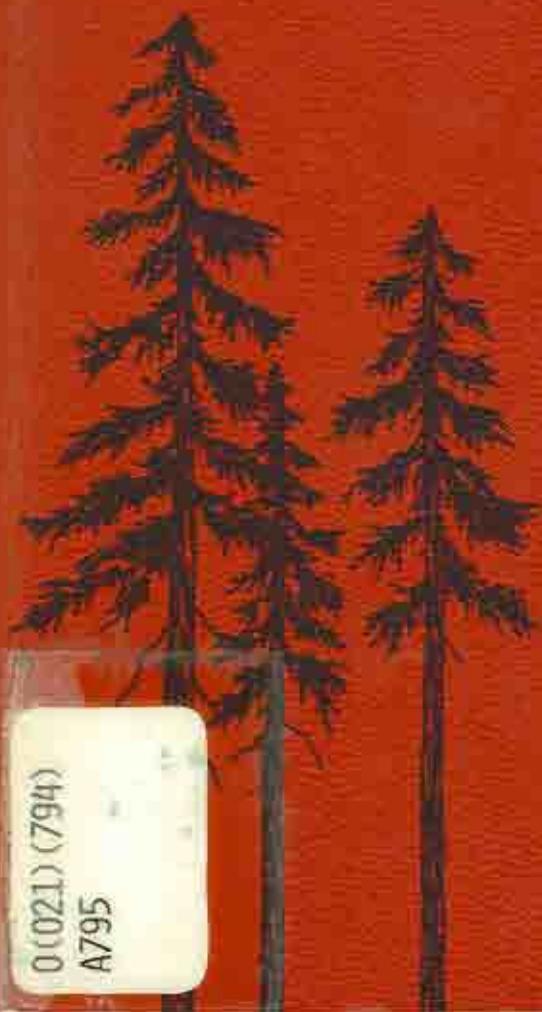


CALIFORNIA FORESTRY HANDBOOK

by
T. F. Arvola



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF FORESTRY

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CALIFORNIA FORESTRY HANDBOOK

by

T. F. Arvola

State of California
The Resources Agency
DEPARTMENT OF FORESTRY
Sacramento 1978

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FOREWORD

In the late 1940s the California Division of Forestry published two handbooks that proved to be very popular and useful. These were respectively the Redwood Forest Handbook by Jack Reveal and Arnold Wallen and the California Pine Region Forest Handbook by George A. Craig and William P. Maguire. Although these handbooks have been out of stock for a number of years, there still has been a demand for them, despite the fact that they contain some outdated information and lack recent knowledge of value in forestry practices today.

To fill this need we decided to publish a new combined version of these handbooks; this was made possible by financial assistance from the U.S. Forest Service. The main purpose of this book is to provide a practical forestry guide for the management of the 3.6 million acres of commercial forest lands held in farm and small ownerships in California. These lands represent 47 percent of the 7.6 million acres of privately owned commercial forest land in the state. This reference is therefore written for use principally by such forest owners, timber operators, and forest technicians. Of course, forestry students and professional foresters may have some use of this text, but in no way will it supplant much more elaborate publications like the Forestry Handbook produced by the Society of American Foresters and many other technical references a forester must utilize. The California Forestry Handbook will not make a forester out of a person, nor preclude the need for use of consulting foresters in the management of many small ownerships. However, this handbook may make it possible for a tree farmer, timber operator, or technician to understand and apply practical forestry knowledge to enhance his or her situation and thereby improve forest management practices in California.

The author of this handbook is Tobe Arvola, a Fellow in the Society of American Foresters. In addition to obtaining a forestry degree from the University of California in 1938, the author took pre-forestry courses at Humboldt State University and did graduate study in meteorology at UCLA and the University of Chicago. He served as Deputy State Forester in charge of resource management programs for the California Division (now Department) of Forestry for 27 years. Early in his career he also had a number of years of experience in timber management with the U. S. Forest Service, the redwood industry, and as the first manager of Jackson State Forest. Since retiring in 1975, the author produced an earlier CDF production—Regulation of Logging in California: 1945–1975.

L. A. Moran
Director of Forestry

ACKNOWLEDGEMENTS

The author has had fine cooperation and assistance from many people and organizations in this endeavor. First to be recognized are the authors and their collaborators of the two original CDF forest handbooks, whose pioneering made it so much easier to produce this work. In fact, some of the organization, figures, and tables which are still appropriate were retained in this combined version.

In addition to generous financial support, U. S. Forest Service staff in San Francisco, through Robert W. Gustafson, was very helpful in supplying technical data, editorial advice, and other assistance. Peter C. Passof of the University of California Cooperative Extension Service deserves special mention for his comprehensive review of the manuscript. Much of the workload fell on the California Department of Forestry, principally Chief of Resource Management James C. Denny, Robert J. Malain, Brian R. Barrette, and other CDF specialists. Credit is also due to Gerald Brown and the CDF graphic services unit, Mae McFadin and assistants of the Department of Conservation for preparation of some tables, Marjorie Blair for typing and proofing, my wife Margaret for proofing help and moral support, Allison Haapala for the cover design, Nancy Rogers for many favors during processing of the manuscript, and the Office of State Printing. There were many other persons within and without the CDF that furnished valuable advice and help, but are too numerous to mention individually, but certainly deserve recognition and a word of appreciation.

T.F.A.

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Timber and wood products are very much a part of our economic base and that base has to be built, protected and enhanced.

Edmund G. Brown Jr.
Governor
1978 Budget Message



Chapter 1

THE TREE

The tree is a wonderful thing in countless ways. It provides us with food, shelter, beauty, inspiration, and over 5,000 different wood products. The tree forms the basic unit of the forest community, so we need to know and understand it in order to use our commercial forests wisely.

Definition and Composition

A tree is a woody perennial plant, typically larger than other plants, and usually with a single, well defined stem supporting a crown of branches. As a conglomerate of roots, stem or trunk, branches, leaves, and fruit, all of which have specialized functions (see Figure I-1)*, the tree is a complex organism. Trees, even of the same species, vary widely in size and shape. This diversity offers us many opportunities for making good use of the great variety of trees that we have.

The roots hold the tree upright, absorb water and nutrients from the soil, conduct them upward, and store food made by the foliage. Oxygen from within the soil is necessary for roots to function. The larger and older roots, which like branches have heartwood, sapwood, and bark, provide the physical support for the tree. The smaller roots, which are hairlike at the extremities, absorb water and minerals needed for growth.

The trunk also serves a number of purposes. It conducts water and nutrients from the roots to the crown, moves food from the crown to other parts of the tree, and it lifts the branches and leaves to collect the sun's energy. The heartwood of the trunk is relatively lifeless compared to the outside layer, from which it was formed. It is darker because its cells contain a deposition of complex compounds, which in many species improve the durability of the wood. The outer sapwood is lighter in color, and composed of living cells that move water and nutrients upward. A microscopic growth layer, called the cambium, located between the sapwood and the inner bark, produces new sapwood and bark cells each year; this causes the tree to grow in diameter.

Like the woody part of the trunk, the bark has its live and dead parts. The spongy, wet inner bark carries food from the leaves to the adjacent cambium layer and the growing tips of branches and roots. The outer bark layer is dry and lifeless; it protects the tree from damage by weather, fire, pests, and physical contact.

The crown of the tree is composed of branches, twigs, foliage, and reproductive organs like flowers and fruit. Using sunlight, water and nutrients from the roots, and carbon dioxide from the air, the leaves manufacture (photosynthesize) the tree's own food in the form of various sugars. Oxygen is a valuable by-product of photosynthesis.

Flowers and fruits of trees vary greatly among species. They provide the most reliable means for identifying different species of plants. Some spe-

*The first digit (roman) of the figure and table numbers represent the chapter, and the second digit (arabic) is the sequential number within the chapter. Tables and figures in the appendix are preceded by A followed by a sequential number.

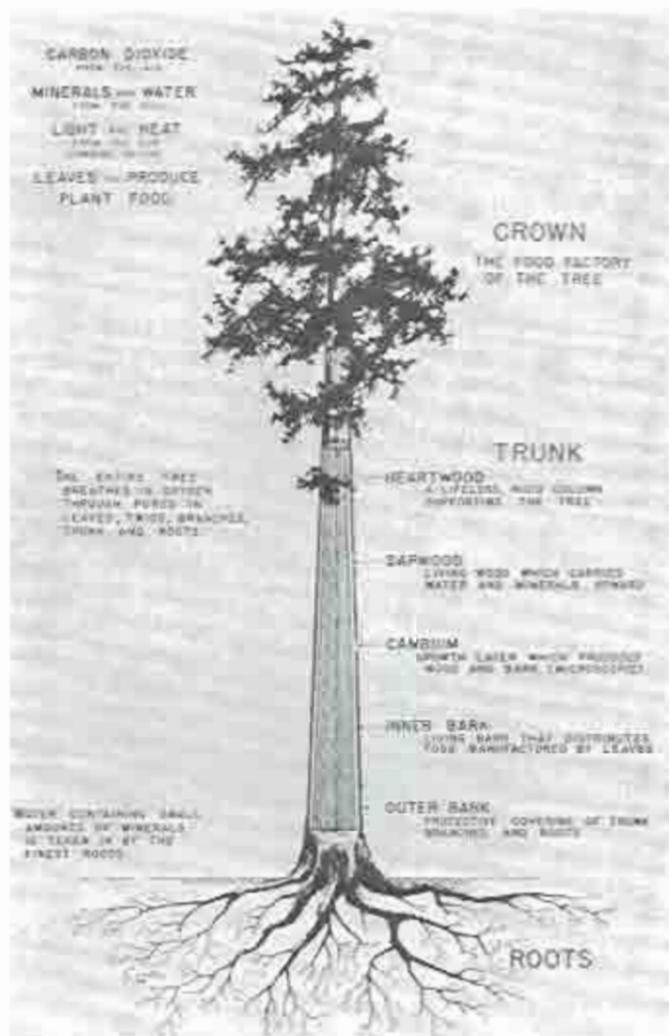


Figure 1-1
Structure and growth of the tree.

cies are monoecious, meaning they contain both male and female flowers on the same tree. Other species are dioecious, having male and female flowers separately on different trees. All the California conifers, except juniper and yew, are monoecious. Similarly, most of our broadleaved trees have flowers of both sexes on the same tree, excepting only Oregon ash, aspen, cottonwood, and the willows. The pines, Sierra redwood, cypress, Port Orford cedar, juniper, and nutmeg require two years to produce mature fruits and seeds; all other conifers require only one year. Most of our broadleaved trees grow their fruits in one year, excepting only some oaks.

How a Tree Grows

All the main parts of a tree contribute to its growth (Figure I-1). As a tree grows, each year its roots, trunk, and branches add a new layer of wood just inside the bark. These annual rings can be readily seen on tree stumps, cross sections of limbs, and the ends of lumber. These concentric rings stand out because each ring has a light-colored band of springwood and a usually narrower and darker band of summerwood. The springwood part is generally wider because it is formed in the growing season when water and other conditions are most favorable. We shall see later that the age and growth information reflected in annual rings is very useful in the management of forests.

The bark layer is also continually growing. Each year a narrow ring is grown on the inside of the bark. This gradually forces the older bark out and causes it to form plates, ridges, and troughs, which slowly deteriorate and erode, especially on the lower trunk.

Elongation of tree stem and branches is a much different process. It is brought about by the formation of terminal and side buds during the fall, which burst and grow lengthwise in the spring. This growth is always an additive process, so the middle of the branches and trunk do not elongate at all, nor is the tree pushed out of the soil like corn or bamboo.

Roots also extend themselves to seek water and nutrients. They elongate in the area behind their tips, whose caps continually produce new cells. Lateral root hairs absorb water and nutrients.

Tree growth depends on the species, age, soil, climate, and growing conditions. Fast-growing, thrifty trees have thick annual rings and large crowns. In conifers, usually one whorl of branches on the stem is produced each year, the spacing of which is a good indicator of growth. Spacing of 12 inches or more between whorls in young trees represents good growth. As a tree matures its top begins to flatten and the whorl spacing diminishes or even ceases.

Trees reproduce from seed or by sprouts (sometimes known as suckers or coppice growth). All of our tree species produce seed. Many hardwoods develop sprouts also, particularly after cutting, but among our conifers only the coast redwood is a sprouter. It also produces burls made up of many buds that are capable of sprouting.

Kinds of Trees

There are many kinds of trees having some value as wood. They are divided into two broad classes—conifers or softwoods, and broadleaved or hardwoods. The softwood-hardwood terminology is somewhat confusing because some softwoods like Douglas-fir are harder than some hardwoods like aspen.

All plants have two kinds of names—common and scientific. Common names often vary by locality, although within professional circles only one

common name is usually used. For instance, ponderosa pine is sometimes termed western yellow pine, blackjack pine, or bull pine, but ponderosa is the accepted common name by botanists and foresters. To avoid this kind of confusion, and to classify plants, botanists developed scientific names. Thus ponderosa pine is named *Pinus ponderosa*, *Pinus* being the genus the tree belongs to and *ponderosa* being the species name. Sometimes a third category is added, the variety; e.g., our boxelder is called *Acer negundo californicum* to distinguish it from the eastern boxelder. See Table I-1 for a listing of our more common native trees, and the Appendix for a reference on tree identification.

Table I-1. The more common native trees of California.

CONIFERS	
Common Name	Scientific Name
Bigcone-spruce	<i>Pseudotsuga macrocarpa</i>
Cypress, MacNab	<i>Cupressus macnabiana</i>
Cypress, Monterey	<i>Cupressus macrocarpa</i>
Cypress, pygmy	<i>Cupressus pygmaea</i>
Cypress, Sargent	<i>Cupressus sargentii</i>
Douglas-fir	<i>Pseudotsuga menziesii</i>
Fir, California red	<i>Abies magnifica</i>
Fir, grand	<i>Abies grandis</i>
Fir, white	<i>Abies concolor</i>
Hemlock, mountain	<i>Tsuga mertensiana</i>
Hemlock, western	<i>Tsuga heterophylla</i>
Incense-cedar	<i>Libocedrus (Calocedrus) decurrens</i>
Juniper, California	<i>Juniperus californica</i>
Juniper, Utah	<i>Juniperus utahensis</i>
Juniper, western	<i>Juniperus occidentalis</i>
Nutmeg, California	<i>Torreya californica</i>
Pine, Bishop	<i>Pinus muricata</i>
Pine, Coulter	<i>Pinus coulteri</i>
Pine, Digger	<i>Pinus sabiniana</i>
Pine, Jeffrey	<i>Pinus jeffreyi</i>
Pine, knobcone	<i>Pinus attenuata</i>
Pine, limber	<i>Pinus flexilis</i>
Pine, lodgepole	<i>Pinus contorta</i>
Pine, Monterey	<i>Pinus radiata</i>
Pine, ponderosa	<i>Pinus ponderosa</i>
Pine, sugar	<i>Pinus lambertiana</i>
Pine, western white	<i>Pinus monticola</i>
Pine, whitebark	<i>Pinus albicaulis</i>
Port Orford-cedar	<i>Chamaecyparis lawsoniana</i>
Redwood, coast	<i>Sequoia sempervirens</i>
Redwood, Sierra	<i>Sequoia gigantea (Sequoiadendron giganteum)</i>
Spruce, Sitka	<i>Picea sitchensis</i>
Western red-cedar	<i>Thuja plicata</i>
Yew, Pacific	<i>Taxus brevifolia</i>

HARDWOODS

Common Name	Scientific Name
Alder, red	<i>Alnus rubra</i>
Alder, white	<i>Alnus rhombifolia</i>
Ash, Oregon	<i>Fraxinus latifolia</i>
Aspen	<i>Populus tremuloides</i>
Boxelder	<i>Acer negundo</i> var. <i>californicum</i>
Buckeye, California	<i>Aesculus californica</i>
California myrtle	<i>Myrica californica</i>
Cascara	<i>Rhamnus purshiana</i>
Chinkapin, golden	<i>Castanea chrysolophylla</i>
Cottonwood, black	<i>Populus trichocarpa</i>
Dogwood, Pacific	<i>Cornus nutallii</i>
Laurel, California	<i>Umbellularia californica</i>
Madrone	<i>Arbutus menziesii</i>
Maple, bigleaf	<i>Acer macrophyllum</i>
Oak, blue	<i>Quercus douglasii</i>
Oak, California black	<i>Quercus kelloggii</i>
Oak, California live	<i>Quercus agrifolia</i>
Oak, canyon live	<i>Quercus chrysolepis</i>
Oak, interior live	<i>Quercus wislizenii</i>
Oak, Oregon white	<i>Quercus garryana</i>
Oak, valley	<i>Quercus lobata</i>
Sycamore	<i>Platanus racemosa</i>
Tanoak	<i>Lithocarpus densiflora</i>
Walnut, California black	<i>Juglans hindsii</i>
Willow	<i>Salix</i> , sp.

The conifers are the more important to us here in California. All of them are evergreen, most bear cones, and have needles or scale-like leaves. The principal ones are the pines, the true firs, and Douglas-fir. We also have a few cedars, hemlocks, and spruces that have commercial value.

The hardwoods, although very valuable in eastern United States, at present do not have as much commercial importance in the west as the conifers. However, a few of our broadleaved species have a good potential for specialty lumber and veneer, and most of them will have increasing use as fuel. They are characterized by flat, usually broad leaves, irregular branching, wide crowns, and varying kinds of fruits. Most of our hardwoods are deciduous, but several are evergreen, e.g., madrone, California laurel, tanoak, and a few oaks.

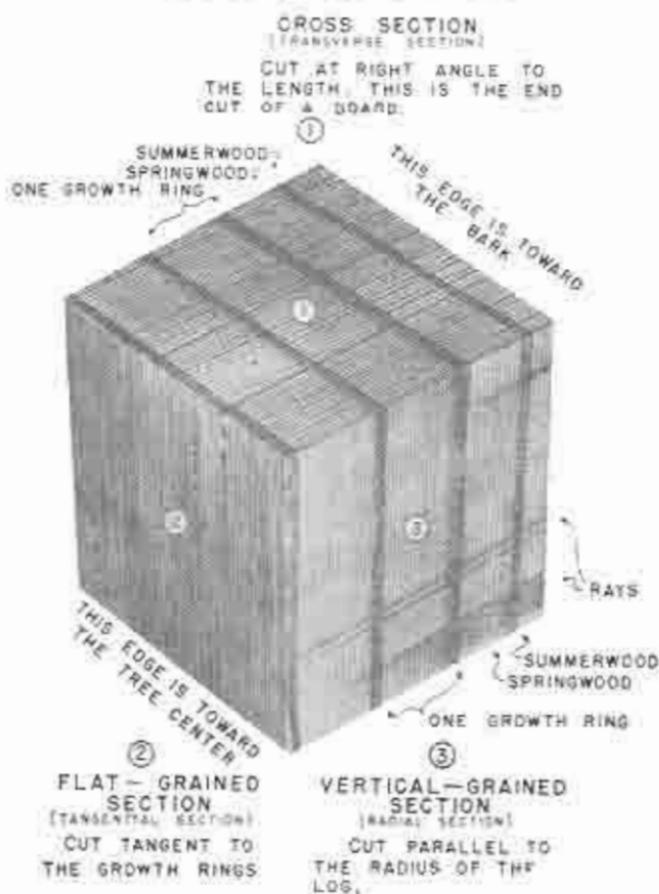
Wood Characteristics

Taking a close look at wood, we find a remarkable structure (Figure I-2). It is largely composed of millions of small, narrow, hollow cells, or fibers which are oriented parallel to the tree's stem. Some cells form rays that are perpendicular to the axis. There are a number of other cells that have specialized functions, like resin ducts in some conifers, and vessels or pores in broadleaved trees.

CALIFORNIA FORESTRY HANDBOOK

SOFTWOOD UNDER THE MICROSCOPE

(BLOCK, ORIGINALLY 3/16" ON SIDE)



From Emanuel Fritz,
School of Forestry, Berkeley, California

Figure 1-2
A detailed view of the structure of wood.
Emanuel Fritz

The composition and arrangement of these various elements, along with the springwood, summerwood, heartwood, and sapwood, determine the characteristics and properties of wood. This can vary widely among the different species, and also between trees of the same species, or even within the same tree. Grain, texture, and figure of wood are affected by these elements and the way a log is sawn. Flat grained lumber is cut tangentially with the annual rings and vertical grained or quarter sawn boards are cut parallel to the radius of the log (Figure 1-2). The cellular make-up of the wood affects weight (which is also influenced greatly by the moisture content), stability (shrink and swell), strength, hardness, workability, and durability.

Scientists have developed a lot of quantitative data of this kind about woods from all over the world, which are readily available for use by wood processors and users. Table I-2 presents data on weight, fuel value, and durability of our more common species in California.

Table I-2. Some properties of selected woods.

Species	Weight		Fuel Value Thousand BTU ^c Cu Ft	Decay Resistance
	Air Dry Sawn ^a Lbs/Cu Ft	Average Logs ^b Lbs/ Bd Ft		
Alder, red	27	8.5	173	Low
Ash, Oregon	34	-	250	Low
Aspen	25	-	156	Low
Chinkapin, Califor- nia	32	-	-	Medium
Cottonwood	24	10.0	160	Low
Dogwood	45	-	307	Low
Douglas-fir	32	8.0	213	Medium
Eucalyptus, blue gum	52	-	389	Low
Fir, true	27	8.5	187	Low
Hemlock, moun- tain	33	-	227	Low
Hemlock, western	27	10.0	224	Low
Incense-cedar	26	-	187	High
Laurel, California	39	-	289	Low
Madrone	45	-	307	Low
Maple, bigleaf	34	-	240	Low
Oak, California black	40	-	280	Low
Oak, canyon live	54	-	373	Low
Oak, Oregon white	50	-	347	High
Pine, Jeffrey	28	-	213	Low
Pine, lodgepole	29	-	213	Medium
Pine, ponderosa	28	9.0	213	Low
Pine, sugar	25	10.0	173	Medium
Pine, western white	27	-	213	Medium
Port Orford-cedar	29	10.0	-	High
Redwood, coast	28	7.5	200	High
Spruce, Sitka	28	6.5	227	Low
Tannak	40	-	280	Low
Walnut, black	38	-	267	High
Western red-cedar	23	8.0	223	High
Willow	31	-	213	Low
Yew	44	-	307	High

^a At 12% moisture content

^b For gross logs 18" in diameter at small end (weight varies widely)

^c British Thermal Unit

Source: various

Chapter II

THE FOREST AND ITS MANAGEMENT

An extensive grouping of trees makes a forest. More specifically, it is a plant community composed predominantly of trees and other vegetation, growing more or less close together. A forest is a complicated and delicate ecosystem consisting of soil, trees, and many associated flora and fauna. Great care and skill are necessary in the use of the forest in order to maintain this balance of nature to a reasonable degree, to prevent irreparable environmental damage, and to keep the forest continually providing its many benefits to us. It is a renewable resource and a big energy producer.

This husbandry requires the application of forestry or forest management—the science, art, and practice of managing and using for human benefit the various natural resources that occur on and in association with forest lands. The forest values include protection of watersheds (a very important function in California); habitat for wildlife, outdoor recreation, other environmental benefits, grazing for livestock, and a whole host of forest products, which is of prime interest to us in this handbook.

Silvics and Silviculture

In order to manage our forests properly for wood crops, we should have some basic knowledge about silviculture in addition to the information about the tree covered in the previous chapter. This gives us an understanding of the life history and characteristics of trees and forest stands (silvics) and how they can be established, grown, and tended (silviculture). How well a tree grows depends on its native characteristics, its relationships with other trees and plants, its setting, and how we treat it.

Site

The growth rate is determined largely by what is called the forest or timber site—a measure of productivity based on how trees respond to the soil and climate of the immediate area. Generally, deep, well-drained, clay-loam soils with plenty of moisture are the best. Soils are classified by series names. Some of the more common better forest soils are shown below (see Watershed Management section in Chapter X for a listing of erosive soils):

Redwood-Douglas-Fir Region

Empire
Hely
Hugo
Josephine
Larabee
Masterson
Melbourne
Mendocino
Orick
Sites

Pine Region

Aiken
Cohasset
Holland
Josephine
McCarthy
Musick
Shaver
Sites

Many of the forest soils in California have been surveyed by the State Cooperative Soil-Vegetation Survey, and maps delineating the various series of soils and the principal vegetation are available at low cost. These maps and legends are of immense value to tree farmers and forest managers. In addition to kinds of soil, they provide data on depth, slope, predominant plant species, erosion potential, and timber site. You can obtain literature, instructions on ordering the maps, and assistance in using them from forest advisers located in various offices of the California Department of Forestry. Soils information is also available from county farm advisers and the U.S. Soil Conservation Service.

Climate in California is the most diverse in the U.S. Usually forest growth is better where annual precipitation is greater. For example, the coast redwood type occurs where rainfall is the highest in the state, and it also has the best growth. In most cases, except in areas of summer rain showers, like the eastside of the Cascade Range and the Sierra Nevada, about 18 inches or more of precipitation is required yearly to sustain natural coniferous forests.

The site quality naturally varies a great deal among forests and even within a single forest. A measurement called site index is used by foresters for various purposes. It represents the height of dominant and codominant trees in a stand at a standard age, usually 100 years. Height in feet of such trees is found by methods described in Chapter V. The age is determined by using an increment borer (see section below on growth). This auger is used to extract a pencil-like core out of a tree trunk at breast height on which the number of annual rings to the center of the tree can be counted. When trees are too thick to bore, the age can be found by counting rings on stumps of felled trees nearby. Using a prepared table like Tables II-1, 2, 3, or site curves in the Appendix, a person can look up the site index. For instance, using Table II-1, a 70-year-old, 134-foot tall dominant tree in the pine region would indicate a site index of 160—a good site. To simplify matters site indices are usually grouped into classes. The classes employed are shown in Table II-4.

There is an easy method to roughly estimate the site quality of a forest, which was briefly mentioned in Chapter I; that is by looking at the distance between the upper branch whorls of thrifty trees. Two-foot or more spacing indicates high site, between one-half and two feet represents a medium site, and less than that a poor site.

Age and Forest Types

Most natural timber stands in California are all-aged (also called uneven-aged); that is, they contain a mixture of immature, mature, and over-mature trees. Typical of all-aged forests is the extensive mixed conifer type in the pine region. Douglas-fir and redwood are also all-aged, but may also grow in even-aged stands, meaning that most trees are approximately of the same age. Red fir and lodgepole pine stands are mostly even-aged. The structure of these two categories is much different; all-aged stands have trees of varying diameters and heights while even-aged stands have trees that are more uniform. Age class is another common term in forestry. It denotes the interval, usually 10 years, into which the age range of tree

Table II-1. Height of average dominant and codominant ponderosa pine at 100 years.

Age	Height, by site index											
	50	60	70	80	90	100	110	120	130	140	150	160
	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet
20	9	12	14	20	25	30	35	40	45	50	55	60
30	14	20	26	32	39	44	51	57	64	70	77	84
40	22	28	33	42	49	55	63	70	77	85	92	100
50	28	35	43	51	59	65	75	80	88	97	105	112
60	34	42	50	58	67	75	83	90	99	107	115	124
70	39	47	56	64	73	80	89	98	108	115	123	131
80	43	52	61	70	79	88	97	106	116	124	132	141
90	47	57	66	75	84	94	104	113	123	132	142	152
100	50	60	70	80	90	100	110	120	130	140	150	160
110	53	63	74	84	94	104	114	124	134	144	154	164
120	55	65	77	88	100	111	122	133	144	154	165	175
130	57	69	80	92	104	116	128	139	151	162	172	182
140	59	71	83	96	108	121	133	145	157	167	179	189
150	60	73	86	99	112	125	138	151	163	175	187	198
160	61	75	89	102	116	129	143	156	169	181	194	207
170	62	77	91	105	119	133	147	161	174	188	201	214
180	63	78	93	108	122	136	151	165	179	192	205	218
190	63	79	94	110	125	139	154	169	183	196	209	221
200	64	80	95	112	126	141	157	172	187	199	212	226

U.S.F.S., Meyer, 1938

Table II-2. Height (in feet) of average dominant and codominant Douglas-fir at 100 years.

Age (years)	Site Class V		Site Class IV			Site Class III			Site Class II			Site Class I		
	Site index 80	Site index 90	Site index 100	Site index 110	Site index 120	Site index 130	Site index 140	Site index 150	Site index 160	Site index 170	Site index 180	Site index 190	Site index 200	Site index 210
	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet
20	21	24	26	29	31	34	37	39	42	44	47	49	52	54
30	27	31	34	37	40	43	46	49	52	55	58	61	64	66
40	34	39	43	47	51	55	59	63	67	71	75	79	83	86
50	41	47	52	57	62	67	72	77	82	87	92	97	102	106
60	48	54	60	66	72	78	84	90	96	102	108	114	120	126
70	56	63	70	77	84	91	98	105	112	119	125	132	139	146
80	62	70	78	86	93	101	109	117	124	132	140	148	156	163
90	68	77	85	94	102	110	119	127	135	144	152	161	170	178
100	73	82	91	100	109	118	127	136	145	154	163	172	181	190
110	77	86	96	105	115	125	134	144	153	163	172	182	192	201
120	80	90	100	110	120	130	140	150	160	170	180	190	200	210
130	83	93	104	114	124	135	145	155	166	176	187	197	207	214
140	85	96	106	117	128	138	149	160	170	181	192	202	213	224
150	87	98	109	119	131	141	152	163	174	185	196	207	218	228
160	88	99	110	121	133	144	154	166	177	188	199	210	221	232
170	89	101	112	123	134	145	156	168	179	190	201	213	224	235
180	90	102	113	124	136	147	158	170	181	192	203	215	226	237

U.S.F.S., McArdle, Meyer, Bruce, 1949

Table II-3. Average total heights of dominant coast redwood by breast-high age and site index.

Age at h. h. (years)	Total height (feet), by site index							
	100	120	140	160	180	200	220	240
20.....	21	31	42	53	63	74	84	95
30.....	34	48	62	76	89	103	117	131
40.....	47	62	76	92	107	122	137	152
50.....	57	73	89	106	122	138	155	171
60.....	67	84	102	119	136	154	171	188
70.....	76	94	112	130	148	166	184	202
80.....	85	104	123	142	161	180	198	217
90.....	93	113	132	152	171	190	210	229
100.....	100	120	140	160	180	200	220	240

U.C., Lindquist and Palley, 1963

Table II-4. Timber site classification systems in California.

<i>Young Growth Coast Redwood</i>		<i>Douglas-Fir</i>		<i>Ponderosa Pine</i>	
<i>Site Class</i>	<i>Site Index*</i>	<i>Site Class</i>	<i>Site Index*</i>	<i>Site Class</i>	<i>Site Index*</i>
I.....	180 or more	I.....	194 or more	I.....	114 or more
II.....	155-179	II.....	164-193	II.....	93-113
III.....	130-154	III.....	134-163	III.....	75-92
IV.....	105-129	IV.....	103-133	IV.....	60-74
V.....	Less than 105	V.....	Less than 103	V.....	Less than 60

* Height in feet at 100 years age.

California Board of Forestry, CAC 14-1060, 1974

crops is divided, e.g., the 10-year age class, 20-year age class. An all-aged forest would contain all age classes, while an even-aged stand would be mostly composed of trees in one class.

Forests are also classed by the type of species found in them. The principal forest types we have are as follows:

<i>Name</i>	<i>Common Species Contained</i>
Pine	Pure stands of various pines
Redwood	Coast redwood, Douglas-fir, grand fir, hemlock
Douglas-fir	Douglas-fir
Fir (true)	Red and white fir
Pine—Douglas-fir—fir (Mixed Conifer)	Ponderosa, Jeffrey, and sugar pine, Douglas-fir, white and red fir, incense-cedar

Where these forest types are found in California is shown in Figure II-1. These commercial forests make up about 16.3 million acres.

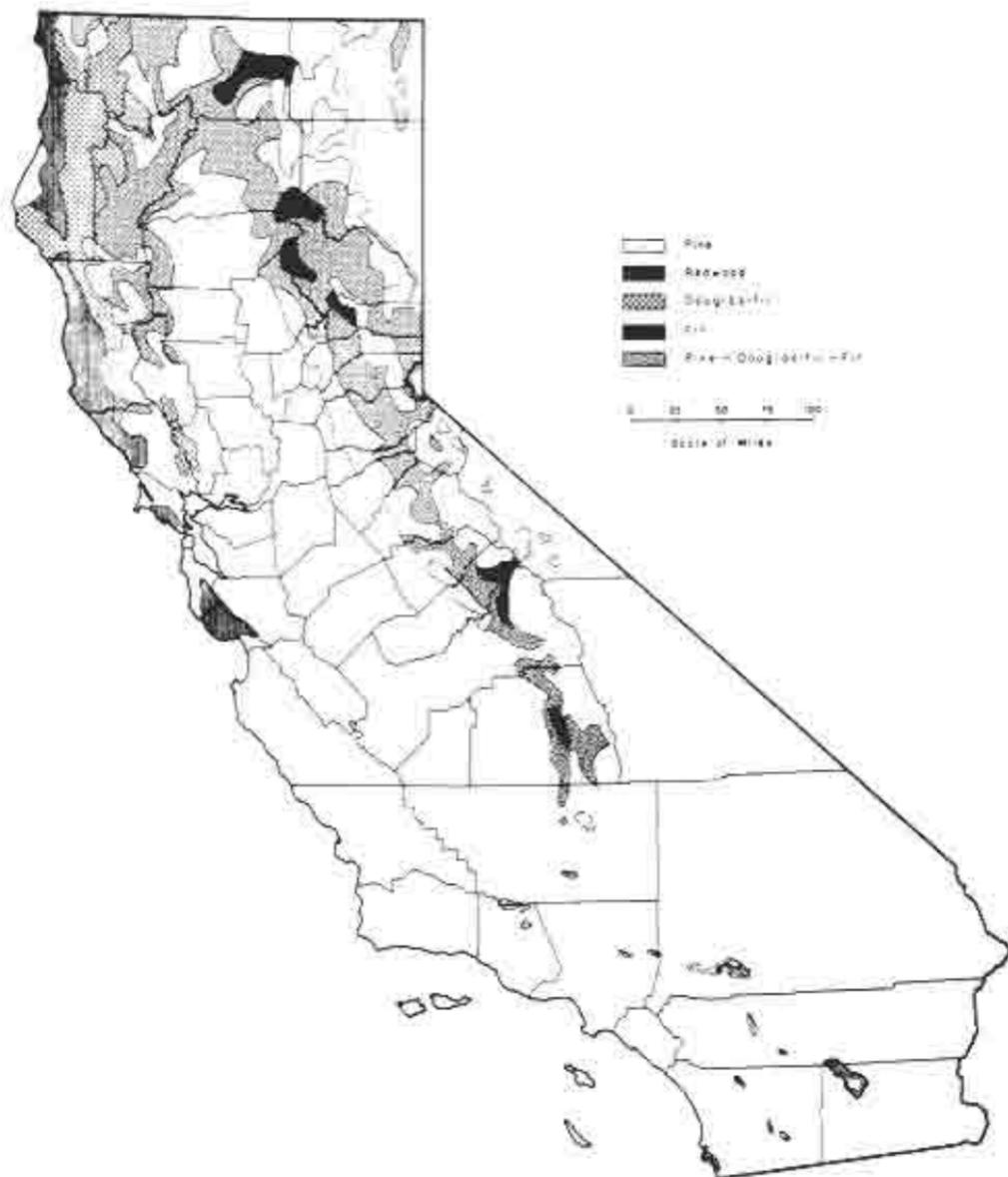


Figure 11-1

Timber croplands of California.

U.S.F.S., Pacific Southwest Forest and Range Experiment Station, 1945

Growth

As noted above, growth depends on site, but it also is related to the age of the trees, the number per acre (called stocking or density), and how well they are distributed. Trees grow well when they are young, and as they reach maturity the growth begins to slow down. For the most favorable growth, ideal stocking and distribution are achieved when trees still have room to grow but none to waste.

Forest growth is affected by competition between trees within a stand and other forms of vegetation. Trees that are too crowded may stagnate, or even die, but still enough trees should be present to utilize the site fully and to make use of available moisture and nutrients. Also, some shading is necessary to cause the dying and self-pruning of lower branches. This makes better grades of sawlogs.

Some trees grow better than others under shade. These are classed tolerant trees, and include species like grand and white fir, the cedars, the hemlocks, and coast redwood. Douglas-fir, Sierra redwood, and red fir are intermediate in tolerance. Intolerant trees include the pines, with sugar pine being somewhat more tolerant than the other pines.

Competition, spacing, and tolerance are all involved in the formation of a forest. Thrifty young trees are tall and have sharp-pointed crowns. As they become older, the trees grow slower in height and the tops become broader. Some trees lose out in the struggle, become suppressed, and succumb. In an all-aged forest having trees of different sizes and ages, the larger and usually older trees have the dominant position. Others nearly like them are codominant, and the laggards are intermediate or suppressed. Foresters use the Dunning's Tree Classification System (Figure II-2) showing this relationship to help decide what trees should be selected for harvest. Although this system was designed primarily for pine, its principles can be used with the application of some judgement to all-age stands of other species.

A measure called basal area is a convenient method used by foresters to keep tab on growing stock of a stand. It is the sum of the cross-section area at breast height of all trees on an acre expressed in square feet. Basal areas on uncut areas may exceed 300 sq. ft. Often basal area needs to be reduced to place the stand in a better growing state. See Figure II-3 and Basal Area Table in the Appendix. How to measure basal area by using a prism is explained in Chapter V.

Growth Prediction

The growth of a forest is the foundation for its management and the basis of continuous production. A tree farmer needs some growth information in order to tell how well the forest is responding to its care, and more importantly, to help decide what amount can be harvested safely. Unfortunately, growth measurements are not easy to obtain, nor are they easy to use in making predictions of the growth of a stand in the future. There are many methods to forecast forest growth, most of which are rather complicated and laborious, and all of them require a lot of professional judgement and skill to give reliable results. Therefore, only a general

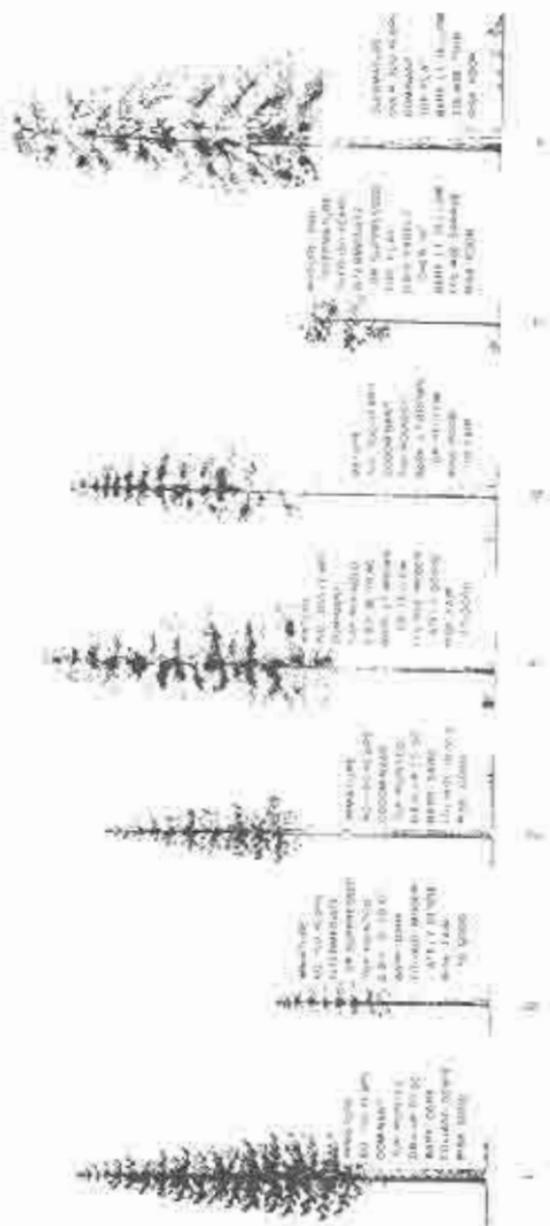


Figure II-2

Dunning's Tree Classification shows ponderosa pine by classes based on age, size, and appearance of bark and crown. Classes 1, 3 and sometimes 5 have crowns 65% or more of total height.

treatment of this subject can be included in this handbook, and a person wanting to measure and predict growth would be well advised to seek professional assistance. Also, Chapter V on forest inventory should be studied if a better understanding of the mechanics is desired.

A handy tool to use to obtain growth information is the increment borer (Fig. II-3) mentioned in the previous section on Site. The growth in diameter (twice the radial growth) in relation to a specified number of years can be measured on the core. For example, if the radial growth of wood (excluding bark) in the past 10 years of a tree 20.1 in. diameter outside the bark was measured to be 2.3 inches, the diameter growth would be 4.6. The expected diameter 10 years hence would be 20.1 plus 4.6 or 24.7 inches. This assumes that the bark thickness remains constant and that the growth would continue at the same rate, which may not be necessarily true in all cases. It should be realized that measuring growth with increment borers, unless carefully done and interpreted, can produce misleading results.



Figure II-3
Using an increment borer.

The growth during the past year is termed current annual growth, while the average growth per year over a period is called periodic annual growth. This periodic measure is the one used the most. The yearly average growth determined by dividing the total volume of a tree or a stand by its age is named mean annual growth.

Basically, growth of a forest can be estimated by three approaches: (1) indirectly by comparison or general observation, (2) indirectly from yield tables, and (3) by direct measurement of the stand. The last category includes many specific methods that can be utilized to meet the wide variety of conditions found in American forestry.

General observations on growth are the easiest and cheapest, and may in some cases be all that would be necessary, especially for smaller forests, or those that are first coming under a management program. However, the results certainly are not precise and should be cautiously used until better information becomes readily available. Under the method, the average net growth per acre per year, e.g., 500 bd. ft., of a similar stand in terms of forest type, age, site, and stocking is accepted and applied to the forest in question. Such growth information may be available from nearby national, state, and industrial forests.

Using *yield tables* under special circumstances is also a convenient and inexpensive way to estimate growth. Yield tables have been prepared for some of the more important species. Some yield tables along with site curves* are shown in the Appendix. In essence, these tables show the volume of timber produced by fully stocked, even-aged stands by decades on different sites. Because most forests are not fully stocked, these production figures have to be proportionately reduced. Thus, where a forest is only 50 percent stocked the yield may be only one-half of that indicated by a normal yield table. One major disadvantage of these tables is that they are mostly based on even-aged stands, so it is difficult to apply them properly to all-aged stands. Also, yield tables are lacking for some important California species and most of our forests are composed of a number of species. Nonetheless, professional foresters with good judgement and experience can make use of such tables to predict growth even for some all-aged stands.

Direct measurement of growth of the stand being managed can be the most accurate approach to take, but all the methods that have been developed require a great deal of detailed technical work, both in the field and the office, and consequently they are quite expensive. This effort and cost may not be justified in all instances. In addition, there are many chances for errors and misinterpretation. However, to give the reader some general idea of this direct approach three of the more common methods are briefly described. A person using them should refer to pertinent references or seek professional help.

The *stand-table projection* or diameter step-up method, of which there are several variants, has been used a lot by foresters. From timber cruise data, a stand table is prepared to show the number of trees by diameter at breast height (dbh) classes—usually two-inch, i.e., 10, 12, 14, etc., by

*The curves are needed to find what the site index is for the stand for which yield data are wanted from the accompanying yield tables.

species or species groups for an average acre of the stand. Thus the current volume of the average acre can be found in an appropriate volume table (Chapt. V); this will be the base for the growth prediction. How much these trees in each diameter class have grown on the average in diameter for a stated period, say 10 years, is determined by making increment borings of a sufficient number of trees that are representative of the forest as a whole. Using that data, the stand table for the average acre can be revised to show what the diameters in each class would be 10 years hence. This assumes that the next decade's growth will be the same as in the past 10 years. The new diameters can be rounded off by two-inch classes so that forecasted volume can be read from a volume table, but this is rather rough. By using the actual anticipated diameters to the nearest tenth-inch and making interpolations between diameter classes in the volume table the accuracy can be improved considerably.

The average gross annual growth of the average acre is the difference between the present volume and the forecasted volume divided by the number of years in the period. However, before this figure can be used for management purposes it should be reduced somewhat to a net growth basis to account for anticipated loss of trees by natural causes—competition, fire, pests, weather, etc. This adjustment cannot be easily made by exact methodology, but it can be arrived at by judgement. In California the forests as a whole lose approximately an average of 129 bd. ft. per acre yearly to mortality, but the range of values is wide.

The second and easier direct method is by using *growth percentages*. Because growth percentages vary by diameter for the same number of annual rings per inch—low for large trees and high for small ones—it is hard to apply a single growth percentage to a stand of trees to forecast growth (Table II-5). Here again, it is necessary to take increment borings of a representative sample of the forest to get the average growth percent

Table II-5. Interest rates being grown by trees.

D.B.H. (i. b.) inches	Number of annual rings per inch radial inch of growth												
	1	2	3	4	5	6	7	8	9	10	11	12	
	Percent												
2		34.0	39.1	44.4	50.3	57.1	63.5	70.0	76.4	82.8	89.2	95.6	102.0
3	88.0	122.7	168.8	224.9	281.0	337.1	393.2	449.3	505.4	561.5	617.6	673.7	729.8
4	205.4	277.5	450.0	622.5	795.0	967.5	1140.0	1312.5	1485.0	1657.5	1830.0	2002.5	2175.0
5	177.5	56.3	33.3	23.6	18.2	15.2	12.4	10.5	8.8	7.9	7.1	6.2	5.4
6	125.2	44.1	26.4	18.9	14.6	12.0	9.5	8.2	7.2	6.3	5.5	4.7	4.0
7	95.2	36.4	22.5	16.1	12.1	9.8	8.2	7.2	6.3	5.5	4.7	4.0	3.4
8	77.5	30.7	19.1	13.6	10.0	8.0	7.0	6.2	5.3	4.6	3.9	3.3	2.8
9	65.5	26.6	16.6	12.3	9.7	7.8	6.7	6.0	5.3	4.6	4.0	3.4	2.9
10	56.1	23.3	14.7	10.7	8.3	6.9	6.0	5.3	4.5	4.0	3.6	3.1	2.7
11	49.3	21.1	13.4	9.8	7.6	6.3	5.6	4.7	4.1	3.8	3.4	3.1	2.7
12	44.0	18.9	12.1	8.9	6.9	5.8	4.9	4.3	3.7	3.4	3.0	2.7	2.4
13	39.7	17.5	11.2	8.2	6.3	5.2	4.6	3.9	3.5	3.1	2.8	2.5	2.2
14	36.2	15.9	10.3	7.6	5.9	4.9	4.2	3.5	3.2	2.9	2.6	2.4	2.1
15	33.1	14.8	9.5	6.9	5.5	4.5	3.9	3.3	2.9	2.7	2.4	2.2	2.0
16	30.6	13.8	8.8	6.5	5.2	4.2	3.7	3.2	2.8	2.5	2.3	2.1	1.9
17	28.4	12.9	8.4	6.1	4.8	4.0	3.5	3.1	2.7	2.4	2.1	2.0	1.8
18	26.6	12.0	7.9	5.8	4.6	3.8	3.3	2.8	2.5	2.3	2.0	1.9	1.8
19	24.9	11.4	7.4	5.5	4.3	3.5	3.1	2.7	2.3	2.1	1.9	1.8	1.7
20	23.3	10.9	7.1	5.2	4.1	3.4	3.0	2.6	2.3	2.0	1.8	1.7	1.6
21	22.1	10.3	6.8	4.9	3.9	3.2	2.9	2.4	2.1	1.9	1.7	1.6	1.5
22	21.0	9.8	6.4	4.7	3.7	3.1	2.7	2.3	2.0	1.8	1.6	1.5	1.4
23	20.0	9.3	6.1	4.5	3.5	2.9	2.6	2.2	1.9	1.7	1.5	1.4	1.4
24	19.0	8.9	5.8	4.3	3.4	2.8	2.5	2.1	1.8	1.7	1.5	1.4	1.4

for each diameter class. The growth percent can be calculated by various formulas, such as the Gevorkiantz formula:

$$p = 456 / (ND)$$

where p = growth percent per year

N = number of rings in the last inch

D = present dbh.

A stock table is prepared from the stand table of the average acre of the forest by multiplying the number of trees in each diameter class by the corresponding value from the right volume table. This then gives the volume in each diameter class, which when totalled is the present volume on the average acre. The corresponding volumes for the next year of the diameter classes are computed by multiplying the present volume in each class by the average growth percent of that class. These figures are added to obtain the forecasted volume of the average acre. The differences between that volume and the present volume is the expected growth in one year. Before this value can be used it has to be adjusted the same way for anticipated mortality as is done in the above stand table projection method.

The third common method to measure the growth of a forest is by using permanent sample plots. This system, often called the *continuous forest inventory* (CFI), usually is the most accurate, but it involves a considerable expenditure of time and money. It requires the establishment of enough sample plots to produce information that is statistically sound. The number of plots, commonly one-fifth or one-fourth acre, depends on area of the stand, the stocking, the variability of the stand, and the accuracy desired. More plots are needed for large tracts than small, poor stocking than good, patchy stands than uniform ones, and when a high degree of accuracy is wanted. Assuming a desired accuracy of 90 percent and average stocking and variability, the number of one-fifth acre plots needed would range from 67 for 40 acres to 100 for 5,000 acres and above. The plot number can be calculated exactly by statistical procedures after some preliminary measurements of the forest regarding stocking and variability, or standard tables like V-5 could be used in most cases.

While the CFI plots are located and permanently marked to determine saw-timber growth, all trees over 10 in. dbh have to be carefully measured for diameter and height. Using these measurements the present volume of all the plots is determined from appropriate volume tables. The plots are remeasured at intervals of 5 to 10 years to obtain the timber volume on the plots at that time. The difference in volume between one measurement time and the succeeding one is the growth for the area contained in all the plots for the stated period. This can be translated to average annual growth per acre by dividing it first by the acreage in the plots and next by the number of years between measurement. If some growth information is wanted at the time when the plots are first measured, increment borings can be made of a representative number of trees in each diameter class, and this can be used to make the first growth forecast

by the stand-table projection or growth percentage method. Except in this case of the first measurement, no adjustment is necessary to obtain net volume, because loss from mortality would be reflected in the successive measurements. However, any volume removed by harvesting any plot areas since last measurement, should be recorded and this included in the growth for that period.

Before closing this subject of growth, some appropriate observations should be made. Growth rates of forests in California have a wide range—from less than 100 bd. ft. per acre per year to as high as 2000 bd. ft. The net average for all California stands is about 300 bd. ft. per acre per year. In general, when the potential net annual growth is much less than 200 bd. ft. per acre for a property not much intensive forestry can be justified. This means that timber management should be ordinarily concentrated on medium and better sites. Getting specific figures for one's property may be difficult and often costly and time-consuming, and the results may not be entirely dependable, because certain assumptions have to be made, e.g., the future growth will be the same as in the past. In some cases, the forecasted growth will be too high, and in others it may be too low. Any figures that are developed, regardless of the method, should be tentative and adjusted downward or upward by trial and error and practical experience.

Management Planning

Beside the care and improvement of the trees, the concept of forest management includes the regulation of the forest so as to promote maximum continuous production of crops. This is called sustained yield. The objective is to eventually achieve a balance between the growth of a forest and the amount harvested. Maintaining a somewhat even flow of crops over time from the forest may be another objective.

Before going into this subject there are a few more terms that should be defined. The term rotation means the general age to which trees will be grown before they are harvested. Different rotation ages are used, depending on such factors as species, growth, site, forest products to be grown, and desires of the tree farmer. Rotations are usually set at or below the age where the mean annual growth of a stand begins to decline from the peak of biological maturity. Short rotations like 40 years may be appropriate for pulpwood, but longer ones of 50 to 100, or even more, are necessary for saw and veneer logs. The term cutting cycle denotes the number of years from one logging to another on the same area, where repeated cuts are made, none of which remove the entire stand. The cycle should equal the number of years it takes for a partially cut stand to produce trees that are ready for another harvest. Many other terms used in forestry are defined in the Appendix.

Regulation

To regulate the forest the tree farmer tries to convert the stand into a healthy condition, where all of the area is adequately stocked in accordance with the site capabilities and where there is a proper distribution of

age classes. In an all-aged stand an owner would want to have a mixture of all age-classes from one year old to the rotation age in the right proportions. Theoretically then, the periodic harvest would be restricted to trees of the rotation age and older classes only, unless some recently defective younger trees also needed removal.

The classic example of a completely regulated even-aged forest would be one containing equal areas of each age class with the area of trees of the rotation age class, e.g., 80 years, being harvested over each decade. Because management of California's forests is relatively recent and has been based largely on virgin timber, we have few examples of a completely regulated forest, yet the principle is still valid for long-range planning purposes.

What can be cut from a forest is dependent upon how well the forest is regulated. One with a great amount of large trees in relation to other sizes would demand a heavier annual cut than usual over enough years to bring about a better distribution of age classes. It also would be necessary in order to convert such slow-growing stands to young, fast-growing trees. Conversely, a forest with little mature timber, poorly stocked areas, or large gaps in age classes should be harvested at a rate less than usual for awhile in order to achieve desired age-class distribution. In other words, the level of cutting should be adjusted so that the forest can be placed into a regulated condition as early as possible (preferably in the first rotation), where all age classes are proportionately represented and an optimum stocking of healthy trees is present.

Allowable Cut

If one has a fully regulated forest, it would be fairly easy to determine the allowable annual cut. It simply would equal the net growth of the stand as indicated by appropriate yield tables or from growth measurements. However, very few, if any, of our forests are yet regulated, and this situation causes a lot of difficulty in arriving at an allowable cut figure.

There are a great many methods for determining allowable cut. They include a few graphic presentations, a wide variety of formulas, and some rather sophisticated computer programs. A lot of data about the forest is required by some of the formulas and by all computer methods. The ease of application depends largely on the complexity of the forest and how it departs from a regulated condition. Nonetheless, a tree farmer should establish by whatever way is most practicable at least a preliminary level of annual allowable cut and be prepared to modify it to meet changing facts and conditions.

It is beyond the scope of this handbook to go very deeply into this subject. The methodology is definitely something that needs professional treatment. However, to illustrate some of the principles involved, a few of the more simple approaches will be explained.

One of these is the *Van Mantel formula* which works best with even-aged stands, and the more regular they are the better the results. It has been principally used for preliminary planning purposes. The formula reads as follows:

$$AC = (2 \times V) / R$$

Where AC = annual allowable cut of the stand
 V = timber volume thereon
 R = rotation period in years

Note that no growth information is required. This formula gives much too low results, especially when board feet are used, because only merchantable trees are included in the volume. As a result, it grossly underestimates actual growth. When used with caution, this formula is an easily applied and valuable check on what the allowable cut might be for a natural forest, but its limitations must be clearly recognized.

Probably with more reservations than in the case of even-aged forests, the Van Mantel formula has been adapted to selection cutting of all-aged forests. Here annual cut would be twice the timber volume times the cutting cycle expressed in years, all divided by the rotation.

The *current growth formula*, often used by foresters, is an empirical or informal method to calculate the allowable cut of forests being deficient in growing stock that are to be placed under management. Its principle is that, if the current growth is known, all that is required is to harvest less than the growth in order to build up the stocking of the forest. The cut is therefore assessed as a fraction of growth: AC = actual growth of the total stand times a reduction factor. The value of the reduction factor is set by judgement, depending on the shortness of the stocking of the forest and silvicultural and economic conditions. Usually the reduction factor runs from 0.6 to something less than 1.0.

A *stand growth percentage method* is one that can be used to set the allowable cut of an all-aged forest, especially one that has satisfactory stocking. The average annual percentage growth rate of the stand as a whole needs to be estimated or known. It can be derived by finding the total annual growth of a stand by methods discussed earlier and dividing that by the total stand volume. The formula for the stand growth percentage method gives the percentage of the stand volume that may be cut and restored by growth for various rates of stand growth and cutting cycles:

$$l = (i \times CC) / [1 + (i \times CC)]$$

Where l = percentage of stand to be cut
 i = average annual growth percent for the stand
 CC = cutting cycle in years

Table II-6 gives for different rates of growth and cutting cycles what percentage of the stand can be harvested and replaced by growth during that time period. By that table, a stand with an average annual growth of 5 percent being cut on a 10-year cutting cycle would have 33 percent of its volume cut every ten years. Of course, this harvest could be spread evenly over each year in the cycle and be concentrated on those areas where the cutting would be most beneficial silviculturally and economically.

Table II-6. Percentage of allowable stand cut for various rates of growth and cutting cycles.

Cutting Cycle (years)	Average Annual Stand Growth Percent (simple interest)						
	2	3	4	5	6	7	8
5	9	13	17	20	23	26	29
10	17	23	29	33	37	41	44
15	23	31	37	43	47	51	55
20	29	37	44	50	55	58	64

It should be remembered that what the forest manager does in the way of improvement of a stand affects the allowable cut possibilities. If the owner has an active, successful reforestation program, uses fast-growing trees, or takes timber stand improvement measures, the allowable cut can be almost immediately set higher than would otherwise be prudent. The reason for this is that in time these practices will increase the yield. Some industrial tree farms also apply fertilizers to increase growth. How much higher the cut can be elevated depends on the amount and intensity of such efforts, and this has to be carefully assessed so that the allowable cut is not raised too much. These kinds of practices have the capacity to increase allowable cut of a forest as much as 30 percent or more.

Management Plans

The reader has seen that the regulation and determination of the allowable cut of a forest are complex, involving many factors. Without going to a great deal of expense, the methodology is not necessarily exact, especially when forests are not in a regulated condition, and much professional judgement based on practical experience has to be exercised. Run-down stands first coming under management certainly do not require precise formulas or methods to determine cut, or sophisticated management planning. In those cases, priority has to be given to rehabilitation and forest improvement until adequate stocking can be established. The basic aim is to have an overall plan to be sure that eventual harvests are within the productive potential of the forest and in line with a reasonable distribution of age and size classes. Whatever is done, it must relate to the owners objectives, the economic situation, the forest itself, and be flexible to take advantage of knowledge gained about the forest and to meet changing conditions.

Forest management is a long-term continuing process and it has to be based on a good knowledge of the property. Decisions have to be made for current operations and also for a long time into the future. Therefore, it is advisable to have a management or working plan for one's forest. It is a written document, including maps and records, that is prepared to maintain the owner's policies and actions by prescribing and controlling the basic operation of a forest over a period of years. The plan should not

be rigid and it should be revised periodically. The contents of a forest management plan are outlined below:

- A. Introduction
 - Location and boundaries
 - Acquisition history
- B. General physiographic features
 - Climate
 - Topography
 - Geology
 - Soil
- C. Forest description
 - Forest type
 - Site
 - Previous cutting
 - Growth potential
 - Access and roads
- D. Economic situation
 - Local markets
 - Transportation
- E. Management objectives
 - Wood products
 - Range
 - Water
 - Wildlife
 - Recreation
- F. Silvicultural treatment
 - Silvicultural systems
 - Logging conditions
 - Pest protection measures
 - Stand improvement
 - Reforestation
- G. Regulation
 - Rotation and cutting cycle
 - Allowable cut
 - Cutting budget and order
- H. Sales policy
- I. Other management factors
 - Acquisition plans
 - Other forest uses
 - Road development
 - Fire protection
 - Zoning and land-use regulation
 - Miscellaneous
- J. Appendix
 - Stock and stand tables
 - Cruise reports
 - Growth data
 - Various maps

Silvicultural Systems

Various cutting systems are used to grow, tend, and harvest forest crops in accordance with a planned program. What system is used depends primarily on the nature of the stand, because, unless the harvested area is to be seeded or planted by man, the chosen method should be favorable towards quick natural reproduction. Other factors to consider are the need for improvement of the stand, type of forest regulation chosen, the economic aspects of the cutting, market considerations, and logging conditions. There are four basic systems in use: (1) clear cutting, (2) seed-tree, (3) selection, and (4) shelterwood. In addition, there are combinations and variations of these cutting systems.

Clear Cutting

Clear cutting is what the name implies—removal of all or most of the trees. The system is appropriate to use on merchantable even-aged stands, especially where the species being harvested needs sunlight to reproduce and grow, or where windthrow is a serious threat to partially cut stands. If natural seeding is being depended on, mature trees should surround the cutting, and the area should not be too large—preferably less than 40 acres. Because natural seeding is not too dependable, aerial or hand seeding and planting of seedlings are commonly done after harvests are made. Clear cutting is a drastic treatment in some ways. It reduces the forest cover so much that soil damage can result, unless appropriate erosion control procedures are undertaken. In clear cutting, cable logging is often employed to reduce damage from skidding and road construction associated with tractor logging. The appearance of clear-cuts is often poor; this can be alleviated by keeping them away from roads and streams, and by using irregular shapes. Clear cutting is used on both private and public land, particularly in old-growth redwood and Douglas-fir in northwestern California and also elsewhere in pure pine and red fir stands.

Seed-Tree Cutting

Seed-tree cutting is the removal of all merchantable trees except those required to naturally seed the area. This is accomplished by leaving at least two (preferably more) designated large trees per acre for good seed production, or by leaving blocks of uncut trees to serve the same purpose. This cutting method may be applied to both all-aged and even-aged forests, although the succeeding crop is quite even-aged, except for the residual trees from the original stand. This system has been widely combined in this state with a minimum cutting diameter limit. Under this version, except for desired seed trees and obviously defective trees, all trees are felled above a prescribed minimum diameter, e.g., 18" dbh. Neither seed-tree cutting nor the combination has been entirely efficient here in regenerating a new crop of trees. Often where the residual stand does not provide enough cover, the site is captured by competing brush which takes many years to be shaded out by trees. Windfall of seed trees and smaller residual timber can also be a problem.

Shelterwood

The shelterwood system is the gradual removal of the timber crop in two or more steps designed for specific purposes. The object is to obtain natural reproduction of the stand under the protection of a forest cover. This system has been rarely used in California, although it has been tried on an experimental virgin redwood forest and an experimental young-growth, mixed conifer forest, both with favorable results.

Selection

The selection cutting method is the most common one in California. It is the periodic removal of certain trees, individually (single tree selection) or in small groups (group selection) from an all-aged forest. The trees or groups of trees selected for harvest are the overmature, suppressed, defective, and some mature trees. The unit-area control system is a form of group selection, where an attempt is made to cut areas of trees of like condition, in effect creating very small clear-cuts. The Dunning's tree classes are a useful guide for marking trees to be cut, especially in older pine forests. Usual practice is to take the poorer risk trees, like numbers 4, 5, and 7 (Figure II-2). Other trees may also be cut for economic reasons, to eliminate unwanted species, or to thin out trees to obtain better spacing. Basal area can also be used as a cutting control. It should not ordinarily be reduced to levels below 70 to 100 square feet, depending on species, forest type, site, stand condition, growth, and other factors.

The cycle between cuttings should be long enough to obtain some reproduction, but short enough to capture trees of poor risk before they die and yet provide enough volume to justify the logging. Cutting cycles in California range from 10 to 20 years.

Where properly applied, the selection system is an excellent one. It produces a diverse all-aged forest that protects the site, it favors continuous reproduction, and rates high from the aesthetic standpoint.

Other Systems

In addition to these four basic silvicultural systems, there are other cuttings that can be made. These include thinnings, sanitation-salvage harvests, and other special cuttings (see Timber Stand Improvement later).

Environmental Factors

In choosing and applying silvicultural systems, one must give serious thought to not only the protection of the forest from the crop standpoint, but also to preventing environmental damage. Non-wood values of the forest are important to the owner and general public alike. They are of sufficient importance to the general welfare that these other values are protected by the State Forest Practice Act and a number of other laws and regulations, which are discussed in Chapter IV. Therefore, the multiple-use concept should be practiced, whereby the soil, water, range, wildlife, recreation, and aesthetic benefits are retained as much as possible. More will be said about this subject in the last two Chapters.

Soil and Water

The soil is the basic resource to a tree farmer. It is a main element of the growing site and should not be wasted away by erosion. Soil erosion can also cause costly road damage, foul other lands, deteriorate the quality of water in springs, lakes, and streams, and deposit sediments in reservoirs and where fish live and spawn.

