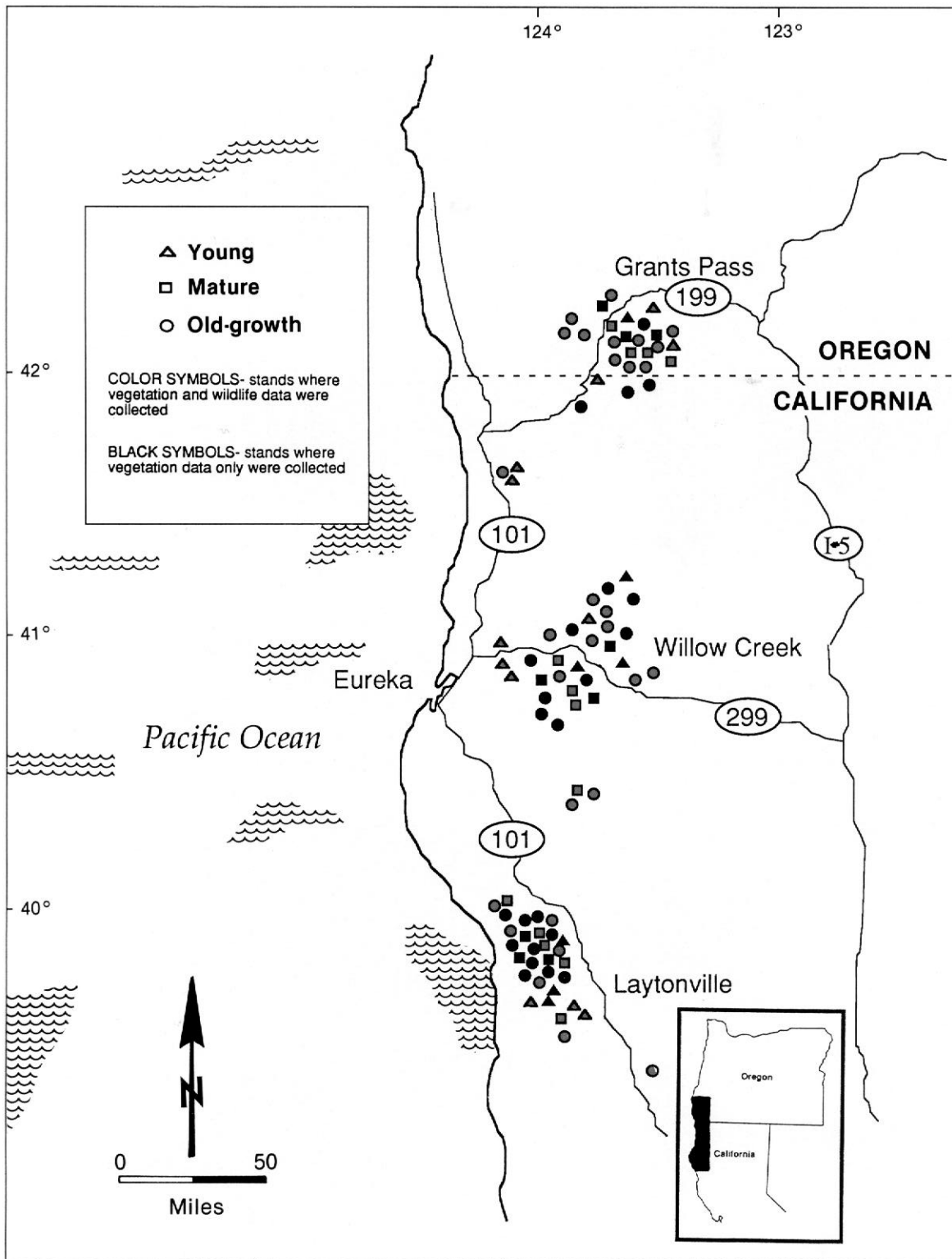




## Part 7

Old-Growth Community  
Studies in Northern  
California and Southern Oregon



Location of study sites.

# Distinctive Features and Definitions of Young, Mature, and Old-Growth Douglas-Fir/Hardwood Forests

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## Abstract

We examined the structure of 70 Douglas-fir/hardwood stands ranging from 40 to 560 years old in northwestern California and southwestern Oregon for features that best distinguished among young (40-100 year), mature (100-200 year), and old-growth (>200 year) forests. Separate analyses of 11 groups of variables representing six components of forest structure identified features of trees, understory cover, snags, and logs as important discriminators. Independently, features of understory and dead-wood components were weak-to-moderate discriminators among forest age-classes. The strongest discriminators were features of tree height and diameter components. A discriminant model using features from several components proved to have the greatest overall discriminating power among forest age-classes. This multiple components model included seven variables: the basal area of conifers 240 m tall, the basal area of conifers 290 cm in

d.b.h., the basal area of conifers <45 cm in d.b.h., the basal area of hardwoods 45 to 90 cm in d.b.h., the cover of hardwoods 18 m tall, the density of hardwood saplings 1 to 2 m tall, and the density of hardwood snags 220 cm in d.b.h. and 22 m tall. We present definitions for young, mature, and old-growth Douglas-fir/hardwood forests based on a wide range of structural features. In addition, we revise the interim old-growth definition for this forest type introducing new minimum standards along with average values  $\pm$  95-percent confidence limits for certain key features.

## Introduction

Old-growth Douglas-fir forests display several distinctive structural features (Franklin and others 1981). These features, which include large live trees, large snags, and large logs, play numerous important roles in forest ecosystems. Controversies surrounding the loss of old-growth from the forested landscapes of Washington, Oregon, and California demand the immediate attention of managers and researchers. To assist managers in their planning efforts, the Old-Growth Definition Task Group (1986) developed interim definitions for certain kinds of old-growth forests with minimum criteria for key features. With new data available, their interim definition for old-growth Douglas-fir/hardwood forest should

be expanded. For comparison, quantitative definitions for mature and young forests are needed. Such comparisons can help managers develop strategies to recognize and conserve key features when manipulating forests.

