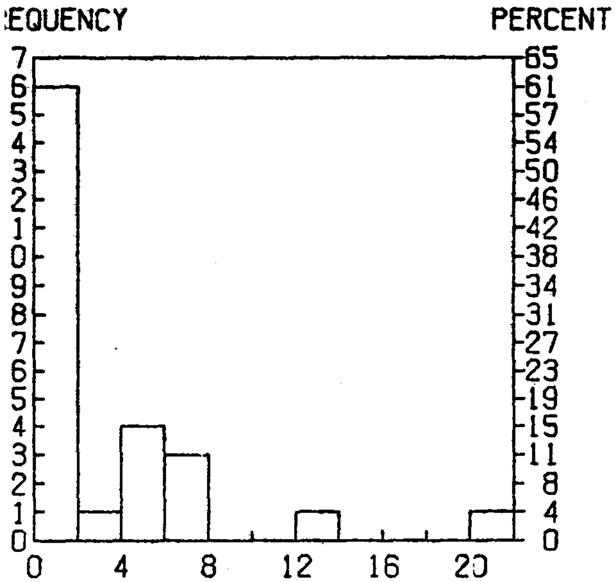
FLAM4 26 VALUES

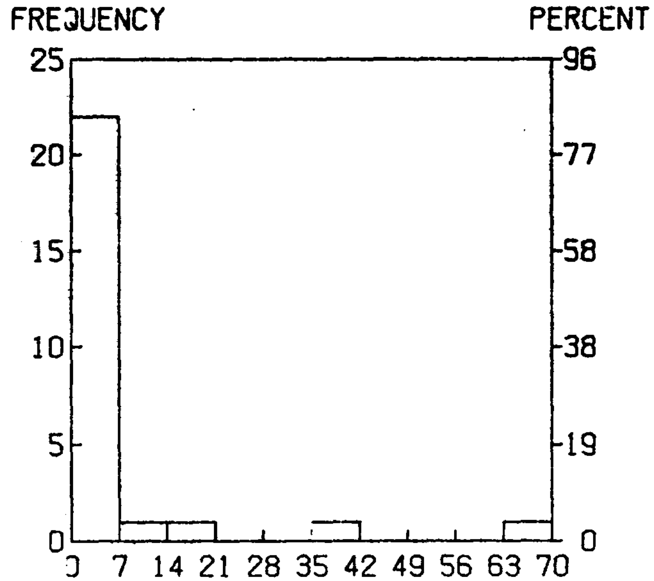
FLAM8 26 VALUES

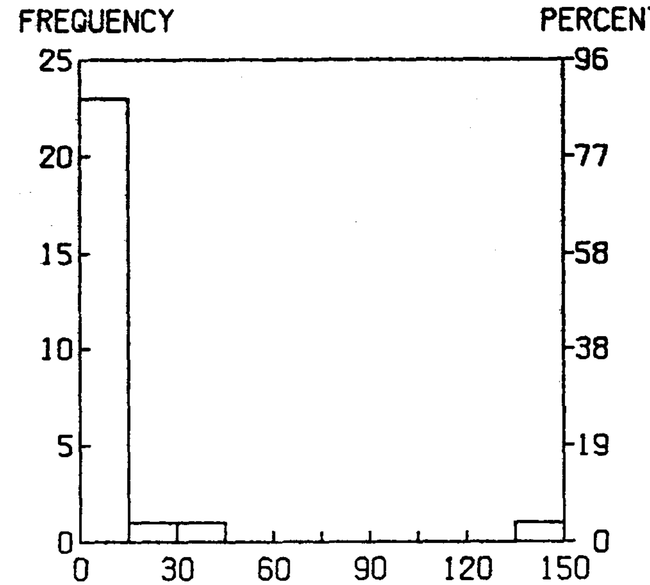
FLAM12 26 VALUES

LUSH HERB ----SUBALPINE HERB

COMMUNITY TYPE 13 - FIRE LINE INTENSITY







All Values less than half of NFFL Model 5

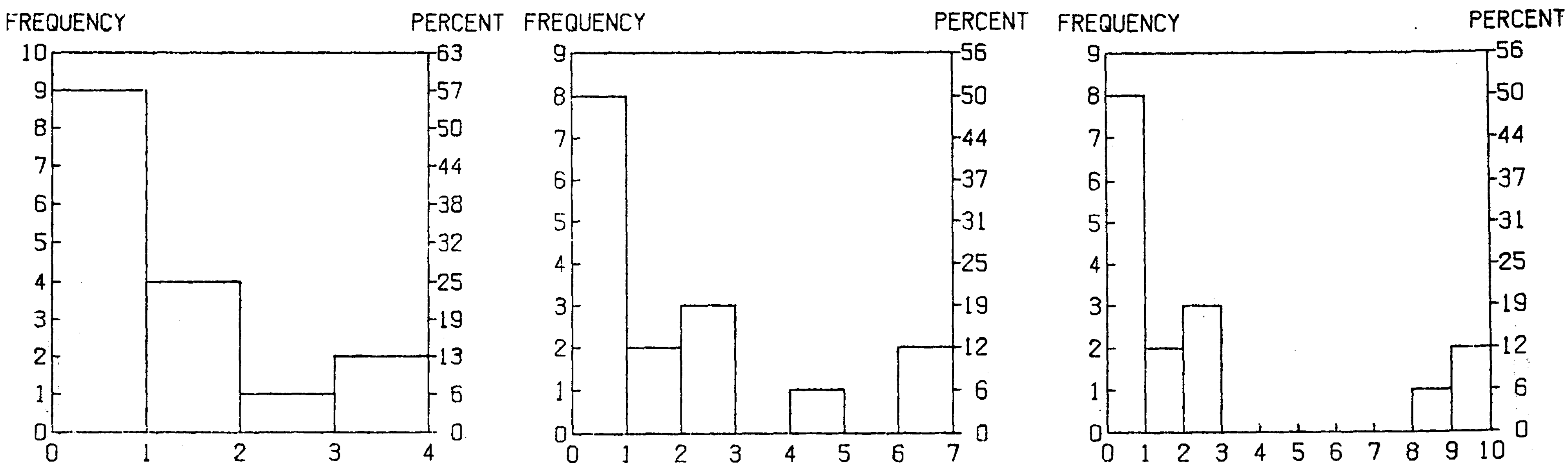
FLI4 26 VALUES

FLI8 26 VALUES

FLI12 26 VALUES

HEATHER MEADOW

COMMUNITY TYPE 14 - RATE OF SPREAD



All values less than half of NFFL Model 5

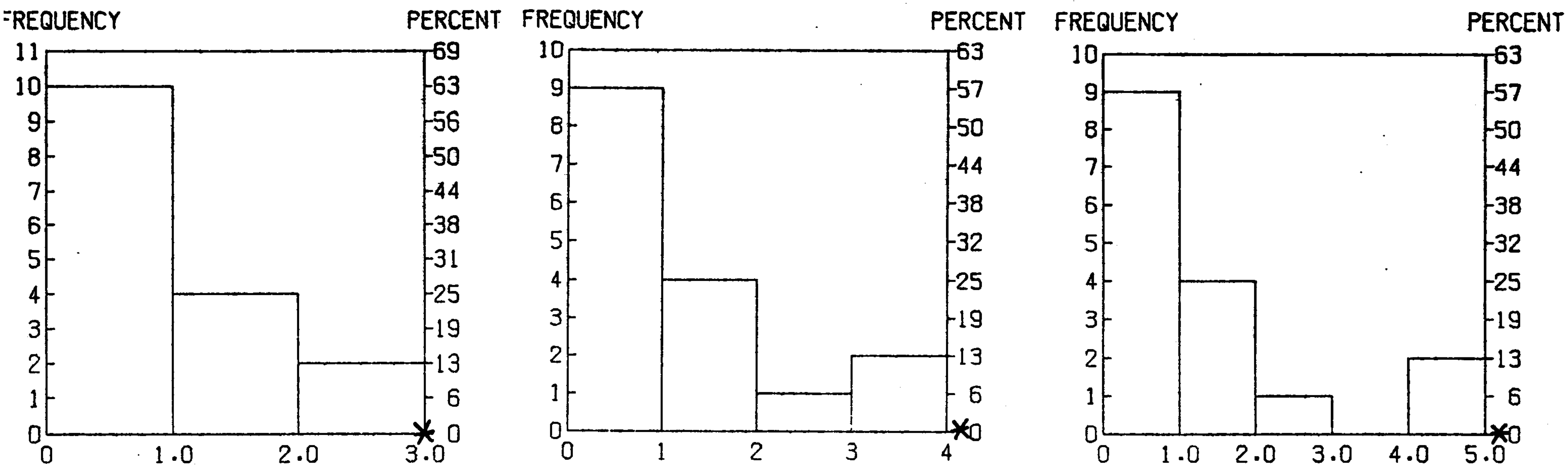
ROS4 16 VALUES

ROS8 16 VALUES

ROS12 16 VALUES

HEATHER MEADOW

COMMUNITY TYPE 14 - FLAME LENGTH



* NFFL Model 5

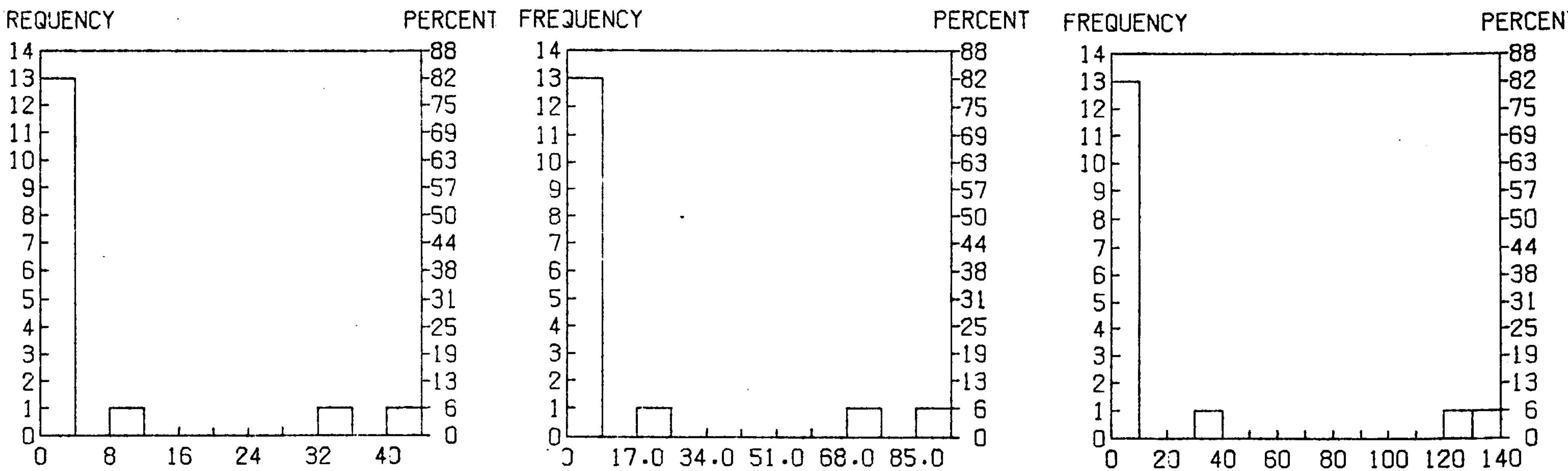
FLAM4 16 VALUES