Fish and Wildlife

In addition to fish, there are many other kinds of wildlife that are affected by forest operations. Logging an area temporarily changes the habitat; some changes may be good temporarily, such as for deer, quail, and song birds that feed on grasses, herbs, and shrubs that come in after a cutting, but other changes may be detrimental to birds like eagles, ospreys, and others, which nest in trees and snags. Woodpeckers are particularly beneficial to a forest because they help control tree-killing insects by feeding on the insects and larvae in defective and dead trees. How a forest is managed will largely determine what the overall wildlife composition will be. Of course, some species like gophers, mice, rabbits, porcupines, and even deer and bear may cause serious injury at times, so these factors have to be considered also and special measures taken to control the damage (see Chapter VIII).

Aesthetics and Recreation

The appearance and cultural resources of a forest are of special concern to the public, who can be critical of the results of forest harvests. This can lead to more legal restraints and can hamper or, in some cases, even prohibit logging. Besides economic gain, a tree farmer receives personal satisfaction and pride from how well beauty, rare and endangered species, and archaeological and historical sites are protected. In some cases commercial forests can be integrated into a beneficial and profitable recreation program, and these attributes are important to such use.

Timber Stand Improvement

Other measures are often applied in the forest besides the basic systems explained earlier. Their purpose is to improve the composition, condition, health, growth, and quality of the trees.

Thinning

A forest manager can make careful intermediate cuttings or thinnings to a good advantage in young stands. If there is a market or personal need for small logs, posts, poles, piling, pulpwood, firewood, Christmas trees, and similar products; such cuttings may pay; otherwise thinning trees is expensive, slow, hard work. Unless it is a paying proposition in terms of useful products, it is not ordinarily done except in those cases where it is especially desirable for silvicultural reasons.

Trees in well-stocked or crowded stands tend to slow down in growth and many die in time. Thinning actually saves the growth of trees that will die before final harvest. A useful tool to see what is happening is the

increment borer, which reveals the annual ring growth. Other indicators of the need for thinning are closeness of trunks, crowding or overlapping of tree crowns, and thin stems. A thinning ordinarily releases the trees from excessive competition and stimulates greater growth on the remaining crop trees. These should be selected early and favored in the thinning process (Figure II-4). This could be done regularly, perhaps every 5 to 10 years, for at least a few decades until the forest reaches a peak condition. However, intermediate cuttings must be carefully done, because as trees grow older they lose their ability to release, and some species release better than others.



Figure II-4

Increase or release in diameter growth of a tree after removal by cutting of some competing trees in the stand is clearly shown in this cross section.

The thinnings should first remove defective, poor-growing, otherwise undesirable trees, and also trees necessary to achieve a better spacing. Here, rules-of-thumb can be handy. One guide that is helpful in the pine region to better space trees is the $D + 4$ rule, which means that optimum spacing between trees would be equal to the tree diameter plus 4 stated in feet. Thus, the desired spacing for 18" dbh trees would be 22 feet. The rule can be modified to better fit local conditions or extended to other forest types by replacing the figure 4 with another number that experience has shown to be appropriate.

Basal area values also can be useful in determining how much to thin, as they are in selection cutting. Figure II-5 shows the relationships between basal area, average dbh, and tree spacing.

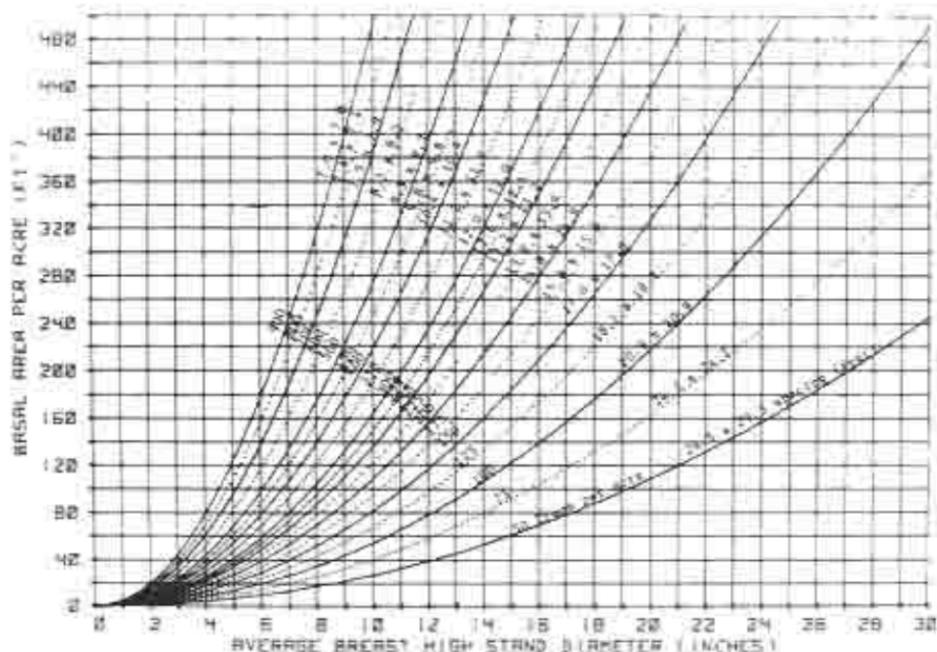


Figure II-5

Stand basal area, average dbh, and tree spacing relationships.

U.S.F.S., Pacific Northwest Forest and Range Experiment Station, 1977.

Pruning

Pruning the lower branches of young trees raises the future quality and value of them for use as saw or veneer logs. Only so-called crop trees that are vigorous, sound, and well-formed should be pruned. Generally, stands are ready for pruning when these trees are from 4 to 12 inches dbh, because they have the potential of putting on another 12 inches of clear wood, which would pay for the pruning. This would take 30 years or more—a long-time investment. Real heavy-limbed trees do not justify pruning because of cost, neither do the lower valued species. Because of the work and expense of pruning, the delimiting is done only to the height that would produce one log 18 feet above ground for a sawlog and 10 feet for a veneer log. Not more than one-fourth the live crown shown should be removed at one time; otherwise the tree's growth could be set back. Curved pruning saws are better to use than axes or clubs, because saws make a neat cut close to the trunk that will heal over sooner (Figure II-6). Light chain saws can be used effectively on the lower and larger limbs, but this has to be carefully done to avoid injury to the operator.

Herbicides and Fertilizers

There are additional stand improvement measures that may be applicable under certain circumstances. Chemicals called herbicides or silvicides are used to decrease competition from unwanted trees and growth. Individual trees or large shrubs, especially sprouting species that grow back

after cutting, can be ringed with an axe and the chemical placed in the cut. Hand-spraying of smaller individual plants can be done also. Aerial application is necessary where broadcast treatment of chemicals is required to control competition to crop trees from brush and hardwoods of no value. It takes specialized knowledge to properly and safely (both from the human and environmental standpoints) to use chemicals, and most if not all are strictly regulated by law. Therefore, a tree farmer contemplating their use would be well advised to consult experts like CDF forest advisers, county agricultural commissioners, licensed pest control operators, manufacturer representatives, and aerial applicator companies.

Fertilization of the forest is a growth and stand improvement measure of some promise. Nitrogen is the main additive although some soils may require other elements. Before forests are fertilized the soils and tree foliage should be checked and consideration given to what fertilizers to use, method of application, costs, and probable returns. The help of specialists should be definitely sought before any fertilization program is initiated to avoid wasteful expenditures and to attain satisfactory response.

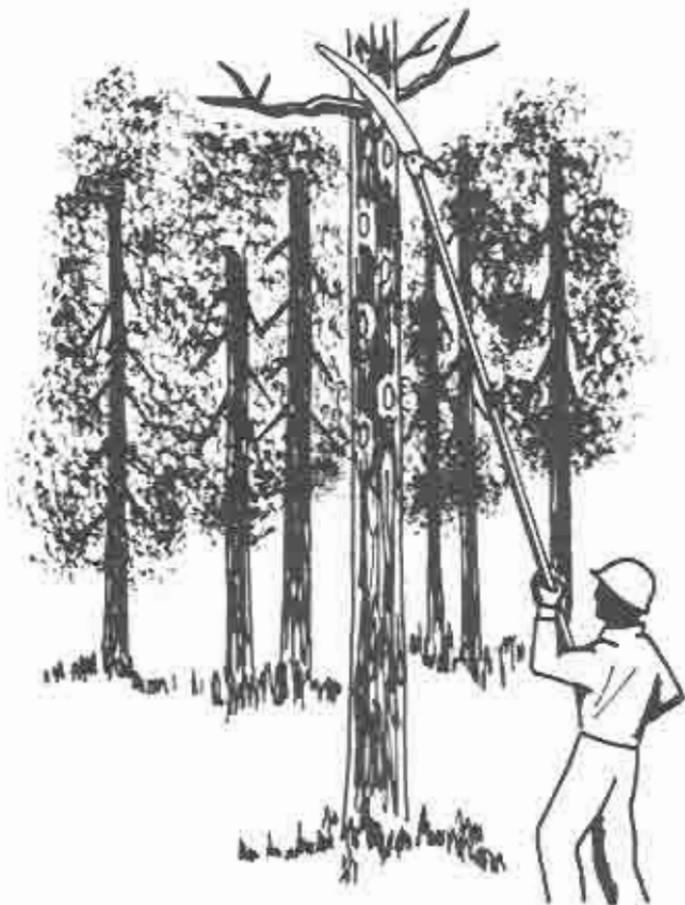


Figure II-6

Pruning the lower limbs of younger trees can improve the quality of the butt log

Reforestation

Reforestation, like many other subjects in this handbook, is a big field, and no attempt is made here to cover it thoroughly, but to only bring out the most essential facts. Fortunately, there are readily available some good written material (see Appendix) and advice on the topic. Several options for reforestation are possible as discussed below.

Natural Seeding

The reproduction of a forest by natural means is obviously preferred whenever possible by tree farmers over that done artificially by hand. To accomplish this, the management practices—cutting systems, logging, site preparation, protection—are designed to favor nature's method and to protect the young unmerchantable trees that are already established and ready to grow to be crop trees. In many cases the results are quite satisfactory and certainly are less costly than artificial reforestation.

To obtain natural reproduction there must be sufficient viable seed, favorable conditions of soil, weather, light, vegetative cover, and minimum chances for depredation by insects, birds, rodents, and other animals. The amount and quality of available seed depends on nearness of seed trees, their species, age, health, and the seed year, which varies greatly from poor to good. In most years seed crops are not satisfactory, depending on species, medium and above crops only occur on the average of every 4 to 5 years. Because the best seed producers are young to mature, thrifty, dominant trees with large crowns, those are the types to be selected for seed trees.

In the case of conifers, one good tree can produce hundreds of cones, each containing scores of seed, but all may not be viable. Thus, literally millions of seed are cast on forest areas when conditions are right. One pound of cleaned seed has thousands of seed, and the viability differs considerably (Table II-7).

Table II-7. Number of clean seed per pound and average germination capacity after stratification for selected California conifers.

<i>Species</i>	<i>Number</i>	<i>Percent</i>
Douglas-fir	42,000	83
Fir, grand	23,200	26
Fir, red	6,600	25
Fir, white	15,100	34
Hemlock, western	297,000	56
Incense-cedar	15,000	50
Pine, Jeffrey	4,000	66
Pine, lodgepole	102,000	80
Pine, ponderosa	12,000	59
Pine, sugar	2,100	56
Redwood, coast	122,000	10
Redwood, Sierra	91,000	25
Western red-cedar	414,000	51

When cones ripen in the fall, they open and release their seed which descend to the ground or are scattered by wind. Conifers have winged seed that enables the seed to fly away from the tree for some distance depending on species, height of the tree, topography, and wind direction and speed. The distance can vary from the immediate ground area below the crown to a number of times the height of the tree of origin. Of course, most seed fall close to the tree and gradually diminish outward. Characteristics and patterns of seedfall in the forest should be observed and an area harvested accordingly, especially clear cuts, in order to obtain the best chances for the success from natural seeding. As noted, the quality or germination percent of seed is quite variable among species and between seed years, so this fact needs to be taken into account also.

A mineral seedbed devoid of most vegetation and organic material is preferred by most conifers. This is shown dramatically by how well trees become established on road cuts and fills and other bare areas. Logging the area in mid-summer of good seed years can be helpful in this respect in that it scarifies the soil and reduces competing ground vegetation, thereby making the site more receptive to seed. And other site preparation measures, like using a tractor to rake or lightly bulldoze the area, in good seed years to accomplish the same effect may be warranted.

A moist soil with favorable growing temperatures during the spring and early summer months is required for seed germination and enough root penetration to follow the moisture level as it recedes in late summer and fall. Consequently, drought years or an exceptionally dry exposed site can be disastrous. Depending on the tolerance of the species, there has to be enough light to support photosynthesis, and seedlings of intolerant species like most pines will die in too much shade.

Crops of forest cones, seed, and young seedlings, may be diminished considerably by insects, fungi, and animals. Damaging insects include cone beetles, cone worms, seed chalcids, maggots, grasshoppers, and many others which are not readily controllable. Fungi-like molds and damping-off disease brought about by warm moist weather are in the same category. Many animals are involved in cone, seed, or seedling depredation—birds, squirrels, chipmunks, mice, rats, gophers, and rabbits. Some methods are available for control of such animal damage, but this is usually done for artificial seeding rather than for natural seeding, and an expert should be consulted especially regarding use of chemicals, some of which if not carefully used can be dangerous to humans, domestic animals, wildlife, and the environment. To justify the added costs of control it should only be done in areas and at times when good seedfall is expected.

Weather factors other than drought that can cause damage are those brought about by extreme conditions. Severe late spring or early fall freezes can kill immature cones, and prolonged stormy weather during the pollination period can cause abortion of cones and low seed quality. Unseasonal low temperatures can also destroy young cones. Spells of cold temperatures during the early growing season can bring about frost-heaving of tender seedlings; excessive temperatures can be lethal also.

Artificial Seeding

To avoid the vagaries of nature and to speed up a rather slow process, a number of methods of artificial reforestation have been developed and are being increasingly used by tree farmers, both large and small, private and public. These practices to upgrade the stocking of a forest can be very rewarding since this can permit earlier increase of the allowable cut of a forest. Because of its ease and relatively low cost, artificial seeding has been quite popular, although it is giving way more and more to planting. Providing seed can be collected or obtained, one of the advantages of direct seeding is that it can be done promptly after catastrophies like fire or to substitute for natural seeding of recent cut-over areas in need of



Figure 11.7
California tree seed zones

restocking. The right kind of planting stock is sometimes difficult to procure, and seeding costs generally average one-fourth to one-half planting costs. But seeding results may not be satisfactory in many cases because of seed and seedling depredation, drought during time of germination and early growth, disease attacks, frost damage, and competition from other plants.

The seed that is to be used should be preferably of species native to the area and meet acceptable purity and germination percent standards. The seed should also be from the local area or a tree seed zone that is compatible in terms of latitude and elevation. Figure II-7 shows the zones recognized in California. A larger copy is available from the Department of Forestry. Seed can be purchased from a number of private suppliers, a list of which can also be requested from the Department.

Seeding in the fall is usually preferred over spring sowing because of less risks. The seed should be pre-conditioned by a moist-cold stratification process, which will break the dormancy of the seed and stimulate germination. A simple way to do this is to (1) soak the seed in tap water for 1-2 days, (2) drain off excess moisture, (3) place seed in plastic bags and close them with a rubber band, and (4) store under temperatures of 32° to 36° F. for about two months prior to use.

Three methods are used to sow the seed: (1) broadcast, (2) spot, and (3) drill. The first of these has been most popular, mostly in the northwestern part of the state, where climatic conditions are more favorable. Usually it is done by using aerial contractors, although for smaller areas a cyclone hand seeder can be employed. Depending on species, from one-half to over one pound of seed is used per acre.

Because seed-eating rodents have been the main cause of failures in direct seeding, it is wise to take some measures to prevent this damage. First, some idea of the rodent population in the area should be obtained; this should be done by wildlife biologists who make sample trappings and prescribe the necessary treatment. This can consist of treating the area with certain chemical baits that temporarily lower the rodent population, or by treating the tree seed with chemicals that repel the rodents, or doing a combination of both treatments. The chemicals in the baits and repellents, if not properly used, can cause damage to other wildlife like birds and fish and affect the water quality of streams and lakes. And they can injure man and domestic animals, so the use of rodenticides and repellents is strictly controlled by law, and use permits must be obtained from the county agricultural commissioner.

Spot seeding has been tried to a considerable extent, particularly on experimental plots and by tree farmers on a limited basis, but the results have not always been too satisfactory. The same problems encountered with broadcast seeding are ever present. A few seeds are implanted into well-spaced (6-8 feet), prepared spots of bare soil by hand tools, corn planters, or special walking-stick seeders. Here chemicals can also be used to control rodent damage. Another rodent control measure is to cover the seeded spot with a small dome-shaped or cylindrical barrier (Figure II-8) made from hardware screen that is pressed into the soil. These devices are

costly when many spots need to be covered and they take more work to pack in, and the screens have to be removed after the start of the second growing season. Before this method is tried it should be tested in the local area to see how well it does the job.

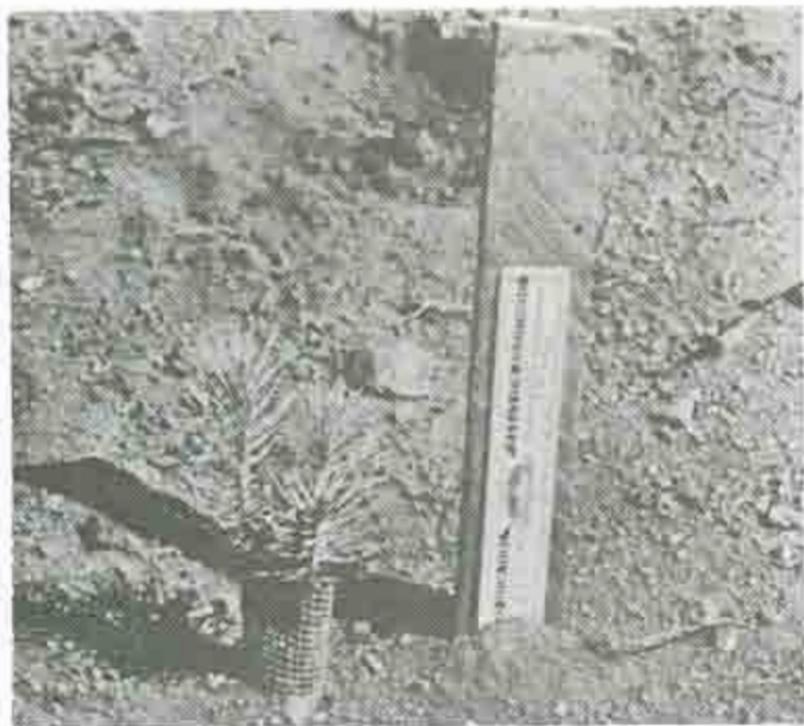


Figure 11-8

A metal screen 4' x 6' is sometimes used to protect a seed spot from rodents.

The last method of seeding is by tractor-drawn drilling machines like the rangeland drill, modified corn planters, and machines especially made for tree seeding purposes. Although the results of a few experiments in California have been encouraging, not much drill-seeding has taken place in this state because our forest lands are mostly too rough and the site needs to be well prepared.

Planting

Planting has become the more favored artificial reforestation method. Although it takes longer to accomplish and is costly, if the proper procedures are followed, the results can be more consistently positive than by seeding. Planting has also supplemented and even replaced natural methods in more and more cases, because prompt re-establishment of trees is a prerequisite for early sustained yield management.

A key decision is where to plant. In general, priority should be given to the lands needing it most, e.g., unstocked areas, and where the potential success and returns will best pay for the investment being made. Thus,

unstocked forest lands should come before those that are only partly stocked, and the high site before medium. From an economic standpoint, low site lands cannot ordinarily justify the expense of planting. Here is where site surveys, soil-vegetation maps, and other references having site and soils information are of inestimable value.

The slope aspect has a bearing also on what trees to plant. Northerly and easterly exposures which are shadier, cooler, and moister, should be planted to the more tolerant species, while the south and west facing slopes should have the more intolerant species.

What species to plant depends on the locality and the wants of the owner. A good rule is that the species to plant should correspond with those that are native to the area, although some proven species of other countries or regions may be in order for special reasons. Most of the planting stock sold in California for timber production consists of ponderosa and Jeffrey pine, coast redwood, Douglas-fir, and sugar pine. Also, mainly for Christmas trees, other species like Monterey pine, red and white fir, Sierra redwood, and Scotch pine are grown by nurseries. Some pine hybrids show much promise in special cases because of fast growth and insect resistance. The trend now is to develop and use super trees which come from seed grown in orchards where the trees have originated from selected wild trees and have demonstrated high growth, good form, and other desirable traits.

Much of the conifer planting stock used in this state is bare-root grown in outside nurseries. It is lifted from nursery beds without soil, packed in a medium of wood waste in bundles of 100 to 1,000, and sold fresh or placed in cold storage until needed. The more common stock is 2-0, meaning it spent 2 years in the seedbed and none in a transplant bed. Some stock may be 1-0, 1-1, 2-2, etc. with the figures representing the years spent in each bed. Trees in the nursery are root-pruned at least once, or sometimes transplanted; both processes promote healthy root development. Increasing amounts of seedlings are grown in greenhouse nurseries, especially by large industrial tree farms in the redwood region. One-year seedlings are grown in special containers having a prepared fertilized growing medium. The trees are carefully removed from the containers with a minimum of root disturbance before placing into the ground upon planting.

Where needs are small, some resourceful tree farmers have successfully planted wild seedlings (wildlings) dug up from the forest or those grown in their own small nursery beds. But this is a painstaking business requiring a "green thumb", and would not ordinarily be the practical thing to do, particularly when plantings to be made are large or sporadic.

When to plant is another important consideration. In California, the best time has been generally in early spring, but late fall and winter planting works in some areas of milder climate. The factors involved here are the physiological condition of the planting stock, soil moisture availability, and anticipated weather during and after planting. The tops of the planting stock must not be growing yet at time of planting and the roots must be ready to start a season of new growth soon after planting. The soil at the planting location should be moist from the top down, and prospects for some further precipitation after planting should exist.

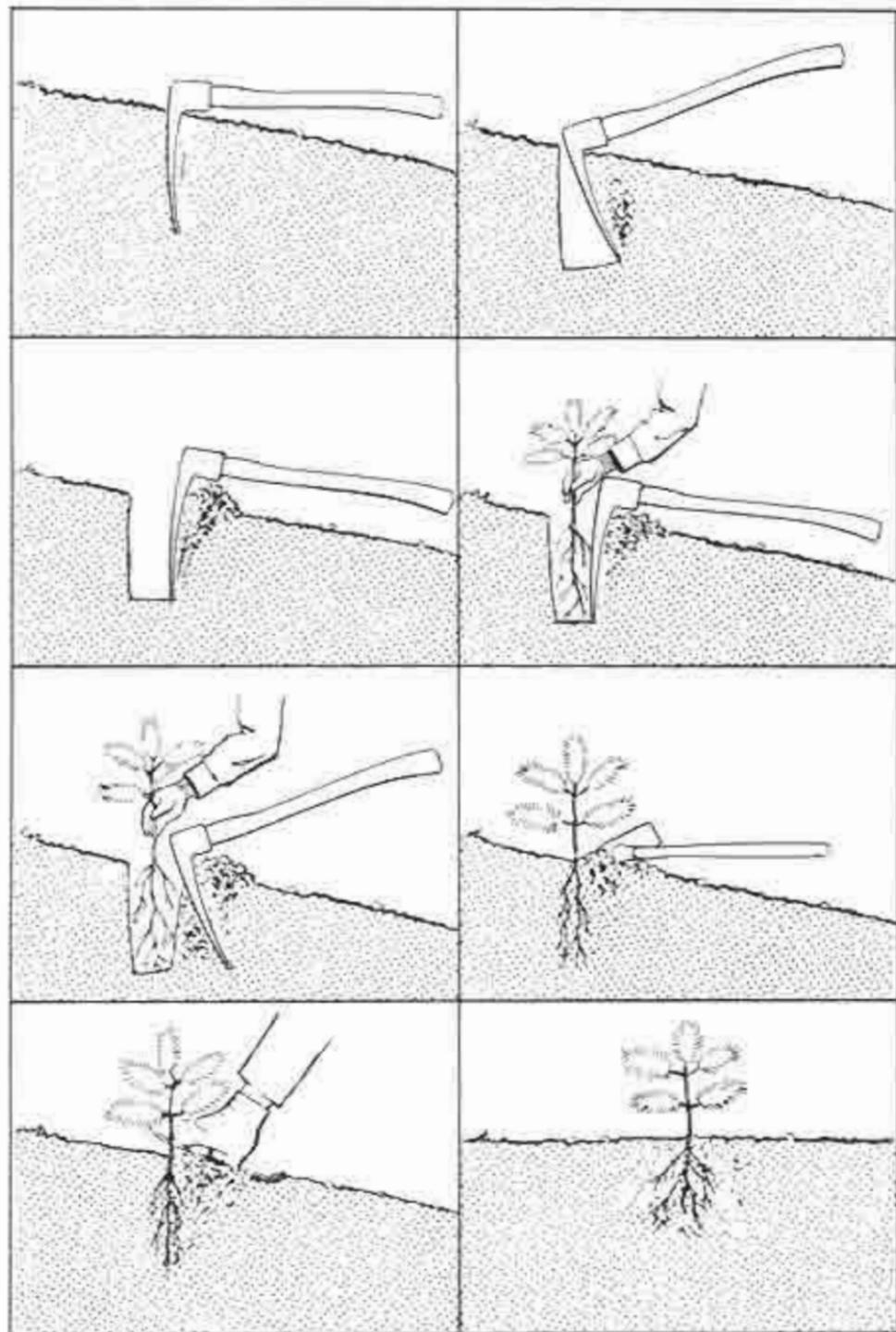


Figure 11-9

A western planting tool is a common hand-planting method in California.

To enhance success of expensive planting endeavors, some sites have to be cleared to mineral soil with tractors, removing slash and competing vegetation. The debris is placed in piles or windrows that can be left or burned during safe periods. Herbicides have been used singly or in combination with mechanical clearing. Sometimes gophers, rabbits, and porcupines have to be controlled by baiting or trapping. The use of chemicals for plant and rodent control may require permission of the county agricultural commissioner.

Trees are planted in a number of ways—by hand tools, powered augers, and tractor-drawn planting machines. The former method is still the most adaptable in this state because of our difficult ground conditions: The western planting tool—a special hoe or mattock (Figure II-9)—, a planting bar, or a dibble for tubed seedlings are the hand tools in common use. The planting stock should be stored and handled carefully to prevent drying and planted with great care. Grass and herbs around the planting spot should be scalped to reduce competition.

The usual spacing now for growing timber is $10' \times 10'$, giving a stocking of 436 trees per acre, but closer or wider spacing may be desired depending on survival expectations, products to be grown, and precommercial thinning plans. The seedlings are ordinarily planted in parallel straight rows. An experienced planter under favorable conditions can plant from 350 to 700 bare-root trees per day. Planting with containerized seedlings is usually much faster. The number of trees per acre resulting from different spacings are given in Table II-8; it is derived from the formula:

$$N = 43,560 / (L \times W)$$

Where N = number of trees per acre

43,560 = the square feet in an acre

L = distance between plants in row

W = distance between rows

Table II-8. Number of trees per acre for various square and rectangular spacings.

Spacing, feet	Number trees per acre	Spacing, feet	Number trees per acre
2 x 2	10,890	8 x 10	544
3 x 3	4,840	8 x 12	434
4 x 4	2,722	8 x 25	218
4 x 5	2,178	9 x 9	528
4 x 6	1,811	9 x 12	400
4 x 8	1,362	10 x 10	436
4 x 10	1,089	10 x 12	363
5 x 5	1,742	11 x 11	360
5 x 6	1,462	12 x 12	300
5 x 8	1,089	12 x 16	292
5 x 10	871	12 x 12	258
6 x 6	1,210	14 x 14	277
6 x 8	908	15 x 15	194
6 x 10	725	16 x 16	170
6 x 12	605	18 x 18	134
7 x 7	880	18 x 20	121
7 x 10	622	20 x 20	109
8 x 8	687	25 x 25	70

The chances for good survival of plantations can be increased in a number of ways. Using native mulch (leaves, humus, etc.) from immediately around the seedlings is one practical way to reduce moisture loss. Of course, watering is out of the question except for valuable seed orchards and other special plantings. Spraying the tops with transpiration inhibitors and fertilization at time of planting have not demonstrated consistent satisfactory benefits. Herbicides may be used for control of grass and weeds near the plantings. Shading of the seedlings with shingles or other devices has improved survival under some conditions. Protection from fire by reducing fire hazards and risks, maintaining firebreaks and fuelbreaks, and keeping access roads open should be planned and provided. Similarly, the forest manager should periodically examine the plantings to detect damage from insects, disease, and animals, and take appropriate corrective measures to control those pests if possible and practicable. There are a number of serious pests of plantations. See Chapter VIII for more explanation about forest protection.

Economics

Obviously, in managing a forest for timber production, the owner must be guided by the economics of the efforts put into the undertaking. In the long run, benefits to be derived from silvicultural measures, increasing the stocking base, careful cutting, regulation of the forest, and stand improvement should exceed the investment costs and interest charges. Sometimes financial consideration may suggest heavier harvests, especially of slow-growing, old-growth trees, and shorter rotations. A central objective of tree farming is to get the greatest possible growth from the forest and at the same time leave the smallest amount of timber on the ground as a capital investment.

From the short-term standpoint, regulating the forest to balance cut with growth and improvement of the stand may not seem financially attractive to a tree farmer. Of course, each situation has to be determined from the condition and potential of the forest and the owner's situation. While investments made in the forest may not pay off in the near future, it should be remembered that they do immediately increase the sale or estate value of the property. This can be compared to putting more money in the bank, although it is true that this capital is not nearly as liquid as money. However, prudent forest management brings about a much nicer looking forest with a higher value.

The economic potential of a forest can be increased by means other than regular timber harvests. These include the harvest of special forest products described in the next chapter and taking advantage of the range, water, wildlife, and recreation resources (see Chapters IX and X).

To encourage tree farmers to make long-term investments in their forest land, the costs of some practices are eligible for cost-sharing by the federal government. A major part of the expense of reforestation, thinning, and pruning may qualify for this financial assistance. In addition, the State provides assistance for reforestation projects. Low-interest loans may be available from the Federal Land Bank for forestry purposes. For information about these kinds of financial assistance see a CDF forest adviser.

Chapter III

WOOD PRODUCTS OF THE FOREST

There is a great variety of tangible and marketable products that can be obtained from the forest. They range in size from large sawlogs down to small tree seed, and the values and uses involved are also quite different. A tree farmer is wise to consider harvesting as many products as possible.

Conifer Sawlogs

By far, the commodity that is generated the most from our forests is in the form of conifer sawlogs; they constitute over 90 percent by volume of all our annual wood production. And sawlogs have the highest value in terms of the total yield of California forests. Good markets exist for logs that can be sawn into lumber.

The specifications for sawlogs mainly depend on needs of the market. Generally, merchantable sawlogs have minimum diameters (inside the bark) of five inches and up, and must be at least 10 feet long plus a trim allowance of 4 inches for every 16 feet. In the pine region the standard log is 16 feet (plus trim) in length, but logs may vary from lengths of 10 feet by even feet to 32 or 40 feet. In the redwood-Douglas-fir region the standard log is 20 feet long, but here again variable in length.

The length to which logs are cut for logging depends on size, weight, logging conditions, machinery used, and type of lumber to be cut. In case of small timber, it may be logged and hauled in tree lengths and not cut or bucked into logs until arrival at the mill.

Logs should be reasonably sound; a quarter or more of the volume should be defect free, depending on value and the logging costs. Low-value logs or those that could be expensive to harvest and deliver to a mill must be sounder than others to pay their way. Where logs can be used for pulpwood or chips it is possible to utilize some defective or cull logs.

Logs can be graded according to quality. There are no statewide or even regional standards for logs in California, and if used, they are the result of requirements of the local market or timber seller-buyer contracts. Sometimes a simple grading system is achieved by segregating old-growth logs from young-growth, large from small, and sawlogs from those useable for veneer and plywood purposes. Usually a small tree farmer would not want to be bothered by grades unless he or she chose to personally harvest and sell the logs and the grading was worth the expense.

The measurement of logs for volume and defect is called scaling and is described in Chapter VI.

Conifer Veneer Logs

Conifer logs of high quality and large size can be more profitably utilized by marketing them as veneer logs, or peelers as they are usually called. Douglas-fir is the leading species, although coast redwood, ponderosa pine, sugar pine, and some true fir are also used for veneer, most of which goes into plywood.

At one time peelers were clear, lower-trunk logs of 30 inches or more in diameter, but now sound logs of lower quality and lesser diameter are being increasingly used to manufacture plywood. Before peeling on the lathe, the logs are sawn into lengths of 8 feet plus some trim allowance. Therefore, logs prepared for this market are bucked into multiples of that length.

Some veneer (named shook) is also produced at a few places in California for manufacture into boxes and other containers mainly for the agricultural industry. The veneer can come from large lathes similar to those in plywood plants, or be sliced or peeled from special bolts or blocks smaller than the usual veneer or peeler logs. Shook blocks 19 inches in length by 18 inches in diameter and larger of knot-free wood are peeled on small lathes. Sometimes these blocks can be made from quite limby trees by just cutting them from between the whorls, and using the remaining knotty and poor quality pieces as fuelwood. The species employed for shook are ponderosa, sugar, and digger pine, Douglas-fir, and Sitka spruce.

Hardwoods

Although California hardwoods don't have the size, form, quality, and diversity of those in eastern U. S., they still have good prospects. They are slowly increasing in use for sawing into lumber and for pulpwood and chipwood where the better stands occur. Species used for lumber include alder, black oak, chinquapin, cottonwood, madrone, sycamore, tanoak, white oak, and a few others.

As for pulpwood and chipwood, eucalyptus has been the principal hardwood species used (see section below). Other hardwoods, like tanoak, have been made into chipwood when the market was especially good.

The stump portion, swelled trunk pieces (large burls), sections with forks of the stem, and other pieces having special figure characteristics of some trees are utilized in the furniture, novelty, and special wood products trade. Black walnut, cottonwood, California laurel, and madrone are the main species in demand. The logs or chunks are sold by the ton.

The utilization of our hardwoods for fuel is discussed in a later section on fuelwood.

Pulpwood and Chipwood

With the installation of pulp mills in California and the development of a foreign export market, pulpwood and chipwood are rapidly expanding forest products. This development has resulted in a much better utilization of our commercial forests and enhanced opportunities for tree farmers to practice more intensive forest management.

Most of the raw material for pulp that is marketed in this state is in the form of chips that are made from sawmill and plywood plant waste. The chips are used or sold for domestic pulp production or exported. Chips are also used to make hardboards (like masonite) and less dense, thicker particleboards. Some chips have come from the chipping of woods wastes by mobile chippers. This probably will increase in the future and include chipping of thinnings and hardwoods.

Chips are measured by the "unit" which is equal to a gross content of 200 cubic feet in uncompacted form. Depending on species and moisture content, a unit weighs from 1800 to 2100 pounds. Loosely packed, the average solid-wood content of a unit is only about 72 cubic feet. The "bone-dry unit" or "B.D.U." in use by some chip purchasers is equivalent to 2,400 pounds of oven-dry chips. The B.D.U. of a load of delivered chips is determined by drying and weighing sample lots.

As mentioned earlier, low quality and cull sawlogs may be chipped for pulp where the logging and handling costs are favorable. Also, pulpwood in form of logs or cordwood can be obtained from thinnings, salvage of fire-killed timber, and special harvests as it is done so much in the east and south, but this latter method is not practiced much yet in California. Woods waste like broken logs, chunks, and tops is collected to some extent and brought to chippers at mills and at pulp plants. Pulpwood in sawlog form is measured by board feet while that in smaller sizes may be measured by the cord—128 gross cu. ft. of wood (see Chapter VI); it roughly equals 500 board feet.

Poles, Piling, and Posts

Roundwood products from the forest in form of poles, piling, and posts can be marketed in a number of areas of the state. These are something that a tree farmer can fairly easily harvest personally and not require too much equipment or a high degree of skill. They can be used to some extent by the forest owner for building purposes, fences, etc. Another advantage is that these roundwood products provide an opportunity to utilize some of the material arising from stand improvement measures, thinnings, and salvage before or after regular logging.

Poles are made in many sizes and for a number of purposes, e.g., utility lines, pole-constructed buildings, and other special purposes. Douglas-fir, western hemlock, ponderosa and lodgepole pine, true firs, and a few other species are used. Poles for usual purposes are made from the smaller diameter trees—from 9 to 22 inches dbh—that are live, straight, sound, tall, and free of heavy limbs. Minimum top diameters run from 5 to 9 inches.

Pole operators classify poles by species, length, minimum top diameter, circumference 6 feet from the butt, and into six bending-strength categories established by the industry. Poles are usually sold by the piece. Most poles in the trade are peeled and treated at commercial plants using preservatives like creosote or other special chemicals to improve their resistance to rot and insects.

Pilings are similar to poles; most here are cut from Douglas-fir and coast redwood. They are made from good quality trees 7 to 20 inches dbh—with minimum top diameters of 5 to 12 inches. Standard specifications are somewhat more complex than for poles and are different for friction piles and end-bearing piles. In addition to certain quality factors, piles in the market are specified by length, minimum circumference at the top and 3 feet from the butt, and must meet certain design standards. They are sold by the lineal foot.

Pilings for wharves in salt water have to be peeled and treated to

prevent damage from sea creatures like the teredo worm and some crustaceans. Piles for driving deep into the subsoil where insects and rot do not flourish usually are not treated, nor necessarily peeled of bark.

Because of the complexities of the specifications of poles and piling, a tree farmer considering the harvesting of them should consult buyers or plants to determine exactly what they require. Also, care should be taken to not hi-grade the forest by cutting future crop trees that would be more valuable for lumber or veneer, or to interrupt the overall silvicultural objectives.

When required, the bark from poles and piles can be more easily removed soon after harvesting to reduce damage from insects and rot and to increase penetration of preservatives. Most peeling is done by machines at the processing plants, which sometimes also shaves or shapes the pieces, rather than by hand peeling with an axe, drawknife, or spud bar.

Round posts are cut from small trees of many species. Those that are naturally durable (see Table 1-2) like redwood, cedar, and juniper are preferred, because if sound, close-grained wood is used, no preservative treatment is necessary. However, less durable species and coarse-grained trees can be utilized also, provided the posts are treated. Some forest owners do this themselves by soaking the butts of dried posts in a solution of pentachlorophenol and diesel oil, or other preservatives. Instructions are available from a CDF forest adviser or county farm adviser. Like many chemicals, preservatives have to be handled carefully. The posts should be peeled in any case by hand or rotating drum debarkers. Posts are usually 6 to 8 feet long and 3 to 6 inches in top diameter.

Split Products

Different kinds of split products are marketable from California trees. The species used depends on the product. Posts 6 to 8 feet in length and 4 to 5 inches thick are split from the heartwood of old-growth redwood and cedars. Splitting tools include wedges, sledge, splitting maul, and the broadaxe.

Stakes for supporting young landscape trees, grape vines, and fencing make up a large portion of the split products business. Grapestakes are split mostly from old-growth coast redwood, although Sierra redwood and western red cedar make good stakes also. The most common length is 6 feet and the thickness is 2 x 2 inches. When stakes are to be used for fencing they are usually resplit or sawn to a 1 x 2 inch size. Special split products like paling and rails are occasionally marketed for construction of rustic fences.

At one time California operators produced a large quantity of split and sawn shakes from select, virgin coast redwood trees, but most of these products consumed here now are made from western red cedar in the Pacific Northwest. The old-time shake is uniform in size— $\frac{3}{4}$ by 6 by 18 or 24 inches, and split across the annual rings to get vertical grain. Besides straight-grained, clear redwood, it can be split from bolts of heartwood of the cedars, sugar pine, and even white fir. A tool with a handle at right angles to the cutting blade, called a froe, is pounded by a wooden mallet to split thin slices.

More popular than the uniform shake is the one that is partly sawn; sometimes it is called the Hollywood shake. Again, it is mainly made from western red cedar and coast redwood. The shakes are first split with a froe from bolts into thick pieces of varying width and then these are each sawn edgewise at an angle to produce tapered shakes. They are either 18 or 24 inches long, and the thickness at the big end is $\frac{1}{2}$ to $\frac{3}{4}$ inches for medium shakes and $\frac{3}{4}$ to $1\frac{1}{4}$ inches for heavy shakes. The operators pack the shakes into bundles where five of them will cover about a "square" or 100 square feet of surface.

There is a limited market for shake and shingle bolts in the northern redwood region. They are sold by the cord. However, bolts for shingle manufacture have virtually disappeared from the California scene. What few shingles that are manufactured here at present mostly come from choice blocks of redwood which are a by-product of sawmill operations.

Fuelwood

Wood is coming into its own again as fuel because of the energy crunch. Until the early 1930s fuelwood was used a lot for both domestic and industrial purposes, but it was gradually replaced by oil and gas. Wood still has a good potential as a source of energy and its use for fuel will increase. Wood is a versatile fuel that can be used in solid form, gasified, or converted into a liquid state. Depending on the heat value of the species (see Table I-2), a cord of some of our denser hardwoods when air dry has about the heat equivalent of a ton of coal. Fuelwood may be in the form of cordwood, hogged and chipped wood, woods and mill wastes, briquets, or charcoal.

Most California hardwoods make excellent fuel. These trees are cut on the lower elevation woodland grazing areas and to some extent from commercial forests having a mixture of hardwoods and conifers. Large limbs, tops, and cull material resulting from harvesting of conifers, can also be made into fuelwood; so can thinnings and salvage from trees killed by fire or pests.

The wood is ordinarily cut and split in 12 to 24 inch lengths mainly for heating purposes—fireplaces, wood-burning heaters, and a little for cook-stoves. It should be air dried before marketing. The cord is the standard measure; it is a closely stacked pile 4 x 4 x 8 feet, or 128 cu. ft. gross. However, the net solid wood content of a cord only averages 80 cu. feet. The tier or rick is also used to sell firewood but it is a confusing unit because it depends on the length of the wood pieces. For 12-inch wood 4 tiers make a cord, and a tier then is a pile of such wood 4 feet high and 8 feet long. In case of 16-inch wood, three tiers equals a cord, and for 24-inch wood, 2 tiers make a cord. Thus, a tier of one length wood is not equivalent to a tier of another length.

Where not utilizable for pulp and other by-products, mill wastes in the form of bark, edgings, trimmings, sawdust, and shavings are used for fuel in some plants to generate power to drive mill machinery. A few large mills produce electricity in excess of their needs and this is sold for domestic consumption. Some mill trimmings and larger pieces of waste wood may be sold for firewood.

Some special wastes are manufactured into briquets and charcoal by processing facilities at the mill. Making charcoal in kilns near the woods has not proved to be very successful because of the great amount of labor required and air pollution problems.

Christmas Trees

The growing and harvesting of Christmas trees has developed into a big business in California, although we still depend on imports from other states (principally Douglas-fir from the Pacific Northwest) for much of our needs. It is a venture that is readily adaptable to many tree farmers, either as a sideline to regular timber operations, or exclusively as a Christmas tree farm. The principal species grown here for this are Douglas-fir, Monterey pine, white and red fir (silver-tip), Sierra redwood, and Scotch pine.

The trees are produced in three ways. Natural commercial timber stands occasionally offer chances for thinnings, especially too densely reforested areas. The second source can be some natural forests, especially high elevation fir areas, where stands which are thick, slow-growing, and



Figure III-1

New Christmas trees can be produced on the stem of a cut tree by the turn-up process.

even-aged are set aside for Christmas tree management. The trees are thinned to get better spacing and side growth of the crowns. Others are just topped during harvest to leave at least one whorl of healthy branches, one or a few of which will turn upwards to form a new stem (Figure III-1). These are called "turn-up" trees. The last production method is the plantation where trees are grown, cultured, and harvested solely for Christmas trees. Many are located on open or agricultural land near urban areas and are operated on a choose-and-cut basis, so that families can have an outing to cut their own trees. There is a lot of literature, advice, and assistance that can be had on the subject of Christmas tree management from CDF forest advisers, county farm advisers, and the California Christmas Tree Growers (CCTG).

Christmas trees are sold by the lineal foot or at a fixed price per tree. They are segregated by species and often graded. Standards for grades have been established by the U. S. Department of Agriculture, copies of which can be obtained from CDF forest advisers and county farm advisers. The CCTG above has also adopted some grading rules.

Miscellaneous Forest Products

There are other products that can be profitably utilized from the forest, most of which depend on special or local markets. The producer needs to search them out and learn what the requirements are. A good first source of information would be the CDF forest adviser or county farm adviser.

Greenery

Christmas greenery, toyon berries, mistletoe, and cones for wreaths and other decorations are in demand during the holiday season. Florists also use considerable amounts of foliage of ferns, huckleberry, salal, and conifers in making floral pieces and displays. The cones preferred are those from sugar, Jeffrey, and other pines. Specifications for these decorative products are set by dealers who buy them by the bunch, bundles, bag, or pound.

Cones for Seed

With the increased interest in reforestation, there has been a corresponding increase in the demand for cones for seed purposes. The buyers include public forestry agencies, some industrial tree farms, private nurseries, and seed companies. The more common species collected are Douglas-fir, ponderosa pine, Monterey pine, red and white fir, and redwood, but other species may be wanted also. The easiest way to collect cones is after tree felling on logging operations that coincide with the maturity of the cones. Sometimes, cones severed by wind or squirrels are handy also. Using long pruning hooks or climbing equipment is another method, but safety precautions should be taken to avoid injury. The cones should be tested for ripeness and soundness before harvesting. This is done by carefully slicing the cone lengthwise with a sharp knife and the good seeds counted on the cut surface. For cones to be acceptable, at least 75 percent of the exposed pine seeds and 50 percent of the other species should be full and sound. Cones are sold by the burlap sack (about two bushels), each

tagged with species and date, elevation, and location of collection. Before one collects cones, advice should be sought from CDF forest advisers, forest-tree nursery operators, or others having experience in the subject.

Burls and Rounds

Burls and rounds of a few species are salable. In case of coast redwood, live burls that will sprout are sold by curio shops, and large pieces of redwood burls are cut for rustic furniture or manufactured into novelties and highly prized items. Burls of California laurel are also turned and made into beautiful novelties. Rounds or cross sections of small, close-grained cedar and redwood logs that are durable are made into patio or garden stepping blocks. Treating with wood preservatives would be necessary in case of non-durable species.

Other Possibilities

A resourceful and enterprising tree farmer could develop markets for other miscellaneous products. Duff from the forest floor is a good soil conditioner for some gardens. Manzanita branches or tops have decorative value. There is limited market for peeled cascara bark in the northwest part of the state. Tanoak bark once was peeled a great deal for tanning of leather, but it has largely been displaced by chemicals.

Chapter IV

HARVESTING TREE CROPS

Harvesting the crop is a critically important function in the management of the forest. If done right, logging can be used to silviculturally improve a forest, but on the other hand it also can be a destructive force to the forest and the environment if it is not done properly. Harvesting is the operation that enables the owner to effect the management plan for the forest—to bring about better distribution of age classes, improve the stand, and promote growth. And more importantly, periodic harvests are the pay-offs for the planning, investments, and work put into the forest.

Like any other major activity, harvesting must be planned. Consideration needs to be given to the care and betterment of the forest, protection of its associated values, and to many other factors about the crop, cutting methods, selling, and legal requirements.

Timing and Location of Harvests

First of all, the timing and location of the harvests should correspond to the needs of the forest as set forth in the management plan. A good practice is to have a cutting budget prepared for at least five years ahead to indicate what amounts can be harvested, how often, and from what parts of the stand. Generally, annual or periodic harvests at longer intervals of about the same volume in accordance with allowable cut estimates are tentatively prescribed in the cutting budget and revised periodically. The cutting is located where the forest needs it most. High priority is given to trees or areas that are defective, of poor vigor, overmature, and to merchantable trees of any particular age class that are overabundant. Of course, quick salvage of trees damaged or killed by fire and pests is important.

Market conditions need to be taken into account also. Obviously, there is no point making a harvest when the market is poor or non-existent; that would be a waste of material and money. Like other commodities, wood products vary in price according to supply and demand and other economic factors, and these cannot be accurately predicted. Whether to harvest or not should depend on whether there is a fair chance to realize a reasonable profit from the crop. Fortunately, standing timber can be held over from one year to the next without too much spoilage, so harvesting can be deferred when market conditions are not right.

Logging should be timed by season also. In California, it is usually done in the spring, summer, and fall months when climatic conditions are more favorable. In wet weather harvesting is more costly, causes more damage to the forest and roads, and has a more deteriorating impact on the soil, streams, and watershed. The markets for wood crops are ordinarily better in the dry months.

Marking the Harvest

As indicated above, what trees to specifically harvest depends on the objectives of the management plan, the condition of the forest, and the

market. Legal requirements also come into play here, because they control such things as stocking to be left and other aspects of logging. These legal factors are discussed in a later section in this chapter.

Depending on the silvicultural method to be employed, the trees or areas to be cut should be marked somehow. In any case, the exterior boundaries of the harvest area should be designated by signs, flagging, or marking on trees so that timber cruisers, potential buyers, and logging personnel can clearly see the layout. It may be advantageous sometimes to set out interior subdivisions also, especially when the logging should be done in a certain order. This type of exterior marking usually would be all that is necessary where clear cutting is going to be done.

Under the seed-tree cutting system, the seed trees are marked individually where they are scattered. When seed-tree blocks are employed just the boundaries are marked. If trees below a certain diameter are also to be left they need not be marked, because those trees can be readily determined by the timber fallers by estimation or measurement. However, trees below the minimum diameter in need of cutting for silvicultural reasons should be appropriately marked.

Under both the shelterwood and selection systems, the individual trees ready for harvest are carefully chosen. As discussed in Chapter II, this marking is primarily based on silvicultural and management needs. However, what species, sizes, and quality are acceptable on the current market should be considered too. Moreover, the tree farmer has to keep economics in mind in order to have a harvest that shows some profit. Within that restraint, for the purpose of forest improvement a person may elect to cut some poor trees that are not salable. In addition to profit opportunity for the forest owner, the proposed harvest should be made attractive to prospective buyers and operators.

Disposable pressurized cans of bright paint are convenient to use for marking purposes. Trigger-type spray guns are also handy in that a tree can be sprayed from a distance of a few feet (Figure IV-1). It is a good idea to mark trees to be cut both at breast height and at stump level; this gives a better record of what trees have been removed and helps prevent the taking of extra trees.

Advance Information Needed

Before a harvest can be planned and scheduled certain basic information is collected by the forest manager. Without it a timber cutting operation would not achieve the desired results in terms of the forest itself, efficiency, and economic gain. Interested buyers want knowledge about the forest in order to make offers.

Timber Cruise

Once the trees have been designated for harvest the area should be cruised by a competent person to find out what volume of timber by species is available for cutting. Cruising procedures are explained in the next chapter. This inventory can be made at time of marking to avoid going over the area another time. A general idea of the size range and



Figure IV-1
Marking trees with a paint gun.

quality of the timber is valuable to have. What existing roads can be used and what additional ones have to be constructed should be sized up and placed on a timber sale map. How the area should be logged, i.e., method and order, and the different logging conditions and problems should be noted during the cruise.

Timber Harvesting Plan

The State Forest Practice Act requires that a timber harvesting plan must be prepared, filed, and cleared for every commercial operation except for emergencies, conversion of timberland into another use, and certain minor harvests. This plan has to be prepared by a registered professional forester, usually at the expense of the operator, who also is primarily responsible for proper filing of it with the Department of Forestry. Since a forest owner has some responsibilities regarding implementation of the plan and conformance to state forest practice regulations, the owner or representative should at least monitor the preparation of the timber harvesting plan. Better yet, the owner should have a forester participate in developing the plan to protect the owner's interests in future forest productivity and management objectives. A lot of data is required, much of which can only be collected in the field. Therefore, as much of this information as possible should be gathered during the cruise. What exactly is required in the plan by the State is spelled out in a printed form and regulations, copies of which can be obtained from CDF offices.

Stumpage Appraisal

After the field work has been completed an appraisal of the value of the timber comes next. It is necessary to have an appraisal in order to establish the minimum sale price of the timber, or stumpage as it is called, which would be offered to prospective buyers. A modified overturn, or profit-ratio, method can be used to appraise stumpage. Simply stated, stumpage value is the difference between the market price less operating costs (including stumpage) with a certain allowance for profit. Expressed as a formula it is:

$$X = [S / (1 + \%)] - C$$

Where X = stumpage value in dollars per thousand bd. ft. measure (MBM)

S = selling price per MBM

C = operating costs per MBM

% = expected percentage of profit

Separate appraisals are made for each species or groups of species having the same value. The appraisal can start with the average mill-run selling price of lumber. However, if there is a local market for logs for which the general price is known, it is easier to start the appraisal there. Information is then needed on expected logging and hauling costs. This may be obtained from local operations or consultants. If not, one would get cost data developed by the U. S. Forest Service and other public forestry agencies from them or a CDF forest adviser and adjust those figures to fit the situation. The profit margin runs from 10 to 20 percent, depending on the risk involved.

To demonstrate this appraisal method, assume that price per MBM paid locally for average Douglas-fir logs delivered at the mill was \$230, logging and hauling costs were \$100 per MBM, and a 15 percent profit was expected. Then, stumpage value $X = [230 / (1 + .15)] - 100 = 100$.

Before any values arrived by this method are accepted they should be compared with known prices for similar timber in the local area. This will serve as a check, and also in some instances comparisons may justify adjusting the values somewhat.

Logging Operations

The tree farmer should decide what logging methods should be used in any harvest. Logging has a big impact on the land and the trees, so methods that cause the least damage should be elected, providing they can do the job within the range of reasonable costs. To choose something that is especially expensive lowers stumpage returns to the forest owner and also affects the operator's potential profit.

Felling and Bucking

The felling and bucking (sawing) of trees into logs in California is still done by using power saws and hand tools like axes, wedges, and sledges. In other parts of the country, where the terrain is flat or nearly so, this operation is being increasingly done by mobile machines that sever the

tree at its base with a scissor-like knife and then lay the tree on the ground. Some machines even delimb the tree, buck and bunch the logs, and haul them to a landing where the logs are loaded onto trucks for delivery to a mill. California's topography being as rough as it is, these kinds of all-purpose machines have limited use here, so felling and bucking will continue to be largely accomplished with chain saws.

Yarding, Loading, and Hauling

Getting logs to the loading area is called skidding or yarding. This is done in a number of ways. Most common is the use of track-laying (Figure IV-2) or rubber-tired tractors to drag the logs to the landing. A variety of special machines have been developed for this purpose: wheeled arches towed behind tractors that elevate the towing cable and chokers connected to the logs, machines that in effect have the arch as an integral part of the tractor, and tractors that have powered arms at the rear that bunch, lift, and hold one end of a few logs as they are skidded to the landing. Bulldozers are needed to build the skid trails as well as for road and landing construction and maintenance.

In general, to minimize damage and for sake of efficiency, the smallest yarding equipment that will do the job should be selected. Tractor logging requires a lot of roads and skid trails, which if not carefully constructed and tended can be harmful. However, generally this kind of logging is the cheapest method where the terrain and weather conditions are right.



Figure IV-2

Specially adapted track-laying skidder

Cable yarding systems powered by stationary machines (donkeys) were once popular in California until they were largely replaced by tractors in the mid-1930s. These were big, complicated, heavy systems that were expensive to buy, install, and operate. These cable systems are finding favor again, but in the form of lighter and more mobile machines. This has been brought about because rougher and less accessible timber areas and smaller trees are being logged. Also, if properly used, cable logging causes less soil disturbance, so it is justified where soil and watershed values are of critical importance. Cable systems can be fairly complicated and require a great deal of know-how and skill, and they are not feasible for small volumes, scattered, or low-value timber.

Logging with balloons and helicopter is also possible in some cases. These methods are very expensive. So far they are mainly used to a limited degree on lands with difficult access, or where extra precautions have to be taken to avoid environmental damage. These areas include very rough topography, highly erodible soils, or those having exceptional watershed values. Being expensive to install and operate, the stumpage value of timber logged in this manner comes out quite low.

Contrary to these technological developments, using animal power for yarding should not be dismissed. Occasionally, horses and mules are still utilized in California forests, and because of increasing energy costs, draft animals may return more and more to the logging scene. They work well in smaller, young-growth timber, and cause the least disturbance.

Various kinds of mobile machines are employed to load logs onto trucks (Figure IV-3). They include front-end loaders, booms, cranes, and power-shovel types.



Figure IV-3
Front-end log loader.

Practically all the hauling of logs from the woods to the mill is done by large trucks. Logging operators often employ contract haulers for this rather than own and run the trucks themselves. In fact, some timber operators have sub-contractors or "gypos" to conduct all or part of the logging.

How to Sell

When one offers to sell some timber a list of potential buyers should be prepared. It may be advantageous to even consult some buyers to get an idea of what kind of timber they want, prices, and specifications. The more competition there is for a timber sale the better the prices for it will be. The public forestry agencies (e.g., USFS, GDF, Bureau of Land Management, Bureau of Indian Affairs) who sell timber are a good source of going price information for stumpage.

Sale Offers

Offers to sell timber must contain certain basic information. The location of the sale area is legally described with estimated acreage and shown on a timber sale map. A listing is made of the amount of timber by species that is being offered, along with the minimum asking price for each. The volumes should be developed from the cruise made during or after the marking of the trees to be cut.

Measurement

The timber owner should be the one to decide by what measurement method the timber will be sold, the log rule to use, whether to sell by cruise or tree measurement, and whether logs are to be scaled at the logging site or away from the woods, e.g., at the receiving mill. Scaling is the procedure for estimating the board feet content of logs by use of special tables called log rules (see Chapter VI).

The most popular log rule in California is the Scribner and its variant the Scribner Decimal C. A few other rules have also been employed such as the Spaulding table.

Selling timber on the basis of tree measurement is convenient. The sale is made for an agreed price payable usually in a lump sum. This method avoids the bother and expense of scaling and is especially adaptable to small, short-term sales of fairly sound timber. However, prospective buyers must have confidence in the cruise arranged by the seller, and should check it on the ground. Timber owners should never sell timber on the basis of a buyer's tree measurement cruise without having it checked by a competent person.

When sales call for scaling of the logs, the logs are measured in the woods after felling and bucking, as they are delivered to the landing, on trucks at a central point, or at the mill site. The timber buyer makes periodic payments to the seller based on the scale figures. Specially trained people called scalers are employed, because the procedures are exacting and estimates have to be made for defect in the logs to arrive at the net board-foot content. Therefore, the sale should be large enough to justify the extra costs of employing scalers, unless the job can be handled by the owner or forest manager. Care should be taken about accepting the

scale of the timber buyer, operator, or mill as a basis for payment. In a few places in California the services of a non-biased private scaling bureau are available to both sellers and buyers.

Sale Contract

Regardless of the measurement methods above, it is very important that the timber is sold under a written contract rather than by an oral agreement. This protects both seller and buyer and minimizes disagreements about provisions of the sale. This document sets forth as clearly as possible the area (including map), time period of the sale, the amount of timber to be cut, rate and way of payment, measurement method, compliance with State laws and forest regulations, logging practices, utilization standards (stump height, acceptable defect, log lengths, trim allowance, and diameters), requirements for road construction and maintenance, treatment of snags and logging slash, and provisions for prevention of damage to the property, improvements, and the environment from the operations and wildfire. Other legal clauses like those on performance bonds and liability must be included also, so the advice of an attorney with experience in timber sale matters should be sought. A sample or a check list for a timber sale agreement that can be adapted to specific situations is available from CDF forest advisers. The agreement should be drafted ahead of time and used in making offers to sell and negotiating sales.

Bidding and Negotiation

Sales can be settled in two principal ways. One is by calling for competitive written bids. This requires the preparation and advertising or circulation of a sale announcement. Those used by the U.S. Forest Service, Bureau of Land Management, and the CDF can serve as samples. It should contain at least the following information:

Location and size of area

Volume and kind of timber by species

Minimum bid prices and deposit

Method of measurement (tree measurement, scale, etc.)

Instructions regarding examination of timber and proposed contract

Final date and place of filing of bids

Reservation of right to reject bids

Using the same information as above, a less formal way to make a sale offer would be for the seller or his agent to visit or call timber buyers and mills to find out their interest and the prices they would be willing to pay. The sale could then be decided by negotiations with the most likely buyer and the contract agreed to and executed.

Supervision

A timber sale agreement is only as good as the supervision and follow-through that the tree farmer provides during and after the harvest operation. This insures that the owner is getting full value for his timber and that the job is being done according to contract and without unnecessary damage. Periodic inspections therefore are advisable. It may be advantageous that this be done by a registered professional forester in case problems result in disagreement or litigation. Also, having a qualified person

present occasionally on the scene prevents problems from arising or growing into bigger ones. The forest owner should also request copies of reports of inspection from the CDF for compliance with state forest practice regulations (see below).

Legal Requirements

Many laws and regulations bear on the harvesting of timber. To protect oneself the tree farmer should have good knowledge about the legal requirements.

Forest Practice Act

Foremost of the legal requirements are the State Forest Practice Act and the forest practice rules and other regulations that have been adopted under the law by the Board of Forestry. The law and regulations are administered and enforced by the Department of Forestry which conducts periodic inspections. These legal standards are intended to not only protect forest values but also those relating to soil, water, fish and wildlife, recreation and aesthetics. The requirements are many and in considerable detail. First to keep in mind is that advance notices of any proposed timber operations must be filed by both the timber owner and operator with the CDF. Then, as mentioned earlier, before logging can commence the operator must file with the Department a timber harvesting plan and have it in approved form. In addition, the person conducting the harvest must have a timber operator's license.

The forest practice rules pertain to the timber operations and cover such subjects as silvicultural methods, stocking to be left after logging, timber felling, yarding, erosion control, logging roads, stream and lake protection, reduction of snag and slash hazards, fire prevention, and insect and disease protection. Where timberland is to be converted to another use the owner must first file for and receive an approved timberland conversion permit. Copies of the Forest Practice Act and the rules and regulations are available from CDF offices, and forest practice inspectors of the Department can comprehensively explain the requirements.

The penalties for violation of the law and regulations can be quite severe—a misdemeanor action in the local court, revocation of the timber operator's license, or injunction to stop operations. The State may require corrective action for some violations with charges levied against the person responsible, which charges also are placed as a lien against the property. While the responsibility for compliance is primarily directed at the operator, others like the timberland owner may also be charged, so it behooves the proprietor to do all that is possible by contract and supervision to see that the operator faithfully abides by the law and regulations. Of special note is that various reports on stocking may be required to be made to CDF for as long as five years after the harvesting, and this responsibility could ultimately fall on the owner.

Environmental Protection

Besides the protection of the environment provided under the Forest Practice Act program, there are a number of other laws and regulations

that apply. The Fish and Game Code and related regulations prohibit obstructions in streams or deposits of materials that are deleterious to fish and their habitat. Where timber operations alter or disturb a stream a notice has to be filed with the Department of Fish and Game.

Fish and Game also has laws to protect various species of wildlife. In addition, the Regional Water Quality Control Boards have adopted regulations to prevent and control deterioration of the streams, lakes, and other bodies of water. They have a keen interest in the erosion and transport of soils and debris into these waters.

Protection of other values like rare and endangered species and cultural-historical sites may be occasionally required as a result of the timber harvesting plan process. Concerned agencies like those above and others are notified of these plans and can participate in the review of the plans. Citizens organizations and individuals can also become involved.

Licensing of Foresters

As the reader has observed, the professional forester has a big role in forestry and timber harvesting in California. In order to practice forestry, by law one must be registered as a professional forester with the State Board of Forestry. This license requires seven years of professional forestry experience of which four years may count if the applicant has a college degree in forestry, and successful completion of an examination as prescribed by the Board. Registered foresters have to live up to certain standards and can lose their license if they fail to do so. Landowners are exempted from the licensing requirement if they personally practice forestry on their own lands, except that timber harvesting plans must always be prepared by registered professional foresters.

While registered foresters may run survey lines of various kinds for forestry purposes, they cannot practice surveying or civil engineering unless licensed in these fields. To avoid trespass upon a neighbor's land, in conducting a harvest, a tree farmer should have a duly recognized property line to go by, or engage a licensed surveyor or registered civil engineer to establish the boundary.

Taxation

Like any other person in business or farming, a forest owner is subject to various forms of taxation. It pays to have an understanding of what is involved in order to stay out of trouble and because these costs can be considerable. A timber property or business is subject to property and yield taxes, income taxes, social security tax, and sales tax. It is not the purpose of this handbook to go into detail on these matters because they are complex. However, enough explanation is given to alert the timberland owner on generally what one faces.