In northwestern California and southwestern Oregon, low-elevation (<1200 m) Douglas-fir forests are mixtures of Douglas-fir and hardwood trees. The hardwoods typically account for major percentages of stand basal areas and include tanoak, Pacific madrone, canyon live oak, golden chinkapin, California-laurel, California black oak, and Oregon white oak. Conifers other than Douglas-fir generally account for minor percentages and include redwood, ponderosa pine, incense-cedar, Port-Orford-cedar, sugar pine, western red-cedar, and Pacific yew.

Franklin and Dyrness (1973) refer to these forests as Douglas-fir on mixed evergreen sites. Sawyer and others (1977) used the name Douglas-fir/hardwood to distinguish these forests from others in Oregon and Washington, where, at lower elevations, Douglas-fir dominates with conifer associates instead of hardwoods.

The structural features of Douglas-fir/hardwood forests change with age. These changes ultimately lead to a forest where Douglas-fir and the hardwoods are self-replacing (Sawyer 1980, Thornburgh 1981). This study identified major features of young, mature, and old-growth Douglas-fir/hardwood forests in northwestern California and southwestern Oregon. We used these features and others from a wide range of forest components to develop definitions of young, mature, and old-growth forests. In addition, our results provided data for revising the interim old-growth definition for this vegetation type. We present new minimum standards and average values along with the 95-percent confidence limits for key features such as large trees, snags, and logs.

### **Location and Environment**

Douglas-fir/hardwood forests extend from southwestern Oregon to central California. Along the coast, these forests replace redwood forests on upland and more xeric sites (Stuart 1987). To the south, Douglas-fir dominance dwindles, and evergreen oaks, tanoak, and Pacific madrone become the dominant trees (Sawyer and others 1977, Wainwright and Barbour 1984). In the mountains, the forest type's upper elevational limit occurs when the hardwoods are replaced by conifers, particularly white fir (Sawyer and Thornburgh 1977).

We conducted this study in the Northern California Coast Range and Klamath Mountains provinces (Irwin 1960). The Northern California Coast Range province extends from Oregon as a narrow band of low coastal mountains. The province widens in southern Humboldt and Mendocino

counties and continues south to the San Francisco Bay region. The Klamath Mountains province is adjacent to the northern Coast Ranges and includes the Siskiyou Mountains of southwestern Oregon and extends to the Yolla Bolly Mountains of California. Soils supporting Douglas-fir/hardwood forests in both provinces are derived predominantly from metasedimentary rocks.

The climate of northwestern California is generally mild with wet winters and dry summers. Average annual precipitation at coastal and low-elevation mountain locations ranges from 650 to >2000 mm. High summer and low winter temperatures are typically near 38 and -7 °C, respectively.

The Northern California Coast Range and Klamath Mountains provinces are characterized by steep and rugged terrain. Abrupt changes in aspect, slope, soil properties, and localized disturbance regimes result in rapid shifts in tree-species dominance and changes in forest structure. In Douglas-fir/hardwood forests, these shifts are expressed as a forest mosaic with patches of conifers, hardwoods, or diverse mixtures. Canopy openings are common and display various stages of forest regeneration.

Fire has played an important role in the origin and development of Douglas-fir/hardwood forests before and since the arrival of European settlers (Agee, this volume; Johnson 1979). Tree-ring studies in the northern California Coast Range concluded that fires occurred so frequently that settlers, and Native Americans before them, set fires regularly (Anonymous 1983). During settlement, original forest lands were often burned repeatedly after timber harvest as a means of converting the areas to farm or grazing lands (Show and Stuart 1932). For these fires to burn out of control and into adjacent forests was not unusual.

Since the early 1900's, fire management has intensified. The suppression of wildfire has resulted in a scarcity of young stands that originated after naturally ignited fires. Most young stands <100 years old in northwestern California originated after logging. In many of these stands, fire was used as a means of reducing slash accumulations. Large quantities of dead wood often remained, however. These young managed stands do not necessarily possess the same structural features as found in young stands that originated after a catastrophic event other than logging.

## **Methods**

### **Study Sites**

Local ecologists proposed more than 100 candidate study stands with tentative age-class assignments. Each candidate was a forest stand of relatively homogeneous structure, floristic composition, and physiography. We selected 70 Douglas-fir/hardwood stands ranging from 40 to 560 years old and

centered in three geographic areas (see frontispiece). Stands were selected to represent three site moisture categories (dry, mesic, or wet) characteristic of each area.

Stand sizes ranged from 5 to about 100 ha. Twenty-two stands were located on the Northern California Coast Range Preserve, a 3200-ha old-growth reserve managed by The California Nature Conservancy and the USDI Bureau of Land Management. Seven stands were located on private lands. The remaining stands were located on lands administered by either the USDA Forest Service or the USDI Bureau of Land Management.

### Field Measurements

We sampled 285 plots, each of which consisted of a series of circular plots ranging from 0.002 to 0.2 ha. The smaller plots were systematically positioned within the 0.2-ha plot. Stands <20 ha were sampled by using three (0.2-ha) plots. Larger stands were sampled by using five (0.2-ha) plots. The first plot in each stand was randomly located. Subsequent plots were positioned at 150-m intervals. Plots were placed a minimum of 50 m from the stand edge.

Snags 250 cm in d.b.h. and 215 m tall were sampled in a 0.2-ha plot. Data on live trees 250 cm in d.b.h., snags 210 cm in d.b.h., total canopy cover, and stand physiography (plot aspect, slope, topographic position, and shape) were collected in a 0.1-ha plot. Live trees 25 to 50 cm in d.b.h., saplings 21 m tall and <5 cm in d.b.h., logs 210 cm in diameter, and the percentage cover of trees and large shrubs 18 m tall were sampled in a 0.05-ha plot. Percentage cover estimates of small shrubs, ferns, herbs, and grasses were made in a 0.02-ha plot. Also estimated in the 0.02-ha plot was the percentage cover of mosses, lichens, rocks, and total vegetation cover in three height-classes; 10.5-m, >0.5- to 1.0-m, and >1.0- to 2.0-m. Four 0.002-ha plots were used to sample seedlings 1 m tall, litter depth, and soil texture. The distance to streams, ponds, and springs was noted.

