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THE YIELD OF DOUGLAS FIR IN THE PACIFIC NORTHWEST
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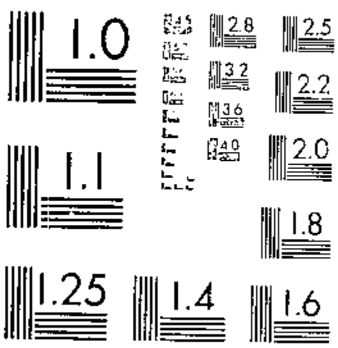

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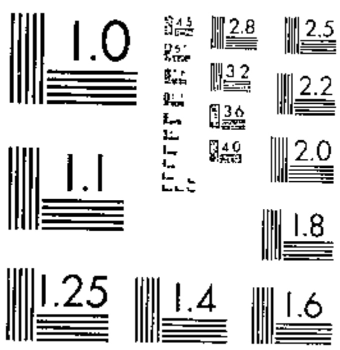

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TECHNICAL BULLETIN No. 201 Revised October 1949
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The Yield of Douglas Fir in the Pacific Northwest

BY

RICHARD E. McARDLE, *Silviculturist*

Pacific Northwest Forest and Range Experiment Station
Forest Service

WITH A SECTION ON APPLICATION OF YIELD TABLES BY

WALTER H. MEYER, *Silviculturist*

AND A SUPPLEMENTAL TREATMENT BY

DONALD BRUCE, *Collaborator*

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D.C.

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THE YIELD OF DOUGLAS FIR IN THE PACIFIC NORTHWEST

By RICHARD E. McARDLE, *silviculturist, Pacific Northwest Forest and Range Experiment Station, Forest Service,* with a section on application of yield tables by WALTER H. MEYER, *silviculturist,* and supplemental treatment by DONALD BRUCE,[1] *collaborator*

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INTRODUCTION

The portion of Oregon and Washington west of the Cascade Range is one of the most important forest regions of the country. Its forests now contain about one-fourth of the entire standing-timber supply of the United States; its lumber mills are now producing yearly about one-fourth of all the lumber cut in the United States. This forest region is of immense economic importance to the Nation, not only because of its present great supply of virgin timber and its large annual contribution of useful lumber products but also because of its great possibilities for the continuous production of superior forest crops in large quantities from lands eminently suited to that purpose alone.

Western Oregon and Washington is spoken of as the Douglas fir region on account of the preponderance of this species, which makes up 66 percent (340,000,000,000 bd. ft.) of the total stand of all species estimated at 515,000,000,000 bd. ft. Here Douglas fir (*Pseudotsuga taxifolia*) reaches its best development, both in size and quality of

[1] Material supplied by Donald Bruce for the 1949 revision (see p. 64) was derived from the basic data used in the compilation of this bulletin.
In the 1961 revision, clarifying material has been added (p. 12), with a reference to a 1955 publication.

the individual trees, and in density and rapid growth of its stands. The original forest of this region covered about 28,000,000 acres, but logging, fires, and land clearing have reduced this area to something less than 24,000,000 acres (*9*).[2]

A vast acreage of primeval forest thus remains, embracing many large tracts of splendid old-growth timber, with trees 5 feet and larger in diameter and cruising over 100,000 board feet per acre. However, not every acre is covered with a dense stand of old-growth trees. Many stands have been thinned by fire, and in some places the old growth has been completely exterminated by fire or logging. Still other stands are decrepit with age. As for the logged-over and burned-over areas, many have satisfactorily restocked with young trees, but others are only sparsely stocked or are entirely barren of second growth. Ownership of forest acreage in the Douglas fir region is rather evenly divided between the public and private owners, but the volume of timber in private ownership is considerably larger.

In this region an immense logging and lumbering industry has come into being within the past few decades. Washington now ranks first among the States in volume of lumber production, and Oregon has second place. Each year approximately 75,000 acres in western Oregon and 145,000 in western Washington are logged over. The 579 sawmills and 144 shingle mills in the western part of these two States in 1927 cut 9,881,414,000 board feet of lumber, and of this, 80 per cent was Douglas fir. Inasmuch as the stand of virgin timber is by no means unlimited, the permanence of this lumber industry, which now contributes 65 per cent of the entire industrial pay roll of Oregon and Washington, hinges to a considerable degree upon the continued production of forest crops from lands chiefly suitable for this purpose.

In western Oregon and Washington, both inside and outside the national forests, at least 15,000,000 acres of land is estimated to be chiefly suitable for the continuous growing of crops of Douglas fir and its associates. As the supply of mature timber becomes less the forests which to-day are immature and the lands which are yet to be reforested will furnish an increasingly large part of the timber supply. Ultimately the lumber production of the entire region must come from such young or second-growth stands.

Since the continued existence and prosperity of the lumber industry in the Pacific Northwest is so dependent upon the growth that takes place in these still immature stands of Douglas fir and upon areas yet to be logged and reforested, it is important to have definite information concerning the potential yields on these forest lands. The owner of timberland who contemplates raising crops of timber on his land in such succession or alternation as to produce a sustained annual yield of a fixed volume, the investor in growing timber, and the manufacturer looking for a future supply of raw material, all are interested in knowing the growth and yield possibilities of Douglas fir stands. They should know how many years it will be before trees now too small to cut will be of merchantable size, how many trees of each size class there will be of various ages during the

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[2] Italic numbers in parentheses refer to Literature Cited, p. 74.

life of the forest, and how large a harvest may be expected at any given age.

Anticipating this need, the Forest Service has prepared the yield figures here presented. They will help anyone who is interested in a future timber crop in this region to determine the profitableness of timber growing on various classes of land, to decide upon the best age at which to cut the timber, to predict the probable future size of the trees, and to estimate the prospective value of the crop.

Opportunity to study the yield of young Douglas fir forests was abundantly afforded by the many areas where such forests of various ages and on various types of land have originated naturally after logging or following severe fires that killed the former stands. Many of these young forests are so uniform and well stocked that they are a fair index of what may be expected hereafter under intensive forest management. Some are very extensive, even aged, uniformly stocked with trees, and unbroken over thousands of acres; others are but small patches surrounded by timber of another age, or, rarely, are a composite of several age classes.

Estimates place the total area of Douglas fir forests originating on old burns and now 20 to 120 years old at 2,500,000 acres in Oregon and 2,000,000 acres in Washington; in addition there are at present in the two States about 500,000 acres of Douglas fir second growth on cut-over lands. Over half of this 5,000,000 acres is privately owned. A survey made in 1922 by the Forest Service on 5,910,529 acres of national forests within the Douglas fir zone showed 2,009,580 acres of Douglas fir under 120 years old. From this survey it appears that about 34 per cent of the stands on the national forests in the Douglas fir zone are less than 120 years old (pl. 1); these areas are rather evenly distributed between the various age classes except that the 1 to 20 year class is relatively larger. This proportion of young growth to old growth probably is not as large on privately owned lands outside the national forests.

The yield tables here given were constructed from measurements of trees on sample areas laid out in a great many representative young forests, and supplemented by the periodic remeasurement of a number of permanent plots which have been under observation for as long as 15 years. Figure 1 shows the location of the 261 individual forests or tracts covered by the study. All told, during the course of the survey measurements were obtained on 2,052 sample plots. Some were in stands only 20 years old, some in stands 160 years old, and others in forests of nearly every age between these extremes. The principal combinations of soil and climatic factors in this region were considered, ranging from localities with very little rainfall to those where over 100 inches of rain falls every year; gravel soils, clay soils, loam soils; and altitudes from a few feet to over 3,000 feet. In this way a series of composite pictures was built up, one illustrating the conditions existing at various ages in forests growing under highly favorable circumstances, another showing the conditions under the least favorable circumstances, and still others illustrating intermediate conditions. The measurements so obtained from representative forest areas, reduced to tabular form, show what probably will be yielded or produced by a forest at different stages in its life. The study of Douglas fir growth was begun in 1909 by

Thornton T. Munger (*8*), was continued in 1911 by E. J. Hanzlik (*4*), and has been materially augmented by a large amount of field work by the author in 1924–25.

THE DOUGLAS FIR REGION AND ITS FORESTS

Douglas fir grows naturally in most of the temperate portions of western North America.[3] It natural range is, roughly, from northern British Columbia southward in the Rocky Mountains through Idaho, Montana, Wyoming, Utah, Colorado, New Mexico, and Arizona to Mexico; and in the coastal States through Washington, Oregon, and as far south as central California. This bulletin is concerned only with the region west of the Cascade Range in Washington and Oregon, where Douglas fir is the dominant forest species and reaches its maximum development, a long narrow strip extending from the upper slopes of the Cascade Range to the Pacific Ocean and from southwestern British Columbia almost to the Oregon-California boundary, an area approximately 100 miles wide and 450 miles long.

Typical of the region are rugged mountains and broad fertile valleys. The soils include sterile gravels, sands, heavy clays, loose friable loams, volcanic ash, and almost every possible combination of these individual classes. As a rule, the mountain soils are mostly clays and loams, and the soils of the valleys are largely loams and gravels; but no hard and fast line of distinction can be made, for the several soil classes are to a great extent intermingled in many areas. Even within a township it is often possible to find several distinct classes of soils.

The climate of the Douglas fir region is exceptionally favorable for conifer growth. Except at high elevations in the mountains, the winters are short and rarely severe. The growing season thus is long and usually free from extremes of heat or cold. The average temperature during the season for tree growth is about 56° F. The amount of annual precipitation varies from an exceptional minimum of about 20 inches on the leeward east slopes of the Olympic Mountains to over 100 inches along the coast and on the upper west slopes. Most of the region has an annual precipitation of 40 to 60 inches. Below 1,500 feet nearly all the precipitation is in the form of rain, but from June to September there is little rain anywhere in the region.

Although Douglas fir predominates in the region and grows under almost every variety of conditions up to the limit of its distribution, the forests of western Oregon and Washington are by no means restricted to this species. According to the species predominating, the Douglas fir region may be divided into three subregions called the fog-belt type, the upper-slope type, and the Douglas fir type proper.

The fog-belt type occurs as a narrow strip along the seacoast, where the rainfall is exceedingly heavy and moisture-dripping fogs

[3] Two species of Pseudotsuga are native to North America: Douglas fir, *P. taxifolia*, and bigcone spruce, *P. macrocarpa*. Some botanists subdivide *P. taxifolia* according to the color of the foliage or form of tree characteristic of different regions. Thus, the green Douglas fir of the Pacific coast is called *P. taxifolia*, the blue Douglas fir of Colorado is called *P. glauca*, and another form intermediate between the green and blue forms is sometimes referred to as *P. taxifolia* var. *caesia*. There are also a number of varieties of Douglas fir recognized by arboriculturists. In Europe, *P. taxifolia* is usually called *P. Douglasii*.

roll in from the ocean even during the summer months. Here the very moist soil and cool atmosphere conditions favor the growth of western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*), often to the exclusion of Douglas fir. In the southern part of the fog-belt type, the valuable Port Orford cedar (*Chamaecyparis lawsoniana*) also takes a prominent place in these forests.

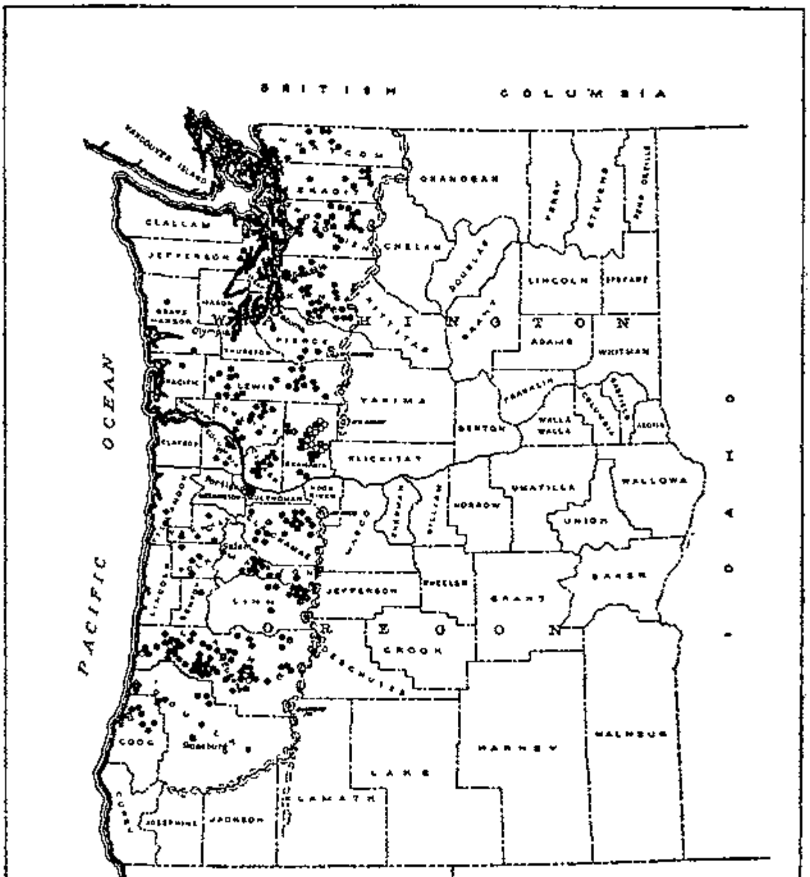

FIGURE 1.—Area in Oregon and Washington included in the Douglas fir yield study. Each solid dot represents a Douglas fir forest in which several (usually about 10) temporary sample plots were laid out and measured. The encircled crosses represent periodic remeasurements of one or a group of permanent sample plots

The upper-slope type of forest occurs at moderate to high altitudes in the Cascade Mountains, where Douglas fir gradually yields its place to western red cedar (*Thuja plicata*), western hemlock, western white pine (*Pinus monticola*), noble fir (*Abies nobilis*), silver fir (*A. amabilis*), alpine fir (*A. lasiocarpa*), mountain hemlock (*Tsuga mertensiana*), and Alaska cedar (*Chamaecyparis nootkatensis*).

The Douglas fir type proper occurs in the valleys of the Puget Sound-Willamette River Basins, on the mountains of the Coast Ranges, and on the foothills and lower slopes of the Cascade Range. These forests consist almost entirely of Douglas fir intermingled with small quantities of western hemlock, western red cedar, lowland white fir (*A. grandis*), and occasionally silver fir, noble fir, and western white pine. The few broad-leaved trees of most common occurrence here and in the fog-belt type are bigleaf maple (*Acer macrophyllum*), red alder (*Alnus rubra*), black cottonwood (*Populus trichocarpa*), and Oregon white oak (*Quercus garryana*).

GROWTH CHARACTERISTICS OF THE FOREST

Young forests, whether on old burns or on logged areas, consist to a high degree of Douglas fir, most stands being over 80 per cent, and many 100 per cent, of this species. This is due to the ability of Douglas fir to establish itself by natural means more successfully than any of its associates in open areas following fire or logging. (Pl. 2.) These young forests as a rule are even aged, the larger trees in any one forest seldom varying by more than a few years.

Although a new forest starts with many thousands of small trees to the acre, only a small proportion of these survive until the stand reaches maturity. (Pls. 3 and 4.) At 10 years of age on reasonably good land there are about 900 trees to the acre, some of them 10 or 12 feet tall and clothed to the ground with living limbs. At 30 years of age at least one-half of these trees are dead, several of the survivors are more than 12 inches in diameter and 90 feet tall, and on all the surviving trees the lower branches, though they still hang on, dry and brittle, have been killed by the intense shade. When the forest is 100 years old there are only about 80 living trees to the acre, but most of them are now 2 or 3 feet in diameter. The larger trees are nearly 200 feet tall and have nearly attained their full height growth; dead branches have dropped off the trunks for at least half the total length; the bark has thickened greatly, become deeply furrowed, and turned a dark gray-brown. The ground is strewn with trees which have died, and the holes so made in the forest canopy admit enough light to permit the establishment of shrubby plants and occasional small hemlocks, cedars, and white firs.

Most of the present young stands of Douglas fir, such as were studied for the purposes of this bulletin, originated naturally following fires which destroyed the previous forests. Other young forests have come in on logged-over areas. The extensive stands of Douglas fir now 60 to 80 years old in the Willamette Valley and on the foothills in Oregon are commonly assumed to have originated about the time that intensive settlement of the valley brought to an end the setting of brush fires by Indians to maintain pasture for their horses.

Overmature forests have a large proportion of other species, mostly western hemlock and western red cedar. This is due to the fact that Douglas fir does not endure heavy shade, and for this reason there is no understory forest of young Douglas fir to take the place of the old trees as they die from old age or lose out to their neighbors in the competition for sunlight. Western red cedar, western hemlock, white fir, and other species which can grow in the shade of the mature forest fill in the places left vacant by the dying Douglas firs.

GROWTH CHARACTERISTICS OF THE TREE

In the Pacific Northwest, Douglas fir is a tall, massive tree with slowly tapering trunk, attaining great size and age. Excepting only the sequoias of California, Douglas fir is the largest tree of the North American forests. Trees 5 or 6 feet in diameter and 250 feet tall are common in mature forests. In general, however, trees more than 8 or 9 feet in diameter and 275 feet in height and more than 500 years old are rare.[4]

The inability of Douglas fir to live in its own dense shade insures, in well-stocked stands, the early death and gradual shedding of the lower branches and the production of clear lumber thereafter. Sensitiveness to shade varies with age, young trees being more shade resistant than old trees. Likewise, trees having favorable growth conditions are more tolerant of shade than those on the poorer sites. Early in life Douglas fir is able to withstand some side shading, but after about the twenty-fifth year the tree is unable to make satisfactory growth or to live in either side or overhead shade.

Young Douglas firs are fairly safe at present from indigenous fungous diseases. Studies by J. S. Boyce indicate that in stands less than 100 years old the loss through decay ordinarily amounts to less than 2.5 per cent of the total merchantable volume of the stand. Damage by tree-killing insects is restricted to a very few species, and the only serious attacks have occurred near the marginal limits of the tree's distribution. Ice storms occasionally break the tops out of trees, and those so damaged seldom recover their places in the forest canopy. Crown fires sometimes destroy many acres of Douglas fir forests, but are rare in young stands. Surface fires, on the

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[4] The greatest diameter so far authentically reported is of a tree until very recently standing in a grove of giant cedars and firs near Mineral, Wash. (Pl. 5.) This tree, measured in 1924 with steel tape and Abney level, had a diameter of 15.4 feet at 4.5 feet above the mean ground level, and a height (up to a broken top) of 225 feet. A large part of the interior of the tree has been burned out at the base, leaving a doorlike opening at one side. The rings of yearly growth are plainly visible in the charred walls of the interior, and by counting these rings the age of the tree was estimated to be 1,020 years (in 1924). Another large tree about 15 feet in diameter was reported in 1900 by E. T. Allen, who writes, "It was about 3½ miles from Ashford, Wash., on the Mount Rainier road, and was a fallen tree which itself lay quite sound, but the stump which was about 25 feet high had been burnt or rotted out from one side, leaving a large opening. I rode a horse into this stump, turned him around, and rode out again. It was a small horse, but you can see it was also a big tree." The tallest Douglas fir on record was reported in 1900 by E. T. Allen. This tree, found near Little Rock, Wash., was 330 feet tall and had a diameter of 71.6 inches. A down tree 380 feet long has been reported, but, unfortunately, the details of the measurement were never recorded and the exact location of the tree forgotten. Other tall trees for which accurate information is available are the following: One near Hoquiam, Wash., 318 feet; one at Little Rock, Wash., 310 feet; one near Darrington, Wash., 325 feet; one near Pawn, on the Siuslaw National Forest in Oregon, 295 feet. Several instances of exceptional volume of individual Douglas fir logs have been reported. At Bellingham, Wash., a log 12 feet in diameter at the butt, 278 feet long, scaled 105,000 board feet, Scribner rule. At Clear Lake, Wash., a log 12.9 feet in diameter at the butt, 170 feet long, scaled 78,000 board feet, Scribner rule. The oldest Douglas fir of which there is any authentic record was found in 1913 by Ranger Hilligoss on the Finney Creek watershed about 30 miles east of Mount Vernon, Wash. The age count was made on a section about 40 feet above the stump, and the age at that point was 1,376 years. Since at least 25 years were required to reach the height at which the age count was made, this tree must have been over 1,400 years old when cut. The next oldest is the tree at Mineral. There may be taller, older, or larger trees than these, but the Forest Service has no record of accurately measured trees which surpass those described.

other hand, do little damage to mature trees protected by their thick bark, but are responsible for a great deal of damage in young stands, scarring the bases of the thin-barked trees and thus exposing them to windthrow or fungous attacks.

Douglas fir reproduces itself only from seed; it does not sprout as do many of the hardwoods and a few of the conifers. The seed matures in August and September and most of it falls from the cones within a month or two; but good seed often continues to be shed until the following spring. As a rule, Douglas fir has a large seed crop over the entire region about every three or four years, the intervening crops being either total failures or light.

Douglas fir normally is a deep-rooted species on the drier loams and very dry gravels, but this characteristic of the root system appears to be determined largely by the quantity of moisture present in the soil. On wet clay soils so shallow a root system is developed that isolated trees are liable to be overthrown by the wind; and windthrow is particularly prevalent in the wet soils of river bottoms.

Douglas fir stands, as well as logs and lumber, are often referred to as "red fir" or "yellow fir," according to the color and quality of the wood. Both kinds of wood may be in the same tree, the coarse-grained center being reddish and the fine-grained outer portions of the stem yellowish. The yellow fir is considered more desirable than red fir because of its color, fine grain, and easy-working qualities. The formation of red fir wood is commonly attributed to rapidity of growth, and since the rate of growth diminishes with age, the trees in old forests are likely to contain a relatively large proportion of the yellow wood. For this reason, young Douglas fir forests are frequently referred to as red fir forests and older stands classed as yellow fir forests.

FACTORS INFLUENCING YIELD OF DOUGLAS FIR

The yield of the growing forest at any given age is determined by site quality and degree of stocking. A brief analysis of these factors will be presented; a complete discussion of them is beyond the scope of this bulletin. The actual yields obtainable from any stand are affected by other factors also, such as the intensity of the utilization and the amount of defect; these are discussed in later paragraphs.