To operate a tree farm and to pay taxes one needs to keep many records. A timber grower may not wish to take the time and effort to develop and maintain a suitable accounting system. Because of its intricacies, this is a job that in many cases probably should be turned over to a specialist, preferably one who knows the timber business and who also handles income tax work along with accounting records.

Property and Yield Taxes

The taxation of forest products is covered by the Forest Taxation Reform Act of 1976 (popularly termed the Timber Yield Tax Law), which is jointly administered by the State Board of Equalization and the County Assessors. Under this law, non-federal timber-producing lands are classified by county zoning ordinances into Timberland Preserve Zones (TPZ) through a process involving the County Assessor, County Planning Commission, and timber owners. Such lands may be used for growing of forest products and compatible uses only, and the usual property or ad valorem taxes on TPZ lands are then based on those limited uses. Only the land is subject to the usual county property tax. Trees both within and outside of a TPZ are no longer subject to separate ad valorem assessment based on timber value, but trees outside a TPZ may be assessed on an ad valorem basis for their aesthetic or amenity value.

Instead of an annual ad valorem tax on timber, a special yield tax has to be paid to the State Board of Equalization for all forest products regardless of zone. This is payable at time of harvest at a rate of 6½ percent of the market value of the products, as determined by the taxpayer from schedules developed by the Board of Equalization. The sale price can't be used. The tax revenue, less some reserve funds, is allocated to the counties from which the products are harvested. The yield tax percent is subject to adjustment by the Board in accordance with criteria in the law and changing conditions.

The amount of products to compute the yield tax is the net measured amount when it is first definitely determined. The Scribner Decimal C rule is used for measurement of logs (see Chapter VI). The tax must be paid on a quarterly basis by the person responsible, who is defined as the owner of the trees immediately prior to felling. Usually, this would be the timber sale purchaser, but the forest owner can be held responsible for timely payment of the tax. The taxpayer is required to keep adequate records to support harvest reports and yield tax returns. Operators on public timber are also required to pay the yield tax. The law requires yield tax payers to register with the State Board of Equalization. More information about the taxation of forest products can be obtained from the assessors within timbered counties and the Timber Tax Division offices of the State Board of Equalization.

Income Taxes

Because of inadequate knowledge on the subject, many forest owners pay more income tax than the law requires—both federal and state. (The California income tax regarding timber is similar to the federal system.) A clearer understanding of the procedures would benefit the taxpayer financially and should at the same time encourage better forest management. The income tax laws contain a few features of advantage to the growing and selling for forest products.

With regard to expenditures, some are capital in nature and can be charged off (capitalized) so that the investment can be recovered proportionately as the timber is harvested. Capital expenditures consist of acquisition cost of the timber (not the land) and expenses for reforestation,

stand improvement, and road construction, and may also include under certain conditions items like taxes and fire protection costs. These capital costs can be written off similarly to depreciation of equipment, except that in the case of timber the charge is called depletion.

Another important advantage in the income tax laws to the tree farmer is that concerning sale of timber. Income from wages, salaries, fees, investments, etc. is classified as ordinary income, and is taxed at graduated rates, according to the income bracket of the taxpayer. However, like the sale of property, income from any timber held over one year that is sold is recognized as capital gains. Such long-term capital gains are taxed under special provisions that usually are more favorable.

Special literature on the application of the income tax to timber can be obtained from the U. S. Forest Service and CDF forest advisers. Help is also available from the Internal Revenue Service, the California Franchise Tax Board, and tax consultants.

Other Taxes

Of course, there are other taxes that affect tree farmers. One is the federal social security or self-employment tax. It is payable when the income is above a certain level, and when 1) the timber was grown on a property that is agricultural as well as a tree farm, 2) the income from forest products is not considered capital gains, and 3) the timber operation is a part of and not separate from the farm business. Regardless of this, where a person has employees to conduct a timber operation, social security taxes must be collected and paid. Information and assistance on these matters are available from local Social Security Administration offices.

The state sales tax may apply to sellers of forest products if such sales are retail. Local offices of the State Board of Equalization can provide more information and issue the necessary seller's permit.

Forestry Organizations

In addition to public agencies, there are a number of private forestry organizations active in California that provide services of one kind or another pertaining to forest harvesting of interest to the tree farmers, forest managers, and timber operators. Depending on the organization, these private organizations are involved in representing their interests before legislative and regulatory bodies, providing professional and technical information through publications and other ways, developing and maintaining forest products standards, insurance programs, collecting and publishing forestry statistics, education of the public about forestry and the forest products industries, and in public relations. Qualifications for membership vary, but regardless of that, all of them can be helpful in some manner even to non-members, e.g., providing information and literature to interested parties. The organizations include the following:

- American Forestry Association
- Associated California Loggers
- Association of Consulting Foresters
- California Christmas Tree Growers

California Forest Protective Association
California Redwood Association
Forest Landowners of California
Society of American Foresters
Western Timber Association
Western Wood Products Association

More information about these organizations and their current addresses can be obtained from CDF forest advisers.

Besides the above, there are two others which deserve mention. These are the Redwood Region Logging Conference and the Sierra Cascade Logging Conference. They annually hold separate regional meetings early in the year at which practical topics on forest harvesting are discussed and where the latest machinery is displayed. Membership is open to anyone by paying a nominal registration fee. A lot can be learned at these conferences.

Chapter V

FOREST INVENTORY

To operate a forest business, the owner and manager should have a sound understanding of how land and timber are measured. The subject of forest measurement is known as mensuration. A working knowledge of both land surveying and mensuration is needed for land custody purposes, acquisition and sale of timberland, appraisal of the values, managing and regulating the forest, making timber harvests, and for administrative purposes like paying taxes of various kinds. While the subject may be rather technical, there's no reason why a tree farmer cannot get a good grasp of it, even to the point of personally being able to do some of the necessary tasks with the common tools used.

Land Subdivision

Except for some lands covered by grants made during the early Spanish occupation, all lands in California were once subdivided by the federal government according to a system of rectangular surveys. This system is used to legally describe land parcels and to settle questions of property boundaries. Figures V-1 and V-2 can be used to illustrate and explain the system.

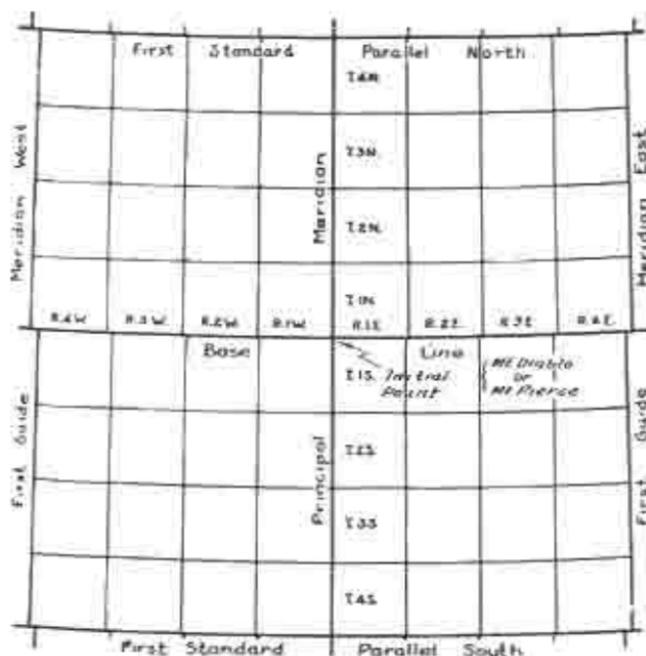


Figure V-1

Standard parallels, meridians, and townships of the U.S. land subdivision system.

Going to the first figure, three initial points were established in the state as bases for the network: Humboldt Base and Meridian (actually Mt. Pierce in Humboldt County), Mt. Diablo Base and Meridian in Contra Costa County, and San Bernardino Base and Meridian in southern California. Most of our timberland is tied to the Mt. Diablo Base and Meridian, usually written MDBM. In addition to the east-west base line, a principal meridian runs in a north-south direction through the initial point. There are guide meridians 24 miles apart that parallel the principal meridian. Similarly, there are lines called standard parallels every 24 miles north and south of the base line.

Within these guide meridians and parallels are additional lines spaced 6 miles apart to form townships. The north-south lines are called range lines and the east-west ones township lines. That means that a township is six miles square.

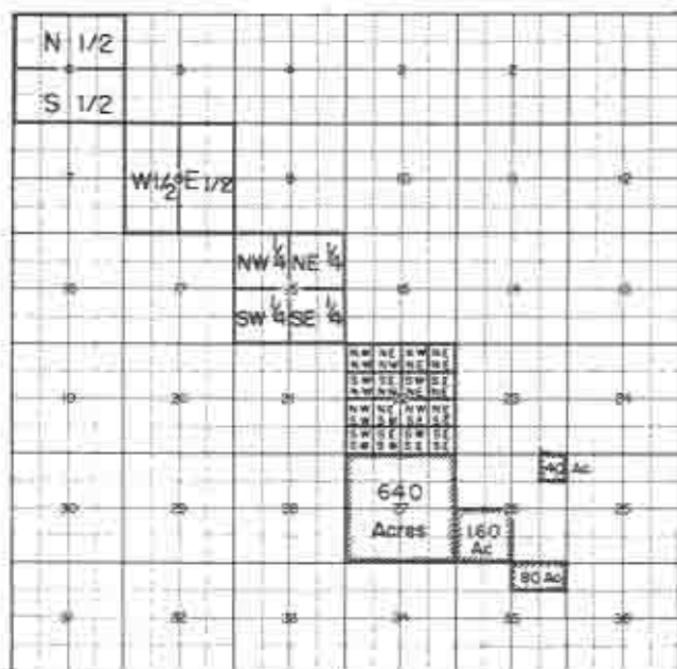


Figure V-2

Normal subdivision of a township and sections

Now using Fig. V-2, each township was subdivided further into one-mile squares—36 in all, unless, due to original surveying errors, some sections were larger or smaller, or even missing. Section corner markers were originally established at the four corners, and additional markers were placed half-way between them to designate the quarter-section corners. Bearing trees were blazed or scribed nearby to reference the corners. Many of the original corner markings (stakes or rock mounds) and bearing trees have disappeared since the original surveys, most of which were made well before the turn of the century.

It is illegal to destroy, change, or deface a survey corner or bearing tree, and only a licensed surveyor or civil engineer can re-establish a corner or legal survey line. Copies of the original field notes on file with the Bureau of Land Management need to be used sometimes to find lost corners and to relocate lines. The local County Surveyor maintains records of resurveys and related data.

Within the township, each section is numbered in accordance with the scheme shown in the figure. The drawing also shows how each section can be further subdivided and described. Thus, the lone 40-acre parcel in Section 26 of the figure is described as the Northeast $\frac{1}{4}$, Northeast $\frac{1}{4}$, Section 26 (NE $\frac{1}{4}$ NE $\frac{1}{4}$ Sec.26), and the 80-acre parcel in Section 35 is the N $\frac{1}{2}$ NE $\frac{1}{4}$ Sec.35. Identification of the township and the base and meridian is needed to complete the description. For example, N $\frac{1}{2}$ NE $\frac{1}{4}$ Section 35 T4S R3W HBM would mean that the parcel is located in the fourth horizontal row south of the Humboldt Base and Meridian and the third vertical row west of that initial point.

During these original surveys, distances were measured by a unit called a chain, which is equal to 66 feet. This unit is still in common use among foresters because it is a handy way to compute acreage. Here are some convenient numbers and conversions to remember:

1 chain	=	66 feet
1 mile	=	5,280 feet = 80 chains
1 acre	=	43,560 sq. ft. = 10 sq. chains
1 section	=	640 acres

Thus, a section is 80 chains by 80 chains, containing 6400 sq. chains, or 640 acres. And, a square 40-acre parcel (called a "forty") would be 20 chains on the side, or 400 sq. chains.

Table V-1. Map scale equivalents.*

Scale 1 to—	Inches per mile	Miles per inch	Feet per inch	Meters per inch	Feet per less inch	Acrea per square inch	Square miles per square inch
600	105.6	0.0095	50	15.2	2	0.56	0.0001
1,200	52.8	0.0189	100	30.5	4	.28	.0004
2,500	25.344	0.0395	208	63.5	8.3	1.00	.0016
4,800	13.3	0.0758	400	121.9	16	3.67	.0057
5,280	12	0.0833	440	134.1	17.9	4.44	.007
10,000	6.286	.1578	833	254.0	35.3	10.00	.0249
15,840	4	.25	1,220	402.3	52.8	40.00	.0625
20,000	3.168	.3	1,584	482.8	63.4	57.60	.0900
24,000	2.64	.38	2,000	609.6	80	91.80	.1431
25,000	2.52	.39	2,083	635.0	85.3	99.64	.1552
31,680	2	.5	2,640	804.7	105.8	160	.2300
45,000	1.408	.7100	3,750	1,143.9	150	322	.5031
63,360	1	1	5,280	1,609.3	211.2	640	1.00
90,000	.704	1.4205	7,200	2,256.0	300	1,200	2.03
96,000	.66	1.5152	8,000	2,438.4	320	1,409	2.30
125,000	.507	1.9729	10,417	3,175.0	416.7	2,401	3.89
500,000	.127	7.8914	41,667	12,700.0	1,666.7	.....	62.5
1,000,000	.063	15.7828	83,333	25,400.0	3,333.3	.....	249
2,000,000	.025	39.4571	208,333	63,500.0	8,333.3	.....	1,596

* The acreage of an irregular area can be estimated from a map with a transparent overlay marked with 64 evenly-spaced dots to a square inch. The value of each dot can be determined by dividing the acres per square inch of the map by 64.

Maps and Aerial Photographs

Maps showing legal subdivision can be obtained from a number of sources. The U. S. Geological Survey (USGS) produces quadrangle maps for all of California; the maps also show topography by contours (lines of equal elevation). The interval between the contours, representing the height between them, varies among maps. Contour maps used in forestry usually have intervals from 40 to 100 feet. The maps can be ordered by mail from the agency or purchased in larger stationery, sporting goods, and engineering supply stores. Some plain maps (without contours) can be obtained or purchased from the CDF, U. S. Forest Service, and the Bureau of Land Management.

Maps have different scales. This is expressed as a fraction, e.g., 1:63,360, or in inches per mile, which for this fractional scale is 1 inch per mile. The scales of the public agency maps referred to above range from 1:24,000 to 1:126,720. Table V-1 shows map scales and their equivalents. The next to



Figure V-3

Vertical-view aerial photograph.

last column can be used to make a fairly good estimate of irregular areas by the procedure explained in the footnote. Instruments called planimeters are also used to determine areas by a tracing process.

In addition to maps, vertical-view aerial photographs are almost indispensable in forestry. Although they do not show some things like subdivision lines, name places, landmark identification, and features hidden by forest cover, photographs contain a wealth of detailed information not found on maps that is very useful to the forest manager. Without any instruments, these photographs quickly give the viewer a general picture of the land—topography, larger streams and water bodies, broad vegetation type, logged area, and other features discernible to the naked eye (Fig. V-3). They are a big help in preparing maps of the tree farm and for timber sales. Color aerial photography has advantages in some situations but the cost is higher than black and white.

By using a stereoscope to view paired photographs (Fig. V-4), the picture can be seen in three dimensions; this reveals much more to a trained person. Field foresters prefer pocket lens stereoscopes because they can be taken into the forest along with the photos of the area. Data on forest and vegetation type, stand density, age class, species composition, tree sizes, and logging conditions can be obtained by close stereoscopic examination. When properly used to minimize effects of distortion found in aerial photographs, especially near the edge, they can supply acreages of areas of interest. A general idea of where to locate roads to avoid rock outcrops and other difficult terrain can be had from the pictures.



Figure V-4
Using a stereoscope.

Foresters can get fair estimates of timber volume by photo interpretation and field sampling. First, areas of similar timber are delineated on the photograph. Then measurements of trees on sample plots within these forest types are made to obtain the average timber volume per acre by forest type. From this average volume figure and the area within the forest types, the forester computes the total stand volume.

Photography scales in forestry range from 1 inch = 500 feet to 1 inch = 5,280 feet (one mile). Those of about 1 inch = 1000 feet are a good scale to use. However, most ready-made aerial photography that can be purchased is 1:20,000 (1 inch = 1,667 feet). Table V-2 gives vertical aerial photography scale relationships.

Table V-2. Vertical aerial photograph scale equivalents.

Representative fraction	Inches per mile	Representative fraction	Inches per mile
1:31,680	2 0	1:15,500	4 088
1:24,000	2 540	1:15,000	4 224
1:23,500	2 696	1:14,500	4 370
1:23,000	2 755	1:14,000	4 528
1:22,500	2 816	1:13,500	4 683
1:22,000	2 880	1:13,000	4 834
1:21,500	2 947	1:12,500	5 0
1:21,000	3 0	1:12,000	5 069
1:20,500	3 017	1:11,500	5 280
1:20,000	3 091	1:11,000	5 510
1:19,500	3 168	1:10,500	5 760
1:19,000	3 249	1:10,000	6 0
1:18,500	3 335	1:9,500	6 104
1:18,000	3 425	1:9,000	6 368
1:17,500	3 500	1:8,500	6 669
1:17,000	3 579	1:8,000	7 0
1:16,500	3 672	1:7,500	7 040
1:16,000	3 740	1:7,000	7 434
1:15,500	3 960	1:6,500	7 920
1:15,000	4 0	1:6,000	8 0

U.S.D.A. Miscellaneous Publication No. 225

Measuring and Running Lines

Land is measured by horizontal distance, not along the slope or ground. The latter distance is greater unless the terrain is flat. Two people are needed to accurately measure distance (called chaining), one forward and one to the rear. In forestry work, the lead person uses a compass (see later section) to keep the line going straight in the right direction (bearing). The one in the rear acts as the party chief, who also records the survey data, and makes corrections from slope to horizontal distance when that is necessary.

Horizontal Chaining

Engineers, surveyors, and occasionally foresters measure distances by using engineering tapes that are 100 to 300 feet long. They are graduated in whole feet, with the first and/or last foot graduated in tenths or hundredths of a foot. The tape has to be kept horizontal, so on slopes it is necessary to break chain, as it is termed. This means to horizontally measure with only part of the tape length each time, whatever the slope will allow. In effect, this process is like a staircase. A plumb bob or "eyeballing" is used to be sure to keep the points of measurement on the tape vertically over those on the ground.

Slope Chaining

Instead of direct horizontal chaining and breaking chain, distances can be measured along the slope, and this converted to horizontal values. If physically possible, the entire length of the chain is advanced and held

parallel to the slope. An Abney level is used to determine the degree of the slope. The following formula can be used to calculate the horizontal distance.

$$D = S \times \text{cosine } A$$

where D = horizontal distance

S = slope distance

A = degree of slope

Changes in elevation (V) between two points can also be computed by the formula: $V = D \times \text{tangent } A$. The tangent values are the same as the percent scale found on most Abney levels.

Table V-3 below gives horizontal conversion values for a 100-ft. tape up to 45 degrees of slope. One column gives the corrected horizontal distance. Where it is desired to set points at a given horizontal distance (e.g., 100 ft.) apart, the corresponding slope distance is approximately given by adding the correction shown in the next column. Values for the horizontal distances and corresponding corrections for degrees of slope not shown in the Table V-3 can be readily obtained from a table of natural cosines or some hand computers.

When running land lines, especially in rough country, foresters prefer special slope or topographic tapes that are about 2½ chains long. These tapes permit the correction of slope distance to horizontal distance without any computations or tables. This is done with the aid of correction

Table V-3. Conversion of slope distance to horizontal distance for a 100-ft. tape

<i>Degree of Slope</i>	<i>Horizontal Distance</i>	<i>*Horizontal Correction</i>	<i>Degree of Slope</i>	<i>Horizontal Distance</i>	<i>*Horizontal Correction</i>
0	100.00	0.00	23	92.05	7.95
1	99.98	.02	24	91.36	8.64
2	99.94	.06	25	90.63	9.37
3	99.86	.14	26	89.88	10.12
4	99.76	.24	27	89.10	10.90
5	99.62	.38	28	88.29	11.71
6	99.45	.55	29	87.46	12.54
7	99.26	.74	30	86.60	13.40
8	99.03	.97	31	85.72	14.28
9	98.77	1.23	32	84.80	15.20
10	98.48	1.52	33	83.87	16.13
11	98.16	1.84	34	82.90	17.10
12	97.81	2.19	35	81.91	18.09
13	97.44	2.56	36	80.90	19.10
14	97.03	2.97	37	79.86	20.14
15	96.59	3.41	38	78.80	21.20
16	96.13	3.87	39	77.72	22.28
17	95.63	4.37	40	76.60	23.40
18	95.11	4.89	41	75.47	24.53
19	94.55	5.45	42	74.31	25.69
20	93.97	6.03	43	73.13	26.87
21	93.36	6.64	44	71.93	28.07
22	92.72	7.28	45	70.71	29.29

* Slope distance minus horizontal distance (100 ft.)

graduations located on the underside of the tape beyond the one-chain mark and on the trailer part of the tape past the two-chain point. An Abney reading is taken of the slope in topographic units related to the tape. (Abney levels are available that have graduations in degrees, percent, and for use with topographic chains, all of which are useful in forestry.) The tape is moved ahead by the indicated amount, using the correction units on the tape. This then represents the true horizontal distance. If wanted, elevation can also be kept track of by the use of this kind of tape, because horizontal distance in chains times the Abney reading gives the difference in elevation in feet. A small metal mirror is handy in brush and timber to flash light towards the person reading the Abney.

Pacing

Many times in running land lines and especially in timber cruising, the accuracy of chaining may not be necessary, and the distances can be measured by pacing. It is faster and a person can do the job alone along with running a compass, conducting a cruise, and making a map.

On level terrain, an average-sized person while hiking takes two natural steps for every five to six feet, or about 12 double steps (called paces) per chain. To pace effectively one needs to determine what the natural pace is and practice pacing a measured course. Hand instruments called tally registers or whackers can be used to count paces or multiples of paces. Digital pedometers, which are attached to the waist belt, automatically give distance (slope) as you walk, but should only be used on easy ground, because the instrument moves every time a foot hits the ground, and adjustments to the given slope distances cannot be readily made by the user.

Some foresters and cruisers take 25 steps to a chain on the flat and mentally count 125 steps for five-chain units called tallies, which are recorded by notes on a tally register. Four of these tallies equal one-quarter mile, or the distance across a forty-acre parcel. The figures used depend on a person's natural pace. On slopes no attempt should be made to maintain a standard pace. Instead, experienced pacers allow for its shortening by only counting when judgment indicates that a truly horizontal pace has been covered. Also, in impenetrable brush or dangerous ground, they estimate by eye the distance ahead to some recognizable point, such as a tree or a rock, and offset around the bad area.

Measurement of Direction

Directions are measured by bearings, like North 45 degrees East (N45°E). Azimuth is more convenient to use; it is the clockwise angle measured from the north, 0 to 360°. Figure V-5 illustrates both of these methods. In forestry work, most lines are run in cardinal directions, that is north-south, east-west.

Foresters use either a hand compass or a staff compass graduated in degrees to maintain direction. To lessen the number of compass readings, sights as long as possible are made ahead on a tree, snag, or other landmark. Because magnetic forces do not correspond to a true north-south

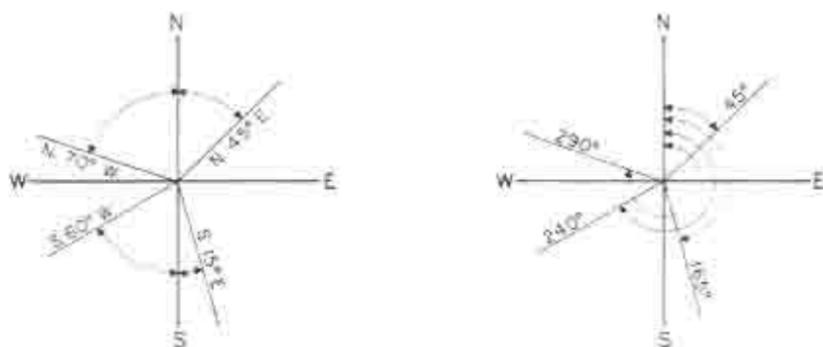


Figure V-5

Selective bearings and corresponding azimuths shown on the left and right, respectively.

direction, a compass needle in California points about 15 to 20 degrees east of the north pole. The difference in degrees between true and magnetic north is known as magnetic declination or variation. This value for your area can be obtained from local foresters, engineers, or surveyors. It can be also found on maps that show magnetic variation (isogonic) lines, like aerial navigation charts. Before using a compass, it should be adjusted to correct for magnetic declination.

On rare occasions compasses are affected by forces, called local attraction, caused by some iron ore deposits, objects of iron or steel, pipelines, electric lines, and wire fences. Iron or steel tools on a person may also cause the compass to deviate.

Measurement of Trees

In managing a forest, a tree farmer needs to measure standing trees in various ways—for site, growth, and timber volume. This requires getting data mainly on diameter and height to a certain top diameter. A number of different instruments are used to make these measurements.

Diameter Measurement

Tree diameters are measured at $4\frac{1}{2}$ feet above the average ground level, except on steep slopes the diameter is taken on the uphill side of the tree. This is called diameter at breast height (dbh). The most reliable method to obtain dbh is with a diameter tape. Although it is placed around the trunk, the tape is graduated in units that represent the diameter in inches. This is derived from the formula where diameter equals circumference divided by pi (3.1416). Most tapes of this kind are 20 feet long and will measure diameters up to 76 inches. Some of these show feet divided into tenths or inches on the reverse side so the tape can be used for other purposes, like measuring plots or log lengths. Special tree calipers are also used to measure tree and log diameters in some situations.

The cruiser stick is quicker than a tape to measure diameter, although it is less accurate. It is an inexpensive, rugged rule about 39 inches long,

whose four sides have graduations for inches, board feet of 16-ft. logs, log height of trees, and diameter. The diameter side is called the Biltmore scale. To measure diameter, the stick is held against the tree at breast height in a horizontal position 25 inches from the eye (Figure V-6). After the zero end of the Biltmore scale is lined up with the left edge of the tree, without moving the head, the viewer sights over the scale to the right side of the tree to obtain the diameter, usually to the nearest even inch. Most trees are not round, so more than one sighting on such should be made to get the average diameter.

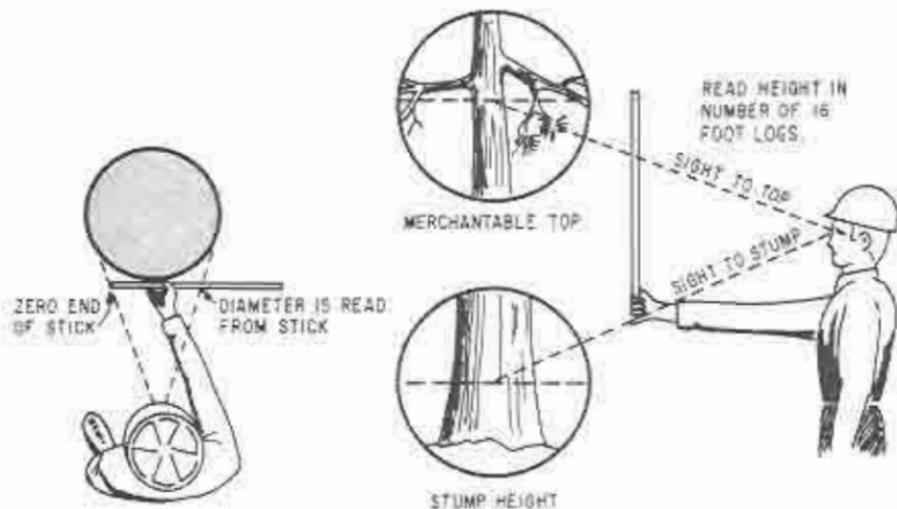


Figure V-6

Measuring diameter and height with a cruiser stick.

In timber cruising, diameters are obtained to the nearest inch or even-numbered inch, depending on the volume table to be used. After a lot of careful practice and with frequent checking with a cruiser stick or tape, a person can learn to estimate diameters by eye. However, since the accuracy diminishes with larger trees, they should be measured, preferably with a tape.

Tree Heights

As explained in Chapter II, the total height of trees in feet has to be measured to determine the forest site. Because a reasonable degree of accuracy is required, Abney levels are often used for this purpose (Figure V-7). Either the percent (tangent) scale or the topographic scale can be employed. With the former, the height of the tree equals the percent reading times the horizontal distance between the tree and the observer. When using the topographic scale, the horizontal distance should be one chain, so the Abney reading then is equivalent to the tree height in feet. The Abney level is sometimes used in timber cruising to obtain the height of very tall trees.

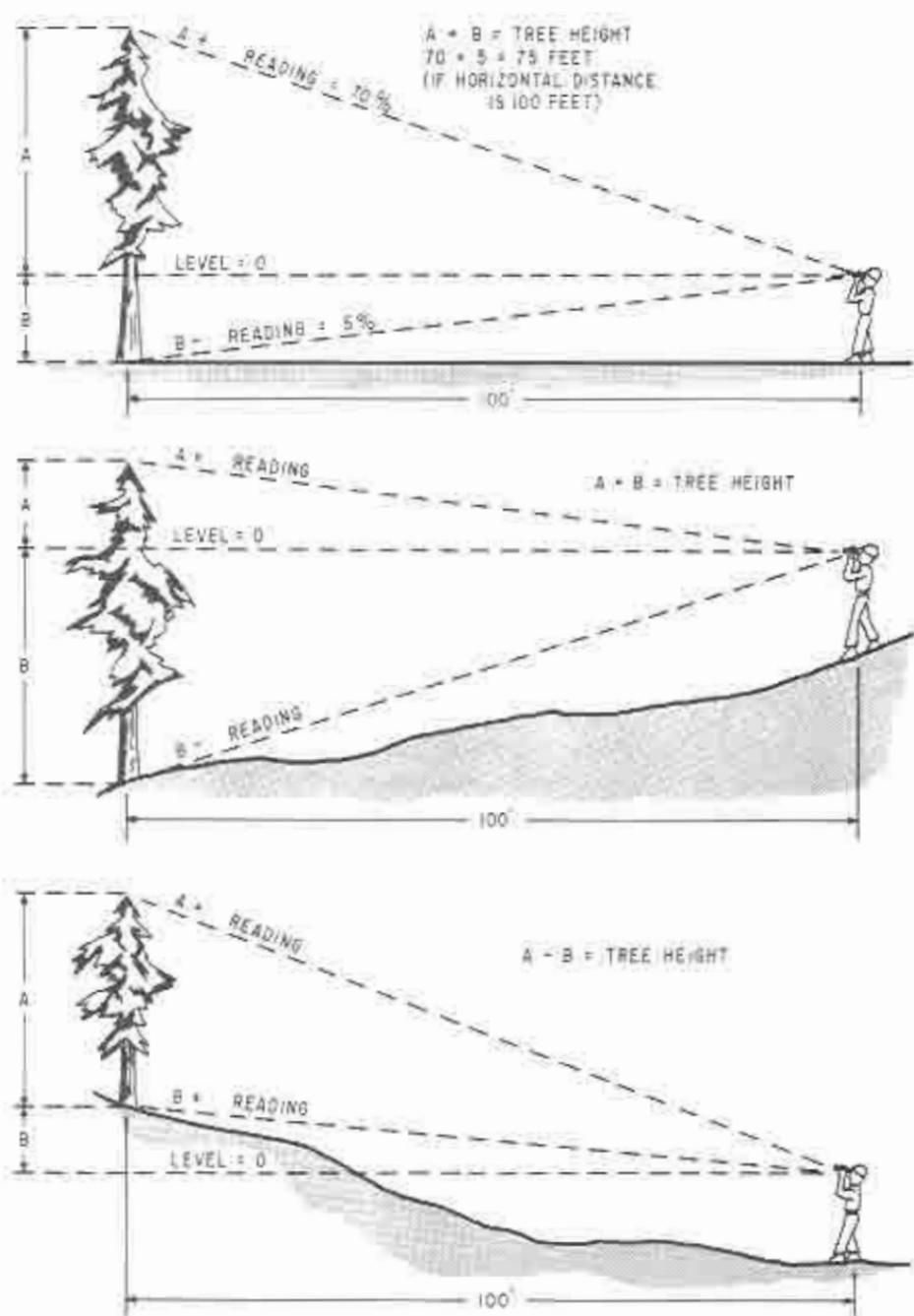


Figure V-7

Measuring tree height with an Abney level calibrated in percent

The number of logs is more conveniently measured by a cruiser stick. One edge of the stick has what is called the Merritt hypsometer scale, which gives number of logs for horizontal distance of one and $1\frac{1}{2}$ chains. The estimator is stationed at either of those distances away from the tree. The stick is held vertical 25 inches from the eye, with the zero end lined up with the stump height of the tree. Simultaneously, a sighting is made to a point up the trunk where the diameter is that specified for the tables to be used for computing volume. This gives the number of logs in the tree. Other hand-held instruments called clinometers are available, but a cruiser stick and an Abney level are ordinarily adequate for general purposes.

Cruiser and foresters often make eye estimates of tree heights in logs. However, as in estimating diameters, practice and checking are in order.

Foresters have other instruments to measure trees than those described, some of which are quite sophisticated and costly. One such is the relaskop, which is an optical device that measures diameters of trees anywhere from stump to top and tree heights without a known horizontal distance. Another instrument is the dendrometer, a modified military range finder. These special tools are usually used only when exacting work is required, especially in large timber.

Volume Measurement

To convert tree diameter and height measurements into volume (usually in board feet), cruisers and foresters have a great variety of tables at their disposal. The more common ones are based on such factors as species, age-class (old- or young-growth), site, log rule, and minimum top diameter. Some of the more useful volume tables are reproduced in the Appendix. For an explanation of the board-foot measurement unit and log (volume) rules see Chapter VI.

These tables give the board-foot volume for trees usually by two-inch diameter classes and by number of logs or heights in feet, both to a specified minimum top diameter. Most tables are based on height in 16-ft. logs, but some for old-growth redwood and Douglas-fir may be for 20- or 32-ft. logs. Because large old-growth redwood trees frequently have a pronounced butt swell, some volume tables for this species are based on diameters 20 feet above the stump, instead of breast height. These diameters run from 6 to 20 inches less than dbh for trees from 24 to 92 inches dbh and have to be measured by a relaskop or estimated by a technique using a plumb bob and a long graduated stick held against and perpendicular to the trunk of the tree.

There are also other volume tables that have increasing use among professional foresters and more universal application, say between species and regions. These include form-factor, taper, and tarif volume tables. Also, local volume tables can be derived from various tables, where only the dbh needs to be measured, and heights ignored. Because of the variety and complexity of volume tables, a tree farmer should consult a local public or private forester to ascertain which is the best to use. The table must be selected before making a cruise, and the measurements and recording conform to that table's specific requirements.

Tree volumes of course can be obtained from formulas and even computer programs. Where volume tables are not handy, the following formula will give approximate values:

$$V = [(3H + 2) / 10] D^2 - (H + 1) D$$

where V = volume in board feet
 H = merchantable height in 16-ft. logs
 D = dbh in inches

There are yield and volume tables showing volume in cubic feet of wood that are used in scientific work and to some extent where the trees are used for fiber rather than boards. They probably will have increasing use in the future. Also, tables in metric* units (cubic meters), now standard for most of the world, will begin to come into use as this country converts to the metric system.

Timber Cruising

Using these land and tree measurements described above, the volume of standing timber on an area can be developed by a sampling procedure called timber cruising. The resulting inventory gives reasonably good data on the species present, size classes, location, and amount of timber. Information also may be collected on grade of timber, defect, site, forest health, logging conditions, and topography. Cruise reports are valuable in buying and selling timberland, appraising the values, making forest management decisions, timber sales, and for financial and tax purposes. Tree farmers often employ registered professional foresters to conduct timber cruises in order to have reports acceptable to others.

Cruise Accuracy

Because cruising only samples a part of the tract and much judgment has to be exercised, the accuracy is variable. It depends on the size of the timber tract and the sample made, the uniformity of the timber, amount of defect, and certainly the skill and care of the cruiser.

The area sampled in cruising can consist of regularly spaced strips or special plots, whose acreage represents a certain percent of the total area. This percent ordinarily ranges from 5 to 20 percent. For a 10 percent cruise, the area of the strips or plots would be 4 acres for a "forty". On small tracts, or timber that is quite valuable or variable, a higher percent is necessary. The percent of area sampled should always be identified on a cruise report.

A cruise may be also selected by degree of accuracy desired. This is a statistical measure indicating the volume figures are within plus and minus a certain percent of being accurate, e.g., plus or minus 10 percent. This, along with the tract size and variability of the stand, determine how much area the sample plots should contain. This percent of accuracy measure is used mostly in plot sampling, as discussed in Chapter II and later in this Chapter under Plot Cruising.

Recording Data

Obviously, the measurements of trees during a cruise must be systematically recorded in a field book or on a form (Figure V-8). The data are

* See Tables A-1 through A-8 in the Appendix for various metric conversion factors.

customarily kept by forty-acre parcels. The sheet for each "forty" (or fractional "forties") should show:

- Names of cruiser and compass operator (if any)
- Number, size, area and location of strip or plot
- Legal description of "forty"
- Timber type (and site if necessary)
- Date of cruise
- Tally of trees by species, dbh, and height

A. Jones, Cruiser, B.A. Jones, Composition						A. Jones, Cruiser, B.A. Jones, Composition					
Strip 12, Width 100, Length 100, Area 2,000			Plot 12, Size 2,000, Total Area 2,000			Location East Sec 7, T 10, R 10			Location East Sec 7, T 10, R 10		
Type Spruce, Date 1-1-55						Type Spruce, Date 1-1-55					
DBH	SP	SP	SP	SP	SP	DBH	SP	SP	SP	SP	SP
16	1					16	1				
18	2					18	2				
20		1				20		1			
22						22					
24			1			24			1		
26				1		26				1	
28						28					
30						30					
32		1				32		1			
34						34					
36						36					
38						38					
40						40					
42						42					
44						44					
46						46					
48						48					
50						50					

Figure V-8

Cruise tally sheets. One on left is for a strip cruise, sheet on the right side is for a plot cruise.

Trees are ordinarily tallied by two-inch classes and heights in logs (16 or 20 ft. as specified in the volume table to be used). To save time and space, the number of trees of the same height can be recorded by dots and lines as follows:

• •• ••• •••• ••••• •••••• ••••••• •••••••• ••••••••• •••••••••• ••••••••••• etc.

1 2 3 4 5 6 7 8 9 10 11

As will be seen later, using this method will also save time in calculating volumes. Reproduction, pole-sized trees under 12" dbh, and other special data may also be recorded, not for volume purposes, but to get information for management needs.

When cull or defect shown by a fire scar, fungus conk, or damage is observed, that is noted so that deductions from the gross volume of a tree can be made to get net volume. This takes a great deal of experience and judgement. Regardless of defect, a tree has to be always measured to a uniform top diameter and the defect deducted accordingly, because measuring a tree by log height to the point of defect or broken top will give inaccurate volumes.

To tally defect, the cruiser indicates the log(s) in which it occurs and the amount of cull next to the tree's number on the cruise sheet. A butt log of a 6-log tree that is one-half defective would be recorded as 6^B_{1/2}. If this amount of defect were in the third log of the same tree, the symbol would be 6³. A 6-log tree with two top logs totally defective or missing would be tallied 4/6. A 7-log tree with a top log missing and completely defective third and fourth logs would be shown as 6/7³⁴.

There are systems that are occasionally used to tally the logs by grade. However, this complicates the procedures. When a 100-percent cruise is being made along with timber marking in preparation for a timber sale, the figures have to be made in separate columns for the trees to be cut and left. Important information on the "forty" regarding forest health, logging conditions, road construction, presence of water and rock can be noted on the reverse side of the sheet.

Preparations for Cruise

The exterior boundaries and legal and intermediate corners of the tract are located and flagged before cruising commences. The acreage should be also determined ahead of time, if possible; otherwise it will have to be developed from a map drawn to scale while cruising. Remember that many "forties" do not contain exactly 40 acres. The accuracy of a cruise is dependent upon having good acreage figures for both the tract and the sample areas.

The next step is for the cruiser to select the proper direction and general spacing of the strips and plot lines so that the sampling is fairly representative. Usually, these lines run in cardinal directions that are most perpendicular to the contours on the tract, but access is also taken into consideration. After sizing up the area and timber, a cruiser decides the percent of the tract to be cruised and the width of the cruise strip or size and number of sample plots. For instance, a 10-percent strip cruise of a "forty" usually is made by two one-chain wide strips 10 chains apart and each located 5 chains from and parallel to the side of the parcel (Figure V-9).

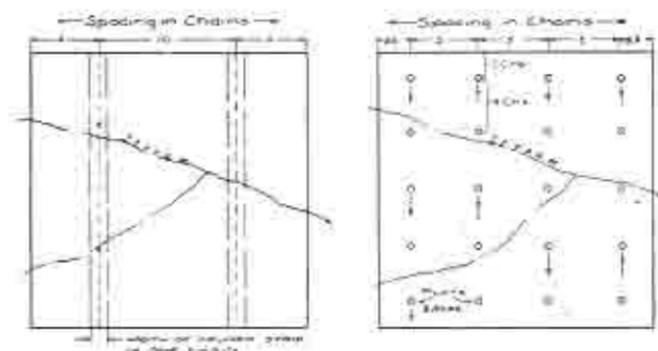


Figure V-9

Location of samples in strip and plot cruising.

In addition to cruising by the "forty" or some other sized parcel, cruises can be made by forest type for management reasons. That being the case, the area of those types must be carefully determined by field mapping. Aerial photos are helpful in delineating these types.

Strip Cruising

Cruising by strips can be done either by one or two persons, usually the latter, because more information can be collected during the work period and having two people in the woods is safer. In that case, one operates the compass, pulls the chain or does the pacing, and maps the area to show legal subdivision lines and corners, road and stream crossings, other prominent land features, non-timber areas, and sometimes even contours. The person in the rear acts as the chief of the party, handles the back end of the chain and makes the correction of slope distance to horizontal (if chaining is done), measures or estimates diameters and heights of trees on the cruise strip, records that data plus other pertinent information. Where only one person cruises by strip, that individual runs the compass, paces, estimates or measures the trees, and records the information.

The cruise may traverse a "forty" one or more times depending on width of strip and percent of cruise wanted. A 10-percent cruise could be obtained by running just one strip two chains wide through the middle, or two evenly-spaced strips one chain in width. Where the "forty" is truly regular, the sample areas in each case would be 4 acres. A 20-percent cruise could require two evenly-spaced strips two chains wide, or four evenly-spaced strips one chain wide, each case containing 8 acres. Ordinarily, one chain wide strips are the better, especially in dense timber or rough country, because its easier to cruise narrow strips, and also having more strips improves the sampling and aids the mapping process. Ten and 20-percent strip cruises are commonly made, and they give fair results in most cases, but bear in mind that smaller tracts, especially of irregular timber, require a higher cruise percent.

The cruiser controls strip width by pacing and occasional checking with the chain or pocket tape. The compass line runs in the middle so the horizontal distance to each side would be one-half the strip width. Trees are considered in the strip if they are more than half inside, and those falling exactly on the line are alternately included or excluded.

The exact total length of the strip(s) is very important, because the sample area is computed by multiplying that figure by the width of the strip. Also, when the parcel being cruised contains bodies of water, meadows, or pieces naturally without timber, as shown by the cruise map or notes, necessary deductions have to be made to obtain the net timbered area.

Plot Cruising

Some foresters in conducting cruises favor plots over strips. Because plots are uniformly and widely scattered, less sample acreage is required, but more lines must be run for a given accuracy. Exact lengths of lines are no longer important since sample area is controlled by the plots. This system is much easier to employ when the cruiser has to work alone.

As in strip cruising, lines are run through the "forty", but instead of measuring the trees enroute, the measurements are made within evenly-spaced plots (usually circular) as shown in Figure V-9. Cruisers generally use plots of one-fifth to one-fourth acre, although other sizes will do. Table V-4 following shows the dimensions of both circular and square plots of

different sizes, and Table V-5 gives the number of one-fifth acre plots needed for certain conditions when one wants to adhere to statistical standards.

The number of plots can be also determined for a stated percent of cruise, like in the case of strip cruising. For example, when using one-fifth acre plots in a 10-percent cruise, four acres within a "forty" has to be sampled, or 20 plots that should be uniformly located as illustrated in Figure V-9.

While the lines are run, the cruiser locates the plot centers and marks them with a compass staff or in some other temporary manner. Measurements are then confined to the trees that are within the radial distance of the marked mid-point of the plots.

Table V-4. Size of selected circular and square plots.

Acres	Radius of circle	Feet on each side	Area in square feet
1/40	18.6	33.0	1,089
1/10	37.2	66.0	4,356
1/5	55.7	99.3	8,712
1/4	58.8	104.4	10,890
1/3	68.0	120.5	14,520
1/2	83.2	147.6	21,780
1	117.75	208.7	43,560
6	263.2	466.7	217,800

Table V-5. Number of one-fifth acre plots (evenly spaced) for three classes of accuracy.

Condition of Stock	Typical			Average			Poverty		
	Good	Medium	Poor	Good	Medium	Poor	Medium	Poor	
area in acres									
Plus or minus 5% accuracy									
40	52	106	160	86	172	171	160	185	
100	23	145	400	133	267	490	400	500	
640	74	223	640	152	356	870	640	1,311	
5,000	40	258	775	159	394	1,145	775	2,100	
10,000	40	259	787	159	397	1,172	787	2,200	
100,000	60	240	799	160	401	1,197	799	2,388	
area in acres									
Plus or minus 10% accuracy									
40	18	40	100	33	67	170	100	150	
100	20	50	100	38	80	218	100	155	
640	20	59	166	40	97	274	168	303	
5,000	20	60	198	40	100	291	198	326	
10,000	20	60	199	40	100	295	199	303	
100,000	20	60	200	40	100	300	200	300	
area in acres									
Plus or minus 20% accuracy									
40	5	14	40	10	22	59	40	60	
100	5	15	47	10	24	69	47	70	
640	5	15	49	10	25	72	49	73	
5,000	5	15	50	10	25	75	50	74	
10,000	5	15	50	10	25	75	50	75	
100,000	5	15	50	10	25	75	50	75	

* Good stocking is $\frac{2}{3}$ to full stocking. Medium stocking is $\frac{1}{2}$ to $\frac{2}{3}$ full stocking. Poor stocking is less than $\frac{1}{2}$ full stocking.

Two-fifths of cruises made will probably come within the indicated percentages of complete accuracy. One-third may exceed these percentages.

B. Coon—U. S. Forest Service

The total acreage within the strips or plots is determined next from the cruise sheets and map. For strips, the sampled acreage is the actual length of the strips in chains, as measured by chaining or pacing, times their width divided by 10. The total acreage of sample plots is their total number times the acreage in each. You see here that distances are not needed.

The average volume by species per acre for the sampled area is calculated by dividing the total volume of each species by the acreage within the sample. This also represents the average volume by species for the tract or land unit being considered.

The total acreage of the tract or subdivision for which the cruise is being tabulated has to be carefully determined from notes on the cruise sheets or map. Gross areas have to be reduced by the acreage within bodies of water, meadows, and non-timber portions to arrive at the net area. This total net figure times the average volumes above gives the total volume for the tract or parcel. Usually, all the final cruise results are placed on a summary sheet showing at least timber volumes by "forty" or other parcel, species, and for the whole tract.

Use of Prisms

Foresters make good use of simple optical prisms in variable plot sampling for various purposes. The prism is an inexpensive, wedge-shaped piece of glass that bends light rays to a certain degree or critical angle, depending on what is called the diopter rating of the prism. One diopter represents an angle of 34.36 minutes. Prisms of different ratings are used according to timber types and sizes.

Instead of dealing with diopter values, the most convenient practice is to have prisms ground to a diopter rating that is exactly equal to a whole basal area factor (BAF), such as 10, 20, 25, 30, 40, etc. As explained later, the BAF is used in computing basal area of stands. Prisms with prescribed BAF's can be purchased from forestry and optical suppliers for a modest cost. Table V-7 below shows the relationships between diopters and BAF's.

Table V-7. Prism diopters and basal area factor equivalents.

<i>Diopter</i>	<i>BAF</i>	<i>Diopter</i>	<i>BAF</i>
3.00	9.802	5.30	30.000
3.03	10.000	6.00	39.169
4.00	17.417	6.10	40.000
4.30	20.000	7.00	53.513
4.80	25.000	7.40	60.000
5.00	27.208	8.00	69.585

In using the prism, the observer holds it horizontally at eye level over the plot center and sights towards the dbh of a tree. Depending on the distance to the tree, the image through the glass of the tree trunk is displaced somewhat toward the thin edge of the prism (Figure V-10). Where the image through the glass superimposes the trunk to any extent, that tree is considered to be within the plot. If the image through the

prism is displaced away from and separate from the trunk, the tree viewed is not in. The resulting sample plot is circular but not having a fixed radius. For small trees within the plot the radius of the plot is small and for large trees the radius is greater. This technique produces what is termed a variable plot, consisting of concentric circles, that is useful in forest sampling.

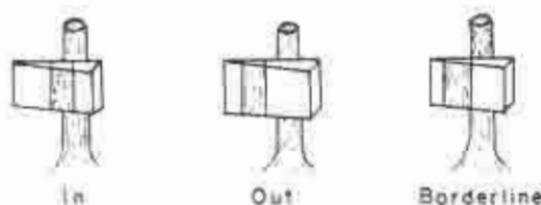


Figure V-10

Displacement of image caused by prisms.

The right prism should be used for the timber to be sampled. A BAF should be chosen that will provide a tree count of between four and eight trees per sample point. The prism ratings that foresters generally employ are as follows:

<i>Timber Size</i>	<i>Diopter</i>	<i>BAF</i>
Very large (48" dbh +)	8	60-70
Large (32"-48")	6	25-40
Medium (16"-32")	5	20-25
Small (16"-)	3-4	10-20

The prism makes it possible to easily determine the basal area per acre of a stand. The basal area (in square feet) per acre at any sampling point equals the number of trees within the plot times the BAF. For example, in using a prism with a BAF of 10, you counted 12 trees within the plot, then the basal area per acre from that sample would be $10 \times 12 = 120$ square feet. In most cases, to have a representative sample, a number of scattered observations would be taken and the average number of trees in those plots computed, which then would be multiplied by the BAF to obtain the average basal area per acre.

As mentioned in Chapter II, basal area is a useful measure in forest management. It serves as an indicator of the degree of stocking or density of a stand—whether it is understocked, normal, or overstocked. The thinning of stands and even the harvests can be based on basal area standards. If a certain minimum basal area were prescribed, the forest manager can use a prism to quickly find out what areas should be cut.

Prisms work real well on flat ground, but where the slope is more than 10 percent, a correction is necessary, because the distances must be horizontal as they are in other forest measurement procedures. This correction can be made by rotating the prism in its plane by the slope angle. This rotation in effect reduces the critical angle of the prism gradually until it becomes zero at 90 degrees of rotation. What happens is that the prism

reaches further away to pick up trees of a given diameter proportionately to the slope to horizontal distance relationships. An Abney level can be used to measure the slope and to also set the rotation angle of the prism. With the slope angle fixed on the Abney, the prism is placed on the Abney barrel and the bulb held level before the viewer sights through the properly rotated prism. Special clinometers are also available to make corrections for slope in prism sampling.

Sometimes a value called the plot radius factor (PRF) of prisms is handy to decide whether a tree, especially one that is not visible or borderline, is in or out of the plot. In those cases, the distance to the tree has to be paced or chained. The plot radius factor varies by the BAF. Every tree has its own plot radius, depending on its diameter and the prism, and a tree of that same size beyond that distance is not within the plot. Thus plot radius in feet equals PRF times the dbh in inches. The PRF for prisms of different BAF's are given in the table below:

Table V-8. Plot radius factor for selected Basal Area Factors.

<i>BAF</i>	<i>PRF</i>	<i>BAF</i>	<i>PRF</i>
10.....	2.750	40.....	1.375
15.....	2.245	50.....	1.230
20.....	1.944	60.....	1.123
25.....	1.739	70.....	1.039
30.....	1.588	80.....	0.972

In addition to basal area measurements, foresters are increasingly using prisms and similar devices to determine the volume of timber stands. The method is called variable plot cruising. It is not the intent of this publication to cover this subject, because it is somewhat more technical than the traditional cruising methods. In essence, the volume per acre is determined by the use of volume tables converted to show volume per square foot of stem area. They are called V-BAR (volume-basal area ratio) tables.

Chapter VI

LOG SCALING

Another field of mensuration is the measurement of logs, or scaling as it is called in forestry circles. Scaling is the process of determining as accurately as possible the net volume of logs by the use of a log rule table, usually in board feet. This information is normally the basis of payment to timber fallers, contract loggers, log haulers, and timber sellers. The results of scaling are more accurate than timber cruising, because the tree in effect is more accessible and measurable.

Required Knowledge

To be a competent scaler, one must have a good basic knowledge about the units of measure used, required scaling equipment, the different log rules, and the procedures. And certainly, skills acquired by study, practice, and experience are a prerequisite, because much good judgement is needed to do a creditable scaling job.

Board-Foot Measure

In the U. S., the board foot is the traditional and still most common unit of measure for the volume in trees and logs. This is because lumber is by far the leading forest product. Consequently, even though this unit was not designed to be a measure of non-lumber products, it is the predominant measure in the forest end of the wood industry. Timber, logs, and lumber are commonly sold and bought by the thousand board feet. To avoid using the zeros, a thousand board feet is stated as MBF, or MBM (thousand board measure).

Nominally, a board foot, lumber tally, is one inch thick and one foot square. A piece of lumber of the same volume, e.g., 2" x 6" x 1 ft., is also one board foot. Whole inches are used as the standard to state thickness and width, regardless of the actual dimensions of the lumber. This came about when sizes in the rough stage were used to describe the same lumber after surfacing. The board footage of lumber can be calculated by this formula:

$$\text{Board feet} = [\text{thickness (in.)} \times \text{width (in.)} \times \text{length (ft.)}] / 12$$

Because of losses in the sawing process, a cubic foot of wood in log form contains less than 12 board feet. Actually, the lumber yield per cubic foot depends on the diameter of the logs, ranging from 4 bd. ft. for logs of 5" diameter to over 9 bd. ft. for 40-inch diameter logs. An average log of 10 inches in diameter has about 7 bd. ft. per cubic foot. The recovery is also dependent on the sizes lumber is cut; the smaller the dimensions are the less board feet there are in a cubic foot.

In addition to this factor, net board-feet scale rarely is the same as the board-feet tally of lumber produced. What the ratio is between the two depends on the taper of the logs, log rule used, mill efficiency, and sizes of logs and lumber that are sawn. In most cases of woods-run logs there is an overrun in mill tally over log scale, ranging from 5 percent to as high

as 60 percent; the average is on the order of 10 to 20 percent. Sometimes, there may be an underrun if the milling process is inefficient.

Log Rules

There are many different log rules in this country, but only a few are used in California. The more common one in California is the Scribner log rule. Like most other rules, it gives the board feet in logs of various diameters (one-inch classes) and lengths by feet. An one-quarter inch wide saw-cut (saw-kerf) is assumed. The Scribner Decimal C rule is the same except that the board feet are rounded to the nearest 10 bd. ft. A more refined Scribner rule was developed cooperatively in 1972 by some West Coast users, and it is receiving wide acceptance because it is more adaptable to computer calculation (see Appendix).

The Spaulding rule, which is close to the Scribner for logs above 12 inches in diameter, has been used in the redwood-Douglas-fir region. Before the law was repealed in 1967, it was the legal rule for the state, meaning that when a log rule was not specified the Spaulding prevailed. The rule is based on an $1\frac{1}{32}$ -inch saw-kerf. The Humboldt rule has been employed some for old-growth redwood; it is derived from the Spaulding rule, with those values being reduced by 30 percent to automatically allow for defect.

The International is the most accurate log rule, but its use has been restricted largely to scientific work. It makes allowance for taper of logs, which none of the above rules do, and has been prepared for both $\frac{1}{8}$ -inch and $\frac{1}{4}$ -inch saw-kerf.

The yield tax law (see Chapter IV) requires reporting by the Scribner Decimal C rule. This may gradually cause the other rules to fade out in California. However, as stated earlier, there is a slow trend in favor of cubic-foot rules, because so many more products are being utilized from logs besides lumber. And, someday we probably will have a cubic metric unit.

Like board-foot measure, there are a number of cubic-foot rules, all of which are based on formula, but of different accuracies. The Smalian's rule is fairly accurate and is used to some extent in the Pacific Northwest by the U. S. Forest Service and private companies. The diameters (inside bark) at both ends of the log have to be measured by this rule. Another cubic-foot rule is called the Huber (see Appendix); it is based on average middle diameter and it is considered to be the most accurate. Where cubic-foot measurement is practiced, a unit called the cunit, which equals 100 cu. ft., is used for ease of operations.

Both the Scribner and Spaulding board-foot rules were prepared by diagramming the lumber that could be cut from various size logs. The International rule is based on a mathematical formula. While log rule tables are more convenient, one could figure board-feet content of logs by formula, such as the one below:

$$V = (.79D^2 - 2D - 4) \times .0625L$$

- where V = volume in bd. ft., approximately Scribner scale
 D = diameter inside bark in inches of log at small end
 L = length of log in feet

Scaling Equipment

In order to scale one need to measure both the diameter and the length of the log. A special tool called a scale stick with a hook or spud on the zero end is used most often by scalers. Up to 6 feet long, the stick is graduated into inches. Some sticks can directly provide the gross volumes for certain log lengths from special graduations on the stick in addition to the marks for inches.

Short log lengths can sometimes be estimated or marked off with the scale stick. A retractable tape of 20 to 50 ft. in length is commonly used, especially to measure longer logs.

Scale sticks are not absolutely necessary to measure diameter. One can use a stiff straight stick graduated in inches or even an 8-foot pocket tape. The cruiser stick will serve the purpose too; it has both an inch scale and graduations for board feet for 16-ft. logs by the Scribner Decimal C rule.

The scaler records the measurements and other data in a special scale book or on multiple-copy scale slips (see Figure VI-1). The latter have the advantage that copies of the scale can be provided to those having an interest, such as faller, contract logger, trucker, seller, and purchaser. The following information may be included on the scaling form:

Log seller	Species
Log buyer	Log number
Timber sale area	Diameter
Scaling location	Length
Load or truck identification	Gross volume
Scaler's name	Deduction for defect
Date	Net volume

Lumber crayon or canned spray-paint is used to mark the sale, log number, or any identification on the log ends, if that information is required. Branding axes are sometimes employed to designate ownership of logs.

Measurement Procedures

Scaling standards and procedures developed by the U. S. Forest Service are widely accepted in California. In general, the explanation of scaling herein follows that system.

Using the above equipment, to arrive at the gross board-feet volume of a log, the scaler essentially has to take two measurements—diameter and length. The former is done by placing a scale stick across the small end of the log and reading the diameter inside the bark (Figure VI-2). The diameter is read to the closest whole inch and recorded on the scale form. In case of logs that are not round, more than one measurement is taken to obtain an average diameter (to the next inch).

STATE OF CALIFORNIA
The Resources Agency
DEPARTMENT OF FORESTRY

FM 54 REL 3-67

ORIGINAL

No. 90199

STATE FOREST

SALES DESCRIPTION _____

AREA DESCRIPTION _____

SCALE# _____

DATE 1/1

LOG NO	LENGTH	DIAMETER	NET VOLUME BY SPECIES OR PRICE GROUPS	DEFECT DEDUCTIONS
1				
2				
3				
4				
5				
6				
7				
8				
9				
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				
0				
TOTAL SCALE				
NUMBER OF LOGS				

Figure VI-1
Sample of a log scale slip.



Figure VI-2

Diameter is measured inside the bark at the small end of the log.

Table VI-1. Standard division of long logs for scaling with 20-foot maximum scaling length.

Length (feet)	Division of log—segment lengths in feet		
	Bottom	Middle	Top
21	11		10
22	12		10
23	12		11
24	12		12
25	13		12
26	14		12
27	14		13
28	14		14
29	15		14
30	16		14
31	16		15
32	16		16
33	17		16
34	18		16
35	18		17
36	18		18
37	19		18
38	20		18
39	20		19
40	20		20
41 ¹	14	14	13
42	14	14	14
43	15	14	14
44	16	14	14
45	16	18	14
46	16	16	14
47	16	16	15
48	16	16	16
49	17	16	16
50	18	16	16

¹ Scale overtrim 20-foot log as a 21-foot, 1-segment log.

² Scale overtrim 60-foot log as a 41-foot, 2-segment log.

In this table any log length and segment division will be used as the overtrim scaling length for the preceding length.

The scaler then obtains the log length. Depending on the sale contract, the length is measured to the nearest foot or even two feet, with the specified allowance for sawmill trimming of 4 inches or more, depending on log length. In case the logger frequently exceeds this allowance, the scaler may apply a penalty scale by increasing the log length to the next foot. Where logs are primarily for lumber manufacture, the log lengths are usually in even-numbered feet. The scaler records the entire length of the log.

Logs longer than 20 feet should be scaled as two or more logs, with the longer one being the butt segment. For example, a 30-foot log would be scaled as a 16-ft. log (large end) and a 14-ft. log (small end) as shown in Table VI-1. This so-called short-log scale gives a higher volume than long-log scale by the common log rules, because they make no allowance for taper. In effect, the board foot-volume is that contained in a cylinder with a diameter at the small end of the log. Where long logs are converted to short segments for scaling purposes, the scaler can obtain the additional diameter(s) by estimation or by measuring both the large and small ends of the long log and pro-rating the taper accordingly. Thus, where a long log is converted into two segments of nearly equal length, the diameter of the larger one in most cases would be the average of the top and bottom diameters (Figure VI-3). Swelled butt logs may require assigned rates of taper because the taper is not uniform. The assumed additional diameters of the logs divided for scaling are not ordinarily recorded, because they are only needed to determine the gross volume of the log.

With these measurements, the scaler enters the gross volume of the log in the scale record. This is done by looking up the values in the appropriate log rule table. Some scalers obtain the volume directly from the scale stick if it is so graduated.

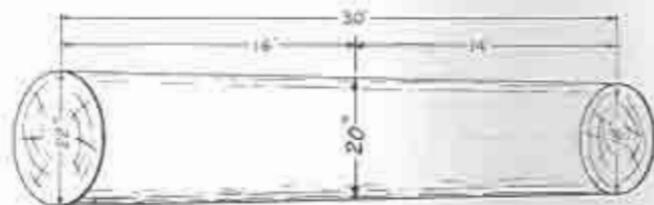


Figure VI-3.

Long logs are scaled as two or more logs.

Defect Deductions

After the gross volume of a log has been figured, the scaler must arrive at the net scale by making deductions for any defect that may be present. The procedure for this is not so precise as for gross volume and more judgement based on experience is necessary. The defects that are recognized in scaling include rot, insect damage, fire scar, shake (separation between annual rings), pitch ring or seam, splitting, checking, break, crook or sweep, crotch, and sometimes excessive number of large knots. If the logs are not for lumber or veneer purposes, only the first three kinds of defect may need to be considered.

As explained earlier, log rules of common usage, e.g., Scribner and Spaulding, do not make allowance for taper. This means that the gross volume of a log is that represented in a straight or right cylinder with a diameter the same as the small end of the log. Therefore, only defect within the confines of that cylinder should be deducted.

The standard method for reduction of scale for interior defects is accomplished by (1) boxing and measuring the defective area at the end of the log where it is the largest, (2) estimating the length of the defect, and (3) computing the deduction by the formula:

$$D = (W \times T \times L) / 15$$

where D = Deduction in bd. ft.

W = Width of defect plus 1 inch in inches

T = Thickness of defect plus 1 inch in inches

L = Length of defect in feet

If the interior defect is not visible at both ends of the log, the scaler has to judge what length it might be. Sometimes, exterior signs like conks, rotten knots, insect activity, and pitch indicate how far the defect extends lengthwise into the log.

Some interior defect such as shake and pitch ring may need special treatment. Logs with these defects often have good wood at the center which should not be deducted. Such a log of 16 feet in length is shown in Figure VI-4, where the outside limit of the shake or bad ring is 16 inches in diameter and the sound interior has a diameter of 12 inches. First the gross deduction would be $17 \times 17 \times 16$ divided by 15, or 308 bd. ft. The sound interior would be the scale of a 16-ft log of 12 inches diameter or 80 bd. ft. Therefore, the net deduction would be 308 minus 80 or 228 bd. ft. (rounded to 23 in case of Scribner Decimal C).