Tree ages in stands were collected by increment coring a minimum of three dominant or codominant canopy Douglas-fir trees from at least three plots. Tree ages in old-growth stands were determined from ring counts on stumps along adjacent roads or clearcuts, or from increment cores, or by a combination of both methods. In plots where trees were cored, we selected at least one healthy codominant or dominant tree near plot center. In young stands, these trees were typically <45 cm in d.b.h. In mature stands, codominant and dominant Douglas-fir trees were typically 45 to 90 cm in d.b.h., and 290 cm in d.b.h. in old-growth stands. Each stand was placed in a forest age-class using the mean age as determined from a minimum of three trees. Mean stand ages ranged from 40 to 560 years. Douglas-fir trees determined to be >560 years old were rarely encountered, even on the most productive sites.

Vascular plants, snags, and logs were identified to species. Each snag and log was assigned to one of five decay-classes (Cline and others 1980). Later, classes 1 and 2 were combined into a sound wood category, and classes 3 through 5 were combined into a rotten wood category.

### Data Analysis

For the purpose of analyses, we defined young stands as those dominated, in terms of relative basal area, by Douglas-fir trees 40 to 100 years old, mature stands as those dominated by Douglas-fir trees 101 to 200 years old, and old-growth stands as those dominated by Douglas-fir trees >200 years old.

Of the 70 stands we selected, we used 56 to determine distinctive features of the three forest age-classes. The 14 young stands had originated after logging. Of 14 mature stands, 7 had originated after logging, and 28 stands were old growth. We reserved 14 stands as a validation set. These stands included 10 old-growth and 4 mature stands. We selected the validation stands to represent the full range of old-growth and mature stand ages and site conditions. We lacked additional managed young stands to include as validation data.

We were interested in identifying features of forest structure that were strong discriminators among young, mature, and old-growth forests. We started our analyses with 60 variables representing six components of forest structure. Because of the importance of certain aspects of forest structure to managers, we viewed dividing the forest into various structural components, such as tree height, tree diameter, snags, and logs as a reasonable approach. Forest components could then be studied separately to reveal important features of each component. Variables were placed into logical groups for analysis. Certain groups were analyzed in terms of more than one unit of measurement (for example, basal area and density). For our analyses, we ended up with 11 groups of variables partitioned into six structural components (table 1). Each group of variables was analyzed independently. Graphical assessment of each variable was used to determine departures from normality. Variables that were not distributed normally were transformed by using a logarithmic or a square-root transformation.

For each group of variables, we used stepwise discriminant analysis (SAS 1985) to assess relative separation among the three age-classes. Each analysis selected a subset of variables that provided maximum discrimination among age-classes. Variables were allowed to enter and to stay in each discriminant function model based on a partial  $F$  test with a significance level of 0.1. A moderate-to-low significance level (50.1) helps to ensure that the variables selected are stable and make a significant contribution to the power of the model.

**Table I-Eleven groups of variables (features) representing 6 forest structure components included in the discriminant function analyses (each group was analyzed independently of all other groups)**

I. Component: Tree height

Group: basal area (m<sup>2</sup>/ha) of trees 25 cm in d.b.h. (1.37 m above ground)

- 1 \* hardwoods <12m tall
- 2 \* hardwoods 12-40 m tall
- \* conifers <12 m tall
- 4 \* conifers 12-40 m tall
- 5 \* conifers 140 m tall

Group: density (stems/ha) of trees ≥ 5 cm in d.b.h.

- 1 hardwoods <12 m tall
- 2 \* hardwoods 12-40 m tall
- 3 \* conifers <12 m tall
- 4 \* conifers 12-40 m tall
- 5 conifers MO m tall

II. Component: Tree diameter

Group: basal area (m<sup>2</sup>/ha) of trees 25 cm in d.b.h.

- 1 \* hardwoods <45 cm in d.b.h.
- 2 \* hardwoods 45-90 cm in d.b.h.
- \* conifers <45 cm in d b h
- 4 \* conifers 45-90 cm in d.b.h.
- 5 conifers 290 cm in d.b.h.

Group: density (stems/ha) of trees ≥ 5 cm in d.b.h.

- 1 \* hardwoods <45 cm in d.b.h.
- 2 \* hardwoods 45-90 cm in d.b.h.
- 3 \* conifers <45 cm in d.b.h.
- \* conifers 45-90 cm in d.b.h.
- 5 conifers 290 cm in d.b.h.

III. Component: Small trees

Group: density (stems/ha) of saplings 1-8 m tall and <5 cm in d.b.h.

- 1 \* hardwoods 1-2 m tall
- 2 \* hardwoods ≥ 2-4m tall
- 3 \* hardwoods 24 m tall
- 4 \* conifers 1-2 m tall
- 5 \* conifers > 2-4 m tall
- 6 \* conifers 24 m tall

Group: density (stems/ha) of seedlings <1 m tall

- 1 \* hardwoods <25 cm tall
- 2 \* hardwoods 25-50 cm tall
- 3 \* hardwoods 250 cm tall
- 4 \* conifers <25 cm tall
- 5 \* conifers 25-50 cm tall
- 6 \* conifers ≥ 50 cm tall

IV. Component: Understory cover

Group: shrubs and trees 58 m tall (percent)

- 1 \* shrub cover
- 2 \* cover of hardwoods
- 3 \* cover of conifers

Group: ground cover (percent)

- 1 \* herb, grass, and fern cover
- 2 \* moss and lichen cover
- 3 \* vegetation cover <0.5 m tall
- 4 \* vegetation cover 0.5-2 m tall
- 5 \* vegetation cover 22 m tall

V. Component: Snags (standing dead trees)

Group: density (snags/ha) of snags ≥ 10 cm in d.b.h. or top diameter

- 1 \* sound snags
- 2 \* rotten snags
- 3 \* hardwood snags 14 m tall
- 4 \* hardwood snags 120 cm in d.b.h. and 12 m tall
- 5 \* hardwood snags 240 cm in d.b.h. and >4 m tall
- \* conifer snags 24 m tall
- 7 \* conifer snags 220 cm in d.b.h. and 22 m tall
- 8 \* conifer snags 140 cm in d.b.h. and 24 m tall