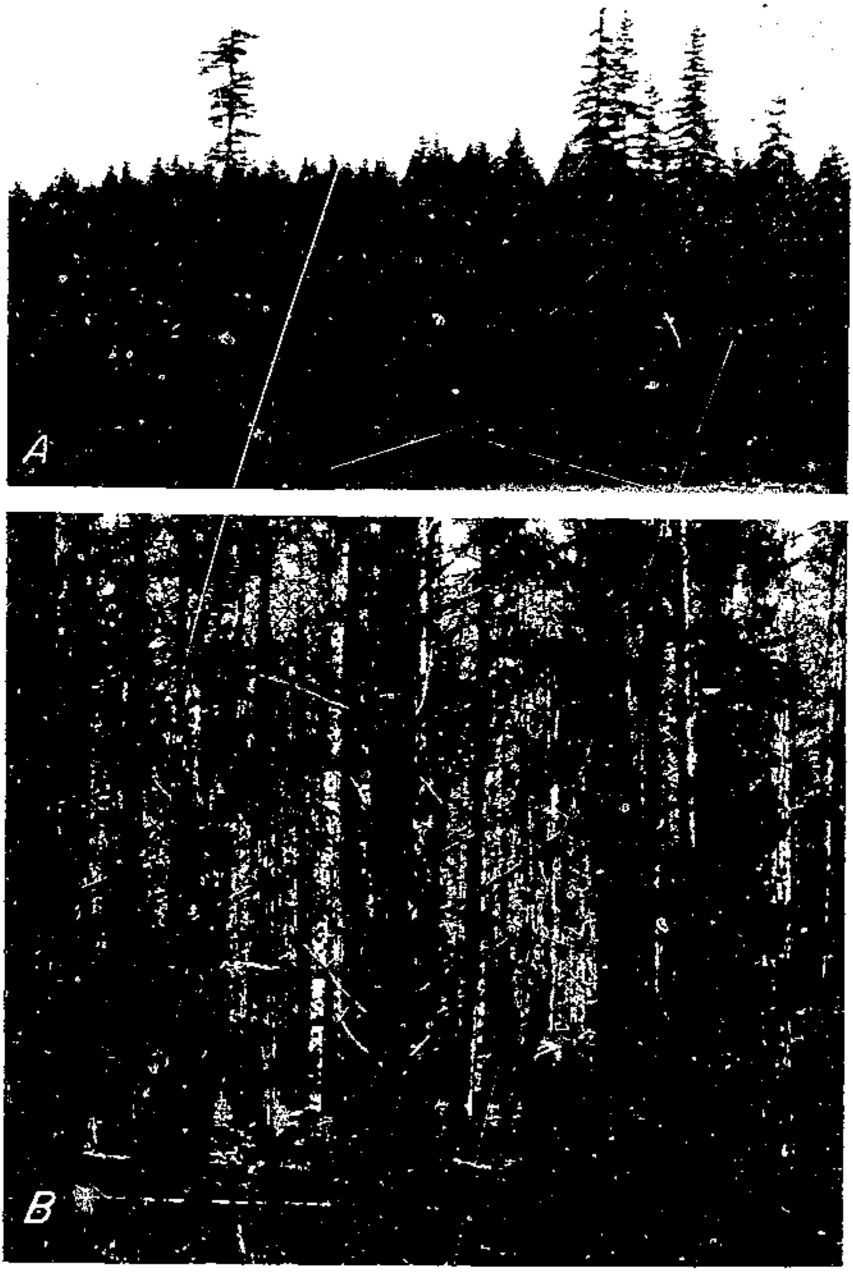
SITE QUALITY

Various combinations of the physical characteristics of forest areas, such as soil, drainage, rainfall, temperature, altitude, slope, and aspect, result in different degrees of favorableness for tree growth. The combined effect of these characteristics on the stand is embraced in the term "site" or "site quality." (Pl. 6.) Between the best and poorest sites in the Douglas fir region is a range in productivity, as measured in cubic feet of wood produced, of over 250 per cent. It would be difficult, if not impossible, to determine the part that each physical factor has in making an area productive, although this study has given some indications of the combinations of factors that contribute toward productivity. For practical purposes in using yield tables it is essential to have only a measure of the combined effect.

F27580

A TYPICAL STAND OF YOUNG DOUGLAS FIR

A healthy stand of Douglas fir about 100 years old in Clackamas County, Oreg. The forest canopy is beginning to open and the light thus admitted to the ground has enabled the establishment of a thick growth of underbrush.



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THRIFTY YOUNG STANDS OF DOUGLAS FIR ARE ABUNDANT ON OLD BURNS AND LOGGED OFF LANDS

A (exterior) and B (interior) views of Douglas fir stands about 45 years old. The remarkably uniform height development of the young trees and the overtopping seed trees are characteristic. Stand B, which is on land that once was cultivated, has 438 trees and 6,789 cubic feet to the acre.

F94941

F217637

THE LIFE CYCLE OF A DOUGLAS FIR FOREST

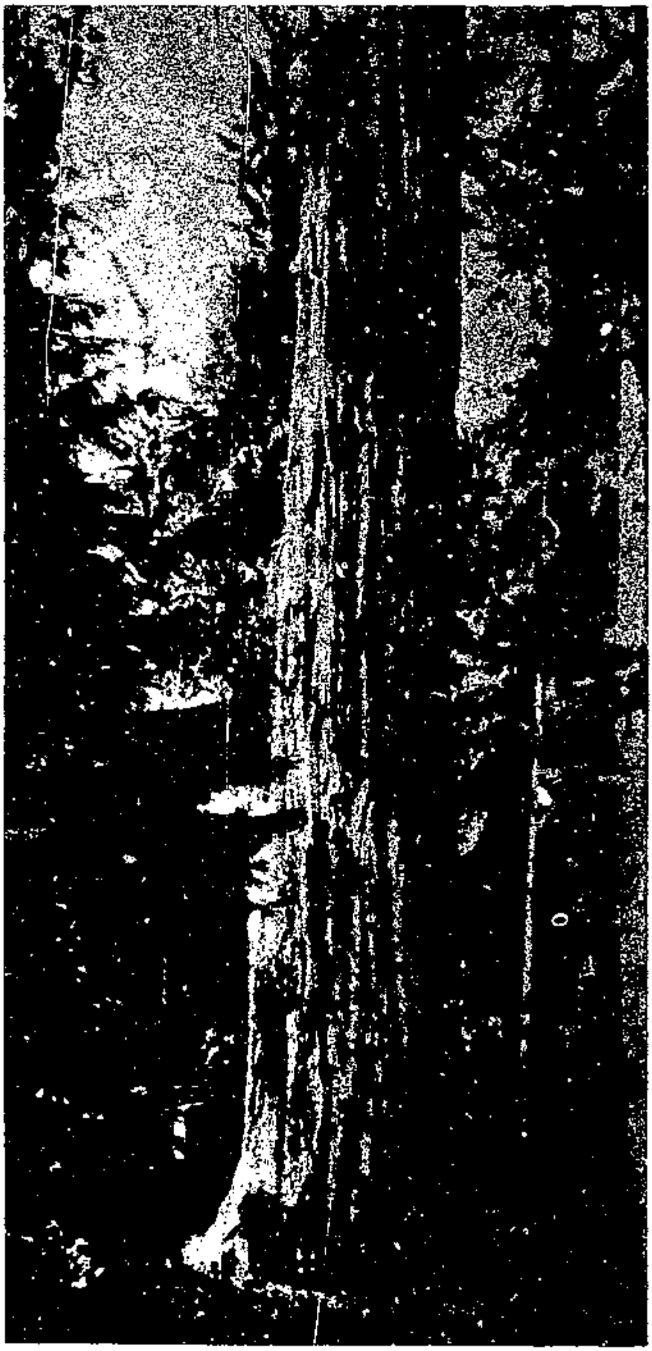
A, A dense stand 9 years old. There are thousands of trees to the acre, some of which are 10 or 12 feet tall. The period of rapid height growth has begun and during the next decade these trees will make their greatest yearly increase in height; B, the stand is now 52 years old, and has retained about 275 trees to the acre, averaging 12.5 inches in diameter, of which 136 trees are 12 inches or larger in diameter with a volume of 27,000 board feet (Scribner full scale). Within the next 20 years many of the dead limbs now persisting on the trees will fall to the ground, and through the death of many of the young trees the stand will open sufficiently to admit sunlight for the establishment of underbrush.

F203835

F95445

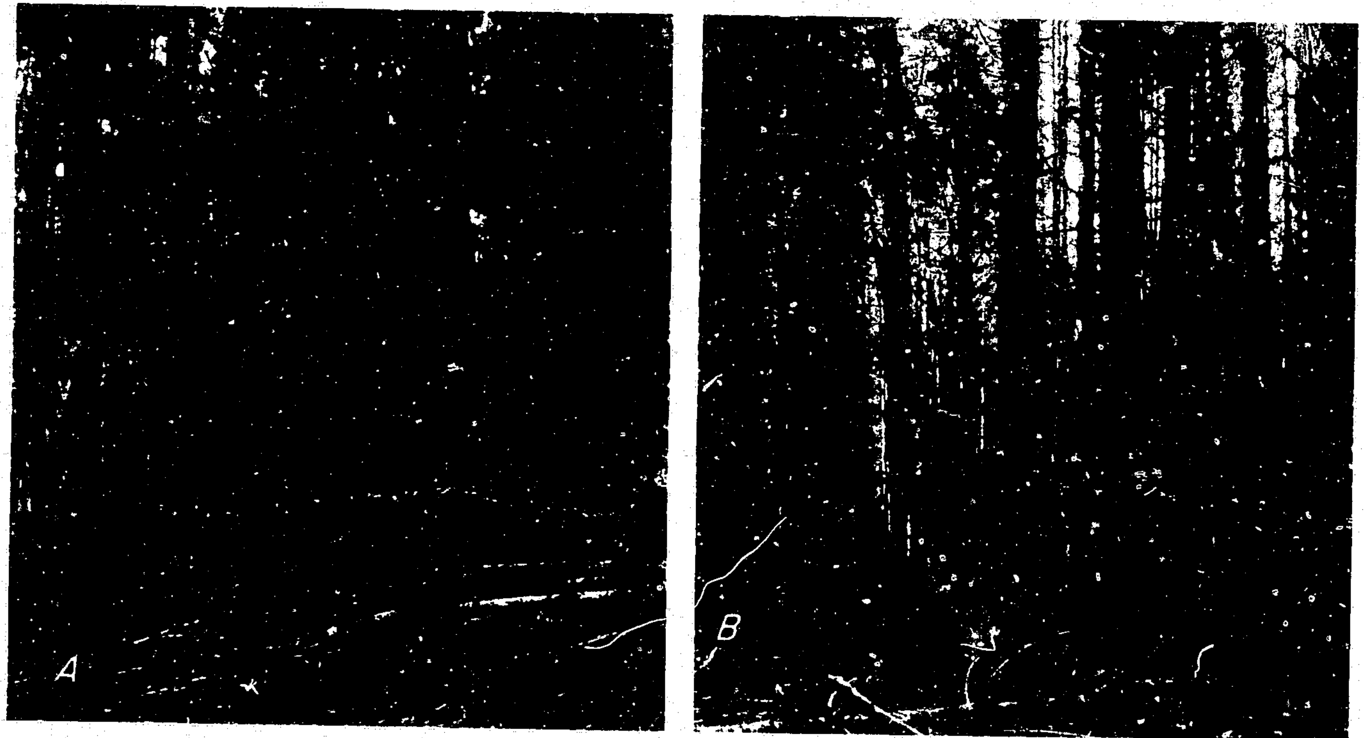
THE LIFE CYCLE OF A DOUGLAS FIR FOREST

A, By the time the stand is 140 years old many of the trees have been shaded out. There are now 170 trees to the acre, averaging 20.2 inches in diameter, and the 158 trees 12 inches and larger in diameter contain 84,500 board feet (Scribner full scale). As a result of growing in a full and evenly stocked stand the trees are straight, and free from large knots; B, when the forest reaches 300 or 400 years old, about 50 or 60 Douglas fir trees to the acre remain. The forest canopy has opened greatly owing to the death of many of the trees, and a number of young hemlocks and cedars are taking full advantage of this opportunity to obtain a dominant place in the forest.



A GIANT DOUGLAS FIR

The largest Douglas fir of which there is an accurate record stands near Mineral, Wash. In 1924, its circumference at 4.5 feet above the ground was 49 feet, equivalent to a diameter of 15.4 feet; height to a broken top was 225 feet; age, 1,020 years. This tree fell recently. (Photograph by Boland.)



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SITE QUALITY AFFECTS GROWTH IN VOLUME

A, Douglas fir on site Class III; the forest is 66 years old, there are 364 trees to the acre, averaging 10.6 inches in diameter, and the volume of the 110 trees 12 inches and larger in diameter is 20,000 board feet (Scribner full scale); B, Douglas fir on site Class II in the same forest; the forest is 70 years old, there are 152 trees to the acre, averaging 16.8 inches in diameter, and the 124 trees 12 inches and larger in diameter have a volume of 52,000 board feet (Scribner full scale).

F195021 F195024

THE EFFECT OF DENSITY OF STOCKING ON QUALITY

A, Limby timber is the result of trees growing in a sparsely stocked stand. This is the kind of timber foresters and timberland owners do not want to grow and which can be avoided with proper forest management. This 64-year-old timber has plenty of volume but will produce lumber of very low quality; B, proper density of stocking results in an excellent stand of timber typical of what may be expected under good forest management. Diameters are smaller than when grown with a wide spacing but there are more trees to the acre and the individual trees have fewer large limbs on the lower portions of their stems. This is the same stand as in A, but here the trees average 200 to the acre of which 175 are 12 inches and larger in diameter, and yield 80,000 board feet (Scribner full scale).

Altitude influences the productivity of an area by shortening the growing season and lowering the mean temperature. Since at high elevations growth begins late and stops early, high-altitude areas are less productive than those at low elevations, even though soil, drainage, and other conditions are favorable. In this study, 89 per cent of the areas ranking as Site I were found below an altitude of 1,500 feet, and no Site I areas were found above 2,000 feet.

Aspect was found to be an important factor in regulating the productivity of forest sites. The most rapid growth was found on slopes facing north, northeast, and east, probably because the soil on these exposures is less subject to the drying rays of the summer sun and consequently remains more moist than on other aspects. Ninety per cent of the Site I areas measured during the course of this study were on north, northeast, and east aspects. The south to west aspects were found to be more variable in their effect on site than the north to east aspects. Although the least productive areas were found on south, southwest, and west aspects, occasional Site I areas and a moderately large number of Site II areas were found on these exposures. All of the Site V plots were on south to west aspects, or on level ground.

Soil undoubtedly plays a most important part in regulating the productivity of any area. Even though there be abundant rainfall, a long, warm growing season, and every other condition conducive to rapid growth, if the soil is lacking in food substances (or if there is an excess of certain substances), if it is extremely shallow or the drainage is deficient, growth will be slow, and large yields will not be attained. The most rapid growth and the largest yields of Douglas fir are obtained on deep, well-drained sandy loam soils. Clay soils apparently rank second in productivity, and those soils which are mainly gravel are the least productive.

It is difficult to separate the effect of rainfall from the effect of other physical factors influencing site quality. The results of this study indicate in general, however, that abundant precipitation is essential for rapid growth and large yields. The most productive areas having favorable soil and altitude were found in localities where the annual precipitation is more than 60 inches. Conversely, on areas where the soil and altitude apparently are favorable, but where the rainfall is less than 30 inches annually, the trees were growing slowly, and the total yields were small.

Slope affects site quality by reason of the fact that, even when other factors remain the same, a change in the gradient may result in an increased or decreased rate of growth.[5]

STOCKING

The completeness of stocking of a forest area has a decidedly important effect on yield, not only on the volume production but also on the quality of the wood produced. Where there are but few trees per acre the increase in volume of individual trees is very rapid, but

[5] Aside from the influence that slope has on site quality, the degree of slope also affects the yield per acre. For horizontally measured acres an increase in slope results in an increased area of soil surface per acre. An increase in gradient likewise makes possible a more advantageous exposure of the crowns with resultant increase in density of stocking, and this holds true even if the hillside acre is surface measured and thus has the same surface area as an acre on level ground. The effect of slope on yield is described in a later paragraph.

trees growing under these conditions will have many large limbs, a gnarled, rough appearance, and lumber from such open-grown trees will contain large knots, will be coarse grained, and consequently will be of low quality. When the trees are closely spaced the limbs on the lower portions of the stems are small and die early because of shading, and the lumber from closely grown trees therefore has fewer and smaller knots, a finer texture, and a higher quality.

The density of stocking may also affect the character of the product (pl. 7), determining, for example, whether a large or a small proportion of the trees has the proper taper or clear surface which renders them suitable for special purposes, such as telegraph poles or piling.

Though quality production is perhaps of as great economic importance as quantity production, the present study was confined to the latter phase, and no systematic information is yet available regarding the quality yields at different ages, for different site qualities, and for different degrees of stocking.

GROWTH AND YIELD TABLES

TERMS USED

The following explanations are given of the terms used in the discussion and tabulation of growth and yield.

Yield.—The volume per acre in fully stocked stands at stated ages by any one of several standards of measure. The yield-table values include only living trees, and do not show the very considerable increase in total yield which can be had by taking advantage of thinnings, even if the thinning operations do no more than remove the trees which normally will die as the stand grows older. No allowance is made in the computations of yield for possible loss in logging through defect and breakage.

Mean annual increment.—The average yearly increase in volume computed for the total age of a stand at any period in its life. See below.

Periodic annual increment.—The average yearly increase in volume during a short period—in this instance a 10-year period is used. The figures for mean annual increment and periodic annual increment are for living trees only and take no account of the trees which die between measurements; nor is allowance made for possible loss in logging through defect or breakage.

Dominant and codominant trees.—Trees with well-developed crowns forming the general level of the forest canopy and occasionally extending above it; the larger trees of the stand. (The group corresponds to the two upper classes of a crown classification having four divisions—dominant, codominant, intermediate, and suppressed trees.)

Age.—As given in this bulletin the age of the stand is the average total age of the dominant and codominant trees. It is the number of years since the stand started from the seed, not the number of years since the previous stand was removed.

Stocking.—Stocking is a term here used in describing the degree to which an area is covered by Douglas fir trees. The ideal or most effective number and distribution of trees is called normal, or full, stocking. Normal stocking, as used here, is not theoretical maximum stocking but represents the condition of a large number of selected acres in natural stands where no accidents have interfered with growth. Normal stocking as indicated in this bulletin can be found on single acres in all parts of the region and in many forests uniformly over an area of 10 or 20 acres.

Assumed utilization.—For tables in cubic feet, the volume is the total cubic volume of the entire stems including stump and top but excluding bark and limbs; for tables of the total stand all sizes of coniferous trees over 1.5 inches in diameter, except those of the understory, are included. The yields in board feet by the Scribner log rule allow for a minimum top diameter of 8 inches, a stump height of 2 feet, a trimming allowance of 0.3 foot for each 16-foot log, and represent the volume of all trees 11.6 inches in diameter (12-inch class) and larger on one fully stocked acre. The yields in board feet according to the International log rule (⅛-inch kerf) allow for a minimum top diameter of 5 inches, a stump height of 1.5 feet, a trimming allowance of 0.3 foot for each 16-foot log, and represent the volume of all trees (1) 6.6 inches in diameter (7-inch class) and larger, and (2) 11.6 inches in diameter and larger on 1 fully stocked acre.[6]

Scale.—The volumes given represent full scale, no allowance having been made for possible loss through defect, breakage, or incomplete woods utilization.

Site quality.—Separation of forest land into the various classes of productivity (sites) is based on the average total height of the dominant and codominant trees. The average total height which has been or will be attained at a given age (in these tables at 100 years) is the "site index," and the tables here presented show the yields for forests of all site indices from 80 to 210.[7] For the sake of compactness, only the 10-foot site indices (as 80, 90, 100) are shown, but intermediate values (as site index 82, 87, 88, etc.) can be obtained by interpolation between two adjoining 10-foot classes. To simplify the application of the tables, the site indices are grouped in five broad classes, called Sites I, II, III, IV, and V. Each site class is arranged in these tables to include three of the 10-foot site-index classes which may be used as high, low, and median values in each site class. The median values of the five site classes correspond to the following site indices:

	Site index
Site I	200
Site II	170
Site III	140
Site IV	110
Site V	80

Total basal area.—The sum of the cross-sectional areas in square feet (including bark), at 4.5 feet above the ground, on 1 acre; com-

[6] Since the International rule assumes rather close utilization, a saw kerf of one-eighth of an inch is here provided. If, however, a ¼-inch saw kerf is used with the International rule, the yields indicated in these tables must be reduced 9.5 per cent.

[7] "Site index" is not a new term, although it has been little used in the United States. Theodore and Robert Hartig used the system in growth and yield studies, and so did Huber, as reported by Sterling (2). Fricke (5) developed a system of site indices similar to the one described here, and Roth (10) proposed a scheme essentially the same, although he did not mention the term "site index."

puted in this bulletin for three groups of living trees, namely, (1) all the trees, (2) those 7 inches in diameter and larger, and (3) those 12 inches and larger.

TABLES OF NORMAL YIELD

Normal-yield tables such as are given in this bulletin take into account the variations in yield due to site and age. But the normal tables do not reckon with the variations in yield due to stocking, degree of defect, or utilization practice. The normal tables are standards to which actual yields of extensive areas can be referenced. In using the yield tables, proper allowance must be made for utilization less complete than is indicated; for possible loss through defect and breakage; and for any estimated degree of stocking more or less than that represented by the normal tables.

Conventional normal yield tables such as the ones in this bulletin show only yields of live timber, or *net yield*. No attempt is made to measure the large segment of the forest that dies during natural stand development.

A recent publication by Staebler (*11*) presents gross yield tables for Douglas fir based on data from the present bulletin and permanent sample plots. Gross yields (net yield plus mortality) give an approximation of maximum yields that might be achieved by intensive management in which mortality can be anticipated and utilized.

DETERMINATION OF SITE QUALITY

Obviously, before yield tables can be used, the site quality of the area in question must be determined. As already stated, the average total height of the dominant and codominant trees at a given age is the accepted index of site. Whenever there is a stand of Douglas fir on the area, either young growth or old growth, site can be determined readily by comparing the average total height of selected dominant and codominant trees with the standard heights corre-

TABLE 1.—*Average total height of dominant and codominant trees, by site classes*

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	37	41	46	50	55	60	64	69	74	78	83	88	92	96
40	48	54	60	66	72	78	84	90	96	102	108	114	120	126
50	56	63	70	77	84	91	98	105	112	119	125	132	139	146
60	63	70	78	86	93	101	109	117	124	132	140	148	156	163
70	68	77	85	94	102	110	119	127	135	144	152	161	170	178
80	73	82	91	100	109	118	127	136	145	154	163	172	181	190
90	77	86	96	105	115	125	134	144	153	163	172	182	192	201
100	80	90	100	110	120	130	140	150	160	170	180	190	200	210
110	83	93	104	114	124	135	145	155	166	176	187	197	207	218
120	85	96	106	117	128	138	149	160	170	181	192	202	213	224
130	87	98	109	119	131	141	152	163	174	185	196	207	218	229
140	88	99	110	121	133	144	154	166	177	188	199	210	221	232
150	89	101	112	123	134	145	156	168	179	190	201	213	224	235
160	90	102	113	124	136	147	158	170	181	192	203	215	226	237

sponding to the age of the stand as given in Table 1 and Figure 2.[3] As an example, if the age of the stand is 50 years, and the average total height of the dominant and codominant trees is 98 feet, Table 1 shows that this height at 50 years corresponds to site index 140, or Site III. Height measurements of 15 or 20 dominant and codominant trees and age counts on about 10 should be sufficient for site-quality determination if the area is homogeneous. Since age counts usually are made several feet above the ground, these counts must be converted (Table 19) to total age.

It is less easy to determine the site class of an old burn or freshly logged area devoid of trees. Where such bare areas are adjacent to standing timber on land of apparently similar site, the nonforested areas may be assumed to be of about the same site as the adjoining forested areas. Methods for determining the site of bare areas are now being sought.

