Forest types of the North Cascades National Park Service Complex

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A forest cover type classification was developed for the North Cascades National Park Service Complex in north central Washington, U.S.A., based on 425 reconnaissance-level plots. Detrended correspondence analysis (DECORANA) was used to ordinate the data. Temperature and available moisture were identified as primary environmental gradients. Two-way indicator species analysis (TWINSPAN) was used to classify the data, resulting in eight forest cover types: ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), subalpine fir (*Abies lasiocarpa*), whitebark pine – subalpine larch (*Pinus albicaulis – Larix lyallii*), mountain hemlock (*Tsuga mertensiana*), Pacific silver fir (*Abies amabilis*), western hemlock (*Tsuga heterophylla*), and hardwood forest. The coniferous forest cover types, with the exception of ponderosa pine, were defined to have open and closed canopy components; each cover type includes a variety of plant associations. The cover types were integrated into a geographic information system used to create a cover type map that was 85% accurate. The forest cover types of the park complex are unique not so much for within-community diversity as for the close juxtaposition of cover types with interior and coastal climatic influences.

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Une classification basée sur 425 parcelles de niveau «reconnaissance» du type de couvert forestier a été élaborée pour le North Cascades National Park Service Complex au centre nord de Washington, É.-U. La technique DECORANA d'analyses des correspondances a été utilisée dans l'ordination des données. La température et l'humidité disponible ont été identifiées comme étant les gradients écologiques primaires. L'analyse à double sens d'espèces indicatrices (TWINSPAN) a été utilisée pour classifier les données et a permis de reconnaître huit types de couverts forestiers : le pin ponderosa (*Pinus ponderosa*), le sapin de Douglas (*Pseudotsuga menziesii*), le sapin de l'ouest (*Abies lasiocarpa*), le pin albicaule – mélèze de Lyall (*Pinus albicaulis – Larix lyallii*), la pruche de Mertens (*Tsuga mertensiana*), le sapin gracieux (*Abies amabilis*), la pruche de l'ouest (*Tsuga heterophylla*) et des forêts de bois dur. Les types de couvert des forêts de conifères, à l'exception du pin ponderosa, ont été définis de façon à comprendre des composantes de voûtes ouvertes et fermées. Chaque type de couvert comprend une gamme d'association végétales. Les types de couvert ont été intégré à un système de données géographiques utilisé pour élaborer une carte de types de couvert qui était précise à 85%. Les types de couverts forestiers du complexe du parc sont uniques pas tellement à cause de la diversité à l'intérieur de la communauté que pour l'étroite juxtaposition des types de couverts subissant les influences climatiques tant internes que côtières.

[Traduit par la revue]

Introduction

The North Cascades National Park Service Complex (Fig. 1) is a 300 000 ha area in north central Washington encompassing North Cascades National Park, Ross Lake National Recreation Area, and Lake Chelan National Recreation Area (collectively called the "park complex"). It includes lowland forests on the moist west side of the Cascades, a range of higher elevation forests that span the crest of the range, and lowland forests on the drier east side. 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 well over 350 cm. Mesophytic species occupy smaller fractions of available habitat and species richness generally increases from west to east, as summers become warmer and winters colder (del Moral and Watson 1978). Within the park complex, the Cascade Range is so wide that some areas west of the crest experience a rain-shadow effect. Numerous species and communities more characteristic of interior (east of the Cascade crest) than coastal forest areas are found in the rain-shadow area (Franklin and Dyrness 1973). Forest disturbance by fire (Douglas and Ballard 1971; Larson 1972), avalanche (Smith 1974), glacial retreat (Oliver *et al.* 1985), and limited logging (before park establishment) is common across the landscape.

The only prior vegetation map was a 1936 commercial forest map completed while the area was managed by the Forest Service. Many forest ecology studies have been completed in the area but none have attempted to describe forest types over the entire park complex. Alpine and subalpine nonforest vegetation have been described in greater detail (Douglas and Bliss 1977).

The objective of this study was to describe and map the major forest cover types of the park complex. This paper describes the forest types of the park complex and the relationships between types based on ordination and classification analysis.

Methods

A total of 425 sample plots was established over the 300 000 ha park complex. Plots were sampled at a reconnaissance level over a wide variety of vegetation and terrain types. Elevation, aspect, and slope were measured by altimeter, compass, and clinometer, respectively. Annual precipitation class (in 50-cm intervals) was later recorded from a statewide precipitation map.

A dimensioned plot of varying size was used to determine tree density of each species by height class (0–3, 3–10, and >10 m). The plot size was small in extremely dense stands (perhaps 25 m^2) and large in more widely spaced stands (100–400 m^2). The height of the dominant layer of each species was recorded, along with its cover class. The overall cover of vegetation was recorded in one of six classes: 1 (0–5%), 2 (6–25%), 3 (26–50%), 4 (51–75%), 5(76–95%), 6 (96–100%). Specific measurements of trees were collected using dimensioned and nondimensioned plots. Nondimen-

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sioned plots were used to record tree basal area by species (with a prism) and cover class of dominant shrubs and herbs. Botanical nomenclature follows Hitchcock and Cronquist (1973).

Detrended correspondence analysis (DCA) was chosen as the ordination technique for the North Cascades data. A FORTRAN program, DECORANA (Hill 1979*a*), was used to analyze the data. An importance value was derived 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 and cover class (on the same scale). Rare species were down weighted by the program using a predefined option. Both species and sample ordinations are computed by DECORANA, with the sample scores being weighted means of the species scores within each sample. DCA is generally robust for many data sets but is weak for data sets with high levels of species turnover and low alpha diversity (Kenkel and Orlóci 1986).

A polythetic divisive method was used to classify the data. TWINSPAN (Hill (1979*b*), a FORTRAN program for two-way species indicator analysis and conceptually related to DCA, was applied using default parameters. This limited the number of levels defined. The default option for "pseudospecies" allows for the division of species with high abundance values into two or more "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. This data set allowed a maximum of three "pseudospecies" to be created. The cut levels for importance values were 0, 2, and 5.

The TWINSPAN output was used to cluster groups of plots together into cover types and to infer similarities between various cover types. Each group of plots was then summarized using density, cover, constancy, and basal area information.