VI. Component: Logs (dead wood on the ground)

Group: density (pieces/ha) of logs 210 cm in diameter at larger end

- 1 \* sound logs
- 2 \* rotten logs
- 3 \* logs >22 cm in diameter and 22 m long
- 4 \* logs >44 cm in diameter and 24 m long
- 5 \* logs 250 cm in diameter and of any length
- 6 \* logs 250 cm in diameter and ≥ 15 m long

Group: biomass (tons/ha) of logs 210 cm in diameter at larger end

- 1 \* sound logs
- 2 \* rotten logs
- 3 \* logs >22 cm in diameter and 22 m long
- 4 \* logs >44 cm in diameter and 24 m long
- 5 \* logs 250 cm in diameter and of any length
- 6 \* logs 250 cm in diameter and 115 m long

\* = variables that were transformed to attain normality

We used Wilks' lambda, which is an inverse measure of class separation ranging from 0 to 1, to assess the discrimination among age-classes. Structure coefficients, which are correlations between variables and canonical variate scores, were used to assess the importance of each variable. Variables with structure coefficients <0.30 were treated as of minor importance and were not used for interpretation of the canonical variates. Eigenvalues were reported as a measure of the relative contribution of each canonical variate to the discriminatory power of each model. The significance of each canonical variate was tested using a decomposition approach to Bartlett's *V* statistic (Bartlett 1947). Canonical variates that were not significant at the 0.05 level or better were disregarded. With equal prior probabilities, the percentage of training stands (the 56 stands used in the discriminant analyses) correctly assigned to their respective age-classes was used as a measure of classification success.

The variables retained by the 11 stepwise discriminant analyses were combined and analyzed in a final stepwise analysis. This final analysis selected variables representing several structural components. The classification error rate for the multiple components model was determined for old-growth and mature stands using the validation data set. We further tested the model for its ability to correctly assign young, mature, and old-growth stands to their respective age-classes using a jackknife classification procedure (Lachenbruch and Mickey 1968).

## Results

### Distinctive Features Within Individual Components

**Tree height (basal area)**—Most of the discrimination among age-classes was due to differences in the basal area of conifers  $\geq 40$  m tall (table 2). Conifers  $< 12$  m tall was of moderate importance. The basal area of tall conifers increased with forest age-class (fig. 1). The basal area of short conifers was highest in the young age-class, which resulted in strong discrimination of young stands from the other two age-classes (fig. 1).

**Tree height (density)**—Conifers 12 to 40 m tall and conifers  $\geq 40$  m tall were both important to the discriminant model (table 2). The higher density of conifers 12 to 40 m tall provided strong discrimination of the young age-class from mature and old-growth forests (fig. 2). Young stands were characterized by a dense layer of conifers intermediate in height, and a very low density of tall conifers. Mature stands generally had a moderately dense lower layer of conifers 12 to 40 m tall and relatively high densities of tall conifers. In old-growth forests, the density of conifers 12 to 40 m tall was typically low compared to young and mature stands. The density of tall conifers in old growth was similar to that of mature forests. The analysis of basal area data indicates, however, that the diameters of conifers  $> 40$  m tall are, on the average, considerably larger than the diameters of tall conifers in mature stands.

**Tree diameter (basal area)**—The basal area of conifers  $\geq 90$  cm in d.b.h. and the basal area of conifers  $< 45$  cm in d.b.h. were the most important features separating age-classes (table 2). The basal area of large-diameter conifers increased with age-class (fig. 3) and was more than two and a half times greater in old-growth than it was in mature stands. Conifers with large diameters were rare in young stands that were dominated by conifers  $< 45$  cm in d.b.h.

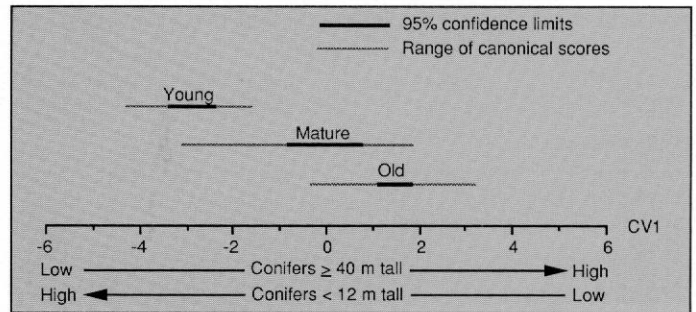


Figure 1—Ordination of forest age-classes according to basal area within tree height-classes (see tables 1 and 2). Significant separation of age-class means was restricted to the first canonical variate (CV1).

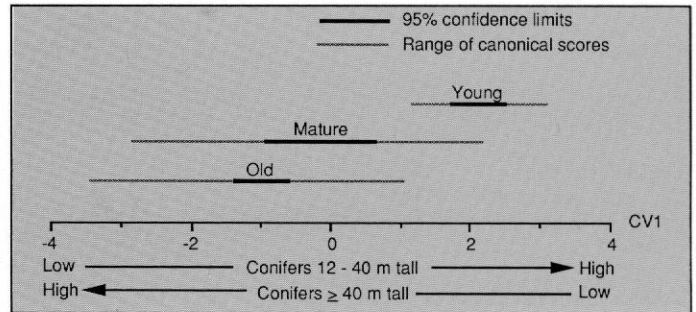


Figure 2—Ordination of forest age-classes according to density within tree height-classes (see tables 1 and 2). Significant separation of age-class means was restricted to the first canonical variate (CV1).