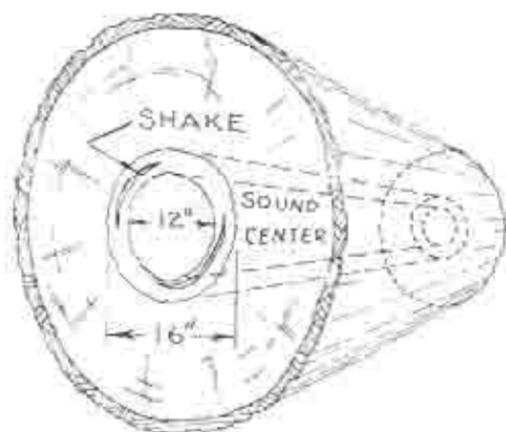


Figure VI-4.

Defect caused by shake or pitch ring.

Side defects have to be approached differently. Deductions for them are made only when the defect comes within the right cylinder of the log, and any defect outside of that is ignored. To determine deductions for side

defects, scalers have to apply logical reasoning and good judgment. For instance, in the case of a fire scar in a butt log shown in Figure VI-5, it is first estimated that about one-third of half the log is affected. Since the whole log contains 1,200 bd. ft., the deduction would be one-third of 600 or 200 bd. ft. The same method can be applied to crook or sweep.



Figure VI-5
Fire scar defect.

There are a number of rules of thumb and special techniques used by scalers to make allowances for defect. Figure VI-6 illustrates some of the more common ways to handle deductions. The two excellent references that are listed in the Appendix contain much more specific instructions than those that can be included here.

Once the scaler decides on the deduction it is entered on the scale form along with the net volume of the log. Those logs that have excessive defect are labelled cull. To be merchantable, logs of high value (e.g., pines, Douglas-fir, redwood) should be one-quarter or more sound, and those of less valuable species like the true firs should be at least one-third good. In some cases cull logs that contain some chippable sound wood are sold for pulp purposes but for a lower price.

Weight Scaling

Instead of scaling individual logs, a system has been developed to obtain the volume by a weighing and sampling process. It is especially applicable to large operations in young or small timber, where it is inconvenient and costly to scale many low-volume logs. While this weighing method can be fairly cheap and accurate, it has such problems as the availability of precise truck scales, the great variation in log weights, the difficulty of understanding and accepting the system, and the statistical knowledge required to implement and control it.

The biggest difficulty is the great variability in weight of logs. Basically, this is governed by the specific gravity of the wood, its moisture content,

and amount of bark and defect. Thus, the weight of logs is affected by such factors as:

- Species
- Locality, climate, and slope aspect
- Season of year
- Position of log in tree
- Amount of defect and sapwood
- Time since felling
- Utilization of snags and windfalls

Because of these variables, before a weight scaling program is put into effect, it is necessary to develop data on what the relationship is between

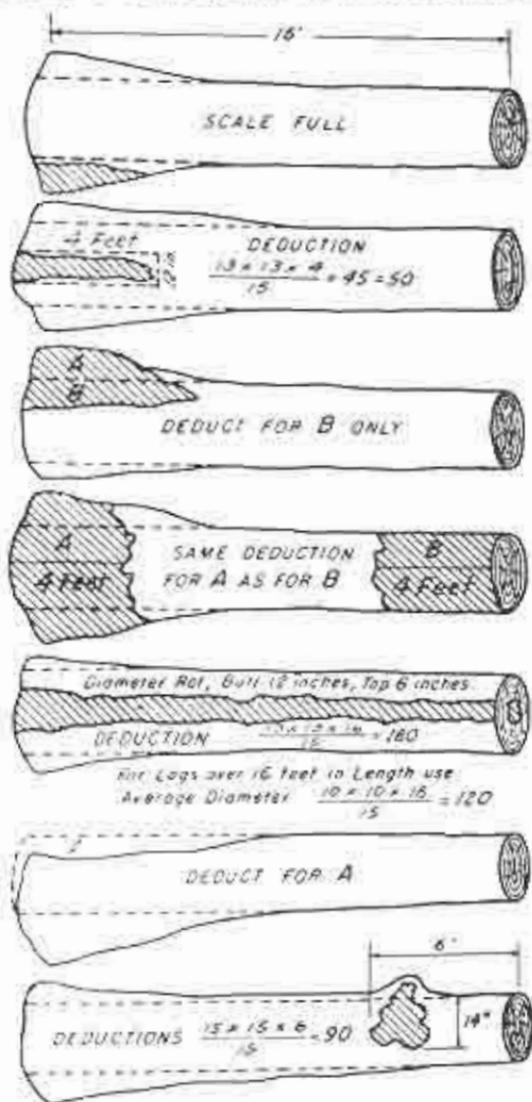


Figure VI-6
Deductions for common defect

the weight of the timber in the particular operation and the net log scale. This is called the weight-volume ratio, expressed as follows:

$$\begin{aligned} W/V &= \text{gross log weight per load/net log scale per load} \\ &= \text{pounds per board foot (net)} \end{aligned}$$

First, enough logs have to be scaled and weighed to get a reasonably good ratio to start with. This may mean scaling and weighing all loads at the beginning of the operation. Then, this figure of pounds per net board foot can be used for a while to convert weight of subsequent loads to board feet without having to do any stick scaling. This ratio runs from 6 to 12 lbs. per bd. ft.

The ratio originally established should not be continued indefinitely. To maintain a high degree of accuracy, the ratio is adjusted periodically by scaling of sample loads. The number of loads to sample is computed by statistical methods, and what loads to scale are randomly selected. Ten percent or more of all the loads are sample-scaled, depending on size and variability of the timber sale. The minimum sample size to compute or adjust the ratio should be about 20 loads. When the W/V ratio is highly variable or the sale volume is less than two million bd. ft., the required sample percent becomes so large that the advantages of weight scaling are lost.

The result of this system is that all the loads from a logging operation are weighed at a convenient place and only part of the loads are scaled. The latter is usually done after the trucks are loaded and weighed, such as at the scales or a mill. To remove possibilities of bias in loading, what truck is to be scaled is kept confidential until arrival at the place of scaling. When sufficient number of loads have been scaled, the weight-volume ratio is re-computed by using a combination of the new and old data.

Other Forms of Scaling

Consulting foresters can provide or arrange for scaling on wood operations and at mills. The services of a private scaling bureau are also available on a contract basis. If a timber or log buyer is not willing to accept the scale of the seller, it is better to have a third party scaler rather than to agree to the scale of the buyer, because scalers and scaling practices are not regulated to any great extent.

The work of scalers should be checked occasionally. This check-scaling is necessary to be sure that the scaler is complying with the terms of the sales contract and standards of the trade. The values involved certainly are considerable and worth the expense of such checks. It is accomplished by the scaler and checker both scaling the same hundred or more logs and comparing the results. Volumes between scaler and checker should be within one percent of each other for sound logs and five percent for logs over 20 percent defective.

Where disputes arise over log scale, they can be settled by each party agreeing to arbitration by a competent third person, such as a forest consultant. The Division of Measurement Standards of the California Department of Food and Agriculture has been called upon occasionally to settle such differences, particularly between contract workers and employers. That agency also inspects and certifies weight scales.

Chapter VII

FOREST ROADS

The successful operation of a forest is dependent upon having a serviceable road system. It provides access to the property for silvicultural and management purposes, serves as a vital link between the harvesting of crops and the market, and it enables the tree farmer to better protect the forest from trespass, pests, and fire. The right kind and number of roads not only make these jobs easier but increases the financial return from the forest as well.

A system that is wisely planned, well constructed, and properly maintained saves money in more ways than one. Logging costs are largely affected by the location and quality of the roads and so are stumpage values. Good roads are cheaper to maintain and can be more easily kept in useable condition permanently. That means that once roads are in place they can serve future harvests besides providing ready access to the forest. Another saving in costs of roads that are laid out, built, and kept up properly is that they do less damage to the soil resource, water quality, and the landscape. No single part of a forest operation can cause as much soil disturbance and erosion as roads, so they need special attention in order to prevent such damage.

Road Planning

Before roads are actually located on the ground, some thought should be given to developing a general plan for the transportation needs of the forest. This might be in the form of a map to be incorporated in the overall management plan that was described in Chapter II. This planning should take into consideration location of markets, useable existing roads on and off the property, topography, management and protection needs, type and order of timber harvest, and other forest uses.

Rights-of-Way

Not all roads adjacent to the property, both public and private, may be available or suitable for use of the tree farmer. This should be determined ahead of time and the road plan developed accordingly. Encroachment onto public roads for access purposes may be regulated, and in fact, log-hauling on them may be even prohibited. Using private roads on adjacent properties may be advantageous to the tree farmer and this should be explored and assured by obtaining necessary right-of-way agreements. Reciprocal easements may be in order where adjacent owners can advantageously move timber or need access over each other's property.

For protection of both the grantor and the grantee, rights-of-way should be in writing and prepared with professional help. A non-specific or floating easement over a parcel without some description may lead to future trouble. The route should be at least described by land features, e.g., along a certain stream or ridge, existing road, or by general direction going through identifiable points. Some cases may justify a description based on a survey. The document should cover other points like compensation,

purpose of right-of-way, width, rights and conditions of use by either party or others, responsibility for construction and maintenance, assignability, liability, time period, and amendment rights and procedures

Routing

The usual pattern in tractor logging is to have the roads below most of the timber that is to be harvested. Typically, the main routes go up the principal drainages with laterals along side drainages, side ridges, and side slopes. The central idea is to avoid too much hauling uphill or adverse grade as it is called. Skidding distances are generally held to distances of 1,000 to 2,000 feet. Long ridges also are used for main roads where appropriate because of ease of construction and maintenance. Having roads on south exposure hastens spring snow melt and drying out of moisture from precipitation.

Cable logging is commonly done uphill. In such cases, the road system is designed to be the opposite of the above. Most roads are therefore above the timber to be logged. Generally, cable systems require less roads and yarding distances may be longer.

Large-scale contour maps, like the USGS quadrangle maps, are necessary in planning a road system. Aerial photographs, especially when viewed stereoscopically, and maps and notes made during a cruise are also useful.

A road system is not installed all at one time. Instead, it is constructed piece by piece to serve the planned harvests of the forest. Ordinarily, the roads necessary for harvest are constructed by the timber purchaser in accordance to the sale contract. It may take the entire cutting period for the forest to complete the network. Thus, road planning must consider contemplated location and timing of harvests, so that as each road segment is established, it becomes an integral part of the system. One example of this where a road will go through a timbered area that will not be logged until later. In that case, the road should be designed to serve that area later as well as the immediate area to be harvested beyond that point.

In some situations, where access to and within the property is inadequate, it may be necessary to develop enough roads ahead of harvests for purposes of silviculture, management planning, and protection. These can be lower standard roads. Preferably, their location should coincide with the planned logging roads and brought up to standard when the latter are established. However, some of these roads may be necessary just for administration and protection; they can be low-standard, 4-wheel drive roads, yet carefully built to prevent damage to the forest and the environment.

Road Location

When it comes time to build a road, the exact location has to be made by on-the-ground reconnaissance or surveying. This is needed to have the proper alinement and grade and to avoid costly construction and maintenance, hard rock outcrops, geologically unstable areas, highly erosive soils, too steep slopes, large cuts and fills, and potential streamside problems and damage. The main idea is to have the least costly road that serves the

intended purpose and fits the terrain.

While engineers do a considerable amount of detailed engineering to locate and design roads, most foresters use less refined methods. In many cases this produces satisfactory results for forestry roads. Using a contour map, aerial photograph, or aneroid barometer (to get elevation readings), the locator first hikes the planned route to size up the situation and to fix control points, such as passes, saddles, favorable stream crossings sites, and places that should be avoided; e.g., rough or unstable areas.

The difference in elevation, or rise as it is termed, and the approximate horizontal distance (from map, photograph, or pacing) between adjacent control points is noted. Dividing the rise by the distance gives the approximate grade of the road segment in percent or the rise in feet for each 100 feet of horizontal distance. The grade in percent is also equal to the tangent of the slope angle expressed in degrees. Tables A-8 and A-9 in the Appendix show the relationship between degree of slope and grade percent. Depending on the class of road wanted, the maximum grade usually varies from 6 to 15 percent. If the computed grade percent is too high, then the length of the road segment must be increased in some manner, e.g., by carefully putting in one or more gentle switchbacks. Table VII-1 suggests grade and other standards for different classes of roads.

Table VII-1. Road standards by class of road.

Item	Class of Road*		
	I	II	III
Average Speed	30 mph	20 mph	10 mph
Maximum Sustained Grade	7 %	10 %	15 %
Maximum Pitch Grade	10 %	12 %	20 %
Minimum Radius of Curvature	100 ft	60 ft	40 ft
Minimum Sight Distance	300 ft	200 ft	100 ft
Minimum Width, traveled way **	16 ft	12 ft	10 ft

* I—main roads, II—laterals, III—spurs

** One lane roads with intervisible turnouts

Once an acceptable approximate grade has been found, the road locator re-runs the line between the control points with an Abney level or similar instrument set on the right percent or its degree equivalent. The location is marked with colored flagging (not blazes) or stakes so that changes can be made as needed. One should be prepared to make many adjustments to the road location for good purposes, e.g. to:

1. Avoid sharp curves (see subsequent section)
2. Miss rock outcrops unless they are soft enough to cut or use as road base material.
3. Keep away from places having evidence of ground creep or slides. If they have to be crossed do so at or near the top so that they are the least disturbed.
4. Detour around erosive and expandable soils, e.g., those of the blue clay type. Use soil-vegetation maps and legends or other soil maps to the best advantage.
5. Stay clear of springs, meadows, and wet places.

6. Minimize the number of large cuts and fills on steep side-hills.
7. Have roads a safe distance from streams (100 feet or more, except at crossings) to prevent damage from high water and the movement of earth or debris from construction and maintenance into the streams.
8. Keep road away from residences and recreation sites to reduce safety hazards and nuisance caused by dust and noise.
9. Minimize areas that would have overly expensive clearing, construction, and maintenance costs—too heavy timber and wrong exposure.

Grade Considerations

Whenever practicable, forest roads should be built to a grade that is favorable (mostly downhill) to the log haul. Adverse (uphill) grades slow down the travel time, consume more fuel, and cause extra wear and tear on the equipment. Level roads don't have these disadvantages, however, they are more difficult to drain properly.

The grade percent of a road depends on such factors as class of road wanted, topography, soil type, and precipitation. Where possible, logging roads have a grade of two to eight percent favorable to the haul. Adverse grades should not exceed six percent except short pieces on spur roads may go as high as 10 percent. Occasionally these limits must be exceeded because of ground conditions. Keeping within these grade standards may increase road construction costs, but this is more than offset by lower road maintenance and haul costs. Erosion on unpaved roads exceeding six percent grade is likely to be significant and special prevention measures may be necessary.

Long sustained grades of the same percent are not the ideal as one would suppose. They too sometimes present drainage problems in that they offer no logical places to divert water from the bank side to the outside of the road. This can cause erosion and gradual deepening of the inside ditch.

Forest managers prefer a slightly broken or rolling grade, but one that is generally favorable to the haul. This will often permit better alignment without a corresponding increase in construction costs. Moreover, undulating grades provide more frequent places for diversion of water, faster water removal, and require less culverts. Changes in grade should be gentle and any adverse sections short and easy so that loaded trucks can maintain a reasonable speed without frequent shifting of gears.

Sometimes, short sections of steep or pitched grade may be justified because of terrain or economics. They can be compensated for by being straight and are preceded by a level stretch or slight downgrade. If used, pitched grades should be designed to control erosion and provide adequate traction.

Alignment and Curvature

The road locator must also consider alignment and curvature because they have an important bearing on efficiency and safety. Curves are circular, that is, arcs of circles connected by straight lines tangent to them; the connecting straight stretches are therefore called tangents. The sharpness

of the curvature may be expressed in either of two ways: (1) by the length of the radius of the circle of which the arc is composed, or (2) by the central angle between two points on the curve 100 feet apart in a straight line. In the latter, the 100-ft. segment is called a chord and the angle subtending it at the center of the circle is termed the degree of curve. The relationship between these two is shown in the following formula.

$$D = 5730/R$$

where D = Degree of curve (for a 100-ft. chord)

R = Radius of curvature

In forestry work curves are expressed by radius of curvature. Using the above formula, a curve having a radius of 100 feet would have a degree of curve of 57.3 degrees or 57 degrees and 18 minutes. Note that the relationship is inverse, that is, a gentle curve has a long radius and a small degree of curve.

Engineers employ a variety of mathematical methods and special tables to lay out curves. One is by measuring the deflection angle at the transit station between the tangent and points along the curve. Others include what are called the external distance, tangent offset, and middle ordinate methods.

Foresters occasionally use these same methods; however, ordinarily they employ a less time-consuming and simpler approach. With experience a person can learn to locate curves satisfactorily by eye with some checking and measuring with a staff compass and tape. The radius of curvature of roads is largely dictated by topography, but accommodations to fit the chosen standards can be made by the right positioning of a road at the middle of the curve, changing direction of the tangents somewhat, or planning more cut or fill. For example, in crossing a draw, if two tangents intersect at a sharp angle, the road could not be located close to the point of the intersection because the radius of curvature would be too short. Instead, to obtain a longer radius of curvature, the road would have to be placed further away from the point of the intersection. Providing these conditions are noted and planned for during the route location, most, if not all, of these kinds of adjustments can be made during the construction phase when it is more convenient to take necessary measurements.

Naturally, where curves are short and gentle they can be located by eye. However, long and complex curves require at least some simple surveying. One can use the following geometric relationship (Figure VII-1) to locate a turn of a road with a wanted radius of curvature:

$$T = R \tan \frac{1}{2} CA$$

where T = distance between intersection of tangents (PI) and where they touch the curve

R = radius of curvature

CA = Central angle of curve (also equal to the external angle between the two tangents at point of intersection)

To illustrate, assume that a 100-ft. radius of curvature is desired at a place where the central angle is 30 degrees. Then, T—the tangent distance—

would be 100 times the natural tangent of 15 degrees (.2679) or 26.79 feet. This distance can readily be taped from the point of intersection of tangent along each to where the curve begins and ends. Table VII-2 shows these tangent distances for a radius of curvature of 10 feet and selected central angles.

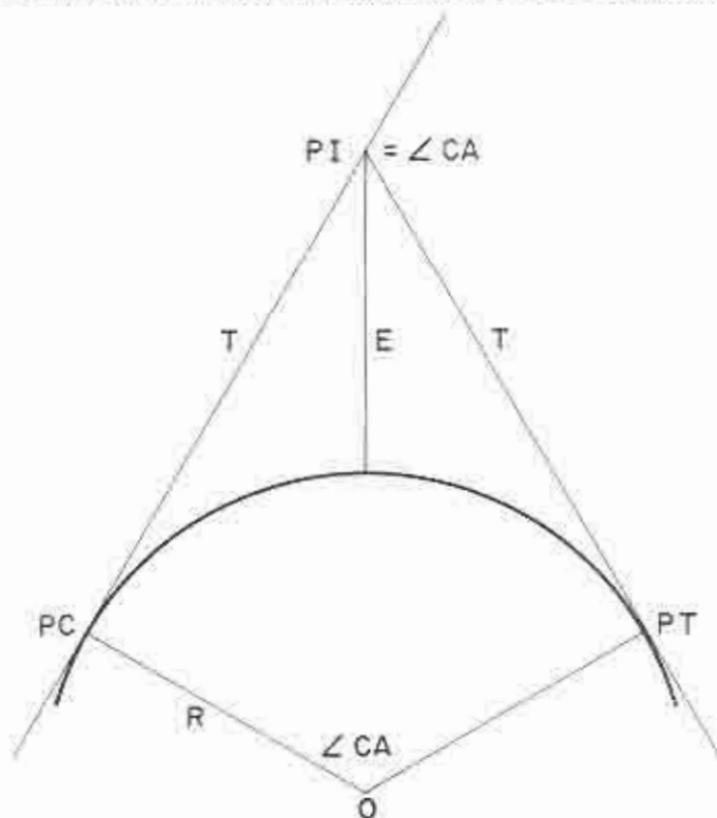


Figure VII-1
Road curve diagram.

Also, the table includes the external distance *E* from the intersection of the tangents and the mid-point of the curve; this is helpful to locate the middle of the curve on the ground. For the above example, the table would give an external distance of 3.5 feet.

The radius of curvature of logging roads varies by the class of road. Of course, curves should be as few as practicable, because they increase travel time and costs and reduce visibility and safety. Except for special situations the radius of curvature should not be less than 40 feet. Table VII-1 gives minimum curvature standards for different classes of roads.

Another critical factor in alignment of roads is sight distance (Table VII-1). This is the continuous length of road ahead visible to the driver. It is important to be able to safely stop a vehicle or to pass another. In addition to proper designing of curves, sight distances can be improved by adequate clearing of roadside obstructions and vegetation, and by a gradual change of upgrade to downgrade on hills. On a single lane roads intervisibility determines frequency of turnouts.

Table VII-2. Tangent distances T and external distances E for curves of radius 10 feet.*

Central Angle	T	E	Central Angle	T	E	Central Angle	T	E
10	0.87	0.04	56	5.32	1.35	101	12.13	5.72
11	0.96	0.05	57	5.43	1.38	102	12.35	5.89
12	1.05	0.06	58	5.54	1.43	103	12.57	6.06
13	1.14	0.06	59	5.66	1.49	104	12.80	6.24
14	1.23	0.07	60	5.77	1.55	105	13.03	6.43
15	1.32	0.08	61	5.89	1.61	106	13.27	6.62
16	1.41	0.10	62	6.01	1.67	107	13.51	6.81
17	1.49	0.11	63	6.13	1.73	108	13.76	7.01
18	1.58	0.12	64	6.25	1.79	109	14.02	7.22
19	1.67	0.14	65	6.37	1.86	110	14.28	7.43
20	1.76	0.15	66	6.49	1.92	111	14.55	7.65
21	1.85	0.17	67	6.62	1.99	112	14.83	7.88
22	1.94	0.19	68	6.74	2.06	113	15.11	8.12
23	2.03	0.20	69	6.87	2.13	114	15.40	8.36
24	2.13	0.22	70	7.00	2.21	115	15.67	8.61
25	2.22	0.24	71	7.13	2.28	116	16.00	8.87
26	2.31	0.26	72	7.26	2.36	117	16.32	9.14
27	2.40	0.28	73	7.40	2.44	118	16.64	9.42
28	2.49	0.31	74	7.54	2.52	119	16.98	9.70
29	2.59	0.33	75	7.67	2.60	120	17.32	10.00
30	2.68	0.35	76	7.81	2.69	121	17.67	10.31
31	2.77	0.38	77	7.95	2.78	122	18.04	10.63
32	2.87	0.40	78	8.10	2.87	123	18.42	10.96
33	2.97	0.43	79	8.24	2.96	124	18.81	11.30
34	3.06	0.46	80	8.39	3.05	125	19.21	11.66
35	3.15	0.49	81	8.54	3.15	126	19.63	12.03
36	3.25	0.51	82	8.69	3.25	127	20.06	12.41
37	3.35	0.54	83	8.85	3.35	128	20.50	12.82
38	3.44	0.58	84	9.00	3.46	129	20.96	13.23
39	3.54	0.61	85	9.16	3.56	130	21.44	13.66
40	3.64	0.64	86	9.32	3.67	131	21.94	14.11
41	3.74	0.68	87	9.49	3.79	132	22.46	14.59
42	3.84	0.71	88	9.66	3.90	133	23.00	15.08
43	3.94	0.75	89	9.83	4.02	134	23.56	15.59
44	4.04	0.78	90	10.00	4.14	135	24.14	16.13
45	4.14	0.82	91	10.18	4.27	136	24.75	16.69
46	4.24	0.86	92	10.35	4.40	137	25.39	17.28
47	4.35	0.90	93	10.54	4.53	138	26.05	17.90
48	4.45	0.95	94	10.72	4.66	139	26.75	18.55
49	4.56	0.99	95	10.91	4.80	140	27.47	19.24
50	4.66	1.03	96	11.11	4.94	141	28.24	19.96
51	4.77	1.08	97	11.30	5.09	142	29.04	20.72
52	4.88	1.13	98	11.50	5.24	143	29.89	21.52
53	4.99	1.17	99	11.71	5.40	144	30.78	22.36
54	5.09	1.22	100	11.92	5.56	145	31.72	23.25
55	5.21	1.27				150	37.32	28.64

* To obtain T and E for longer radius multiply values by appropriate factor, e.g. for 100 ft. multiply by 10.

Width, Cuts, and Fills

The width of a road and how much earth is moved affect costs of construction, maintenance, and use. And they have a significant impact on the forest and its associated values.

Except for large industrial tree farms where there is heavy traffic, roads of one lane should be preferred to those that allow passing anywhere. The vehicles have to move slower and cautiously on a one-lane road, and this increases operating costs to some degree. However, a narrow road is much cheaper to build and maintain, and causes much less soil disturbance. The traveled width of a road depends on the number of lanes and class of road (Table VII-1).

To compensate for the narrowness of one-lane roads, either the traffic has to be controlled or provision should be made to allow safe passing. The latter is the more common practice. This is accomplished by having special short sections of two-lane roads. These turnouts should be intervisible so that a driver can always see where the next turnout is. Where topography is light and grading is not heavy there may be some advantage to carrying the turnout width around the entire length of a blind curve.

Table VII-3. Volume of cuts and fills per 100 feet of road length and side slopes of $1\frac{1}{2}$ to 1.

Average Height (ft.) of Cut or Fill at Road Center	Width of Base of Cut or Crown of Fill (ft.)		
	10	20	30
	cubic yards		
1	43	80	117
2	96	170	244
3	161	272	383
4	238	386	534
5	323	509	794
6	424	645	867
7	532	791	1050
8	651	948	1244
9	784	1117	1450
10	926	1296	1667
11	1080	1450	1820
12	1244	1615	1985
13	1420	1791	2161
14	1607	1978	2348
15	1806	2176	2546
16	2015	2385	2756
17	2235	2606	2976
18	2467	2837	3207
19	2709	3080	3450
20	2963	3333	3704

Logging roads usually require a considerable number of cuts and fills. To avoid wasting soil and to reduce costs the amount cut should equal the required fill volume, plus 10 to 20 percent to allow for shrinkage and settlement, except in the case of rock. Table VII-3 can be used as a guide

to calculate volumes of cuts and fills. The cuts should be made so that the slopes are stable and have no overhanging banks or tree roots. Also, side-casting of the cut material over the road edge should be carefully done, especially on steep slopes above streams, so that it does not cause any harm. Table VII-4 shows cut slope ratios for various soil conditions. Where cuts are less than four feet or so, flatter slopes up to 3 to 1 are not too costly and will revegetate easier than steeper ones. To facilitate maintenance by a grader machine, and to have a safe road, the slope from the road to the bottom of the inside ditch should be flatter than the sidehill cut.

Table VII-4. Cut slope ratios (horizontal distance to vertical distance) for various conditions.

<i>Soil Conditions</i>	<i>Natural Ground Slope</i>	<i>Slope Ratio</i>
Normal soil	0-30 percent	1½ to 1
Normal soil	30-55 percent	1 to 1
Normal soil	55 percent plus	¾ to 1
Hard pan	All slopes	¾ to 1
Solid rock	All slopes	¼ to 1

The stability of fills is especially critical since disturbed loose materials are used to form them. Care should be taken to not include stumps, slash, and other organic material. End hauling of fill material should be downhill and short as possible. Where practicable, earth fill should be placed in layers from 6 to 8 inches thick with each layer compacted by the staggered passage of construction equipment or by use of rubber-tired or sheepfoot rollers.

In normal practice, the slope ratio of the fills is 1½ to 1. For most soils, this slope is considered the steepest that can be effectively protected from erosion, even when revegetated. In some clay and silty soils, slopes ranging between 2 to 1 and 4 to 1 may be available, especially on more shallow fills. Fills of clean angular rock may be on the order of 1½ to 1.

Subgrade and Surface

Grading and preparation of the roadbed are important operations in road construction. The road is only as good as the subgrade on which it is located. The base has to be firm and stable, especially on fills or stretches of soft ground. Where suitable, only native material in or near the right-of-way is utilized. Sometimes it is necessary to haul in loose or crushed rock, decomposed granite, cinders, or gravel from nearby borrow pits or sources to strengthen weak subgrades. All-weather roads require such treatment for most if not all their entire length.

Plastic non-woven fabrics can also be used advantageously to stabilize roads, particularly over wet, unstable soils. A layer of the fabric is unrolled along the subgrade and covered by a course of rock or other base material. This technique reduces the amount of road base needed. The support membrane, which allows water to pass through it, keeps the aggregate and the subsoil from mixing, diffuses wheel loading forces, facilitates drainage and drying of the road, and keeps the bottom from dropping out of the road.

The wearing surface of a road does not have much capacity to carry loads but is of great value in protecting the road base from the traffic. A loose surface does not serve the purpose, nor does one where the surface material has been worn through or displaced. The serviceability of the road surface depends on its construction, the condition of the subgrade, drainage, and maintenance. A properly stabilized road has a smooth hard-wearing surface that will not wash or blow away. The surface needs to have enough abrasive resistance and shear strength to carry the expected traffic without breaking up under the weather conditions of use. Some roads or stretches of road require stabilization treatment. This is accomplished by increasing the compactness and density of the native soil through the addition of other materials. A stabilized surface is composed of a mixture of 1) well-graded, crushed rock or gravel of one inch or less in size, 2) fine aggregate of sand to fill the voids, and 3) an 8 to 10 percent clay binder, which contains and holds some moisture. When mechanically mixed the thickness is from 6 to 10 inches; this eventually compacts to a depth of 4 to 6 inches.

In addition to having a proper surface mixture, some heavily used and long-season roads are treated or paved with special materials to bind the surface, to reduce dust, and to control erosion. These include various forms of bitumen or asphalt, oils, and even chemicals like calcium chloride. The latter has to be carefully used because it is somewhat corrosive to equipment and leaching may sterilize adjacent soils or affect water quality.

Drainage and Erosion Control

Roads have to be drained well in order to keep them usable, to ease maintenance, and to prevent erosion of the adjacent land and fouling of nearby waters. Erosion caused by not having proper drainage can cause a lot of costly damage. While provision for the right facilities may raise construction costs considerably, in the long run it pays off for roads that will serve the forest in the future as well as the immediate present.

Surface Drainage

To provide for rapid surface drainage roads are cross-sloped. They may be outsloped, crowned, or insloped. Tangent sections of better class roads are commonly crowned in the center and sloped to both sides, and the curves are sloped in or out. Roads of light use and those with small cuts and fills may be outsloped most of their length.

The selection of the cross pitch is influenced by the local rainfall pattern, erodibility of the soil, type of road surface, and the gradient. For roads of 4 percent or less in grade, the following cross-slope pitches are used:

Natural soil or loose gravel	— $\frac{1}{4}$ " to $\frac{1}{2}$ " per foot
Compacted mix	— $\frac{3}{16}$ " to $\frac{3}{8}$ " per foot

For gradients in excess of 4 percent the above values should be increased by 20 percent for each one percent increase in road grade. This will shed water to the side rather than have it run down the road. When the grade is more than 8 percent, cross sloping alone does not suffice and intercepting dips or drains should be used to prevent runoff along the

roadway. Untreated shoulders of the road should be pitched 50 percent steeper than the traveled way.

For out-sloped roads exceeding 8 percent in grade or other situations, one can choose among three common methods to safely dispose of water from the road. For low standard roads so-called "thank-you ma'ams" may be constructed. These are shallow rounded ditches running across and at right angles to the road. This kind of dip is usually unsatisfactory because it impedes traffic, doesn't drain well, and wears out easily.

An improved dip (also called water break or water bar) is a smooth shallow ditch or depression of at least six inches in depth in the roadway that is at an angle of 45 to 60 degrees from the centerline of the road. These dips are installed on tangents, below outcurves, above incurves, seldom through fills, and elsewhere as needed on both out-sloped and in-sloped road sections. The spacing is governed by the road grade (see next paragraph). Figure VII-2 depicts a typical drainage dip installation.

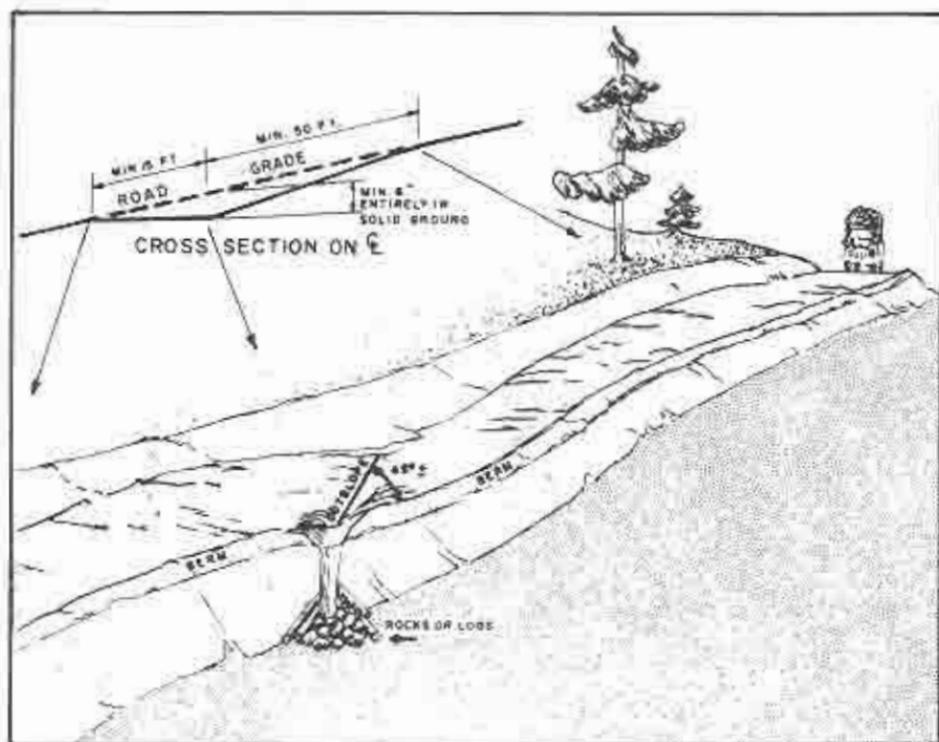


Figure VII-2
Typical drainage dip installation

A yet better method is to use an open-top box culvert made on the site from durable or treated lumber or poles, or pre-fabricated from corrugated, galvanized steel (Figure VII-3). The trough opening should be 3 to 4 inches wide and 4 to 8 inches deep. To clean out properly a flow-line gradient of $\frac{1}{2}$ inch or more per foot of length is required. The usual

distance between intercepting dips or open-top culverts are shown below. The spacing should be closer where rainfall is high and the roadbed is very erosive.

2- 5 percent road grade:	300-500 feet
6-10 percent road grade:	200-300 feet
11-15 percent road grade:	100-200 feet
16-20 percent road grade:	50-100 feet

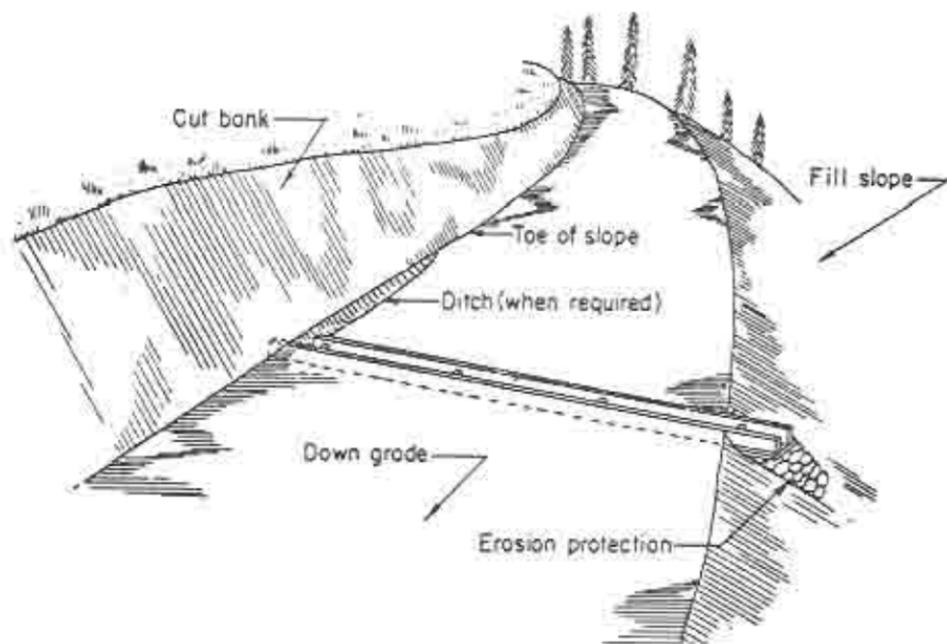


Figure VII-3
An open-top culvert installation.

Side Ditches

Except in case of out-sloped roads, water from the sidehill and from the surface must be transported by side ditches to a water course or a special drainage facility that allows the water to pass under the road. In addition, these channels provide subdrainage of the road and intercept undesirable intrusion of ground water from the sidehill.

The size of the ditch should be sufficient to carry any anticipated volume of storm water and prevent the heaviest flow from reaching the road surface. Ditches should have a grade of at least two percent. One that does not drain well may overflow or become a catch basin that can saturate the road subgrade. The side ditches should be relieved by occasional steeper pitches and frequent outlet ditches and culverts.

Cross-Road Drainage

Closed culverts are needed to move water from inside and under the road to the outside. These can be closed box culverts made from durable or treated wood, but metal corrugated pipe is preferable. While it may

cost more, metal culvert is easier to place, does a better job, and lasts much longer. Metal pipe up to 6 feet in diameter is factory-built in various lengths. Larger diameter pipe is assembled on the job from prefabricated plates.

The length of the culvert is related to width of the roadway, its slope, and angle of the culvert to the centerline of the road. It should be straight except some installations may require a gentle or broken angled alignment horizontally or even vertically. The pipe should extend at least $1\frac{1}{2}$ feet beyond the edge of the road at each end to prevent erosion, and the spill side should be protected with rocks, other non-erodible material, or special discharge aprons. Headwalls of concrete and wood or steel debris barriers may be necessary at the entry of the culverts to prevent washing and clogging.

Culverts should be large enough to carry the maximum flow expected. Where culverts are used to just transport water from the inside ditches to the outside of the road, they need not be large. Generally, the culvert grade should be at least one or two percent more than the entering waterway, but at least 6 inches drop in 100 feet of length. A 10-percent grade will ordinarily prevent sedimentation within the culvert, but grades over that may cause damage by scouring, and some inside paving may be required.

Large culverts—18 inches or more in diameter—are used where natural drainages and streams cross the roadway. These culverts should have the same alinement as that of the stream and they should be placed high enough to allow for some sedimentation at the entrance. They must also be cleared with the Department of Fish and Game.

Where the waterway is used by fish, the culvert should be installed so that their movement is not restricted. Things to watch are too steep a pitch, thin flows caused by oval pipe, precipitous drops, and no resting pool at the low end.

Sizes of these culverts must be designed to meet flood-stage requirements, rather than normal conditions. The factors involved include intensity, duration, and frequency of maximum rainfall, area and shape of the watershed drained by the water course, soil, and vegetative cover. Engineers have formulas, special tables, and other devices to compute the needed sizes. Table VII-5, which was derived from an empirical formula, gives culvert openings for various drainage areas. In addition to reviewing local rainfall records, clues as to the size of culvert needed can be obtained by looking at existing crossings of the same water course, other similar drainages with culverts, and evidence of flood runoff, e.g., water-deposited debris, bank cutting. Basically, the culvert opening should equal or exceed the cross-sectional area of the entering water course at high stage. In some cases, like shallow fills, it may be better to install two smaller pipes in parallel with well compacted earth separating them.

Extreme care must be taken in placing culverts in order to have them function properly. Also, poorly installed pipe can become severely damaged or possibly wash out. A common mistake is to place culverts too low, with no allowance for sedimentation and settling. Culverts should be put on a firm foundation of earth to prevent transverse bending or breaking

due to uneven settlement caused by weight of the fill or clogging. The fill around and top of the pipe should be firmly tamped. The height of the fill above the culvert should be one-half the pipe diameter, and at the least 12 inches.

Fords can also be utilized to cross drainages, particularly where there may be flash floods, high seasonal runoff peaks, or frequent passage of debris. This type of crossing can be less expensive than a large culvert or a bridge. To protect water quality and to prevent stream damage a ford carrying a large amount of traffic should be paved. It consists of a reinforced concrete slab across the water course and a connecting discharge apron or energy dissipator on the down-stream side.

Table VII-5. Culvert openings required for various drainage areas.

Drainage area		Waterway openings required (sq. ft.)			
Acres	Sq. mi.	Mountainous land	Hilly land	Rolling land	Flat land
1	0.0016	0.9-2.0	0.8-1.7	8.0-1.3	0.8-1.1
2	.0031	1.3-3.1	1.0-2.7	0.8-2.3	0.8-1.7
4	.0062	2.5-4.7	1.7-4.1	1.1-3.4	0.8-2.6
8	.0125	4.3-7.2	2.9-6.2	1.9-5.2	1.0-3.9
10	.016	5.1-8.2	3.4-7.1	2.2-6.0	1.2-4.5
15	.023	6.8-10	4.6-9.0	3.0-7.6	1.5-5.8
20	.031	8.3-13	5.7-11	3.8-9.1	1.9-6.8
30	.047	12-16	7.7-14	5.1-12	2.6-8.8
40	.062	14-19	9.5-17	6.4-14	3.2-10
60	.094	19-25	13-21	8.8-18	5.4-16
100	.156	28-33	19-29	13-24	6.4-18
150	.234	38-47	26-37	17-31	8.6-23
200	.312	48-59	32-44	21-37	11-28
250	.39	56-59	38-50	25-42	14-35
300	.47	64-79	43-58	29-47	16-38
400	.62	80-98	53-71	36-56	18-42
500	.78	95-116	64-85	42-64	21-48
600	.94		73-97	48-72	24-54
800	1.25		90-120	60-85	30-64
1000	1.56			71-98	36-73
1500	2.34			96-125	48-94
2000	3.12				60-112
2500	3.91				71-128
3000	4.70				81-142

Note: Within size ranges given above, use larger openings for factors contributing to rapid runoff of surface water such as high rainfall intensity, impervious soil, lack of ground cover. Use smaller openings for low rainfall intensity, open country, porous soil, sodded or wooded areas.
S.A.F., Forestry Handbook, 1955.

Bridges are required on occasion to cross larger streams. Some timber operators construct bridges from large logs laid side by side and held together by cable straps or cross timbers. However, for safety purposes and to prevent rot, the end bearings should not be just the stream bank, nor should the deck be made of earth. Instead, substantial abutments should be constructed and the deck planked. Other types of bridges are also utilized but they should be of proven engineering design.

Revegetation of Slopes

Where soil and climate are favorable, erosion of disturbed roadside slopes can be controlled by seeding or planting of vegetation. Annual grasses like ryegrass are commonly employed in areas of mild climate. CDF forest advisers, Soil Conservation Service technicians, and county farm advisers can provide information on species to use, sowing rates, and application methods. Fertilization of non-fertile soils should be considered. Generally, what is wanted is a quick, temporary cover that eventually is replaced by the natural vegetation.

Some preparation may be necessary on steep or cut slopes. Furrowing helps hold the seed and plants. Mulching with hay, straw, duff, chips, special cellulose sprays, top soil, or brush improves revegetation results. Some mulches on steeper slopes have to be held in place by staking and jute or wire netting. Vines and cuttings (wattles) of sprouting species like willow are sometimes planted, but because it has to be done by hand labor the cost is high.

Roadside Treatment

In addition to revegetation control of erosion, there are other measures that could be taken to improve the appearance and protection of the forest (Figure VII-4). Most of this is done during the clearing of the right-of-way. Stumps that remain in position should be cut as low as practicable. Skidding away of uprooted stumps that cannot be burned will improve the looks of the roadside, as well as making the road more effective for fire control purposes. Non-utilized wood material, brush, and debris near the road should be eliminated or reduced. Debris left near the road increases chances for fouling of ditches, culverts, and drainage installations. Snags within 200 feet that are not nesting sites for important and rare birds should be felled and utilized or disposed of by some means.

Spoil or excess cut material can be an eyesore unless it is used somehow, spread, or placed properly. Excess rock can be used to good advantage to protect fill slopes and stream banks.

The appearance of the roadside should be considered during adjacent timber operations. A lighter cut, careful logging, more complete slash disposal, and cleaning up landings are some ways to do this. The accumulation of the litter should be prevented and controlled.

Road Maintenance

Regular maintenance of roads safeguards the investment in the road, protects the adjacent forest, and lowers operating costs. Its importance cannot be stressed too much, because many roads are lost or become inoperable for lack of maintenance, and the damage done to the surrounding land can be considerable.

Roads that are expected to be used intermittently, such as for custody and fire purposes, can be put to bed. First, they are graded, ditched well, and cross drainages cleaned out. The traffic on them is controlled by locked gates, especially during the wet season when they can become rutted. An inspection after heavy storms may reveal some necessary prevention measures.



Figure VII-4

Road nearing completion Latour State Forest

When roads are being actively used they should receive constant maintenance. At the beginning of the season they should be graded and the ditches cleared. Some additional grading of dirt and gravel roads may be necessary during the logging season. Roads that are not oiled or paved which are undergoing heavy traffic should be sprinkled with water enough times per week to keep the surface bound and to reduce dust. It is a good idea to have the water truck equipped with a pump to draft from ponds or streams and a hose to transfer water to fire trucks and to operate a fire hose. At the close of the logging period, the roads should receive a final blading and the ditches and drainage facilities cleaned out in preparation for the winter storms. Traffic on them should be restricted unless they are designed as all-weather roads.

Chapter VIII

FOREST PROTECTION

A forest can be destroyed or severely harmed by fire, pests, and the weather. The first two forces are especially serious in most of California; but with good planning, the application of protection measures, and the use of special management practices, the losses can be kept to a minimum. Insurance coverage is not cheap, if available at all, so a tree farmer should take necessary precautions to prevent or lessen fire and pest damage. Assistance and services from the CDF and USFS are available to help with this important job.

Forest Fires

Fire is the most spectacular enemy of the forest. Besides killing timber, wildfire can burn people, destroy property, and deplete soil and watershed values. Over 90 percent of the fires are man-caused, mostly through carelessness of the general public in smoking and using fire. Although forest fires resulting from timber operations account for less than five percent of the total, they too on occasion have taken their toll.

Prevention

Since people cause the bulk of the fires, much effort has to be put into trying to prevent fires from starting. A number of different approaches are taken, but prevention largely means education.

Since so many fires are caused by the general public, children included, the forestry agencies, the timber industries, and others individually and collectively publicize the need to prevent forest fires. Examples are the Smokey Bear and Keep California Green and Golden programs. The fire prevention message is freely communicated by the press, radio, television, posters, signs and other means.

There are a number of laws and regulations regarding fires. The fire laws applicable to timber operations are mostly contained in the Public Resources Code; a violation of them is a misdemeanor with penalties in form of a fine or imprisonment. Persons causing a wildfire may also be held liable for the costs of suppression and damages to the forest and improvements. Department of Forestry offices can provide copies of fire laws upon request.

One of these laws requires permits for using fire between April 1st and December 1st in and north of the counties of San Francisco, Alameda, Stanislaus, Mariposa and Mono. Permits are required year around in the rest of the state. The Forest Practice Rules also have certain protection requirements. The enforcement of these laws and regulations is a form of prevention. The investigation of the cause of fires is a necessary part of law enforcement and fire prevention.

Vehicles, industrial and logging equipment, and chimneys also can start forest fires. Therefore, they must have effective devices for arresting sparks that meet legal standards and specifications, and are periodically inspected.

Tree farmers and timber operators have a lot at stake so it is to their advantage to become personally involved in fire prevention. They can participate at least at the local level in fire prevention education and publicity. It is to their benefit to also be on the alert to report fires to the protection agency and to help in the investigation of fires. Some owners and operators cooperate in aerial patrols that supplement the detection of fires from forestry agency lookouts and after-work watch services on timber operations.

Attention should be paid to see that timber operations and workers on the property are conforming to laws, regulations, and contract provisions pertaining to smoking, fire tool requirements, and fire in general. The more important items include posting fire rules, regulation of smoking and lunch and warming fires, care in blasting and welding, watching cable lines and blocks (pulleys) for friction fires, caution in using chain saws and other spark emitting equipment, prohibiting uncovered glass containers, and inspection for fire for at least one hour after close of daily operations. During critical periods, thought should be given to closing the forest to public entry, conducting special patrols, restricting operations to the safe part of the day, or even shutting down completely.

Using existing and forecasted weather and other fire conditions data, protection agencies each afternoon during the fire season calculate a prediction of the fire danger rating for the next day for local ranger districts or other geographical units. The burning index is released daily by radio, telephone, or news media to all forest fire stations, timber operators, other forest users, and the general public in adjective form—low, normal, high, and extreme. It is posted also along roads by ranger or fire stations and on or near timber operations. In addition to alerting forest users about fire conditions, the index can be used to prohibit campfires and controlled burning, restrict forest use, and stop logging or other hazardous operations during bad periods.

Hazard Reduction

The elimination or reduction of fuels is really another means of fire prevention. Hazard reduction also has other benefits; it lessens the chance for a fire to start and it retards the spread and reduces the intensity once a fire is ignited.

Critical fire hazards within at least 100 feet of roads on logging areas require special attention. Fuels in the form of branches, tops, chunks, and similar materials should be treated by removal, safe piling and burning, chipping, or burying. Snags not being used for nesting by rare and important birds within the same road zone should be felled. They are dangerous because lightning strikes can start fires in them, and when aflame for whatever reason, snags can throw sparks out over a wide area. They can be bad from the standpoint of safety to workers and road travelers.

This roadside treatment is very important because that is where most fires start. Furthermore, roads are often used as firebreaks from which to fight fires and start controllable backfires. In some instances the roadside should be converted to what is called a fuelbreak, which is still better as a place to stop or fight a fire. In addition to the usual treatment of dead

and down fuels and snags, an effective fuelbreak requires the elimination of shrubs, small unnecessary trees, and the pruning of all branches up to 8 feet high on trees, so that any fire within the fuelbreak zone travels slowly and burns less intensely.

Some abatement of slash resulting from logging operations away from the roadside may be also necessary. How much should be done depends on the forest type, topography, cutting system employed, the requirements of the Forest Practice Rules, and the fire and insect risks present (see following section on insect protection). Where the forest is only partially cut, the branches of unutilized portions of felled or knocked down trees can be severed so that they are in greater contact with the ground (Figure VIII-1). This lopping process, along with winter rains and snow, hastens the rotting of the limbs, eventually reducing this dangerous forest fuel. Nutrients from the decomposed slash are returned to the soil.



Figure VIII-1

Logging area where slash was lopped.
Latour State Forest.

Careful burning of slash during safe weather conditions is substituted for lopping in some cases. An example is a clearcut where the heavy slash is not only a fire hazard but also impedes regeneration of the area. Either hand or bulldozer piling or windrowing is employed. Piles are sometimes covered with building paper so that they remain dry after the fall rains commence, after which they can be more safely burned. Long windrows of slash should be segmented to keep the fire under control and to allow

ready passage of fire equipment. A few operators use broadcast burning to dispose of slash after clear-cuts, but the risk should be lessened by surrounding the area with effective firebreaks and restricting the burning to safe periods during the non-fire season. Depending on time and place, any kind of burning may require permits from both fire protection and air pollution control agencies.

Like slash, snags within logging areas should be disposed of where necessary for fire protection. Exceptions are snags that house eagles, hawks, owls, waterfowl or rare and endangered species. Snags should not be felled into streams or water bodies. In addition to roadsides, the felling of snags along strategic ridges is very important to control of wildfire.

Hazard reduction at landings and the surrounding area justify special consideration because of the concentration of workers, equipment, logging debris, and other fuels. The slash and snag hazards around landings should be abated before operations commence and not put off until later. As debris accumulates from operations it should be placed in a safe location surrounded by a firebreak. This should be then burned after the fall rains start and before the next fire season.

Dangerous materials like engine fuels and explosives should be safely stored and marked. Oily rags, used oil and engine filters, litter and other similar items should be carefully discarded.

Most of the hazard reduction and slash treatment is achievable through provisions of a timber sale contract, where the purchaser or timber operator does the work with the logging crews and equipment already on the job. The timber owner can obtain additional clean-up by personally making fuelwood from remaining dead and down material, or opening up the area to the public for the same purpose on a fee or free basis. Controls would be necessary for the latter operations to prevent fires and damage to the residual trees.

Fire Readiness

Both owners and operators should be prepared to suppress fires on or near the forest. A number of steps can be taken in advance that will make it easier and faster to control a fire. Ready access to a fire means faster control and less damage. Therefore, all roads in addition to those used for current operations should be opened for fire season. Besides providing access, roads generally can stop the spread of fire if they are cleared of flammable debris. Firebreaks and fuelbreaks should be also checked and maintained.

State law requires fire-fighting tools at certain places on logging operations. One key place is at active landings where a sealed cache of tools must be kept, plainly marked, and inspected periodically. In addition to the tool box at landings, there are other tools required for operating areas, vehicles and tractors used thereon, and logging camps or headquarters. Local rangers can advise you about specific requirements. Besides adequate spark arrestors, fallers with gasoline-powered chain saws must have an extinguisher or shovel handy to immediately put out a fire caused by the sawing operations.

It is good business to make dozers and water trucks available for fire

duty when called upon. Some owners and operators have one or more pickup trucks like patrol and supervisory vehicles equipped with a small pump, water tank, hose, and fire tools. Water tanks or ponds should be developed and marked so those sources can be effectively used in fire-fighting.

All supervisors and employees of the forest owner and logger should be instructed to immediately report fires to the authorities and to promptly take control action. In addition, some training would be advisable; help in this can be obtained from the local protection agency.

A written fire plan is another requirement of the Forest Practice Rules. Every timber operator must file a plan by not later than April 1st of each year, or if the operation commences later, the filing has to be at the least 10 days prior to that time. Having a fire plan at hand when a fire is reported saves a lot of time.

Although only operators are expected to have them, non-operating owners will find such plans valuable; forms and assistance are available from the CDF. Fire plans should contain the following information:

- Name, address, telephone numbers, and fire duties of key personnel

- Frequency and call letters of the firm's radio network

- Location and number of available firefighters on operation

- Kind, type, and location of fire-fighting tools (Figure VIII-2) and equipment, including bulldozers and water trucks

- General procedure for detecting, reporting, and controlling fires

- Map and location description of current logging and hazardous areas

- Name, address, and telephone of nearest fire lookout and protection agency ranger

Fire Control

The California Department of Forestry has the responsibility for control of forest fires on private and state lands. The U. S. Forest Service and a few counties do this job under contract with the CDF in conjunction with their own protection responsibilities. Regardless of this governmental service, according to law every owner also has a basic responsibility to control wildfires. This must be done within the ability and means of the owner, especially by fast initial attack on a fire prior to arrival of the fire control agency. Remember that, in addition, where fires are caused or spread because of the violation of fire laws and regulations or negligence on part of an owner or operator, that person can be held responsible for both suppression costs and damages to others.

Forest fires mostly travel on the surface and these are called ground fires. Occasionally, with right conditions of weather, fuel, and slope, they flare up into the branches and tops of brush and trees to create a more dangerous crown fire. This kind is the more difficult to suppress.

The local climate and immediate weather conditions are important factors in the starting, spread, and crowning of fires. The wind speed and air humidity are critical elements—the stronger the wind and the lower

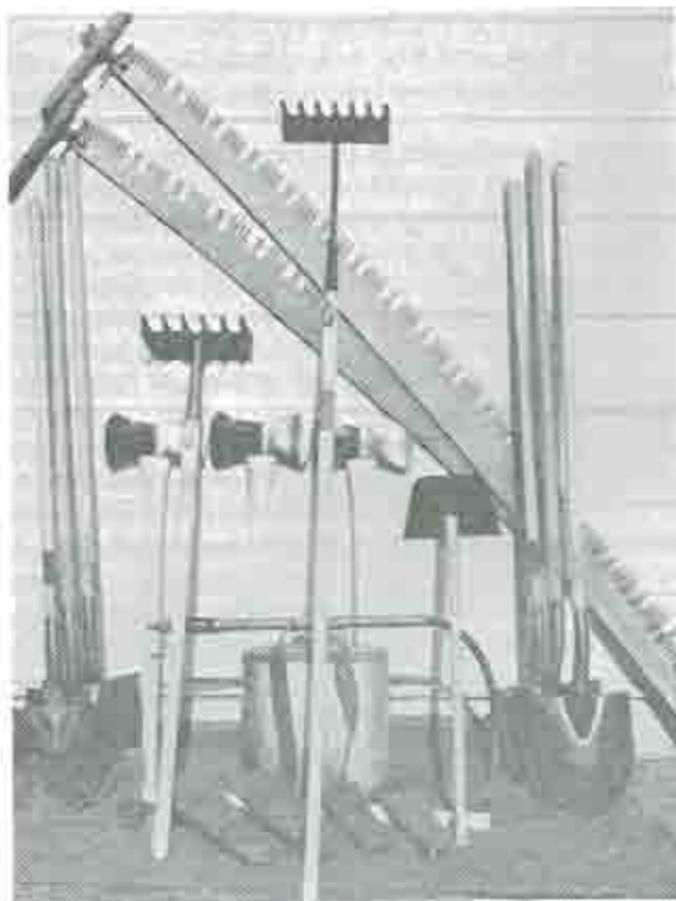


Figure VIII-2

Hand tools to keep handy in a cache for fire fighting.

the humidity the faster a fire will ignite and travel. Winds of over 20 miles per hour combined with relative humidities of less than 30 percent can cause fires to burn briskly when forest fuels are dry enough to burn.

Fuel moisture is used as another indicator of burning. It is measured by weighing a wood stick of standard size and composition that is kept on a wire rack close to duff-covered ground at forestry weather stations. The weight of the stick varies with the moisture it contains and represents forest fuel conditions. A fuel moisture of less than 8 percent and low air humidity indicate that care about fire is in order. As mentioned previously, the fire protection agencies have a fire danger rating or burning index that combines all the factors involved that is used to advise the public and forest users what can be expected about fire. It is a good tool in planning daily timber operations, burning slash, and in fighting fires.

In the main, controlling a forest fire consists of two phases: 1) stopping the spread, and 2) putting it out, in that order and priority. The principle of fire control is illustrated by what is called the fire triangle in Figure

VIII-3. The sides represent heat, air, and fuel. Break anyone of them and the fire dies. This is done by cooling, smothering, or removing the fuel. Thus, flames can be extinguished by dirt, water, chemical retardants, beating, or cutting the fire off from the fuel supply. The traditional control method consists of firefighters or bulldozers constructing fire lines around and as close to the fire as possible. These lines are scraped down to mineral soil and made from a few to many feet wide, depending on the situation. Clean dirt may be thrown or placed to knock down the fire adjacent to the line. Water from backpack pumps or fire hoses connected to pumpers can be similarly employed. These control lines serve as places from which backfires are sometimes ignited to combat the main blaze. Where hazards and values are high, the protection agencies dispatch aircraft to drop water or retardants to directly attack a fire before protection forces arrive and to help them construct and hold fire lines. Firefighters are parachuted or delivered by helicopter into inaccessible areas.



Figure VIII-3
The fire triangle.

Effective fire control demands expert knowledge, skill, and specialized tools and equipment. Wildfires are often difficult to suppress and they can threaten the lives of firefighters and people in the vicinity. The protection agencies have the trained personnel, technology, radio communications, special equipment, and other resources to combat anything from spot fires to major conflagrations. The latter may mean a campaign of many days, employing hundreds of people, scores of pieces of big equipment, like bulldozers, a communications network, and setting up one or more fire camps to serve as a headquarters and a place to feed and keep firefighters. Therefore, the leadership and main job of attacking fires should be ordinarily left to the protection agency. However, the law expects that the personnel and equipment of the timber owner and operator of the land involved should be made available to combat the fire.

Once a fire is promptly reported to the authorities, tree farmers and timber operators should not hesitate to take immediate steps to control it.

This is where the fire plan described earlier goes into effect. Listed below are some guidelines for controlling a fire:

1. Size up the fire quickly and decide on the point(s) of attack, taking into consideration the wind, slope, fuels (slash, snags, brush, etc.), intensity of the fire, values at stake, ease of line construction, and natural or other breaks like streams, rock outcrops, and roads.
2. If possible, stop the main spread of the fire at its head by building a fire line or other means, and then work on the flanks and the rear to completely encircle the fire.
3. If the fire head is too hot to handle directly, attack the flanks from the bottom or rear and work rapidly toward the head.
4. Extinguish spot fires away from the main fire.
5. When the fire is surrounded by lines or otherwise contained, widen and improve the lines at the critical points, taking necessary steps to prevent burning material from rolling across the line by ditching or other methods, and extinguish or fall burning snags.
6. Take mop-up action by extinguishing burning stumps, roots, chunks, logs, and heavy fuels near the lines.
7. Patrol the fire to keep it under control until it is absolutely safe.

Prescribed Burning

Fire is not always an enemy; it can be a useful tool in certain situations. At one time in this state, broadcast burning (also known as light burning) was done periodically in open stands on easy terrain to reduce accumulated forest fuels. This is still done to some extent in the southern states to primarily assist in regeneration of stands. Broadcast burning of logging slash was also a common practice until the 1930s in California. This kind of burning was discontinued because of increasing value of the timber damaged or lost and the risk and liability involved.

Running a fire through an area still has a place in land management. It can be used to reduce forest fuels, prepare seedbeds and planting areas, and to remove brush from potential forest and range lands (see next chapter). However, because fires are dangerous, the procedures have to be carefully prescribed. This means consulting a fire control specialist, obtaining necessary permits, preparing good fire lines, selecting safe weather conditions, firing in the right manner, and having sufficient personnel and equipment to handle the burn.

Forest Insects

While forest insect epidemics are not as spectacular, they damage and kill more trees in California than fire. Besides the forest resource loss, dead trees in large numbers may increase the fire hazard and thereby threaten scenic and watershed values. Although some insect-killed trees are salvageable so that the timber loss is ameliorated, prevention and suppression measures are a necessary part of forest management.

Insect Identification

Practically all of our bothersome insects are native to California forests. As in some gardens and agriculture, some insects in the forest are beneficial. Some prey on destructive species and others only work in dead wood, breaking down slash, snags, and windfalls. The bulk of the damage is caused by beetles of various kinds that attack the bark and stems of trees, but other species on occasion can injure or kill trees or parts of them.

The bark beetles are of most concern to tree farmers and forest managers. During the mating season in the spring and summer, these beetles bore into the bark of the tree trunks and mine many tunnels along the inner bark and cambium layer in which they lay eggs. The resulting hatch of larvae or grubs burrow new tunnels and grow in size. After a few weeks the larvae go into a pupal stage wherein they are gradually transformed into adult beetles. These adults bore out through the bark, fly away, and start a new life cycle. One or more hatches occur each year. The various bark beetles are selective as to the tree species they attack and their borings and tunnels have characteristic patterns enabling the beetles to be readily identified. The tunneling in effect usually girdles the tree; this leads to fading of foliage and death of at least part of the tree. Sometimes healthy trees resist the insects by exuding pitch that smothers the insect; this is called pitching-out.

The western pine beetle (*Dendroctonus brevicomis*) is probably the worst of these pests (Figure VIII-4). It primarily attacks the larger, mature or older, ponderosa pine, aggressively moving from tree to tree once an infestation has been established. The western pine beetle particularly hits trees which have had their tops killed by the *Ips* engraver beetle or trees damaged by lightning or wind, and those weakened by drought and for other reasons. A slightly different bark beetle known as the Jeffrey pine beetle (*D. jeffreyi*) works on Jeffrey pine in a similar way. Both beetles may also attack overstocked areas of young growth.

The mountain pine beetle (*Dendroctonus monticolae*) is the main insect enemy of sugar pine (Figure VIII-4), but it also attacks western white, lodgepole, and ponderosa pine, and a few other less common trees. This species attacks both young and old stands, especially the former where excessive competition between trees may create stress.