The normal-yield tables are presented in three ways: Table 2 for total stand, all sizes of trees included; Table 3 for that part of the

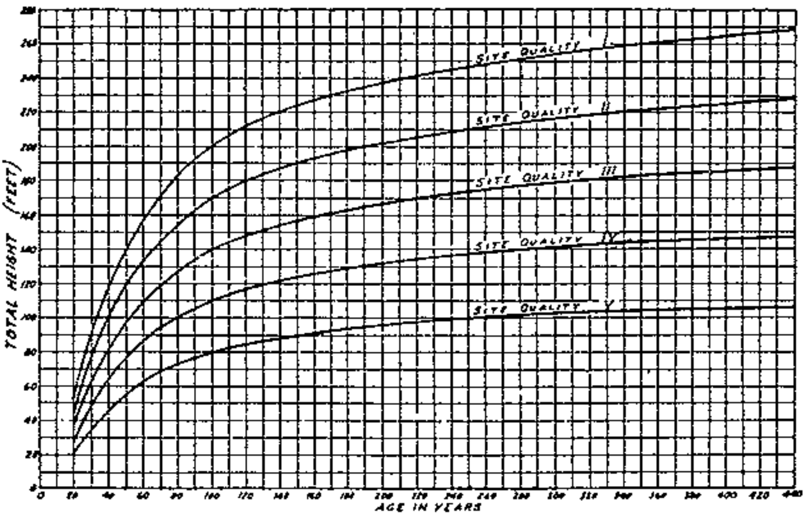

FIGURE 2.—Average total height of dominant and codominant trees

stand 7 inches in diameter and larger; Table 4 for the stand 12 inches in diameter and larger.

YIELD TABLES FOR TOTAL STAND

Table 2 comprises a group of yield tables covering the whole stand and includes four items, the total number of trees per acre, the diameter of the average tree at breastheight, total basal area, and the cubic volume of the entire stems. The values for each item are arranged by site indices from 80 to 210 in 10-foot classes. Figures 3 to 6 present the same data by means of curves but include only the median values for each of the five site classes. All conifers (but not understory trees, if present) 1.5 inches in diameter and larger are included in the table for the total stand.

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[a] The figures in Table 1, and Figure 2 up to 160 years are based on the measurement of stands used in the yield study, but for the benefit of those who may want to determine site quality of land now supporting old-growth timber the figures in Figure 2 have been extended to 440 years by W. H. Meyer. The extension is based on the measurement of heights in 40 different forests by various members of the Forest Service.

Table 2.—*Yield tables for Douglas fir on fully stocked acre, total stand*

TOTAL NUMBER OF TREES

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
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
20	6,920	5,500	4,150	3,069	2,324	1,815	1,460	1,210	1,012	880	756	654	571	490
30	2,700	2,200	1,800	1,472	1,219	1,030	865	735	640	555	483	408	350	300
40	1,530	1,275	1,090	927	798	680	585	510	445	385	335	282	240	203
50	1,050	890	764	659	572	496	430	377	331	290	248	208	176	150
60	780	670	580	500	439	380	337	296	261	228	195	164	138	116
70	625	537	468	405	352	310	274	242	214	186	160	135	113	95
80	525	455	394	345	303	266	232	207	182	159	136	115	97	81
90	451	398	347	304	266	235	205	180	158	138	118	100	84	71
100	403	352	311	271	239	209	184	161	142	123	106	89	75	64
110	362	319	281	247	217	188	166	146	128	111	95	81	69	58
120	331	292	259	224	197	173	152	134	116	101	87	74	63	53
130	305	271	240	209	184	161	141	124	108	94	80	69	59	49
140	284	252	224	195	171	149	131	115	101	88	75	64	55	45
150	266	238	211	184	160	141	123	108	95	82	71	60	51	42
160	250	225	200	175	152	133	117	102	90	78	67	57	48	40

DIAMETER OF AVERAGE TREE AT BREASTHEIGHT

Age (years)	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
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
20	1.3	1.5	1.8	2.2	2.6	3.0	3.4	3.8	4.2	4.5	4.9	5.3	5.7	6.2
30	2.6	3.0	3.4	3.9	4.4	4.9	5.5	6.0	6.5	7.0	7.6	8.3	9.0	9.8
40	3.8	4.4	4.9	5.5	6.1	6.8	7.4	8.0	8.7	9.4	10.2	11.2	12.2	13.3
50	4.9	5.6	6.3	7.0	7.7	8.5	9.3	10.1	10.9	11.8	12.8	14.0	15.3	16.7
60	6.0	6.8	7.6	8.5	9.3	10.2	11.1	12.0	12.9	14.0	15.2	16.6	18.2	19.9
70	7.0	7.9	8.8	9.8	10.8	11.8	12.8	13.8	14.8	16.0	17.5	19.1	20.9	22.8
80	7.9	8.9	9.9	10.9	12.0	13.1	14.3	15.4	16.6	17.9	19.6	21.3	23.3	25.5
90	8.7	9.7	10.8	11.9	13.1	14.3	15.6	16.9	18.2	19.6	21.4	23.3	25.6	28.0
100	9.4	10.5	11.6	12.8	14.2	15.5	16.9	18.2	19.7	21.2	23.1	25.1	27.6	30.1
110	10.1	11.3	12.4	13.7	15.2	16.6	18.0	19.5	21.0	22.6	24.6	26.9	29.4	32.2
120	10.7	11.9	13.2	14.6	16.1	17.6	19.1	20.7	22.3	24.0	26.1	28.5	31.1	34.2
130	11.3	12.5	13.9	15.3	16.9	18.5	20.1	21.7	23.5	25.3	27.5	30.0	32.7	36.0
140	11.9	13.1	14.5	16.0	17.7	19.4	21.1	22.8	24.5	26.5	28.8	31.4	34.3	37.8
150	12.4	13.7	15.1	16.7	18.4	20.2	22.0	23.8	25.6	27.7	30.0	32.8	35.8	39.4
160	12.9	14.2	15.7	17.4	19.1	21.0	22.8	24.7	26.6	28.9	31.2	34.1	37.2	41.0

TOTAL BASAL AREA

	Sq. ft.	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*
20	64	70	76	81	86	89	92	95	97	98	99	100	101	102
30	96	105	114	122	129	135	140	144	147	150	152	153	154	155
40	121	132	143	153	162	170	177	182	186	189	191	193	195	196
50	140	153	165	177	187	196	204	210	214	217	220	222	224	226
60	154	169	182	195	207	217	226	232	237	241	244	246	248	250
70	166	183	197	211	224	235	244	251	256	260	264	266	268	270
80	177	194	210	224	238	249	259	266	271	276	280	283	285	287
90	185	204	220	235	249	262	272	279	285	290	294	297	299	301
100	193	212	229	245	260	273	283	291	297	302	306	309	312	314
110	200	220	238	254	269	282	292	301	307	313	317	320	323	325
120	206	226	245	261	277	290	301	310	316	322	326	329	332	335
130	213	233	251	268	284	298	309	318	325	331	335	338	341	344
140	218	238	257	275	291	305	317	326	333	338	343	347	350	353
150	223	243	263	281	298	312	324	333	340	346	351	354	357	360
160	227	248	268	287	304	318	331	340	347	353	357	361	364	367

TOTAL YIELD IN CUBIC FEET

	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.*
20	520	620	730	870	990	1,120	1,250	1,380	1,490	1,550	1,650	1,730	1,830	1,920
30	1,330	1,610	1,930	2,270	2,630	2,980	3,300	3,610	3,880	4,110	4,330	4,530	4,750	4,990
40	2,110	2,520	3,020	3,560	4,150	4,690	5,250	5,750	6,160	6,550	6,900	7,220	7,500	7,830
50	2,840	3,410	4,080	4,780	5,540	6,300	7,050	7,730	8,300	8,840	9,320	9,770	10,150	10,560
60	3,500	4,200	5,010	5,880	6,880	7,760	8,700	9,490	10,200	10,860	11,450	12,000	12,500	12,960
70	4,090	4,920	5,820	6,830	8,000	9,100	10,150	11,060	11,900	12,360	13,300	13,950	14,500	15,080
80	4,580	5,510	6,530	7,690	9,000	10,240	11,350	12,400	13,360	14,220	14,990	15,700	16,350	16,970
90	5,000	6,010	7,120	8,400	9,810	11,160	12,390	13,500	14,600	15,540	16,400	17,190	17,880	18,500
100	5,350	6,420	7,620	9,000	10,510	11,940	13,270	14,460	15,600	16,610	17,550	18,370	19,140	19,820
110	5,640	6,780	8,050	9,500	11,080	12,610	14,000	15,290	16,500	17,560	18,510	19,390	20,200	20,940
120	5,900	7,080	8,410	9,920	11,580	13,180	14,600	15,990	17,240	18,340	19,320	20,220	21,090	21,870
130	6,130	7,340	8,720	10,290	12,000	13,650	15,140	16,560	17,870	19,000	20,000	20,980	21,840	22,660
140	6,340	7,600	9,020	10,620	12,370	14,080	15,610	17,090	18,410	19,590	20,540	21,610	22,520	23,360
150	6,520	7,810	9,280	10,920	12,710	14,490	16,080	17,560	18,910	20,130	21,270	22,250	23,170	24,030
160	6,670	8,000	9,500	11,200	13,040	14,850	16,490	18,010	19,380	20,650	21,820	22,830	23,780	24,660

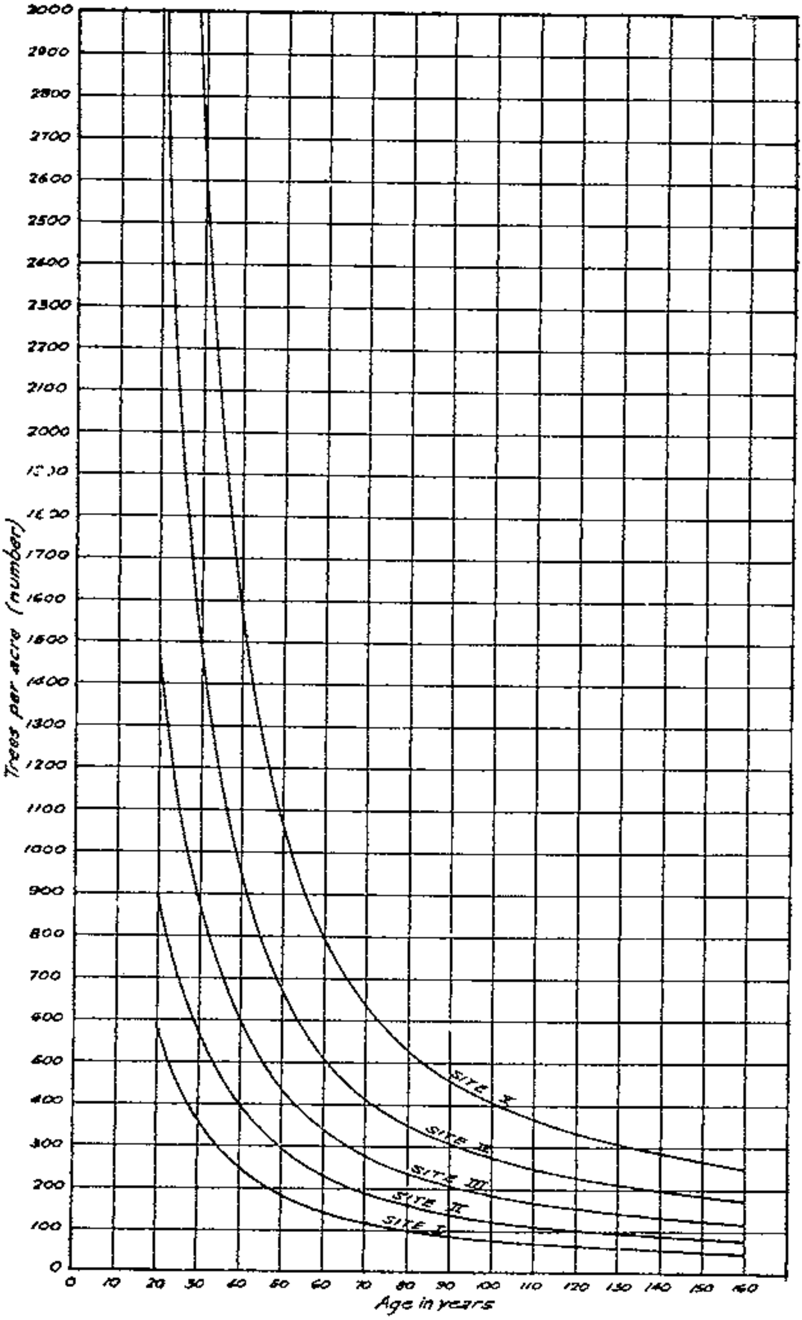

FIGURE 3.—Total number of trees per acre

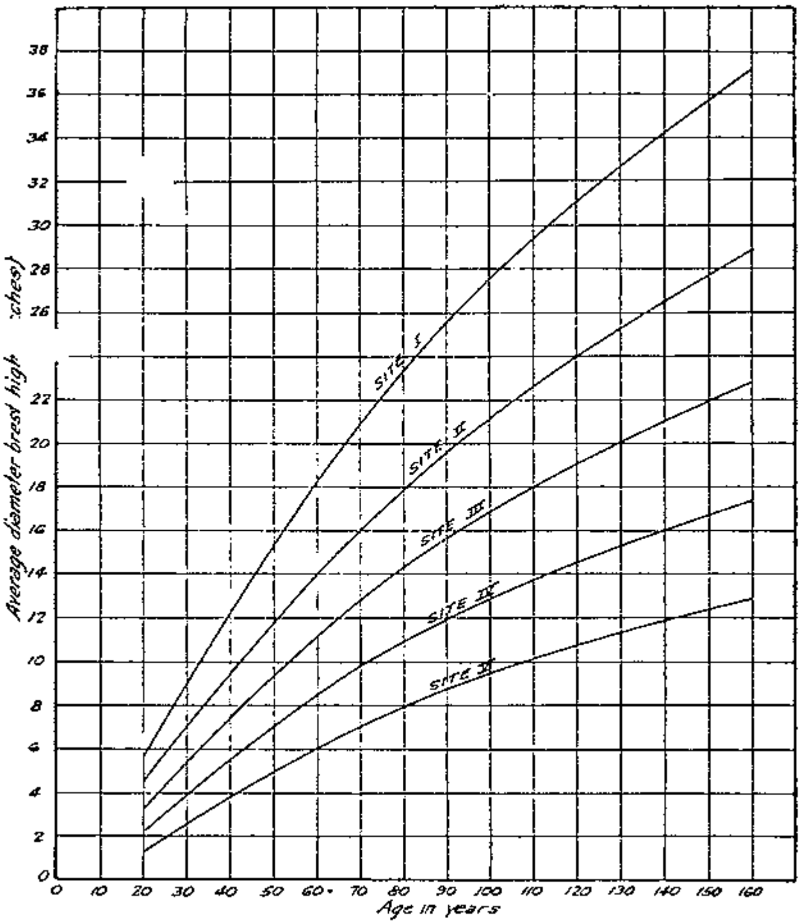

FIGURE 4.—Diameter of average trees at breastheight, total stand

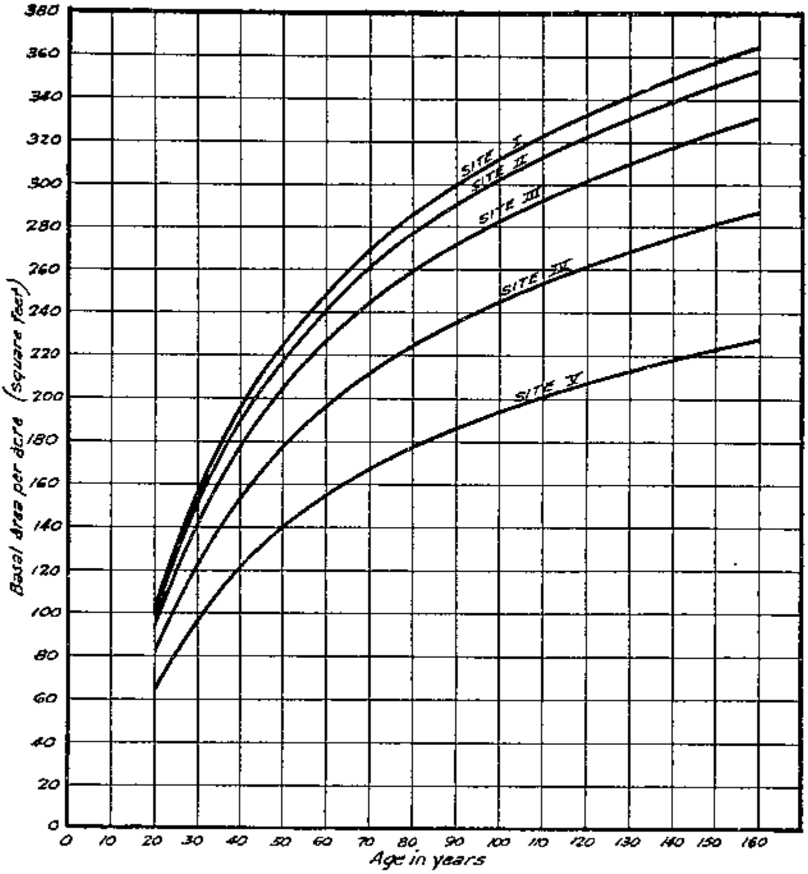

FIGURE 5.—Total basal area per acre

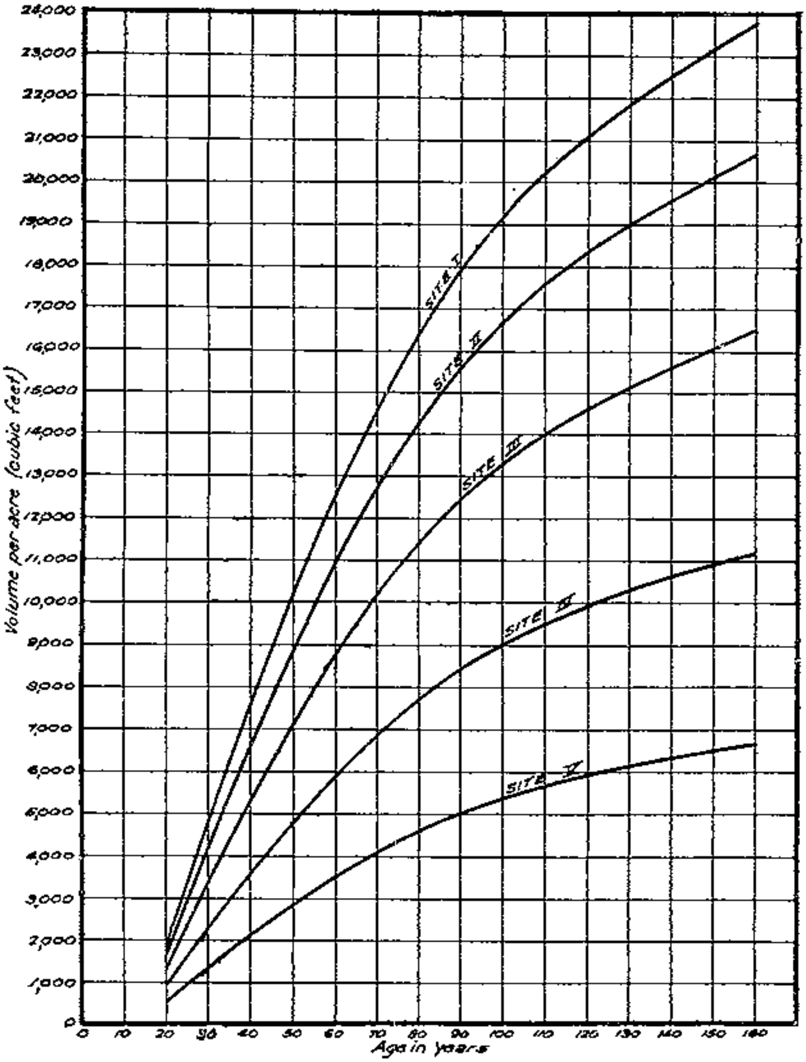

FIGURE 6.—Total yield per acre in cubic feet

YIELD TABLES FOR STAND OF TREES 7 INCHES IN DIAMETER AND LARGER

For the stand of trees 7 inches in diameter and larger, Table 3 records the number of trees, the diameter of the average tree, total basal area, cubic volume, and board-foot volume by the International log rule. Figures 7 and 8 illustrate the change in number of trees and in board-foot volume, with age.

The tables and graphs are self-explanatory with the possible exception of the graph for number of trees. (Fig. 7.) The number of

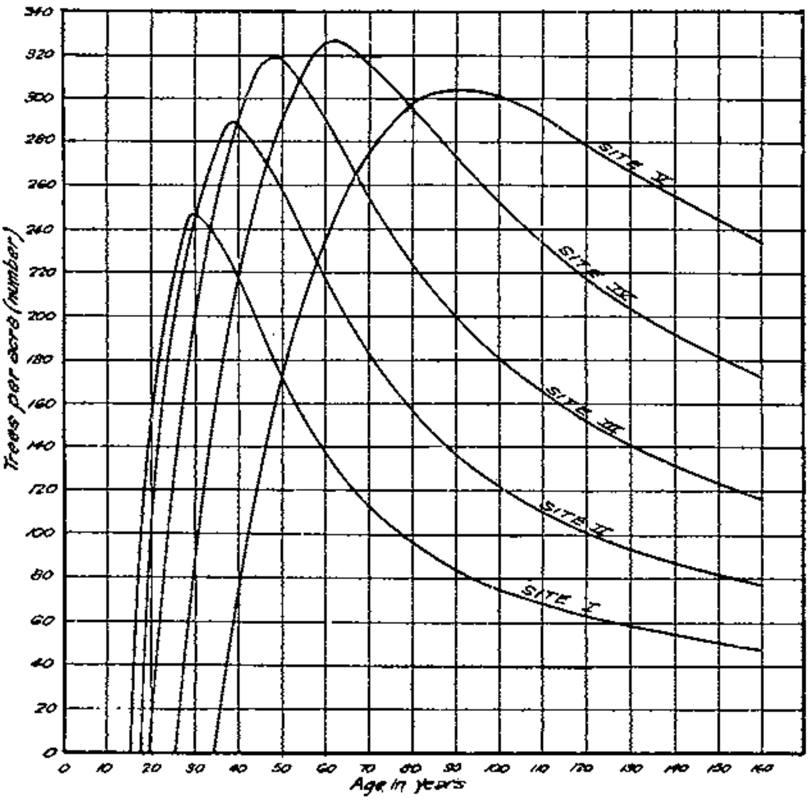

FIGURE 7.—Number of trees per acre 7 inches in diameter and larger

trees larger than 7 inches in diameter must increase as the stand grows older and the trees gain in diameter. The trees which die and drop out of the stand during this period presumably are small trees, mostly less than 7 inches in diameter. Since the stand must some time reach an age when all the trees in the stand are over 7 inches in diameter, trees dying after that time must come from the ranks of the 7-inch and larger trees. Hence, after a certain age, there is a decrease in the total number of these trees; this accounts for the sudden reversal in direction of the curves.

During the period when part of the total number of trees are smaller than 7 inches in diameter, the diameter of the average tree in the stand 7 inches and larger is greater than the diameter of the average tree in the total stand, and basal area and cubic volume are less. Later the values become equal in both stand groups.