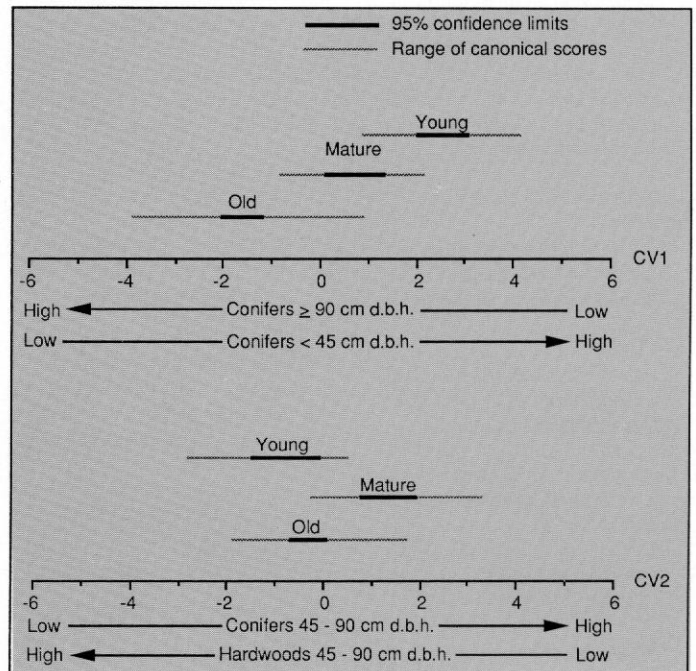


Figure 3—Ordination of forest age-classes according to basal area within tree diameter-classes (see tables 1 and 2). Significant separation of age-class means occurred for both canonical variates (CV1 and CV2).

**Table 2—Variables selected by stepwise discriminant analyses on 11 groups of variables representing six forest structure components. Data reported for forest age-classes are means with standard errors in parentheses**

Variable selected	Forest age-class			Structure coefficient	
	Young	Mature	Old growth	CV1	CV2 <sup>a</sup>
<b>I. Component: Tree height</b>					
group: basal area of trees ≥5 cm in d.b.h.					
Conifers ≥40 m tall	3.2 (1.1)	25.7 (4.0)	40.1 (2.4)	0.97	
Conifers <12 m tall	1.1 (.2)	.8 (.2)	.3 (.1)	-.61	
Wilks' lambda	0.227		Eigenvalue	3.31	
Exact <i>F</i> statistic (df = 4, 104) (significant at <i>P</i> < 0.001)	28.62		(%)	99	
Classification success (%)	100	57	82		
group: density of trees ≥5 cm in d.b.h.					
Conifers 12-40 m tall	321.2 (54.0)	138.6 (27.3)	38.8 (7.3)	.82	
Conifers ≥40 m tall	8.4 (3.1)	48.3 (7.7)	43.5 (2.1)	-.79	
Wilks' lambda	.297		Eigenvalue	1.69	
Exact <i>F</i> statistic (df = 4, 104) (significant at <i>P</i> < 0.001)	21.74		(%)	87	
Classification success (%)	93	72	68		
<b>II. Component: Tree diameter</b>					
Group: basal area of trees ≥5 cm in d.b.h.					
Conifers ≥90 cm in d.b.h.	1.1 (.6)	12.5 (2.5)	34.8 (2.4)	-.94	-.13
Conifers 45-90 cm in d.b.h.	7.8 (1.5)	19.3 (1.9)	8.4 (1.1)	.09	.94
Conifers <45 cm in d.b.h.	14.4 (2.5)	6.7 (1.5)	2.0 (.4)	.82	-.09
Hardwoods 45-90 cm in d.b.h.	5.3 (1.3)	2.8 (1.0)	5.4 (.7)	-.12	-.43
Wilks' lambda	.139		Eigenvalue	3.22	.70
Exact <i>F</i> statistic (df = 8, 100) (significant at <i>P</i> < 0.001)	21.00		(%)	82	18
Classification success (%)	100	71	89		
Group: density of trees ≥5 cm in d.b.h.					
Conifers ≥90 cm in d.b.h.	1.1 (.6)	13.5 (2.9)	28.9 (1.7)	-.97	.03
Conifers 45-90 cm in d.b.h.	31.1 (6.1)	56.9 (6.3)	21.7 (2.7)	.29	.94
Conifers <45 cm in d.b.h.	501.3 (80.9)	233.9 (53.0)	74.8 (13.8)	.80	-.05
Wilk's lambda	.190		Eigenvalue	2.67	.43
Exact <i>F</i> statistic (df = 6, 102) (significant at <i>P</i> < 0.001)	21.97		(%)	86	14
Classification success (%)	86	79	89		
<b>III. Component: Small trees</b>					
Group: density of saplings 1-8 m tall and <5 cm in d.b.h.					
Hardwoods 1-2 m tall	322.3 (53.4)	274.5 (76.3)	633.0 (70.6)	.58	.76
Conifers ≥4 m tall	67.9 (19.3)	19.0 (9.6)	17.6 (4.9)	-.78	.45
Conifers 1-2 m tall	175.7 (68.1)	123.8 (47.8)	114.7 (32.1)	-.25	-.03
Wilks' lambda	.483		Eigenvalue	.54	.34
Exact <i>F</i> statistic (df = 6, 102) (significant at <i>P</i> < 0.001)	7.46		(%)	61	39
Classification success (%)	79	64	61		