The Douglas-fir beetle (*Dendroctonus pseudotsugae*) is a serious pest that prefers windthrown, felled, injured, or weakened Douglas-fir. It is a big problem in decadent, overmature stands of Douglas-fir.

The engraver beetles (Figure VIII-5) consisting of two different genera (*Ips* and *Scolytus*), work somewhat differently than the bark beetles. The engravers prefer thin-barked young trees, tops of older trees, and fresh slash from logging, wind, and snow breakage. Their attacks are similar to the bark beetles, consisting of borings and tunneling in the cambium layer and inner bark. They usually generate more hatches per season than the bark beetles. The pine engravers, consisting of a number of species within the genus *Ips*, infest all species of pines. Their attacks often lead the way to more lethal damage by the bark beetles. The fir engravers of the *Scolytus* genus attack true firs and Douglas-fir.

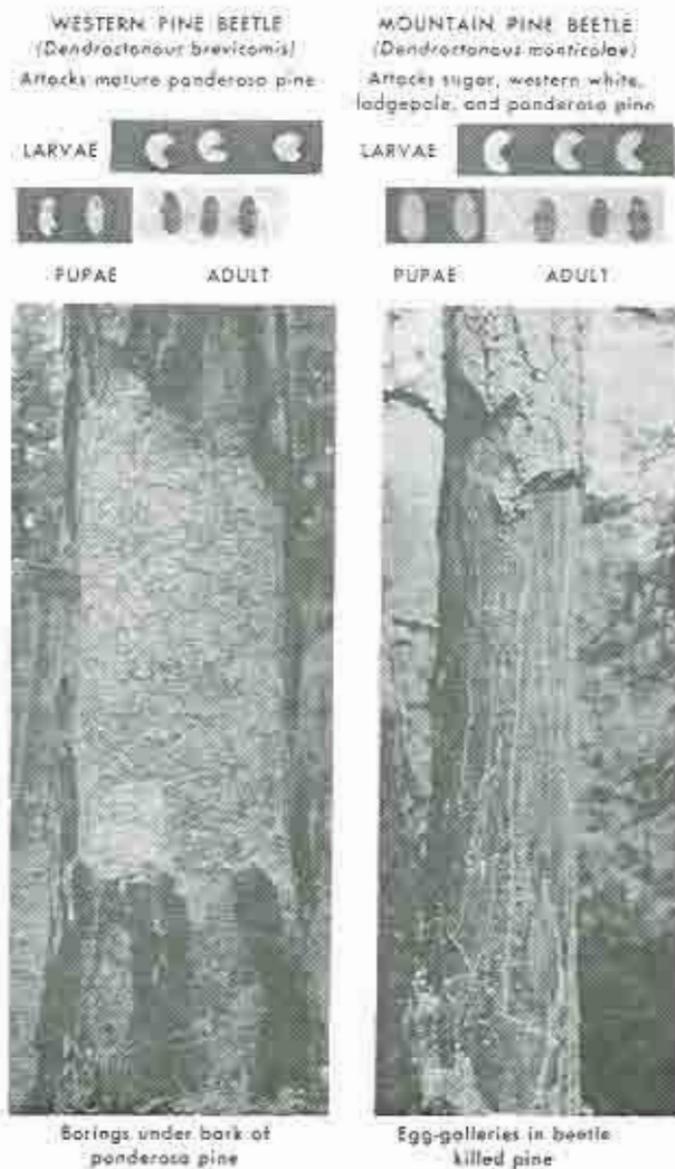


Figure VIII-4
Two principal forest insects of California pines

PINE ENGRAVER BEETLES

(Ips confusus and Ips oregoni)

Attacks ponderosa, sugar, Jeffrey, coulter, and lodgepole pine

ADULT (Twice natural size)
(Ips confusus)

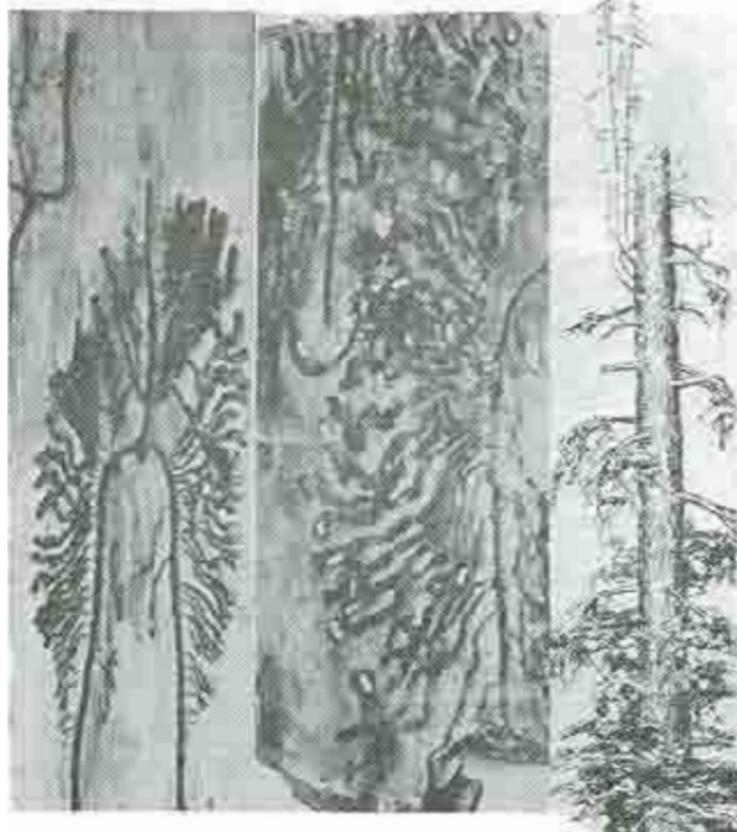
FIR ENGRAVER

(Scolytus ventralis)

Attacks true firs and Douglas fir



ADULT (Twice natural size)

*Ips confusus* mines in inner bark of ponderosa pine*Ips oregoni* larvae and borings in Jeffrey pine bark

Typical top of repeatedly attacked fir

Figure VIII-5
Pine and engraver beetles.

Sometimes, the fir flathead borer (Figure VIII-6) of the genus *Melanophila* can be troublesome in attacking pines, Douglas-fir, true firs, and hemlock. Unlike the bark and engraver beetles, the adults do not bore into the bark; instead they deposit their eggs on the surface or in crevices. The grubs damage the tree by boring into the inner bark and destroy the cambial region. The borer attacks overmature trees, those on poor sites, or fire-damaged trees.

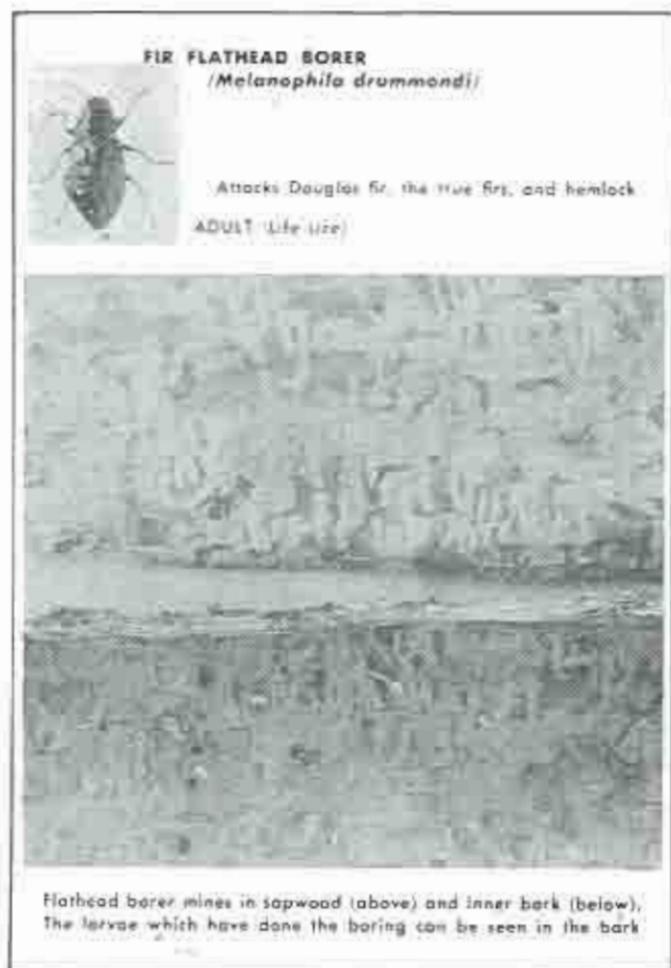


Figure VIII-6

The fir flathead borer (*Melanophila drummondii*)

There are additional forest insects of economic importance (Table VIII-1), however, they do not cause near the damage that the above do. Defoliation like that caused by the Douglas-fir tussock moth and white fir sawfly can raise havoc on an extensive scale in true fir stands. As noted in Chapter II, other insects interfere with cone and seed production and consume seed. And there can be damage also from needle and twig insects of various kinds, especially in plantations.

Table VIII-1. Other forest insects of economic importance in California.

<i>Common Name of insect</i>	<i>Scientific name</i>	<i>Species attacked</i>	<i>Part affected</i>	<i>Remarks</i>
Douglas-fir tussock moth	<i>Orgyia pseudo-togata</i>	White fir and Douglas-fir	foliage	One generation per year. Feeds on new foliage.
Black pine—leaf scale	<i>Nuculaspis californica</i>	Ponderosa and sugar pine	foliage	One generation per year. Scales weaken trees by sucking juices from needles. Bark beetles may kill weakened trees.
White fir sawfly	<i>Neodiprion</i> sp.	White fir	foliage	One generation per year. Larvae feed on previous year's foliage.
Pine resin midge	<i>Cecidomyia piniopsis</i>	Ponderosa pine	twigs	One generation per year. Lateral twigs fade in May and June. Attacks young trees of sapling size.
Douglas-fir gall midges	<i>Contarinia</i> sp.	Douglas-fir	foliage	One generation per year. Needles are infested as new growth begins. Current needles fall off Oct. and Nov. Attacks young trees.
Grasshopper	<i>Oedaleonotus onigma</i>	All pines	foliage	One generation per year. Hoppers destroy all needles. Attacks occur after grass is cured. Affects new plantations.

C.D.F., Hunt, 1978.

Detection, Reporting, and Investigation

To preclude the possibility of an infestation getting a toehold, forest owners and managers should constantly watch for signs of insect activity. An attack on a single tree may not be significant, but when a group of trees show damage this is a danger signal. Early detection of insect activity means better chances for control and smaller losses.

Symptoms of insect attack vary considerably, depending on the insect and tree species involved and the time of the year. In case of the more common beetles described above, the first sign is the appearance of faded or red-topped trees. The foliage changes from green to straw color, then to reddish brown as the girdled tree dries out. Other clues are found on the trunk. Bark beetles in pines cause pitch tubes; these are whitish or brownish masses of boring dust and pitch on the outside of the bark at points where the beetles have entered the tree. Bark beetles in Douglas-fir, and the engravers, do not make pitch tubes as such so the only outward evidence consists of some streaming pitch on the bark, entrance holes, and boring dust. Positive proof of attack for most beetles can be obtained by chopping out a section of the bark to see if there are any tunnels or galleries on the inside.

The Forest Practice Rules require timber owners, operators, and registered professional foresters to assist the State in locating and reporting pest outbreaks. The report can be made to CDF forest practice inspectors or forest advisers, who will investigate the situation to determine the cause. They have access to state and federal entomologists when needed to check the infestation and decide what control measures, if any, should be taken.

The public forestry agencies usually conduct an aerial survey each fall to detect and locate pest attacks. This information, including data received from ground observations of owners, operators, and foresters, reveals existing or potential epidemics. The compilation is reviewed by the California Forest Pest Control Action Council, an organization of interested private and public agencies and organizations, to decide what action should be undertaken. A report of the pest conditions and recommendations is then published by the CDF and widely distributed.

Some situations may need more investigation. The forestry agencies with the help of the owners conduct a biological evaluation to obtain the necessary information. These findings are particularly helpful to make pest control decisions.

Prevention

Much insect damage can be prevented or lessened by good forest management practices. Trees become weaker as they grow older or when their vigor is affected, e.g., by site, weather, competition, mechanical injury, and disease. The risk of insect attack varies according to conditions of tree age, vigor, health, and timber management.

One measure of risk of bark beetle attack is Keen's classification system for ponderosa pine shown in Figure VIII-7. The high-risk trees should be harvested as early as possible. The principles of this system can be applied to some extent to other trees; that is, the degree of insect risk is shown by

the health of foliage, twigs, and crown. High-risk trees rarely recover their ability to resist insects.

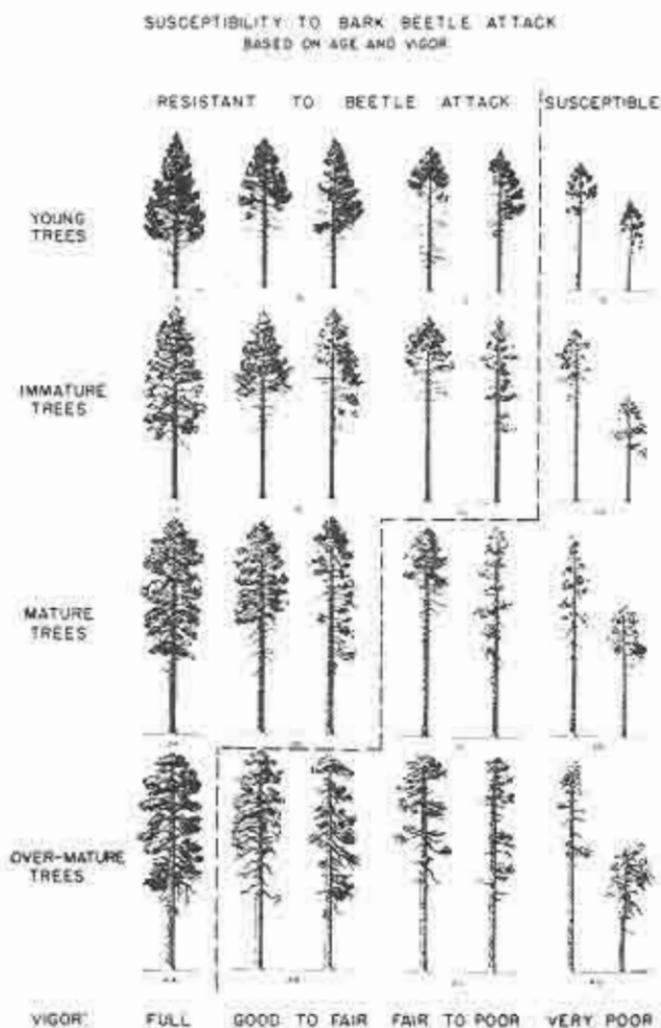


Figure VIII-7

Keen's ponderosa pine tree classification.

In addition to early harvest of high-risk trees, the following practices will reduce and avoid damage from insects:

1. Make periodic light sanitation cuts of trees of poor thrift and declining vigor to prevent the development of high-risk trees, thus keeping the forest in a healthy, vigorous, growing condition.
2. Eliminate breeding places by prompt salvage of recent fire-weakened or killed trees, those struck by lightning, infested trees, and fresh windfalls. Insect damage cannot be reduced by disposing of old windfalls, chunks, or forest debris, because tree-killing insects do not live in dead wood.

3. Do not leave cut green trees in the woods during spring and summer; prevent damage to residual trees during logging.
4. Treat slash by immediate lopping or other safe methods, especially during the spring and summer, so that it will not become a breeding ground for some insects.
5. Through other silvicultural and management practices promote vigorous, thrifty growth of the forest.

Control

Once it has been determined by forest entomologists that an insect epidemic exists, consideration has to be given by the owner and the authorities as to whether direct control action is possible and necessary in order to reduce damage. While a few insects may not be controllable, there are means to suppress the more common and serious insects like the bark beetles. This requires the joint efforts of the forest owner and the state and federal forestry agencies.

Under state law and policy, every owner has a responsibility to initiate control measures, but the state and federal governments are also involved. When an epidemic occurs and control is justified and possible, the Director of Forestry declares a zone of infestation. Upon approval of the Board of Forestry, this declaration authorizes control of the insects where the costs are shared between the land owners and the CDF, and sometimes local government and the USFS. The state agency operates the project where mostly private and state lands are included; however, the project may be a cooperative one where federal lands are also being treated, or the entire job done by the USFS under a contract with CDF.

Depending on what insects are causing the epidemic, the control methods vary. The usual procedure in the case of bark beetles requires the felling and bucking of infested trees and the burning of the bark, or ground-spraying it with a safe insecticide. To be effective, the treatment must be done as soon as the needles fade while the insects are still in the tree. Normally, beetles spend the winter under the bark so this is the best time to act.

Logging of infested trees at the right time is another way to control insect damage. Salvage logging yields utilizable wood and reduces the control costs considerably. There should be no delays in removing the felled trees from the woods, because the beetles can emerge and re-infest new trees. For the same reason, the logs should be utilized quickly if the mill is in or near a forested area.

Aerial sprays have had to be used a few times in California to suppress outbreaks like the Modoc budworm and Douglas-fir tussock moth. More selective spraying by hand and from the ground is done in the case of plantations, seed orchards, and Christmas tree farms.

Like other chemicals in forestry operations, insecticides have to be used with great care. Experts must select the correct spray, determine the formulation, and prescribe application rates and methods in order to prevent injury or damage to workers, other people, domestic animals, fish and wildlife, and the environment. The use of certain chemicals has to be under the supervision of a state-licensed pest control applicator and under

permit issued by the county agricultural commissioner. Neighboring owners, forest users, and agencies concerned with fish and game and water quality must be notified.

In addition to the indirect approaches covered under Prevention (consisting of silvicultural and sanitation measures), other possibilities appear to have some promise. These consist of various biological approaches, e.g., using scents to attract and concentrate insects where they can be treated in some manner, infesting insects with bacteria and viruses, encouraging predator insects and birds, and reducing reproduction of insects through introduction of individuals that have been sterilized by radiation. As these new methods develop they will be preferable to insecticides that may be harmful.

Forest Diseases

Diseases constitute another major destructive agent in California forests. They kill trees outright, predispose them to attack by insects, and decay wood. Most of these pests are various fungi or plant parasites.

Kinds of Diseases

Heart rots are the leading cause of wood decay. The causal fungi enter the tree through the roots, fire and lightning scars, trunk and other wounds, and open knots. They spread by spores shed by fruiting bodies or conks growing on the trees. Under moist conditions, these tiny spores germinate and send filaments into the wood, exuding substances as they travel that cause the wood to decay. Ordinarily, the amount of decay increases with the age of the tree.

A few root diseases are also troublesome. Mortality from the root fungus *Fomitopsis annosus* especially is more common than is realized, particularly in some pine stands. Spread occurs from one tree to another through overlapping roots. Killing of young growth around old, infected stumps is not uncommon, as the fungus will live in the roots of harvested trees for years. Besides death of surrounding trees, pines may be weakened to the extent that they are ready prey for bark beetles. Table VIII-2 lists the principal timber decays of California conifers.

There are 20 or more tree rusts (genus *Cronartium*) in this state's commercial forests. The most serious one is the white pine blister rust (*C. ribicola*) that infects sugar pine and other 5-needled pines. It is an invader that originated in Europe. The rust enters through the needles, grows into the twig, and gradually forms a spindle-shaped swelling there. In late spring the bark on the canker cracks and liberates orange spores. These air-borne spores cannot infect other pines directly, but cause another form of the rust on currant and gooseberry bushes. Then new colorless spores from the underside of rusted leaves are released and infect pine needles during the damper fall months. Pine branches are killed after two years or more and the rust can grow into the main trunk, eventually killing the tree. The rust is most damaging on smaller trees in the northern and moister part of the state.

Sometimes, gall rusts damage California hard pines. They form round, persistent cankers or galls on twigs, branches, and occasionally on trunks

Table VIII-2. Principal timber decays of California conifers.

Common name of decay	Causal fungus	Type of decay	Part affected	Tree species attacked	Occurrence of conks	Remarks
Red ring rot	<i>Phellinus pini</i> (<i>Fomes pini</i>)	Small white pocket rot	Trunk	Douglas-fir (Occasional in pines and other conifers)	Frequent	Common. Decay often extensive
Brown stringy rot	<i>Echinodontium tinctorum</i>	Light brown or reddish stringy rot	Trunk	White fir and red fir	Frequent	Common. Decay often extensive
Pocket dry rot	<i>Polyporus amarus</i>	Brown, cubical pocket rot	Trunk	Incense-cedar	Occasional	Common. Decay extensive
Red-brown butt rot	<i>Phaeolus schweinitzii</i> (<i>Polyporus schweinitzii</i>)	Brown cubical rot	Butt	Douglas-fir and pines	Fairly common, usually on ground	Common. Decay usually ending in butt log
Brown trunk rot	<i>Phomitopsis officinalis</i> (<i>Fomes laricis</i>)	Brown cubical rot	Trunk	Douglas-fir, sugar pine, ponderosa pine	Occasional	Occasional. Decay sometimes extensive
Redwood pocket rot	<i>Poria sequoiae</i>	Large brown pocket rot	Butt and trunk	Coast redwood	Occasional, usually hidden	Fairly common in old stands
<i>Fomitopsis</i> (<i>Fomes</i>) root rot	<i>Fomitopsis annosa</i> (<i>Fomes annosus</i>)	Light brown spongy rot	Roots and butt	White fir, red fir, ponderosa pine, sugar pine	Occasional, usually hidden	Most common butt rot of white and red fir. Kills pine on eastside
Shoestring root rot	<i>Armillariella mellea</i>	Light brown spongy rot	Butt and roots	White and red fir	Fairly common, short-lived	Common. Decay usually ending in butt log
Red ray rot	<i>Dichotomis squalex</i> (<i>Polyporus anceps</i>)	Reddish pocket rot	Trunk and top	Ponderosa pine	Almost never on living trees in California. Occurs on slash	Occasional. Mostly in N.E. California

of both mountain and coastal species. Orange spores are produced in crevices of the bark of the swelling in spring or early summer and can spread directly to other pines, without going through an intermediate host as blister rust does. Infection takes place on tree growth of the current year, and the galls appear from 6 months to 2 years later. The twig or branch carrying the infection is dead within a few years. These rusts are serious in pine plantations, including those for Christmas trees.

Dwarf mistletoes (genus *Arceuthobium*) affect pines, firs, and Douglas-fir. Infection starts in twigs and the resulting parasite lives indefinitely, causing swellings or irregular growth called witches brooms on branches and trunks. Swellings on tree trunks develop into cankers, through which decay may enter. The female plants produce sticky seeds that are forcefully shot out when ripe in early fall to adhere to new infection sites. It takes from 3 to 5 years after germination for new plants to be readily visible. Heavy infection can ruin young trees, and the growth of older trees is frequently impaired, sometimes followed by rot. Bark beetles as part of the pest complex will attack and kill trees infected with mistletoe.

There are other trouble-causing diseases that tree farmers must face occasionally. An example of this is the *Elytroderma* needle disease; it infects ponderosa and Jeffrey pine in cold locations, killing needles and dwarfing twigs. Diseased needles turn red in spring before the new tree growth commences. Repeated infections will kill trees and cause them to be susceptible to insect attack. Some other needle diseases damage young Douglas-fir and red and white fir, thereby reducing their value as Christmas trees. Table VIII-3 lists a few additional diseases affecting California forests.

Table VIII-3. Additional diseases affecting California forests.

<i>Common name of disease</i>	<i>Scientific name</i>	<i>Species attacked</i>	<i>Part affected</i>	<i>Remarks</i>
Black staining root disease	<i>Verticillium dadiella wagenetii</i>	All pines and Douglas-fir	Roots and butt	Brownish-black stain in outer sapwood. Fungus acts like Dutch elm disease. Will move through soil via roots.
None	<i>Cytospora abietis</i>	Red fir	Branches	Disease enters dwarf mistletoe infections. Dead branches turn dark red.
Phloem necrosis	<i>Dermia pseudotsugae</i>	Douglas-fir	Tops and branches	Attacks plantations and young natural stands. Sunken cankers girdle tops and branches.
Red band needle blight	<i>Scirrhia pini</i>	Monterey and Bishop pines	Foliage	Pine plantations within 15 miles of the coast in Humboldt, Del Norte and Mendocino counties are subject to attack. Entire plantations have been killed.

Forest nurseries, plantations, and seed orchards have unique problems with plant diseases. They justify special attention and treatment because losses can be sudden and severe.

Detection, Reporting, and Investigation

The same general procedures as for insects should be followed to detect, investigate, and report damage resulting from forest diseases. At the first signs of any abnormal disease attacks, the forest owner or manager should notify the CDF and ask for help. These incidents and investigations are compiled yearly similar to those about other pest losses to keep track of disease conditions in the state, and this is combined in the same annual report.

Prevention and Control

Very few direct control techniques for forest diseases have been developed. Instead, control has to be achieved mainly by instituting prevention and indirect practices. Basically, this means making a forest healthy and vigorous by silvicultural, management, and sanitation measures such as the following:

1. Harvest old, diseased, weakened, or damaged trees that are declining in vigor.
2. Prevent fire and logging damage to trees.
3. Where rusts have formed on trees in plantations and Christmas tree farms, prune out the galls before they become too numerous, and remove old gall-bearing trees nearby.
4. In case of dwarf mistletoe, harvest all infected trees of merchantable size and remove smaller trees that are heavily infected. Prune out branches bearing the parasite only when practicable.
5. Reduce competition by control of unwanted brush or hardwoods.
6. Through other silvicultural and management practices promote vigorous, thrifty growth of the forest.

At one time California had an extensive program of blister rust control. Forestry crews would locate and destroy by grubbing or herbicides all currant and gooseberry plants within and near stands of sugar pine. This attempt to suppress the alternate host was discontinued because costs of eradication and maintenance rose too high, and the disease continued to spread despite the containment efforts, especially in the wetter northern parts of the state. Some sugar pine trees have demonstrated a natural resistance to blister rust, and cuttings and seeds of these select trees are being used to grow seed orchards. Eventually, the disease may be checked by planting resistant trees as the original ones are harvested or destroyed.

Prevention measures may be appropriate where *Fomitopsis annosa* root disease is a threat to valuable pine and fir forests. Infection starts by spores landing and germinating on freshly cut stumps, followed by the disease moving down into the roots. Then, the infection is largely spread underground from the roots of infected stumps and trees to those of adjacent trees. Centers of infection in high-risk areas may be prevented by quick killing of the roots of harvested trees by treating the surface of fresh

stumps with a dry mixture of commercial borax. However, treatment of this kind will not suppress an existing heavy infection center. The only alternative is to clear-cut the area and reforest it with the more resistant species.

Animal Damage

There are some animals that can damage young trees by feeding on them, trampling, and in other ways. These mammals range in size from small rodents to elk, and include both domestic and wild animals. Most of them are valuable to us or the ecosystem from the overall standpoint so any damage caused to forests has to be prevented or controlled on a rather selective basis.

Animal Pests

In addition to the depredation on seed and seedlings mentioned in Chapter II, rodents injure small trees of all species. Losses can be serious when they occur in plantations, seed orchards, and Christmas tree farms. The damage is caused by chewing, bark-stripping, or cutting by gophers, beaver, chipmunks, squirrels, mice, woodrats, and rabbits. A large rodent, the boomer or mountain beaver, is a serious pest in young redwood and Douglas-fir stands in Del Norte County.

The porcupine feed on the inner bark of ponderosa pine, usually in the late summer, fall, and winter. In doing so, they may cause extensive damage in young stands by girdling the tops of the trees. They live in dens and rest trees; the rest trees usually range from 4 to 20 inches dbh.

In some cases, deer can be a big problem in young forests. When more preferred browse becomes short, deer will feed on the foliage of Douglas-fir and occasionally other species. This browsing does not ordinarily kill the tree, but it retards the growth until the tree outgrows the reach of the animals. Elk do similar damage in northern parts of the redwood region on Douglas-fir and redwood. Some trampling by deer and elk occurs in recently seeded or planted areas.

Another animal pest in the northern redwoods is the bear. It climbs young trees to strip the bark and feed on the inner parts. Because of its size, the bear also breaks branches and tops of the trees during the feeding process.

Domestic animals like sheep and cattle can be destructive at times. Trampling and breaking of trees cause the most damage, but feeding on the foliage also happens, especially by sheep.

Checking Damage

Some animal damage is easy to identify, especially that from the large hooved species because of distinctive tracks. Identifying damage by smaller mammals, such as rodents, is more difficult. They are elusive, often nocturnal, and do not leave much sign, except for the burrowing kind like gophers. Teeth marks and other peculiarities of the animal are used as clues.

It is important to know what animal species is involved, because prevention and control measures vary. Local CDF and other foresters can be

helpful in diagnosing animal damage. Sometimes, it may be necessary to obtain the expertise of animal biologists from the Department of Fish and Game or the U. S. Fish and Wildlife Service. The latter agency has specialists that can identify damage from non-game as well as game species.

The annual forest pest conditions report mentioned earlier in this chapter also contains data on animal damage throughout the state. This is based on reports submitted by biologists, foresters, and tree farmers. Keeping tab on the situation is necessary to locate trouble areas, to plan prevention and control measures, and to identify research needs.

Prevention and Control

Where animals are injuring forests to an intolerable degree consideration should be given to taking steps to prevent or reduce the damage. The nature of the problem varies greatly because of the many kinds of animals, tree species, and habitats. Therefore, each situation requires selective analysis and treatment.

The damage caused by wildlife should be investigated by a competent biologist before any prevention or control is prescribed. The control of rodents may be possible by various means: chemical retardants, lethal baits, or trapping. Rodenticides of any kind have to be very carefully handled; their use is strictly regulated and has to be cleared by the county agricultural commissioner. Moreover, the application of most of them has to be under the supervision of a licensed pest control applicator.

The harvesting of a forest greatly changes the habitat, often resulting in an early invasion of plants that are quite attractive to deer and elk. This may lead to an overpopulation of animals and serious depredation on young trees. There are a few compounds available that are sprayed on the foliage to deter feeding, but the method is costly and considered temporary. Plastic netting has been effective but also costly. Another solution is an indirect one—to bring about a better balance between the animal population and the habitat by applying wildlife management principles and through game regulations (see Chapter X). The animal numbers may be reduced by adjusting seasons, special hunts, and the taking of either sex. Bear damage can be reduced by similar programs of hunting and trapping. Tree farmers can relieve a problem by allowing these activities by the public on their properties.

The prevention and control of damage by livestock is basically a range management matter (see Chapter IX). The browsing and trampling may be due to trespass; it should be controllable by complaints to the offending parties or legal action, if necessary. Stocking the forest with too many animals is another source of trouble. Permanent or drift fencing may be helpful in both preventing trespass and keeping livestock out of sensitive reproduction areas.

Other Tree Losses

Natural events, like the weather, sometimes cause tree losses of various kinds. Occasionally, windstorms cause severe blowdown. Some windfall may be prevented or lessened by cutting practices that do not expose the

residual stands too much to strong prevailing winds. The borders of clear-cuts and ridges are critical places. Not much can be done in instances of more devastating storms. Wind-downed timber should be quickly salvaged to utilize the material and to reduce insect and fire hazards.

Besides wind, lightning is a tree destroyer. It breaks and splits trees and ignites fires in dead tops and snags. Strikes on live trees may kill them or make them more susceptible to insect and disease attack. Where practicable, damaged or dead trees should be cut or harvested as soon as possible.

Extremes in soil moisture lower tree health and sometimes kill trees. Too much water by flooding will do this; so will drought. Logging and road construction may alter natural surface drainage which may lead to flooding. Excessive soil disturbance and root cutting may bring about drought conditions to a tree or a group of trees.

Extremes in temperature likewise affect tree health. Sudden drops in temperature to well below freezing following a mild period can kill tops of fast-growing conifers. This quick freezing injures the inner bark of the tree. However, only vigorous tops that are exposed to the sun are affected. If the tree is not an insect hazard it may recover or grow a new top. Hot temperatures during the growing period before new foliage and twigs harden may cause some desiccation and burning, especially when accompanied by strong, dry winds, but usually the consequences are not serious. Air pollution also affects tree health in some areas.

In addition to protection from fire, pests, and weather, forests and residual stands need to be guarded from damage that may be caused by human activity. Public access should be controlled to prevent indiscriminate travel by vehicles, cutting of trees, and vandalism. The productivity of the site is at stake as well as the future value of crops to the landowner.

Chapter IX

FOREST-RANGE MANAGEMENT

As pointed out in Chapter II and elsewhere in this handbook, a forest has other important resources besides wood that deserve attention of owners and managers. Some of these non-wood values have tangible uses that are marketable. A good example of this is forage that grows within and adjacent to forests. It's fairly common to find forested properties that produce both timber and grazing income.

Multiple Use

Before discussing range management and other forest uses (Chapter X), the concept of multiple use needs to be explained. Multiple use is a popular term in conservation and forestry. It is defined as a practice that fulfills two or more objects of management, particularly in utilization of a forest. This is a desirable objective because there is an opportunity to include it in most management programs, at least to some extent. Single-purpose forestry has little place in modern land management. Multiple use does not mean that each acre is managed intensively for more than one purpose. Instead, it embodies the principle that a forest is composed of a number of values that occur in varying mixes. In parts of the forest, wood or any other resource may be the dominant value and is treated accordingly. An example is a meadow within a forest that logically would be utilized for grazing, but a meadow also stores an immense quantity of water, provides feed for certain wildlife, and is an excellent visual asset to a property. Thus, the concept of multiple use is to manage a forest as a whole for all its potential uses and to stress certain ones in those parts where biological and other natural factors so dictate. Compatibility is the key to multi-purpose management.

In addition to timber growing, other main uses of a forest include grazing, water yield, fish and wildlife production, and recreation. Associated with these are the aesthetics or beauty and the environmental attributes of a forest. Although these values are immeasurably important, this book cannot cover these subjects in as much detail as for timber production, because each of them is a big topic in itself. To do justice to them would really require separate handbooks. Nonetheless, our purpose is to emphasize that a forest has a number of resources and all of them should be wisely managed.

Forest-Range Use

A significant amount of the land being grazed by domestic livestock in California is forested range. On many forests the earnings from grazing are substantial and second only to timber growing. While some damage may be done to trees and the site by domestic animals, if properly done, forests can provide both wood and forage without impairment of either or any other resource. In fact, the right kind and amount of grazing can benefit tree growing.

Proper utilization of these two resources requires the practice of for-

estry and range management together. The latter is an art and science separate from forestry that is involved in the procurement of maximum sustained use of the forage crop without jeopardy to other values or uses of the land. Range includes many kinds of grazing lands—uncultivated pastures, prairies, natural grasslands, some brushlands and deserts, and areas having a mixture of forage plants and trees. We are primarily concerned here with the last of these broad types of range.

Because it is an integration of plant ecology, soil technology, and animal husbandry, range management is a profession in itself. Many foresters have a working knowledge of this subject; however, much of the range lands are managed directly by, or with the advice of, range specialists. Tree farmers wanting assistance in this field can obtain it from county farm advisers, the Soil Conservation Service, the U. S. Forest Service, private consultants, and brush-range improvement specialists of the California Department of Forestry.

Range Plants and Types

Grazing animals consume many kinds of plants, from small forbs to woody vegetation. Most range areas contain a mix of grass, forbs, and shrubs. What livestock feed upon and how a desirable forage cover can be maintained need to be understood in order to manage a range resource.

Kinds of Plants

Overall, grasses constitute the most important forage for livestock and for many wild animals. There are a great number of grass species. The more desirable ones are the perennials, especially some fescues, because they are excellent feed, provide a more dependable forage supply, and add more stability to the ecosystem. However, annuals have a place also, especially to provide winter or early spring forage in milder, lower-elevation areas. Table IX-1 lists the more common grasses, palatable forbs, and browse species found on forest-ranges.

The forbs are next in importance. They are low growing, non-grasslike annual or perennial broadleaved plants, the top growth of which dies each fall. The many species of forbs exceed those of grasses; they range from highly valuable clovers to weeds and poisonous plants.

Many shrubs and a few broadleaved trees are another source of feed to livestock and big game animals. Browse, as it is called, includes deciduous or evergreen shrubs or trees, the sprouts, twigs, stems, vines, and leaves of which are cropped. These plants are valuable, because the seasonal nutritive content tends to vary less than in grasses and forbs, and they add variety to the diet and enhance the nutritional intake. Sheep, goats, and deer usually prefer browse and forbs over grass.

Table IX-1. Common forage plants of California forest-ranges with comparative grazing values.*

Grasses	Forbs	Browse (shrubs)
G Perennial brome-grasses	G Bur-clover	G Deet brush
G Perennial fescues	G Filaree	G Bitter brush
G Needlegrasses (<i>Stipa sp.</i>)	G Clovers	G Winterfat
G Oatgrass	G Cow parsnip	G Service berry
G Bluegrasses (<i>Poa sp.</i>)	F-G Mules-ears	G Mountain mahogany
G Soft chess	F Yarrow	G Aspen
G Wild oats	F-P Lupines †	F-G Oaks
G Wild-rye	F-P Vetches	F-G Willow
F Rippgut brome	P Tarweed	F Chamise
F Red brome	P Turkey mullein	F Fireweed
F Foxtail fescue		F-P Sagebrush
F-P Downy chess		P Manzanita
F-P Wild barley		P Rabbitbrush
P Nitgrass		P Cherries (<i>Prunus sp.</i>)

* G—Good, F—Fair, P—Poor.

† Many species poisonous.

CDF, Dodge, 1978.

Range Types

Ranges can be broadly classified by their vegetative composition and potential grazing value or carrying capacity. The main broad groupings found in or adjacent to forested lands in this state are described below:

Meadow types have the best carrying capacity, but they are limited in area and have to be handled carefully to maintain their productivity. Overgrazing can not only decrease the valuable forage plants, but it can cause erosion, gulying, and resulting draining of the huge amounts of water stored underground. Some meadows are wet and others are dry on the surface.

Wet meadows are found in valleys and even on slopes where water is abundant, such as at high elevations. Usually, the forage, consisting of sod-forming herbs, sedges, and rushes, and some grasses, stays green throughout much of the summer. Bluegrasses, bent grasses, and clover grow on the drier sites of the meadow.

East of the Cascade and the Sierra Nevada, there are dry meadows on flats and small valleys, where spring snow-melt provides water. The plants in these meadows, which dry out by midsummer, include bunch grasses, like the Nevada bluegrass. Another dry form is the sedge meadow found on flats and benches on the eastside and high in the mountains. There, sod-forming sedges grow profusely, independently or along with bunch grasses and other plants.

Prairies, or natural grassy glades, which are interspersed within forested areas of the north coast region, are another good forage producer. The dominant plants are such perennials as oat grass, tufted hairgrass, fescues, reed grass and some annuals and a variety of forbs. These prairies are

located on natural grassland soils.

Foothill ranges and woodland-grass areas within and adjacent to the lower-elevation conifer forests, especially bordering the Central Valley, are extensive and provide a large amount of grazing, mostly during the rainy season. In the early days these ranges included highly prized perennial bunch grasses accompanied by various forbs. The dominant plants no longer are these valuable species; they have been replaced in large part by annuals, many of them invaders from abroad. A few of these, like wild oat, soft chess, filaree, and bur-clover, have good value as forage, but some of the species present today are poor to worthless or even damaging to livestock.

Brushfields or chaparral also contain feed for livestock as well as wildlife, but it takes many acres to support an animal. In addition to the browse, grass and forbs grow in openings and along margins. These brush stands are characteristic of dry sites on slopes and ridges in the foothills and mountains. The composition of the brushfields varies considerably according to soils and climate. They are mostly evergreen and many will sprout when cut or burned. The common dominants include various forms of chamise, manzanita, ceanothus, sagebrush, and scrub oak, accompanied by other shrubs. Some chaparral areas are the result of old wildfires in timber, and others are caused by brush invading overgrazed areas of former grassland and woodland-grass types.

Intra-forest ranges are composed of conifers and a wide selection of intermingled grasses, forbs, and browse plants, including some hardwood trees. While they have low carrying capacities, some commercial forests supply forage during the critical dry season. The pine and the mixed conifer types are used quite a bit for grazing. Douglas-fir stands have less forage potential, while redwood and red fir produce little range feed. However, all timberlands after harvest form a better range type temporarily, because of the modification of the forest canopy and logging disturbance. Grasses, forbs, and shrubs usually multiply for a few years, providing an increased amount of forage until new trees become established and shade out the understory plants.

Subalpine weed-grass type occurs above the commercial timber zone, generally on steep slopes. Where located on lava soils, it is an important forage type. Plant composition is quite variable, but usually includes some bunch grasses, sage brush and other browse, forbs like wooly mules-ears and lupines, and scattered trees.

Burned types are transient variations of brush and forest-ranges. They are the result of wildfires, slash burning, or fires set to try to improve the range where little or nothing was done to get a complete burn or to control subsequent woody plants. Burning can adversely affect timber and watershed values and can alter the site markedly. Intense fire can reduce the protective humus, change the chemical and physical properties of the soil, and will expose the surface directly to the sun and rain. The value of the resulting forage is highly variable—some bad, some good.

In the case of brushfields, for a few years after a burn there is a temporary flush of grasses, forbs, and sprouts that offer fair grazing. Much of this is caused by the ash nutrients. The original shrubs become re-established

by seed or sprouting, and these plants while young have some browse value. However, depending on the site, forage capacities for livestock are generally low, and the wildlife that are attracted to the area reduce the available feed. Fire as a range improvement tool is explained in a later section.

Burned timber areas are invaded mostly by fireweed and other forbs and shrubs. Some grasses may appear also. These plants, especially some of the more desirable shrubs like deer brush and other ceanothus species, provide considerable forage for a few years. Careful grazing of these areas during this period can be helpful in checking competition from these plants to conifer reproduction.

Range Evaluation

In order to properly manage any forage the manager must know its biological potential, condition and trend, and carrying capacity. Range scientists and practitioners have developed various procedures for making this evaluation.

Basic Site

The basic quality of the site should be determined first. Soil, climate, slope, density of existing forest cover, and other factors affecting the quality of forage growth need investigation to determine the potential of the site. Some open forests and associated lands present an immediate opportunity for range management while others, like wholly dense forests, may not.

Using data on the basic qualities of the site and the condition of the range, a manager can decide whether a grazing program would be feasible for a forest property. Economic factors such as costs of fencing, water development, herding, and necessary range improvements along with prospective income must be considered too. Grazing fees on nearby public lands can be used to judge market value of grazing leases; this information is obtained from the U. S. Forest Service and Bureau of Land Management. When the returns will be of little consequence it may be better to keep the forage for wild game. In some situation, where forage is in short supply, reducing grazing competition from domestic animals may lessen the possibilities of wildlife damage to trees.

Range Condition

Next to be examined is the current condition of the range resource. Composition, vigor, and density of the forage plants are key indicators of range condition. This is important because management will be governed by it. The trend in the condition, whether it is improving or worsening, indicates what present grazing practices are doing to the range resource. What is happening to the soil as to packing and erosion, the tree crop, and other values should be checked also.

The evaluation is made by one or more of the following:

1. Noting the condition of big game animals and livestock, both during and at the close of the season, but keeping in mind that they may be getting enough food by depleting the range.

2. Observing the general appearance of the range—forage cover, soils, and associated tree and other values.
3. Looking for certain indicator plants.
4. Studying in detail key plants or areas.

With adequate forage, both domestic and wild animals will look healthy. However, this criterion should not be used alone, because animals can be in good shape, especially from early to midseason, when overall the range may be deteriorating.



Western false-hellebore (skunk-cabbage) increases rapidly on meadows where the water table is lowered by gullying; these meadows can be restored by erosion control and conservative use.



On bunchgrass ranges a marked increase in woolly mules-ears indicates overuse of the grasses. (Photos by L. T. Burcham.)

Figure IX-1

Two common indicators of range conditions.

Table IX-2. Some indicator plants of range conditions.

Plant names	Characteristics	Indication	Management action
Hoary Chess (<i>Hesperis matronalis</i>); also called daisy, bronze, sheep-grass	Grass; low annual, with hairy leafage and drooping overhead.	Overuse of range	Adjust range use to favor perennial grasses.
Red top kangaroo (<i>Bromus rubens</i>)	Grass; annual, with distinct purple to red color when dry; seed heads in contact, with rigid axis.	Repeated burning or severe overuse accompanied by (bush) erosion.	Adjust range use; erosion control measures.
Woolly false-hellebore (<i>Vernonia filiformis</i>); also called skunk cabbage, corn lily	Tall rosette herb, with unbranched leafy stem; leaves parallel-veined; showy white flowers in terminal clusters.	An increase in this plant on cow-pings and moist streamers along drying of soil from lowered water table; decrease shows improvement in range.	Erosion control structures to raise water level; very conservative use or non-use until range begins to mend.
Tarweed (<i>Hebeconia tripartita</i>)	Annual weed of sunflower family; sticky, pungently-scented leaves; yellow flowers.	On perennial grass ranges indicates overgrazing.	Adjust range use to capacity of perennial grasses; grasses early to remove tarweed when young.
Turkey Mutton (<i>Eremostylus arifolius</i>)	Annual herb; prickly gray leaves, with three main veins.	When abundant in annual grass types it indicates over-use.	Rotation grazing to permit annual grasses to set seed and rest range area.
Buttercup (<i>Ranunculus repens</i>); also called crookneck	Annual or perennial herb; solitary yellow or white flowers; extensive root system; usually in wet meadow types.	Overuse of sodges and muds; drying out of meadow type.	Adjust grazing to favor re-establishment of meadow vegetation; minimum cost of to maintain water table.
Woody Mulwerry (<i>Wrightia rostrata</i>); also called big sunflower, axon stock	Perennial herb of sunflower family; large leaves with white waxy hairs; bright yellow flowers.	On long-barren ranges increase of this plant indicates deterioration of fuelbarrens; decrease indicates improvement of range.	Adjust ranges of use and number of animals to favor perennial grasses.

L. T. Burdick, 1919-5; R. P.

A better measure of range conditions, especially in connection with the above, is through general observation of the range. This includes looking at soil compaction and erosion, quantity and vigor of forage plants, availability of water for livestock, rodent activity, and damage to trees and the watershed.

The presence of certain plants are good indicators of environmental range conditions (Figure IX-1). These indicator plants invade areas that are overused or abused in some manner. Table IX-2 lists some of these indicator plants and their characteristics.

The replacement of one kind of plants by others under changing environmental conditions is called plant succession. It is a natural phenomena in the development of permanent or climax plant types that can be affected by man and animals. Successional trends up and down this scale of development are schematically shown below for California annual range (left), and for perennial range (right).

Annual Range		Perennial Range (of montane zone)
Wild oats (<i>Avena</i> sp.)		Slender wheatgrass (<i>Agropyron trachycaulum</i>)
Soft chess (<i>Bromus mollis</i>)		Blue grasses (<i>Poa</i> sp.)
Ripgut brome (<i>Bromus rigidus</i>)	↑	Needlegrasses (<i>Stipa</i> sp.)
Bur-clover (<i>Medicago hispida</i>)	—	Perennial fescues (<i>Festuca</i> sp.)
Foxtail fescue (<i>Festuca megalura</i>)	↓	Junegrass (<i>Koeleria cristata</i>)
Filaree (<i>Erodium</i> sp.)	↑	Spike trisetum (<i>Trisetum spicatum</i>)
Red brome (<i>Bromus rubens</i>)	—	California brome (<i>Bromus carinatus</i>)
Tarweed (<i>Hemizonia</i> sp.)	↓	Aster (<i>Aster</i> sp.)
Silver hairgrass (<i>Aira caryophyll- lea</i>)	↑	Pentstemons (<i>Pentstemon</i> sp.)
Turkey mullein (<i>Eremocarpus setigerus</i>)	↓	Sagebrush (<i>Artemisia</i> sp.)

U.C., Sampson, Chase, Hedrick, 1951.

Another sign of range condition is the extent to which key species are grazed, especially the more palatable and abundant plants. For example, a dry meadow is properly used when about a quarter of the bunchgrasses is ungrazed, the soil between plants is only slightly trampled, and the grazed plants have at least 1"-1½" stubble. In addition, some critical range localities may provide worthwhile information for management purposes. These key areas represent the various types that range technicians study in a more formal, detailed way to evaluate the effects of grazing.

Carrying Capacity

After an area has been determined suitable for grazing land and its condition evaluated, the manager needs to know what numbers of animals on the average it can support without deterioration of the range and other resources. Setting the correct carrying capacity maintains a good balance of desirable species and sustains forage production. The capacity of a range is related to climatic conditions and management practices.

Grazing capacity can be expressed in number of animal unit months (AUM) a range can sustain in the course of an average year. An AUM is the amount of forage needed to feed a mature cow, or its equivalent (five sheep) for one month. It equals 300 pounds of total digestible nutrients or 3/10 tons of hay. The AUM is a measure of how many stock to put in an area; it is used also by public land agencies as a unit for grazing fees. The acreage required per AUM varies widely by kind and condition of the

range—from less than one acre for productive meadows, one to three acres for annual and grassland types, 30 or more acres for chaparral and coniferous forest types. As an example, a 900-acre property exclusively of the latter type would support perhaps 30 cows during the month(s) that the range plants are flourishing.

Management Practices

The production of ranges can be increased by a number of practices. They seek to obtain better distribution of the livestock, equalize utilization of the forage, increase the forage plants, control poisonous plants, other unwanted species, and rodent damage, and safeguard the soil and watershed resource. Where the forest owner does not personally use the range, the costs of some practices can be borne by or shared with the range lessee.

Watering Facilities

Of high priority is the need to provide adequate water supplies for the livestock. This allows more stocking of animals, and if spaced properly, they are distributed better and utilize the forage more evenly. If possible, water should be available so that cattle do not have to travel more than one-half mile for it in rough country, one mile in rolling terrain, or two miles on gentle ground. For sheep, the water should be within 1½ miles in rough topography to three miles in easy country. Table IX-3 gives the daily water and salt requirements for livestock.

Table IX-3. Water and salt requirements for range livestock.

<i>Class of stock</i>	<i>Water requirement per head (gallons per day)</i>	<i>Salt requirement per head (pounds per month)*</i>
Cattle	10 to 12	1.0 to 2.5
Horses.....	10 to 12	3.25 to 3.75
Sheep.....	25 to 1.5	25 to 1.0

* Includes an allowance for weathering losses

Salt Needs

Salting is another effective practice of encouraging proper distribution of stock and utilization. It also promotes good weight gains. Because it leads to excessive concentration and range damage, salt should be placed away from watering facilities and meadows, such as on accessible ridges, benches, and openings in the forest, where the area is large and level enough for stock movement. It should be also placed to draw animals away from sensitive areas into lightly used or hard-to-get areas. Salt should be distributed throughout the range at intervals of about one mile for cattle and horses and with more spacing for sheep.

Control of Stock Movement

Fencing, or other means, may be necessary to keep livestock within bounds and to prevent trespass on other property. However, in a few counties or parts thereof (Lassen, Modoc, Shasta, Siskiyou, Trinity) open range is still practiced and stock cannot be considered in trespass unless the lands strayed upon are fenced. Therefore, except in those places, it is the livestock owner's responsibility to keep grazing animals off lands for which there is no lease or permit.

In addition to property line and other permanent fencing, temporary or moveable drift fences are useful to distribute livestock properly. Herding the animals about may be necessary occasionally for the same reason.

Seeding and Fertilization

Broadcast seeding and fertilization by hand or aircraft can improve forage growth where it is needed on some ranges. Selective hand-seeding in forested areas on skid trails, landings, and roadsides prevents erosion as well as furnishing some forage. Seeding sites and conditions are highly variable and each project should be studied by a range technician beforehand as to species to use, timing, sowing rates, methods, and rodent control needs. Large areas should not be seeded in total until some field tests have demonstrated probable success. The same caution applies to fertilization.

Poisonous Plants

There are many plants that are noxious or poisonous to one or more domestic livestock. The more common ones are listed in Table IX-4. Some plants can be lethal; others cause sickness, growth loss, or malformation of offspring. Stock do not eat these plants by choice. Heavy injury or loss is the exception where wholesome forage is in adequate supply. Thus, the control of these plants depends largely on proper range management. Some practices to reduce stock damage are:

1. Avoid too early use or overuse of the range.
2. Delay placing stock in poisonous plant areas until stock have become adjusted and the forage is in good condition.
3. While moving stock, travel slowly through areas of poisonous plants so that the animals will have time to select the right forage.
4. Withhold grazing of poisonous plant areas to allow re-establishment of better plants.
5. Eradicate the worst poisonous plants by grubbing, frequent cutting, or chemicals.

Table IX-4. Common noxious or poisonous plants of California forest-ranges.

Plant	Animals Affected		
	Cattle	Horses	Sheep
Bracken fern (<i>Pteridium aquilinum</i>)	X	X	X
Waterhemlock (<i>Cicuta</i> sp.)	X	X	X
Poisonhemlock (<i>Conium</i> sp.)	X	X	X
Larkspur (<i>Delphinium</i> sp.)	X		
Lupine (<i>Lupinus</i> sp.)	X	X	X
Locoweed (<i>Astragalus</i> sp. & <i>Oxytropis</i> sp.)	X	X	X
Death camas (<i>Zygadenus</i> sp.)	X	X	X
Klamath weed (<i>Hypericum perforata</i>)	X	X	X
Milkweeds (<i>Asclepias</i> sp.)	X	X	X
Skunk cabbage (<i>Veratrum</i> sp.)		X	X
Western azalea (<i>Rhododendron occidentale</i>)			X

C.D.F., Dodge, 1978

Control of Rodents

The control of rodents, such as the ground squirrel, may be necessary where they are a problem. Their depredation may reduce from one-fourth to one-half the forage, besides causing other damage like soil erosion and feeding on tree seed and reproduction. Rodent populations are sometimes kept in balance by hawks, other raptors, and preying animals. The advice of county farm advisers, agricultural commissioners, soil conservation technicians, fish and wildlife authorities, and licensed pest control applicators should be sought.

Erosion and Watershed Repair

Erosion depletes many ranges, especially meadows and prairies. Overgrazing of these valuable forage areas reduces protective plant cover leading to sheet erosion of the topsoil. Sometimes, gullying follows; it causes a lowering of the water table and allows invasion of less desirable plants like conifers, brush, and unpalatable species. Better regulation of grazing and clogging gullies with brush, debris, and rocks can stabilize or improve the situation.

Controlled Burning

As stated previously, controlled burning can be used to improve and convert brush ranges into better forage. Fire should be employed very discriminately and in a safe manner. To obtain the best results, only sites that have the basic capability to respond satisfactorily should be chosen. Examination of the soil or study of soil maps will indicate what areas have a reasonable chance of success. In addition to preparation of secure firelines, the selected areas preferably should be carefully prepared by bulldozing, crushing, chaining, or chopping to place the fuel into manageable form. The burning should take place under the required permits (fire and air pollution control) during the right weather conditions. This is after the treated fuel has dried to some extent. The firing method should be one that will safely consume most of the woody material. The success of the

project will be enhanced greatly by follow-up seeding and especially regulated grazing. Safe, selective herbicides can be effectively used to control post-burn woody sprouts. Literature, advice, and assistance on brush range improvement and controlled burning are available from the CDF and county farm advisers.

Grazing Systems

Livestock operators and range scientists have devised a number of different grazing systems. The purpose of the system is to promote the most efficient land management practicable. It should conserve or improve the forage production, and other resources, and yet allow an optimum level of livestock production. The chosen system should be one that can be integrated and compatible with the overall management of the property and still protect the timber, water, wildlife, and recreation values.

Grazing can be either continuous throughout the grazing season or year, or it can be based on partial use. The system must be picked specifically for each range by considering growth and maintenance requirements of the forage plants and livestock, the grazing habits of the animals, and the quantity and location of the feed. There are five main grazing systems that one can employ.

Continuous Grazing

The traditional grazing system allows livestock to graze a range throughout the year in mild climates, or throughout the season when the area is growing accessible forage. The use pattern is generally the same each year, except for adjustment because of weather factors. Uniform grazing is achieved by the management practices described earlier in this chapter—watering, salting, fencing, and herding.

Continuous grazing is convenient. It requires the least investment in range improvements, less handling of livestock, and generally, it utilizes the different kinds of forage when they are most nutritious.

There are disadvantages to continuous grazing. Livestock tend to concentrate too much in the better areas, thereby damaging the forage and soil. Poor distribution of the animals and uneven utilization of the plants waste forage in some places.

Deferred Grazing

Grazing is delayed on some ranges or areas to favor reproduction, early growth, and physiological needs of forage plants. Deferred grazing is often selected for ranges where the grazing period would otherwise include all or part of the growing season. The system generally is best adapted to ranges in need of rehabilitation. This is accomplished by promoting firm establishment of new growth and full development of the reproductive organs of the plants. Usually, deferment of grazing is combined with rotation grazing.

Rotation Grazing

This system provides for the orderly rotation in the grazing of two or more parts of a range. The use of these parcels is alternated within the

grazing season, the year, or between years with no-grazing periods in between in order to rest the range. The purposes of this system are to keep the forage on the entire property in good condition, utilize the range evenly, and to avoid damage to soil, the watershed, or tree crops. It is best adapted to ranges in fair and better condition.

Fencing or herding is usually required for rotation grazing. This alternate use might be obtained to some degree also by change in yearly location where livestock begin grazing and controlling livestock distribution by herding, salting or watering.

Deferred-Rotation Grazing

This is a combination of the above two systems. Under this method, grazing is deferred for awhile on part of the range during the growing season for one or more years. Then, the use of the other parcels are deferred in rotation. Grazing takes place on the entire range for at least part of each grazing season or year.

On ranges with summer grazing about one-third the season remains after forage seed has matured. Three different grazing units are needed to practice a deferred-rotation season. Use is delayed in each parcel for two-thirds of the season at least every third year. As in rotation grazing, fencing or other means to distribute the stock according to the plan are required.

Rest-Rotation Grazing

This is a more sophisticated system that is a further refinement of the deferred and rotation grazing systems. This plan has the additional feature of having complete rest on certain parts of the range during certain seasons or years. The long rest period restores the condition of the forage by allowing the more desirable species to grow and reproduce.

Choosing the System

The system to employ on a property depends on its soil, vegetation, climate, and livestock involved, and the objectives of the management. The plan of use should be developed cooperatively between the owner, manager, range adviser, and the user.

No management practice—season of use, rate of stocking, distribution of livestock, range improvement, or grazing system—will by itself materially improve any range. All must be combined into a management plan to be successful in achieving the most effective and efficient use of the range and other resources. Investments often have to be made to secure the best results and to provide reasonable returns to the landowner and livestock operator.

Regardless of the grazing system, the guiding principle of proper range management is that conservative use is necessary to maintain the right kinds and amount of forage species. The chief causes of rangeland depletion are too early grazing and too close cropping during the normal grazing period. A range long overgrazed has usually lost most of its best forage plants. A substantial percent of the current amount of palatable vegetation and seed stalks need to be left at the end of the grazing season to maintain a range in good condition.

Protection of Timber

Historically, there has been a serious conflict between grazing and timber production. This doesn't have to be; studies have shown that usually damage to trees from livestock is due to faulty grazing management. Other problems have arisen from unwise attempts to convert timberlands to range and range improvement burning that was not properly controlled.

There are a number of contributing factors in the damage of trees by livestock, namely:

1. Where proper forage is limited or unsuited to livestock, trees are harmed by browsing and breakage.
2. Too early grazing, prior to full development of forage plants, results in excessive browsing of trees and trampling of young tree seedlings. Grazing during periods when snow covers part of the ground forage in early spring and late fall also leads to browsing and trampling.
4. Poor distribution of livestock is another reason for trampling and browsing of trees.

Despite these dangers, range utilization has benefits besides those of an economic nature. The right kind of grazing can increase reproduction of trees by planting of seeds by the hooves of the livestock. The competition to tree seedlings is decreased by animals feeding on herbaceous plants. Similarly, browsing on hardwoods keep those species in check in conifer stands. Another benefit to forests from grazing comes from reducing forest fuels in the form of grass, forbs, and shrubs. Moreover, some livestock trails can be used to start fireline construction.

The key to achieving compatibility and mutual benefits between range and forest production is wise management. If each resource is handled correctly, the impact of one on the other is lessened and the total output is better than by not having an integrated management plan.

Chapter X

WATER, WILDLIFE, RECREATION

In addition to timber and range, the other valuable uses of forests are watershed management, fish and wildlife production, and outdoor recreation. These resources may not offer much in the way of a saleable, physical product like wood and forage; nonetheless they provide many benefits to both forest owners and society in general. In many situations, the tree farmer can personally utilize these resources and even market a service based on them within the framework of a multiple-use program.

Watershed Management

Water is a necessity for all living things. It is especially critical here in California because of our large population, irregular geographical distribution of precipitation, and its seasonal nature, marked by occasional severe drought years. Consequently, California has spent more on water development, transport, and protection of quality than any other state in the U. S.

The annual average yield of water from California lands is 67,788,000 acre-feet. Besides this native water, additional amounts are imported. Most of this water has its source in the wildlands, about 60 percent coming from the commercial forests alone. Because of the importance of wildlands to water production, forest owners and managers have a vital role in the protection and management of watersheds.

The Hydrologic Cycle

To carry out this responsibility, one should have an understanding of the hydrologic cycle (Figure X-1) and the various factors involved. Some of them can be manipulated and thereby affect quantity and quality of water yield, flood runoff, erosion, and sedimentation.

The natural distribution and transport of water in its various forms (solid, liquid, vapor) follow the hydrologic cycle. It can be expressed by the formula:

$$RO = P - E - T - (\text{or } +) S$$

where RO = runoff or water yield

P = precipitation

E = evaporation

T = transpiration

S = storage of water in ground

Precipitation by rain, sleet, snow, hail, fog, mist, dew, and frost is the principal source of water on the earth's surface. All are derived from the atmosphere where moisture exists as vapor, particles of water, and snow or hail. These forms are created and precipitated to the ground by various weather phenomena.

Evaporation is one process by which water from the land and water bodies returns directly to the atmosphere in the form of vapor. The rate is a function of 1) solar radiation, 2) temperature, 3) wind, 4) atmospheric

WATER STORAGE IN ATMOSPHERE

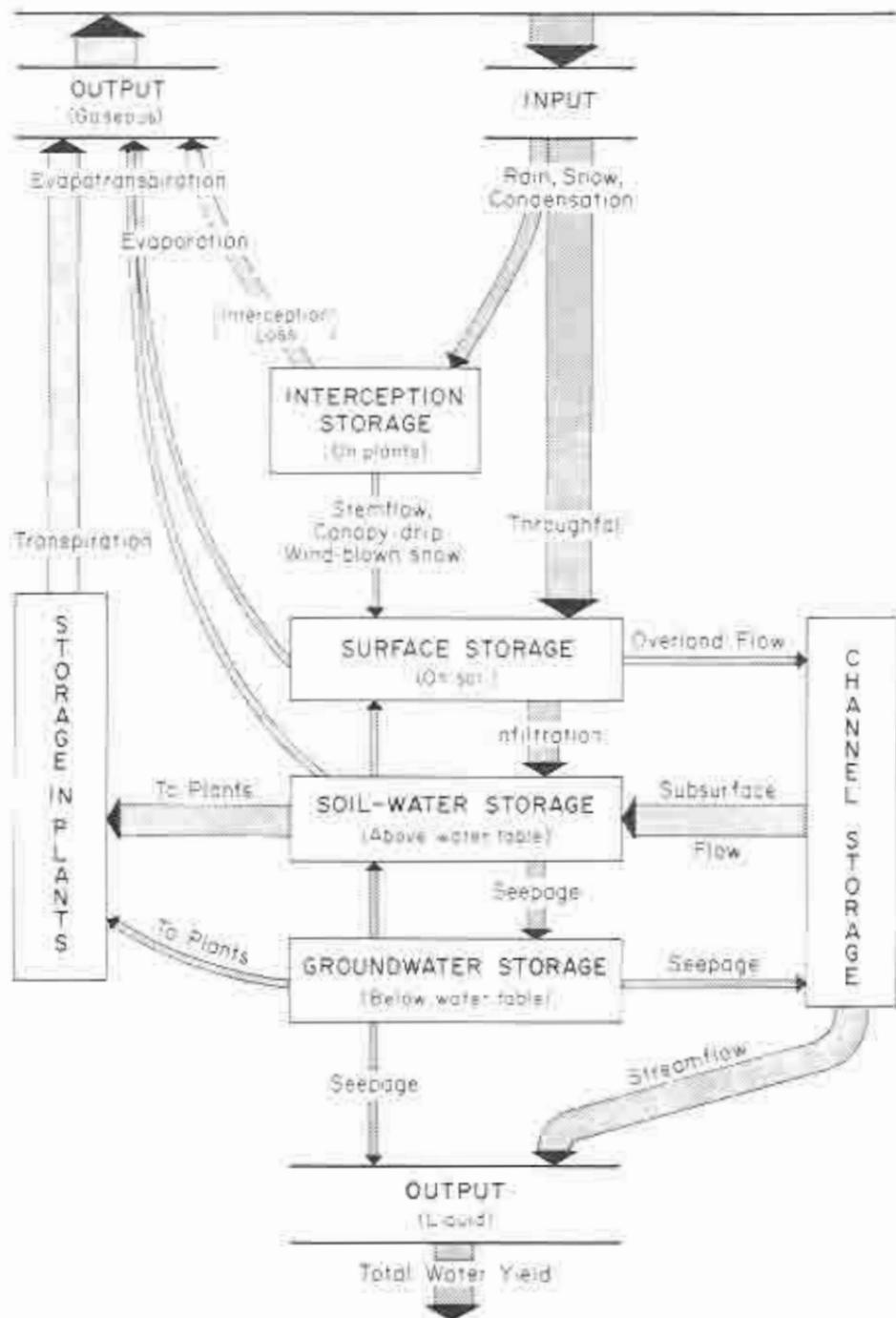


Figure X-1
The hydrologic cycle.

pressure, and 5) humidity. It is affected greatly by the interception and holding of precipitation by vegetation or surface objects. The result is a sizeable reduction in the water reaching the ground. For instance, studies have shown that a ponderosa pine can intercept from 22 to 40 percent of the precipitation. However, occasionally the interception is temporary and the water still gets to the ground from flow down the plant stems and fog drip.