FLAM8 16 VALUES

FLAM12 16 VALUES

HEATHER MEADOW

COMMUNITY TYPE 14 - FIRE LINE INTENSITY



All values less than half of NFFL Model 5

FLI4 16 VALUES

FLI8 16 VALUES

FLI12 16 VALUES

APPENDIX 3

LAYERS OF THE GEOGRAPHIC INFORMATION BASE

Landsat Cluster Layer

This layer contains the grouped Landsat clusters of generalized cover type information before the ecological models were applied to produce the vegetation map. The layer consists of grouped classes that for convenience were called: dark conifer (mostly mature forest), light conifer (open or yopung growth forest), dark deciduous and light deciduous (which later became the high shrub and hardwood forest types), herbaceous, rock/bare ground, snow/ice, water, and shadow.

Elevation Layer

This layer contains elevation information for each pixel, recorded in 100 ft elevation groups. 1= 0-100ft, etc., up to 108= 10,700-10,800 ft. Source was DMA (Defense Mapping Agency) tapes.

Slope Layer

This layer contains slope information for each pixel in 5 percent slope classes. 1= 0-5%, 2= 5-10%, etc., up to 13= 60-65%. Steeper slopes are in two groups: 14= 65-100%, and 15= >100% slopes. Source was DMA tapes.

Aspect Layer

This layer contains aspect classes in 45 degree azimuth groups. 0= flat, 1= North (+ or - 22.5 degrees from true north), 2= Northeast (22.6-67.5 degrees), etc. 3= E, 4= SE, 5= S, 6= SW, 7=W, 8=NW. Source was DMA tapes.