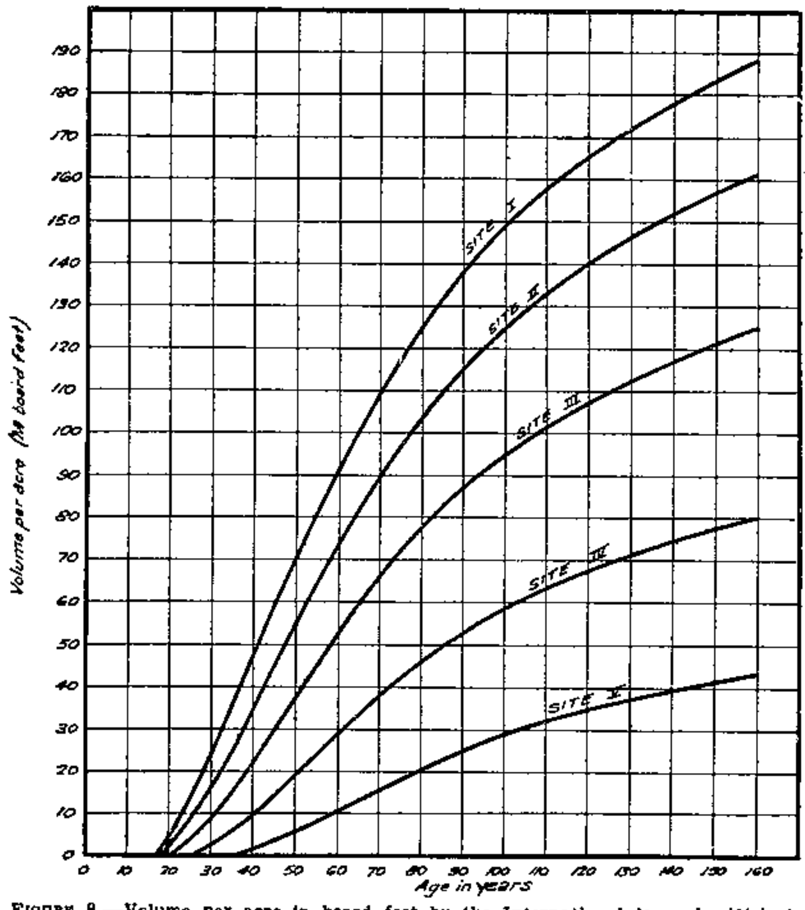

FIGURE 8.—Volume per acre in board feet by the International log rule (⅛-inch kerf), trees 7 inches in diameter and larger

YIELD TABLES FOR STAND OF TREES 12 INCHES AND LARGER IN DIAMETER

Table 4 records, for that part of the stand in and above the 12-inch diameter class, the number of trees, diameter of the average tree, total basal area, cubic-foot volume, board-foot volume by the International log rule and board-foot volume by the Scribner log rule. Figures 9 and 10 illustrate the change with age in the number of trees and Scribner board-foot volume.

TABLE 3.—*Yield tables for Douglas fir on fully stocked acre, trees 7 inches in diameter and larger*

NUMBER OF TREES

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
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
20	0	0	0	0	0	0	7	45	76	99	119	134	148	160
30	0	0	31	82	121	165	199	220	235	246	254	255	247	235
40	70	124	173	217	250	278	292	298	300	288	269	245	218	192
50	170	220	261	290	311	322	318	302	282	259	231	201	173	148
60	234	276	306	326	322	308	291	269	244	218	190	162	137	116
70	275	305	322	316	299	279	255	231	207	183	158	134	113	95
80	298	318	312	296	275	250	225	202	179	157	136	115	97	81
90	304	307	295	274	250	224	200	177	156	137	118	100	84	71
100	301	293	276	252	229	204	182	160	141	123	106	89	75	64
110	292	278	259	235	210	186	165	145	128	111	95	81	69	58
120	279	263	243	218	193	171	152	134	116	101	87	74	63	53
130	267	250	229	204	181	159	141	124	108	94	80	69	59	49
140	256	237	216	192	169	149	131	115	101	88	75	64	55	45
150	245	227	205	182	160	141	123	108	95	82	71	60	51	42
160	235	217	196	173	152	133	117	102	90	78	67	57	48	40

DIAMETER OF AVERAGE TREE AT BREASTHEIGHT

Age (years)	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
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
20	0	0	0	0	0	0	7.3	7.5	7.7	7.9	8.1	8.3	8.5	8.7
30	0	0	7.4	7.6	7.8	8.0	8.3	8.6	8.8	9.1	9.4	9.7	10.2	10.7
40	7.6	7.8	8.1	8.4	8.7	9.0	9.3	9.7	10.1	10.5	11.1	11.8	12.7	13.6
50	8.1	8.4	8.7	9.1	9.5	9.9	10.4	11.0	11.6	12.3	13.1	14.2	15.4	16.8
60	8.6	9.0	9.4	9.9	10.5	11.1	11.7	12.4	13.3	14.2	15.4	16.7	18.2	19.9
70	9.1	9.6	10.1	10.7	11.5	12.3	13.1	14.0	15.0	16.1	17.5	19.1	20.9	22.8
80	9.6	10.1	10.8	11.6	12.5	13.4	14.4	15.5	16.6	17.9	19.6	21.3	23.3	25.5
90	10.0	10.7	11.5	12.5	13.5	14.6	15.7	16.9	18.2	19.6	21.4	23.3	25.6	28.0
100	10.5	11.3	12.2	13.3	14.4	15.6	16.9	18.2	19.7	21.2	23.1	25.1	27.6	30.1
110	10.9	11.9	12.9	14.0	15.3	16.6	18.0	19.5	21.0	22.6	24.6	26.9	29.4	32.2
120	11.4	12.4	13.5	14.8	16.2	17.6	19.1	20.7	22.3	24.0	26.1	28.5	31.1	34.2
130	11.9	12.9	14.1	15.5	16.9	18.5	20.1	21.7	23.5	25.3	27.5	30.0	32.7	36.0
140	12.4	13.5	14.7	16.1	17.7	19.4	21.1	22.8	24.5	26.5	28.8	31.4	34.3	37.8
150	12.8	13.9	15.3	16.8	18.4	20.2	22.0	23.8	25.6	27.7	30.0	32.8	35.8	39.4
160	13.2	14.4	15.8	17.4	19.1	21.0	22.8	24.7	26.6	28.9	31.2	34.1	37.2	41.0

BASAL AREA

	Sq. ft.	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*
20	0	0	0	0	0	0	2	14	26	34	42	50	59	67
30	0	0	10	26	42	58	74	88	100	112	122	131	139	146
40	22	43	63	84	106	124	141	154	165	174	181	186	190	194
50	60	86	109	133	154	172	186	198	206	213	217	221	224	226
60	95	124	148	171	190	206	218	227	234	239	243	245	248	250
70	124	152	177	197	215	229	240	248	254	259	263	266	268	270
80	148	174	196	216	233	247	257	264	271	276	280	283	285	287
90	165	190	212	231	248	261	271	279	285	290	294	297	299	301
100	178	203	224	242	259	272	283	291	297	302	306	309	312	314
110	189	213	234	252	268	281	292	301	307	313	317	320	323	325
120	199	222	243	260	277	290	301	310	316	322	326	329	332	335
130	207	229	250	267	284	298	309	318	325	331	335	338	341	344
140	213	236	256	274	291	305	317	326	333	338	343	347	350	353
150	219	242	263	281	298	312	324	333	340	346	351	354	357	360
160	225	248	268	287	304	318	331	340	347	353	357	361	364	367

YIELD IN CUBIC FEET

	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.*
20	0	0	0	0	0	0	150	340	460	590	760	950	1,170	1,330
30	0	0	280	630	1,020	1,500	2,000	2,420	2,880	3,270	3,660	4,000	4,370	4,700
40	380	930	1,520	2,180	2,850	3,650	4,360	5,040	5,640	6,120	6,610	7,000	7,390	7,800
50	1,320	2,080	2,940	3,780	4,730	5,690	6,550	7,400	8,090	8,720	9,230	9,740	10,150	10,560
60	2,340	3,280	4,220	5,260	6,400	7,480	8,500	9,380	10,150	10,840	11,440	12,000	12,500	12,960
70	3,230	4,260	5,300	6,490	7,770	8,970	10,040	11,020	11,900	12,660	13,300	13,950	14,500	15,020
80	3,970	5,060	6,200	7,480	8,860	10,170	11,340	12,400	13,360	14,220	14,990	15,700	16,350	16,970
90	4,520	5,680	6,920	8,300	9,760	11,120	12,390	13,500	14,600	15,540	16,400	17,190	17,880	18,500
100	5,000	6,200	7,500	8,930	10,490	11,940	13,270	14,460	15,600	16,610	17,550	18,370	19,140	19,820
110	5,390	6,630	7,960	9,470	11,080	12,610	14,000	15,290	16,500	17,560	18,510	19,390	20,200	20,940
120	5,740	6,980	8,340	9,910	11,580	13,180	14,600	15,990	17,240	18,340	19,320	20,220	21,090	21,870
130	6,010	7,270	8,680	10,290	12,000	13,650	15,140	16,560	17,870	19,000	20,000	20,980	21,840	22,660
140	6,240	7,520	8,980	10,620	12,370	14,060	15,610	17,090	18,410	19,590	20,640	21,610	22,520	23,360
150	6,450	7,750	9,280	10,920	12,710	14,490	16,080	17,560	18,910	20,130	21,270	22,250	23,170	24,030
160	6,640	7,970	9,500	11,200	13,040	14,850	16,490	18,010	19,380	20,650	21,820	22,830	23,780	24,660

TABLE 3.—*Yield tables for Douglas fir on fully stocked acre, trees 7 inches in diameter and larger*—Continued

YIELD IN BOARD FEET, INTERNATIONAL RULE (1/8-INCH KERF)

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
	Bd. ft.	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*
20	0	0	0	0	0	0	200	800	1, 500	2, 100	2, 800	3, 900	4, 900	6, 000
30	0	0	1, 000	2, 400	4, 300	6, 200	8, 400	10, 700	13, 300	16, 000	18, 800	21, 400	24, 400	27, 600
40	1, 500	3, 800	6, 400	9, 200	13, 400	17, 400	22, 000	26, 000	30, 500	34, 900	39, 000	43, 000	47, 000	51, 500
50	5, 900	9, 500	13, 600	19, 000	25, 100	31, 400	37, 100	43, 300	49, 200	55, 000	60, 000	65, 200	70, 500	75, 300
60	10, 500	15, 900	21, 700	28, 900	37, 000	44, 500	52, 000	59, 500	66, 200	72, 800	79, 000	85, 100	90, 800	96, 200
70	15, 400	22, 100	29, 500	37, 900	47, 200	56, 500	65, 600	74, 300	82, 000	89, 000	96, 000	102, 400	108, 500	114, 500
80	20, 300	27, 800	36, 300	45, 700	56, 300	66, 800	77, 200	86, 800	95, 200	103, 200	110, 900	118, 100	124, 700	131, 100
90	24, 900	32, 700	41, 900	52, 200	63, 900	75, 700	86, 700	96, 800	106, 100	114, 700	123, 000	130, 800	137, 700	144, 000
100	28, 800	37, 200	46, 700	58, 100	70, 600	83, 000	94, 700	105, 600	115, 100	124, 400	133, 500	141, 500	148, 900	155, 400
110	32, 000	41, 000	51, 300	63, 200	76, 300	89, 500	101, 500	113, 000	123, 400	133, 000	142, 000	150, 100	157, 900	164, 900
120	34, 700	44, 000	55, 100	67, 500	81, 400	94, 700	107, 200	119, 200	130, 100	140, 300	149, 400	157, 500	165, 500	172, 700
130	37, 000	46, 900	58, 600	71, 000	85, 800	99, 300	112, 200	124, 700	136, 200	146, 500	155, 700	164, 000	172, 000	179. 500
140	39, 200	49, 500	61, 400	74, 300	89, 700	103, 500	116, 900	129, 900	141, 400	152, 000	161, 300	169, 900	178, 000	185, 400
150	41, 300	51, 700	63, 900	77, 500	93, 000	107, 800	121, 100	134, 500	146, 100	156, 700	166, 500	175, 200	183, 300	190, 900
160	43, 300	54, 000	66, 200	80, 100	96, 000	110, 900	125, 000	138, 900	150, 400	161, 100	171, 400	180, 300	188, 100	196, 000

Table 4.—*Yield tables for Douglas fir on fully stocked acre, trees 12 inches in diameter and larger*

NUMBER OF TREES

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
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
20	0	0	0	0	0	0	0	0	0	0	2	5	7	10
30	0	0	0	0	0	2	6	12	18	27	36	46	57	69
40	0	0	0	7	16	26	37	49	61	75	89	101	109	113
50	1	8	17	29	44	61	79	97	110	120	128	129	126	118
60	12	24	39	58	79	101	118	129	137	141	137	129	118	105
70	27	45	65	90	113	129	139	144	145	140	130	118	105	92
80	44	67	92	114	132	143	148	148	143	133	120	107	93	80
90	62	88	112	130	142	149	149	145	136	124	110	97	84	71
100	78	105	126	141	148	149	145	137	127	115	101	88	75	64
110	93	118	136	146	150	146	139	130	119	106	93	81	69	58
120	105	127	142	149	148	142	134	123	111	99	87	74	63	53
130	114	133	146	150	145	138	128	116	105	93	80	69	59	49
140	122	138	148	149	142	133	123	110	99	87	75	64	55	45
150	127	141	149	147	138	129	117	105	94	82	71	60	51	42
160	132	143	147	144	135	125	113	100	89	78	67	57	48	40

DIAMETER OF AVERAGE TREE AT BREASTHEIGHT

Age (years)	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
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
20	0	0	0	0	0	0	0	0	0	0	12.4	12.5	12.6	12.8
30	0	0	0	0	0	12.4	12.5	12.7	12.8	13.0	13.2	13.4	13.7	14.0
40	0	0	12.4	12.6	12.7	12.9	13.1	13.3	13.6	13.9	14.3	14.7	15.2	15.8
50	12.4	12.6	12.8	13.1	13.3	13.6	13.9	14.1	14.5	15.0	15.6	16.3	17.1	18.1
60	12.7	13.0	13.2	13.6	13.9	14.3	14.7	15.2	15.6	16.2	17.1	18.0	19.2	20.6
70	13.0	13.3	13.7	14.1	14.5	15.0	15.6	16.2	16.8	17.7	18.7	20.0	21.4	23.2
80	13.3	13.7	14.1	14.6	15.2	15.8	16.5	17.2	18.0	19.0	20.3	21.8	23.6	25.7
90	13.6	14.0	14.5	15.1	15.9	16.6	17.4	18.2	19.2	20.4	21.9	23.6	25.6	28.0
100	13.9	14.4	15.0	15.7	16.5	17.3	18.4	19.3	20.4	21.8	23.4	25.3	27.6	30.1
110	14.2	14.7	15.4	16.2	17.1	18.1	19.2	20.3	21.6	23.1	24.8	26.9	29.4	32.2
120	14.5	15.1	15.8	16.7	17.7	18.8	20.0	21.3	22.7	24.2	26.2	28.5	31.1	34.2
130	14.8	15.5	16.2	17.2	18.3	19.5	20.8	22.2	23.7	25.4	27.5	30.0	32.7	36.0
140	15.0	15.8	16.6	17.7	18.9	20.2	21.6	23.2	24.7	26.6	28.8	31.4	34.3	37.8
150	15.3	16.1	17.0	18.1	19.5	20.8	22.4	24.0	25.7	27.8	30.0	32.8	35.8	39.4
160	15.6	16.4	17.4	18.6	20.0	21.5	23.1	24.9	26.7	28.9	31.2	34.1	37.2	41.0

TABLE 4.—*Yield tables for Douglas fir on fully stocked acre, trees 12 inches in diameter and larger*—Continued

BASAL AREA

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
	Sq. ft.	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*
20	0	0	0	0	0	0	0	0	0	0	2	4	6	9
30	0	0	0	0	0	1	6	10	16	24	33	44	58	74
40	0	0	2	7	14	23	34	48	62	80	100	120	139	155
50	1	7	15	27	42	61	83	106	127	149	170	187	200	211
60	11	21	37	59	84	113	140	164	183	202	217	229	238	244
70	25	44	67	98	130	160	186	207	224	238	249	257	264	268
80	42	69	100	133	166	197	220	238	251	263	272	278	283	287
90	62	95	129	162	196	224	245	261	273	283	289	294	298	301
100	82	119	155	188	219	244	264	279	289	297	303	308	311	314
110	102	140	176	208	238	262	280	293	302	309	314	319	323	325
120	120	158	194	225	253	276	293	305	313	319	324	329	332	335
130	136	173	209	239	266	287	304	314	322	329	334	338	341	344
140	150	187	221	251	277	297	313	323	331	337	343	347	350	353
150	163	199	233	261	286	306	320	330	339	346	351	354	357	360
160	175	210	242	271	295	313	328	338	346	353	357	361	364	367

YIELD IN CUBIC FEET[1]

Age (years)	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
	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.*
20	0	0	0	0	0	0	0	0	0	0	30	80	140	200
30	0	0	0	0	0	70	150	300	490	730	1,020	1,400	1,850	2,450
40	0	0	60	190	430	760	1,190	1,660	2,250	2,960	3,770	4,750	5,650	6,450
50	60	170	470	850	1,430	2,200	3,100	4,120	5,200	6,300	7,380	8,440	9,290	10,000
60	310	680	1,200	1,990	3,030	4,225	5,650	7,000	8,200	9,400	10,400	11,330	12,050	12,750
70	720	1,360	2,190	3,400	4,970	6,550	8,000	9,400	10,650	11,820	12,750	13,650	14,330	14,950
80	1,240	2,110	3,300	4,800	6,500	8,380	9,940	11,380	12,570	13,720	14,650	15,500	16,230	16,900
90	1,820	2,980	4,370	6,100	8,050	9,800	11,430	12,850	14,100	15,230	16,200	17,050	17,850	18,500
100	2,410	3,690	5,350	7,170	9,130	10,950	12,620	14,000	15,300	16,410	17,440	18,300	19,140	19,820
110	3,000	4,500	6,190	8,050	10,020	11,880	13,530	14,980	16,290	17,430	18,450	19,350	20,200	20,940
120	3,570	5,150	6,890	8,760	10,760	12,620	14,300	15,760	17,100	18,270	19,300	20,220	21,090	21,870
130	4,120	5,720	7,470	9,360	11,360	13,240	14,920	16,410	17,760	18,960	20,000	20,980	21,840	22,660
140	4,600	6,190	7,960	9,860	11,880	13,790	15,450	16,980	18,350	19,580	20,640	21,610	22,520	23,360
150	5,000	6,600	8,390	10,300	12,320	14,250	15,910	17,480	18,870	20,130	21,270	22,250	23,170	24,030
160	5,350	6,950	8,750	10,700	12,750	14,690	16,340	17,950	19,350	20,650	21,820	22,830	23,760	24,660

[1] See appendix table 22, p. 65, for cubic-foot yield table for fully stocked Douglas fir, trees larger than 5.0 inches d. b. h. (Forest Survey standard).

YIELD IN BOARD FEET, INTERNATIONAL RULE (1/8-INCH KERF)[2]

	Bd. ft.	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*
30	0	0	0	0	0	0	0	1,200	2,300	4,400	6,700	9,100	12,500	16,400
40	0	0	0	900	2,400	4,300	7,200	10,500	14,300	19,300	24,400	31,000	37,500	43,600
50	0	800	2,500	5,400	9,000	13,800	19,800	26,600	33,900	41,900	49,600	57,600	64,600	71,100
60	1,800	4,200	7,800	12,800	19,200	27,400	37,200	46,500	55,000	64,200	72,600	81,000	88,300	95,000
70	4,400	8,600	14,500	22,100	32,600	43,300	54,100	64,200	74,000	83,600	92,500	100,900	108,400	115,000
80	7,600	14,000	21,800	31,800	44,600	56,800	68,800	79,700	90,000	99,900	109,200	117,000	124,700	131,000
90	11,200	19,200	28,900	40,200	54,600	67,800	81,000	92,400	103,500	113,500	122,800	130,800	137,700	144,000
100	15,200	24,800	35,400	48,000	63,100	77,000	90,700	102,900	114,400	124,200	133,400	141,500	148,900	155,400
110	19,600	29,600	41,500	55,000	70,200	85,100	98,900	111,300	123,000	133,000	142,000	150,100	157,900	164,900
120	23,800	34,000	47,000	60,800	76,300	91,900	105,600	118,400	130,000	140,300	149,400	157,500	165,500	172,700
130	27,200	38,000	51,400	65,800	81,600	97,400	111,300	124,400	136,000	146,500	155,700	164,000	172,000	179,500
140	30,400	41,700	55,100	70,000	86,300	102,300	116,500	129,700	141,300	152,000	161,300	169,900	178,000	185,400
150	33,200	45,000	58,600	74,000	90,500	106,600	121,000	134,300	146,000	156,700	166,500	175,200	183,300	190,900
160	35,900	48,100	61,900	77,600	94,500	110,400	125,000	138,700	150.200	161,100	171,400	180,300	188,100	196,000

YIELD IN BOARD FEET, SCRIBNER RULE[3]

	Bd. ft.	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*
30	0	0	0	0	0	0	300	900	1,500	2,600	4,000	6,000	8,000	10,500
40	0	0	0	200	1,200	2,600	4,500	6,500	9,000	11,900	15,500	19,600	24,400	29,400
50	30	200	1,600	3,300	5,500	8,400	12,400	17,000	22,200	27,400	32,700	38,400	44,100	50,000
60	1,100	2,600	4,800	8,100	12,500	18,000	23,800	29,600	36,200	42,800	49,300	55,900	62,000	68,300
70	2,400	5,300	9,000	14,000	20,600	27,900	35,200	42 500	50,000	57,200	64,600	71,500	78,200	85,000
80	4,400	8,600	13,900	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	45,200	55,000	64,000	72,900	81,000	89,210	97,200	104,800	112,300
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	47,500	58,500	69,400	79,400	89,200	98,300	107,000	115,200	123,700	131,200
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	139,000
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	146,100
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	29,600	39,700	51,600	64,000	76,600	88,600	100,300	111,000	121,200	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	115,400	125.700	135,400	144,400	153,500	162,000

[2] Volumes shown allow for a minimum top diameter of 5 inches (see p. 11). See appendix table 23, p. 66, for yield in board feet, International rule (1/4-inch kerf) to an 8-inch top.

[3] Volumes shown allow for a minimum top diameter of 8 inches and for scaling by 16-foot logs (see p. 11). See appendix table 24, p. 67, for yield in board feet, Scribner rule, for trees 15.6 inches in diameter and larger to a 12-inch top, scaled by 32-foot logs.

APPLICATION OF NORMAL-YIELD TABLES TO ACTUAL STANDS

PRINCIPLES AFFECTING NORMALITY

The normal-yield tables in this bulletin indicate the volume yields and other stand values that may be expected in normally stocked forests. Such values were actually found in natural stands, but only on plots selected for their uniform distribution of trees and freedom from openings. Normal stocking does not occur uniformly over large areas in the natural stands of the present day, nor is it likely that full stocking will prevail in the forests of the immediate future.