Transpiration is the release of water vapor into the air from vegetation. The amount is related to vegetative cover, the growth activity of the plants, and weather conditions, varying by hour, day, and season. It is also affected by the available ground water.

Although plants do not consume much water in the absolute sense, they do take water from the soil, use it in their physiological processes, and release it as a vapor so that it is not readily available. A single tree can extract hundreds of gallons of water per day from the soil. In general, on a per-acre basis, transpiration from brushlands and forests is from 5 to 25 inches per year, or more. Certain plants whose roots reach the water table (phreatophytes) and riparian or stream-bank plants like alder and willow are notorious users of water. Transpiration is the primary source of water use in forests, in contrast to evaporation from the soil, since the canopy intercepts most of the solar energy.

Storage of water in the ground consists of soil moisture and as free water below the water table in porous strata or formations known as aquifers. Because of variations in amount of stored water and the nature of the geological structure, the runoff from a watershed may not equal the input less evapo-transpiration losses. When the watershed is saturated and the ground water table is at its highest level, the outflow is at a maximum. However, some watersheds leak because of their geological structure, so the runoff is less than would be expected. Conversely, some watersheds yield water from deep underground storage by artesian springs, in which case the runoff is increased.

Water moves from the land surfaces into the soil mantle by infiltration. The rate is high when the soil is dry and low when the soils approach their capacity to hold water (field capacity). Moreover, infiltration is affected by amount and kind of plants, ground litter, soil structure and texture, turbidity of the water, and character and depth of frozen soil. Movement of water deeper into the soil and below is called percolation.

Effects of Soil and Vegetation

Obviously, soil and vegetation affect the functioning of a watershed. This needs to be understood by forest managers and users because management activities change the amount and composition of the plant cover and the accompanying soil resource to a significant degree. However, these effects can be altered by land management.

Vegetation has minimal effect on precipitation, most of which is caused by cyclonic and convective storms. However, forests improve the microclimate and bring about a little precipitation from fog drip and by interception of moisture-laden clouds at high elevations. Most important is the amelioration of high temperatures, low humidities, and wind movement

at ground level that are often destructive to young seedlings and unfavorable from the standpoint of wildfire.

Interception and transpiration cause some water loss, but this is offset by other benefits. One gain is that this movement of water into the air also improves the local climate by cooling the air and increasing the humidity. Interception of precipitation by plant foliage breaks the impact of raindrops on the ground and prevents puddling and erosion of the soil.

The infiltration capabilities of soil and vegetation are especially valuable to watershed management. Good infiltration prevents or decreases flood runoff and extends the time of water yield. Both the amount and rate of infiltration into the soil are governed by a number of factors. One of these is the porosity of the soil that can be decreased by compaction. The kinds and combinations of particles in a soil—clay, silt, sand, rock—largely determine porosity. Soil texture and depth also affect water-holding capacity. The vegetal litter and humus form organic matter in the soil that makes it more porous, binds small particles into aggregates, holds moisture, and adds nutrients.

Much of the erosion and flood runoff damage is caused by surface flow of water. Some erosion is natural or geologic and some is accelerated because of human activity. Soil is moved by sheet, gully, and channel or streamside erosion. The rate is related to the gradient and water velocity; for instance, doubling of the velocity increases erosive power four times. Mass movements also occur sometimes in form of slips and slides, especially in unstable areas. Erosion is also materially affected by the kind of soil (see Chapter II—Site). The more erodible soils of California forest areas are listed below:

Redwood-Douglas-Fir Region	Pine Region
Atwell	Chaix
Casper	Corbett
Empire	Chawanakee
Hely	Heitz
Larabee	Lytton
Mendocino	McCarthy
Modesty	Shaver
Tonini	Tish Tang
	Windy

(C.D.F. Stone)

Vegetation may decrease erosion in three ways: 1) the canopy reduces dislodgement of soil by rain drop impact, 2) plants and humus facilitate infiltration and thereby reduce surface flows, and 3) the velocity of overland flow of water is greatly decreased by the vegetation and its debris. Generally, the denser the cover the more the water flow is held back with the peak discharges correspondingly lowered. Vegetation along roads and streambanks particularly deters erosion at those critical places.

Water Utilization

Because water is such a valuable commodity in California, its use and protection are strictly regulated. Moreover, the laws and regulations on

water rights are quite complex. Basically, water is a public resource and people's individual rights to it are limited. An owner has rights to water that can be tapped by springs and wells on the property without much restriction. The use of surface water from streams and lakes, however, is controlled by the State. To assure continuance of these riparian rights, an owner should file for a permit from the State Water Resources Control Board. That agency can also supply literature on water rights and the various regulations.

The quality of water in streams, lakes, and underground sources is also protected by laws and regulations of the above agency. This control is administered by local Regional Water Quality Control Boards. Similarly, as noted in Chapter II, the Department of Fish and Game has laws and regulations to prevent damage to streams, lakes, and fish habitat. Besides protecting these resources because of legal mandates, water and watersheds have a personal value to an owner for domestic and land-use reasons.

Some landowners find it worthwhile to impound water behind dams or in ponds to increase and extend supplies for domestic, agricultural, and livestock purposes. Assistance in the design of such facilities is available from the State Department of Water Resources and the Soil Conservation Service. Dams of more than six feet in height that store more than certain acre-feet minimums must be built under a permit from the Department of Water Resources and meet strict safety standards. Dams on streams used by migrating fish need a passage structure.

Water is measured in a number of ways. In addition to inches (precipitation) and gallons, water is measured by such units as 1) acre-feet, 2) cubic feet per second (cfs) of flow, also called second-feet, and 3) miners inch. An acre-foot is water one foot deep over one acre; it equals 43,560 cu. ft. or 325,851 gallons. A cubic foot of water equals 7.48 gallons or 62.4 pounds. The miners inch, a carryover measure from the early mining days, is still used in mountain areas. It is a flow of water through a one-inch square notch with the incoming water level $6\frac{1}{2}$ inches above the bottom of the notch, and is equivalent to 1.53 cubic feet per minute. The Appendix contains other measures and conversion factors useful in forestry.

Impact of Forest Land Management

Forests and other vegetation provide positive benefits for water production. Land-use activities can alter those benefits, easily in a negative, or less so in a positive way; it all depends on the attitude and actions of the land manager. If the manager accepts the concept that soil and water resources have value like trees and forage, much can be accomplished to conserve watersheds.

It is not a simple job to protect the watershed values while timber is being harvested and the forage grazed. To do so the tree farmer should adopt a program of wise use of these crops with appropriate limits on watershed damage. To achieve this goal, the land manager must know these limitations, the basic cause of damage, and what protective methods need to be applied. Some areas remain relatively stable under rather intensive use while others are much more sensitive. The differences in susceptibility are due to variations in geology, soil, climate, topography, and cover.

A number of the impacts on watersheds from timber harvesting and grazing are clearly recognizable from experience and scientific studies. Water storage and yield are affected by some timber operations. The effects can be positive if more water is produced or if the flow can be extended over a longer period. On the other hand, peak flows may be increased and cause damage in some cases.

Both timber harvesting and grazing can compact the soil and expose it to erosion. The consequences of some erosion may be serious to the property owner, neighboring lands, downstream improvements, and water users. It's well recognized that excessive erosion lowers the site quality and can damage road systems. Agricultural lands and improvements of various kinds on and off the property may be impaired by deposition of eroded materials. Sediment from erosion spoils fish habitat in streams and water bodies, reduces storage capacity of reservoirs, and lowers water quality.

Perhaps a more widespread impact is that soil disturbance can lower the quality of water in streams, lakes, and reservoirs. The addition of soil particles, organic material, nutrients, and debris degrades the water; this limits its use, lowers potability, impairs waterways and facilities, and increases treatment costs. Disturbance of the sides and channels of streams adds to the problem. Removal of vegetation along streams increases erosion and water temperatures so that fish life and other aquatic populations may be reduced or even eliminated.

Different impacts on the watershed are caused by the various forest operations. The cutting of trees by itself probably has the least effect. Some cutting techniques improve summer water supplies by increasing snow deposition and slowing snow melt. More commonly, removal of trees reduces transpiration losses; this may be good or not, depending on the circumstances. Water yield is increased, which may be desirable, but not so when the cutting takes place on poorly drained, slide-prone areas, because the greater amount of water left in the soil may increase likelihood of mass soil movement. The eventual decay of the tree roots reduces the anchoring and binding of the soil. While many slides occur in undisturbed areas, their frequency may be increased by timber cutting and the road development and yarding that accompany it.

Physical damage or increased hazard of surface erosion from yarding comes about in three ways: exposure of the soil, deep disturbance, and compaction. Exposure of the soil is usually of least consequence unless extensive or on highly erosive soils. Some light disturbance of the top soil may enhance the germination and establishment of a new tree crop. However, deeper disturbance resulting from bulldozer cutting of skid-roads and landings, skidded logs plowing the soil, and heavy equipment activity, especially during wet weather, can lead to erosion problems. Compaction damage varies enormously according to kind of soil, its moisture content, kind of logging equipment, and frequency of traffic. Severe compaction adds to the likelihood of faster runoff and erosion; it also may retard subsequent establishment and growth of reproduction. Compaction depends on degree of harvesting, and is greatest with tractor logging and least with off-the-ground cable or aircraft methods.

The construction and use of roads create a very large share of the

watershed damage associated with management activities, as much as 90 percent in many cases. Roads on gentle to moderate slopes on stable terrain have small impact except through careless construction and maintenance practices. Difficulties and hazards multiply where roads are built on steep topography, cut into erosive or unstable soils, encroach on streams, or when constructed during wet weather. The resulting disturbance that is not localized or revegetated causes soil and debris movement, deteriorates the site, lowers water quality, and clogs water courses. Mass soil movement is a frequent risk with mountainous roads. Poor road maintenance also harms watershed values in much the same way.

Slash disposal operations may have a negative effect on watershed values. Some treatment of slash is favored in many situations because it lowers fire hazards and improves the site for regeneration of a new tree crop, and in doing so contributes to retention and establishment of a protective cover. If properly done, slash burning does little damage to a watershed, but if uncontrolled or too hot, soil cover and structure may be degraded. This can lead to more water and wind caused erosion, reduction in infiltration, and the introduction of ash, soil sediments, and nutrients into nearby streams.

Aside from timber harvesting, watersheds can be harmed by other forest uses. Heavy feeding by livestock, wildlife overpopulation, and concentrated recreation use can increase surface runoff by reducing plant density and by increasing soil compaction from trampling. Plants lose their vigor by continual too-close cropping and heavy trampling; productivity drops, tops and roots die back, and protective cover and litter dwindle. Original cover is often replaced by plants less efficient in staving off erosion, and continued overuse exposes dangerous high proportions of bare soil.

Prevention and Control of Damage

It has been demonstrated that the way land-use is conducted has immediate and long-term impacts on watersheds. Well planned operations will keep watershed degradation to a minimum level. Although careful operations may add significantly to the costs of forest management, it is an expense that is necessary to protect personal and public interest in watershed values. Forest owners need to recognize this cost and to balance it, together with other resource expenditures, against the benefits and returns.

Principal measures aimed at prevention and control of watershed deterioration resulting from timber harvesting, grazing, and other operations are as follows:

1. Avoid or modify timber cutting on unstable areas to prevent mass soil movement, because of geological disturbance by logging, reduction in soil anchorage by roots, and lowered transpiration losses that can result in oversupply of soil moisture on the area.
2. Adapt equipment and methods of logging to reduce gouging and deep soil disturbance. Consider using cable systems on sensitive areas.

3. Prohibit or reduce use of tractors on erosive, steep slopes and sloppy (saturated) ground. As a rough guide, 30-percent slopes approach the desirable maximum for tractor operations on non-rocky soils.
4. Keep skid trails and landings well drained by diverting surface water to areas where sediments can filter out and erosive energy be safely dissipated. The installation of diversion ditches or water bars after logging is important, and these should be checked during the wet season to see that they are functioning properly.
5. Do not yard logs along, across, or in stream channels. Instead, skid logs away from streams and suspend them fully at necessary crossings. Keep logging debris out of streams and carefully remove any that gets into streams that may cause damming, obstruction of fish passage, diversion of flow, bank cutting, and lowering of water quality.
6. Plan road, landing, and skidtrail locations in advance of construction to reduce soil disturbance and to lower construction, maintenance, and use costs (see Chapter VII).
7. Learn to recognize and avoid trouble spots for roads from the standpoint of geology, soils, seeps.
8. Avoid steep road grades and provide adequate drainage facilities.
9. Locate roads and landings at a safe distance from streams, and leave a margin of protective trees and vegetation. Keep roads on benches and ridges and away from swales and depressions.
10. Minimize earth movement during road construction.
11. Provide regular maintenance to prevent road and watershed damage.
12. Where slash or other burning is necessary, it should be carefully prescribed and controlled (see Chapter VIII). Avoid slash burning adjacent to streams.
13. Graze forage moderately under a carefully prepared range management plan (see previous Chapter).
14. Manage wildlife populations and recreation use wisely to avoid watershed damage (see subsequent sections).

Fish and Wildlife

Forests and the associated atmosphere, soil, vegetation, and water are natural homes for a vast number of species of the animal kingdom, such as birds, rodents, fur bearers, game, other animals, and fish. Many species that live in and around forests are found nowhere else, and when woodlands are harmed, some creatures become fewer or disappear. To save the beautiful and useful kinds of fish and wildlife, their habitats must first be protected, because that is the source of their food, water, shelter, and a place to breed, hide, and live.

Forests and Fish

Like the raw water resource, streams, lakes, and the fish belong to the public regardless of who owns the land. As pointed out earlier, laws exist

to protect these resources. The inland fisheries resource ranks high in terms of economic value; it supports a valuable salmon industry in California and provides much sport fishing that has both recreational and monetary value. The streams in the forests not only have resident fish like trout, but some also produce migrating or anadromous species such as salmon, steelhead trout, sturgeon, and shad. Some small streams are important producers of salmon and trout even though they may intermittently dry.

Many physical, chemical, and biological conditions affect fish life—oxygen, carbon dioxide, minerals, alkalinity, food, shade, temperature, drought, and flood. Many kinds of fish, especially salmon and trout, require clean, cool water with adequate levels of dissolved oxygen and mineral nutrients. The gravelly stretches and riffles are of special importance for reproduction and food production, and these need to be relatively free of sediment. Natural reproduction is more efficient and desirable than expensive and less effective planting of hatchery-reared fish.

Food for trout and young salmon is supplied from both land and water, about 10 percent from the former and 90 percent by the water itself. A myriad of insect larvae of many sizes, shapes, and varieties that cling to objects under water are the dominant food. Waters that drain soils from forests and ranges are rich in this insect life. Also fed upon are crayfish, small snails, clams, small fish, and other life forms.

The fisheries can be materially affected by forestry and range practices. In general, the same factors that are involved in watershed protection covered in the first section of this chapter pertain to fish.

As noted, surface erosion and mass soil movement perhaps have the greatest influence on both the fish and their habitat. The resulting debris and sediments block streams and smother spawning beds, fish eggs, and young fish. The quality of the water is lowered by the addition of soil particles, ash from burning, and organic material. When the latter decomposes it consumes the oxygen in the water and releases carbon dioxide and other harmful gases; this can kill fish. The effects that timber cutting and grazing have on water yield may be damaging at times. Less vegetal cover causes faster runoff, higher peak discharges, more erosion, and lower stream flows during the late dry season. The removal of streamside shade can raise water temperatures to lethal levels for fish; this puts portions of the stream out of production and creates thermal barriers for passage of resident and migrating fish.

It was stated earlier in this chapter that by far the greatest potential for watershed damage is from roads. This is equally true for the fisheries resource. The major causes of damage to fish and fish habitat from roads are:

1. Roads located too close to streams.
2. Siltation from unstabilized slopes and road damage.
3. Landslips triggered by poorly located, constructed, or maintained roads.
4. Removal or disturbance of too much tree and other vegetative cover along streams, causing higher water temperatures, bank erosion, and diminished food supply.

5. Disturbance of beds and banks of streams during construction of crossings—bridges, culverts, and fords.
6. Improperly installed or maintained culverts that inhibit or prevent fish passage.

Chapter VII on Forest Roads also discusses standards and practices for protection of watersheds and fisheries.

Terrestrial Wildlife

Terrestrial wildlife constitute another valuable public resource that is a source of beauty, biological study, recreation, and income. Animals also contribute to the natural woodland balance; e.g., birds and mammals that prey on insects and rodents that are harmful to forest and range resources. As other resources are protected and managed so must wildlife be, in order to fully realize these benefits; they accrue to the forest owner and society alike.

A main element of wildlife management is vegetative habitat. It has most of the things wildlife need for living—food, cover, water, and living space. Each species eats specific foods, some vegetative and some animal, which in turn are derived directly or indirectly from plants. Vegetation and other natural features form the cover and ecological niches that protect animals while they feed, sleep, breed, play, and travel. All wildlife need water; it is obtained from surface sources, dew, snow, and succulent plants. The last habitat requirement is enough space to preclude overcrowding and too much competition.

A given habitat can only support a certain number of each species of wildlife. This carrying capacity of the habitat is related to the arrangement and availability of food, cover, and water. One good arrangement is where these components occur in close, mixed blocks with a lot of transitional edges between different types of vegetation (called edge effect). Many wildlife benefit from this because they commonly live on the edges, not the centers, of different types of cover. There are many types of wildlife habitat and each requires certain management to provide the greatest benefits to the animals it supports.

Each species resides in the biotic community (all the plants and animals together in the immediate area) that best meet its needs, or in several communities. These communities are subject to slow successional changes because of weather, soil development, plant growth, and other factors. Resultingly, the plants and animals are replaced over time by other species that are better equipped to survive in the changed habitat. Natural succession can be disrupted by land-use disturbances, for example, burning, grazing, and timbering. Many wildlife species benefit from some disturbances that hold back plant succession to intermediate stages. However, some wildlife species need a stable or climax habitat (e.g., a mature forest) to survive.

The riparian habitat is perhaps the most productive and vital of all the plant communities for wildlife. Most species are very dependent upon this cover and are sensitive to its disturbance. Hardwoods (particularly oak) and brush in combination also rank high as wildlife habitat. This is followed

by mixed types containing conifers, hardwoods, and brush. A few animals are peculiar to just pure plant types like conifers and brush alone.

Wildlife Management

Wildlife are managed by skillful treatment of the animal populations and the habitat. The tools used to manage populations include regulation of hunting and trapping, refuges, stocking with native or exotic species, habitat protection or improvement, and predator control. The regulation of hunting and trapping must be flexible and based on biological principles in order to be effectively applied by wildlife managers. The habitat approach is the real key to wildlife management, because without a suitable environment animal numbers and health cannot be maintained regardless of other methods.

Various land-uses change the cover and habitat for wildlife. The effects can be either good or not, it all depends on how it is done. Woodland that is intensively grazed is usually a poor place for most wildlife. Overgrazing and trampling destroy the more desirable forage plants and young trees. Thus the habitat becomes deteriorated to the point that wild animal numbers and even species are reduced.

While selective, controlled burning may improve some habitats, indiscriminate burning and wildfire may cause damage. Intense fires can burn animals and seriously impair the habitat by reducing cover for shelter and decreasing food and water supplies.

Timber harvesting can have a dramatic impact on wildlife habitat. If correctly planned and executed, it can serve wildlife purposes. Forest practices can be used to produce or insure diversity and stability of both plant and animal communities, or to provide better habitat for selected animals. These practices offer the most practicable broadscale approach to alteration of the forest habitat that is available to wildlife managers to achieve their goals. However, no single forestry practice or system is a panacea for wildlife, and management must be both appropriate and flexible to accomplish the desired overall results. Some forest practices to consider for protection and enhancement of the wildlife resource are:

1. Choose a cutting system that favors variety of habitat. Group selection cutting, small clearcuts that are well spaced, and fairly heavy single-tree harvesting result in diversity of wildlife habitat.
2. Retain streamside cover and protect meadows.
3. Harvest trees in ways that create most edge effect.
4. Reserve some patches of brush within or adjoining the forest for edge effect and habitat diversity.
5. Save live trees with hollow trunks and limbs for such animals as raccoon, opossum, squirrel, chipmunk, wood duck, owl, sparrow hawk, woodpecker, and insect-eating and song birds of various kinds. Hollow windfalls also are homes for some animals.
6. Save some hardwoods, especially oaks, as a source of food for many birds and mammals. Black oak acorns (mast) alone provide feed for 45 species, including woodpeckers, pigeons, jays, raccoons, squirrels, wild pig, and deer.

7. Keep snags that are not hazardous for fire and safety reasons, or any snag that contains nesting birds of valuable species, e.g., eagle, osprey. Snags house countless species of birds, mammals, and insects that decompose wood and provide food for wildlife.

8. Protect and develop water sources for wildlife.

Biologists of the Department of Fish and Game, U. S. Fish and Wildlife Service, U. C. Cooperative Extension, and the U. S. Forest Service can provide literature and advice on wildlife protection and enhancement. In fact, the first agency will help forest owners assess their properties from the standpoint of managing them intensively for wildlife. Some private wildlife consultants are also available in California.

Species Protection

Most native wildlife were abundant during the early days, but this has changed mainly because of land development and use, and to some extent by hunting and trapping. However, some species that fell to a low level due to humans have recovered because of various wildlife protection measures. On the other hand, some species that once were widespread now have much smaller populations and ranges, and a few are extinct. Elk, antelope, bighorn sheep, marten, fisher, wolverine, some fox, and some raptors have become fewer. Contrary to popular belief, such predators as coyotes and raptors are not necessarily bad and shouldn't be exterminated, but they may need some control where they cause damage to domestic animals.

To prevent a virtual disappearance of declining wildlife, both the federal and state governments have officially recognized some species within California as endangered, threatened, or rare. Protection programs for these species have been jointly developed by the public agencies concerned with help from private wildlife organizations. Laws, regulations, and environmental impact processes are utilized to give special attention to the preservation of these critical species, and their habitat. At this time of writing, the critical species associated with California's forest and associated lands are as follows.

<i>Endangered</i>	<i>Threatened</i>	<i>Rare</i>
California condor	Lahonton cutthroat	Bighorn sheep
Bald eagle	trout	Wolverine
Peregrine falcon	Painte cutthroat	Siskiyou Mt.
San Joaquin kit fox	trout	salamander
Owens River pupfish		Kern Canyon
		salamander
		Modoc sucker
		Rough sculpin

Less critical than the above, yet of real concern, are unique species like prairie falcon, spotted owl, tule elk, Little Kern golden trout, and redband trout. Certain raptors—golden eagle, hawks, owls—and waterfowl deserve special consideration also.

Forest Recreation

Recreation is the last, but certainly not the least important, of the various forest uses covered in this handbook. As its name implies, recreation means to recreate, revive, divert, amuse, and gratify the human body, mind, and spirit. To fill these needs there is a broad range of recreational opportunities within and near forests. They encompass sight-seeing, resting, picnicking, camping, hiking, photography, bird-watching, trail riding, snow sports, boating, swimming, fishing, hunting, berry-picking, second homes, and studying geology, botany, zoology, archeology, and history.

Parks, forests, and other lands in public ownership provide most of the outdoor recreation, and they contain fairly elaborate facilities to handle the expanding use. Some of these public lands, like parks and wilderness areas, are dedicated to recreational use of one kind or another while others are based on the multiple-use concept. In most cases, timber and range management can be compatible with recreation. Industrial tree farmers are increasingly allowing public use of their lands and some have even provided facilities for that purpose on a free or fee basis. Other forest owners may wish to consider implementing a recreational program, or at least taking steps to conserve aesthetic or recreational values for personal, moral, or social reasons.

Protection of Recreational Resources

Where recreation of one or more kinds is to be integrated into overall property management certain steps are necessary to protect and even improve natural features. The treatments may be necessary only on part of the forest. Some of these entail costs, but this may be at least partially offset by economic returns and pride of accomplishment.

The basic drawing power of wildlands for recreation is the natural landscape and its varying characteristics due to terrain, vegetation, water bodies, topographic features, and cultural past. The impressions are mostly visual, but sound, smell, and touch also play an important part. Visual perception may be broad, sweeping or panoramic vistas or localized on special features of contained settings. The effects may be ephemeral, changing by weather, season, light on water, and animal occupancy. Variety and deviations add to the richness of the landscape. Another main attraction of forests is that in this pleasant setting there is something to do that can be hardly done elsewhere.

How we manage timberlands has a big effect on the visual resource and the potential recreational activities. Some measures that a tree farmer should consider are:

1. Determine where special precautions are justified—along main roads and trails used by the public, at vista points, adjacent to streams and water bodies, around meadows, at known or recognized Indian campsites and other archeological and historical sites, and near habitation, parks, and campgrounds.
2. Cut trees conservatively in high-priority areas, removing dangerous trees and snags that may be a liability or safety hazard. Where clear-cuts are made in areas visible to forest users keep them small, irregular in shape, and well spaced.

3. Make special cuttings to improve vistas along main roads, trails, and places where people congregate.
4. Cut trees and vegetation near road curves to open the view and in the interest of safety.
5. Carefully harvest the important areas to avoid unnecessary damage to residual trees, other vegetation, soil, and valuable features.
6. Abate slash hazards and clean up debris in high-use areas by crushing, chipping, or careful burning. Fuelbreaks along main roads will reduce fire risk and hazard and facilitate control of wildfires. Control public access to active logging and hazardous fire areas.
7. Adopt and post rules about public use, road and trail travel, trail bikes, snowmobiles, fire prevention, property and resource damage, firearms, and sanitation.
8. Protect and enhance fish and wildlife habitat as explained earlier in this chapter.
9. Widen roads near streams and other key places to provide parking for recreationists and people wanting to fish or hunt.

Recreation Programs

Besides protection of recreational resources, forest owners may wish to adopt public use programs. The minimum that could be done is to open the forest to free use for sight-seeing by road or trail, fishing, hunting, berry-picking, and unimproved picnicking or camping. To control these activities some landowners post informational signs or require permits subject to regulations. Use without some logical controls is not advisable, because continual free access may give prescriptive rights to the public, meaning that the owner would have difficulty in keeping people off the property once that right had been established.

In situations where recreational values and use are high, tree farmers may choose to implement more intensive recreation programs. These involve considerable expenditures, management time, and risk so charges would be in order. There are a number of different projects that one could undertake. All of them require special knowledge, skill, and experience to put into effect and to stay within resource and legal requirements.

One paying recreational program that may not require too much investment or expenditures is the use of the property for hunting. The acreage has to be productive and substantial enough to support wildlife in sufficient numbers to attract hunters. The size of area needed varies by species and the habitat that is available.

Two methods are used to charge for the service. One is to collect a daily fee per hunter, and the other is to lease exclusive access or hunting rights on the property to a club. The latter method is common for large properties, especially for the hunting of game species, e.g., deer and quail. All kinds of arrangements are possible to accommodate unattached hunters, e.g., rustic campgrounds, simple cabins, and more elaborate facilities where food and lodging services are provided by the owner or a concessionaire. Clubs may provide their own facilities under the hunting lease.

It is a good idea to have a wildlife improvement and management plan where intensive hunting will take place. To initiate such a program, one should have the property examined by a qualified biologist. Game managers of the Department of Fish and Game are helpful in making such assessments, and the services of private wildlife consultants are likewise available on a fee basis. These experts can estimate existing wildlife populations, appraise the habitat, and recommend positive steps to improve the property for hunting.

Sporting activities similar to hunting may be possible with respect to fishing. Here it may be just charging a modest fee to allow a person to cross the property to get to native fishing waters. Fish ponds are another possibility, but this would require technical assistance and capital expenditures. See Water Utilization section in this chapter for state regulations on dams.

The biggest recreational use of forest property is for outings that involve diverse activities. Forests along highways are especially adaptable for picnicking areas and campgrounds. Places near streams, lakes, or other natural features are most popular. In addition to accessibility and location, the more important factors are water, sanitation, and space.

As the public recreational agencies have learned after many years of experience, the development and operation of campgrounds take careful planning and administration. Facilities have to be installed to accommodate the camper—camp roads and trails, signs, parking, camp sites, fireplaces, tables, water systems, garbage disposal, and sanitation. The last three are regulated by law, usually by the county health department. The development and maintenance costs can be considerable so the whole operation should be well planned to avoid costly mistakes and pitfalls. Fortunately, standard designs and specifications have been formulated through the years and these are available at least for inspection at National Forests, State Forests, National Parks, State Parks, and similar agencies. Visits to nearby campgrounds also would reveal much information of value.

How to charge for use of developed recreation areas is another matter to investigate. Two general methods are employed—manual and mechanical. The former is handled by a person collecting fees at an entrance gate or doing daily patrols. A cheaper and more flexible way is by self-registration. The camper obtains a combination registration form and envelope from a central point, fills in the necessary information, and deposits it with the fee into a strong-box. Part of the registration form is posted at the chosen campsite.

Mechanical collections can be made by coin-operated gates, ticket-vending machines, or parking meters. The first two require electricity. Mechanical systems are not foolproof, they require maintenance and repair and are subject to vandalism.

Precautionary Measures

In addition to the many considerations explained above, there are a number of other important points that a forest owner should fully realize when embarking upon a recreation program, especially one of intensive character. The exposure to liability is definitely increased. This requires

keeping the property and facilities in a safe condition. Felling or pruning of unsafe trees within campgrounds is a good practice. Insurance coverage should be sought to supplement prevention measures.

An income-producing recreation program affects the owner's property taxes. As described in Chapter IV, commercial timber is ordinarily covered by the yield tax law, but another use, such as recreation, will increase the basic land tax. The effect of this added cost has to be recognized in making decisions on recreational developments.

As any other use, recreation can have an impact on forest and associated values. Overuse compacts soils, causes erosion, destroys vegetation, reduces wildlife, deteriorates beauty, and pollutes waters. The cutting of firewood around campgrounds can be harmful unless regulated. Therefore, recreation has to be managed in a way that the environment is not adversely affected. Some forms of recreation in the forest, such as motorcycle and jeep travel, have to be rigidly controlled. An ever-present danger is wildfire, so slash and other hazards in or near public areas must be abated, campfires contained by stoves and fireplaces, and rules adopted on fire use and smoking.

Forests can continue to be the most important force in outdoor recreation, providing many and varied opportunities for a vast number of people, as well as providing other goods and services. It is all a question of balancing the multiple uses that forests offer so that no values are seriously impaired. As repeatedly stated in this handbook, this takes good planning and management.

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Terminology in Forestry *

Advance Growth. (or Reproduction). Young trees that have become established naturally before harvests are made.

Adventitious Bud. One that develops on any part of a stem, leaf, or root outside the usual order of time or position, and lacks vascular connection to the pith.

Afforestation. Establishment of a tree crop on an area from which it has always or very long been absent. See also Forestation and Reforestation.

Age Class. One of the intervals, commonly 10 years, into which the age range of trees (and sometimes other vegetation) is divided for classification or use.

All-Aged. Of a forest, crop, or stand that contains trees of all or most age classes. Also called Uneven-Aged. See also Even-Aged.

Allowable Cut. Amount of forest produce that may be harvested, annually or periodically, from a specified area over a stated period, in accordance with the objects of management.

Aneroid. Portable barometer used in the field to determine differences in ground elevation.

Animal Unit Month. Amount of feed necessary to maintain one mature cow (or five sheep) properly for 30 days.

Annual (Growth) Ring. Growth layer of wood produced in one year.

Aquifer. A deep rock or geological horizon holding water or permitting its passage.

Area Ignition. Simultaneous or quick successive firing of all parts of an area to be burned in order to produce a fast, hot spread, and clean burn. See also Controlled Burning and Prescribed Burning.

Aspect. Direction or exposure of terrain towards which a slope faces.

Azimuth. The horizontal angle or bearing of a point, measured clockwise from true north. The azimuth plus 180 degrees is termed the back azimuth.

Back Cut. In felling, the cut made on the backside of the tree, after, and a few inches higher than the front undercut.

Backfire. Fire set along the inner edge of a control line to consume the fuel in the path of a wildfire, or change the direction of the fire's convection column.

Backpack Pump. A portable sprayer with hand-pump fed from a tank fitted with backpack straps, used in fire control and pesticide applications.

Barber's Chair. High slab-like splinters, resembling a chair-back, left standing on a stump above the undercut as a result of faulty felling or heavy lean of a tree.

Bare-Root Stock. Planting stock with naked roots. See also Container Stock.

Bark Gauge. Instrument for measuring the bark thickness of live trees in making growth studies.

Barron Tool. Long-handled combination hoe and rake used in building fire line in light fuels. See also McLeod Tool and Pulaski Tool.

Basal Area. Cross-sectional area of a tree stem, including bark, generally at breast height.

Bench Mark. Marked point on the ground whose elevation has been determined and officially recorded.

Biltmore Stick. Graduated stick used to measure tree diameters. See also Cruiser Stick.

* Adapted from Terminology of Forest Science, Technology, Practice and Products. Society of American Foresters, 1971 (amended 1977) and other various sources.

Block. (1) a pulley used in cable logging, (2) a forest management unit or logging area (see also *Compartment* and *Working Circle*).

Blue-Stain. Common form of fungal stain of sapwood and light-colored wood of improperly stored logs and lumber, principally the pines.

Board Foot. Nominally (not exactly) a board 1 in. x 12 in. x 1 ft., or equivalent, used in measuring logs and lumber.

Bole. Trunk of a tree past the pole stage.

Bolt. Short piece of round or split wood cut for fuelwood, shakes, shingles, veneer, etc. Also called *billet* or *block*.

Borrow Pit. An excavation away from the construction site to provide road material.

Broadcast. (1) Burning—controlled fire over an entire designated area. (2) Seeding—sowing seed more or less evenly over a whole area.

Broadleaved. Trees or shrubs of a botanical group, usually having conventional leaves, in contrast to needle-leaved, cone-bearing trees (*Conifers*). Broadleaved trees are also called *Hardwoods*.

Buck. To saw felled trees into shorter lengths.

Burl. Protuberance of abnormal growth on a tree trunk composed of a mass of buds, some of which may sprout, particularly the coast redwood.

Butt. Base of a tree, or larger end of a log.

Butt Rigging. Various combinations of swivels, shackles, links, or straps to permit connections between cable lines or logging chokers.

Cambium. Layer of cells just beneath the bark of woody plants from which new wood and bark cells develop.

Canker. Definite, relatively localized necrotic gall with lesion, primarily of the bark and cambium of trees and shrubs caused by pests. See also *Call*.

Canopy. More or less continuous cover of branches and foliage formed collectively by the crowns of adjacent trees or other woody growth.

Cant Hook. Stout wooden lever, fitted with a gripping lip at the end and a hinged hook, used in turning logs and cants. See also *Peavey*.

Carrying Capacity. Maximum stocking of animals on a given range or wildlife area without diminishing the forage crop in either amount or quality, or the value of related resources. The same concept can be applied to recreation use.

Catface. Defect on the surface of a tree or log resulting from a fire or other wound where healing has not re-established the normal cross section. See also *Fire Scar* and *Goosepin*.

Cellulose. Carbohydrate that is the principal constituent of wood and forms the framework of cells.

Chain. Length measure used in land surveying divided into 100 links, and equal to 66 feet.

Check. Lengthwise separation of wood, which usually extends across annual rings, commonly resulting from drying stresses.

Cheese Block. Wedge-shaped moveable wedge-block set on a bunk of a truck or railroad car to hold logs in place. Also called *chock*.

Choker. A noose of wire rope by which a log is pulled or lifted in yarding.

Clearcutting. Removal of the entire standing tree crop, sometimes done in patches.

Climax. Culminating stage in plant succession for a given environment, the vegetation being conceived as having reached a highly stable condition. See also *Succession*.

Clinometer. Simple instrument for measuring angles of elevation or depression. See also Hypsometer.

Codominant. One main crown class of trees with their tops in the upper canopy but lower than the dominant trees. See also Dominant, Intermediate, and Suppressed.

Cold-Trail. To build a Fire Line right along the edge of a wildfire when it is burning slowly or very little, taking advantage of favorable burning conditions.

Compartment. Unit of a forest designated as a basis for management, commonly a subdivision of a Block or Working Circle in a large forest.

Compression Wood. Abnormally dense wood that often forms on the lower side of branches and of leaning trunks of conifers.

Conifer. Tree that bears cones and in most cases have needle or scale-like leaves. Also collectively called Softwoods. See also Broadleaved and Hardwoods.

Conk. Projecting fruit-body of a wood-destroying fungus.

Container Stock. Young trees grown in pots, tubes, or other receptacles. See also Bare-Root Stock.

Controlled Burning. Planned application of fire to natural fuels, including brush and slash, with intent to confine it to a predetermined area. See also Area Ignition, Light Burning, and Prescribed Burning.

Coppice Forest. Forest originating from sprouts or root suckers.

Cord. Measure of pulpwood, roundwood, or fuelwood representing a stack 4 ft. x 4 ft. x 8 ft. or 128 cubic ft. See also Tier.

Crook. Defect in logs, poles, or piling, consisting of an abrupt curvature. See also Sweep.

Crown. Upper part of a tree or other woody plant, carrying the main branch system and foliage.

Crown Fire. Intense forest fire burning and spreading in the crown of trees.

Cruise. Survey to determine the kind, quantity, and quality of timber on an area, commonly including the collection of topographic, logging, and other pertinent data.

Cruiser Stick. Graduated stick to measure diameter and heights of trees and to occasionally scale logs. See also Biltmore Stick, and Scale.

Cull. 1) Trees, logs, or lumber of merchantable size rejected because of defect(s); 2) Deduction from gross volume of trees or logs to adjust for defect(s).

Cunt. Measure of solid wood content equal to 100 cu. ft.

Cutting Cycle. Planned, recurring lapse of time between successive cuttings under the selection system, normally a stated proportion of the rotation age.

Damping Off. Rotting of seedlings, before or soon after emergence, by soil fungi attacking at ground level.

Deciduous. Of perennial plants that are normally leafless for some time of the year.

Decay. Decomposition of wood by fungi and other micro-organisms, resulting in softening, progressive loss of strength and weight, and often changes of texture and color. Also called dote or rot.

Deck. Pile or stack of logs; if stored they form a cold deck, otherwise a (hot) deck.

Defect. Any irregularity or imperfection in a tree, log, or wood product that reduces the soundness, durability, strength, or utility.

- Deflection.* Amount of sag in a cable used in cable logging; the greater the deflection the greater the load the cable can support. See also Skyline.
- Degrade.* Any process that lowers the value of timber and forest products.
- Density.* 1) Weight per unit volume. 2) Number of stocking of trees (stand) or animals per unit area at a given time. See also Stocking.
- Diameter Breast High (DBH).* Point at which diameters of trees are usually measured, 4½ ft. above the average ground level.
- Diameter Class.* Any of the intervals (usually two-inch) into which a range of diameters of trees or logs may be divided for classification and use.
- Diameter Limit.* Smallest, and occasionally the largest, size to which trees or logs are to be cut, measured, or used.
- Diameter Tape.* Tape measure specially graduated so that the diameter may be read directly when the tape is placed around a tree or log.
- Dieback.* Progressive dying from the end of any part of a plant.
- Dioecious.* Having male and female flowers on different plants. See also Monoecious.
- Dominant.* One main crown class of trees with their tops in the uppermost layers of the canopy. See also Codominant, Intermediate and Suppressed.
- Donkey.* Portable power unit (originally a steam engine), usually mounted on skids, and equipped with winch drums and cables, used in skidding and loading logs.
- Durability.* Capacity of wood to last in service, with particular reference to decay.
- Ecology.* Study of plants and animals in relation to their environment.
- Elite Tree.* One that has been shown by testing to be capable of producing progeny with superior qualities. See also Plus Tree and Tree Seed Orchard.
- Environment.* All the living organisms and related factors of a site.
- Epidemic.* Of populations of living things, e.g., pests, that build up, often rapidly, to highly abnormal and generally injurious levels, in contrast to endemic or normal populations.
- Evapo-Transpiration.* Conversion of water by plants into vapor that is released to the atmosphere. See also Interception and Transpiration.
- Even-Aged.* Of a forest composed of no, or relatively small, differences in age. See also All-Aged and Uneven-Aged.
- Faller.* A person who fells trees, also called chopper in California redwood region.
- Field (Moisture) Capacity.* Water that a soil in place retains, when drainage has become negligible. See also Wilting Point.
- Financial Rotation.* A rotation age of a forest determined solely by financial considerations. See also Rotation Age.
- Firebreak.* Any natural or constructed barrier utilized to segregate, stop and control the spread of fire, or to provide a control line from which to work. See also Fire Line and Fuelbreak.
- Fire Hazard.* Fuel complex, defined by volume, type, condition, arrangement, and location, that determines the degree of both of ease of ignition and of fire suppression difficulty. See also Fire Risk.
- Fire Line.* Control line from which flammable materials have been removed by cutting, scraping, or digging down to mineral soil. Also called fire trail. See also Cold-Trail and Firebreak.
- Fire Retardant.* Any substance that by chemical or physical action reduces flammability of forest fuels, usually added to water.

Fire Risk. Chance of a fire starting, as affected by nature and incidence of causative agencies, e.g., travellers, lightning. See also Fire Hazard.

Fire Scar. A fresh or healing injury of the cambium of a woody plant, caused by fire. See also Catface and Goosepin.

Forb. Any herbaceous plant that is neither a grass nor at all like one. See also Herb.

Forest. Plant community predominantly of trees and other woody vegetation, growing more or less close together.

Forestation. Establishment of a forest, naturally or artificially, on an area, whether previously carrying a forest or not. See also Afforestation and Reforestation.

Forest Management. Practical application of economic, scientific, and social principles to the administration and working of a forest.

Forestry. Science, art, and practice of managing and using for human benefit the natural resources that occur on and in association with forest lands.

Forest Type. Category of forest defined by its vegetation, particularly its species composition. See also Type Map.

Form Class (Factor, Quotient). Any of the intervals into which a numerical expression of the taper of a tree or log may be divided for classification or use. See also Taper.

Forty. Land subdivision unit nominally a 40-acre square.

Frass. Waste of insect feeding in wood.

Froe. Long wedge-shaped blade for splitting wood into shingles, shakes, and other split products.

Fuelbreak. Strip from which forest fuels and woody vegetation have been reduced by thinning, pruning, or removal well ahead of time to slow down or stop a wildfire, or to provide a control line from which to work. See also Firebreak.

Fuel Moisture Stick. Special wooden stick of known dry weight that is used to determine changes in moisture content and flammability of forest fuels.

Gall. Pronounced excrescence of greatly modified tissue structure in plants caused by insects or other organisms. See also Canker.

Gill Poke. Originally a horizontal stiff-arm or swinging boom used to poke logs off railroad cars at a log pond; also a tree run over and damaged during skidding usually leaning and thereby being a fire and safety hazard.

Gin Pole. Simple hoisting and loading device, consisting of a block and tackle suspended from near the top of a single pole or mast.

Goosepin. Large hollow at base of tree, particularly in old-growth redwoods, caused by fire and rot, so named because pioneers used such trees and stumps for pens for geese, and other domestic animals.

Grapple. Powered mechanical arms on a tractor, the skidding device, or loading machine to bunch and hold logs during transport or movement.

Growing Stock. All the trees growing in a forest or in a specified part of it, generally expressed in terms of number or volume. See also Normal Growing Stock.

Gun(ning) Stick. A hinged two-legged device inserted into an undercut of a large tree (e.g., old growth redwood) to point direction of fall.

Gy(p)po. Contractor who fells or yards timber on a piece-rate basis.

Habitat. Abode, natural or otherwise, of a plant or animal considered particularly in relation to nutrient supplies and other environmental factors affecting it.

Hardening Off. Preparing seedlings or rooted cutting in a nursery for transplanting or planting out by gradually reducing water, shade, and shelter, and thus making them more resistant to desiccation and temperature changes.

Hardwood. See Broadleaved.

Haul-Back (Line). Cable, lighter than associated cables, that travels between the power unit and a block near the logs being transported, to return the main line and chokers for the next load (turn).

Heartwood. Inner layers of wood which have ceased to contain living cells and in which the reserve materials have been removed or converted into more durable substances. See also Sapwood.

Heel-In. To store young plants before transplanting or planting out, by burying the roots in a trench.

Height Class. Any of the intervals (in feet or number of logs) into which tree heights may be divided for classification or use.

Herb. Any seed-producing plant that does not develop persistent woody tissue above the ground, including both forbs and grasses. See also Forb.

High-Lead (Cable) Logging. Method of powered cable logging in which the main block is fastened high on a spar tree (or equivalent) to enable the front end of the logs being skidded to be lifted clear of the ground.

Herbicide. Any chemical or other preparation used to control unwanted vegetation. Also called phytocide, silvicide. See also Pesticide.

Hook Tender. Foreman of a skidding or yarding crew.

Humus. More or less decomposed (plant and animal) residues in the soil, duff and litter excluded.

Hypsometer. Any instrument for measuring the heights of standing trees. See also Clinometer.

Increment. Increase during stated period of time in girth, diameter, basal area, area, height, volume, quality, biomass, or value of individual trees or stands.

Increment Borer. Auger-like instrument with hollow bit and an extractor, used mainly to extract a thin radial cylinder of wood from trees having annual growth rings, so as to determine increment and age; but also, in wood preservation, the depth of penetration of the preservative.

Indicator Plant. Any plant that, by its presence, frequency, or vigor, indicates any particular property of the site.

Interception. That part of the precipitation that, in the course of contact with the vegetation, evaporates and so never reaches the ground. See also Evapo-Transpiration and Transpiration.

Intermediate (Crown Class). One main crown class of trees with their tops in the middle canopy. See also Dominant, Codominant, and Suppressed.

Intolerance. Incapacity of a tree to develop and grow in the shade of and in competition with other trees. See also Tolerance.

Jammer. Light-weight, two-drum winch with a wooden spar, generally mounted on a vehicle, which is used for both skidding and loading.

Kerf. Narrow slot cut by a saw in advancing through wood.

Landing. Any place where round timber is assembled for further transport, usually in the woods.

Larva. Early immature form of insect between the egg and adult stage. See also Pupa.

Leave Tree. Tree (usually designated to be) left standing in an area where it would otherwise be felled. Also called residual tree.

Light Burning. Periodic broadcast burning to prevent accumulation of hazardous forest fuels. See also Controlled Burning and Prescribed Burning.

Lignin. Non-carbohydrate, structural constituent of wood and some other plant tissues, which encrusts the cell walls and cements the cells together.

Limb. To sever branches from logs or a felled tree. See also Lop.

Log. Any useable section of the bole, or of the thicker branches, of a felled tree, after limbing and cross-cutting; e.g. a sawlog. Also to harvest timber. See also Peeler (Log) and Sawlog.

Logging. Felling and harvesting of timber, particularly as logs.

Logging Arch. Stout, arched, steel frame mounted on wheels or tracks, for use with a tractor in skidding, one end of the log(s) being slung beneath the arch.

Log Rules. Tables showing the estimated or calculated amount of board feet in logs of given diameter and length. See also Scale.

Long Butt. A section of the lower end of a felled tree, cut off to remove and discard cull material.

Lop. To sever, and sometimes scatter, branches from a felled tree, so that the resulting slash will lie close to the ground. See also Limb.

Magnetic Declination. Angle between true and magnetic north at any point.

Management (or Working) Plan. Written document aiming at continuity of policy and action, and both prescribing and controlling basic operations in a forest over a period of years.

Marking Timber. Act of selecting and designating trees to be cut or left for harvesting, usually done by blaze or paint spray.

Mast. Fruit of oak and other trees, particularly where considered food for wildlife and livestock.

McLeod Tool. Short-handled combination hoe, or cutting tool and rake, with or without removable blades, used in building fire line. See also Barron Tool and Pulaski Tool.

Mensuration. That branch of forestry concerned with the determination of the dimensions, form, increment, and age of trees, individually or collectively, and of their products.

Milacre. An area of one thousandth of an acre (6.6 ft. x 6.6 ft.) commonly used in vegetation and regeneration studies. See also Quadrat.

Molly Hogan. Circle of a twisted strand of wire rope used for temporary linking of eyesplices of cable, especially Straw Line or accessory equipment. Also called molle.

Monoecious. Having male and female flowers on the same plant. See also Dioecious.

Mopping Up. Making a fire safe after it has been controlled, especially concentrating the work near control lines.

Mortality. The loss to a population of trees, other plants, and animals from all lethal causes.

Multiple Use. Management practice to wisely use without impairment, two or more resources associated with forest and related lands.

Normal Growing Stock. Growing stock found in an ideal forest, its attributes including optimum stocking, volume, and yield relative to objects of management. See also Growing Stock.

Overrun. The excess of the amount of a conversion process (e.g., lumber sawing) over the estimated volume or log scale, usually expressed as a percentage. See also *Underrun*.

Peavey. Stout wooden lever, fitted with a spike at the end, and a hinged hook, used in handling and turning logs. See also *Cant Hook*.

Peeler (Log). Log considered suitable in size and quality for producing rotary-cut veneer. Also called *veneer log*.

Pesticide. Any chemical or other preparation used to control populations of injurious organisms, particularly animal. Also *insecticide*, *rodenticide*, etc. See also *Herbicide*.

Phreatophyte. Plant, usually riparian, that uses large amounts of water from underground, or nearby water bodies, and is more or less independent of precipitation.

Pitch (Resin) Pocket. Well-defined, lens-shaped opening between or within annual rings of conifer wood, usually containing pitch, either solid or liquid, and occasionally bark.

Piling. Collective term for piles—long, round timbers that are driven deep into the ground to support structures.

Piling and Burning. Piling logging slash by hand or machine and subsequently burning the individual piles.

Pith. Soft central core of the stem and some roots of trees and other plants.

Plantation. Forest crop or stand raised artificially, usually by planting.

Planting Stock. Seedlings, transplants, cuttings, and occasionally wild plants (wildlings) for use in planting.

Plus Tree. Tree judged, but not tested, to be unusually superior in genetic qualities. See also *Elite Tree* and *Tree Seed Orchard*.

Point Sampling. Forest sampling by variable sized plots, using prisms or other optical devices. Also called *prism sampling*.

Pole. 1) Young tree from 4 to 12 inches in diameter breast height, 2) Round timber of stated length ready for use without conversion (except peeling and preservation) for utility lines or construction.

Post. Round, split, or sawn length of timber used for fencing, pillars, and in construction.

Prescribed Burning. Controlled application of fire to wildland fuels, in either their natural or modified state, under such conditions of weather, fuel moisture, soil moisture, etc., as to allow the fire to be confined to a predetermined area and at the same time to produce results to meet planned objectives of management. See also *Area Ignition*, *Controlled Burning*, and *Light Burning*.

Pruning, Artificial. Considered removal, close to or flush with the stem, of side branches, live or dead, and of multiple leaders, from a standing tree for improvement of the tree or its products.

Psychrometer. Instrument consisting of two thermometers, one with a dry bulb and the other with a wet bulb, used to determine relative humidity.

Pulaski Tool. Combination axe and adz-like hoe used in fire line construction. See also *Barron Tool* and *McLeod Tool*.

Pulpwood. Cordwood or logs prepared primarily for manufacture into paper, fibreboard, or other wood pulp products.

Pupa. Advanced, but yet immature, generally immobile, insect stage between larva and adult. See also *Larva*.

Quadrat. Small, clearly demarcated, sample area of known size on which forestry and ecological observations are made. See also *Milacre*.

Quarter Corner. Land subdivision corner for a quarter of a section (160-acre unit) other than a section corner or the section center.

Range Management. Art and science of planning and directing the utilization of grazing land so as to secure sustained maximum production of livestock and forage, consistent with other uses and conserving natural resources.

Reforestation. Re-establishment of a tree crop on forest land. See also *Afforestation* and *Forestation*.

Regeneration. Renewal of a tree crop, whether by natural or artificial means, also the young crop itself.

Regulation. Manipulation of the Growing Stock so that it contains a proper proportion of young, middle-aged, and mature trees in order to obtain continuous production, or sustained yield.

Release. Freeing a tree or group of trees from immediate competition by cutting, or otherwise eliminating, growth that is overtopping or closely surrounding them.

Rigging. Cable, guy lines, blocks, and hooking equipment used for hauling and loading (logs).

Rotation (Age). Planned number of years between the formation or regeneration of a tree crop or stand and its final cutting at a specified stage of maturity. See also *Financial Rotation*.

Sapwood. Outer layers of wood which, in the growing tree, contain living cells and reserve materials, and generally lighter in color than Heartwood.

Sawlog. Log considered suitable in size and quality for producing sawn timber or lumber. See also *Log* and *Peeler (Log)*.

Scale. To measure cut timber and fuelwood, usually with a graduated (scale) stick, the contents of cut timber in terms of the log rule or measuring unit. See also *Log Rules*.

Schoolmarm. Coniferous tree with a forked or double trunk.

Second Growth. Loose term for young trees, left or grown since the first harvest. See also *Young Growth*.

Section. Standard subdivision of land used in official surveys, intended to be one mile square.

Seed-Tree Cutting. Removal in one cut of the mature timber from an area, save for a small number of seed-bearing trees left singly or in small groups.

Selection Cutting. Periodic removal of crop-sized trees, individually or in small groups, usually from an uneven-aged forest. Also called *selective cutting*.

Shake. 1) Lengthwise separation of wood, usually between and parallel to annual rings. 2) Thin section split from a Bolt used for roofing.

Shelterwood Cutting. Even-aged silvicultural system in which, in order to provide a source of seed and/or protection for regeneration, the old crop is removed in two or more successive stages.

Silvics. Study of the life history and general characteristics of forest trees and stands. See below.

Silviculture. Science and art of growing and tending forest crops, based on a knowledge of *Silvics*.

Sinker. Log heavier than water.

Site. Productive capacity of an area to produce forests or other vegetation, related to climatic, biotic, and soil factors. For forest crops, it is expressed by a site index

based on height of dominant trees in a stand at a certain age. Site indices are sometimes grouped into site classes.

Skidding. Loose term for hauling logs as developed originally from stump to a landing or roadside. Also called Yarding.

Skyline (Cable) Logging. Loose term for powered cable logging where the log is partly or wholly suspended in the air. See also Deflection.

Slash. Residue of trees left on the ground after logging, fire, or storm.

Snag. Standing dead tree or section thereof.

Softwoods. Pertaining to conifer trees. See also Broadleaved and Hardwoods.

Soil Horizon. Any layer of soil that may be distinguished from adjacent layers because it differs in physical, chemical, or biological characteristics, usually designated as A, B, and C horizons.

Soil Series. Basic unit of soil classification, consisting of soils that are alike in all major profile characteristics save texture of the surface layer, and having similar horizons. See also above.

Spar (-Tree). Tall standing tree, trimmed and topped, and generally braced with guy lines, near whose top cables and other rigging are hung in cable logging or loading. See also Tail Tree.

Spot Fire. Fire set outside of perimeter of main fire by flying sparks or embers.

Springboard. Short board or plank, its end (usually equipped with a metal lip) that is notched into the trunk, on which the faller stands when necessary to work at a level not reachable from the ground. Other boards termed staging are sometimes placed on springboards to build a working platform partly around large trees.

Springwood. More or less open and porous tissue marking the inner part of each annual ring, formed early in the growing season. See also Summerwood.

Spud. Hand tool for barking or peeling round timber.

Stand. 1) Community of trees possessing sufficient uniformity in composition, structure, age, arrangement, or condition to be distinguishable from adjacent forest communities to form a silvicultural or management unit. 2) Amount of timber on an area, generally expressed in volume per area.

Stand Table. Summary table showing Stocking or number of trees by species and diameter class for a given area.

Stem Analysis. Analysis of a complete tree (felled) stem by counting and measuring the annual growth rings on a series of cross sections taken in different heights, in order to determine its past rates of growth.

Stereo(scopic) Pair. Two aerial photographs with sufficient overlap and consequent duplication of detail, to make possible stereoscopic (three dimensional) examination of an object, or an area, common to both.

Stocking. Loose term for an amount of anything on a given area, particularly in relation to what is considered the optimum, used in forest, range, and wildlife management. See also Density (2).

Strap. Short length of cable with an eye spliced at each end for attaching blocks and other rigging to trees, stumps, etc.

Straw Line. Light wire rope used for moving logging cable and accessory equipment into positions.

Stumpage. 1) Standing timber itself or volume thereof. 2) Value of standing timber in terms of amount per unit (e.g., thousand bd. ft.).

Stump Scaling. Measurement of stump diameters to estimate volume of removed trees by using special or adjusted volume tables, frequently in case of timber trespass or cutting of unauthorized trees.

Succession. Gradual supplanting of one community of plants by another as the site changes with time. See also Climax.

Summerwood. Dense, fibrous outer portion of each annual ring, usually without conspicuous pores, formed late in the growing period, not necessarily in the summer. See also Springwood.

Suppressed (Crown Class). One main crown class of trees with their tops in the lower canopy, beneath the Dominant, Codominant, and Intermediate trees, and of poor vigor.

Sustained Yield. Yield that a forest can produce continuously at a given intensity of management, planned to achieve at the earliest practical time a balance between growth and cutting.

Sweep. Gradual bend in a tree, log, pole, or piling, considered as a defect. See also Crook.

Tail Tree. Spar Tree at outer end of a cable logging operation.

Tally Counter (or Whacker). Any device for recording numbers mechanically, e.g., in pacing or timber cruising.

Taper. Decrease in thickness, generally in terms of diameter, of a tree stem or log from the base upward. See also Form Class.

Thinning. Felling made in an immature crop or stand in order primarily to accelerate diameter increment but also, by suitable selection, to improve the average form of trees that remain, classically without permanently breaking the canopy.

Tier. Stack of fuelwood, pulpwood, or other material of a width equal to the length of the pieces, 4 ft. high x 8 ft. long. Also called rick. See also Cord.

Tight-Lining. Procedure in cable logging whereby the cables are tightened so as to 1) lift the load of logs as it is being yarded, such as in a running skyline system, or 2) move cable laterally from one location to an adjacent one after merely changing the location of the tail-block.

Timber. Broad term for standing trees, and certain products thereof.

Timber Stand Improvement (TSI). Loose term for thinning, pruning, and weeding a timber stand to improve the composition, structure, condition, and growth.

Tolerance. Capacity of a tree to develop and grow in the shade of and in competition with other trees. See also Intolerance.

Transpiration. Process by which water vapor passes from foliage of other parts of a living plant to the atmosphere. See also Interception and Evapo-Transpiration.

Transplant. Seedling after it has been lifted and replanted one or more times to another bed in a nursery.

Tree. Woody perennial plant, typically large and with a single well-defined stem carrying a more or less definite crown.

Tree Farm. Area, privately owned, dedicated by the owner to the production of timber crops.

Tree Seed Orchard. Plantation of trees, assumed or proven genetically to be superior, that is intensively protected and managed to improve the genetic quality of seed crops, and to obtain frequent, abundant, and easily harvestable seed. See also Elite Tree and Plus Tree.

Type Map. Map showing the distribution of various types of trees, other vegetation, soil, or site throughout a forest area. See also Forest Type.

- Undercut.* Deep notch cut into the base of a tree to govern the direction in which it is to fall and also to prevent butt splitting. See also Back Cut.
- Underrun.* Amount by which the conversion of logs into other products (e.g. lumber) is less than the estimated volume or log scale, usually expressed as a percentage. See also Overrun.
- Uneven-Aged.* Of a forest, crop, or stand, composed of intermingling trees that differ markedly in age. Also called All-aged. See also Even-aged.
- Virgin Forest.* Natural forest virtually uninfluenced by human activity, such as cutting. Also called old-growth forest.
- Volume Table.* Table showing, for one or more species, the average volume of trees of given sizes in a specified unit.
- Weed Tree.* Any tree, or tree species, of little or no economic value, more particularly when menacing more desirable timber trees. See also Wolf Tree.
- Widow-Maker.* Loose limb or piece of tree hanging in the crown of a tree that is dangerous to woody workers.
- Wilderness.* Undeveloped, uninhabited area established by a government in order to conserve its primeval character and influence for public enjoyment, under primitive conditions, in perpetuity.
- Wildland.* Uncultivated land, other than fallow, neglected or maintained for such purposes as wood or range-forage production, wildlife, recreation, protective watershed cover, wilderness.
- Wildlife Management.* Practical application of scientific and technical principles to wildlife populations and habitats so as to maintain them, essentially for recreational or scientific purposes.
- Wildling.* Naturally grown, in contrast to a nursery-raised seedling, sometimes used in forest planting.
- Wilting Point.* Soil moisture content at which plants will wilt beyond recovery. See also Field (Moisture) Capacity.
- Windfall.* Tree or trees thrown or their stems or parts broken off by wind. Also called blowdown in the collective sense.
- Witches Broom.* Abnormally bushy, local growth of parts of branch systems on woody plants, characterized by short intervals and excessive branching (brooming), generally caused by disease.
- Witness Tree.* One of several trees scribed and officially recorded to mark locations of a Section Corner or Quarter Corner. Also called bearing tree.
- Wolf Tree.* Vigorous tree generally of bad growth form with a dominantly wide crown, that occupies more growing space than its value warrants, so harming potentially better neighbors.
- Working Circle.* Unit of a large forest organized for a particular object and under one set of management plan prescriptions, and embodying one silvicultural system or a designated combination of systems.
- Yarding.* Moving timber from stump to a central point or landing by animal or motive power, usually followed by loading into a transport by trucks or other carriers to a conversion plant. Also called Skidding.
- Yield Table.* Table showing, usually for one tree species, the growth pattern of a normal or managed even-aged forest, derived from measurements at regular intervals covering its useful life, and including data on site, diameter, height, stocking, and volume.
- Young Growth.* Young trees left or grown since the first or subsequent harvest. See also Second-Growth and Virgin Forest.

Table A-1. Length; unit conversion factors, with appropriate values.

Inches	Links	Feet	Yards	Rods	Chains	Miles	Centimeters	Meters	Kilometers
1	0.12500 (1)	0.08333 (1)	0.02778 (1)	0.00227 (1)	0.00013 (1)	0.000016 (1)	2.54000 (25)	0.0254 (25)	0.000025 (25)
12	1.50000 (12)	1.00000 (12)	0.33333 (12)	0.02639 (12)	0.00215 (12)	0.00021 (12)	30.48000 (30)	3.04800 (30)	0.000305 (30)
36	4.50000 (36)	3.00000 (36)	1.00000 (36)	0.07896 (36)	0.00645 (36)	0.00064 (36)	91.44000 (91)	9.14400 (91)	0.000914 (91)
0.0007	0.00875 (7)	0.00292 (7)	0.00097 (7)	0.00008 (7)	0.000005 (7)	0.0000007 (7)	0.17500 (175)	0.0175 (175)	0.00000175 (175)
25.32 (40)	4.97600 (40)	3.28080 (40)	1.09060 (40)	0.14960 (40)	0.01240 (40)	0.00124 (40)	645.168 (645)	64.5168 (645)	0.0645168 (645)
268	25	26.1	3.5	1	0.25 (1)	0.00125 (1)	0.025 (1)	2.53827 (25)	0.00025 (25)
292	100	96	22	4	1 (1)	0.0125 (1)	0.1 (1)	20.1168 (20)	0.001168 (20)
		2,280	1,760	320	80	1	4	1,609.347 (1,609)	1.609347 (1,609)
		660	220	40	10	0.125 (1)	1	20.1168 (20)	0.201168 (20)
		3,281.52	1,093.61	156.826 (200)	49.7086 (50)	0.02125 (1)	4,976.00 (50)	1.000 (1)	0.001 (1)

¹ Surveyor's chain: the engineer's chain = 100 links of 1 foot each is not used.