Precipitation Layer

The precipitation layer contains 10 precipitation zones. Each zone is a 20 inch band of total annual precipitation, but certain 20 inch bands were separated by geographical location to aid the vegetation modeling process. The 40-60 inch, 60-80 inch, and 80-100 inch zones were divided into "west" and "east" components. There is no 0-20 inch zone. The first zone is 20-40 inches. Next is 40-60 West, defined as west of UTM 655000E, and then 40-60 East, east of that UTM. This separates the Ross Lake area from Stehekin and points east. The next zone is 60-80 West, defined as the 60-80 inch zone west of Happy Creek on Ruby Mountain, and 60-80 East, east of Happy Creek. The next zones are 80-100 West, which includes all 80-100 inch zones west of a line along Panther Creek up to Fourth of July Pass, and 80-100 East, which includes all points east of this line. The othe precipitation zones are 100-120 inches, 120-140 inches, and >140 inches. Source of these zones was the State of Washington precipitation map, from which isohyeths were drawn, slightly adjusted for topographic effects at the 1:100,000 scale of the park special map, and in certain zones divided into east and west components as mentioned above.

Cover Type Layer

This layer consists of the final cover type classes described in the text: ponderosa pine (open), Douglas-fir (closed and open), subalpine fir (closed and open), whitebark pine/subalpine larch (closed and open), mountain hemlock (closed and open), Pacific silver fir (closed and open), western hemlock (closed and open), hardwood forest, high shrub, lowland grass, lush herbaceous (subalpine herb), heather meadow, rock/bare ground, snow/ice, water, and shadow.

National Fire-Danger Rating System Layer

This layer consists of the NFDRS models identified in the text: C, H, L, O, R, H/G, H/F, H/Q, F/Q, S/L, other (water, rock, etc.).

Northern Forest Fire Laboratory Fuel Model Layer

This layer consists of the NFFL fuel models identified in the text: 1, 8, 9, 1/5, 4/5, 8/1, 8/5, other (water, rock, etc.).

APPENDIX 4

INTERPRETATION OF THE VEGETATION MAP

The map classes are explained in detail in the text of the report. The map, however, is printed without a topographic overlay, so that exact locations are sometimes difficult to determine. The color scheme has been designed so that valley bottoms generally are darker colors and ridges are lighter colors, particularly if they are rocky or snow-covered.

The map has been printed at the scale of the park special map, 1:100,000. Several options are available to more precisely locate oneself on the map. The first option is simply to compare the area visually between maps. A second option is to produce a mylar (clear plastic) of the park special map and overlay it on the cover type map. If this is done, a precise fit may be difficult, because both the mylar and the paper of the cover type map shrink and swell due to humidity. This option is the best available, however. The third option is to create small mylars or thermofax-type transparencies to overlay; this is a small scale variant of the second option and much cheaper.

Mylar copies of the park special map are available at cost from the U.S. Geological Survey (Attn. GDM), 345 Middleton Road, Menlo Park, CA 94025. Ask for the North Cascades NP map, 42X48", 1 composite clear positive mylar, .007 in thick film (sturdier than .004), L.R. (which places the printing on the back side of the mylar so you can scribble and erase the face without erasing the emulsion), using all plates except open water, woodland. Use culture/projection, black lettering, blue line drainage, blue lettering, red roads/lettering, landlines (50% bia), BLM lettering (50% bia), contours/nos., sand (USGS 17). The detailed instructions are necessary because each map has to be individually made; they are not stock items. Furthermore, the water pattern and especially the woodland pattern (green on the regular park special map) are to be avoided on the mylar. The park will have flat (rather than folded) copies of the cover type map in limited quantities if the mylar option is adopted by users of the map.

Cost of the mylar changes over time. They are quite expensive however; be prepared to spend >$150 per copy.