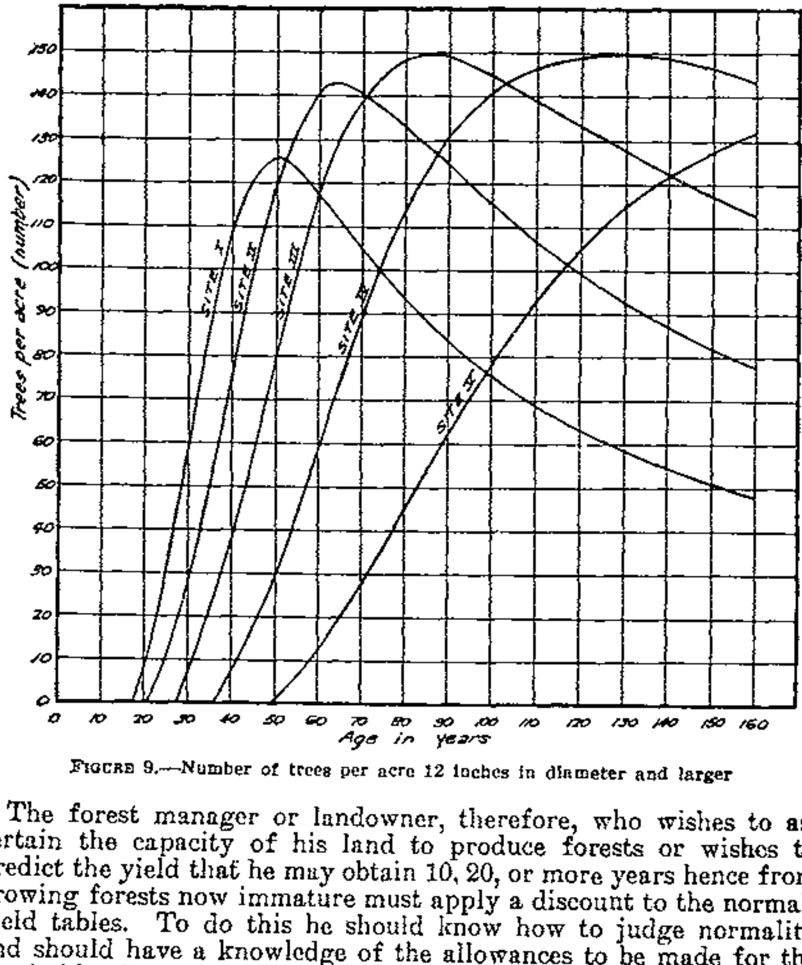

FIGURE 9.—Number of trees per acre 12 inches in diameter and larger

The forest manager or landowner, therefore, who wishes to ascertain the capacity of his land to produce forests or wishes to predict the yield that he may obtain 10, 20, or more years hence from growing forests now immature must apply a discount to the normal-yield tables. To do this he should know how to judge normality and should have a knowledge of the allowances to be made for the inevitable disparities between the actual average stands and the standard fully stocked stands.

Small areas, but not extensive forests of Douglas fir in this region, are sometimes overstocked in reference to the standard tables. Large areas may appear fully and uniformly forest clad, but closer inspection nearly always discloses "holes" or blank spaces that aggregate enough to bring the stand volume materially below that of the normal-yield tables.

In considering the relationship of actual stands to the normal standard for any area of homogeneous forest, it is obvious that only minor holes or breaks in the uniform continuity of the canopy are considered—those less than about 150 feet across. Upon the quantity of these small blank spaces depends the degree of understocking. Breaks that are large enough to be mapped, such as those made by meadows, rivers, or cutting operations, or changes in the forest type under consideration, are eliminated as "surveyable openings" and so have no part in affecting the degree of understocking.

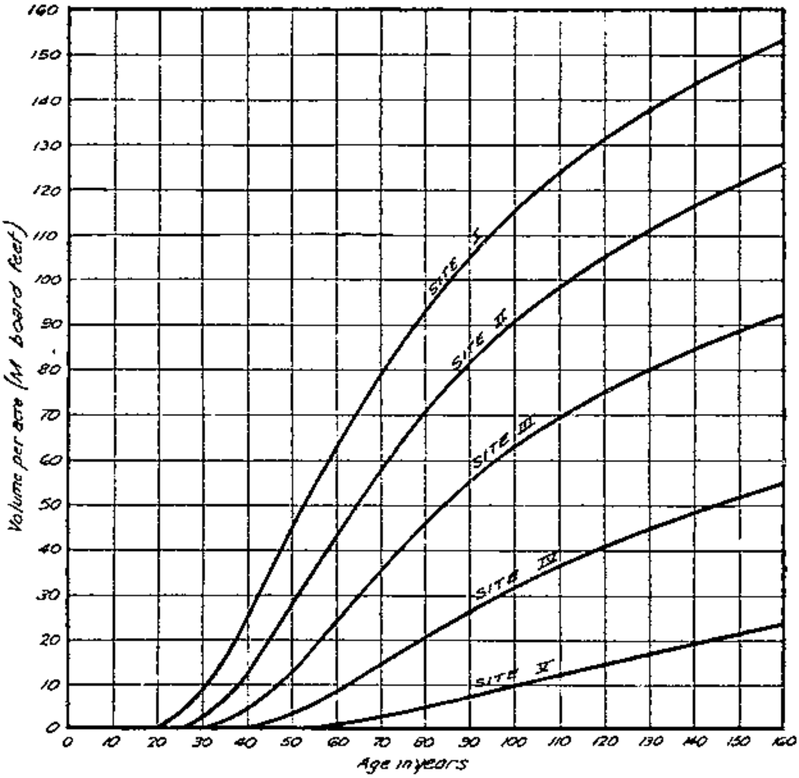

FIGURE 10.—Volume per acre in board feet by the Scribner log rule, trees 12 inches in diameter and larger

Obviously these surveyable openings must be listed according to their respective types in the forest inventory, but should not be confused with those minor and well-nigh universal breaks and thin places in the canopy of any natural forest which cause the condition of understocking.

In order to ascertain the relationship between the stand values of average extensive forests and the normal yield table values for selected plots, a special study was conducted during the field seasons of 1926 and 1927, following the conclusion of the collection of the data for the normal-yield tables. An answer was sought for such practical questions as the following: What causes and what constitutes understocking? Does the understocked stand always remain understocked or does its relationship to the normal change during its life? How may the degree of understocking or overstocking be recognized? By how much must the normal yield tables be discounted to give correct values for actual average stands? What field operations and office technic are necessary to employ normal-yield tables in determining the probable production of extensive actual stands?

This study of average stands comprised the running of 62 miles of very detailed strip surveys through 83 Douglas fir forests of various ages, the analyzing of 493 sample-plot records to test their relationship to normality, and finally the making of a complete survey of a 4,000-acre forest as a basis for perfecting the technic of yield-table application. The results of this research are published elsewhere,[9] and but a brief summary of the findings will be given here.

VARIABILITY OF STANDS

Uniformity in the stocking of a forest is rare; variability seems to be general and the range from one acre to another quite wide. This was found to be so in comparing individual acres on strip cruises of the study referred to. The degree of stocking, as expressed in volume of cubic feet, ran all the way from 25 to 138 per cent of the normal stocking indicated by the yield tables, and averaged 80.5 per cent. Two-thirds of the individual acres came within 20 per cent of the average cubic volume, either above or below; i. e., between 60 and 100 per cent of the yield-table volumes. The individual-acre basal areas show similar departures from the normal; and this is also true of the board-foot volume by the International rule.

Tracts of several acres may vary in respect to cubic-foot volume, basal area, and board-foot volume (International rule) from as little as 40 or 50 per cent of normal stocking to as much as 120 or 130 per cent. When still larger tracts are considered, the range in departures from the normal is not quite so wide. Over extensive areas the stand values will be approximately 80 per cent of those in the normal yield tables. This may be taken as a fair regional approximation since it is based on a survey of 83 forests, but a discount for local application to single stands, which may differ widely from the average, must be ascertained by methods described below wherever detailed yield oredictions are to be made.

CAUSES OF UNDERSTOCKING

A variety of causes may affect the stocking of a stand, actually producing small holes or gaps in the forest canopy which can be picked out as a strip is run. On the average, the sum of such determinable small interruptions amounted in this study to 10 per cent of the area, although understocking itself was 20 per cent below the normal. The remaining 10 per cent is probably attributable to the wide spacing of trees. Understocked stands seem to have both actual holes in the canopy and thin spots due to wide spacing, both conditions contributing alike to subnormal stand volume.

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[9] MEYER, W. H. A STUDY OF THE RELATION BETWEEN ACTUAL AND NORMAL YIELDS OF IMMATURE DOUGLAS FIR FORESTS. 1930. [Unpublished manuscript.]

The principal causes of understocking include—

(1) An insufficient number of seedlings per acre when the stand originated to fully utilize the soil and crown space;

(2) Topographic or soil conditions, such as ledges, swampy spots, or water-courses, which preclude occupation by trees of the type under consideration;

(3) Breaks in the canopy of the main coniferous stand occupied by clumps of hardwoods, which are not considered in the final yields;

(4) Openings caused by action of such factors as fire, wind, snowbreak, and insects or other depredators; and

(5) Minor openings made by man, such as the cutting of a few trees to make way for roads or trails.

EFFECT OF SLOPE ON YIELD

It has been mentioned that slope is one of the elements that control site quality. But apart from this consideration there is a difference in stand values, or stocking, with changes in slope, site for site. All the normal-yield table values are for acres measured on the horizontal, which is significant in topography such as that in the Douglas fir region, where slopes of 80 per cent or more are not uncommon. The slopes of the areas upon which the normal-yield tables were based averaged probably between 20 and 30 per cent. The question has often been raised whether the yields did not increase with increase in slope, just as the surface area of a horizontally measured acre increases. It seems natural that this should be so since the soil surface and crown exposure increase for the horizontally measured acre with increase in gradient. A test of 433 sample plots indicated that this condition did prevail up to a certain point and that the largest yields were found on slopes of about 40 per cent. Broadly speaking, on 40 per cent slopes the basal area of the stand averages 6 per cent and the cubic foot volume 9.5 per cent above that on the average or 25 per cent slope, whereas on level areas the values are 6 per cent and 5 per cent, respectively, less than the normal.

In this connection it is significant that a horizontally measured acre on a 40 per cent slope has 4.6 per cent more surface area than one on the average 25 per cent slope, and a level acre has 2.8 per cent less surface area than an acre on a 25 per cent slope. It is obvious, therefore, that in the application of these normal-yield tables to areas where no stand tally is available there should be some correction for slope if the bulk of the area is on land the slope of which is different from that for which the tables were made.[10]

INDICES OF STOCKING

In the study referred to an attempt was made to determine the most reliable criterion to use in judging normality of stocking. The ultimate definition of stocking should be made in terms of volume. Volume computations, however, are tedious and make the application of normal yields much more time-consuming without appre-

[10] Suggested corrections for slope, all referenced to the horizontally measured acre, are as follows, expressed in cubic-foot volume:
On level areas discount figures in normal-yield tables 5 per cent.
On 10 to 25 per cent slopes no discount or increase need be made.
On 30 to 50 per cent slopes increase figures in normal-yield tables 5 per cent.
On 60 per cent slopes make no discount or increase.
On 80 per cent slopes discount figures in normal-yield tables 10 per cent.

ciably increasing the accuracy. Therefore it is advisable to seek in a simpler stand value, such as number of trees or basal area, an index to the degree of volume stocking.

A study of the factors which might be used in Douglas fir forests for a determination of the degree of stocking confirms the conclusion reached by other investigators in other forest types, that the total number of trees per unit area is a very unsatisfactory, if not useless, index. On the other hand, basal area was found to be a most reliable index and one easily obtained, since it requires only a tally of the stand and simple computations. The relation between basal area and cubic-foot or International-rule board-foot volume is very regular; the degree of normality of any tract will be approximately the same whether expressed in basal area, in cubic-foot volume, or in International-rule board-foot volume. To illustrate: Should a tract be found to have a basal area approximately 75 per cent of that given in the normal-yield tables, it is probable that its cubic-foot contents and its International-rule board-foot contents would be approximately 75 per cent of that given in the normal-yield tables for the same age and site class, yet the number of trees per acre is quite apt to bear a different ratio to the normal-yield values.

In the younger stands, where many of the trees are below 12 inches in diameter and therefore can not be measured in terms of board-foot volume by the Scribner rule, it was found, as would be expected, that the ratio of their Scribner-rule volume to the normal values was very erratic. However, in stands where most of the living trees were 12 inches or more in diameter, the number of such trees was a fairly good indication of the degree of stocking in terms of Scribner board-foot volume. Nevertheless, the ratio between the number of trees 12 inches or larger and the Scribner-rule volume of such trees is not a straight-line relationship, as in the case of some other stand values, but can be defined by a curve, from which are derived the ratios shown in Table 5.

TABLE 5.—*Comparison of percentages of stocking as determined by number of trees 12 inches d. b. h. and larger and by board foot volume (Scribner rule)*

Number of trees	Corresponding volume	Number of trees	Corresponding volume	Number of trees	Corresponding volume
Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
30	34	70	78	110	111
40	46	80	87	120	118
50	58	90	95	130	125
60	68	100	103		

ALLOWANCES FOR INCOMPLETE UTILIZATION AND FOR DEFECTS

In the application of yield tables to actual cases, a very important consideration is the discount that should be made for defect in the trees, for breakage in logging, and for incomplete utilization. Earlier pages have indicated that the normal-yield tables assume all trees to be sound and make no allowances for breakage and wastage, yet inevitably there will be a certain amount of disparity between the normal and the realizable volumes, even under most intensive practices. In predicting future yields it is necessary to assume prophetically that certain standards of utilization will apply years hence and discount the normal yields accordingly.

No general rules can be given for these discounts; they will vary greatly from stand to stand with age, topography, type of logging, character of product, and all the other variables. In making yield predictions the forester must depend largely on experience and judgment for the fixing of defect and utilization allowances.

A few general statements may be a guide. As there is little rot in immature stands of Douglas fir the correction on that account is inconsequential. The timber destroyed in logging or left in the woods unutilized in immature Douglas fir forests that are of good merchantable size, has been estimated by A. H. Hodgson (*5*) to amount to 12 or 15 per cent of the volume of the original stand. It may amount to very much more than this sometimes, particularly where some of the trees are not of a size to be merchantable for the product sought, and are left uncut, a prey to wind and fire. Present-day utilization is therefore at least 15 to 20 per cent below the normal-yield table values; how much less the discount should be for stands to be cut one, two, or three decades hence, is problematical.

It should be clear that the above discussion of utilization standards is based on tree or log measurement and takes into consideration only the portion of the forest stand that is taken out of the woods and has no reference to the material that is wasted or fails of utilization in the manufacturing process—such as sawdust, slabs, and trimmings—except as these are allowed for by the log rules themselves.

TREND OF UNDERSTOCKED STANDS TOWARD NORMALITY

There is in nature a tendency toward equilibrium, which in forest growth appears to manifest itself in a trend toward normality. Understocked stands tend automatically to become more like the normal stand of the same age, and the converse is probably true of overstocked stands. Positive information on this point is meager, and nothing could be learned from the analysis of data from plots measured but once. However, the statistical history of some Douglas fir permanent sample plots that have been under observation since 1910 leads to the tentative conclusion that the change toward normality goes on at the rate of 4 per cent each decade (*4*). There is apparently much irregularity in the progress of stands toward normality, because of occasional accidental setbacks. Until further data are gathered from permanent plots over a longer term of years, this percentage rate of increase should be used conservatively in correcting yield predictions, and only with stands within the age range of the permanent plots so far studied, namely, between 40 and 80 years. Data on the rate of regression of overstocked plots toward normal conditions are still too scanty to justify even tentative conclusions.

METHODS OF CONDUCTING YIELD SURVEYS

The preceding paragraphs have shown briefly the relation between actual and normal stands and how these differences may be judged. To develop the technic by which a set of normal-yield tables might be applied to a large area preliminary to making yield predictions for a forest management plan, an actual survey was made of an area of over 4,000 acres. Although space will not permit a complete account of this yield survey, its principal steps are outlined here to serve as a model or illustration for forest managers who have such surveys to make for either small or large properties. This experimental project was carried on in more detail than need be the case in extensive practice, in order that by using intensive methods the relative importance and practicability of each step in the field and office work might be tested.

On the test area of over 4,000 acres, on the Sauk River watershed of the Snoqualmie National Forest, Wash., 2,631 acres were mapped as second-growth Douglas fir type and this comprised the area for which yield predictions were to be made. The remainder of the tract was old-growth mature timber, hardwood type, and rivers or other surveyable openings, and so was excluded from consideration.

FIELD WORK

The purpose of the field work is to obtain (1) a map showing the location and size of each area of uniform site and uniform age class, and (2) a tally of the diameter and height of the trees by site and age groups and by legal subdivisions if desired. The tract is sampled by means of strips covering only a small percentage of the actual area.

The most convenient crew consists of three men, one of whom acts as compass and map man, the second as caliper man or estimator, and the third as rear chainman taking borings and heights and correcting distances for slope.

Horizontal and vertical control is run as in the usual timber-cruising projects, by means of established section lines, rights of way, surveys, traverses, and so forth. The intensity of the control will depend upon whether a topographic map exists or has to be made.

Strips 1 chain in width are run at 10 or 20 chain intervals, depending upon the complexity and size of the area, thus giving a 10 or 5 per cent estimate. In a typical survey the compass man runs the line, carries the chain, and makes the map on a scale of 8 inches to the mile. The estimator tallies all the trees on the strip in 2-inch classes, actually measuring as many as possible, and tallying within the class all diameters 0.4 inch below and 0.5 inch above; for instance, trees 11.6 to 13.5 inches in diameter are tallied in the 12 to 13 inch class. Since the largest chance for error in any survey is in maintaining the proper width of the strip, this should be checked continually, either by pacing or by means of a small range finder with which the caliper man can easily and quickly determine whether a certain tree is inside or outside the belt. The rear chainman takes borings to ascertain the age of the trees on that strip, converting the number of rings at breastheight to total age by means of the values found in Table 19, and, for convenience, rounding off the age of each stand to the nearest decade. He also takes, with hypsometer or Abney level, total heights of average-sized dominant and codominant trees, in order to make the site determination. After such a crew is well organized, they can work as fast as a 2-man timber survey crew using a chain and correcting for slope, if not a little faster.

Wherever the site or age class changes, a new tally sheet is started by the estimator. If the estimate is desired by 40-acre divisions the tally sheet should be changed also after each forty. This frequent change of tally sheets means that all three members of the crew must work in close contact so that the sheets will not be changed without a corresponding change in the map.

The five site-quality groups, I to V, will be used ordinarily, the site-index system being applicable only to small tracts or single stands in which the sites are not too variable. All three members of the crew should be on the watch continually for a change in site, as indicated by the average height of the larger trees in the stand. No site or age class distinction less than 2 chains along the strip need be made. Before concluding the field work a careful check should be made between the tally sheets and the map to discover whether any discrepancies exist.

OFFICE WORK

The office work differs more than the field work from the conventional methods of timber surveys. It will therefore be described in greater detail, and will be illustrated by computations drawn from the above-mentioned actual survey.

First, the field maps are combined into a project map, drawn either to the same scale of 8 inches to the mile or to a smaller scale if more convenient. A legend must be chosen that will show without confusion the several site and age classes of the major type under consideration and the areas of other types. With a planimeter the acreage of the individual site-age classes is compiled. In some surveys it may be desirable to keep these by legal 40-acre divisions, but this increases the work two to three fold and should be avoided when not necessary.

When the site and age class acreages have been compiled, the tallies applying to each of the individual areas must be worked up. The total basal area and the number of trees in diameter classes 12 inches and larger are first computed. Should the portion of the strip in the tally not be an even acre, the basal area and number of 12-inch trees must be converted to the acre basis. Following this, the values are applied to the total area inside the individual area under consideration, and total basal areas and total number of 12-inch trees are found. For instance, in the example given in Table 6, section 19, forty 11, has 5.4 acres in age class 80, Site Class III. Basal area for this class is 116.1 square feet per acre; trees in and over the 12-inch diameter class number 50. Thus the total basal area for the class is 627 square feet, and the total number of trees is 270. In the illustrative survey (Tables 6 and 7) the present-stand volumes were also computed. However, in all prospective yield surveys, if a knowledge of the present volumes is not essential for immediate purposes the computations should not be made, since to do so greatly increases the amount of office work.

TABLE 6.—*Sample form for summarizing stand values in a yield survey by 40-acre subdivisions*

Section	Forty	Age	Site	Planimeter reading (double)	Area of stand	Basal area	Trees 12 inches in diameter and over	Volume	
								Cubic measure	Scribner rule
		Years		*Sq. in.*	*Acres*	*Sq. ft.*	*No.*	*Cu. ft.*	*Bd. ft.*
19	11	80	III	1.08	5.4	627	270	29,060	146,390
		80	IV	.05	.3	43	21	1,660	6,960
		80	V	4.63	23.0	2,414	736	59,090	92,460
		90	IV	.06	.3	54	24	2,030	6,530
		Outs.		2.24	11.0				
Total					40.0	3,138	1,051	91,840	252,340

TABLE 7.—*Sample of summary of yield figures by site-age classes*

SITE III

Age	Area	Basal area	Trees 12 inches and more in diameter	Volume	
				Cubic measure	Scribner rule
Years	*Acres*	*Sq. ft.*	*Number*	*Cu. ft.*	*M bd. ft.*
60	13.1	920	630	38,900	158
80	126.75	23,840	10,080	1,087,300	5,297
90	88.55	15,190	7,250	694,000	3,277
100	367.4	66,570	27,270	3,272,300	16,502
120	82.55	14,230	6,210	718,900	3,622

SITE IV

	And so forth for other sites and ages				
Summary	2,631.0	475,460	185,530	24,789,300	131,645

This 40-acre tally can be further simplified by adding all site and age classes together, thus obtaining a forty estimate, which, however, has no use in the yield prediction.

After the computations are completed for each individual tally sheet they are combined in a single table arranged by age and site classes, in which each age and site class contains all the areas of that particular category in the whole survey. This grouping is necessary in order to facilitate further computation, except for small areas or those where the types are not complex.

The last step before making the yield predictions is to compute the average degree of stocking found in the various site and age classes. This is done by dividing the total basal area of each site-age class by the number of acres to get the average basal area per acre and then comparing this with the basal area per acre of the fully stocked or normal forest of the same age and site. The ratio is the degree of stocking expressed as percentage of normal.

For instance, in Table 7, "age 80, Site III," has a total basal area of 23,840 square feet on 126.75 acres, or an average of 188.1 square feet per acre. According to Table 2, the basal area of this age-site class in the normal forest is 259 square feet. Dividing 188.1 by 259 gives 72.6 per cent, which is listed as 72.5 per cent in Table 8, in which normality is given to the nearest 0.5 per cent.

TABLE 8.—*Sample form for computation of yield predictions 30 years hence*

Age class	Area	Normality		Corresponding Scribner-rule normality	Predicted volume per acre for normal stocking		
		Basal area	Trees 12 inches or more in diameter		Cubic measure	International rule	Scribner rule
	Acres	*Per cent*	*Per cent*	*Per cent*	*Cubic feet*	*Board feet*	*Board feet*
60-year	13.10	31.0	40.5	46.5	12,390	86,700	55,000
80-year	126.75	72.5	53.5	61.5	14,000	101,500	69,400
90-year	88.55	63.0	55.0	63.0	14,600	107,200	75,000
100-year	367.40	64.0	51.0	59.0	15,140	112,200	80,000
120-year	82.55	57.5	56.0	64.0	16,080	121,100	88,600
	Etc., etc., etc., for all remaining site and age classes						
Total	2,631						

Age class	Predicted volume per acre reduced to correspond to actual stocking			Predicted volume for total area		
	Cubic measure	International rule	Scribner rule	Cubic measure	International rule	Scribner rule
	Cubic feet	*Board feet*	*Board feet*	*Cubic feet*	*Board feet*	*Board feet*
60-year	3,841	26,877	25,575	50,317	352,089	335,032
80-year	10,150	73,588	42,681	1,286,512	9,327,279	5,409,817
90-year	9,198	67,536	47,250	814,483	5,980,313	4,183,988
100-year	9,690	71,808	47,200	3,560,106	26,382,259	17,341,280
120-year	9,246	69,632	56,709	763,257	5,748,122	4,680,915
	Etc., etc., etc., for all remaining site and age classes					
Total				27,038,374	204,020,968	161,291,474

Similarly the Scribner board-foot volume ratio of normality can be computed; but it should be remembered that this scale rule, being an arbitrary and somewhat erratic unit of volume measurement, can not be expected to give always a consistent and accurate index of the stocking; furthermore, it should only be applied to site and age classes in which the majority of the trees are over 12 inches in diameter. In this comparison the actual number of trees 12 inches and over for the site-age group under consideration is first divided by the number in the comparable normal stand. (Table 4.) Then, since the normality ratios of trees 12 inches and larger and of Scribner-rule volumes, unlike those of basal area and cubic-foot volume, are not the same, it is necessary to adjust the percentage of stand to get the correct Scribner-rule volume ratios of normality according to Table 5. For instance, if the percentage of normal number of trees 12 inches and larger is 50, the percentage of Scribner-rule volume would be 58, and the latter figure would be entered in the compilation table under "Corresponding Scribner-rule normality."