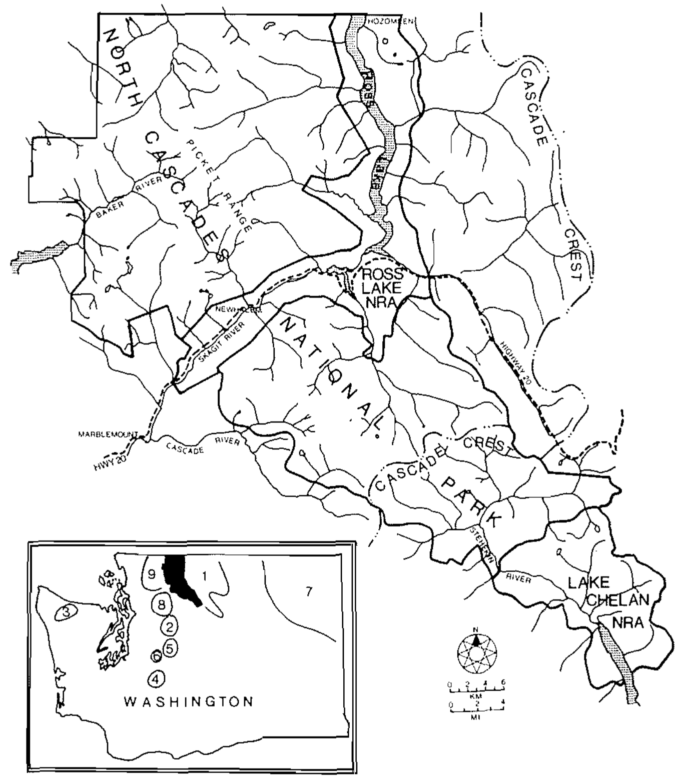

FIG. 1. Location of the North Cascades National Park Service Complex in Washington. Numbers within inset of Washington State are areas referred to in Table 5.

Results

Forest ordination

The diverse environments encountered in the field gave rise to long DCA axes lengths for sample ordinations with high eigenvalues and standard deviations. 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 SD; groups of samples at both ends of the gradients may contain no species in common (Hill 1979*a*). The standard deviations and eigenvalues (in parentheses) for the first four axes were 6.24 (0.691), 5.94 (0.485), 7.15 (0.388), and 5.30 (0.251).

Species found at low elevations tended to be at the left of axis 1 in the species ordination, while species found at high elevations were to the right (Fig. 2). This elevational gradient was substantiated by regressing axis 1 sample scores onto sample plot elevations. The coefficient of determination (r^2) of 0.71 ($p < 0.001$) indicated that elevation was strongly and linearly related to axis 1 scores. Elevation is most likely representing effects of temperature and other correlated factors (e.g., snowmelt date), the actual environmental gradients influencing floristic distribution along axis 1.

Axis 2 of the species ordination appears to be a moisture gradient that has a wider spread of data points to the left side of axis 1 (low elevation) than the right side (high elevation). The polarization of points on axis 2 can occur when a gradient expresses itself more completely at one end of the axis (Hill and Gauch 1980).

The rankings of species on axis 2, within narrow axis 1 score ranges, is consistent with species drought tolerance rankings from Minore (1979). Within a given axis 1 range (e.g., 0−200, 200−400, 400−600, >600) species are ranked with drought sensitive trees at low axis 2 scores and drought tolerant species at high axis 2 scores.

The moisture gradient represented by axis 2 is a complex one. A regression of axis 2 sample scores on annual precipitation had a coefficient of determination of 0.10 ($p < 0.001$) showing it was weakly related to axis 2 scores. This is due to the larger spread of scores at the low elevation end than at the high elevation end of axis 1, so that a mesic site at low elevation has an axis 2 score equal to a wet site at high elevation. Also, effective moisture availability is not well characterized by total precipitation alone. Another set of regressions was developed using an adaptation of the technique of Stage (1976), who used an index combining the effects of aspect and slope on tree growth. Axis 2 scores were regressed on a "moisture index" composed of 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 0.17 ($p < 0.001$), indicating a stronger relation when environmental factors other than precipitation that influence moisture availability are taken into account. Three more regressions were run on data separated into three groups of axis 1 scores to reduce the distortion effect at low elevation: 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 ($p < 0.001$), 0.15 ($p < 0.001$), and 0.15 ($p < 0.005$), respectively, suggesting a higher association of axis 2 scores with an index of moisture availability at lower elevations. The statistical relationship, while not strong, is consistent with the assumption that effective moisture is a more important floristic discriminator at low elevations. Common understory species grouped by ordination position are summarized in Table 1.