APPENDIX 5

TENTATIVE LIST OF FORESTED PLANT ASSOCIATIONS IN THE NORTH CASCADES NATIONAL PARK SERVICE COMPLEX

Pinus ponderosa-Pseudotsuga menziesii/Agropyron spicatum
Pseudotsuga menziesii/Symphoricarpos albus
Pseudotsuga menziesii/Holodiscus discolor
Pseudotsuga menziesii/Calamagrostis rubescens
Pseudotsuga menziesii/Arcostaphylos uva-ursi
Pseudotsuga menziesii/Pachistima myrsinites
Pseudotsuga menziesii/Vaccinium spp.
Pseudotsuga menziesii/Berberis nervosa-Gaultheria shallon
Abies grandis/Pachistima myrsinites
Abies lasiocarpa/Pachistima myrsinites
Abies lasiocarpa/Vaccinium spp.
Abies lasiocarpa/Phyllodoce empetriformis
Abies lasiocarpa-Larix lyallii/Phyllodoce empetriformis-Vaccinium deliciosum
Abies lasiocarpa-Pinus albicaulis/Vaccinium spp.
Tsuga mertensiana/Vaccinium membranaceum
Tsuga mertensiana/Rhododendron albiflorum
Tsuga mertensiana/Vaccinium alaskense
Tsuga mertensiana/Menziesia ferruginea
Tsuga mertensiana/Phyllodoce empetriformis-Vaccinium deliciosum
Abies amabilis/Oplopanax horridum
Abies amabilis/Vaccinium membranaceum
Abies amabilis/Vaccinium membranaceum-Pachistima myrsinites
Abies amabilis/Vaccinium alaskense
Abies amabilis/Rhododendron albiflorum
Abies amabilis/Menziesia ferruginea
Abies amabilis/Rubus lasiococcus
Tsuga heterophylla/Gaultheria shallon
Tsuga heterophylla/Berberis nervosa
Tsuga heterophylla/Pachistima myrsinites
Tsuga heterophylla-Thuja plicata/Pachistima myrsinites-Berberis nervosa
Tsuga heterophylla/Vaccinium spp.
Tsuga heterophylla/Acer circinatum
Tsuga heterophylla/Polystichum munitum
Tsuga heterophylla/Oplopanax horridum

APPENDIX 6

PLANT SPECIES LIST

NORTH CASCADES MAPPING: SPECIES LIST

01-01-1980 AT 06:32

sp#	symbol	plantnam
4	ABAM	ABIES AMABILIS, Pacific silver fir
12	ABGR	ABIES GRANDIS, grand fir
7	ABLA	ABIES LASIOCARPA, subalpine fir
38	ACCI	ACER CIRCINATUM, vine maple
43	ACGL	ACER GLABRUM, Douglas maple
15	ACMA	ACER MACROPHYLLUM, bigleaf maple
29	ACMI	ACHILLEA MILLEFOLIUM, yarrow
202	ACCO	ACONITUM COLUMBIANUM, Columbian monkshood
57	ACRU	ACTAEA RUBRA, baneberry
164	ADBI	ADENOCAULON BICOLOR, trail plant
151	AGSP	AGROPYRON SPICATUM, bluebunch wheatgrass
32	AIXX	AGROSTIS SP., bentgrass
106	AGXX	AGROPYRON SP., wheatgrass
163	ALXX	ALLIUM SP., wild onion
37	ALRU	ALNUS RUBRA, red alder
62	ALSI	ALNUS SINUATA, slide alder
42	AMAL	AMELANCHIER ALNIFOLIA, serviceberry
30	ANMA	ANAPHALIS MARGARITACEA, pearly everlasting
150	ANXX	ANEMONE SP., anemone
201	AFXX	ANGELICA SP., angelica
152	ATXX	ANTENNARIA, pussy-toes
224	AQFO	AQUILEGIA FORMOSA, columbine
179	AQXX	AQUILEGIA SP., columbine
28	ARUV	ARCTOSTAPHYLOS UVA-URSI, kinnickinnick
115	ARXX	ARENARIA SP., sandwort
116	ARCO	ARNICA CORDIFOLIA, heartleaf arnica
195	ARDI	ARNICA DIVERSIFOLIA, sticky arnica
93	ACXX	ARNICA SP., arnica
162	AMXX	ARTEMISIA SP., sage
197	ARSY	ARUNCUS SYLVESTER, goatsbeard
182	ASCA	ASARUM CAUDATUM, wild ginger
147	ASDE	ASPIDOTIS DENSA, podfern
87	ASXX	ASTER SP., aster
76	ATFI	ATHYRIUM FILIX-FEMINA, lady fern
105	BASA	BALSAMORHIZA SAGITTATA, balsamroot
171	BEAQ	BERBERIS AQUIFOLIUM, tall Oregon grape
18	BENE	BERBERIS NERVOSA, Oregon grape
247	BEOC	BETULA OCCIDENTALIS, water birch
175	BEPA	BETULA PAPYRIFERA, paper birch
82	BLSP	BLECHNUM SPICANT, deer fern
153	BRTE	BROMUS TECTORUM, cheatgrass
107	CARU	CALAMAGROSTIS RUBESCENS, pinegrass
219	CMXX	CALAMAGROSTIS SP., reedgrass
129	CLXX	CALOCHORTUS SP., mariposa lily
216	CTXX	CALTHA SP., marshmarigold
122	CAXX	CAREX SP., sedge
138	CAME	CASSIOPE MERTENSIANA, white heather
227	CAPA	CASTILLEJA PARVIFLORA, small-flowered paintbrush
118	CSXX	CASTILLEJA SP. , paintbrush
102	CEVE	CEANOTHUS VELUTINUS, snowbrush
6	CHNO	CHAMAECYPARIS NOOTKATENSIS, Alaska yellow-cedar
36	CHUM	CHIMAPHILA UMBELLATA, prince's pine
34	CHXX	CHRYSANTHEMUM SP., chrysanthemum