² 1 nautical mile (termed "knot" as unit of velocity) = 1.1516 statute miles = 1.852 km = 1 minute of arc on the earth's surface at the Equator.

³ British units: 1 yard = 0.91430 m; 1 foot = 30.4797 cm; 1 inch = 2.53998 cm; 1 hand = 4 inches = 10.16 cm; 1 span = 2 inches = 5.08 cm; 1 cubit = 18 inches = 45.72 cm.

⁴ 1 millimeter = 0.1 cm; = 0.00107 inch = 0.00033 foot.

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Table A-2. Area or surface; unit conversion factors, with appropriate values.

Square inches	Square links	Square feet	Square yards	Square rods	Acres	Square centimeters	Square meters	Hectares	Square kilometers
1	0.015625 (16)	0.006944 (16)	-----	-----	-----	6.45160 (645)	0.000645 (645)	-----	-----
62,726 (63) 144	1	0.436 (16)	-----	0.0001 (16)	0.00001 (16)	404,687.2 (404)	0.0404687 (404)	-----	-----
1,296	20,901.8 (20)	1	0.111111 (11)	0.00027 (11)	0.000027 (11)	6,451.60 (645)	0.000645 (645)	-----	-----
0.750 (15)	-----	0.000750 (15)	-----	-----	-----	1	0.0001 (1)	-----	-----
1,545,967	24,710.7 (11)	10,763.97 (11)	1,195.99 (11)	0.03247 (11)	0.000247 (11)	10,000	1	0.0001 (1)	-----
	10,000	4,226	484	1	0.1	0.000156 (1,546)	404.687 (404)	0.0404687 (404)	0.000404687 (404)
		45,560	4,840	10	1	0.001562 (1,562)	4,046.87 (4,046)	0.404687 (404)	0.00404687 (404)
		27,478,400	3,907,600	5,400	840	1	2,500,000 (2,500)	250,000 (250)	2.500000 (250)
		67,638.7	11,979.9 (12,000)	24,710.7 (25)	2.47104 (25)	0.000067 (67)	10,000 (10,000)	1	0.01 (1)
		10,763,967	1,195,986	2,471.04 (250)	247.011 (250)	0.206104 (206)	1,000,000 (1,000)	100	1

¹ Area = 0.01 (sq.) and 0.0012 square inch.

² Square chain = 16 square rods.

³ 477 = 220 yds. 10 = 230 feet; 477 = 3.16 (1/10) the square.

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Table A.3. Volume and capacity; unit conversion factors and values.

United States measure of volume ¹		United States dry measure: quarts	United States apothecaries ² and liquid measure ³				Metric system		
Cubic inches	Cubic feet		Fluid ounces	Pints	Quarts	Gallons	Cubic centimeters ⁴	Liters ⁵	Cubic meters (Ceters)
1	0.000578	0.016887	0.354113 (15)	0.017716 (0.001 (15))	0.017716 (15)	0.004329	16.3872 (16)	0.016387 (0.001 (16))	-----
4,728	1	29.774 (29)	937.3	59.8442 (60)	29.5222 (30)	1.48609 (1.5)	28.317	28.317 (28)	0.028317 (0.001 (28))
1.80468 (1.8)	-----	-----	1	0.0625 (15)	0.03125 (15)	-----	29.5737 (30)	0.029573 (0.001 (30))	-----
26.875 (27)	-----	0.429687 (0.43)	16	1	0.5	0.125 (15)	473.179 (473)	0.473179 (0.47)	-----
57.75 (58)	0.003429 (0.003)	0.859375 (0.86)	32	2	1	0.25 (15)	946.359 (946)	0.946359 (0.94)	0.000946 (0.001)
291	0.133657 (0.13)	3.43747	128	8	4	1 (1)	3785.43 (3,800)	3.78543 (3.8)	0.003785 (0.001 (3.8))
0.001029 (0.001)	-----	0.000008	0.003814 (15)	0.002118 (15)	0.001057 (15)	-----	-----	0.001057 (0.001)	0.000001 (0.00001)
61.0239 (61)	0.003317	0.068104	33.8147 (34)	2.11342 (2)	1.05671 (1)	0.264179 (0.26)	1,000.027 (1,000)	1 (1)	0.001 (0.001)
-----	-----	-----	Bushels	-----	-----	-----	-----	-----	-----
85.306625 (85)	0.008885 (0.009)	1	0.03125 (15)	-----	1.36947 (1.37)	0.209019	1,101.21	1.101198 (1.1)	0.001101 (0.001)
3,156.42	1.24449 (1.24)	32	1	-----	37.3367 (37)	0.369177 (0.37)	30,729.29	30.72929 (30)	0.030729 (0.03)
-----	35.3147 (35)	908.079 (908)	26.3774	-----	1,056.64 (1,000)	284.179 (285)	1,000,000	999.979 (1,000)	1 (1)

¹ 1 cubic yard = 27 cubic feet = 21.66 bushels = 0.76457 m³ (eters).

² 1 gill = 7.21875 cubic inches = 4 fluid ounces = 0.25 [15] liquid quart = 0.125 [15] liquid pint = 0.0625 [15] liquid ounce = 0.118298 liter.

³ 1 cubic millimeter = 0.001 cm³ = 0.000061 cubic inch.

⁴ 1 liter = volume pure water at 4° C. and 760 mm pressure weighing 1 kg = 0.008378 bushel = 0.001368 cubic yard.

⁵ 1 cubic foot = 0.80356 bushel = 0.037037 cubic yard.

⁶ The British imperial gallon = 16 pounds distilled water at 62° F. (and barometer at 30 inches) = 277.418 cubic inches = 1.20094 U. S. gallons = 0.16054 cubic foot = 4.54596 liters.

⁷ 1 cubic centimeter = 0.000001 cubic meter.

⁸ The British imperial bushel = 8 British gallons = 219.342 cubic inches = 1.02208 United States bushels = 36.37 liters.

⁹ 1 m³ = 1.358 cubic yards.

Table A-4. Weight; unit conversion factors and values.

Grains ¹	Avoirdupois weight ²			Troy and apothecaries' weight			Metric system ³		
	Drams	Ounces	Pounds	Drams	Ounces	Pounds	Milli-grams	Grams	Kilo-grams
1	0.03527 (1/28)	0.002286 (316)	0.000143 (7000)	0.016667 (1/60)	0.002083 (1/240)	0.000174 (5700)	54.7868 (65)	0.064799 (1/15)	.....
27.34375	1	0.0625 (316)	0.003906 (2560)	0.45578 (1/2)	0.056950 (1/18)	0.004767 (1/210)	.....	1.771845 (.....)	.....
437.5 (440)	16	1	0.0625 (1/16)	7.258 (1/14)	0.9115 (1/11)	0.075933 (1/13)	.....	28.34955 (28)	.....
7,000	256	16	1	116.667 (1/8)	14.5833 (1/7)	1.21528 (1/8)	.....	453.592 (450)	0.453592 (1/2)
90	2.194286 (2)	0.137143 (59)	0.008571 (117)	1	0.125 (1/8)	0.010417 (1/96)	.....	3.887935 (4)	.....
480	17.55429 (11)	1.09714 (1/2)	0.06857 (1/15)	8	1	0.083333 (1/12)	.....	31.10346 (31)	.....
5,760	370.681 (13)	15.1657 (1/3)	0.822857 (5/6)	96	12	1	.....	373.2418 (375)	0.373241 (1/3)
0.015432 (1/64)	0.000964	.....	.....	0.000257	.....	.....	* 1	0.001	.....
16.43200 (13)	0.264555	0.03527 (1/8)	0.002286	0.257296	0.032153 (1/31)	0.002079	1,000	1	0.001
	Hundred weight			Short tons	Long tons		Milliers, tonnes, or metric tons		
	1	.....	100	0.95 (1/10)	0.945 (1/10)	.....	0.945559 (1/10)	.....	45,359.24 (45)
	20	.....	2,000	1	0.95256 (1/10)	.....	0.90718 (1/10)	.....	907.1849 (900)
	22.4	.....	2,240	1.12 (1/10)	1	.....	1.01602 (1)	.....	1,016.05 (1,000)
	22.96	.....	2,296.69 (1/10)	1.10237 (1/10)	0.984209 (1/10)	.....	1	.....	1,000
16,432.4	0.022048	55.27396 (35)	2.204528 (215)	0.001108	0.000984	2.679228 (215)	0.001	1,000	1

¹ The grain is common to avoirdupois, troy, and apothecaries' systems.

² British units include 1 hundredweight (long, or one-twentieth long ton) = 8 quarters = 8 stone = (12 pounds = 50.8 kg; 1 stone = 14 pounds = 6.35 kg).

³ 1 ounce (avoirdupois) = 0.001 cubic foot of water at 62° F., or 62.06° F.

⁴ 1 metric carat = 200 mg = 3.08647 grains.

⁵ 1 tonne = 10 quintals = 100 myriagrams.

U.S.D.A. Misc. Publication 225 (Tables A-3 and 4)

Table A-5. Velocity; unit conversion factors and values.

Feet per minute	Feet per second	Miles per hour	Knots per hour	Meters per minute	Meters per second	Kilometers per hour
1	0.01667 (160)	0.01136 (110)	0.00868 (85)	0.30480 (30)	0.00068 (68)	0.01488 (15)
60	1	0.68181 (68)	0.30240 (30)	18.288 (18)	0.30480 (30)	1.0927 (1.1)
88	1.4667 (15)	1	0.80368 (80)	26.822 (27)	0.44704 (45)	1.6093 (1.6)
101.337 (100)	1.6894 (17)	1.1315 (11)	1	30.887 (31)	0.51479 (51)	1.8525 (1.8)
3.28083 (33)	0.05408 (54)	0.03728 (37)	0.02237 (22)	1	0.01667 (16)	0.06 (0.06)
196.850 (200)	3.2682 (33)	2.20628 (22)	1.94258 (19)	60	1	2.6 (2.6)
54.680 (55)	0.91347 (91)	0.621370 (62)	0.53958 (54)	16.967 (17)	0.27778 (28)	1

Table A-6. Power; unit conversion factors and values.

Foot-pounds per minute	Foot-pounds per second	Watts	Kilogram-meters per second	Force de cheval	Horse-power	Kilowatt
1	0.01667 (16)	0.0226 (23)	0.0025 (25)	-----	-----	-----
60	1	1.3558 (14)	0.13825 (14)	0.00134 (13)	0.00134 (13)	-----
44.2337 (45)	0.73756 (74)	1	0.10137 (10)	0.00136 (14)	0.00134 (13)	0.001 (0.001)
433.9798 (434)	7.23300 (72)	0.80665 (81)	1	0.01308 (13)	0.01315 (13)	0.0068 (0.007)
82.548.2	542.475	735.499	75	11	0.9863 (10)	0.7355 (0.74)
33.000	550	745.7 (750)	76.64	1.0587 (11)	1	0.7457 (0.75)
44,203.7 (44,000)	737.36	1.000	101.972 (100)	1.356 (14)	1.34 (13)	1

1 watt = 10⁷ ergs per second = 1 joule per second

1 force de cheval = 1 metric horsepower.

Table A-7. Weight or pressure as applied to area; unit conversion factors and approximate values.

Pounds per square foot	Pounds per square inch	Feet of water column or head ¹	Kilograms per square meter	Grams per square millimeter	Millimeters of mercury column ²	Atmospheres
1	0.006944 (7)	0.016016 (16)	4.8824 (5)	0.48824 (5)	-----	0.00047 (0.0005)
144	1	2.30664 (23)	703.067 (700)	70,306.7 (70,000)	51.7134 (52)	0.068044 (0.07)
62.428	0.433539	1	304.801	30,480.1	22.4198 (22)	0.02956 (0.03)
0.204817 (20)	0.00422	0.00281	1	0.1	-----	0.000066 (6.6 × 10 ⁻⁵)
2.94817 (3)	0.01622	0.0281	10	1	-----	0.000566 (5.66 × 10 ⁻⁴)
2.78437 (28)	0.010357	0.016016	4.13.80545	1.320545 (13)	7.1	0.001516 (0.0015)
2,116.25	14.061 (14)	33.8948	10,332.54	1,033,254	760	1

¹ Pressure unit = 1 bar = 1 dyne per square centimeter = 0.0010197 gram per square centimeter = 0.010197 kilogram per square meter = (approximately) 0.00001 atmosphere. 1 megadyne = 10⁶ dynes per square centimeter = 0.98694 atmosphere.

² At 4° C., or 39.2° F.

³ At 0° C., or 32° F. 1 inch of mercury column = 70.726 pounds per square foot = 1.13294 foot of water = 34.534 kilograms per square meter = 29.4004 millimeters of mercury = 0.034421 atmosphere.

⁴ 1 pound per square inch = 0.078 ton per square foot

⁵ 1 foot of water = 0.882648 inch of mercury = 0.30480 meter of water

⁶ The specific gravity of mercury at 0° C.

⁷ 1 millimeter of mercury = 0.003937 inch of mercury = 0.013595 meter of water.

⁸ 1 atmosphere = 29.9272 inches of mercury = 10.33254 meters of water.

Table A-8. Weight as applied to volume; unit conversion factors and approximate values.

Grains per cubic inch	Pounds per cubic yard	Pounds per bushel	Pounds per cubic foot	Pounds per gallon	Kilograms per cubic meter	Grams per cubic centimeter
1		0.307208	0.248557 (14)	0.0330 (150)	3.307425 (4)	0.000984 (1350)
	1		0.037037 (137)		0.393279 (13)	0.000595 (13)
2 25518 (214)		4	0.303581 (133)	0.107421 (133)	22.8718 (13)	0.012879
4 05097 (4)		8	0.607162 (134)	0.214842 (137)	45.7436 (151)	0.025758
30 3030 (30)		16	1.214324 (134)	0.429684 (141)	91.4872 (151)	0.051516
	1.68556 (134)	0.077589	0.062428 (134)	0.008344 (120)	119.826 (120)	0.119826 (13)
232.827 (250)	1.68556 (1,700)	16 000 (80)	62.4285 (1021)	8.34545 (8)	1,000	1

1 pound per cubic foot = 1.60358 kilograms per hectoliter = 0.033 ton per cubic yard.

1 pound per gallon = 3.78541 kilograms per liter.

1 grain per cubic centimeter = 1 tonne (metric ton) per cubic meter = (approximately) 1 kilogram per liter.

Table A-9. Grade percent and equivalent degree of slope.

Grade (Percent)	Slope in degrees	Grade (Percent)	Slope in degrees	Grade (Percent)	Slope in degrees	Grade (Percent)	Slope in degrees
1	0 34.4	11	6 16.8	21	11 51.6	55	28 48.6
2	1 8.7	12	6 50.6	22	12 34.4	60	30 57.8
3	1 43.1	13	7 24.4	23	12 57.2	65	33 1.4
4	2 17.4	14	7 58.2	24	13 29.7	70	34 59.0
5	2 51.7	15	8 31.8	25	14 2.2	75	36 32.2
6	2 56.0	16	9 5.4	30	16 42.0	80	38 20.0
7	4 0.3	17	9 38.9	35	19 17.4	85	40 21.9
8	4 34.4	18	10 12.2	40	21 44.1	90	41 54.2
9	5 5.6	19	10 45.5	45	24 13.7	95	43 31.9
10	5 42.6	20	11 18.6	50	26 33.9	100	45 0

1 Equivalent of customary expressions of grade are as follows:

Grades and slopes: 1 foot per chain = 1.54 percent; 1 foot per mile = 0.01875 percent; 1 millimeter per meter = 0.1 percent; 1 foot per thousand = 0.1 percent; 1-percent grade = 37.8 inches per mile = 52.8 feet per mile = 13 millimeters per meter = 10 feet per thousand feet = 1 foot per 154.5 chains = 0.66 feet per chain.

Table A-10. Degree of slope and equivalent grade percent.

Degree of slope	Grade	Degree of slope	Grade	Degree of slope	Grade	Degree of slope	Grade
0 30	Percent	0	Percent	0 20	Percent	0	Percent
1	0.873	5	8.710	10	16.711	10	32.492
1 30	1.740	5 30	9.629	15	17.630	15	34.432
2	2.619	6	10.510	16	19.438	20	39.307
2 30	3.492	6 30	11.394	17	21.236	22 30	41.421
3	4.366	7	12.278	18	23.027	25	46.631
3 30	5.241	7 30	13.165	19	24.812	30	57.735
4	6.116	8	14.054	20	26.595	35	70.021
4 30	6.993	8 30	14.945	25	28.375	40	83.919
	7.870	9	15.838	30	30.155	45	100.0

Table A-11. Areas of circles (basal area).

Diameter Inches	Area Sq. Ft.	Diameter Inches	Area Sq. Ft.	Diameter Inches	Area Sq. Ft.
1	0.005	21	2.405	41	9.168
2	0.022	22	2.640	42	9.621
3	0.049	23	2.885	43	10.085
4	.087	24	3.142	44	10.559
5	.136	25	3.409	45	11.044
6	.196	26	3.687	46	11.541
7	.267	27	3.976	47	12.048
8	.349	28	4.276	48	12.566
9	.442	29	4.587	49	13.095
10	.545	30	4.909	50	13.635
11	.660	31	5.241	51	14.186
12	.785	32	5.585	52	14.748
13	.922	33	5.940	53	15.321
14	1.069	34	6.305	54	15.904
15	1.227	35	6.681	55	16.499
16	1.396	36	7.069	56	17.104
17	1.576	37	7.467	57	17.721
18	1.767	38	7.876	58	18.348
19	1.969	39	8.296	59	18.986
20	2.182	40	8.727	60	19.635

Approximate basal area can be calculated

by multiplying $(DBH)^2 \times .00545$.

Table A-12. Volume, young-growth coast redwood, board feet, Spaulding rule to an 8-inch top.

D.B.H. (inches)	Volume by total height in feet																No. of trees	
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190		
11	20	22	25	27	29	32	34	36										6
12	25	31	36	41	46	51	56	61										9
13	31	39	47	55	64	72	80	88	96									8
14	36	48	59	71	82	94	105	117	128									16
15	42	57	72	87	102	117	132	147	162	177								13
16	47	66	85	104	123	142	160	179	198	217								20
17	52	75	98	121	144	167	190	213	236	259	283							16
18	57	85	112	139	167	194	222	249	277	304	331							29
19	62	94	126	159	191	223	255	287	319	351	383							21
20	67	104	141	178	215	252	289	326	363	400	437							22
21		115	157	199	241	283	325	367	409	452	494	536						14
22		125	172	220	268	315	363	410	458	505	553	601						19
23		136	189	242	295	349	402	455	508	562	615	668						14
24		146	206	265	324	383	442	502	561	620	679	739						31
25		157	223	288	354	419	485	550	616	681	746	812	877					24
26			241	313	384	456	528	600	672	744	816	888	960					27
27			259	337	416	495	574	652	731	810	888	967	1046					25
28			277	363	449	535	620	706	792	877	963	1049	1134					36
29			297	390	483	576	669	762	855	948	1040	1133	1226	1319				18
30			316	417	517	618	718	819	920	1020	1121	1221	1322	1422				24

31		445	553	661	770	878	986	1095	1203	1311	1420	1528	1636	1745	17	
32		474	590	706	823	939	1056	1172	1288	1405	1521	1637	1754	1870	32	
33		503	628	752	877	1002	1127	1251	1376	1501	1626	1750	1875	2000	16	
34		533	666	800	933	1066	1200	1333	1466	1600	1733	1866	2000	2133	24	
35		564	706	848	991	1133	1275	1417	1559	1702	1844	1986	2128	2270	16	
36			747	898	1050	1201	1352	1504	1655	1806	1958	2109	2260	2412	13	
37			789	949	1110	1271	1432	1592	1753	1914	2075	2235	2396	2557	8	
38			832	1002	1172	1343	1513	1683	1854	2024	2195	2365	2535	2706	14	
39			875	1056	1236	1416	1597	1777	1957	2137	2318	2498	2678	2859	1	
40			920	1111	1301	1492	1682	1873	2063	2254	2444	2634	2825	3015	4	
41				1167	1368	1569	1770	1971	2172	2373	2573	2774	2975	3176	2	
42				1224	1436	1648	1859	2071	2283	2494	2706	2917	3129	3341	4	
43				1282	1505	1728	1940	2173	2396	2618	2841	3063	3286	3509	3	
44				1343	1577	1811	2045	2279	2513	2746	2980	3214	3448	3682	4	
45				1405	1650	1895	2141	2386	2631	2877	3122	3367	3613	3858	4	
46					1724	1982	2239	2496	2753	3010	3267	3524	3781	4039	4	
47					1800	2070	2339	2608	2877	3146	3415	3684	3954	4223	1	
48					1878	2159	2441	2722	3004	3285	3567	3848	4129	4411	2	
49					1957	2251	2545	2839	3133	3427	3721	4015	4309	4603	1	
50					2037	2344	2651	2958	3265	3572	3878	4185	4492	4799	7	
No. of trees	2	4	10	30	32	20	69	90	122	94	45	13	13	6	1	560

U.C. Lindquist and Falley, 1959

Table A-13. Volume, young-growth coast redwood, cubic feet to a 4-inch top.

D.B.H. (inches)	Total height (feet)																		No. of trees
	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	
4		3	7	10	13														1
5	4	9	14	18	23														6
6	9	16	22	29	36	42													2
7		23	31	40	49	57													4
8		30	41	52	63	74	85												9
9		39	52	66	79	93	11												6
10		47	64	81	98	11	15												4
11		56	76	96	12	14	16	18	20	22									9
12		66	89	11	14	16	18	21	23	25									9
13		77	10	13	16	18	21	24	27	29	32	35							8
14		87	12	15	18	21	24	28	31	34	37	40							16
15		10	13	17	21	24	28	31	35	38	42	46							13
16		11	15	19	23	27	31	35	39	43	48	52	56						20
17		12	17	22	26	30	35	40	44	49	53	58	62						16
18		14	19	24	29	34	39	44	49	54	59	64	69	74					20
19		15	21	26	32	38	43	49	54	60	66	71	77	82					21
20		16	23	29	35	42	47	54	60	66	72	78	85	91					22
21		18	25	32	38	45	52	59	66	72	79	86	93	100					14
22		19	27	34	42	49	57	64	72	79	87	94	102	109					19
23		21	29	37	45	54	62	70	78	86	94	102	110	119	127	135			14
24		23	32	40	49	58	67	76	84	93	102	111	120	129	138	146			31
25		24	34	43	53	62	72	82	91	101	110	120	130	139	149	158			21
26		26	36	47	57	67	78	88	98	109	119	129	140	150	160	171	181		27
27			39	50	61	72	83	94	106	117	128	139	150	161	172	183	194		25
28			41	53	65	77	89	101	113	125	137	149	161	173	185	197	208		36

Table A-14. Volume, old-growth coast redwood, board feet, Scribner rule, to a top utilization diameter of 50 percent of D.O.B. at 20 feet.

D. O. B. 20 Ft.	Necks at 20-Foot Load										Top D. I. B.	
	1	2	3	4	5	6	7	8	9	10		
16	120	230	310									12
18		240	370	470	600							12
20		280	430	570	740							12
22		330	530	710	910							12
24			670	880	1,100							12
26			810	1,060	1,300							13
28			950	1,270	1,530							14
30			1,100	1,470	1,790	2,180						15
32			1,300	1,690	2,030	2,460	2,900					16
34			1,450	1,910	2,300	2,800	3,290	3,790				17
36			1,750	2,150	2,590	3,180	3,690	4,230				18
38			1,840	2,400	2,900	3,500	4,100	4,680				19
40			2,090	2,690	3,220	3,860	4,500	5,200				20
44			2,500	3,240	3,980	4,650	5,500	6,210				22
48				3,810	4,700	5,680	6,680	7,420				24
52				4,570	5,600	6,470	7,640	8,800				26
56				5,200	6,500	7,660	8,950	10,450				28
60					7,420	9,120	10,330	12,030	13,300			30
64					8,450	10,300	11,730	13,680	15,150			32
68					9,600	11,670	13,770	15,300	17,660			34
72					10,900	12,980	15,450	17,130	19,640			36
76					12,200	14,360	17,100	19,100	21,770	23,720		38
80					13,500	15,870	17,360	21,030	23,990	26,150		40
86					15,900	18,800	21,740	24,230	27,640	30,120		43
92					18,100	20,890	24,790	28,690	31,530	34,370		46
98					20,750	23,680	28,070	31,300	35,670	39,890		49
104					22,250	26,020	31,610	35,240	40,160	43,750		52
110					25,750	29,720	35,240	39,270	44,780	48,830		55

Table A-15. Volume, young-growth Douglas-fir, board feet, Scribner rule to an 8-inch top.

Revised from Forest Inventory and Analysis, U.S. Forest Service, 1990

Diameter at breast	Volume		Board feet	
	cu ft	cu m	board ft	board m
8	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00
18	0.00	0.00	0.00	0.00
19	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00
23	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00
26	0.00	0.00	0.00	0.00
27	0.00	0.00	0.00	0.00
28	0.00	0.00	0.00	0.00
29	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00
31	0.00	0.00	0.00	0.00
32	0.00	0.00	0.00	0.00
33	0.00	0.00	0.00	0.00
34	0.00	0.00	0.00	0.00
35	0.00	0.00	0.00	0.00
36	0.00	0.00	0.00	0.00
37	0.00	0.00	0.00	0.00
38	0.00	0.00	0.00	0.00
39	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00
41	0.00	0.00	0.00	0.00
42	0.00	0.00	0.00	0.00
43	0.00	0.00	0.00	0.00
44	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00
46	0.00	0.00	0.00	0.00
47	0.00	0.00	0.00	0.00
48	0.00	0.00	0.00	0.00
49	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00

Table A-18. Volume, Sitka spruce (old and young), board feet, Scribner rule to an 8-inch top.

D. b. h. (Inches)	Volume in cords of board-feet when total height of tree in feet is—																			
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	
12	8	4	6	8	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
13	8	4	6	8	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
14	7	3	5	7	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
15	9	5	7	9	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
16	11	7	9	11	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
17	13	8	10	12	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
18	14	9	11	13	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
19	15	10	12	14	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
20	16	11	13	15	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
21	17	12	14	16	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
22	18	13	15	17	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
23	19	14	16	18	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
24	20	15	17	19	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
25	21	16	18	20	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
26	22	17	19	21	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
27	23	18	20	22	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
28	24	19	21	23	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
29	25	20	22	24	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
30	26	21	23	25	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42

345	365	385	405	425	445	465	485	505	525	545	565	585	605	625	645	665	685	705	725	745	765	785	805	825	845	865	885	905	925	945	965	985	1005																																																																		
10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100									
101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200
201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300
301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400
401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500
501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600
601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700
701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800
801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900
901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000

Table A-19. Volume, Sitka spruce (old and young), cubic feet to a 4-inch top.

D. b. h. (inches)	Cubic-foot volume when total height of tree in feet is--													
	20	40	60	80	100	120	140	160	180	200	220	240	260	
6	3.1	2.9	4.6											
8		6.0	9.1	11.9										
10		9.9	13.7	18.0	22.2									
12			11.1	14.4	18.8	22.8								
14		17	27	36	47									
16			30	41	53	60								
18			37	50	62	75								
20			46	60	75	90	107	130						
22				53	70	87	107	125	140					
24				59	82	103	124	144	162	179				
26				68	95	119	142	164	185	203	220			
28				78	108	136	159	184	209	235	264			
30				90	121	151	179	207	233	268	298			
32			103	134	168	200	232	267	301	331	364			
34				117	183	220	255	293	331	364	404			
36				160	200	241	280	322	361	401	441			
38				173	218	264	307	352	396	439	485	524		
40				187	241	287	338	388	438	486	528	568		
42					258	308	360	408	464	511	563	612		
44					277	329	382	432	485	540	600	651	704	
46					294	350	414	468	527	586	651	704	765	
48					314	375	441	502	565	632	694	755	820	
50					332	399	469	534	604	674	736	799	864	
52					350	427	500	568	640	704	769	831	894	
54						441	517	598	674	754	831	914	994	
56						520	611	701	791	882	966	1,052	1,133	
58						601	697	793	894	991	1,089	1,177	1,273	
60						683	786	885	987	1,093	1,193	1,245	1,333	
62							868	968	1,068	1,166	1,266	1,369	1,470	
64							950	1,050	1,150	1,250	1,350	1,452	1,558	
66							1,032	1,132	1,232	1,332	1,434	1,538	1,644	
68							1,117	1,217	1,317	1,421	1,521	1,624	1,730	
70							1,202	1,302	1,402	1,507	1,607	1,710	1,816	
72							1,287	1,387	1,487	1,592	1,692	1,793	1,896	
74							1,372	1,472	1,572	1,677	1,777	1,878	1,982	
76							1,457	1,557	1,657	1,762	1,862	1,963	2,066	
78							1,542	1,642	1,742	1,847	1,947	2,048	2,152	
80							1,627	1,727	1,827	1,932	2,032	2,133	2,236	
82							1,712	1,812	1,912	2,017	2,117	2,218	2,322	
84							1,797	1,897	1,997	2,102	2,202	2,303	2,406	
86							1,882	1,982	2,082	2,187	2,287	2,388	2,492	
88							1,967	2,067	2,167	2,272	2,372	2,473	2,576	

Table A-20. Volume, western hemlock (old and young), board feet, Scribner rule to an 8-inch top.

Species..... WESTERN HEMLOCK (Tough heterophyllite)
 Unit of measure..... Board-foot
 Variables..... D.B.H. and number of 16-foot logs
 Log rule..... Scribner
 Boiling length for logs..... 16 feet
 Stump height..... 2 feet
 Top d.i.d..... 8 inches
 Trim allowance per log..... 0.3 feet
 Method..... Kiln-dry short
 Number of trees..... 1,526
 Location of trees..... Young and old stands in Oregon and Washington
 Accuracy..... Analytical deviation 0.25 percent low
 Author..... W. H. Meyer, Pacific Northwest Forest and Range Expt. Sta.
 Source..... Table 49 in U. S. Dept. Agr. Tech. Bul. 546
 Year..... 1937

D.B.H. (inches)	Volume in tons of board-foot when number of 16-foot logs is:											
	2	3	4	5	6	7	8	9	10	11	12	13
12	10	16	22	28	34	40	46	52	58	64	70	76
14	13	19	27	34	41	48	55	62	69	76	83	90
16	16	23	31	41	50	59	68	77	86	95	104	113
18	19	28	37	48	58	70	81	92	103	114	125	136
20	22	32	43	55	67	80	93	106	119	132	145	158
22	25	36	48	61	75	89	103	117	131	145	159	173
24	28	40	53	67	82	97	112	127	142	157	172	187
26	31	44	58	73	88	103	118	133	148	163	178	193
28	34	48	63	79	95	111	127	143	159	175	191	207
30	37	51	67	84	101	118	135	152	169	186	203	220
32	40	54	71	89	107	125	143	161	179	197	215	233
34	43	58	76	95	114	133	152	171	190	209	228	247
36	46	61	80	100	120	140	160	180	199	219	239	259
38	49	65	85	105	126	146	166	186	206	226	246	266
40	52	69	89	110	131	152	173	194	215	236	257	278
42	55	73	94	115	137	159	181	203	225	247	269	291
44	58	77	99	120	143	166	189	212	235	258	281	304
46	61	81	103	126	149	173	197	221	245	269	293	317
48	64	85	107	131	154	179	204	229	254	279	304	329
50	67	89	111	137	160	185	210	236	262	288	314	340
52	70	93	115	142	166	192	217	244	271	298	325	352
54	73	97	120	148	172	199	223	251	279	307	335	363
56	76	101	125	154	178	206	230	259	288	317	346	374
58	79	105	130	160	184	213	237	267	297	327	357	385
60	82	109	135	166	190	220	245	275	305	336	366	396
62	85	113	140	172	196	227	253	283	313	343	375	407
64	88	117	145	178	202	234	261	291	321	351	384	418
66	91	121	150	184	208	241	269	299	329	359	392	429
68	94	125	155	190	214	248	277	307	337	367	400	440
70	97	129	160	196	220	255	285	315	345	375	408	451
72	100	133	165	202	226	262	293	323	353	383	416	462
74	103	137	170	208	232	269	301	331	361	391	424	473
76	106	141	175	214	238	276	309	339	369	399	432	484
78	109	145	180	220	244	283	317	347	377	407	440	495
80	112	149	185	226	250	290	325	355	385	415	448	506
82	115	153	190	232	256	297	333	363	393	423	456	517
84	118	157	195	238	262	304	341	371	401	431	464	528
86	121	161	200	244	268	311	349	379	409	439	472	539
88	124	165	205	250	274	318	357	387	417	447	480	550
90	127	169	210	256	280	325	365	395	425	455	488	561
92	130	173	215	262	286	332	373	403	433	463	496	572
94	133	177	220	268	292	339	381	411	441	471	504	583
96	136	181	225	274	298	346	389	419	449	479	512	594
98	139	185	230	280	304	353	397	427	457	487	520	605
100	142	189	235	286	310	360	405	435	465	495	528	616
102	145	193	240	292	316	367	413	443	473	503	536	627
104	148	197	245	298	322	374	421	451	481	511	544	638
106	151	201	250	304	328	381	429	459	489	519	552	649
108	154	205	255	310	334	388	437	467	497	527	560	660
110	157	209	260	316	340	395	445	475	505	535	568	671
112	160	213	265	322	346	402	453	483	513	543	576	682
114	163	217	270	328	352	409	461	491	521	551	584	693
116	166	221	275	334	358	416	469	500	529	559	592	704
118	169	225	280	340	364	423	477	508	537	567	600	715
120	172	229	285	346	370	430	485	516	545	575	608	726
122	175	233	290	352	376	437	493	524	553	583	616	737
124	178	237	295	358	382	444	501	532	561	591	624	748
126	181	241	300	364	388	451	509	540	569	600	632	759
128	184	245	305	370	394	458	517	548	577	608	640	770
130	187	249	310	376	400	465	525	556	585	616	648	781
132	190	253	315	382	406	472	533	564	593	624	656	792
134	193	257	320	388	412	479	541	572	601	632	664	803
136	196	261	325	394	418	486	549	580	609	640	672	814
138	199	265	330	400	424	493	557	588	617	648	680	825
140	202	269	335	406	430	500	565	596	625	656	688	836
142	205	273	340	412	436	507	573	604	633	664	696	847
144	208	277	345	418	442	514	581	612	641	672	704	858
146	211	281	350	424	448	521	589	620	649	680	712	869
148	214	285	355	430	454	528	597	628	657	688	720	880
150	217	289	360	436	460	535	605	636	665	696	728	891
152	220	293	365	442	466	542	613	644	673	704	736	902
154	223	297	370	448	472	549	621	652	681	712	744	913
156	226	301	375	454	478	556	629	660	689	720	752	924
158	229	305	380	460	484	563	637	668	697	728	760	935
160	232	309	385	466	490	570	645	676	705	736	768	946

Table A-21. Volume, western hemlock (old and young), cubic feet to a 4-inch top.

Diameter at 4 in. top		Height		Volume	
ft.	in.	ft.	in.	cu. ft.	cu. ft.
10	10	10	0	1.000	1.000
10	12	10	0	1.200	1.200
10	14	10	0	1.400	1.400
10	16	10	0	1.600	1.600
10	18	10	0	1.800	1.800
10	20	10	0	2.000	2.000
10	22	10	0	2.200	2.200
10	24	10	0	2.400	2.400
10	26	10	0	2.600	2.600
10	28	10	0	2.800	2.800
10	30	10	0	3.000	3.000
10	32	10	0	3.200	3.200
10	34	10	0	3.400	3.400
10	36	10	0	3.600	3.600
10	38	10	0	3.800	3.800
10	40	10	0	4.000	4.000
10	42	10	0	4.200	4.200
10	44	10	0	4.400	4.400
10	46	10	0	4.600	4.600
10	48	10	0	4.800	4.800
10	50	10	0	5.000	5.000
10	52	10	0	5.200	5.200
10	54	10	0	5.400	5.400
10	56	10	0	5.600	5.600
10	58	10	0	5.800	5.800
10	60	10	0	6.000	6.000
10	62	10	0	6.200	6.200
10	64	10	0	6.400	6.400
10	66	10	0	6.600	6.600
10	68	10	0	6.800	6.800
10	70	10	0	7.000	7.000
10	72	10	0	7.200	7.200
10	74	10	0	7.400	7.400
10	76	10	0	7.600	7.600
10	78	10	0	7.800	7.800
10	80	10	0	8.000	8.000
10	82	10	0	8.200	8.200
10	84	10	0	8.400	8.400
10	86	10	0	8.600	8.600
10	88	10	0	8.800	8.800
10	90	10	0	9.000	9.000
10	92	10	0	9.200	9.200
10	94	10	0	9.400	9.400
10	96	10	0	9.600	9.600
10	98	10	0	9.800	9.800
10	100	10	0	10.000	10.000
10	102	10	0	10.200	10.200
10	104	10	0	10.400	10.400
10	106	10	0	10.600	10.600
10	108	10	0	10.800	10.800
10	110	10	0	11.000	11.000
10	112	10	0	11.200	11.200
10	114	10	0	11.400	11.400
10	116	10	0	11.600	11.600
10	118	10	0	11.800	11.800
10	120	10	0	12.000	12.000
10	122	10	0	12.200	12.200
10	124	10	0	12.400	12.400
10	126	10	0	12.600	12.600
10	128	10	0	12.800	12.800
10	130	10	0	13.000	13.000
10	132	10	0	13.200	13.200
10	134	10	0	13.400	13.400
10	136	10	0	13.600	13.600
10	138	10	0	13.800	13.800
10	140	10	0	14.000	14.000
10	142	10	0	14.200	14.200
10	144	10	0	14.400	14.400
10	146	10	0	14.600	14.600
10	148	10	0	14.800	14.800
10	150	10	0	15.000	15.000
10	152	10	0	15.200	15.200
10	154	10	0	15.400	15.400
10	156	10	0	15.600	15.600
10	158	10	0	15.800	15.800
10	160	10	0	16.000	16.000
10	162	10	0	16.200	16.200
10	164	10	0	16.400	16.400
10	166	10	0	16.600	16.600
10	168	10	0	16.800	16.800
10	170	10	0	17.000	17.000
10	172	10	0	17.200	17.200
10	174	10	0	17.400	17.400
10	176	10	0	17.600	17.600
10	178	10	0	17.800	17.800
10	180	10	0	18.000	18.000
10	182	10	0	18.200	18.200
10	184	10	0	18.400	18.400
10	186	10	0	18.600	18.600
10	188	10	0	18.800	18.800
10	190	10	0	19.000	19.000
10	192	10	0	19.200	19.200
10	194	10	0	19.400	19.400
10	196	10	0	19.600	19.600
10	198	10	0	19.800	19.800
10	200	10	0	20.000	20.000
10	202	10	0	20.200	20.200
10	204	10	0	20.400	20.400
10	206	10	0	20.600	20.600
10	208	10	0	20.800	20.800
10	210	10	0	21.000	21.000
10	212	10	0	21.200	21.200
10	214	10	0	21.400	21.400
10	216	10	0	21.600	21.600
10	218	10	0	21.800	21.800
10	220	10	0	22.000	22.000
10	222	10	0	22.200	22.200
10	224	10	0	22.400	22.400
10	226	10	0	22.600	22.600
10	228	10	0	22.800	22.800
10	230	10	0	23.000	23.000
10	232	10	0	23.200	23.200
10	234	10	0	23.400	23.400
10	236	10	0	23.600	23.600
10	238	10	0	23.800	23.800
10	240	10	0	24.000	24.000
10	242	10	0	24.200	24.200
10	244	10	0	24.400	24.400
10	246	10	0	24.600	24.600
10	248	10	0	24.800	24.800
10	250	10	0	25.000	25.000
10	252	10	0	25.200	25.200
10	254	10	0	25.400	25.400
10	256	10	0	25.600	25.600
10	258	10	0	25.800	25.800
10	260	10	0	26.000	26.000
10	262	10	0	26.200	26.200
10	264	10	0	26.400	26.400
10	266	10	0	26.600	26.600
10	268	10	0	26.800	26.800
10	270	10	0	27.000	27.000
10	272	10	0	27.200	27.200
10	274	10	0	27.400	27.400
10	276	10	0	27.600	27.600
10	278	10	0	27.800	27.800
10	280	10	0	28.000	28.000
10	282	10	0	28.200	28.200
10	284	10	0	28.400	28.400
10	286	10	0	28.600	28.600
10	288	10	0	28.800	28.800
10	290	10	0	29.000	29.000
10	292	10	0	29.200	29.200
10	294	10	0	29.400	29.400
10	296	10	0	29.600	29.600
10	298	10	0	29.800	29.800
10	300	10	0	30.000	30.000
10	302	10	0	30.200	30.200
10	304	10	0	30.400	30.400
10	306	10	0	30.600	30.600
10	308	10	0	30.800	30.800
10	310	10	0	31.000	31.000
10	312	10	0	31.200	31.200
10	314	10	0	31.400	31.400
10	316	10	0	31.600	31.600
10	318	10	0	31.800	31.800
10	320	10	0	32.000	32.000
10	322	10	0	32.200	32.200
10	324	10	0	32.400	32.400
10	326	10	0	32.600	32.600
10	328	10	0	32.800	32.800
10	330	10	0	33.000	33.000
10	332	10	0	33.200	33.200
10	334	10	0	33.400	33.400
10	336	10	0	33.600	33.600
10	338	10	0	33.800	33.800
10	340	10	0	34.000	34.000
10	342	10	0	34.200	34.200
10	344	10	0	34.400	34.400
10	346	10	0	34.600	34.600
10	348	10	0	34.800	34.800
10	350	10	0	35.000	35.000
10	352	10	0	35.200	35.200
10	354	10	0	35.400	35.400
10	356	10	0	35.600	35.600
10	358	10	0	35.800	35.800
10	360	10	0	36.000	36.000
10	362	10	0	36.200	36.200
10	364	10	0	36.400	36.400
10	366	10	0	36.600	36.600
10	368	10	0	36.800	36.800
10	370	10	0	37.000	37.000
10	372	10	0	37.200	37.200
10	374	10	0	37.400	37.400
10	376	10	0	37.600	37.600
10	378	10	0	37.800	37.800
10	380	10	0	38.000	38.000
10	382	10	0	38.200	38.200
10	384	10	0	38.400	38.400
10	386	10	0	38.600	38.600
10	388	10	0	38.800	38.800
10	390	10	0	39.000	39.000
10	392	10	0	39.200	39.200
10	394	10	0	39.400	39.400
10	396	10	0	39.600	39.600
10	398	10	0	39.800	39.800
10	400	10	0	40.000	40.000
10	402	10	0	40.200	40.200
10	404	10	0	40.400	40.400
10	406	10	0	40.600	40.600
10	408	10	0	40.800	40.800
10	410	10	0	41.000	41.000
10	412	10	0	41.200	41.200
10	414	10	0	41.400	41.400
10	416	10	0	41.600	41.600
10	418	10	0	41.800	41.800
10	420	10	0	42.000	42.000
10	422	10	0	42.200	42.200
10	424	10	0	42.400	42.400
10	426	10	0	42.600	42.600
10	428	10	0	42.800	42.800
10	430	10	0	43.000	43.000
10	432	10	0	43.200	43.200
10	434	10	0	43.400	43.400
10	436	10	0	43.600	43.600
10	438	10	0	43.800	43.800
10	440	10	0	44.000	44.000
10	442	10	0	44.200	44.200
10	444	10	0	44.400	44.400
10	446	10	0	44.600	44.600
10	448	10	0	44.800	44.800
10	450	10	0	45.000	45.000
10	452	10	0	45.200	45.200
10	454	10	0	45.4	

Table A-22. Volume, old-growth white fir (*A. concolor*), Site II, board feet, Scribner Decimal C to an 8-inch top.

Diameter breast high	Number of 16-foot logs											Date	
	1	2	3	4	5	6	7	8	9	10	11		
	Volume—board feet, in tens												
10	6	0	12	15									
12	8	8	13	18									1
14	5	9	15	22									3
16	5	11	18	25	32								5
18	5	12	20	30	39								10
20		13	23	35	46	58							16
22		15	28	42	55	69							23
24		16	31	48	64	80	98	112	128				23
26		18	36	55	75	93	112	130	148				26
28			42	63	85	107	126	149	172				30
30			46	70	94	120	144	169	194				38
32			52	79	108	134	162	189	216				31
34			58	88	119	148	179	209	239	269			28
36					131	165	197	234	266	298			34
38					144	181	218	256	293	330			40
40					156	199	240	281	322	363			44
42					172	214	253	298	343	387			47
44					186	235	286	335	385	433	482		5
46					210	264	310	364	418	470	524		3
48					221	280	338	396	454	512	569		2
50					242	300	366	428	491	554	616		1
52					269	333	394	461	528	595	662		
54					290	358	424	490	560	628	716		1
56					305	373	452	526	603	679	755		
58					317	400	482	563	644	726	808		
60					326	422	517	609	697	773	864		
62					333	452	556	645	738	822	920		
64					332	481	574	675	773	869	982		
66					331	518	622	731	832	945	1050		
68					328	558	660	774	875	990	1110		
70					342	567	691	801	922	1042	1176		
72					425	588	725	840	978	1102	1225		
Total													300

Table A-23. Volume, young-growth white fir (*A. concolor*), board feet, International 1/8" rule to a five-inch top.

DBH	TOTAL HEIGHT IN FEET															Basic Number of Trees	Average Height Feet	
	40	50	60	70	80	90	100	110	120	130	140	150	160	170				
	VOLUME IN BOARD FEET																	
8	17	23	32	43	57											49	32	
9	21	30	43	58	77	79										55	58	
10	25	39	54	80	106	101	118									57	64	
11	29	46	65	95	126	127	147	168								54	69	
12	33	53	77	101	127	131	177	203								41	74	
13	37	61	90	118	149	150	211	241	272							46	79	
14		73	105	140	175	217	247	283	318	354						42	84	
15		85	123	162	203	244	285	327	369	410						34	89	
16		94	140	185	233	280	325	374	420	468						29	94	
17		105	157	208	260	314	366	422	473	531	585					22	99	
18		118	174	232	290	350	412	470	533	593	654					15	103	
19			257	324	392	468	538	604	660	727						15	107	
20			282	355	429	500	570	652	725	800						12	111	
21			311	390	472	554	636	720	804	885						8	115	
22			340	426	515	607	698	790	882	972						9	119	
23			372	460	567	666	764	863	961	1060	1155					9	123	
24			404	508	615	722	829	936	1043	1150	1255	1365				9	126	
25			439	554	672	790	907	1025	1143	1260	1375	1490				5	129	
26			479	604	732	860	990	1120	1250	1375	1505	1630				6	133	
27				652	793	935	1075	1215	1360	1500	1640	1780				4	136	
28				707	858	1010	1160	1315	1470	1620	1770	1920				2	139	
29				768	930	1090	1255	1420	1585	1745	1910	2070				4	143	
30				826	1005	1190	1355	1535	1710	1880	2065	2240					4	146
31						1204	1450	1646	1835	2010	2220	2410					1	148
32						1340	1545	1750	1955	2155	2355	2560					3	151
33						1430	1650	1860	2080	2300	2515	2735	2950				4	154
34						1513	1740	1972	2203	2435	2665	2895	3130					157
35								2086	2330	2570	2810	3055	3290				1	159
36								2205	2460	2710	2970	3225	3480				1	162
37								2320	2590	2865	3140	3410	3680					164
38								2445	2730	3015	3295	3580	3860				1	166
39								2570	2870	3170	3475	3775	4080					168
40								2690	3000	3320	3635	3950	4270					170
	Total.....															336		

Table A-24. Volume, young-growth white fir (*A. concolor*), cubic feet

DBH	TOTAL HEIGHT IN FEET																	Basis Number of Trees	Average Height Feet				
	25	30	35	40	45	50	60	70	80	90	100	110	120	130	140	150	160			170			
	VOLUME IN CUBIC FEET																						
4	0.85	1.05	1.24	1.43	1.59															26			
5	1.28	1.55	1.85	2.16	2.48	2.77	3.07														33		
6	1.78	2.16	2.56	3.00	3.46	3.89	4.30	5.62														39	
7	2.87	3.37	3.94	4.53	5.15	5.74	6.32	7.52													34	45	
8	3.66	4.38	4.98	5.72	6.51	7.31	8.11	9.38	11.2	12.7											54	51	
9		5.35	6.14	6.99	7.94	8.95	10.0	11.0	12.7	15.8											55	57	
10			7.44	8.44	9.47	11.8	14.4	16.8	19.2	21.9												57	63
11			8.84	9.98	11.2	13.8	16.7	19.0	22.8	25.7	28.4											54	69
12		10.4	11.7	13.1	16.0	19.1	23.0	26.6	30.0	33.4												42	74
13		12.1	13.6	15.1	18.4	21.8	25.1	30.5	34.9	38.2	42.6											45	80
14			15.6	17.8	21.0	24.8	29.2	34.6	39.6	44.3	49.0	53.2										42	85
15			17.7	19.8	23.0	28.1	32.7	38.0	44.0	50.2	55.6	60.0										34	90
16				22.8	26.9	31.0	36.0	42.4	49.3	56.3	62.5	68.4										29	95
17				25.2	30.2	35.4	40.6	47.0	54.5	62.5	69.8	76.7	83.2									22	99
18			28.1	33.7	39.4	45.4	51.0	59.7	68.9	77.0	85.4	93.6										15	103
19				32.0	37.9	43.9	50.4	57.3	65.4	73.5	80.0	89.5	103									16	108
20					41.0	48.1	55.5	63.2	71.6	82.4	90.0	108	113									11	112
21					53.2	60.8	69.0	77.2	88.4	102	114	124	133									8	115
22					58.3	66.5	75.4	84.7	95.1	107	123	136	147									9	119
23					63.0	72.8	82.2	91.8	103	117	133	147	160									12	122
24					69.3	79.1	89.5	99.8	111	125	143	159	174	187								9	126
25					75.3	85.0	95.7	108	120	134	153	171	187	202								6	129
26					81.3	92.4	104	116	129	143	162	183	201	218								6	132
27					100	112	125	139	154	172	194	215	233									4	135
28					108	121	135	149	164	183	206	230	251	270								2	138
29					116	130	145	159	175	194	218	245	267	290								4	140
30					124	140	155	171	188	207	231	261	286	308								4	143
31							165	182	200	220	243	275	303	328								1	145
32							175	194	213	233	257	290	321	348								2	148
33							187	206	225	247	271	304	339	368								4	150
34							198	218	238	261	285	319	357	389								1	153
35								210	231	253	276	302	335	376	411							1	155
36									268	291	317	351	394	432								1	157
37									282	306	334	367	411	455									159
38									297	323	352	384	427	475								1	161
39									313	341	369	401	444	496									163
40									329	358	388	421	462	517									165
	Total																	608					

Table A-25. Volume, old-growth sugar pine, Site II, board feet, Scribner Decimal C rule.

Diameter breast high, inches	Number of 16-foot logs											
	1	2	3	4	5	6	7	8	9	10	11	12
	Volume—board feet, in tons											
12.....	3	8	13									
14.....	3	10	15	22								
16.....	5	11	17	26	33							
18.....	5	12	20	29	39	48						
20.....	4	13	23	33	43	55	65					
22.....	6	15	26	38	52	65	77	88				
24.....	10	17	30	44	61	75	90	104				
26.....		18	24	31	40	50	60	72	82			
28.....		20	30	40	50	62	74	88	102	116		
30.....			38	50	62	76	90	104	120	136		
32.....			51	64	78	93	108	124	140	156		
34.....				69	84	100	116	132	148	164		
36.....				100	121	142	164	186	208	230	252	
38.....				111	134	157	180	204	228	252	276	
40.....				122	146	170	194	218	242	266	290	314
42.....					182	227	272	317	362	407	452	497
44.....					201	251	301	351	401	451	501	551
46.....					222	278	333	388	443	498	553	608
48.....					244	300	357	413	470	526	583	639
50.....					269	333	398	462	526	591	655	719
52.....					294	370	448	525	603	680	758	835
54.....					323	406	490	574	658	742	827	911
56.....					354	443	534	627	718	810	902	994
58.....					382	482	582	682	782	882	982	1082
60.....						517	622	729	836	942	1048	1156
62.....						551	667	788	909	1030	1151	1273
64.....						579	699	825	951	1077	1203	1329
66.....						594	711	832	950	1075	1207	1333
68.....							732	854	976	1100	1224	1350
70.....							753	874	1007	1140	1277	1410
72.....							785	914	1054	1191	1331	1468
74.....							822	966	1100	1246	1392	1532
76.....							858	1007	1149	1302	1454	1598
78.....							898	1053	1202	1362	1522	1671

U.S.F.S., Dunning, 1925

Table A-26. Volume, young-growth sugar pine, board feet, International $\frac{1}{4}$ " rule to a 4-inch top.

Diameter breast high	Total height of trees--feet											Buses
	30	40	50	60	70	80	90	100	110	120	130	
	Volume--board feet											
<i>Inches</i>												<i>Trees</i>
8.....	0	10	18	29								105
9.....	6	15	26	40	54							64
10.....	8	20	34	50	67	83						73
11.....	10	26	41	61	80	98	118					75
12.....		32	50	72	95	118	135					54
13.....		38	58	84	107	131	155	175				39
14.....		45	68	95	122	150	174	200				35
15.....			79	108	138	168	205	235				23
16.....			90	122	156	189	220	253				24
17.....				136	173	211	247	284				31
18.....				151	193	234	275	317	355			50
19.....				166	213	258	305	352	394			13
20.....				182	235	285	338	388	433	485		5
21.....					258	317	371	425	473	522		3
22.....					282	342	407	465	520	583		2
23.....					306	372	443	505	565	637		2
24.....					332	405	478	547	618	693		
25.....					440	518	592	670	753	840		
26.....						475	560	637	725	814	900	
27.....						512	600	685	782	877	992	
28.....						550	642	735	839	942	1053	
29.....						588	685	786	890	1003	1136	
30.....						627	729	839	955	1070	1213	
31.....						668	777	890	1015	1135	1283	
32.....						709	825	941	1065	1200	1352	
Total.....	23	107	180	100	77	61	40	18	7	7		368

U.S.F.S., Dunning, 1923

Table A-27. Volume, young-growth sugar pine, cubic feet.

Diameter breast high	Total height of tree—feet												Bases
	10	20	30	40	50	60	70	80	90	100	110	120	
	Total volume—cubic feet												
<i>Inches</i>													<i>Feet</i>
4.....	0.2	0.9	1.9										48
5.....	1.0	3.6	2.3	3.0									47
6.....		2.3	3.2	4.0	5.3	6.8							80
7.....		3.2	4.2	5.3	5.8	6.3							81
8.....		4.0	5.2	6.7	8.5	10.5	13.0						96
9.....			6.4	8.2	10.2	12.8	15.6	18.4					64
10.....			7.8	10.0	12.5	15.3	18.8	21.7					75
11.....			9.3	11.9	14.8	18.0	21.7	25.0					78
12.....			13.0	17.3	21.1	25.2	29.9	33.8	38.2				52
13.....				16.3	20.2	24.5	29.0	33.7	38.6	43.5			39
14.....				18.0	23.0	28.0	33.0	38.5	44.0	49.5			37
15.....					21.0	31.7	37.6	43.8	50.0	56.9			23
16.....					23.3	35.8	42.3	49.0	56.1	62.8			33
17.....					40.0	47.5	55.0		62.3	70.0			33
18.....					44.5	52.0	61.0		68.8	77.0	86.0		19
19.....						48.4	57.0		75.0	84.8	94.7		13
20.....						54.8	64.0	73.0	81.3	92.2	103.5	113.3	4
21.....							69.7	79.0	88.0	99.8	111.7	123.3	3
22.....							75.3	85.0	94.8	107.2	120.0	133.2	2
23.....							80.8	90.0	101.4	114.7	128.5	143.0	2
24.....							86.4	97.0	108.0	121.2	137.0	153.0	
25.....								114.3	129.8	148.8	168.6		
26.....									121.0	137.0	154.0	172.0	
27.....									137.3	144.7	162.7	181.5	
28.....									133.9	152.0	171.0	190.9	
29.....									145.2	169.7	179.2	200.0	
30.....									146.7	167.2	187.7	209.8	
31.....									153.0	174.8	196.0	219.2	
32.....									159.8	182.4	204.2	226.0	
Total.....													814

Table A-28. Volume, old-growth ponderosa pine, board feet, Scribner Decimal C rule.

Diameter breast high, inches	Number of 16-foot logs												Diameter inside bark of top inches	
	1	2	3	4	5	6	7	8	9	10	11	12		
	Volume—board feet, in tons													
10	4	7												7
12	4	8	15											8
14	5	10	17											8
16	6	12	19	27										8
18	7	14	23	32	41									8
20	9	18	29	38	48	58								9
22	11	24	35	46	58	71	84							9
24	15	30	44	57	71	86	102							9
26	20	39	55	70	87	104	123	143						10
28	26	48	68	86	106	126	146	169						10
30	35	60	83	105	128	150	172	198	230					10
32		72	100	125	152	176	201	230	260					10
34		86	119	148	176	200	230	260	290	330				11
36		110	140	170	200	230	260	290	330	360				11
38			170	200	230	260	290	330	360	400	450			11
40			200	230	260	290	330	370	400	450	500			11
42			240	270	300	330	370	410	450	500	550			11
44				300	330	370	410	450	500	550	600	660		12
46				330	370	420	460	500	560	610	660	710		12
48				360	420	470	510	560	610	660	720	770		12
50					470	520	570	610	670	720	780	830		12
52					520	570	630	670	730	780	840	890		12
54					570	630	690	730	790	850	910	960		12
56						690	750	790	850	920	980	1040		12
58						750	790	850	920	990	1060	1130		12
60							790	860	920	990	1070	1150	1230	13
62								920	980	1060	1150	1240	1340	13
64								980	1060	1130	1230	1340	1450	13
66								1060	1130	1210	1320	1440	1570	13
68									1200	1300	1410	1560	1690	13
70									1280	1390	1500	1660	1820	14
72									1560	1680	1800	1970	2160	14
74										1580	1700	1880	2080	14
76										1680	1800	1990	2200	14

U.S.F.S., Region 5, 1906-1911

Table A-29. Volume, young-growth ponderosa pine, board feet, Scribner rule to an 8-inch top.

Tree diameter at breast height (inches)	Board foot volume (Scribner log rule) by total tree height in feet									
	60	70	80	90	100	110	120	130	140	150
12.....	50	60	80	100	110	120	140	150	.....	.....
14.....	80	110	130	150	160	200	220	240	260	.....
16.....	120	160	180	210	240	270	300	340	360	.....
18.....	170	210	240	290	340	370	410	460	500	.....
20.....	220	270	320	370	440	480	530	580	640	.....
22.....	270	340	410	470	540	600	670	740	810	890
24.....	330	420	500	580	660	740	820	910	1,000	1,090
26.....	410	510	600	690	790	900	1,000	1,090	1,190	1,290
28.....	490	590	700	820	940	1,060	1,170	1,270	1,370	1,480
30.....	560	690	810	960	1,090	1,220	1,340	1,450	1,570	1,670
32.....	.....	800	950	1,100	1,240	1,390	1,510	1,630	1,750	1,860
34.....	.....	910	1,090	1,240	1,400	1,540	1,690	1,810	1,940	2,060
36.....	.....	1,040	1,250	1,380	1,590	1,710	1,850	1,990	2,130	2,260
38.....	.....	1,170	1,370	1,520	1,720	1,880	2,030	2,180	2,320	2,470
40.....	.....	1,300	1,500	1,670	1,880	2,040	2,210	2,370	2,520	2,580
42.....	.....	.....	.....	1,820	2,030	2,210	2,380	2,560	2,730	2,800
44.....	.....	.....	.....	1,970	2,180	2,380	2,570	2,760	2,930	3,000
46.....	.....	.....	.....	2,110	2,340	2,530	2,750	2,940	3,130	3,290
48.....	.....	.....	.....	2,250	2,490	2,720	2,930	3,130	3,330	3,500
50.....	.....	.....	.....	2,400	2,640	2,890	3,110	3,320	3,530	3,710

U.S.F.S., Meyer (1938), Josephson, 1941.

Table A-30. Volume, young-growth ponderosa pine, cubic feet.

Diameter at breast height (inches)	Volume* by total height																	
	25 feet		30 feet		40 feet		50 feet		60 feet		70 feet		80 feet		90 feet		100 feet	
8.....	Cv. Ft.	Cv. Ft.	Cv. Ft.	Cv. Ft.	Cv. Ft.	Cv. Ft.	Cv. Ft.	Cv. Ft.	Cv. Ft.	Cv. Ft.	Cv. Ft.	Cv. Ft.	Cv. Ft.	Cv. Ft.	Cv. Ft.	Cv. Ft.	Cv. Ft.	Cv. Ft.
8.....	0.1	0.3	0.1	0.3	0.2	0.4	0.2	0.5	0.2	0.6	0.3	0.7	0.3	0.8	0.4	0.9	0.4	1.0
10.....	0.1	0.3	0.1	0.4	0.3	0.5	0.3	0.7	0.4	0.9	0.5	1.1	0.6	1.2	0.7	1.3	0.8	1.4
12.....	0.1	0.4	0.2	0.5	0.4	0.7	0.5	0.9	0.6	1.2	0.8	1.4	1.0	1.6	1.1	1.7	1.2	1.9
14.....	0.2	0.5	0.3	0.6	0.5	0.9	0.7	1.1	0.8	1.4	1.0	1.7	1.3	2.0	1.4	2.1	1.5	2.2
16.....	0.2	0.6	0.4	0.7	0.6	1.1	0.8	1.3	1.0	1.6	1.2	1.9	1.5	2.2	1.6	2.3	1.7	2.4
18.....	0.3	0.7	0.5	0.8	0.7	1.2	0.9	1.4	1.1	1.7	1.3	2.0	1.6	2.4	1.8	2.5	1.9	2.6
20.....	0.3	0.8	0.6	0.9	0.8	1.3	1.0	1.5	1.2	1.8	1.4	2.1	1.7	2.5	1.9	2.6	2.0	2.7
22.....	0.4	0.9	0.7	1.0	0.9	1.4	1.1	1.6	1.3	1.9	1.5	2.2	1.8	2.6	2.0	2.7	2.1	2.8
24.....	0.4	1.0	0.8	1.1	1.0	1.5	1.2	1.7	1.4	2.0	1.6	2.3	1.9	2.7	2.1	2.8	2.2	2.9
26.....	0.5	1.1	0.9	1.2	1.1	1.6	1.3	1.8	1.5	2.1	1.7	2.4	2.0	2.8	2.2	2.9	2.3	3.0
28.....	0.5	1.2	1.0	1.3	1.2	1.7	1.4	1.9	1.6	2.2	1.8	2.5	2.1	2.9	2.3	3.0	2.4	3.1
30.....	0.6	1.3	1.1	1.4	1.3	1.8	1.5	2.0	1.7	2.3	1.9	2.6	2.2	3.0	2.4	3.1	2.5	3.2
32.....	0.6	1.4	1.2	1.5	1.4	1.9	1.6	2.1	1.8	2.4	2.0	2.7	2.3	3.1	2.5	3.2	2.6	3.3
34.....	0.7	1.5	1.3	1.6	1.5	2.0	1.7	2.2	1.9	2.5	2.1	2.8	2.4	3.2	2.6	3.3	2.7	3.4
36.....	0.7	1.6	1.4	1.7	1.6	2.1	1.8	2.3	2.0	2.6	2.2	2.9	2.5	3.3	2.7	3.4	2.8	3.5
38.....	0.8	1.7	1.5	1.8	1.7	2.2	1.9	2.4	2.1	2.7	2.3	3.0	2.6	3.4	2.8	3.5	2.9	3.6
40.....	0.8	1.8	1.6	1.9	1.8	2.3	2.0	2.5	2.2	2.8	2.4	3.1	2.7	3.5	2.9	3.6	3.0	3.7
42.....	0.9	1.9	1.7	2.0	1.9	2.4	2.1	2.6	2.3	2.9	2.5	3.2	2.8	3.6	3.0	3.7	3.1	3.8
44.....	0.9	2.0	1.8	2.1	2.0	2.5	2.2	2.7	2.4	3.0	2.6	3.3	2.9	3.7	3.1	3.8	3.2	3.9
46.....	1.0	2.1	1.9	2.2	2.1	2.6	2.3	2.8	2.5	3.1	2.7	3.4	3.0	3.8	3.2	3.9	3.3	4.0
48.....	1.0	2.2	2.0	2.3	2.2	2.7	2.4	2.9	2.6	3.2	2.8	3.5	3.1	3.9	3.3	4.0	3.4	4.1
50.....	1.1	2.3	2.1	2.4	2.3	2.8	2.5	3.0	2.7	3.3	2.9	3.6	3.2	4.0	3.4	4.1	3.5	4.2

U.S.F.S., Meyer, 1938.