Forest classification

The classification dendrogram (Fig. 3) shows an early divi-

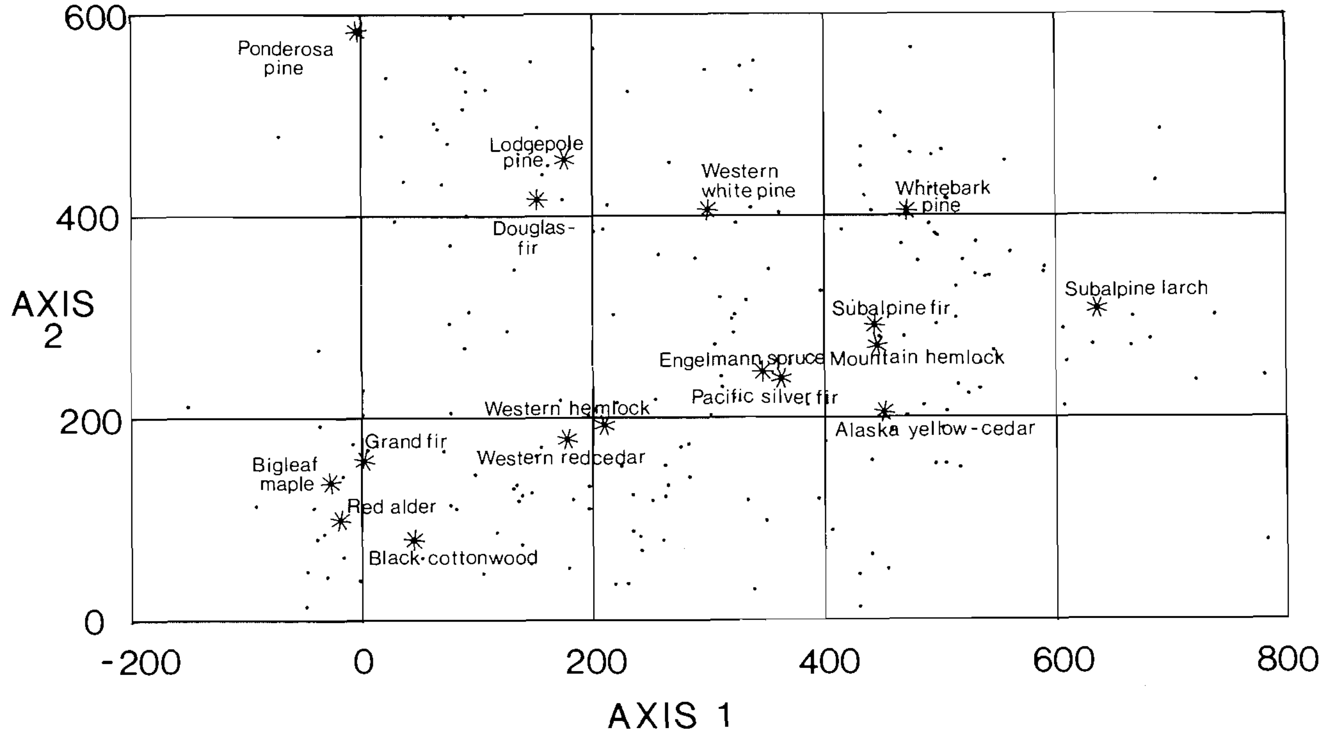

FIG. 2. Ordination space occupied by common tree species along axis 1 (temperature) and axis 2 (moisture).

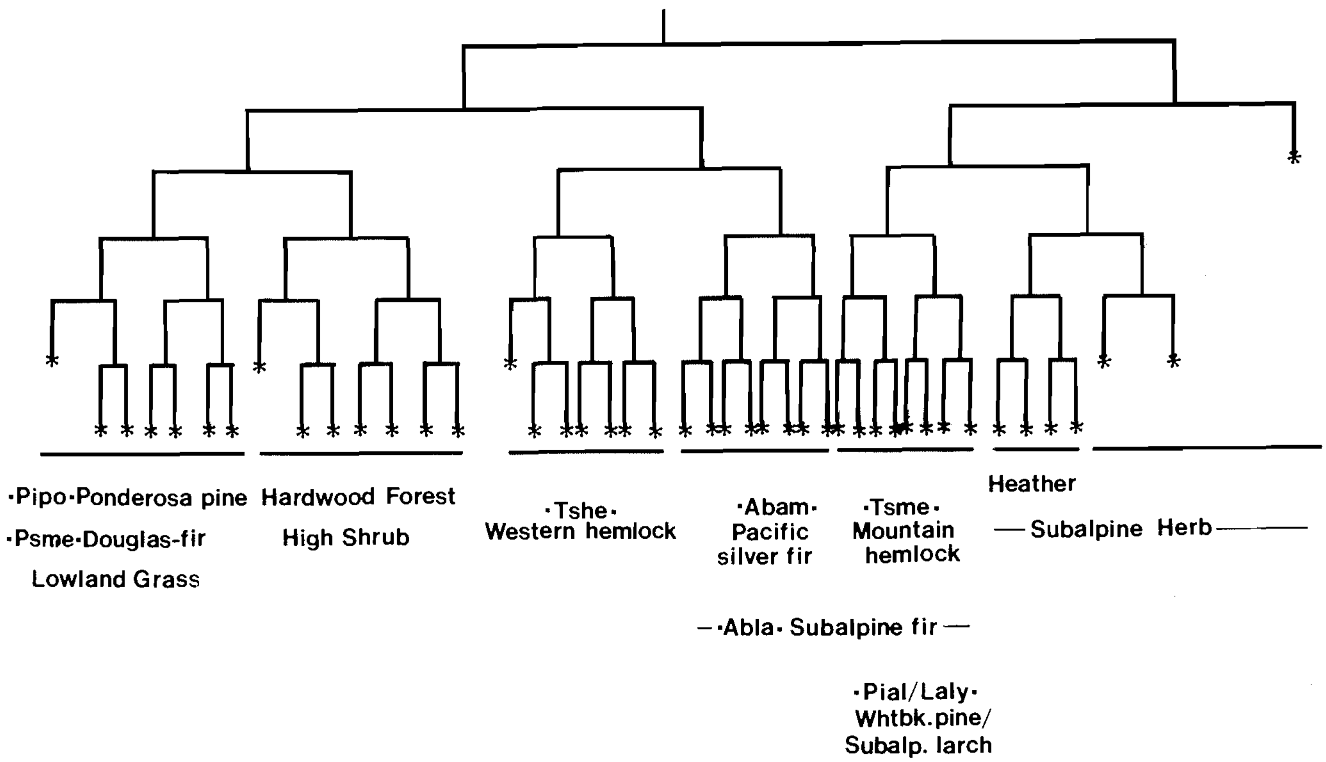

FIG. 3. Clustering of vegetation plots showing major cover types.

sion into three major groups, which are then further subdivided. The first group (at left) is composed of dry, lowland forest, shrub, and grass types plus the deciduous forest types. The second group (middle) includes westside lowland and montane forests. The third group (right) contains the subalpine to alpine community types. Floristically, the subalpine types, whether dry or moist, are more closely related to one another than to their associated lowland types.

Among the lower elevation types, the clustering of the dry forest and shrub types with the deciduous types is probably due to the fact that both the drier forests and the deciduous types are more frequently disturbed than the wetter westside forest

TABLE 1. Common understory species of North Cascades forests arranged by ordination scores on axes 1 and 2. Species within each relative temperature group of axis 1 are listed in order of low to high (wet to dry) axis 2 scores