NORTH CASCADES MAPPING: SPECIES LIST
01-01-1980 AT 06:32

sp#	symbol	plantnam
217	CIXX	CIRSIUM SP., thistle
97	CLLA	CLAYTONIA LANCEOLATA, springbeauty
49	CLUN	CLINTONIA UNIFLORA, bead-lily
91	COXX	CORALLORHIZA SP., coral-root
61	COCA	CORNUS CANADENSIS, bunchberry
155	CONU	CORNUS NUTTALLII, dogwood
55	COST	CORNUS STOLONIFERA, dogwood
144	COCO	CORYLUS CORNUTA, hazelnut
109	CRCR	CRYPTOGRAMMA CRISPA, rockbrake
131	CRST	CRYPTOGRAMMA STELLERI, Steller's rockbrake
146	CYFR	CYSTOPTERIS FRAGILIS, bladder-fern
89	DAGL	DACTYLIS GLOMERATA, orchardgrass
112	DEXX	DELPHINIUM SP. , larkspur
167	DIFO	DICENTRA FORMOSA, bleeding heart
137	DIHO	DISPORUM HOOKERI, fairy-bells
200	DIXX	DISPORUM SP., fairybells
242	ELXX	ELYMUS SP., ryegrass
123	EPAN	EPILOBIUM ANGUSTIFOLIUM, fireweed
100	EPXX	EPILOBIUM SP., willow-herb
158	EQXX	EQUISETUM SP., horsetail
154	ERFI	ERIGERON FILIFOLIUS, threadleaf fleabane
235	ERPE	ERIGERON PEREGRINUS, subalpine daisy
191	EGXX	ERIGERON SP., daisy
177	ERLA	ERIOPHYLLUM LANATUM, woolly sunflower
99	ERXX	ERIOGONUM SP., buckwheat
134	ERGR	ERYTHRONIUM GRANDIFLORUM, glacier lily
90	FEID	FESTUCA IDAHOENSIS, Idaho fescue
226	FEVI	FESTUCA VIRIDULA, green fescue
31	FEXX	FESTUCA SP., fescue
27	FRXX	FRAGARIA SP., strawberry
85	GAAP	GALIUM APARINE, bedstraw
183	GAXX	GALIUM SP., bedstraw
212	GAHU	GAULTHERIA HUMIFUSA, alpine wintergreen
66	GAOV	GAULTHERIA OVATIFOLIA, Oregon wintergreen
19	GASH	GAULTHERIA SHALLON, salal
206	GEXX	GENTIANA SP., gentian
53	GOOB	GOODYERA OBLONGIFOLIA, rattlesnake-plantain
77	GYDR	GYMNOCARPIUM DRYOPTERIS, oak fern
64	HELA	HERACLEUM LANATUM, cow-parsnip
40	HEMI	HEUCHERA MICRANTHA, alumroot
210	HEXX	HEUCHERA SP., alumroot
68	HIAL	HIERACIUM ALBIFLORUM, hawkweed
108	HICY	HIERACIUM CYNOGLOSSOIDES , houndstongue hawkweed
160	HISC	HIERACIUM SCOULERI, woolly-weed
113	HIXX	HIERACIUM SP., hawkweed
39	HODI	HOLODISCUS DISCOLOR, ocean spray
143	HYCA	HYDROPHYLLUM CAPITATUM, ballhead waterleaf
65	HYXX	HYDROPHYLLUM SP., waterleaf
238	IRXX	IRIS SP., iris
228	JUXX	JUNCUS SP., rush
140	JUCO	JUNIPERUS COMMUNIS, mountain juniper
14	LALY	LARIX LYALLII, subalpine larch
[illegible]	LAXX	LATHYRUS SP., peavine