Table A-31. Volume, old-growth incense-cedar, board feet, Scribner Decimal C rule to an 8-inch top.

Diameter breast high, inches	Number of 16-foot logs							
	1	2	3	4	5	6	7	8
	Volume—board feet, in tons							
2	3	5	11					
4	4	8	13					
6	6	11	15					
8	8	11	18					
10	11	15	21	30				
12	16	21	25	34				
14	19	25	29	39	51			
16	23	31	34	45	57			
18	27	35	40	51	65	83		
20	33	41	46	58	72	92		
22	40	49	55	67	85	107	129	
24	47	57	64	78	94	117	143	
26	55	66	74	87	107	134	165	
28	64	76	85	100	122	151	178	
30	75	87	97	113	133	162	174	196
32	86	100	110	128	148	179	197	217
34	98	113	124	142	165	196	211	238
36	111	128	139	158	182	205	221	261
38	125	143	155	176	202	221	251	295
40	140	157	170	192	221	241	271	308
42	156	172	185	208	241	265	296	344
44	173	189	203	227	265	296	326	380
46	191	207	222	243	285	320	365	420
48	210	226	242	262	305	340	390	457
50	230	247	264	282	326	370	420	497
52	251	269	287	307	348	396	461	540
54	273	292	311	329	371	420	481	587
56	296	316	335	352	396	440	500	637
58	320	341	361	376	420	480	540	697
60	345	367	388	403	440	500	560	760

U.S.F.S., Region 5, 1909-1911

Table A-32. Volume, young-growth, incense-cedar, board feet, International 1/4" rule to a 4-inch top.

Diameter breast high	Total height of tree—feet						Trees
	30	40	50	60	70	80	
	Volume—board feet						
8	3	12	21				3
10	4	15	27				5
12	5	18	33				7
14	6	22	38	57			10
16	7	27	47	66	85		13
18	8	32	57	77	97		17
20	9	38	67	89	113		21
22	10	45	79	103	126	152	26
24	11	53	92	119	144	174	32
26	12	62	107	135	161	197	39
28	13	72	124	151	182	222	47
30	14	83	142	170	201	249	57
32	15	95	162	191	220	277	68
34	16	108	184	214	241	307	81
36	17	122	208	239	265	339	96
38	18	138	234	267	292	374	113
40	19	155	262	298	320	411	132
42	20	174	292	331	350	451	153
44	21	195	324	367	383	494	176
46	22	218	359	406	420	540	201
48	23	243	397	453	460	590	228
50	24	270	438	505	503	643	257
52	25	300	482	562	550	700	288
54	26	332	530	625	600	761	321
56	27	367	581	693	653	826	357
58	28	405	636	767	710	895	395
60	29	446	695	847	760	968	436
Total							30

U.S.F.S., Dunning, 1923

Table A-33. Volume, young-growth incense-cedar, cubic feet.

Diameter breast high	Total length of tree—feet						Total
	20	30	40	50	60	70	
4	0.6	1.3					1.9
5	1.1	2.0					3.1
6	1.6	2.8	3.7	5.0			5.1
7	2.1	3.6	5.1	7.0			7.8
8	2.7	4.5	6.2	8.5			11.2
9	3.4	5.4	7.6	10.2			16.2
10	4.1	6.3	8.8	12.0	16.3		27.4
11			10.0	14.2	17.7		41.9
12			12.2	16.4	21.4	22.5	52.5
13				15.0	23.4	26.7	65.1
14				21.8	28.8	34.8	85.4
15				23.9	33.4	37.9	95.2
16				28.0	36.0	40.0	104.0
17				31.2	38.4	42.4	112.0
18				35.0	43.2	47.1	125.3
19				39.4	48.0	51.0	138.4
20				44.9	53.0	54.0	151.9
Total							331

U.S.F.S.: Dunning, 1927.

Table A-34. Volume, old growth lodgepole pine, board feet, Scribner Decimal C rule to an 8-inch top.

Diameter breast high, inches	Number of 16-foot logs					
	1	2	3	4	5	6
12	2	3	11	18		
14	3	5	14	18		
16	5	12	17	20	31	
18	11	15	21	24	34	
20	16	20	27	30	45	
22	20	25	33	41	55	64
24	25	30	39	50	64	75
26	30	34	46	55	73	80
28	36	42	54	59	90	105
30	40	48	65	70	100	120
32	54	67	75	94	111	130
34	65	78	88	109	130	148
36		70	105	127	142	158
38		82	118	136	162	180
40			134	154	181	205
42			150	174	202	228
44			169	194	224	252
46			188	215	248	276
48				234	272	302

U.S.F.S.

Table A-35. Volume, young-growth Sierra redwood, board feet, Scribner rule to a 6-inch top.

DBH (INCH)	MERCH. HEIGHT (FEET)															
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
12	3	15	30	47	68	92	118	147	178	211	246	284	323	363	408	453
14	6	18	36	57	82	111	142	177	213	250	298	349	391	441	493	549
16	7	22	42	67	97	131	168	209	253	300	351	404	460	519	581	646
18	8	25	49	78	112	151	194	241	292	347	405	467	532	600	672	746
20	9	29	55	89	128	172	221	274	332	395	461	531	605	683	764	849
22	10	32	62	100	143	193	248	308	374	444	518	597	681	768	859	955
24	12	36	69	111	160	215	276	343	416	494	577	665	757	854	956	1062
26	13	40	77	122	176	237	305	379	459	545	636	733	835	943	1055	1172
28	14	43	84	134	193	260	334	415	503	597	697	803	915	1033	1155	1284
30	15	47	91	146	210	282	363	451	547	649	759	874	996	1124	1258	1397
32	16	51	99	158	227	306	393	489	592	703	821	946	1078	1217	1361	1512
34	18	55	106	170	243	329	424	526	638	757	885	1019	1162	1311	1467	1629
36	19	59	114	182	263	353	454	565	684	812	949	1094	1246	1406	1573	1748
38	20	63	122	195	281	378	486	604	731	868	1014	1169	1332	1502	1681	1868
40	22	67	130	208	299	402	517	643	779	923	1080	1245	1418	1600	1791	1989
42	23	71	138	221	317	427	549	682	827	982	1147	1322	1506	1699	1901	2112
44	24	75	146	234	336	452	581	723	876	1040	1214	1399	1594	1799	2013	2236
46	26	80	154	247	355	478	614	763	925	1098	1282	1478	1684	1900	2126	2362
48	27	84	163	260	374	503	647	804	974	1157	1351	1557	1774	2002	2240	2488
50	29	88	171	273	393	529	680	845	1024	1216	1421	1637	1865	2105	2355	2616
52	30	93	179	287	412	555	714	887	1073	1276	1491	1718	1957	2209	2471	2745
54	31	97	188	300	432	581	748	929	1126	1337	1562	1799	2050	2313	2589	2876
56	33	101	196	314	452	609	782	972	1177	1398	1633	1882	2144	2419	2707	3007
58	34	106	205	328	472	635	816	1015	1229	1459	1705	1964	2238	2526	2826	3140
60	36	110	214	342	492	662	851	1058	1281	1522	1777	2048	2333	2633	2946	3273

Table A-36. Volume, young-growth Sierra redwood, cubic feet.

DBH (INCHES)	TOTAL HEIGHT (FEET)													
	40	50	60	70	80	90	100	110	120	130	140	150	160	170
12	7	9	12	15	17	20	23	26	29	33	36	39	43	46
14	9	12	15	19	22	26	30	33	37	42	46	50	54	59
16	11	15	19	23	27	32	36	41	46	51	56	61	67	72
18	13	18	22	27	33	38	44	49	55	61	67	74	80	87
20	16	21	26	32	38	45	51	58	65	72	79	87	94	102
22	18	24	31	37	44	52	59	67	75	83	92	100	109	118
24	21	28	35	43	51	59	68	77	86	95	105	115	125	135
26	23	31	40	48	57	67	77	87	97	108	119	130	141	153
28	26	35	44	54	64	75	86	97	109	121	133	146	159	171
30	29	39	49	60	72	84	96	108	121	135	148	162	176	191
32	32	43	55	67	79	92	106	120	134	149	164	179	195	211
34	35	47	60	73	87	101	116	132	147	163	180	197	214	231
36	39	52	65	80	95	111	127	144	161	178	196	215	234	253
38	42	56	71	87	103	120	138	156	175	194	214	234	254	275
40	45	61	77	94	112	130	149	169	189	210	231	253	275	297
42	49	65	83	101	121	140	161	182	204	226	249	273	296	321
44	53	70	89	109	130	151	173	196	219	243	268	293	319	345
46	56	75	96	117	139	162	185	210	235	261	287	314	341	369
48	60	80	102	125	148	173	198	224	251	278	306	335	364	394
50	64	86	109	133	158	184	211	239	267	296	328	357	388	420
52	68	91	115	141	168	195	224	253	284	315	347	379	412	446
54	72	97	122	149	178	207	237	269	301	334	367	402	437	473
56	76	102	129	158	188	219	251	284	318	353	389	425	462	500
58	81	108	137	167	198	231	263	300	336	373	410	449	488	528
60	85	114	144	176	209	244	279	316	354	393	432	473	514	556

Table A-37. Volume, blue-gum eucalyptus, board feet,
Spaulding rule to a 6-inch top.

DBH	Number of 16-foot logs									
	1	2	3	4	5	6	7	8	9	10
11	20	48	80	117	160					
12	25	52	86	128	170					
13	32	60	97	140	182					
14	42	75	110	152	199					
15	60	91	125	173	220	300				
16	77	110	145	192	240	328				
17	99	133	170	218	269	357	427	512	665	
18	122	160	193	249	300	392	466	555	710	
19		190	226	292	337	432	510	601	770	
20		222	281	322	375	472	555	650	815	
21			300	362	418	520	605	705	875	
22			351	405	460	580	655	760	938	
23			386	452	510	622	715	821	1005	
24			438	502	560	680	772	885	1072	
25				557	618	741	840	952	1145	1279
26					673	803	910	1028	1225	1350
27					742	875	981	1102	1305	1439
28					815	949	1060	1182	1392	1527
29					887	1023	1142	1271	1482	1620
30					965	1101	1228	1358	1572	1715
31					1047	1190	1313	1450	1670	1812
32					1130	1275	1402	1541	1765	1917
33						1367	1502	1640	1820	2020
34						1460	1596	1745	1973	2129
35						1557	1695	1847	2080	2233
36						1655	1798	1947	2185	2342
37						1760	1900	2050	2295	2455
38						1860	2002	2155	2402	
39						1970	2110	2263	2520	
40								2375		
41								2490		

Table A-38. Volume, blue-gum eucalyptus, cubic feet to a 6-inch top.

DBH	Number of 16-foot logs								
	1	2	3	4	5	6	7	8	9
10	8	12							
11	9	13							
12	10	14							
13	11	16	21	28					
14		18	24	30	37				
15		20	27	34	41	49	56		
16			30	39	47	55	63	72	
17			33	43	52	61	71	80	
18			36	47	58	68	79	88	
19			40	53	64	75	87	97	
20				58	70	82	95	106	
21					76	89	103	116	
22					84	97	112	126	
23					90	105	120	136	152
24					97	114	131	148	165
25					104	122	140	159	178
26					112	131	152	171	191
27					120	141	163	184	204
28						152	174	197	219
29						161	186	210	236
30						171	199	224	249
31						182	212	237	263
32						193	224	251	279
33						204	236	266	294
34						216	249	280	309
35						228	263	295	324
36						240	277	309	339
37						252	290	324	354
38						265	304	338	369
39						278	317	352	382
40							331	366	396
41							344	379	409
42								402	
43								404	

Table A-39. Volume, coast live oak, blue oak, California white oak, interior live oak, tanoak, madrone, for California Central Coast, cubic feet to a 4-inch top.

DBH inches	HEIGHT IN FEET											
	5	10	15	20	25	30	35	40	45	50	55	
4	0.3	0.4	0.6	0.7	0.9	1.0						
6	0.6	1.1	1.4	1.8	2.1	2.4	2.7	3.0	3.3			
8	1.2	2.0	2.7	3.3	4.0	4.6	5.1	5.7	6.2	6.7	7.2	
10		3.2	4.4	5.4	6.4	7.4	8.3	9.2	10.1	10.9	11.8	
12		4.8	6.5	8.1	9.8	11.0	12.4	13.7	15.0	16.3	17.5	
14		6.7	9.1	11.3	13.4	15.4	17.3	19.2	21.0	22.7	24.5	
16			12.1	15.1	17.9	20.6	23.2	25.6	28.0	30.4	32.7	
18			15.7	19.5	23.1	26.6	29.9	33.1	36.2	39.3	42.2	
20			19.7	24.5	29.1	33.4	37.5	41.6	45.5	49.4	53.1	
22				30.2	35.8	41.1	46.3	51.2	56.0	60.7	65.3	
24				36.5	43.2	49.7	55.9	61.9	67.7	73.4	78.9	
26				43.4	51.4	59.1	66.5	73.6	80.6	87.3	93.9	
28				51.0	60.4	69.4	78.1	86.5	94.6	102.5	110.3	
30					70.2	80.7	90.7	100.5	109.9	119.1	128.1	
32					80.8	92.8	104.4	115.6	126.5	137.1	147.4	
34					92.1	105.9	119.1	131.9	144.3	156.4	168.2	
36					104.3	119.9	134.9	149.3	163.4	177.1	190.4	
38						134.8	151.7	168.0	183.7	199.1	214.2	
40						150.7	169.6	187.8	205.4	222.5	239.4	
42						167.6	188.5	208.6	228.4	247.5	266.2	
44						185.4	208.6	231.0	252.7	273.8	294.5	
46						204.2	229.7	254.4	278.3	301.6	324.4	
48								279.0	305.3	330.8	355.8	
50								304.9	333.6	361.5	388.8	
52								332.0	363.3	393.7	423.4	
54								360.4	394.3	427.3	459.6	

DBH	HEIGHT IN FEET										
	60	65	70	75	80	85	90	95	100	105	110
4											
6											
8	7.7	8.2									
10	12.6	13.4	14.1								
12	18.7	19.9	21.0								
14	26.1	27.8	29.4								
16	34.9	37.1	39.5	41.4	43.5	45.6	47.6	49.6	51.6	53.5	55.5
18	45.1	48.0	50.8	53.5	56.2	58.9	61.5	64.1	66.6	69.2	71.7
20	56.7	60.3	63.8	67.3	70.7	74.0	77.3	80.6	83.8	86.9	90.1
22	69.8	74.2	78.5	82.7	86.9	91.0	95.1	99.1	103.0	107.0	110.8
24	84.3	89.6	94.8	100.0	105.0	110.0	114.9	119.7	124.5	129.2	133.9
26	100.3	106.6	112.8	118.9	125.0	130.9	136.7	142.5	148.2	153.8	159.3
28	117.9	125.3	132.6	139.7	146.8	153.7	160.6	167.4	174.0	180.6	187.2
30	136.9	145.5	154.0	162.3	170.5	178.6	186.6	194.4	202.2	209.9	217.4
32	157.5	167.5	177.2	186.8	196.2	205.5	214.7	223.7	232.6	241.5	250.2
34	179.7	191.0	202.7	213.1	223.8	234.4	244.9	255.2	265.4	275.5	285.4
36	203.5	216.3	228.9	241.3	253.4	265.4	277.3	289.0	300.5	311.9	323.2
38	228.9	243.3	257.4	271.3	285.0	298.5	311.8	325.0	337.9	350.8	363.4
40	255.8	272.0	287.8	303.3	318.6	333.7	348.6	363.3	377.8	392.1	406.3
42	284.5	302.4	320.0	337.3	354.3	371.1	387.6	403.9	420.1	436.0	451.7
44	314.7	334.5	354.0	373.1	392.0	410.5	428.8	446.9	464.7	482.4	499.8
46	346.6	368.5	389.9	411.0	431.7	452.2	472.3	492.2	511.9	531.3	550.5
48	380.2	404.2	427.7	450.8	473.6	496.0	518.1	539.9	561.5	582.8	603.8
50	415.5	441.7	467.4	492.6	517.5	542.0	566.2	590.0	613.6	636.8	659.6
52	452.5	481.0	508.9	536.5	563.5	590.2	616.5	642.5	668.1	693.5	718.6
54	491.1	522.1	552.4	582.3	611.7	640.7	669.2	697.4	725.3	752.8	780.0

Table A-40 Volume, red alder, board feet, Scribner Dec. C rule to a 10-inch top.

D. B. H. inches	Number of 9-foot logs									
	1	2	3	4	5	6	7	8	9	10
	Volume—board feet, in tons									
10.....	3									
11.....	3									
12.....	3	6	9							
13.....		6	9	11	14	16				
14.....		7	10	12	16	18				
15.....		8	10	14	17	21	25	30		
16.....		8	11	16	19	23	27	32	43	49
17.....		10	12	18	22	26	30	36	46	53
18.....			14	20	25	29	33	40	46	53
19.....			16	22	27	32	37	44	50	58
20.....			18	25	30	35	42	48	54	62
21.....			20	28	33	40	45	52	59	67
22.....				31	37	44	50	56	64	73
23.....				35	41	48	55	62	69	77
24.....					46	54	60	66	74	83
25.....					51	59	65	72	79	89
26.....					57	64	70	77	84	94
27.....					70	78	82	90	96	106
28.....					76	82	88	96	106	111
29.....					82	88	94	101	111	

U.S.F.S. Meyer, 1931

Table A-41. Volume, young-growth madrone, tanook, and black oak, high site, board feet (8-inch top), cubic ft. (4-inch top).

D.b.h. (inches)	Board Feet Volume, Scribner Dec. C			Cubic Feet Volume		
	Pacific madrone	Tanoak	Calif. black oak	Pacific madrone	Tanoak	Calif. black oak
4	—	—	—	1	—	—
5	—	—	—	2	1	1
6	—	—	—	3	2	3
7	—	—	—	5	4	5
8	—	—	—	7	5	7
9	1	1	1	10	8	9
10	2	2	2	13	10	12
11	3	3	4	16	13	15
12	5	4	5	20	16	20
13	7	5	7	25	19	24
14	9	6	9	30	23	29
15	12	8	12	36	27	34
16	15	10	15	43	32	40
17	18	12	18	50	37	46
18	22	15	21	58	43	52
19	26	18	25	67	49	60
20	30	20	29	76	55	67
21	35	24	32	86	62	75
22	40	27	38	97	69	84
23	45	31	43	109	77	94
24	51	35	48	121	85	104
25	57	40	54	135	94	114
26	64	44	60	149	103	125
27	71	50	66	164	113	137
28	78	55	73	180	123	149
29	86	61	80	196	134	162
30	94	67	88	214	145	176

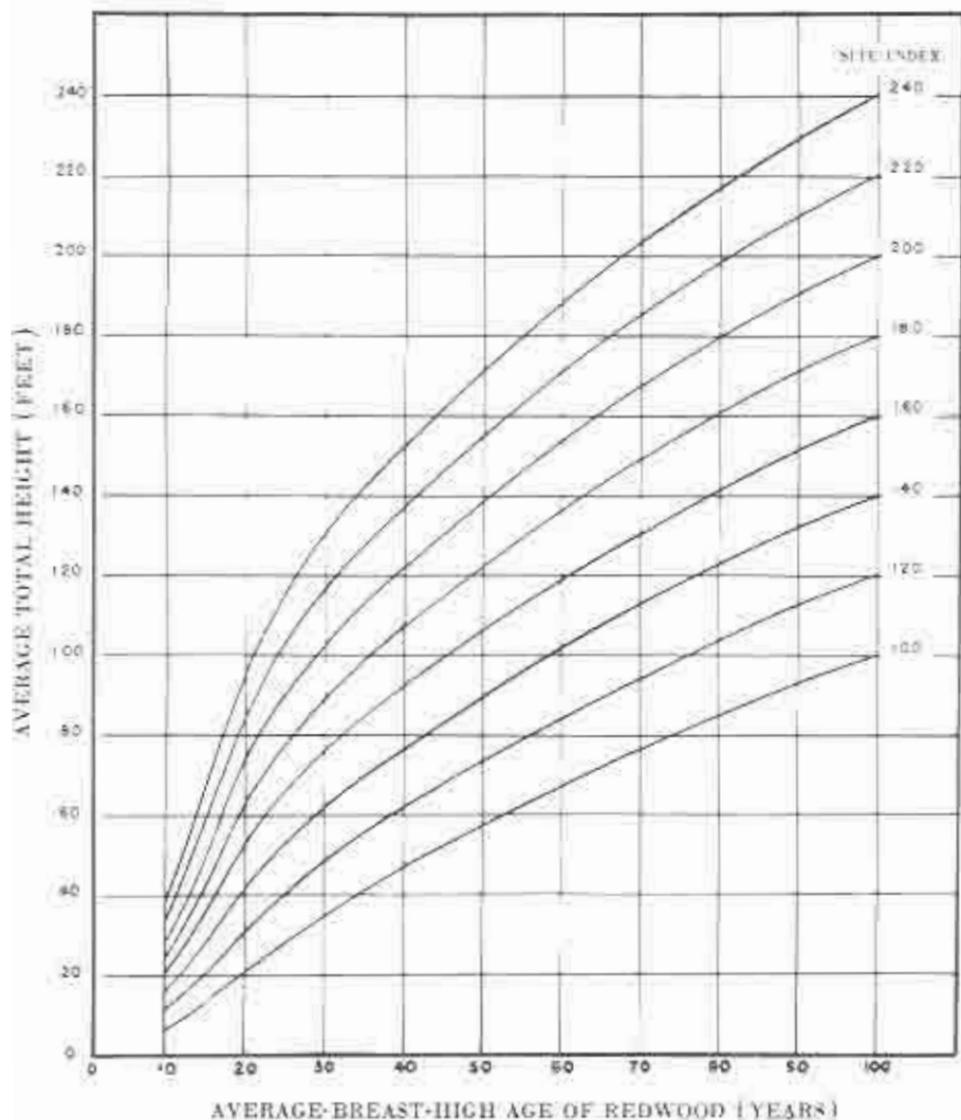


Figure A-1. Site index values of dominant redwood by height and breast-high age classes.

U.C., Lindquist and Palley, 1963

Table A-42. Yield table, young-growth coast redwood stand, all species, per acre, board feet, international $\frac{1}{4}$ " rule, trees larger than 10.5 inches dbh to an 8-inch top.

Age (years)	Diameter (dbh)							
	10	12	14	16	18	20	22	24
20		600	2,500	7,000	14,500	23,000	35,000	46,500
30	900	3,100	9,500	19,600	31,500	32,300	71,600	93,200
40	2,800	8,800	20,400	36,900	57,000	82,100	108,500	137,500
50	7,300	16,500	33,700	55,300	82,000	112,700	146,000	181,300
60	14,400	27,400	48,900	74,500	106,100	142,100	180,900	221,000
70	22,800	40,400	65,000	91,500	130,000	170,900	214,400	259,500
80	32,400	53,700	81,500	114,300	153,500	198,200	244,800	291,500
90	44,000	67,400	98,300	133,800	176,400	224,100	273,000	325,700
100	55,700	81,300	114,600	152,300	198,100	248,500	301,700	357,600

U.C. Lindquist and Palley, 1963

Table A-43. Yield table, young-growth coast redwood stand, all species, per acre, cubic feet, trees larger than 4.5 inches dbh to a 4-inch top.

Age (years)	Diameter							
	10	12	14	16	18	20	22	24
20	200	450	1,000	2,270	3,090	5,010	7,860	9,940
30	500	1,050	2,500	4,400	7,040	10,000	13,000	16,200
40	1,000	2,300	4,500	7,250	10,350	14,250	18,000	22,000
50	2,100	3,800	6,800	10,100	14,000	18,500	23,000	27,800
60	4,000	5,820	9,230	12,900	17,450	22,480	27,580	33,020
70	5,200	8,000	11,750	15,880	20,820	26,350	32,000	38,000
80	6,900	10,140	14,190	18,640	23,090	29,080	36,060	42,540
90	8,800	12,260	16,580	21,340	27,050	33,450	39,940	46,860
100	10,600	14,280	18,880	23,940	30,010	36,820	43,720	51,080

U.C. Lindquist and Palley, 1963

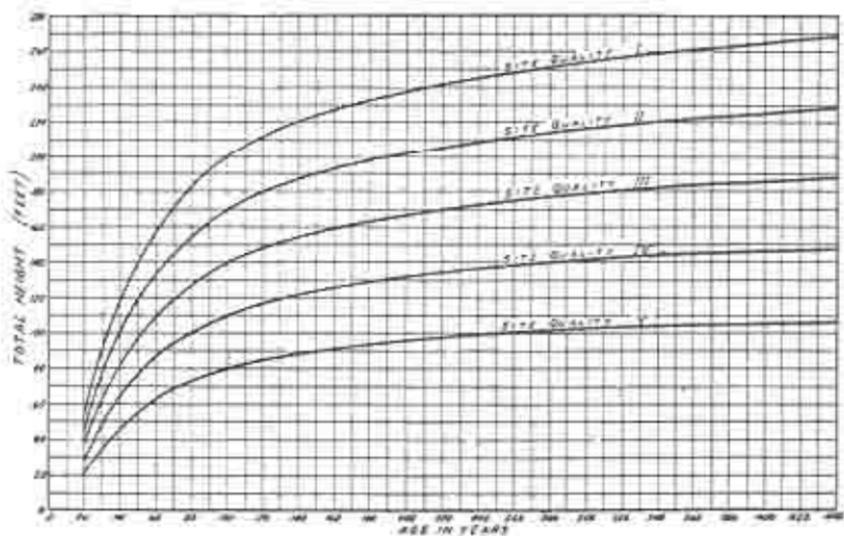


Figure A-2. Site index values of dominant and codominant Douglas-fir trees
 U.S.P.S. McArdle, Meyer, Bruce, 1949

Table A-44. Yield table, Douglas-fir, fully stocked acre, board feet, Scribner rule, trees larger than 12 inches dbh to an 8-inch top.

Age/Site Index	80	90	100	110	120	130	140	150	160	170	180	190	200	210
	<i>Dbh. ft.</i>	Dbh. ft.	Dbh. ft.	Dbh. ft.	Dbh. ft.	Dbh. ft.	Dbh. ft.	Dbh. ft.	Dbh. ft.	Dbh. ft.	Dbh. ft.	Dbh. ft.	Dbh. ft.	Dbh. ft.
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	1,100	2,600	4,800	8,100	12,500	18,000	23,800	29,800	36,200	42,800	49,300	55,900	62,000	68,300
70	2,400	5,300	9,000	14,000	20,000	27,000	35,200	42,500	50,000	57,200	64,000	71,200	78,200	85,000
80	4,400	8,600	13,000	20,100	28,600	37,000	45,700	54,300	62,100	70,000	78,000	85,400	92,500	99,800
90	6,900	12,000	18,600	26,000	35,700	45,000	55,000	64,000	72,900	81,000	89,200	97,200	104,800	112,200
100	9,600	15,400	22,800	31,400	42,000	52,400	62,800	72,400	81,800	90,400	98,900	107,100	115,100	122,900
110	12,200	18,900	26,700	36,300	47,000	58,500	69,400	79,400	88,500	96,300	104,000	111,500	118,700	125,200
120	14,700	21,800	30,400	40,700	52,400	63,900	75,000	85,500	95,500	105,100	114,100	122,500	131,100	138,900
130	17,000	24,600	33,800	44,700	56,700	68,700	80,000	91,000	101,100	111,000	120,000	128,900	137,700	145,100
140	19,200	27,200	36,800	48,300	60,600	72,900	84,500	95,900	106,200	116,300	125,500	134,500	143,500	152,000
150	21,300	29,900	39,700	51,600	64,000	76,600	88,600	100,300	111,000	121,300	130,700	139,500	148,700	157,200
160	23,300	31,900	42,200	54,600	67,100	80,100	92,400	104,400	115,600	125,700	135,400	144,400	153,500	162,000

U.S.F.S., McArdle, Meyer, Bruce, 1949.

Table A-45. Yield Table, Douglas-fir, fully stocked acre, cubic feet, trees larger than 12 inches dbh.

Age/Site Index	80	90	100	110	120	130	140	150	160	170	180	190	200	210
	<i>Cu. ft.</i>	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0	170	470	850	1,430	2,200	3,100	4,100	5,200	6,300	7,300	8,400	9,200	10,000
70	310	680	1,200	1,990	3,020	4,225	5,620	7,000	8,280	9,400	10,400	11,300	12,000	12,700
80	720	1,360	2,190	3,400	4,970	6,550	8,000	9,400	10,650	11,820	12,750	13,550	14,300	14,900
90	1,230	2,110	3,300	4,800	6,500	8,300	9,940	11,380	12,570	13,720	14,650	15,500	16,230	16,900
100	1,820	2,960	4,370	6,100	8,050	9,800	11,430	12,850	14,100	15,200	16,150	17,000	17,800	18,500
110	2,410	3,990	5,750	7,770	10,130	12,620	14,800	16,300	17,610	18,740	19,700	20,500	21,200	21,800
120	3,000	4,500	6,390	8,650	10,920	13,520	15,300	16,700	17,850	18,850	19,750	20,550	21,250	21,850
130	3,570	5,150	7,200	9,760	12,420	14,300	15,700	16,900	17,800	18,600	19,350	20,050	20,700	21,300
140	4,120	5,720	7,970	10,750	13,600	15,620	16,810	17,750	18,500	19,150	19,750	20,350	20,900	21,450
150	4,600	6,190	8,600	11,500	14,500	16,600	17,800	18,650	19,350	19,950	20,500	21,050	21,600	22,150
160	5,000	6,600	9,200	12,300	15,500	17,700	18,900	19,700	20,350	20,900	21,450	22,000	22,550	23,100
170	5,330	6,950	9,750	12,700	16,000	18,300	19,500	20,300	20,900	21,450	22,000	22,550	23,100	23,650

U.S.F.S., McArdle, Meyer, Bruce, 1949.

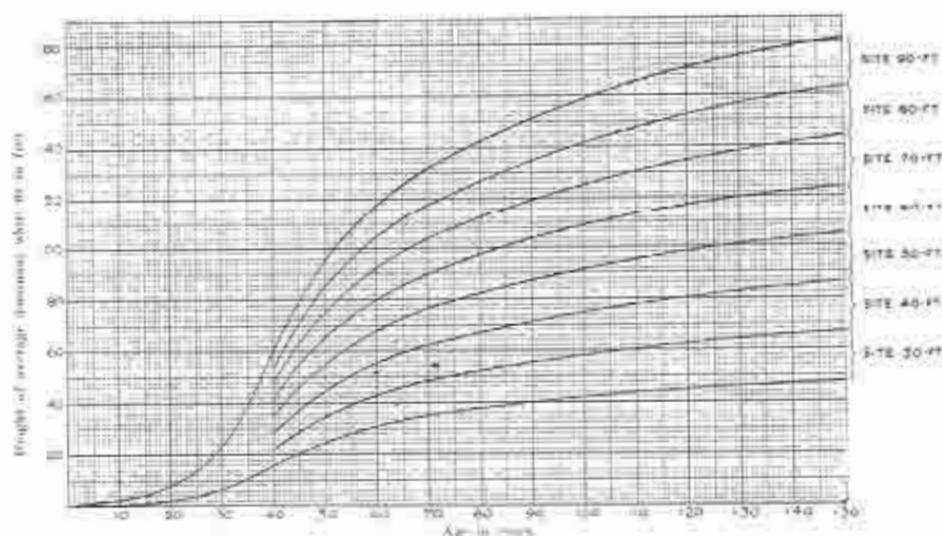


Figure A-3 Site index values of white fir (*A. concolor*) trees

U. C. Schumacher, 1926

Table A-46 Yield table, normal, white fir (*A. concolor*), per acre, board feet (in tens), International $\frac{1}{8}$ rule, trees 8 inches dbh and over to a 5-inch top.

Age	Site Index at 50 Years					
	40	50	60	70	80	90
	board feet in tens					
50	220	970	2060	3190	4320	5240
60	920	2110	3650	5260	6900	8150
70	1570	3050	5000	5960	8930	10440
80	2110	3760	6000	8220	10410	12200
90	2560	4330	6750	9180	11770	13610
100	2900	4840	7400	10070	12740	14780
110	3170	5190	7920	10500	13610	15600
120	3390	5450	8360	11310	14260	16380
130	3600	5780	8810	11810	14850	17100
140	3750	5970	9140	12380	15300	17670
150	3880	6160	9380	12540	15700	18130

U. C. Schumacher, 1926

Table A-47. Yield table, normal, white fir (*A. concolor*), per acre, cubic feet in tens, trees 4 inches dbh and over.

Age	Site Index at 50 Years						
	30	40	50	60	70	80	90
	cubic feet in tens:						
50	213	270	380	530	870	810	900
60	300	380	530	740	940	1140	1260
70	360	450	640	900	1140	1370	1520
80	400	500	710	1000	1270	1520	1690
90	430	550	770	1080	1370	1660	1840
100	460	590	820	1150	1460	1760	1960
110	480	610	860	1200	1540	1850	2050
120	500	635	890	1250	1590	1920	2130
130	515	655	920	1295	1640	1980	2200
140	530	670	940	1330	1680	2030	2260
150	545	690	965	1360	1720	2080	2310

U.C., Schumacher, 1926

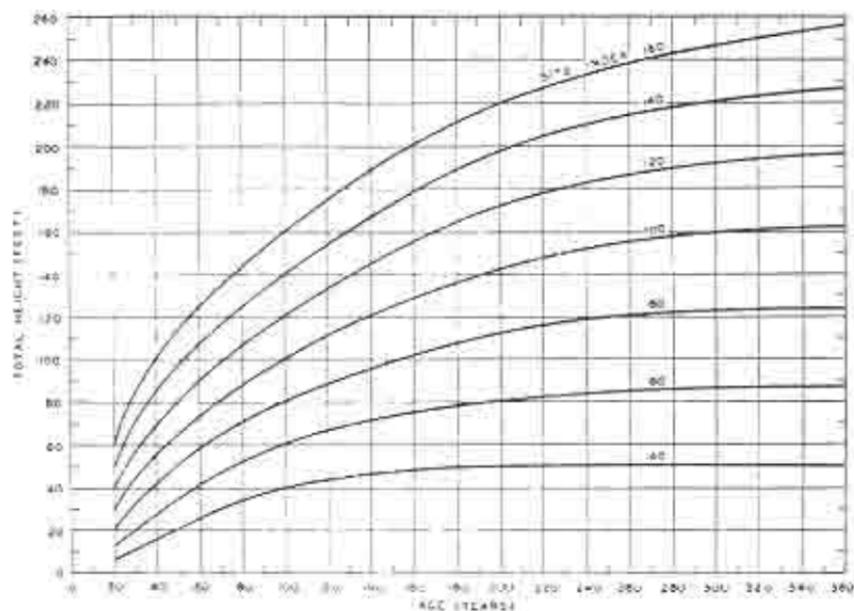


Figure A-4. Site index values of dominant and codominant ponderosa pine trees of average breast high diameter.

U.S.F.S., Meyer, 1938

Table A-48. Yield table, ponderosa pine, fully stocked acre, board feet, Scribner rule, trees 11.6 inches dbh and over.

Age (years)	Volume per acre, by site index—																										
	40		50		60		70		80		90		100		110		120		130		140		150		160		
	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.	Bo. ft.
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200																											

U. S. F. S., Meyer, 1935.

Table A-49. Yield table, ponderosa pine, fully stocked acre, cubic feet, trees 11.6 inches dbh and over.

Age (years)	Volume per acre, by site index—																										
	40		50		60		70		80		90		100		110		120		130		140		150		160		
	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	
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U. S. F. S., Meyer, 1935.

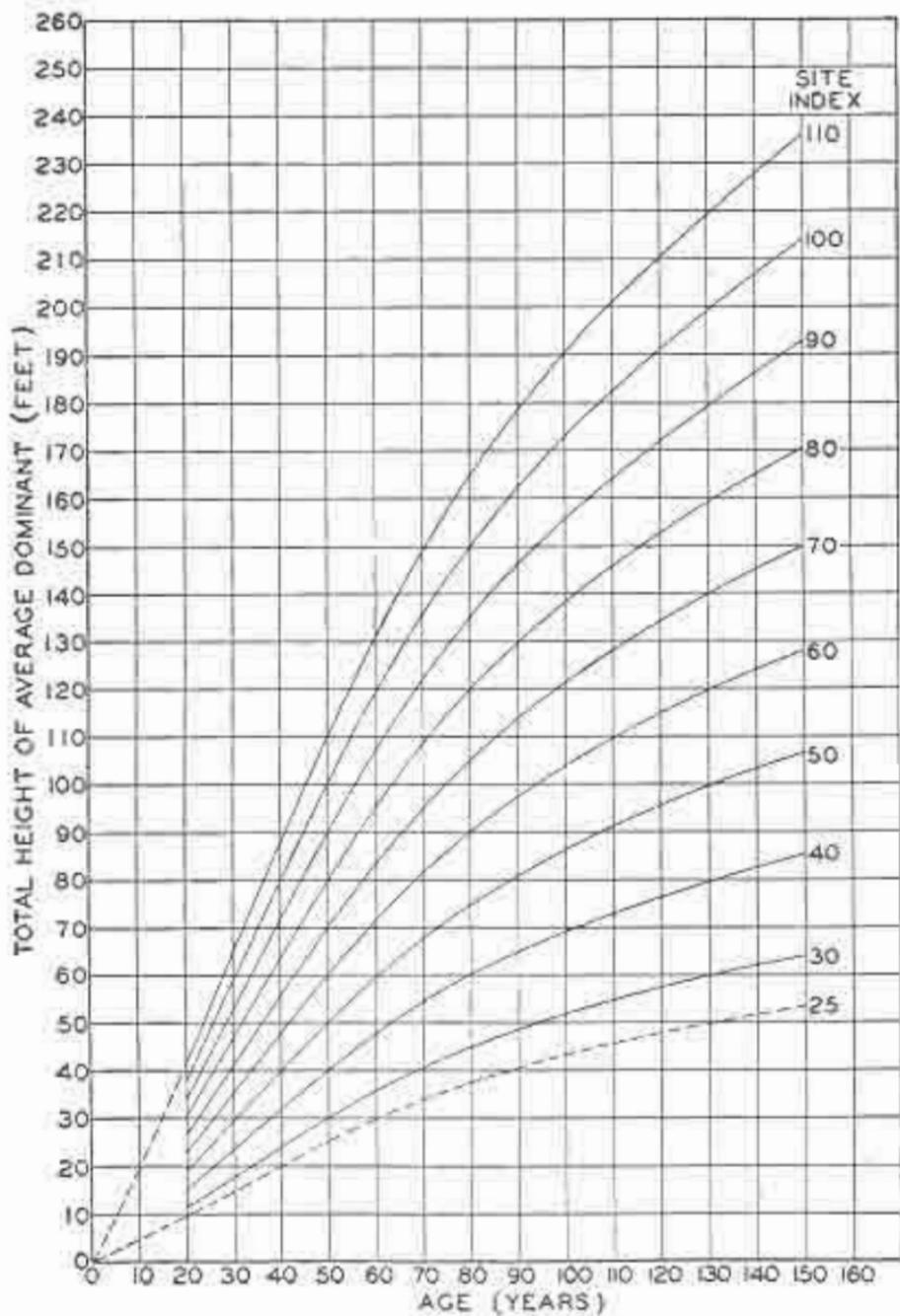


Figure A-5. Site index values of dominant trees in mixed conifer stands in California of average basal area.

Table A-50. Yield table, mixed conifer stands, California, per acre, board feet, International $\frac{1}{8}$ " rule, trees 8 inches dbh and over to a 5-inch top.

Age (years)	Board feet per acre on site index—									
	25	30	40	50	60	70	80	90	100	110
30			53	100	1,050	2,120	3,840	6,080	8,670	11,110
40	705	840	1,740	3,210	5,540	9,110	14,300	20,000	26,800	33,450
50	2,300	2,580	4,950	8,500	13,250	20,140	28,850	40,100	50,800	60,700
60	4,725	5,100	9,470	15,750	23,460	34,830	47,900	61,860	76,730	90,200
70	8,330	9,050	17,450	28,500	43,460	65,850	95,400	125,250	155,100	184,900
80	11,900	12,850	24,950	42,700	65,350	97,650	143,400	193,400	253,800	313,900
90	15,450	16,580	32,950	57,000	86,000	128,000	186,750	254,400	333,200	412,000
100	18,600	20,000	39,100	68,850	103,150	154,250	223,400	303,400	394,200	495,600
110	21,030	22,900	45,100	81,450	121,100	178,000	254,200	345,400	448,200	562,600
120	24,600	26,550	52,400	95,750	142,400	210,000	303,500	406,400	520,200	644,700
130	27,000	29,000	58,350	108,400	162,500	239,000	324,500	430,400	554,200	688,900
140	29,330	31,450	63,250	119,600	180,500	266,000	358,400	474,200	608,200	752,900
150	31,900	34,000	68,000	129,550	197,000	291,000	395,200	518,000	662,000	825,600

U. S. F. S., Dunning, 1933

Table A-51. Yield table, average mixed conifer stands, California, per acre, cubic feet, trees 8 inches dbh and over.

Age (years)	Volume in cubic feet per acre on site index—										
	25	30	40	50	60	70	80	90	100	110	
30			1,075	1,424	1,800	2,200	2,650	3,200	3,770	4,380	4,950
40	1,040	1,400	2,410	3,080	3,770	4,530	5,500	6,500	7,550	8,650	9,800
50	2,300	2,580	4,480	5,480	6,420	7,500	8,700	9,900	11,100	12,400	13,800
60	2,350	3,330	4,510	6,790	7,920	9,350	10,900	12,300	13,900	15,500	17,100
70	3,560	4,000	5,350	6,850	8,190	9,800	11,200	12,700	14,300	15,900	17,500
80	4,000	4,340	6,160	7,800	9,320	11,000	12,800	14,600	16,400	18,200	20,000
90	4,420	5,000	6,730	8,600	10,500	12,700	15,200	17,800	20,400	23,000	25,600
100	4,400	5,000	7,400	9,420	11,500	13,900	16,600	19,500	22,600	25,800	29,000
110	5,240	5,950	8,000	10,200	12,300	14,900	17,900	21,000	24,200	27,500	30,800
120	5,900	6,390	8,560	10,900	13,200	16,000	19,100	22,600	26,000	29,600	33,200
130	5,900	6,700	9,080	11,500	14,000	17,000	20,300	24,000	27,900	31,900	35,900
140	6,220	7,070	9,550	12,200	14,750	17,750	21,400	25,200	29,000	32,900	36,800
150	6,350	7,400	10,000	12,700	15,450	18,500	22,400	26,400	30,400	34,400	38,400

U. S. F. S., Dunning, 1938

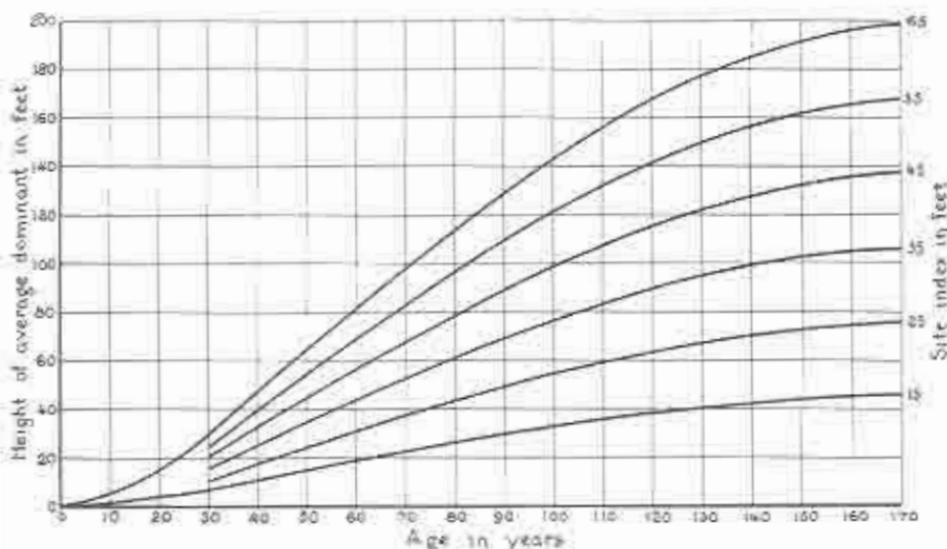


Figure A-6 Site index values of average dominant red fir trees.

U. C., Schumacher, 1928

Table A-52. Yield table, normal, red fir, per acre, board feet in tens, International $\frac{1}{4}$ " rule, trees 8 inches dbh and over to a 5-inch top.

Age	Site Index at 50 Years				
	20	30	40	50	60
	board feet in tens				
50	—	210	605	1200	1920
60	150	695	1440	2380	3370
70	495	1460	2500	3680	5040
80	1030	2360	3710	5200	7110
90	1780	3380	5020	7050	9430
100	2560	4450	6570	9120	11900
110	3460	5770	8400	11250	14500
120	4400	7280	10450	13800	17200
130	5280	8600	12200	15600	19600
140	6040	9660	13600	17300	21600
150	6700	10800	14500	18400	23000

U.C. Schumacher, 1928

Table A-53. Yield table, normal, red fir, per acre, cubic feet in tens, trees 2 inches dbh and over.

Age	Site Index at 50 Years				
	20	30	40	50	60
	cubic feet in tens				
50	180	245	320	405	500
60	245	340	435	560	695
70	320	440	570	720	900
80	405	555	720	905	1140
90	495	680	880	1110	1385
100	595	815	1055	1340	1670
110	720	980	1270	1610	2010
120	845	1165	1510	1915	2390
130	965	1320	1715	2170	2720
140	1060	1455	1895	2395	3000
150	1135	1560	2010	2550	3180

U.C. Schumacher, 1928

Table A-54. Revised Scribner Decimal C log rule, logs 8 to 20 feet long, board feet in tens.

DBH inches	Log Length in Feet							
	8	10	12	14	16	17	18	20
4	1	1	1	1	1	1	1	1
5	1	1	1	1	2	2	2	2
6	1	1	1	2	2	3	3	3
7	1	2	2	2	3	3	3	4
8	2	2	3	3	4	4	4	5
9	3	3	4	4	5	6	6	7
10	3	4	4	5	7	7	8	8
11	4	5	6	7	8	8	9	10
12	5	6	7	8	10	10	11	12
13	6	7	9	10	11	12	13	14
14	7	9	11	12	14	15	16	18
15	8	10	12	14	16	17	18	20
16	9	12	14	16	18	20	21	23
17	11	13	16	19	21	23	24	27
18	12	15	18	21	24	25	27	30
19	14	17	21	24	28	30	31	35
20	15	19	23	27	30	32	34	38
21	17	21	25	29	33	35	38	42
22	19	24	28	33	38	40	42	47
23	20	25	30	35	40	43	45	50
24	23	29	34	40	46	49	52	57
25	25	31	37	44	50	53	56	62
26	27	34	41	48	55	58	62	68
27	29	36	44	51	58	62	65	73
28	30	38	46	53	61	65	68	76
29	33	41	49	57	66	70	74	82
30	36	44	53	62	71	75	80	89
31	37	46	55	64	74	78	83	92
32	39	49	59	69	78	83	88	98
33	40	50	60	70	80	85	90	100
34	44	55	66	77	88	93	98	109
35	46	58	69	81	92	98	104	115
36	51	64	77	90	103	109	116	129
37	53	67	80	93	107	113	120	133
38	56	70	84	98	112	119	126	140
39	60	75	90	105	120	128	135	150
40	64	79	95	111	127	135	143	159
41	67	84	101	117	134	143	151	168
42	70	87	105	122	140	148	157	174
43	74	93	111	130	148	157	167	185
44	76	95	114	133	152	161	171	190
45	79	99	119	139	159	168	178	198
46	83	104	124	145	166	176	186	207
47	86	108	130	151	173	184	194	216
48	90	112	135	157	180	191	202	225
49	94	117	140	164	187	199	211	234

DBH inches	Log Length in Feet							
	8	10	12	14	16	17	18	20
51	97	122	146	170	195	207	219	243
52	101	127	152	177	202	215	228	253
53	105	132	158	184	210	224	237	263
54	109	137	164	191	218	232	246	273
55	113	142	170	198	227	241	255	283
56	118	147	176	206	235	250	264	294
57	122	152	183	213	244	259	274	304
58	126	158	189	221	252	268	284	315
59	131	163	196	229	261	278	294	327
60	135	169	203	237	270	287	304	338
61	140	175	210	245	280	297	315	350
62	145	181	217	253	289	307	325	361
63	149	187	224	261	299	317	336	373
64	153	193	232	270	309	328	348	386
65	159	199	239	279	319	339	358	398
66	165	206	247	288	329	350	370	411
67	169	212	254	297	339	360	381	424
68	175	219	262	306	350	371	393	437
69	181	226	271	316	361	384	406	451
70	186	232	279	325	372	395	418	465
71	191	239	287	335	383	407	431	479
72	197	247	296	345	395	419	444	493
73	203	254	305	356	406	432	457	508
74	209	262	314	366	418	445	471	523
75	215	269	323	377	430	457	484	538
76	221	277	332	387	443	470	498	553
77	227	284	341	398	455	483	512	569
78	234	293	351	410	468	497	527	585
79	241	301	361	421	481	511	541	601
80	247	309	371	433	494	525	556	618
81	254	317	381	444	508	540	571	635
82	261	326	391	456	521	554	586	652
83	267	334	401	468	535	568	602	668
84	275	343	412	481	549	584	618	687
85	281	351	421	491	561	596	631	702
86	287	359	431	503	575	611	646	718
87	295	368	442	516	589	626	663	737
88	301	377	452	527	603	640	678	755
89	308	385	462	539	616	655	693	770
90	315	393	472	551	629	669	708	787

Prepared by Northwest Log Rule Advisory Group, 1972, recognized by C.D.F., U.S.F.S., State Board of Equalization, and others.

Table A-55 Log volume, cubic feet, Huber formula.

Length (feet)	Contents (cubic feet) according to middle diameter, in inches—																														
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	
6	0.25	0.25	0.5	1	1	1	2	2	3	3	4	4	5	5	6	6	7	8	8	10	11	12	13	14	15	16	17	18	20	21	22
8	.25	.5	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	10	11	12	13	14	15	16	17	18	20	21	22	
10	.25	.5	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	10	11	12	13	14	15	16	17	18	20	21	22	
12	.5	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	10	11	12	13	14	15	16	17	18	20	21	22	22	
14	.5	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	10	11	12	13	14	15	16	17	18	20	21	22	22	
16	.5	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	10	11	12	13	14	15	16	17	18	20	21	22	22	
18	.5	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	10	11	12	13	14	15	16	17	18	20	21	22	22	
20	.5	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	10	11	12	13	14	15	16	17	18	20	21	22	22	
22	.5	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	10	11	12	13	14	15	16	17	18	20	21	22	22	
24	.5	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	10	11	12	13	14	15	16	17	18	20	21	22	22	
26	.5	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	10	11	12	13	14	15	16	17	18	20	21	22	22	
28	.5	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	10	11	12	13	14	15	16	17	18	20	21	22	22	
30	.5	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	10	11	12	13	14	15	16	17	18	20	21	22	22	
32	.5	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	10	11	12	13	14	15	16	17	18	20	21	22	22	
34	.5	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	10	11	12	13	14	15	16	17	18	20	21	22	22	
36	.5	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	10	11	12	13	14	15	16	17	18	20	21	22	22	
38	.5	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	10	11	12	13	14	15	16	17	18	20	21	22	22	
40	.5	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	10	11	12	13	14	15	16	17	18	20	21	22	22	

Length
(feet)

Contents (cubic feet) according to middle diameter, in inches—

	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	
4	24	25	27	28	30	32	33	35	37	38	40	42	44	46	48	50	52	55	57	59	61	64	66	68	71	73	76	79	
5	30	32	35	37	40	43	44	48	52	55	58	61	63	66	69	72	75	79	82	85	88	92	95	99	103	106	110	114	118
6	36	38	42	45	49	52	55	58	62	65	69	72	75	79	82	85	89	92	95	99	103	106	110	114	118	122	126	130	134
7	42	44	47	49	52	55	58	61	64	67	71	74	77	81	84	88	92	95	99	103	107	111	115	120	124	128	133	137	
8	48	50	53	55	58	62	65	69	73	77	81	84	88	92	96	101	105	109	113	118	123	127	132	137	142	147	152	157	
9	53	57	60	64	67	71	75	79	83	87	91	95	99	104	108	113	118	123	128	133	138	143	148	154	159	165	171	177	
10	59	63	67	71	75	79	83	87	92	96	101	106	110	115	120	125	131	136	142	147	152	159	165	171	177	183	190	196	
11	65	69	73	78	82	87	91	96	101	106	111	116	121	127	133	138	144	150	156	162	169	175	181	188	195	202	209	216	
12	71	75	80	85	90	95	100	105	110	115	121	127	133	138	145	151	157	164	170	177	184	191	198	205	213	220	228	236	
13	77	82	87	92	97	102	108	113	119	125	131	137	144	150	157	163	170	177	184	192	199	207	214	222	230	238	247	255	
14	83	88	94	99	105	111	116	122	128	135	141	148	155	162	169	176	183	191	199	206	214	223	231	239	248	257	266	275	
15	89	95	100	106	112	118	124	131	138	144	151	158	166	173	181	188	196	205	213	221	230	238	247	257	266	275	285	295	
16	95	101	107	113	119	125	132	140	147	154	161	169	177	185	193	201	210	218	227	236	245	254	264	274	284	294	304	314	
17	101	107	114	120	127	134	141	148	156	164	173	180	188	196	205	214	223	232	241	250	259	269	279	289	299	309	319	329	
18	107	113	120	127	134	142	149	157	165	173	182	190	199	208	217	226	235	245	255	265	275	285	295	305	315	325	335	345	
19	113	120	127	134	142	150	158	166	174	183	192	201	210	219	229	238	248	258	268	278	288	298	308	318	328	338	348	358	
20	119	126	134	141	149	158	166	175	184	192	202	211	221	231	241	251	261	271	281	291	301	311	321	331	341	351	361	371	
21	125	132	140	148	157	165	174	183	192	202	212	222	232	242	252	262	272	282	292	302	312	322	332	342	352	362	372	382	
22	131	139	147	156	164	173	182	192	202	212	222	232	242	252	262	272	282	292	302	312	322	332	342	352	362	372	382	392	
23	137	145	154	163	172	181	191	201	211	221	231	241	251	261	271	281	301	311	321	331	341	351	361	371	381	391	401	411	
24	143	151	160	170	179	189	199	209	219	229	239	249	259	277	289	302	314	327	340	354	368	382	396	411	425	440	454	471	
25	148	158	167	177	187	197	207	217	227	237	247	257	267	289	303	314	327	341	355	369	384	398	412	428	443	459	475	491	
26	154	164	174	184	194	205	216	227	238	250	262	275	287	300	313	327	340	355	369	383	398	414	429	445	461	477	494	511	
27	160	170	180	191	202	213	224	236	248	260	272	285	298	312	325	339	354	368	383	398	414	429	446	462	478	495	513	530	
28	166	177	187	198	209	221	232	244	257	269	282	296	309	323	337	352	367	382	397	413	429	445	462	479	496	514	532	550	
29	172	183	194	205	217	228	241	253	266	279	292	306	320	335	349	364	380	395	411	428	444	461	478	496	514	532	551	569	
30	178	189	200	212	224	236	249	262	276	289	303	317	331	346	361	377	393	409	426	442	460	477	495	513	532	550	569	588	
31	184	195	207	219	231	244	257	271	284	298	313	327	342	358	373	389	406	423	440	457	475	493	511	530	549	569	589	609	
32	190	202	214	227	239	252	265	279	293	308	323	338	353	369	385	402	419	436	454	472	490	509	528	547	567	587	608	628	
33	196	208	220	233	246	260	274	289	304	319	334	349	364	381	398	415	432	450	468	487	506	525	544	564	584	605	627	648	
34	202	214	227	240	254	268	282	297	312	327	343	359	375	392	410	427	445	464	482	501	521	541	561	582	603	624	646	668	
35	208	221	234	247	261	276	291	307	323	339	357	375	393	412	431	450	469	488	508	528	548	569	590	611	632	654	676	698	
36	214	227	241	254	269	284	299	314	330	346	363	380	398	415	434	452	471	491	511	531	552	573	594	616	638	661	683	707	
37	220	233	247	261	276	291	307	323	339	356	373	391	409	427	446	465	485	505	525	546	567	588	610	632	655	679	702	726	
38	226	240	254	269	284	299	315	332	348	366	383	401	420	439	458	478	498	518	539	560	581	604	627	650	673	697	721	746	
39	232	246	261	276	291	307	324	340	358	375	393	412	431	450	470	490	511	532	553	575	598	620	643	667	691	716	740	766	
40	238	252	267	283	299	315	332	349	367	385	403	422	442	462	482	503	524	545	567	590	613	636	660	684	709	734	759	785	

Table A-56. Comparison of log rules.

Top diameter made bark	Board foot values for 16-foot logs by log rules and in percentage of International log rule, 1/4-inch kerf								
	International log rule, 1/4-inch kerf	Scribner decimal C		Spankhorn		Hasseloh's		Doyle's	
		Bd. ft.	Bd. ft.	Percent	Bd. ft.	Percent	Bd. ft.	Percent	Bd. ft.	Percent
4	5	10	200						
5	10	10	100					1	10
6	20	20	100					4	20
7	30	30	100					9	30
8	40	39	73					16	40
9	50	49	80					25	50
10	60	60	92	50	77			36	56
11	80	70	88	53	79			49	61
12	95	80	84	77	81			64	67
13	113	100	87	94	82			81	70
14	133	110	81	114	84	80	50	100	74
15	160	140	88	137	86	97	61	121	76
16	180	160	80	161	89	113	63	144	80
17	205	180	88	188	92	132	64	169	82
18	230	210	91	216	94	141	66	196	85
19	260	240	92	243	94	171	65	225	87
20	290	290	97	276	95	192	67	258	88
21	320	300	94	309	96	219	67	299	90
22	355	320	90	341	96	239	67	329	91
23	390	380	97	376	96	264	68	361	92
24	425	400	94	412	97	288	68	400	94
25	460	460	100	449	98	311	68	441	95
26	500	500	100	488	98	342	68	484	97
27	540	550	102	528	95	371	69	529	94
28	585	580	98	569	97	399	68	576	98
29	620	610	97	612	97	430	69	625	99
30	675	660	98	659	97	460	68	676	100
31	720	710	98	709	97	492	68	729	101
32	770	740	96	748	97	527	68	784	102
33	820	780	95	796	97	559	68	841	103
34	875	800	91	845	96	592	68	900	103
35	925	890	95	897	97	629	69	961	104
36	980	920	94	930	97	665	69	1,024	105
37	1,040	1,020	99	1,006	97	708	69	1,089	105
38	1,095	1,070	98	1,064	97	745	69	1,156	106
39	1,155	1,120	97	1,124	97	788	69	1,225	106
40	1,220	1,200	98	1,185	97	830	69	1,296	106

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- A-17 Volume, old-growth Douglas-fir, board feet, Scribner rule to an 8-inch top.
- A-18 Volume, Sitka spruce (old and young), board feet, Scribner rule to an 8-inch top.
- A-19 Volume, Sitka spruce (old and young), cubic feet to a 4-inch top.
- A-20 Volume, western hemlock (old and young), board feet, Scribner rule to an 8-inch top.
- A-21 Volume, western hemlock (old and young), cubic feet to a 4-inch top.
- A-22 Volume, old-growth white fir (*A. concolor*), board feet, Scribner Decimal C to an 8-inch top.
- A-23 Volume, young-growth white fir (*A. concolor*), board feet, International $\frac{1}{8}$ " rule to a 5-inch top.
- A-24 Volume, young-growth white fir (*A. concolor*), cubic feet.
- A-25 Volume, old-growth sugar pine, site II, Scribner Decimal C rule.
- A-26 Volume, young-growth sugar pine, board feet, International $\frac{1}{8}$ " rule to a 4-inch top.
- A-27 Volume, young-growth sugar pine, cubic feet.
- A-28 Volume, old-growth ponderosa pine, board feet, Scribner Decimal C rule.
- A-29 Volume, young-growth ponderosa pine, board feet, Scribner rule to an 8-inch top.
- A-30 Volume, young-growth ponderosa pine, cubic feet.
- A-31 Volume, old-growth incense-cedar, board feet, Scribner Decimal C rule to an 8-inch top.

- A-32. Volume, young-growth incense-cedar, board feet, International $\frac{1}{4}$ " rule to a 4-inch top.
- A-33. Volume, young-growth incense-cedar, cubic feet.
- A-34. Volume, old-growth, lodgepole pine, board feet, Scribner Decimal C rule to an 8-inch top.
- A-35. Volume, young-growth Sierra redwood, board feet, Scribner rule to a 6-inch top.
- A-36. Volume, young-growth Sierra redwood, cubic feet.
- A-37. Volume, blue-gum eucalyptus, board feet, Spaulding rule to a 6-inch top.
- A-38. Volume, blue-gum eucalyptus, cubic feet to a 6-inch top.
- A-39. Volume, coast live oak, blue oak, California white oak, interior live oak, tanoak, madrone, for California Central Coast, cubic feet to a 4-inch top.
- A-40. Volume, red alder, board feet, Scribner Decimal C rule to a 10-inch top.
- A-41. Volume, young-growth madrone, tanoak, and black oak, high site, board feet (8-inch top), cubic feet (4-inch top).
- A-42. Yield table, young-growth coast redwood stand, all species, per acre, board feet, International $\frac{1}{4}$ " rule, trees larger than 10.5 inches dbh to an 8-inch top.
- A-43. Yield table, young-growth coast redwood stand, all species, per acre, cubic feet, trees larger than 4.5 inches dbh to a 4-inch top.
- A-44. Yield table, Douglas-fir, fully stocked acre, board feet, Scribner rule, trees larger than 12 inches dbh to an 8-inch top.
- A-45. Yield table, Douglas-fir, fully stocked acre, cubic feet, trees larger than 12-inches dbh.
- A-46. Yield table, normal, white fir (*A. concolor*), per acre, board feet (in tens), International $\frac{1}{4}$ " rule, trees 8 inches dbh and over to a 5-inch top.
- A-47. Yield table, normal, white fir (*A. concolor*), per acre, cubic feet in tens, trees 4 inches dbh and over.
- A-48. Yield table, ponderosa pine, fully stocked acre, board feet, Scribner rule, trees 11.6 inches dbh and over.
- A-49. Yield table, ponderosa pine, fully stocked acre, cubic feet, trees 11.6 inches dbh and over.
- A-50. Yield table, mixed conifer stand, California, per acre, board feet, International $\frac{1}{4}$ " rule, trees 8 inches dbh and over to a 5-inch top.
- A-51. Yield table, average mixed conifer stand, California, per acre, cubic feet, trees 8 inches dbh and over.
- A-52. Yield table, normal, red fir, per acre, board feet in tens, International $\frac{1}{4}$ " rule, trees 8 inches dbh and over to a 5-inch top.
- A-53. Yield table, normal, red fir, per acre, cubic feet in tens, trees 2 inches dbh and over.
- A-54. Revised Scribner Decimal C log rule for logs 8 to 20 feet long, board feet in tens.
- A-55. Log volume, cubic feet, Huber formula.
- A-56. Comparison of log rules.

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* There are many more references and publications of value on specific topics. See your local CDF forest adviser, USFS and BLM offices, and forestry schools for a more complete coverage and places to obtain.