Scientific name	Common name
Axis 1 score <100: very warm	
Spiraea douglasii	Douglas' spiraea
Viburnum edule	Highbush cranberry
Berberis nervosa	Oregon grape
Prunus emarginata	Bitter cherry
Holodiscus discolor	Ocean spray
Ceanothus velutinus	Snowbrush
Bromus tectorum	Cheatgrass
Axis 1 score 100–300: warm	
Rubus spectabilis	Salmonberry
Oplopanax horridum	Devil's club
Polystichum munitum	Sword fern
Gaultheria shallon	Salal
Vaccinium parvifolium	Red huckleberry
Chimaphila umbellata	Prince's pine
Pachistima myrsinites	Oregon boxwood
Arctostaphylos uva-ursi	Kinnikinnick
Adenocaulon bicolor	Trail plant
Axis 1 score 300–500: cool	
Lysichitum americanum	Skunk cabbage
Sorbus sitchensis	Mountain ash
Heracleum lanatum	Cow parsnip
Rubus lasiococcus	Dwarf bramble
Vaccinium alaskense	Alaska huckleberry
Vaccinium membranaceum	Big-leaf huckleberry
Juniperus communis	Mountain juniper
Anaphalis margaritacea	Pearly everlasting
Axis 1 score 500–700: cold	
Vaccinium deliciosum	Blue-leaf huckleberry
Valeriana sitchensis	Sitka valerian
Veratrum californicum	False hellebore
Festuca viridula	Green fescue
Phlox diffusa	Spreading phlox
Vaccinium myrtillus	Dwarf bilberry
Axis 1 score >700: very cold	
Polygonum bistortoides	American bistort
Phyllodoce glanduliflora	Yellow heather
Arnica diversifolia	Sticky arnica

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.

The second of the three major groups is composed of the westside lowland and montane types. There is a clear division between the lower elevation groups where western hemlock dominates and middle elevation groups where Pacific silver fir dominates. Douglas-fir, western hemlock, and mosses are common to both groups.

The third group is composed of 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 subalpine fir and generally moist mountain hemlock forest types.

The initial classification resulted in 22 plant cover types. Eight coniferous forest types were identified, each with an

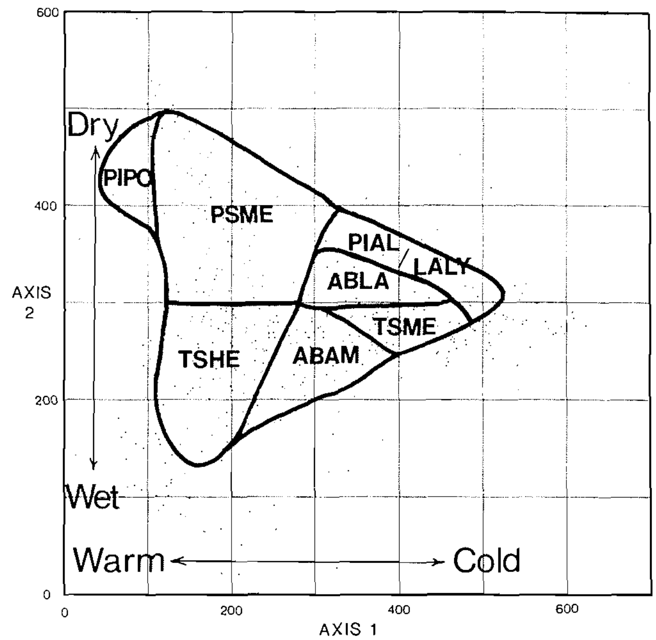

FIG. 4. Ordination space occupied by major forest cover types along temperature and moisture axes. Pipo, ponderosa pine; Psme, Douglas-fir; Tshe, western hemlock; Abam, Pacific silver fir; Tsme, mountain hemlock; Abla, subalpine fir; Pial–Laly, whitebark pine – subalpine larch.

open and closed canopy component. The open or closed canopy status was defined by Landsat spectral signatures; open canopy had substantial deciduous, herbaceous, or inert (soil–rock) cover. The remaining six other plant cover types were hardwood forest, high shrub, lowland grass, fescue meadow, lush herbaceous, and heather meadow. These non-coniferous cover types each include a wide range of plant communities. High shrub consists of alder or willow thickets along avalanche tracks. The lowland grass type is composed of herbaceous-dominated vegetation below 1300 m elevation, such as recent clear-cuts, fields, and gravel bars. The fescue meadow and lush herbaceous types are high elevation herb communities, which were combined into a subalpine herb type in the final classification. The heather meadow type is found at high elevation on gentle slopes with late snowmelt. The non-forest types comprise over 16% of the total land base of the park complex, substantiating the ecological and esthetic significance of nonforest vegetation in the region. Because of the very general nature of the nonforest type groupings and existing descriptions (Douglas and Bliss 1977), specific cover type summaries are limited to the forested cover types.

The conifer forest cover types, initially defined by TWINSPAN output, included ponderosa pine, Douglas-fir, grand fir, subalpine fir, whitebark pine – subalpine larch, mountain hemlock, Pacific silver fir, western hemlock, and hardwood forest. Some cover types were combined with others after field checking revealed they covered less than 0.1% of the study area: the closed canopy ponderosa pine type and both open and closed canopy grand fir type were placed within the Douglas-fir cover type; Douglas-fir was a substantial component of each of the eliminated types. The position of each cover type on the two-dimensional ordination was determined by plotting each sample within a cover type onto the sample ordination (Fig. 4).

The coniferous forest types are defined as cover types rather

TABLE 2. Characteristics of forest cover types in the North Cascades National Park Service Complex

Cover type	n	Average elevation (m)	Elevation range (m)	Average slope (%)	Average precipitation (cm)	Area of type (ha)	Land base (%)
Pipo (open)	1	536	—	50	76	493	0.2
Psme (closed)	42	728	299–1539	36	160	26 798	9.7
Psme (open)	36	880	256–1706	47	137	12 523	4.6
Abla (closed)	6	1335	1128–1585	42	221	17 105	6.2
Abla (open)	20	1652	1219–1896	53	241	11 072	4.0
Pial–Laly (closed)	0	—	—	—	—	2 034	0.7
Pial–Laly (open)	21	1912	1557–2231	52	203	1 888	0.7
Tsme (closed)	25	1436	1006–1737	43	254	11 381	4.1
Tsme (open)	19	1572	1030–1780	50	257	7 063	2.6
Abam (closed)	43	1220	716–2506	36	246	24 546	8.9
Abam (open)	5	1316	926–1603	47	239	9 284	3.4
Tshe (closed)	82	710	161–1231	34	211	24 128	8.8
Tshe (open)	17	718	304–1234	52	208	9 903	3.6
Hardwood forest	18	623	238–945	28	175	998	0.4
Nonforest types	176	—	—	—	—	44 837	16.3
Inert (rock, etc.)	—	—	—	—	—	71 086	25.8

than "climax" or potential vegetation types (sensu Daubenmire 1968). However, because the ordination and classification analysis used an importance value comprised of relative tree density as well as cover, dominant tree regeneration is represented in the data from which cover types were defined, and the cover types often are synonymous with potential vegetation.