NORTH CASCADES MAPPING: SPECIES LIST
01-01-1980 AT 06:32

sp#	symbol	plantnam
214	LEGL	LEDUM GLANDULOSUM, mountain Labrador-tea
243	LEXX	LEDUM SP., Labrador-tea
161	LECO	LEWISIA COLUMBIANA, Columbia lewisii
73	XLIC	LICHEN, lichen
204	LIXX	LIGUSTICUM SP., licorice-root
124	LICO	LILIUM COLUMBIANUM, tiger lily
25	LIBO	LINNAEA BOREALIS, twinflower
199	LICA	LISTERA CAURINA, twayblade
128	LONU	LOMATIUM NUDICAULE, barestem lomatium
98	LOXX	LOMATIUM SP., desert-parsley
186	LOCI	LONICERA CILIOSA, orange honeysuckle
168	LOIN	LONICERA INVOLUCRATA, bearberry honeysuckle
84	LNXX	LONICERA SP., honeysuckle
189	LUPE	LUETKEA PECTINATA, partridgefoot
141	LULA	LUPINUS LATIFOLIUS, broadleaf lupine
145	LULE	LUPINUS LEPIDUS, Lyall lupine
67	LPXX	LUPINUS SP., lupine
135	LUXX	LUZULA SP., woodrush
69	LYXX	LYCOPODIUM SP., clubmoss
176	LYAM	LYSICHITUM AMERICANUM, skunk cabbage
173	MEXX	MELICA SP., oniongrass
60	MEFE	MENZIESIA FERRUGINEA, fool's huckleberry, rusty-leaf
215	MIXX	MIMULUS SP., monkeyflower
196	MIBR	MITELLA BREWERI, Brewer's mitrewort
41	MOPA	MONTIA PARVIFOLIA, miner's lettuce
58	MOXX	MONTIA SP., miner's lettuce
24	MOSS	MOSS , moss
70	OPHO	OPLOPANAX HORRIDUM, devils club
44	OSCH	OSMORHIZA CHILENSIS, sweet-cicely
52	PAMY	PACHISTIMA MYRSINITES, Oregon boxwood
239	PAFI	PARNASSIA FIMBRIATA, fringed grass-of-Parnassus
244	PSXX	PARNASSIA SP., grass-of-Parnassus
221	PERA	PEDICULARIS RACEMOSA, leafy lousewort
142	PDXX	PEDICULARIS SP., lousewort
213	PEDA	PENSTEMON DAVIDSONII, Davidson's penstemon
111	PNXX	PENSTEMON SP., penstemon
139	PEFR	PETASITES FRIGIDUS, coltsfoot
110	PEXX	PETASITES SP., coltsfoot
222	PHAL	PHLEUM ALPINUM, alpine timothy
190	PHDI	PHLOX DIFFUSA, spreading phlox
95	PHXX	PHLOX SP., phlox
78	PHEM	PHYLLODOCE EMPETRIFORMIS , red heather
194	PHGL	PHYLLODOCE GLANDULIFLORA, yellow heather
174	PHMA	PHYSOCARPUS MALVACEAE, ninebark
8	PIEN	PICEA ENGELMANNII, Engelmann spruce
13	PIAL	PINUS ALBICAULIS, whitebark pine
9	PICO	PINUS CONTORTA, lodgepole pine
10	PIMO	PINUS MONTICOLA, western white pine
11	PIPO	PINUS PONDEROSA, ponderosa pine
96	PAXX	POA SP., bluegrass
127	POPU	POLEMONIUM PULCHERRIMUM, skunk-leaved polemonium
211	PLXX	POLEMONIUM SP., polemonium
218	POBI	POLYGONUM BISTORTOIDES, American bistort