After the computation of the degrees of stocking of all age and site classes have been made, the yield predictions themselves can be made. Briefly, this is done by reading first the values for cubic-foot volume or board-foot volume from the normal-yield tables (Tables 2, 3, or 4) at the age for which the prediction is to be made, and then reducing them by the proportion that the actual stand is understocked (or enhancing the normal-yield values if overstocked), and finally applying the altered figures to the whole area.

In the example given in Table 8 it is assumed that all stands will be cut 30 years hence.

To make clear the several steps in this procedure, a single line of calculation will be followed through. Age class 60, Site III, has an area of 13.1 acres, a total basal area of 920 square feet, and 630 trees 12 inches or more in diameter at breastheight. The normal values per acre for this age and site are 226 square feet basal area and 118 trees 12 inches and larger. (Tables 2 and 4.) The gross basal area of the age class, 920 divided by 13.1 and then divided again by 226, gives 31 per cent of normal stocking. Similarly 630 trees divided by 13.1 and then by 118 gives 40.75 per cent, the ratio of normality in number of trees 12 inches and larger. According to Table 5, this 40.75 corresponds to a Scribner-rule volume percentage of normality of 46.5. These values are then entered in the computation form under " Normality."

Thirty years hence this 60-year stand will be 90 years old. The normal values at this age for volume in cubic measure, and board measure by International rule and Scribner rule are 12,390, 86,700, and 55,000 feet, respectively, and are listed under " normal stocking " per acre. To the cubic-foot volume and board-foot volume by International rule the present day basal area normality percentage at 60 years (31 per cent) is applied; that is to say, 12,390 and 86,700 are multiplied by 31 per cent and the values entered in the columns marked " Reduced for actual stocking." The normal Scribner volume is multiplied by 46.5 per cent and entered in the third column of this group. Finally the reduced amounts are multiplied by the total acreage and the results entered in the last three columns as the volume 30 years hence for the total area.

This is repeated for each age-site class and totaled for the entire tract.

The question may arise as to why no correction was made in this comparatively young age class (60 years) for the advance it may make to a normal condition. In this particular survey there was only 13.1 acres of this age class out of a total of 2,631 acres. A correction would have been of little weight in the final result; and it is a good rule in practice to adopt methods to fit each case and to avoid refinements when they are useless.

However, to exemplify the methods through which correction for advance to a more normal condition may be obtained, the 13.1 acres in age class 60 will be treated as if it were large enough to be of significance. Stands of this age—between 40 and 80 years on the average—are expected to approach a more normal condition at a rate of about 4 per cent per decade. In 30 years the increase in normality ratio would thus be 12 per cent, which when added to the actual percentages of 31 and 46.5 for basal area and Scribner volume indicate ratios, respectively, of 43 and 58.5 per cent. Normal volumes of 12,390 and 86,700 in cubic measure and board measure by International rule are multiplied by 43 and board measure of 55,000 by Scribner rule by 58.5, giving predicted volumes per acre of 5,328 cubic feet, 37,281 board feet International and 32,175 board feet Scribner. For the whole acreage in age class 60, 13.1 acres, the total predicted volume will then be 69,797 cubic feet, 488,381 board feet International, and 421,492 board feet Scribner, compared to the uncorrected volumes of 50,317 cubic feet, and of 352,089 and 335,032 board feet, respectively. In actual computations, of course, the volumes would be rounded off to the nearest hundred in cubic feet and the nearest thousand in board feet.

After the computations have been completed and before the report is written, the results should be arranged in suitable summaries, covering such items as—

Area of each type expressed in acres and in percentage of the total.

Area of each site and age class of second-growth Douglas fir in acres and in percentage of total area in the type.

Average stocking (obtained by multiplying the areas in each site-age class by the degree of stocking, summing these reduced areas, and dividing the sum by the total area in the type).

Predicted volumes in cubic feet, board feet International, and in board feet Scribner.

Additional summaries can be suggested to fit each case, such as when the forty estimates are of consequence, or when certain areas are blocked out for cutting while others remain uncut until some future time.

ADDITIONAL CONSIDERATIONS

A number of further questions are likely to arise in the application of yield tables. One question is in regard to the making of predictions for cut-over or burned areas which have not yet become restocked. On areas which are not restocked to seedlings but which have a good chance to stock, a period of one to five years must be added to allow for one or two good seed years.

Uneven agedness of a forest is often a complicating factor. Accidents, such as fire, may overcome the tendency of second-growth Douglas fir to be strictly even-aged, and make a stand two-aged. When this is so, the more important age class—i. e., the one with the larger amount of timber—should be used when calculating the stocking percentages. Planted forests should theoretically have a more uniform and complete stocking than natural stands. Especially where survival of the young trees has been good, plantations above normal in volume stocking might be looked for. As no artificial stands were investigated in this study, positive information on this point is still lacking for Douglas fir forests.

To obtain a knowledge of the variability of a tract and of the relation of its stand values to the normal, either sample strips or sample plots may be measured. This study showed that, if the width of strip is properly controlled, sampling by strips is more reliable than sampling by plots, in spite of the fact that as a general rule the error incurred in the measurement of a plot is proportional to the length of its perimeter. The variability of stocking in a forest is so great that a sample strip gives a truer average of conditions than a series of sample plots.

The area on which the illustrative survey was made had a large assortment of age classes, great diversity of types and sites, and a ruggedness quite typical of the region, and therefore made a good illustrative area to work out every complication of technic. But in many actual instances conditions would be more regular, and the methods could be modified accordingly, particularly on small areas. The smaller the area the less will be the variation of age and site class, and therefore the more possible will it be to treat each individual site and age class by itself instead of grouping them by site-age classes. At times the site-index system will be found preferable and will give more accurate results. This is the case especially in the poor site classes when the site quality does not fall upon the exact center of the class. Thus, stands in the upper range of Site V will have contorted Scribner board-volume percentages. The fact that it is contorted may not affect the predictions, but yet gives a wrong impression of the stocking. Therefore, if the areas in these sites are of consequence, an apparently more correct result is obtainable if the average site index is computed and checked against the site-class value.

CHECK UPON THE METHOD OF COMPUTING YIELDS

An approximate check upon this method of computing yields can be made by applying the yield tables to the present ages and comparing the yields derived in this way with the actual volumes computed from the tally sheets directly. In the illustrative survey this resulted in an estimate by yield tables of 23,754,000 cubic feet and an actual computation of 24,789,000 cubic feet, or an underestimate of 4.2 per cent. Computing the volume in board feet by Scribner rule gave an underestimate of 1.6 per cent. It can hardly be expected that yield calculations will always attain this degree of accuracy.

RÉSUMÉ OF METHODS OF MAKING YIELD PREDICTIONS

The preceding pages have shown the relationship of the actual forest to the normal, the reasons why the former is usually understocked, and the methods of judging the degree of understocking; and the technic of making an actual yield survey of an extensive tract has been described. The principal allowances to make in using normal tables for yield predictions of actual tracts may be briefly summed up as follows:

1. Before classifying in site and age groups the area for which yield predictions are to be made, the areas of surveyable openings and of other types are taken out.

2. The stand values of each site and age group are discounted by the percentage that each is understocked (or overstocked), basal area being used as the index of normality.

3. In understocked stands between 40 and 80 years of age, allow for progress toward normality at the rate of 4 per cent each decade.

4. If the slopes are markedly different from those for which the normal-yield tables were prepared, increase (or decrease) the predicted yields accordingly. (This applies only when an actual stand tally has not been made.)

5. Discount the predicted yield for assumed defect, breakage, and probable waste in wood utilization.

6. Where restocking is not established add a sufficient number of years to the rotation period to assure it.

Yield predictions of course assume good silviculture and good protection. If the stand is prevented from restocking as expected, or if disastrous fires thin down the stand, the most carefully made yield predictions will be quite futile.

The first requisites of accurate yield prediction are a thorough knowledge of the forest, accurate determination of age, site, and area, correct stand tallies, and good judgment as to what the stand will do. The mechanics of applying the tables and making the several mathematical allowances is secondary to "knowing your forest."

INCREMENT TABLES

The mean annual increments in cubic feet, in board feet by the International rule, and in board feet by the Scribner rule, are given in Table 9, and are also shown graphically in Figures 11 to 16.

TABLE 9.—*Mean annual increment on a fully stocked acre according to three units of measurement: (1) Cubic feet; (2) board feet, Scribner rule; and (3) board feet, International rule, (1/8-inch kerf)*

Total age (years)	Site class					Total age (years)	Site class				
	I	II	III	IV	V		I	II	III	IV	V
CUBIC FEET [1]											
20	92	77	63	44	28	100	191	168	133	90	63
30	158	136	109	76	44	110	183	160	127	86	51
40	188	164	131	89	53	120	178	153	121	82	49
50	203	177	141	96	57	130	168	146	116	79	46
60	208	181	144	98	58	140	161	140	111	75	44
70	207	181	144	98	58	150	154	134	106	72	43
80	204	178	142	96	57	160	148	130	103	69	42
90	198	173	138	03	56						
BOARD FEET, SCRIBNER RULE [2]											
20	20	-	-	-	-	100	1,149	902	626	314	96
30	287	87	4	-	-	110	1,125	894	630	330	111
40	610	208	112	5	-	120	1,092	876	625	340	122
50	880	540	248	00	-	130	1,059	851	613	345	130
60	1,033	714	396	140	18	140	1,025	830	601	349	137
70	1,117	820	506	201	36	150	990	808	590	349	142
80	1,154	878	571	250	58	160	950	786	578	346	146
90	1,160	900	609	290	77						
BOARD FEET, INTERNATIONAL RULE [3]											
20	245	80	-	-	-	100	1,489	1,238	947	680	288
30	813	540	200	50	-	110	1,432	1,195	920	574	295
40	1,185	880	550	230	50	120	1,382	1,155	895	562	293
50	1,410	1,100	742	380	118	130	1,322	1,115	864	549	288
60	1,512	1,214	864	482	175	140	1,271	1,075	838	531	282
70	1,550	1,280	937	542	220	150	1,222	1,040	809	520	278
80	1,555	1,285	966	572	254	160	1,178	1,018	781	500	275
90	1,530	1,274	961	578	277						

[1] Volume in cubic feet includes all trees.

[2] Volume in board feet by the Scribner rule includes only those trees 12 inches or more in diameter.

[3] Volume in board feet by the International rule includes only those trees 7 inches or more in diameter.

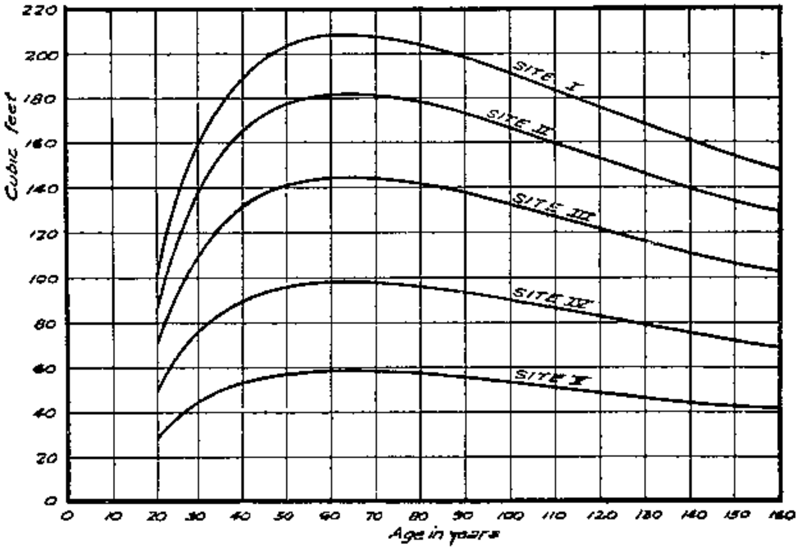


FIGURE 11.—Mean annual increment per acre in cubic feet for total stand

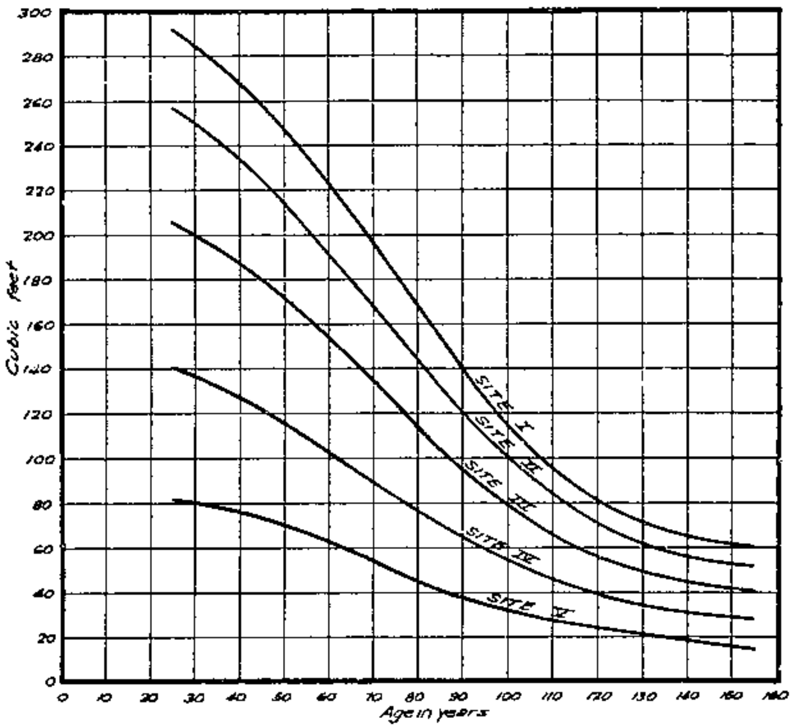


FIGURE 12.—Periodic annual increment per acre in cubic feet for total stand. Ten-year periods are used

The periodic annual increments, by 10-year periods, are given in cubic feet, International board feet, and Scribner board feet in Table 10, and are also illustrated in Figures 11 to 16.

Table 10.—*Periodic annual increment on a fully stocked acre according to three units of measurement: (1) Cubic feet; (2) board feet, Scribner rule; and (3) board feet, International rule (⅛-inch kerf)*

Age period (years)	Site class					Age period (years)	Site class				
	I	II	III	IV	V		I	II	III	IV	V
CUBIC FEET [1]											
20 to 30	292	256	205	140	81	90 to 100	127	110	87	60	35
30 to 40	276	243	194	132	78	100 to 110	106	92	72	50	29
40 to 50	258	225	180	121	73	110 to 120	88	77	61	42	28
50 to 60	236	203	163	109	66	120 to 130	76	66	53	37	23
60 to 70	210	180	145	96	58	130 to 140	68	59	47	33	21
70 to 80	182	156	125	83	49	140 to 150	64	54	43	30	18
80 to 90	155	132	104	71	41	150 to 160	61	52	41	28	15
BOARD FEET, SCRIBNER RULE [2]											
20 to 30	760					90 to 100	1,030	940	780	540	270
30 to 40	1,655	930	420			100 to 110	870	790	660	490	260
40 to 50	1,960	1,540	790	310		110 to 120	740	680	500	440	245
50 to 60	1,805	1,550	1,140	460		120 to 130	645	590	500	395	230
60 to 70	1,625	1,440	1,140	585	130	130 to 140	575	530	450	355	220
70 to 80	1,430	1,280	1,050	610	200	140 to 150	520	485	410	325	205
80 to 90	1,230	1,105	930	585	250	150 to 160	480	450	380	300	200
BOARD FEET, INTERNATIONAL RULE [3]											
20 to 30	1,890	1,320	840			90 to 100	1,100	970	830	580	390
30 to 40	2,260	1,890	1,370	700		100 to 110	900	810	680	500	320
40 to 50	2,320	2,000	1,520	980	340	110 to 120	760	680	570	430	270
50 to 60	2,060	1,820	1,490	1,000	450	120 to 130	660	590	500	380	240
60 to 70	1,800	1,600	1,340	890	490	130 to 140	590	530	450	340	220
70 to 80	1,540	1,390	1,160	780	490	140 to 150	530	480	420	320	210
80 to 90	1,320	1,170	990	680	460	150 to 160	480	440	380	300	200

[1] Volume in cubic feet includes all trees.
[2] Volume in board feet by the Scribner rule includes only those trees 12 inches or more in diameter.
[3] Volume in board feet by the International rule includes only those trees 7 inches or more in diameter.

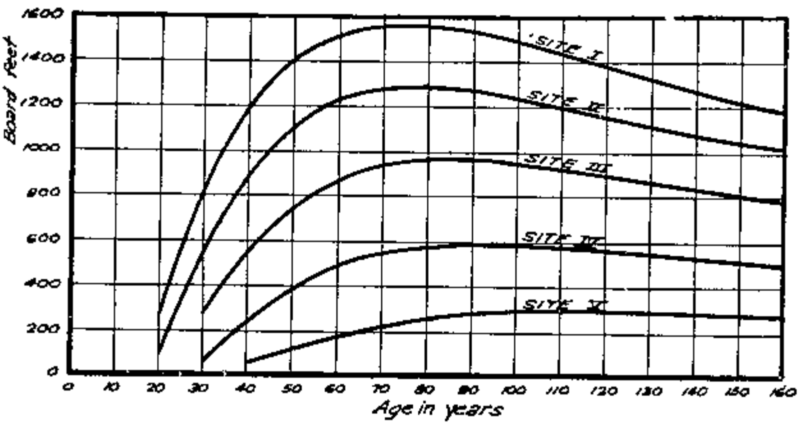


FIGURE 13.—Mean annual increment per acre in board feet by the International log rule for trees 7 inches in diameter and larger

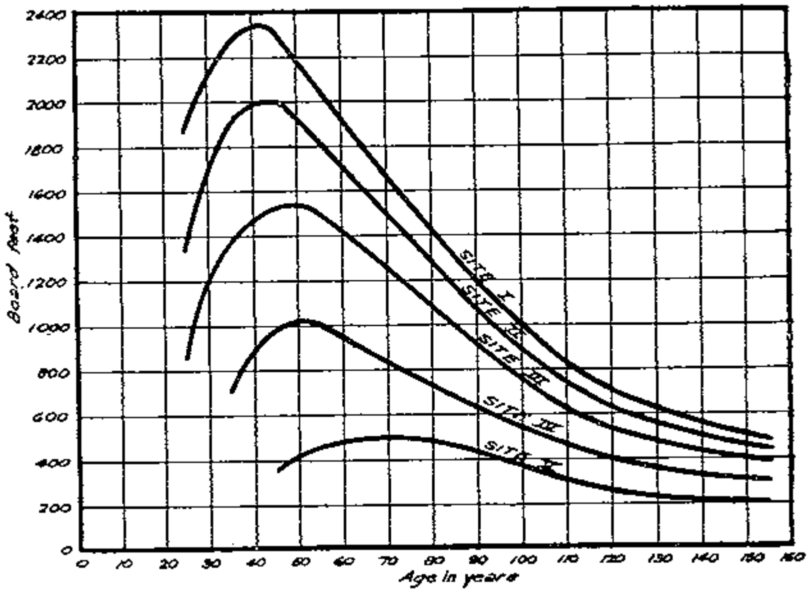


FIGURE 14.—Periodic annual increment per acre in board feet by the International log rule for trees 7 inches in diameter and larger. Ten-year periods are used

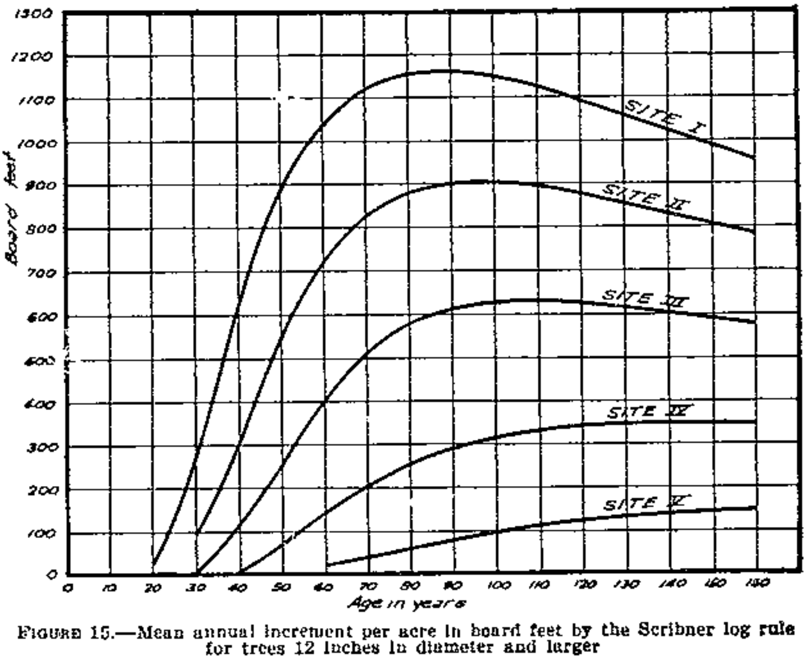


FIGURE 15.—Mean annual increment per acre in board feet by the Scribner log rule for trees 12 inches in diameter and larger

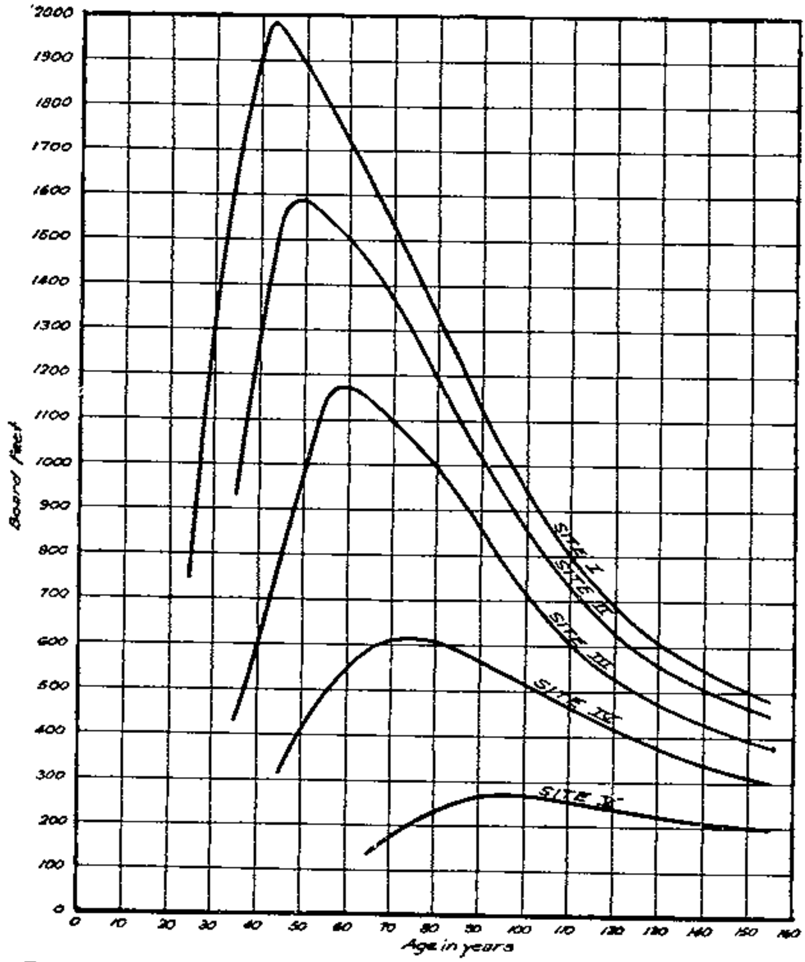


FIGURE 16.—Periodic annual increment per acre in board feet by the Scribner log rule for trees 12 inches in diameter and larger. Ten-year periods are used

The mean annual increments indicate for any given age of stand the average yearly increase in volume per acre up to that age. That is, if a forest on Site I were cut at 40 years of age, the average yearly increase in volume would be only 188 cubic feet per acre; if cut at 60 years, the average yearly growth would be 208 cubic feet; or if cut at 100 years, 191 cubic feet per acre.