Cover types that are composed of relatively shade-tolerant species tend to increase the area of the ordination space they occupy from the open canopy samples to the closed canopy samples (Fig. 5). The closed canopy western hemlock and Pacific silver fir types overlap with the open canopy types of their more shade-intolerant community neighbors, Douglas-fir and mountain hemlock – subalpine fir. The succession from Douglas-fir to western hemlock forest in the western Cascades 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 and Mitchell 1967). At North Cascades, there are places where each of the above species are considered "climax." Where they occur in a mix, the more tolerant species dominate more of the sample space in the closed canopy delineation of the ordination.

The cover types with an interior climate influence have slightly higher proportions of cover in open canopy. Open canopy proportions for interior types ponderosa pine (1.0), Douglas-fir (0.32), and subalpine fir (0.39) exceed those of their respective coastal counterparts western hemlock (0.29), Pacific silver fir (0.27), and mountain hemlock (0.38). This is consistent with the hypothesis of del Moral and Watson (1978) that tree spacing is higher towards the east in the Cascades owing to increased competition for available moisture.

Forest cover type descriptions

Summary data for the forest cover types, based on averages of the sample plots in the TWINSPAN groupings, include physical characteristics of each forest cover type (Table 2), tree basal area, cover, and constancy (Table 3), tree density by height class (Fig. 6), and shrub constancy (Table 4). The cover types are arranged in Table 2 as they might be found in a transect from the eastern to the western side of the park complex.

Pipo (Ponderosa pine)

Ponderosa pine is the driest and lowest elevation cover type, in the dry, southeastern portion of the park complex. Only one plot remained after the closed canopy plots in this type were integrated into the Douglas-fir type; this type covers only 0.2% of the land base of the park complex but is more important to the east of the park. Ponderosa pine is codominant with Douglas-fir in these rocky sites where canopy closure will likely never occur. Big-leaf maple is also found in lower canopy positions. *Agropyron spicatum* (bluebunch wheatgrass) is a common understory component along with the shrubs listed in Table 4.

Psme (Douglas-fir)

The Douglas-fir cover type is widespread at low to middle elevation on slightly moister sites than the ponderosa pine type. A majority of tree basal area and cover consists of Douglas-fir; common shrubs are *Pachistima myrsinites*, *Arctostaphylos uva-ursi*, and *Ceanothus velutinus*. This cover type contains a substantial component of lodgepole pine, which is best represented in the taller canopy classes; Douglas-fir dominates the regeneration in both open and closed canopy portions of the cover type. Grand fir is occasionally present in the overstory or understory but was too limited in distribution to warrant a separate cover type. Areas where grand fir would grow are usually dominated by western red-cedar or western hemlock, which are superior competitors (Daubenmire and Daubenmire 1968).

Abla (subalpine fir)

The subalpine fir cover type is high elevation forest in the drier environments of the park (Table 2); its moist counterpart to the west is the mountain hemlock cover type. Subalpine fir constitutes almost half of the basal area and is the dominant conifer in all height classes (Table 3, Fig. 6). *Vaccinium membranaceum* is a dominant among shrubs in the closed canopy type; the open canopy type has seven shrubs with constancy >25%. The open component includes subalpine meadows that are being invaded by coniferous trees owing to the 1920–1940 regional drought and warming that reduced snow loads and increased growing season length (Franklin *et al.* 1971).

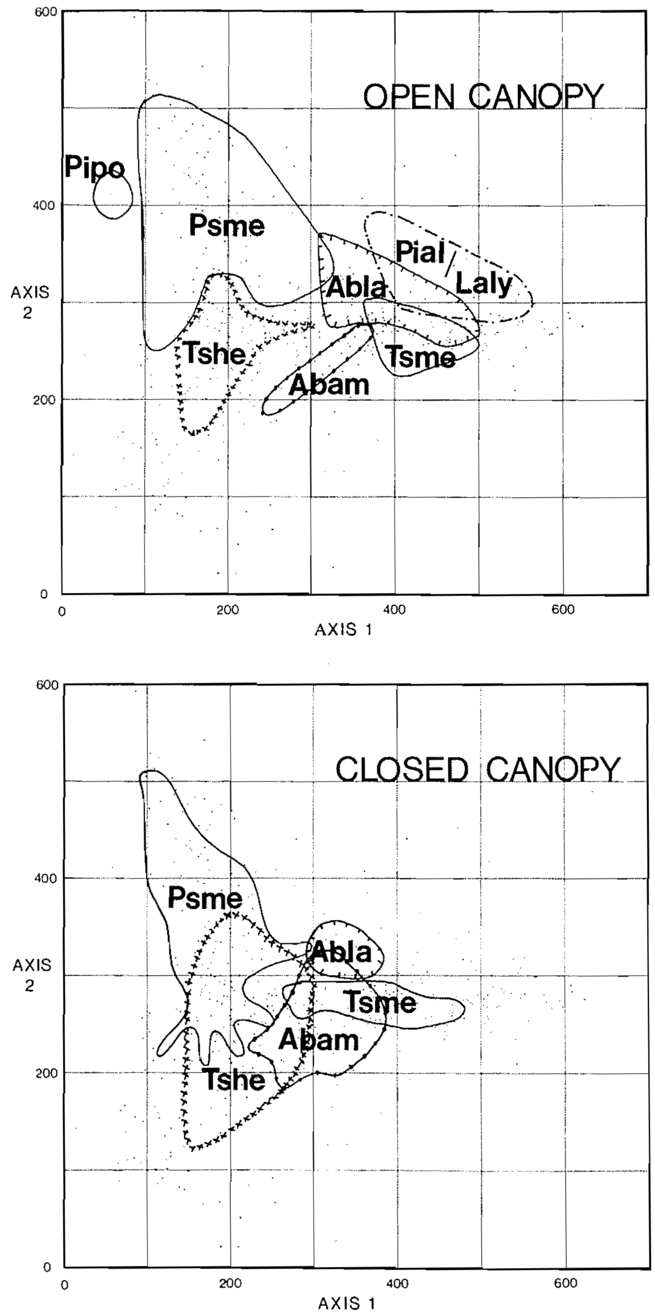

FIG. 5. Ordination space occupied by closed canopy and open canopy forest types. Lines encompass the range of plots classified in a given cover type.