Table 2—continued

Variable selected	Forest age-class			Structure coefficient	
	Young	Mature	Old growth	CV1	CV2 <sup>a</sup>
III. Component: Small trees (continued)					
Group: density of seedlings					
<1 m tall					
Hardwoods 25-50 cm tall	1307.1 (305.0)	1370.4 (314.2)	1496.7 (144.3)	0.30	
Hardwoods ≥50 cm tall	783.1 (150.1)	617.5 (148.4)	1050.3 (102.0)	.79	
Wilks' lambda	0.776		Eigenvalue	.28	
Exact <i>F</i> statistic (df = 4, 104)			(%)	97	
(significant at <i>P</i> < 0.02)	3.52				
Classification success (%)	36	57	64		
IV. Component: Understory cover (percent)					
Group: shrubs and trees ≤8 m tall					
Cover of hardwoods	12.5 (2.3)	16.8 (4.3)	25.0 (2.2)	.82	
Cover of conifers	5.2 (1.3)	3.1 (.9)	2.3 (.4)	-.60	
Wilks' lambda	.684		Eigenvalue	.43	
Exact <i>F</i> statistic (df = 4, 104)			(%)	95	
(significant at <i>P</i> < 0.002)	5.43				
Classification success (%)	57	36	68		
Group: ground cover					
Moss and lichen cover	5.3 (2.2)	13.7 (4.8)	18.0 (3.4)	.89	
Vegetation cover 0.5-2 m tall	15.9 (2.2)	15.2 (4.2)	24.0 (2.5)	.69	
Wilks' lambda	.750		Eigenvalue	.27	
Exact <i>F</i> statistic (df = 4, 104)			(%)	86	
(significant at <i>P</i> < 0.01)	4.01				
Classification success (%)	50	43	68		
V. Component: Snags (standing dead trees)					
Group: density of snags ≥10 cm in d.b.h.					
Sound snags	43.1 (9.1)	46.4 (8.2)	14.2 (1.7)	.82	.33
Hardwood ≥20 cm in d.b.h. and ≥2 m tall	6.7 (2.3)	20.0 (5.1)	5.1 (1.2)	.31	.92
Rotten snags	46.1 (7.8)	39.2 (7.4)	17.6 (2.0)	.79	.05
Conifer ≥40 cm in d.b.h. and ≥4 m tall	1.6 (.5)	1.4 (.5)	4.9 (1.0)	-.48	.22
Wilks' lambda	.394		Eigenvalue	.99	.27
Exact <i>F</i> statistic (df = 8, 100)			(%)	78	22
(significant at <i>P</i> < 0.001)	7.41				
Classification success (%)	50	57	82		
VI. Component: Logs (dead wood on the ground)					
Group: density of logs ≥10 cm in diameter at largest end					
Logs >44 cm in diameter and ≥4 m long	29.1 (8.1)	7.2 (2.4)	24.7 (3.0)	.48	
Logs ≥50 cm in diameter	129.1 (24.8)	100.3 (12.1)	81.8 (5.7)	-.35	
Sound logs	59.2 (12.3)	61.8 (16.4)	80.1 (8.8)	.40	
Wilks' lambda	.526		Eigenvalue	.67	
Exact <i>F</i> statistic (df = 6, 102)			(%)	83	
(significant at <i>P</i> < 0.001)	6.45				
Classification success (%)	50	57	71		

Table 2—continued

Variable selected	Forest age-class			Structure coefficient	
	Young	Mature	Old growth	CV1	CV2 <sup>a</sup>
VI. Component: Logs (continued) Group: biomass of logs ≥10 cm in diameter at larger end Logs >44 cm in diameter and ≥4 m long	16.2	(5.1)	3.5 (1.1)	18.2 (3.6)	1.00
Wilks' lambda	0.828			Eigenvalue	.21
Exact <i>F</i> statistic (df = 2, 53) (significant at <i>P</i> < 0.02)	5.49			(%)	100
Classification success (%)	21	71	54		

<sup>a</sup> Structure coefficients not shown where CV2 was not significant (*P* > 0.05).

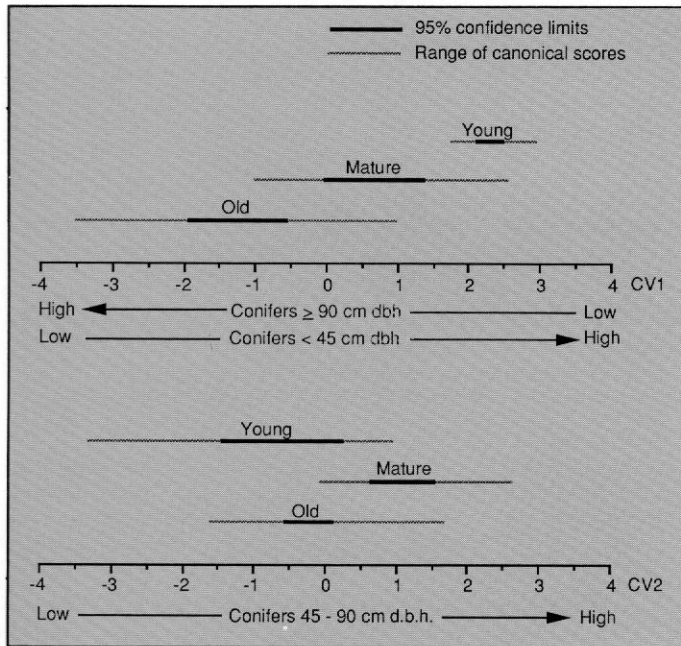


Figure 4—Ordination of forest age-classes according to density within tree diameter-classes (see tables 1 and 2). Significant separation of age-class means occurred for both canonical variates (CV1 and CV2).

Two other variables, the basal area of conifers 45 to 90 cm in d.b.h. and hardwoods 45 to 90 cm in d.b.h. were important in discriminating mature stands from young and old-growth (table 2). Mature stands were further distinguished from young and old-growth stands by having higher basal area of conifers 45 to 90 cm in d.b.h. and lower basal area of hardwoods 45 to 90 cm in d.b.h. The basal area values of medium-sized conifers and medium-sized hardwoods in the young age-class were very similar to old growth. As stands advance to a mature stage, hardwoods become overtopped by taller

conifers, resulting in an increase in hardwood mortality. As mature stands develop further, the upper tier of conifers undergoes natural thinning and the hardwoods typically return.

**Tree diameter (density)**—Three diameter-classes of conifers were important to the discriminant model (table 2). Separation of the three age-classes was strong (fig. 4) and very similar to that provided by the basal-area model. The density of conifers ≥90 cm in d.b.h. increased with age-class, and the density of conifers <45 cm in d.b.h. decreased. Mature forests had the greatest densities of conifers 45 to 90 cm in d.b.h., which was important in discriminating mature from the other two age-classes.