The rate of volume growth is not constant throughout the life of a forest; hence the average annual increase in volume reaches a maximum and thereafter diminishes. Thus a forest on Site I reaches the maximum of average annual increase in Scribner board-foot volume at about 90 years of age.

The periodic annual increment, as used in these tables, indicates the decade of most rapid volume growth. The largest yearly increases in cubic-foot volume, for example, occur, in forests on Site I, during the third decade of their life. During this period 292 cubic feet per acre are added annually, whereas only 236 cubic feet per year are produced during the 50 to 60 year period, and 106 cubic feet per year during the 100 to 110 year period.

The amount of increase varies according to the productive capacity of the site. During the decade of greatest productivity a forest on Site V adds annually only 270 Scribner board feet per acre, whereas on Site I an average of 1,960 board feet is produced during the decade of most rapid volume growth.

A thorough discussion of the choice of rotation age and other problems of forest management is obviously beyond the scope of this bulletin. Theoretically, the age at which to harvest the forest crop is the age at which mean annual increment culminates, since this coincides with the period of maximum average annual increase in volume. But so many other factors than maximum quantity production in minimum time enter into a choice of rotation age that each case must be decided according to the prevailing conditions. It may be that quality instead of quantity is desired, or that financially it is impossible to withhold cutting until the time of maximum volume production, or that trees of a certain size are desired for a certain purpose; any one of these considerations alone will then control the length of rotation. All these points and many others must be taken into account when deciding upon a suitable rotation for a crop of timber.

STAND TABLES

For some purposes it is essential to know the approximate number of trees in each diameter class. Table 11 shows for selected site qualities the approximate number of trees in each 2-inch diameter class at various periods in the life of a stand from 20 to 160 years of age. Additional tables for other ages and site qualities may be prepared by following the procedure outlined in the appendix.

TABLE 11.—*Stand table for Douglas fir*[1]

SITE I

2-inch-diameter class	Number of trees by age classes							
	20 years	40 years	60 years	80 years	100 years	120 years	140 years	160 years
2–3	131							
4–5	223	8						
6–7	157	27						
8–9	60	42	7					
10–11		48	12	3				
12–13		43	16	4	2			
14–15		36	18	8	2	2		
16–17		20	18	9	5	2	1	
18–19		11	19	10	6	3	2	
20–21		5	16	11	6	4	2	
22–23			13	10	7	4	3	
24–25			9	10	7	5	4	
26–27			5	9	6	6	4	
28–29			5	8	7	5	4	
30–31				6	7	5	4	
32–33				4	6	5	4	
34–35				3	4	5	5	
36–37				2	4	5	4	
38–39					2	4	4	
40–41					2	3	4	
42–43					2	2	3	
44–45						1	2	
46–47						1	2	
48–49						1	1	
50–51							1	
Over 50							1	
Total	571	240	138	97	75	63	55	

SITE II

2-inch-diameter class	20 years	40 years	60 years	80 years	100 years	120 years	140 years	160 years
2–3	398	9						
4–5	363	60	3					
6–7	119	89	13	3				
8–9		90	33	6	3			
10–11		77	35	16	4	3		
12–13		41	38	20	10	4	3	2
14–15		19	38	22	13	7	4	2
16–17			30	21	13	9	6	3
18–19			20	20	14	10	8	5
20–21			10	19	15	10	8	6
22–23			8	14	13	11	8	7
24–25				8	13	11	9	7
26–27				5	10	9	8	7
28–29				5	6	9	8	7
30–31					4	6	7	6
32–33					3	5	7	6
34–35					2	3	4	6
36–37						2	3	5
38–39						2	3	3
40–41							2	2
42–43								2
44–45								2
Total	880	385	228	159	123	101	88	78

[1] Table 11 shows for a fully stocked acre the approximate number of trees in each 2-inch diameter group for given ages and site qualities. In this table the total number of trees will check with the values given in Table 2, but the number of trees 7 inches and larger and 12 inches and larger in diameter may not always be identical with the values for corresponding ages and site qualities as given in Tables 3 and 4. This discrepancy is to be expected since stand tables are, at best, only an approximation; their purpose is only to illustrate in about what order the trees are distributed among the various diameter classes.

TABLE 11.—*Stand table for Douglas fir*—Continued

SITE III

2-inch-diameter class	Number of trees by age classes							
	20 years	40 years	60 years	80 years	100 years	120 years	140 years	160 years
2-3		52						
4-5		159	22					
6-7		175	54	14				
8-9		129	67	29	15	6	3	
10-11		54	73	35	21	10	5	5
12-13		16	55	39	24	16	10	6
14-15			39	37	26	19	14	9
16-17			18	32	26	19	14	12
18-19			9	22	23	20	16	12
20-21				14	21	18	16	13
22-23				10	13	15	14	13
24-25					8	13	13	12
26-27					7	7	10	11
28-29						5	6	9
30-31						4	5	6
32-33							5	4
34-35								3
36-37								2
Total		585	337	232	184	152	131	117

SITE IV

2-inch-diameter class	20 years	40 years	60 years	80 years	100 years	120 years	140 years	160 years
2-3		261	22					
4-5		353	103	25				
6-7		234	129	58	33	13	7	3
8-9		79	121	57	44	27	14	9
10-11			83	85	46	32	25	19
12-13			32	61	49	38	27	22
14-15			10	36	45	36	30	24
16-17				16	27	30	28	24
18-19				7	16	23	25	22
20-21					11	14	18	21
22-23						7	10	13
24-25						4	7	9
26-27							4	5
28-29								4
Total		927	500	346	271	224	195	175

SITE V

2-inch-diameter class	20 years	40 years	60 years	80 years	100 years	120 years	140 years	160 years
2-3			148	15	8			
4-5			305	90	57	26	11	6
6-7			214	125	92	57	37	21
8-9			91	132	97	69	51	41
10-11			22	100	85	73	57	45
12-13				45	42	56	50	43
14-15				18	22	32	43	42
16-17						18	19	26
18-19							16	15
20-21								11
Total			780	525	403	331	284	250

VOLUME TABLES

The volumes of the trees on the sample plots of the yield study were computed with the aid of volume tables. Tables 12 to 16 cover volumes in cubic feet classified by diameter and total height of trees; merchantable volume in board feet, Scribner rule, classified by diameter and log lengths, and by diameter and total height of trees; and merchantable volume in board feet, International rule, classified by diameter and log lengths, and by diameter and total height of trees.

These volume tables are based on the measurement of nearly 2,000 trees, most of which were obtained in 1909 by T. T. Munger, of the Forest Service, and the rest in 1921–1924 by J. S. Boyce, then of the Bureau of Plant Industry. The tables were constructed by the author according to the procedure developed by Donald Bruce and L. H. Reineke of the Forest Service.

The volumes shown in the tables include no allowance for defect (all the trees measured having been scaled full). These tables are applicable to Douglas fir trees less than 160 years old which are within the specified range of diameters and heights.

TABLE 12.—*Cubic-foot volume table for second-growth Douglas fir*

[Western foothills of Cascade Mountains, Washington and Oregon—All site qualities, 1926]

D. b. h., inches	Height of tree in feet																							Basis, trees
	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	
	Volume in cubic feet																							
2	0.22	0.35	0.45	0.56	0.69																			
3	.51	.75	.98	1.21	1.45	1.70																		10
4	.88	1.30	1.70	2.06	2.55	2.88	3.1																	56
5	1.39	1.99	2.61	3.18	3.80	4.30	4.89	5.50																80
6	1.97	2.85	3.70	4.50	5.35	6.14	6.95	7.76																66
7	2.61	3.86	4.96	6.02	7.15	8.22	9.30	10.40	11.2	12.2														59
8	3.38	4.97	6.35	7.84	9.12	10.7	12.3	13.3	14.4	15.8	17.2	19.0												68
9	4.24	6.19	7.95	9.98	11.6	13.5	15.2	16.6	18.1	20.0	21.7	23.5												64
10	5.20	7.55	9.82	11.8	14.2	16.4	18.5	20.1	22.0	24.4	26.3	28.7	31.1											63
11	6.26	9.10	11.7	14.3	17.0	19.5	22.0	24.0	26.3	29.1	31.7	34.2	37.3	40.4	43.1									50
12		10.8	13.8	16.8	20.0	22.8	25.9	28.3	31.1	34.6	37.4	40.5	44.0	47.9	51.3	54.2								53
13		12.4	16.0	19.5	23.2	26.5	30.2	33.3	36.7	40.3	43.7	47.3	51.4	55.8	59.6	63.0								63
14		14.2	18.4	22.4	26.6	30.4	34.7	38.5	42.3	46.1	50.0	54.2	58.8	63.8	68.2	72.5	78.0	82.9						95
15			21.0	25.6	30.2	34.8	39.5	43.7	48.0	52.2	56.5	61.2	66.5	71.9	76.9	82.0	88.0	93.6	99.9					87
16			23.7	28.8	33.9	39.2	44.3	49.2	53.9	58.4	63.1	68.2	74.4	80.5	86.0	92.6	98.8	105.0	113.0					79
17			26.4	32.2	38.0	43.8	49.2	54.8	60.0	64.8	70.0	75.8	82.8	89.5	95.5	103.0	110.0	117.0	125.0	134	145			72
18			29.3	35.7	42.2	48.4	54.5	60.4	67.0	71.3	77.2	83.7	91.4	99.0	106.0	114.0	122.0	130.0	139.0	157	160			65
19				39.5	46.5	53.3	59.8	66.1	72.4	77.8	84.7	91.6	100.0	108.0	116.0	125.0	134.0	143.0	153.0	162	176	186	195	65
20				43.4	51.1	58.3	65.5	72.2	79.0	84.8	92.1	99.8	109.0	118.0	127.0	137.0	147.0	157.0	168.0	178	192	204	214	60
21				47.5	55.6	63.5	71.2	78.3	85.7	92.0	100.0	108.0	118.0	128.0	138.0	148.0	159.0	170.0	183.0	194	208	222	234	66
22				51.7	60.2	69.0	77.0	84.8	92.5	99.2	108.0	117.0	127.0	138.0	149.0	160.0	172.0	185.0	198.0	210	225	240	253	62
23					65.0	74.3	83.0	91.0	99.4	107.0	115.0	125.0	136.0	148.0	160.0	172.0	185.0	199.0	213.0	227	243	258	273	59
24					69.8	80.0	89.0	97.8	105.0	114.0	123.0	133.0	144.0	157.0	170.0	184.0	198.0	213.0	229.0	245	262	277	294	67
25						85.7	95.0	104.0	113.0	122.0	131.0	142.0	154.0	168.0	182.0	196.0	212.0	228.0	245.0	262	282	297	315	51
26						91.5	101.0	111.0	120.0	129.0	139.0	150.0	162.0	178.0	193.0	208.0	226.0	243.0	261.0	281	300	317	337	58
27							107.0	117.0	128.0	137.0	147.0	159.0	172.0	188.0	204.0	220.0	239.0	258.0	278.0	298	320	337	360	53
28								122.0	135.0	145.0	155.0	168.0	181.0	198.0	216.0	233.0	253.0	274.0	295.0	317	341	359	384	42
29								131.0	142.0	152.0	163.0	177.0	191.0	209.0	227.0	246.0	268.0	290.0	310.0	335	360	382	408	46
30								138.0	149.0	160.0	171.0	185.0	200.0	220.0	239.0	259.0	282.0	307.0	327.0	354	381	403	434	56
31								144.0	156.0	167.0	179.0	194.0	210.0	230.0	251.0	272.0	299.0	321.0	344.0	372	400	426	457	31

32								151.0	163.0	175.0	188.0	203.0	220.0	241.0	263.0	285.0	312.0	336.0	362.0	391	421	449	482	34
33								158.0	171.0	183.0	196.0	212.0	230.0	252.0	276.0	299.0	325.0	350.0	378.0	409	442	472	506	31
34										191.0	204.0	221.0	240.0	263.0	289.0	310.0	338.0	365.0	395.0	428	462	496	532	29
35										199.0	212.0	231.0	250.0	275.0	300.0	322.0	352.0	381.0	412.0	447	483	519	560	19
36											220.0	239.0	259.0	286.0	310.0	335.0	366.0	396.0	430.0	465	504	543	582	16
37											228.0	248.0	269.0	298.0	321.0	348.0	379.0	412.0	447.0	485	525	565	605	12
38											237.0	257.0	279.0	307.0	332.0	360.0	393.0	427.0	465.0	503	547	588	632	10
39											244.0	266.0	289.0	316.0	343.0	372.0	407.0	443.0	482.0	523	567	612	657	7
40											253.0	275.0	298.0	325.0	353.0	384.0	421.0	458.0	500.0	542	590	636	683	6
41														334.0	365.0	398.0	435.0	475.0	518.0	562	610	660	708	3
42														343.0	376.0	410.0	448.0	490.0	535.0	581	632	683	734	9
43														353.0	387.0	422.0	462.0	506.0	553.0	601	653	707	760	4
44														362.0	398.0	435.0	476.0	522.0	572.0	622	675	732	786	3
45														372.0	409.0	448.0	489.0	537.0	589.0	642	696	754	812	3
46														382.0	420.0	460.0	504.0	553.0	607.0	662	718	778	842	7
47														391.0	432.0	473.0	517.0	569.0	625.0	682	739	802	863	2
48														401.0	442.0	486.0	532.0	585.0	643.0	701	762	826	889	1
49														410.0	453.0	498.0	545.0	600.0	662.0	721	782	850	914	7
50														419.0	464.0	511.0	559.0	615.0	680.0	742	805	874	941	
51														428.0	475.0	523.0	572.0	631.0	698.0	767	826	898	966	3
52														438.0	487.0	536.0	586.0	647.0	716.0	782	848	922	993	1
53														448.0	498.0	548.0	600.0	663.0	735.0	803	868	945	1,018	
54														457.0	510.0	562.0	615.0	679.0	754.0	825	890	970	1,045	1
																								1,956

The volume is total cubic volume of the stem, including stump and top, but excluding bark. Prepared from curved form factors. Block indicates extent of basic data. Aggregate volume by table is 0.2 per cent lower than aggregate volume of basic data.

TABLE 13.—*Board-foot volume table (Scribner rule—16-foot logs) for second-growth Douglas fir*

[Western foothills of Cascade Mountains, Washington and Oregon—All site qualities, 1926]

D. b. h., inches	Number of 16-foot logs													Cone frustum form factor	Basis, trees
	1¼	2	3	4	5	6	7	8	9	10	11	12	13		
	Volume in board feet														
12	62	80	133	183	235	286	338	-	-	-	-	-	-	0.925	51
13	63	84	140	197	254	310	370	-	-	-	-	-	-	.908	61
14	64	88	147	210	274	338	400	-	-	-	-	-	-	.894	95
15	65	91	155	226	296	365	435	-	-	-	-	-	-	.880	87
16	67	96	163	242	320	399	478	-	-	-	-	-	-	.868	79
17	69	102	178	262	347	430	515	-	-	-	-	-	-	.858	72
18	71	109	190	280	370	459	550	640	729	-	-	-	-	.849	65
19	73	115	207	305	403	503	602	701	801	901	-	-	-	.840	65
20	75	123	221	330	435	543	651	758	865	970	-	-	-	.833	60
21	77	129	240	355	469	584	700	815	930	1,046	-	-	-	.829	66
22	80	136	258	383	509	633	760	884	1,011	1,136	1,260	-	-	.823	62
23	84	143	277	414	551	688	827	964	1,101	1,239	1,375	-	-	.820	59
24	-	151	292	438	584	728	882	1,035	1,188	1,340	1,495	1,641	-	.819	67
25	-	160	311	466	623	780	942	1,109	1,275	1,440	1,602	1,763	-	.816	51
26	-	170	333	500	666	832	1,013	1,190	1,368	1,546	1,724	1,895	-	.813	58
27	-	180	351	530	708	889	1,078	1,268	1,458	1,648	1,835	2,020	2,215	.810	53
28	-	188	371	560	750	941	1,144	1,346	1,551	1,752	1,956	2,152	2,361	.808	42
29	-	-	-	602	800	1,005	1,220	1,433	1,650	1,862	2,077	2,282	2,507	.803	46
30	-	-	-	638	850	1,032	1,291	1,518	1,749	1,975	2,202	2,420	2,656	.801	56
31	-	-	-	675	901	1,130	1,370	1,609	1,850	2,091	2,330	2,562	2,810	.800	31
32	-	-	-	716	955	1,195	1,449	1,700	1,954	2,211	2,462	2,707	2,968	.799	34
33	-	-	-	751	1,005	1,260	1,530	1,800	2,070	2,340	2,613	2,873	3,127	.797	31
34	-	-	-	791	1,059	1,333	1,614	1,898	2,180	2,463	2,745	3,006	3,295	.793	29
35	-	-	-	839	1,115	1,402	1,700	1,998	2,295	2,590	2,885	3,160	3,461	.791	19
36	-	-	-	882	1,175	1,494	1,782	2,095	2,410	2,721	3,025	3,318	3,630	.789	16
37	-	-	-	930	1,228	1,545	1,873	2,205	2,530	2,860	3,166	3,478	3,810	.786	12
38	-	-	-	978	1,290	1,614	1,955	2,305	2,660	2,985	3,315	3,642	3,990	.783	10
39	-	-	-	1,020	1,354	1,690	2,049	2,415	2,790	3,137	3,487	3,825	4,190	.781	7
40	-	-	-	-	1,410	1,779	2,150	2,523	2,892	3,266	3,634	3,995	4,380	.779	6
41	-	-	-	-	1,478	1,861	2,250	2,633	3,015	3,398	3,768	4,135	4,530	.776	3
42	-	-	-	-	1,541	1,937	2,340	2,735	3,138	3,528	3,920	4,301	4,717	.773	9
43	-	-	-	-	1,609	2,020	2,440	2,850	3,258	3,672	4,086	4,490	4,917	.770	4

44					1,663	2,090	2,520	2,949	3,386	3,812	4,240	4,651	5,100	.768	3
45					1,730	2,171	2,625	3,065	3,508	3,950	4,391	4,822	5,290	.764	3
46					1,790	2,255	2,724	3,180	3,638	4,094	4,550	5,008	5,495	.761	6
47					1,854	2,330	2,810	3,225	3,770	4,247	4,720	5,197	5,709	.759	2
48					1,920	2,420	2,927	3,414	3,905	4,400	4,890	5,400	5,935	.755	1
49					1,985	2,511	3,020	3,534	4,051	4,572	5,075	5,582	6,120	.752	7
50						2,606	3,130	3,660	4,190	4,725	5,259	5,774	6,330	.750	
51						2,690	3,227	3,775	4,328	4,878	5,440	5,976	6,555	.748	3
52						2,775	3,330	3,908	4,480	5,055	5,620	6,168	6,758	.743	1
53						2,864	3,440	4,034	4,616	5,230	5,820	6,395	7,000	.740	
54						2,944	3,550	4,153	4,760	5,389	6,010	6,610	7,240	.739	1
															1,433

Prepared by the frustum form factor method. Stump height 2 feet. (Trees scaled in 16-foot logs with 0.3-foot trimming allowance to 8 inches d. i. b. in top, Scribner decimal C rule. Volume shown in this table as full scale. No allowance made for defect. Block indicates extent of basic data. Aggregate volume by table is 1.06 per cent lower than aggregate volume of basic data.)

TABLE 14.—*Board-foot volume table (Scribner rule—total height) second-growth Douglas fir*

[Western foothills of Cascade Mountains, Washington and Oregon—All site qualities, 1926]

D. b. h., inches	Total height in feet																				Basis, trees
	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	
	Volume in board feet																				
12	32	50	69	87	105	124	140	155	176	196	225										51
13	39	61	83	107	130	150	170	190	212	238	270										61
14	47	74	101	129	155	175	201	225	252	282	318	354									95
15		88	118	148	180	207	233	262	290	324	364	410									87
16		102	136	170	205	235	265	296	330	368	410	466									79
17		115	154	193	230	263	296	331	370	412	460	522	584								72
18			174	215	257	294	329	367	410	460	510	580	640	714							65
19			192	239	283	325	363	403	450	508	564	640	710	782	858						65
20			213	262	311	355	397	440	494	558	618	694	774	854	942	1, 032					60
21				285	338	388	438	480	538	608	676	754	844	930	1, 026	1, 122					66
22				309	367	420	470	520	584	658	732	820	914	1, 010	1, 114	1, 222					62
23					397	455	507	562	630	708	788	882	986	1, 090	1, 204	1, 322	1, 438				59
24					426	489	545	607	676	758	848	950	1, 058	1, 172	1, 296	1, 422	1, 548	1, 670			67
25					458	524	584	648	724	811	909	1, 018	1, 134	1, 257	1, 393	1, 527	1, 667	1, 801			51
26					492	562	626	692	770	866	971	1, 088	1, 210	1, 346	1, 495	1, 645	1, 794	1, 938			58
27					524	598	666	728	821	920	1, 034	1, 158	1, 287	1, 435	1, 597	1, 757	1, 921	2, 075			53
28						638	708	782	870	975	1, 096	1, 230	1, 368	1, 535	1, 699	1, 874	2, 048	2, 215			42
29						674	750	828	920	1, 032	1, 162	1, 304	1, 450	1, 627	1, 803	1, 989	2, 180	2, 354			46
30						712	792	876	972	1, 088	1, 228	1, 379	1, 536	1, 720	1, 909	2, 104	2, 308	2, 497			56
31							838	922	1, 023	1, 148	1, 296	1, 454	1, 622	1, 813	2, 014	2, 222	2, 436	2, 635			31
32							878	970	1, 076	1, 207	1, 366	1, 529	1, 711	1, 906	2, 100	2, 340	2, 569	2, 778	3, 019	3, 246	34
33							922	1, 016	1, 129	1, 267	1, 434	1, 601	1, 797	1, 999	2, 226	2, 458	2, 702	2, 921	3, 180	3, 424	31
34							964	1, 060	1, 182	1, 327	1, 512	1, 694	1, 880	2, 092	2, 333	2, 576	2, 833	3, 084	3, 338	3, 598	29
35								1, 112	1, 238	1, 387	1, 565	1, 747	1, 964	2, 180	2, 439	2, 694	2, 963	3, 227	3, 496	3, 780	19
36								1, 158	1, 291	1, 447	1, 628	1, 818	2, 046	2, 278	2, 544	2, 812	3, 096	3, 370	3, 657	3, 956	16
37								1, 208	1, 347	1, 510	1, 692	1, 889	2, 128	2, 372	2, 651	2, 931	3, 225	3, 514	3, 818	4, 132	12
38								1, 256	1, 401	1, 575	1, 753	1, 962	2, 208	2, 465	2, 759	3, 049	3, 358	3, 657	3, 981	4, 315	10
39											1, 814	2, 035	2, 286	2, 558	2, 867	3, 167	3, 491	3, 800	4, 136	4, 488	7
40											1, 874	2, 106	2, 362	2, 651	2, 970	3, 280	3, 619	3, 943	4, 299	4, 667	6
41											1, 932	2, 176	2, 437	2, 746	3, 068	3, 398	3, 752	4, 086	4, 459	4, 844	3
42											1, 990	2, 244	2, 513	2, 839	3, 168	3, 516	3, 885	4, 229	4, 622	5, 022	9
43											2, 045	2, 310	2, 586	2, 932	3, 266	3, 632	4, 018	4, 372	4, 781	5, 200	4
44											2, 101	2, 375	2, 659	3, 011	3, 365	3, 747	4, 149	4, 520	4, 939	5, 373	3

45											2,156	2,440	2,732	3,094	3,463	3,865	4,282	4,663	5,102	5,526	8
46											2,207	2,500	2,801	3,174	3,559	3,978	4,413	4,807	5,258	5,720	7
47											2,262	2,563	2,869	3,258	3,657	4,096	4,546	4,950	5,420	5,890	2
48											2,320	2,630	2,946	3,348	3,762	4,219	4,683	5,097	5,585	6,065	1
49											2,373	2,690	3,027	3,433	3,859	4,335	4,816	5,245	5,744	6,236	7
50											2,426	2,753	3,107	3,516	3,960	4,453	4,949	5,388	5,907	6,409	
51											2,485	2,821	3,189	3,599	4,059	4,568	5,082	5,536	6,060	6,579	3
52											2,540	2,884	3,268	3,685	4,159	4,686	5,215	5,679	6,225	6,752	1
43											2,593	2,947	3,351	3,769	4,259	4,804	5,348	5,822	6,388	6,925	
44											2,658	3,010	3,434	3,853	4,357	4,922	5,481	5,965	6,554	7,093	1
																					1,434

Prepared by applying curved board foot-cubic foot ratios to cubic foot volume table. Stump height 2 feet. Volume includes all of stem to 8-inch d. i. b. in top except stump and 0.3-foot trimming allowance for each 16-foot log. Gross scale—no allowance for defect. Block shows extent of basic data. Aggregate volume by table is 0.1 per cent higher than aggregate volume of basic data.