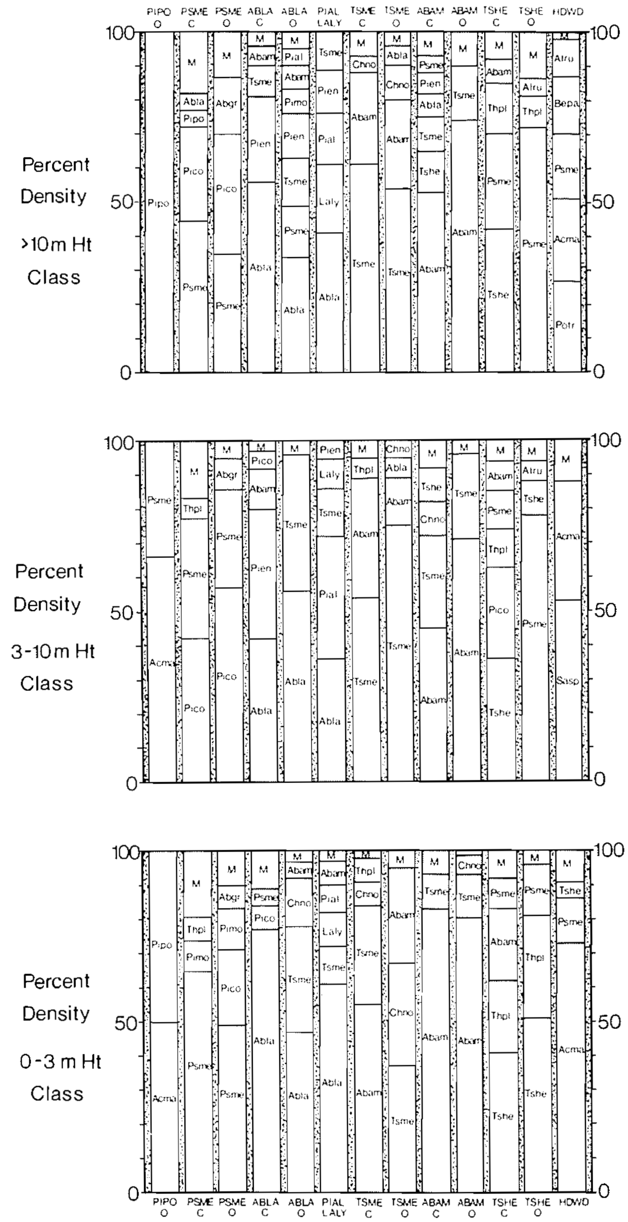

FIG. 6. Density of major tree species in each forest cover type by height class: 0–3, 3–10, and >10 m. Miscellaneous trees comprising less than 5% of relative density are combined as "M" at top of each graph.

Pial–Laly (whitebark pine –subalpine larch)

The whitebark pine – subalpine larch cover type is a higher elevation and sometimes a drier variant of the subalpine fir cover type. The data are from only the open canopy component, as no plots were sampled from the closed canopy component. The closed canopy component is essentially a subalpine fir type with minimal coverage of either whitebark pine or subalpine larch. Similar canopy coverage in this type was found by del Moral (1979) 50 km to the south. Tree basal area, cover, and constancy are dominated by subalpine fir. Either subalpine larch or whitebark pine is an associated dominant, more often separately with subalpine fir than with each other. Different habitat requirements for the larch and pine result in a complementary rather than competitive relationship between the two species in these marginal forest environments (Arno and Habeck 1972). The dominance of subalpine fir in the understory suggests that this type might eventually be dominated by subalpine fir, but successional dynamics at tree line are not easily predicted. Engelmann spruce may often be found as a codominant in this type (Fig. 6). Associated with subalpine larch are *Phyllodoce empetriformis, Cassiope mertensiana*, and *Luetkea pectinata*, while *Juniperus communis* and *Pachistima myrsinites* are more often associated with whitebark pine.

Tsme (mountain hemlock)

Further to the west, in more moist subalpine environments, is the mountain hemlock cover type. The open canopy portion of this type is often in a tree-line environment. Annual precipi-

TABLE 3. Basal area (Ba), cover (Cov), and constancy

Species	Pipo (o)[a]			Psme (c)[a]			Psme (o)			Abla (c)			Abla (o)		
	Ba[b]	Cov[c]	Con[d]	Ba	Cov	Con	Ba	Cov	Con	Ba	Cov	Con	Ba	Cov	Con
Abies amabilis				T	T	5		T	3	3	2	66	1	1	50
Abies grandis				T	1	7	2	1	6						
Abies lasiocarpa				1	1	12	1	1	11	13	22	100	9	15	90
Acer glabrum					T	2									
Acer macrophyllum	T	1	100	T	1	7	1	1	8						
Alnus rubra					T	2									
Betula papyrifera				1	1	5		1	6						
Chamaecyparis nootkatensis										1	1	33	1	2	50
Cornus nuttalli								T	3						
Larix lyallii															
Picea engelmannii				3	1	10		1	6	7	8	50	1	T	15
Pinus albicaulis								1	8				1	T	5
Pinus contorta				6	4	26	9	4	31	1	1	50	1	T	10
Pinus monticola				T	1	7	T	1	8						
Pinus ponderosa	10	1	100	5	3	24	4	3	42						
Populus trichocarpa					T	2		T	3						
Prunus emarginata					T	2		T	3						
Pseudotsuga menziesii	10	1	100	26	38	100	19	13	94	T	2	50	4	T	20
Taxus brevifolia															
Thuja plicata				1	2	26	T	1	6						
Tsuga heterophylla					1	14	T	T	3	T	T	17			
Tsuga mertensiana										4	1	17	3	12	75
Salix scouleriana				T	T	2									
Salix spp.				T	1	12	T	1	6						

[a]o, open canopy portion; c, closed canopy portion.
[b]Basal area is in metres squared per hectare. T, trace.
[c]Cover is by cover class: 1, 0–5%; 2, 6–25%; 3, 26–50%; 4, 51–75%; 5, 76–95%; 6, 96–100%. T, trace.
[d]Constancy is in percent.

tation averages 35–50 cm more than that of the drier subalpine types, and tree basal area of this type is twice as much. Mountain hemlock contains from 56 to 68% of the basal area, with Pacific silver fir a codominant, particularly at lower elevation. Pacific silver fir is also well represented in the understory (Fig. 6), suggesting a codominance of these two species in the type over time; these data do not suggest that Pacific silver fir will replace mountain hemlock, as has been suggested in other areas (Franklin and Mitchell 1967). *Phyllodoce empetriformis, Vaccinium membranaceum*, and *Rhododendron albiflorum* are common shrubs in this cover type.