**Small trees (saplings)**—Two sapling variables, the density of conifers ≥4 m tall and the density of hardwoods 1 to 2 m tall were important to the model (table 2). They provided moderate separation of the forest age-classes (fig. 5). The young age-class was the most distinct because of the high density of conifer saplings ≥4 m tall. Mature and old-growth forests were similar in their densities of conifer saplings. The most important feature distinguishing old growth was a high density of hardwood saplings 1 to 2 m tall. Discrimination of the mature age-class was due to densities of hardwood saplings that were typically lower than the densities found in young and old-growth forests.

**Small trees (seedlings)**—The analysis of seedling variables selected hardwoods ≥50 cm tall and hardwoods 25 to 50 cm tall (table 2). Overall, discrimination was weak. Old-growth was the most distinct age-class (fig. 6). The separation was primarily due to the density of hardwoods ≥50 cm tall, which was typically highest in old growth and lowest in mature forests.

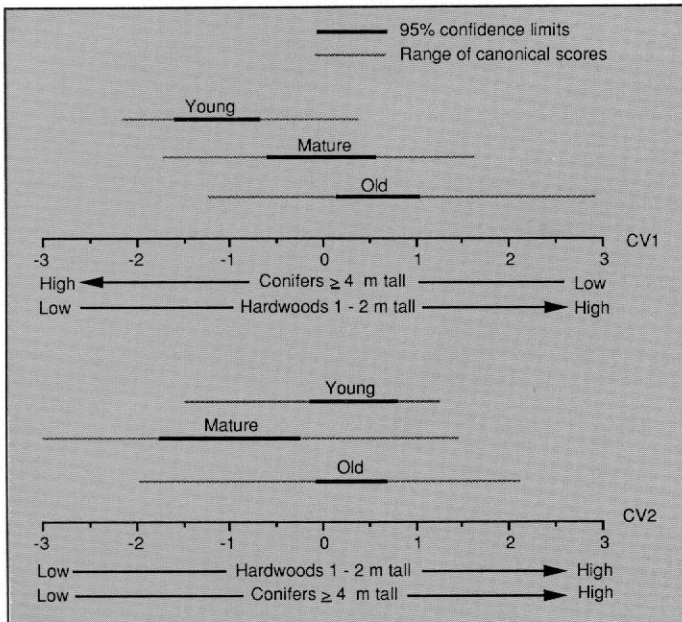


Figure 5—Ordination of forest age-classes according to density within height-classes of small trees 1 to 8 m tall (see tables 1 and 2). Significant separation of age-class means occurred for both canonical variates (CV1 and CV2).

**Understory cover (shrubs and small trees)**—Two variables, the cover of hardwoods  $\leq 8$  m tall and the cover of conifers  $\leq 8$  m tall, were important to the model (table 2). Discrimination was moderate. The cover of hardwoods increased with age-class, and the cover of conifers decreased (fig. 7). Old growth was the most distinct age-class. The cover of hardwoods in old growth averaged twice that of young stands, and the cover of conifers in young stands averaged twice that of old growth.

**Understory cover (ground cover)**—The analysis selected the combined cover of mosses and lichens, and the total vegetation cover from 0.5 to 2 m tall (table 2). Discrimination between young and mature stands was weak. Old growth was the most distinct age-class (fig. 8). Old growth showed the greatest development of moss and lichen cover, the more important variable in the model. Old growth also had the highest cover of vegetation 0.5 to 2 m tall.

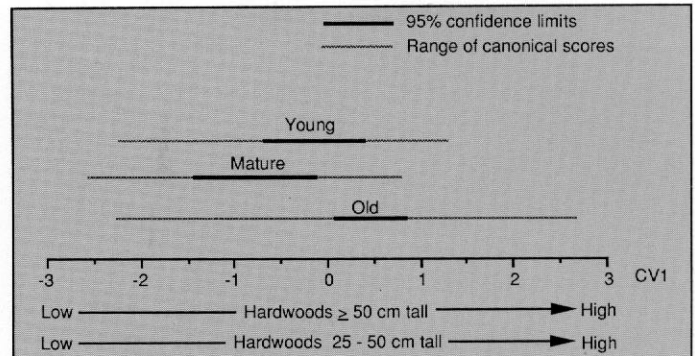


Figure 6—Ordination of forest age-classes according to density within height-classes of small trees  $<1$  m tall (see tables 1 and 2). Significant separation of age-class means was restricted to the first canonical variate (CV1).

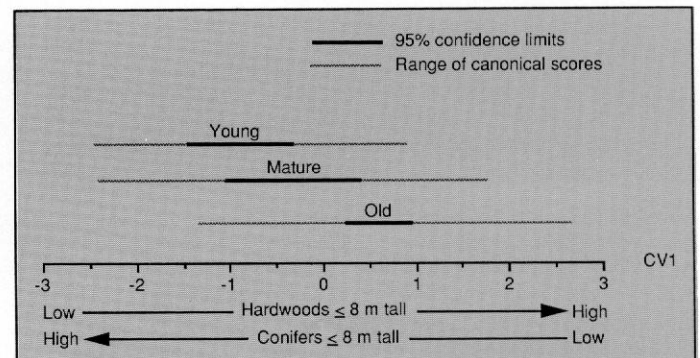


Figure 7—Ordination of forest age-classes according to understory cover of shrubs and small trees  $\leq 8$  m tall (see tables 1 and 2). Significant separation of age-class means was restricted to the first canonical variate (CV1).

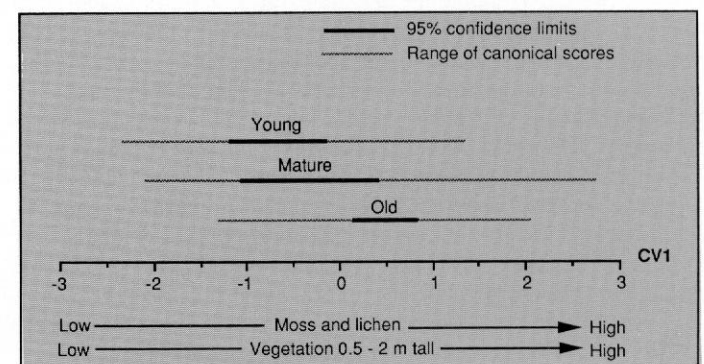


Figure 8—Ordination of forest age-classes according to ground cover variables (see tables 1 and 2). Significant separation of age-class means was restricted to the first canonical variate (CV1).