NORTH CASCADES MAPPING: SPECIES LIST

01-01-1980 AT 06:32

sp#	symbol	plantnam
21	POMU	POLYSTICHUM MUNITUM, sword fern
16	POTR	POPULUS TRICHOCARPA, black cottonwood
225	PPXX	POPULUS SP., poplar
132	POXX	POTENTILLA SP. , cinquefoil
136	PREM	PRUNUS EMARGINATA, bitter cherry
176	PRVI	PRUNUS VIRGINIANA, chokecherry
103	PRXX	PRUNUS SP., cherry
1	PSME	PSEUDOTSUGA MENZIESII, Douglas-fir
50	PTAQ	PTERIDIUM AQUILINUM, bracken fern
240	PYDE	PYROLA DENTATA, toothleaf pyrola
178	PYSE	PYROLA SECUNDA, one-sided wintergreen
92	PYUN	PYROLA UNIFLORA, woodnymph
46	PYXX	PYROLA SP., shinleaf; wintergreen
133	RAXX	RANUNCULUS SP. , buttercup
74	RHAL	RHODODENDRON ALBIFLORUM, Cascade azalea
169	RIXX	RIBES SP., gooseberry
23	ROXX	ROSA SP., rose
119	RULA	RUBUS LASIOCOCCUS, dwarf bramble
83	RUNI	RUBUS NIVALIS, snow bramble
54	RUPA	RUBUS PARVIFLORUS, thimbleberry
80	RUPE	RUBUS PEDATUS, strawberry bramble
166	RUSP	RUBUS SPECTABILIS, salmonberry
156	RUUR	RUBUS URSINUS, Pacific blackberry
94	RUXX	RUBUS SP., blackberry
17	SASC	SALIX SCOULERIANA, Scouler's willow
51	SAXX	SALIX SP., willow
220	SACE	SAMBUCUS CERULEA, blue elderberry
236	SARA	SAMBUCUS RACEMOSA, black elderberry
56	SMXX	SAMBUCUS SP., elderberry
192	SAOC	SAXIFRAGA OCCIDENTALIS, western saxifrage
232	SXXX	SAXIFRAGA SP., saxifrage
130	SELA	SEDUM LANCEOLATUM, lance-leaved stonecrop
114	SDXX	SEDUM SP., stonecrop
33	SEXX	SENECIO SP., senecio
170	SHXX	SHEPHERDIA SP., buffalo-berry
208	SIPR	SIBBALDIA PROCUMBENS, creeping sibbaldia
47	SMRA	SMILACINA RACEMOSA, false Solomon's seal
86	SLXX	SMILACINA SP., false Solomon's seal
241	SOCA	SOLIDAGO CANADENSIS, meadow goldenrod
229	SOSC	SORBUS SCOPULINA, Cascade mountain-ash
75	SOSI	SORBUS SITCHENSIS, mountain-ash
248	SRXX	SORBUS SP., mountain-ash
104	SPBE	SPIRAEA BETULIFOLIA, birchleaf spiraea
234	SPDE	SPIRAEA DENSIFLORA, subalpine spiraea
184	SPDO	SPIRAEA DOUGLASII, Douglas' spiraea
20	SPXX	SPIRAEA SP., spiraea
159	STXX	STREPTOPUS SP., twisted-stalk
101	SYAL	SYMPHORICARPOS ALBUS, snowberry
157	SYXX	SYMPHORICARPOS SP., snowberry
45	TABR	TAXUS BREVIFOLIA, western yew
63	THOC	THALICTRUM OCCIDENTALE, meadowrue
125	THXX	THALICTRUM SP. , meadowrue
3	THPL	THUJA PLICATA, Western redcedar

NORTH CASCADES MAPPING: SPECIES LIST

01-01-1980 AT 06:32

sp#	symbol	plantnam
71	TITR	TIARELLA TRIFOLIATA, foamflower
249	TOME	TOLMEI MENZIESII, youth-on-age
26	TRLA	TRIENTALIS LATIFOLIA, starflower
88	TRRE	TRIFOLIUM REPENS, Dutch clover
198	TRXX	TRIFOLIUM SP., clover
230	TROV	TRILLIUM OVATUM, trillium
246	TLXX	TRILLIUM SP., trillium
2	TSHE	TSUGA HETEROPHYLLA, Western hemlock
5	TSME	TSUGA MERTENSIANA, mountain hemlock
237	URXX	URTICA SP., nettle
59	VAAL	VACCINIUM ALASKENSE, Alaska huckleberry
187	VACA	VACCINIUM CAESPITOSUM, dwarf huckleberry
79	VADE	VACCINIUM DELICIOSUM, blue-leaf huckleberry
35	VAME	VACCINIUM MEMBRANACEUM, big huckleberry
203	VAMY	VACCINIUM MYRTILLUS, dwarf bilberry
48	VAPA	VACCINIUM PARVIFOLIUM, red huckleberry
22	VAXX	VACCINIUM SP., huckleberry
207	VASC	VALERIANA SCOULERI, Scouler's valerian
149	VASI	VALERIANA SITCHENSIS, Sitka valerian
165	VLXX	VALERIANA SP., valeriana
148	VECA	VERATRUM CALIFORNICUM, California false-hellebore
233	VEVI	VERATRUM VIRIDE, false-hellebore
205	VEXX	VERATRUM SP., false-hellebore
223	VECU	VERONICA CUSICKII, Cusick's speedwell
209	VRXX	VERONICA SP., speedwell
185	VIED	VIBURNUM EDULE, highbush cranberry
245	VBXX	VIBURNUM SP., viburnum
121	VIGL	VIOLA GLABELLA , stream violet
72	VIXX	VIOLA SP., violet

	TOTAL
sp#	29,843.00

Printed 241 of the 241 records.