Abam (Pacific silver fir)

At lower elevation on the westside, the Pacific silver fir cover type has the highest average basal area (67 m^2/ha for the closed canopy portion) of all the types. Roughly half of the basal area of the type is in Pacific silver fir (Table 3), and the understory tree layer is also heavily weighted towards fir (Fig. 6). This cover type is a middle elevation type in the western part of the park and is also found as a valley bottom type in the drier eastern valleys, along with occasional Engelmann spruce and Douglas-fir. Dominant shrubs in the type include *Vaccinium membranaceum, Sorbus sitchensis*, and *Vaccinium alaskense* and *Vaccinium ovalifolium*.

Tshe (western hemlock)

The lowest elevation coniferous forest type on the west side of the park complex is the western hemlock cover type (Table 2). In the area of the park complex, it is represented by relatively high elevation or dry western hemlock forests. Consequently, average tree basal area is not as great as for the Pacific silver fir type (Table 3). Douglas-fir is a seral codominant in the closed canopy portion of the type and is clearly dominant in the open canopy portion of the type (Table 3, Fig. 6). Regeneration in both portions is dominated by western hemlock (Fig. 6). Western red-cedar becomes a codominant with western hemlock in the drier sites within this cover type. Common shrubs include *Acer circinatum, Berberis nervosa, Pachistima myrsinites*, and *Vaccinium* spp.

Hardwood forest

The hardwood cover type is defined on the basis of overstory dominance by deciduous trees and includes a wide variety of tree species and sites. Most commonly, this type occurs at low elevation where disturbance, primarily by flooding, has occurred within the past 50 to 80 years. Big-leaf maple, black cottonwood, and Douglas-fir dominate the overstory, while willow is a common midcanopy dominant (Fig. 6). This type appears largely seral to the other low elevation coniferous forest types.

A number of plant community types, or associations, were recognized within the forest cover types (Table 5). Similar types in nearby areas recognized in other studies are also noted. Of the 34 associations listed, only 1 is not common in nearby areas where preliminary classifications have been completed. The *Tsuga heterophylla – Thuja plicata/Pachistima myrsinites – Berberis nervosa* association, which occurs in the Skagit River – Ross Lake corridor appears to be unique for the Cascades but is close to the *Tsuga/Pachistima* or *Thuja/Pachistima* associations in eastern Washington and northern Idaho (Daubenmire and Daubenmire 1968) and in southern British Columbia (Illingsworth and Arlidge 1960).

(Con) of tree species in forest types of the North Cascades

Pial–Laly			Tsme (c)			Tsme (o)			Abam (c)			Abam (o)			Tshe (c)			Tshe (o)			Hdwd		
Ba	Cov	Con	Ba	Cov	Con	Ba	Cov	Con	Ba	Cov	Con	Ba	Cov	Con	Ba	Cov	Con	Ba	Cov	Con	Ba	Cov	Con
T	T	19	18	22	92	7	8	70	33	45	100	24	52	100	3	2	43	T	1	18	T	T	6
															T	T	6	T	T	6	T	T	6
9	12	95	1	T	44	3	1	20	2	1	16				T	T	4						
																		T	T	6	T	T	6
															T	T	2	1	1	6	6	11	83
															T	T	7	1	1	22	2	3	50
															T	T	1	T	T	6	2	1	28
			1	1	28	1	2	55	1	1	26	T	1	20	T	T	1						
															T	T	1	1	T	6	T	1	22
4	2	48																					
2	1	29	T	T	4				6	1	21	2	T	20	1	T	9						
4	5	81				T	T	10															
									T	T	2				T	T	5	1	1	18			
			T	T	12				T	T	9	T	T	20	T	1	16	T	T	6			
																					T	T	6
									T	T	2				T	T	1				7	5	44
																					1	1	11
T	T	5	3	1	20	1	T	5	4	1	30				21	15	74	16	45	82	6	2	50
									T	T	2				T	T	6						
			2	1	20				1	1	23	4	1	20	16	15	90	1	8	82	1	1	28
			T	T	1				10	2	30	6	4	40	22	31	89	1	8	76	T	T	11
1	2	52	32	40	100	25	31	95	10	6	60	8	10	80	1	1	11						
																		T	T	6			
						T	T	5													3	1	17

TABLE 4. Constancy of common shrubs in the forest types of the North Cascades

	Pipo (o)	Psme (c)	Psme (o)	Abla (c)	Abla (o)	Pial–Laly	Tsme (c)	Tsme (o)	Abam (c)	Abam (o)	Tshe (c)	Tshe (o)	Hdwd
Acer circinatum									12	20	45	35	
Alnus sinuata										20			5
Amelanchier alnifolia	100	29	25										
Arctostaphylos uva-ursi		33	42	17	10								
Berberis nervosa		36	14								41	76	22
Cassiope mertensiana					25	52	8	25					
Ceanothus velutinus		19	42										
Cornus stolonifera													11
Gaultheria shallon		12									17		
Holodiscus discolor	100	19	8										
Juniperus communis						19							
Luetkea pectinata					40	48	16	15					
Menziesia ferruginea					10		12	15	12	20			
Oplopanax horridum									12		30	12	
Pachistima myrsinites		66	66		35	33			19		33	47	33
Phyllodoce empetriformis					55	71	44	65					
Physocarpus malvaceus	100												
Rhododendron albiflorum						19	52	30		20			
Rubus parviflorus												29	50
Rubus spectabilis										20	6		11
Sorbus sitchensis				34	40		8	40	21	40			
Spiraea betulifolia		21	19	17									
Symphoricarpos albus													11
Vaccinium alaskense									16				
Vaccinium deliciosum					45	24	8	35					
Vaccinium membranaceum		26	8	83	40		56	55	65	80	27	17	
Vaccinium spp.		19	8	17		38	36		23		39	23	
Vaccinium parvifolium											6		22

NOTE: Cover type acronyms are explained in Fig. 4. o, open canopy portion; c, closed canopy portion.