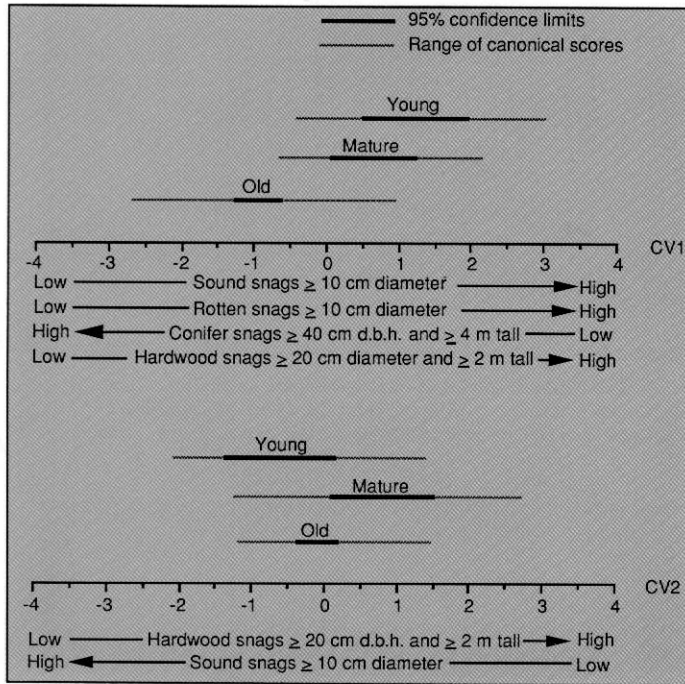


Figure 9—Ordination of forest age-classes according to density within size- and decay-classes of snags (see tables 1 and 2). Significant separation of age-class means occurred for both canonical variates (CV1 and CV2).

**Snags (density)**—The density of sound snags and the density of rotten snags were the two most important variables to the model (table 2). The model was strongest in discriminating old-growth from young and mature stands. Old growth was characterized by having the lowest densities of sound and rotten snags (fig. 9). A higher density of large conifer snags  $\geq 40$  cm in d.b.h. and  $\geq 4$  m tall also contributed to the discrimination of old growth. Young and mature forests were similar to one another in their densities of sound, rotten, and large conifer snags. A fourth variable, the density of hardwood snags  $\geq 20$  cm in diameter and  $\geq 2$  m tall was important in discriminating mature stands. In young, mature, and old-growth forests, hardwoods are typically an important contributor to the snag component. Hardwoods can be especially important in mature stands, however, where they often account for up to 90 percent of the total snag density.

**Logs (density)**—Three variables were selected, all of similar importance to the model (table 2). Although separation between the young and mature age-classes was poor, discrimination of old growth was fairly strong (fig. 10). Old growth was distinguished from the two younger classes by having the highest density of sound logs and the lowest density of logs  $\geq 50$  cm in diameter. Mature stands typically had low densities of large logs  $>44$  cm in diameter and  $\geq 4$  m long. Young and old-growth stands had similar densities of logs

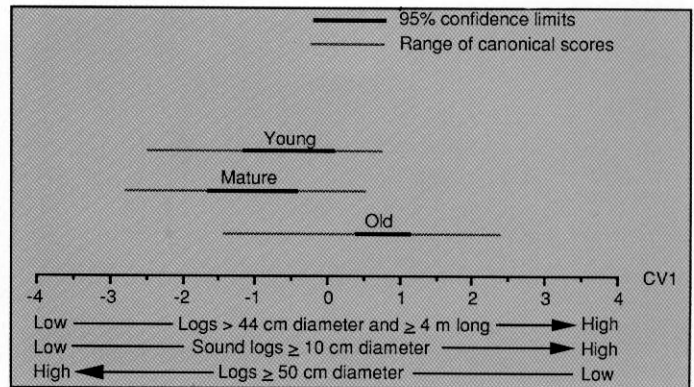


Figure 10—Ordination of forest age-classes according to density within size- and decay-classes of logs (see tables 1 and 2). Significant separation of age-class means was restricted to the first canonical variate (CV1).

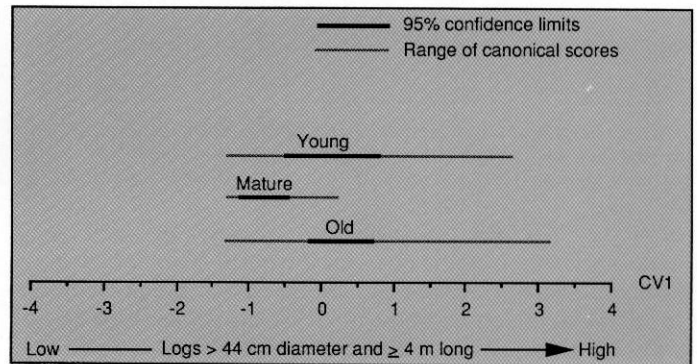


Figure 11—Ordination of forest age-classes according to biomass within size- and decay-classes of logs (see tables 1 and 2). Significant separation of age-class means was restricted to the first canonical variate (CV1).

$>44$  cm in diameter and  $\geq 4$  m long. In young stands, the abundance of large pieces of wood on the ground was evidently an artifact of the logging methods practiced more than 40 years ago.

**Logs (biomass)**—Only one variable was selected by the analysis of log biomass (table 2). The biomass of logs  $\geq 44$  cm and  $>4$  m long provided essentially no power in distinguishing old growth from the young age-class (fig. 11); both of which showed similar averages. A low biomass of large logs, however, clearly separated mature from the young and old-growth classes.

#### Distinctive Features Based on Multiple Components

Stepwise discriminant analyses of the 11 groups of variables representing six forest-structure components (table 1) selected 28 variables (table 2). A final stepwise analysis selected 8 of the 28 variables and produced a model that was very