TABLE 5. Forested plant associations in the North Cascades National Park Service Complex

Plant association	Recognized in areas nearby[a]
Pinus ponderosa — Pseudotsuga menziesii/Agropyron spicatum	1, 7
Pseudotsuga menziesii/Symphoricarpos albus	1, 7
Pseudotsuga menziesii/Holodiscus discolor	1
Pseudotsuga menziesii/Calamagrostis rubescens	1, 7
Pseudotsuga menziesii/Arctostaphylos uva-ursi	1, 7
Pseudotsuga menziesii/Pachistima myrsinites	1
Pseudotsuga menziesii/Vaccinium spp.	1
Pseudotsuga menziesii/Berberis nervosa — Gaultheria shallon	6
Abies grandis/Pachistima myrsinites	1, 7
Abies lasiocarpa/Pachistima myrsinites	1, 7
Abies lasiocarpa/Vaccinium spp.	1
Abies lasiocarpa/Phyllodoce empetriformis	1
Abies lasiocarpa — Larix lyallii/Phyllodoce empetriformis — Vaccinium deliciosum	1
Abies lasiocarpa — Pinus albicaulis/Vaccinium spp.	1
Tsuga mertensiana/Vaccinium membranaceum	2, 5, 8, 9
Tsuga mertensiana/Rhododendron albiflorum	2, 8, 9
Tsuga mertensiana/Vaccinium alaskense	2, 8, 9
Tsuga mertensiana/Menziesia ferruginea	7
Tsuga mertensiana/Phyllodoce empetriformis — Vaccinium deliciosum	2, 5, 8, 9
Abies amabilis/Oplopanax horridum	2, 3, 4, 5, 8, 9
Abies amabilis/Vaccinium membranaceum	2, 5, 8, 9
Abies amabilis/Vaccinium membranaceum — Pachistima myrsinites	1
Abies amabilis/Vaccinium alaskense	2, 3, 4, 5, 8, 9
Abies amabilis/Rhododendron albiflorum	1, 4
Abies amabilis/Menziesia ferruginea	4
Abies amabilis/Rubus lasiococcus	4
Tsuga heterophylla/Gaultheria shallon	2, 3, 4, 5, 8, 9
Tsuga heterophylla/Berberis nervosa	2, 5, 8, 9
Tsuga heterophylla/Pachistima myrsinites	7
Tsuga heterophylla — Thuja plicata/Pachistima myrsinites — Berberis nervosa	Unique
Tsuga heterophylla/Vaccinium spp.	2, 3, 5, 6, 8, 9
Tsuga heterophylla/Acer circinatum	3
Tsuga heterophylla/Polystichum munitum	2, 3, 4, 5, 8, 9
Tsuga heterophylla/Oplopanax horridum	2, 3, 4, 8, 9

[a]Sources: 1, Williams and Lillybridge (1983); 2, Henderson and Peter (1983); 3, Henderson and Peter (1982*a*); 4, Franklin *et al.* (1979); 5, Henderson and Peter (1982*b*); 6, del Moral and Long (1977); 7, Daubenmire and Daubenmire (1968); 8, Henderson and Peter (1984); 9, Henderson and Peter (1985).

Discussion

The distribution of forest cover types at North Cascades is primarily influenced by environmental gradients of temperature and moisture that have been used to describe forest distribution for the region (Franklin and Dyrness 1973). Temperature has been described as the primary gradient separating major forest types in the Oregon Cascades, with moisture expressing itself as a differentiating factor within the lower elevation forest types (Zobel *et al.* 1976). 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. These same gradients are important for the North Cascades area, although they were identified without direct measurement of environmental variables.

Detrended correspondence analysis appeared to produce a reasonable ordination in this study. Two of its admitted defects, sensitivity to "oddball" samples and poor estimation of discontinuous gaps in the data (Hill and Gauch 1980), were overcome by using many samples widely distributed over the park complex and choosing the down-weighting option for rare species. No attempts were made to compare detrended correspondence analysis with other ordination techniques (c.f. Beals 1984), as it performed well for this data set for interpretations of lower order axes. Higher order axes, which sometimes have contained more ecological information than axis 2 in other studies (Beals 1984), were not useful in the North Cascades ordination.

The cover type analysis was designed to be integrated with a geographic information system (GIS) for the park complex, so that cover types could be defined using "layers" of the GIS: Landsat data and digitized information on annual precipitation, slope, aspect, and elevation. The ordination results suggested that elevation could be used as a predictor of the temperature gradient and precipitation, aspect, and slope as predictors of the moisture gradient. The classification results provided logical groupings of plots from which ranges of elevation, precipitation, slope, and aspect of each cover type could be summarized. Using plot information within each cover type, a series of predictive cover type models was developed so that each 50 by 50 m cell within the park complex and surrounding area was assigned a forest, nonforest, or rock, snow—ice, or water cover type. Maps of the cover type classification were field checked and had an overall accuracy of 84.3%. Limited copies of the vegetation map are available from the first author (Agee *et al.* 1985).

The upper Skagit River – Ross Lake area within the park complex has been identified as a botanically interesting area owing to its transitional nature between moist coastal and dry interior forests: the slopes and valleys on the west side of Ross Lake are said to have more coastal characteristics with some continental elements, while those east of the lake have more continental characteristics with some coastal influences (Franklin and Dyrness 1973). Our data suggest that there are few, if any, combinations of plants defining unique community types in this area. The uniqueness of the area lies in its close juxtaposition of coastal and interior communities. For example, a typical zonal vegetation sequence on the coastal west side would be analogous to moving along a line in Fig. 4. from the bottom left upwards towards the right: western hemlock, Pacific silver fir, and mountain hemlock. Similarly, a typical sequence on the interior eastside could be found along a line from the upper left down towards the right: ponderosa pine, Douglas-fir, and subalpine fir. The slopes around Ross Lake, especially on the west side of the lake, often follow a coastal sequence on mesic north aspects and an interior sequence on warmer, drier south aspects. The zonal sequence for south aspects is Douglas-fir, occasionally Pacific silver fir, and subalpine fir, while on north aspects it is Douglas-fir or western hemlock, Pacific silver fir, and mountain hemlock.

The North Cascades National Park Service Complex contains a wide array of forest cover types of the region, missing only good representation of the ponderosa pine type. Because of its preserve status, it will remain a significant natural laboratory into the future. This forest cover type classification, incorporated into a dynamic geographic information system, will serve as an information base for many future ecological studies.

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