TABLE 15.—*Board-foot volume table (International rule—16-foot logs) for second-growth Douglas fir*

[Western foothills of Cascade Mountains, Washington and Oregon—All site qualities, 1926]

D. b. h., inches	Number of 16-foot logs													Cone frustum form factor	Basis, trees
	1¼	2	3	4	5	6	7	8	9	10	11	12	13		
	Volume in board feet														
7	19	30	44	58	71	87								0.808	58
8	23	38	61	82	108	131	155							.954	68
9	25	47	77	105	137	170	201							1.018	64
10	27	55	91	129	168	208	250							1.034	63
11	29	62	106	151	198	245	297							1.032	50
12	31	66	118	171	225	282	340							1.025	53
13	32	74	132	192	254	318	382							1.018	63
14	33	79	145	213	283	355	429							1.009	95
15	34	86	160	237	313	392	473	553	636					.999	87
16	35	94	176	261	346	433	523	614	706					.984	79
17	36	100	191	290	385	480	578	671	769	866				.972	72
18	37	105	207	314	417	524	630	735	840	947				.959	65
19	38	113	223	340	452	568	682	795	911	1,027				.945	65
20	39	120	240	365	487	611	737	858	985	1,108	1,230			.930	60
21	40	128	257	393	523	656	792	925	1,058	1,191	1,323			.915	66
22	41	136	273	417	557	700	846	990	1,135	1,282	1,430			.900	62
23	43	145	293	447	598	750	907	1,060	1,217	1,372	1,528			.892	59
24	45	155	312	478	640	807	975	1,138	1,306	1,472	1,638	1,805		.884	67
25	47	165	335	510	684	861	1,043	1,220	1,400	1,579	1,755	1,936		.879	51
26		174	357	545	732	923	1,117	1,309	1,500	1,693	1,884	2,075		.874	58
27			377	580	780	985	1,192	1,398	1,601	1,810	2,017	2,220		.870	53
28							1,278	1,494	1,712	1,930	2,149	2,366		.870	42
29							1,363	1,592	1,822	2,050	2,281	2,515		.868	46
30							1,443	1,688	1,937	2,184	2,430	2,677		.865	56
31							1,534	1,792	2,055	2,318	2,580	2,842		.863	31
32							1,619	1,898	2,175	2,451	2,730	3,015	3,300	.861	34
33							1,700	2,002	2,305	2,602	2,905	3,155	3,450	.860	31
34							1,810	2,105	2,415	2,715	3,015	3,320	3,625	.855	29
35							1,890	2,215	2,535	2,860	3,190	3,500	3,820	.853	19
36							1,998	2,335	2,675	3,010	3,350	3,690	4,020	.850	16
37							2,090	2,440	2,805	3,165	3,510	3,870	4,220	.847	12
38							2,195	2,570	2,950	3,320	3,690	4,070	4,440	.843	10
39							2,298	2,680	3,075	3,465	3,855	4,255	4,640	.840	7

40							2,415	2,818	3,230	3,632	4,040	4,450	4,845	.839	6
41								2,935	3,360	3,795	4,215	4,650	5,060	.837	3
42								3,070	3,515	3,955	4,395	4,835	5,270	.832	9
43								3,190	3,655	4,115	4,580	5,045	5,500	.830	4
44								3,315	3,805	4,280	4,760	5,235	5,710	.829	3
45									3,955	4,440	4,940	5,430	5,910	.827	3
46									4,095	4,605	5,118	5,630	6,120	.823	7
47									4,240	4,770	5,305	5,840	6,355	.820	2
48									4,370	4,930	5,495	6,060	6,600	.819	1
49									4,535	5,110	5,680	6,250	6,805	.817	7
50									4,675	5,265	5,860	6,455	7,040	.812	
51										5,428	6,050	6,690	7,310	.810	3
52										5,598	6,235	6,890	7,538	.809	1
53										5,750	6,430	7,100	7,750	.806	
54										5,930	6,610	7,310	8,010	.802	1
															1,741

Prepared by the frustum form factor method. Stump height 1.5 feet. Trees scaled in 16-foot logs with 0.3-foot trimming allowance to 5 inches d. i. b. in top, International rule (⅛-inch kerf). Gross scale—no allowance for defect. Block shows extent of basic data. Aggregate volume by table is 1.01 per cent lower than aggregate volume of basic data.

TABLE 16.—*Board-foot volume table (International rule—total height) for second-growth Douglas fir*

[Western foothills of Cascade Mountains, Washington and Oregon—All site qualities, 1926]

D. b. h., inches	Total height in feet																						Basis, trees
	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	
	Volume in board feet																						
7	12	18	24	32	40	48	56	66	78														58
8	16	22	32	42	52	64	76	88	102														68
9	20	30	42	54	66	82	96	112	128	144													64
10		36	52	66	84	102	120	138	158	180	200												63
11		46	62	80	102	124	146	168	194	218	242												50
12		54	76	98	122	148	174	200	230	260	288	320											53
13		64	90	114	144	176	206	238	270	302	336	374	416										63
14			104	134	166	202	240	274	310	346	388	430	480	524									95
15				154	190	232	270	312	352	392	440	486	544	592									87
16				176	214	260	304	350	394	440	494	546	612	662									79
17				198	238	290	338	388	438	490	548	608	678	734	814								72
18					264	322	372	426	484	540	606	672	747	812	894	974							65
19					288	349	405	466	528	588	659	734	813	886	974	1,061	1,143						65
20						378	442	507	576	642	718	799	883	969	1,063	1,156	1,250	1,341					60
21							479	550	623	693	775	864	955	1,053	1,152	1,254	1,358	1,454					66
22							519	594	672	747	834	930	1,028	1,139	1,244	1,354	1,468	1,575					62
23							559	637	720	798	893	997	1,102	1,221	1,336	1,456	1,578	1,696	1,829				59
24							599	682	768	852	953	1,065	1,177	1,308	1,429	1,559	1,690	1,821	1,969	2,099			67
25							640	727	817	907	1,013	1,134	1,256	1,392	1,524	1,664	1,803	1,951	2,104	2,251			51
26							683	774	868	964	1,075	1,206	1,336	1,481	1,620	1,770	1,921	2,078	2,245	2,405			58
27							728	824	922	1,023	1,141	1,280	1,420	1,571	1,719	1,879	2,043	2,211	2,389	2,564			53
28								874	978	1,080	1,210	1,354	1,506	1,663	1,824	1,091	2,170	2,351	2,537	2,726			42
29									1,038	1,150	1,281	1,432	1,597	1,759	1,930	2,104	2,300	2,494	2,692	2,894			46
30									1,096	1,215	1,351	1,509	1,688	1,851	2,034	2,223	2,428	2,636	2,849	3,066			56
31									1,154	1,282	1,423	1,582	1,775	1,942	2,139	2,343	2,560	2,776	3,006	3,238			31
32										1,347	1,495	1,660	1,863	2,036	2,248	2,461	2,688	2,921	3,164	3,416	3,678	3,930	34
33										1,411	1,563	1,737	1,952	2,128	2,348	2,583	2,820	3,063	3,321	3,593	3,865	4,132	31
34										1,477	1,635	1,818	2,043	2,223	2,454	2,701	2,951	3,206	3,484	3,771	4,060	4,350	29
35										1,540	1,705	1,897	2,120	2,316	2,556	2,813	3,080	3,347	3,646	3,948	4,250	4,562	19
36										1,605	1,779	1,974	2,199	2,408	2,658	2,930	3,212	3,493	3,803	4,125	4,452	4,769	16
37										1,667	1,851	2,052	2,278	2,490	2,759	3,041	3,338	3,636	3,964	4,301	4,646	4,985	12
38										1,733	1,926	2,133	2,359	2,592	2,865	3,169	3,469	3,784	4,127	4,479	4,846	5,233	10

39	-	-	-	-	-	-	-	-	-	-	-	2, 210	2, 438	2, 685	2, 968	3, 288	3, 598	3, 931	4, 284	4, 651	5, 043	5, 435	7
40	-	-	-	-	-	-	-	-	-	-	-	2, 290	2, 517	2, 778	3, 071	3, 408	3, 730	4, 078	4, 444	4, 828	5, 240	5, 642	6
41	-	-	-	-	-	-	-	-	-	-	-	-	2, 597	2, 870	3, 178	3, 525	3, 860	4, 225	4, 603	5, 003	5, 432	5, 847	3
42	-	-	-	-	-	-	-	-	-	-	-	-	2, 675	2, 962	3, 285	3, 645	3, 989	4, 367	4, 765	5, 177	5, 629	6, 054	9
43	-	-	-	-	-	-	-	-	-	-	-	-	2, 756	3, 052	3, 387	3, 764	4, 116	4, 514	4, 922	5, 352	5, 816	6, 263	4
44	-	-	-	-	-	-	-	-	-	-	-	-	2, 835	3, 157	3, 492	3, 882	4, 247	4, 657	5, 080	5, 527	6, 014	6, 471	3
45	-	-	-	-	-	-	-	-	-	-	-	-	2, 915	3, 247	3, 597	4, 001	4, 376	4, 804	5, 237	5, 702	6, 208	6, 678	3
46	-	-	-	-	-	-	-	-	-	-	-	-	2, 995	3, 341	3, 701	4, 121	4, 515	4, 949	5, 394	5, 881	6, 403	6, 890	7
47	-	-	-	-	-	-	-	-	-	-	-	-	3, 075	3, 433	3, 806	4, 239	4, 635	5, 098	5, 554	6, 058	6, 597	7, 097	2
48	-	-	-	-	-	-	-	-	-	-	-	-	3, 153	3, 526	3, 911	4, 359	4, 763	5, 251	5, 704	6, 236	6, 793	7, 303	1
49	-	-	-	-	-	-	-	-	-	-	-	-	3, 234	3, 618	4, 012	4, 475	4, 885	5, 403	5, 856	6, 413	6, 985	7, 510	7
50	-	-	-	-	-	-	-	-	-	-	-	-	3, 315	3, 710	4, 118	4, 592	5, 017	5, 555	6, 013	6, 595	7, 180	7, 722	-
51	-	-	-	-	-	-	-	-	-	-	-	-	3, 394	3, 802	4, 220	4, 709	5, 148	5, 705	6, 168	6, 772	7, 374	7, 916	3
52	-	-	-	-	-	-	-	-	-	-	-	-	3, 472	3, 894	4, 327	4, 829	5, 281	5, 859	6, 329	6, 949	7, 569	8, 113	1
53	-	-	-	-	-	-	-	-	-	-	-	-	3, 551	3, 986	4, 434	4, 946	5, 411	6, 011	6, 484	7, 126	7, 761	8, 310	-
54	-	-	-	-	-	-	-	-	-	-	-	-	3, 634	4, 079	4, 540	5, 066	5, 546	6, 164	6, 645	7, 304	7, 946	8, 503	1
																							1, 741

Prepared by applying curved board foot-cubic foot ratios to cubic foot volume table. Stump height 1.5 feet. Volume includes all of stem to 5 inch d. i. b. in top except stump and .03-foot trimming allowance for each 16-foot log. Gross scale—no allowance for defect. Block shows extent of basic data. Aggregate volume by table is 0.45 per cent lower than aggregate volume of of basic data.

APPENDIX

BASIC DATA

It was impractical to get measurements of forests for every age and site quality, but a good distribution among the possible combinations of age and site quality was obtained. Table 17 shows the distribution by age and site index classes of the forests forming the basis for these yield tables.

The geographical distribution of the sample plots has been illustrated in Figure 1. No attempt was made to have an equal number of plots for every county; in some counties there are only a few age-site quality combinations and for these counties there were fewer plots measured than for counties where there are many varieties of growth conditions. In Oregon, 128 tracts were measured comprising 1,008 plots; and in Washington, 133 tracts comprising 1,044 plots.

TABLE 17.—*Distribution of composite plots by age and site-index classes*

Age class	Distribution by site-index class														Total
	80 to 89	90 to 99	100 to 109	110 to 119	120 to 129	130 to 139	140 to 149	150 to 159	160 to 169	170 to 179	180 to 189	190 to 199	200 to 209	210 to 219	
20 to 29						1	2	2	1						6
30 to 39					1	2	4	4	5			1		1	18
40 to 49	1		1	1	3	2	2	5	2	3	4	1	1		26
50 to 59			1	2	3	1	5	6	12	9	6	1	2		48
60 to 69	1	1		2	3		5	9	13	8	2	6			50
70 to 79	1		2	3	3	4	3	9	7	6	4	3			45
80 to 89					1		5	2	2	2	1	2			15
90 to 99						1	1	1	1		3	1			8
100 to 109						3		3	1	1	1				9
110 to 119								1			2	1			4
120 to 129							1		3	2	1				7
130 to 139									1		2	1			4
140 to 149						1			2						3
150 to 159									1						1
160 to 169															0
170 to 179										1					1
Total	3	1	4	8	14	15	28	42	51	[illegible]	26	17	3	1	245

In these tabulations, a "tract" represents a forest of uniform age and site quality in which a group of plots were measured. The number of plots per tract varied from 1 to 33, but, as a rule, each tract comprised 5 to 10 plots. The original field work before any plots were discarded covered the following: [11]

Tracts	261
Individual plots	2,052
Total acreage of plots	1,371.05

The plots varied in size from one-sixteenth of an acre to 4 acres. The distribution of plots by size is shown in Table 18.

TABLE 18.—*Distribution of individual plots by size of plot*

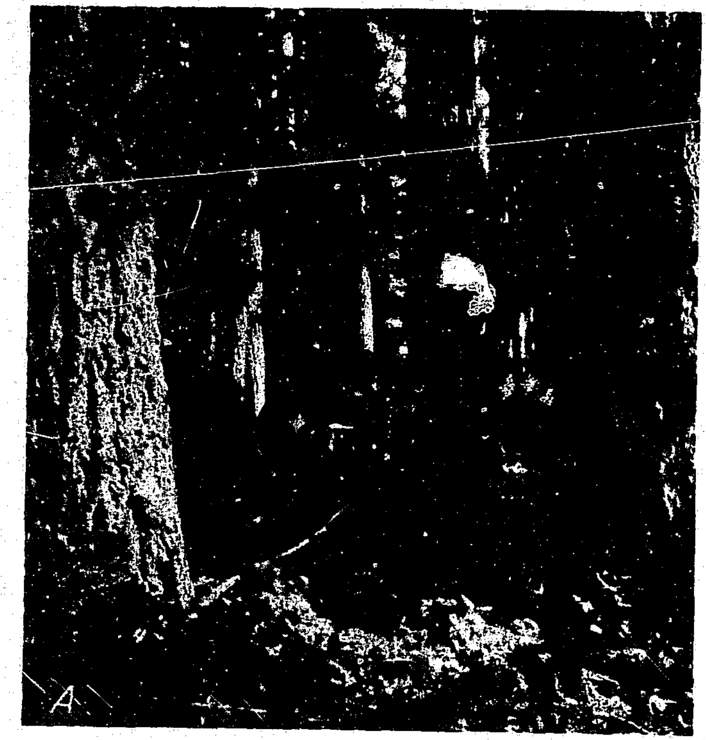
Size of plot	Plot	Size of plot	Plot
	Number		*Number*
1/16 acre	21	1 acre	953
1/8 acre	38	2 acres	1
1/4 acre	414	4 acres	1
1/2 acre	605		
3/4 acre	16	Total	2,049

TECHNIC OF PREPARING YIELD TABLES

FIELD WORK

It is customary in constructing yield tables to select a single plot as representative of a forest tract of uniform age and site quality. (Pl. 8.) In this

[11] These figures include a few periodic measurements of permanent sample plots in Douglas fir, each remeasurement being considered as a tract.



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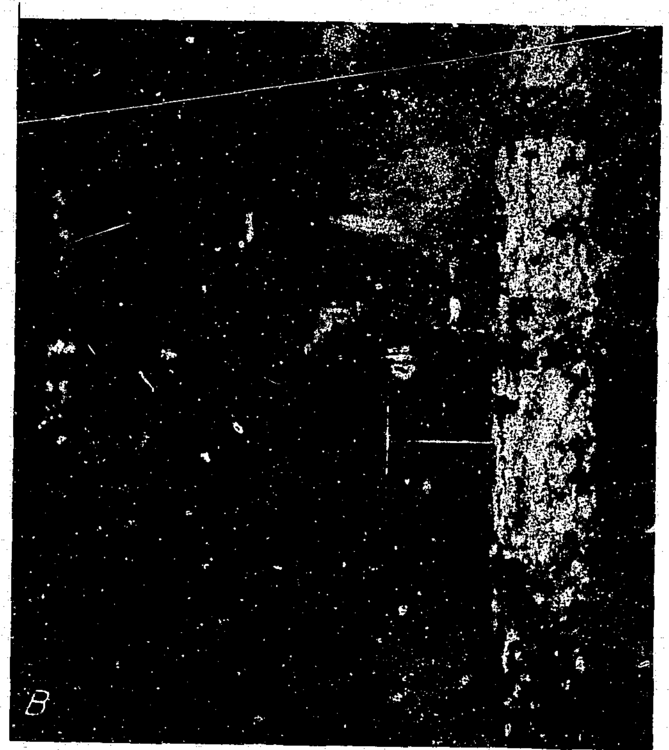

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YIELD TABLES ARE BASED ON THE MEASUREMENT OF SAMPLE PLOTS IN TYPICAL FORESTS

A, Measuring the diameters of trees on sample acres is one of the first steps in the preparation of yield tables; B, the age of a tree is determined by counting the annual rings of growth on stumps or by counting the growth rings on a small core of wood extracted from the standing trees with an increment borer.

study it was possible to take advantage of the natural occurrence of Douglas fir in extensive even-aged stands of uniform site quality and to measure several plots in each forest. The group of plots for each forest subsequently was averaged to obtain a composite plot. By thus sampling the seemingly homogeneous conditions in various parts of each forest, more accurate yield tables have been obtained than would be possible with but one plot to the tract, no matter how carefully it might be selected. This assumption was supported when the data were analyzed, for although each plot of a tract was selected by inspection as representing normal stocking, considerable variation was found between sister plots in the same tract.

The plot boundaries were surveyed with a compass and steel tape. All plots except, perhaps, half a dozen were square. Arbitrary limits of error in closure of plot surveys were set at 3 feet for 1-acre plots, 2 feet for half-acre plots, and 1 foot for quarter-acre plots.

All living trees on the plots were calipered and recorded by inch classes according to species. Hardwoods and the small trees of the understory, although they were not used in the yield computations, were measured for diameter and recorded.

For each tract enough total-height measurements were taken with steel tape and Abney level (or Forest Service hypsometer) to draft a curve of height over diameter.[12] These trees were selected throughout the tract and were representative of the group of plots.

Age determinations were made by counting the annual rings on increment borings, or on stumps where a part of the stand was being logged adjacent to the plots. The age counts were made throughout the stand on representative trees of every crown class, although most attention was given to the dominant and codominant trees because the average age of these trees was taken as the age of the stand. Since the age determinations were usually made at several feet above the ground level, it was necessary to add to the ages obtained at these heights the number of years required to reach the height of stump or increment boring. Table 19, based on 1,228 measurements of dominant Douglas fir seedlings, was used to convert the ring count to total age.

TABLE 19.—*Height growth of dominant Douglas fir seedlings*

Height above ground (feet)	Growing period required, by site classes—				
	I	II	III	IV	V
	Years	*Years*	*Years*	*Years*	*Years*
1	3	3	3	4	5
2	4	5	6	6	7
3	5	6	7	8	9
4	6	7	8	9	10
5	7	8	9	10	11

For each forest in which measurements were taken a description was prepared recording details of the stand as a whole. The following items were included in this description: Location, relief, field estimate of site quality, soil, ground cover, underbrush, reproduction, the stand itself, injuries, and history of the stand.

OFFICE COMPUTATIONS

The first step in the office computations was the elimination of tracts that could not be used. Certain essential information pertaining to some tracts apparently had been lost in the years between 1911 and 1924; other tracts obviously were unsuitable because of indeterminate age, or because the stand had been thinned or cut into. Sixteen tracts comprising 46 plots (32.725 acres) were so discarded.

Individual plots of some of the remaining tracts likewise were discarded because species other than Douglas fir predominated or because there was doubt as to the uniformity of age as compared with the other plots of the same tract. Seventeen plots (15.525 acres) were so eliminated.

[12] The height measurement of trees on steep slopes was greatly facilitated by the development of a method permitting the use of surface measure instead of horizontal measure in obtaining the distance from the observer to the tree. A full description of this method has been published by R. E. McArdle and R. A. Chapman (6).

The remaining plots were then analyzed by tracts. Individual plots were discarded if their total basal area differed from the average basal area of the tract by more than twice the standard deviation about the average. Seventy-three plots (48.51 acres) were so eliminated because of overstocking or understocking. There were left, after the elimination of these data, 245 tracts comprising 1,916 individual plots.

The remaining plots of each tract were combined into one composite plot to be used in all subsequent analyses as representative of that particular site and age class. This was done by averaging the number of trees in each diameter class, and converting these averages, where necessary, to a 1-acre basis. The basal area of each diameter class of the composite plot was computed. From a curve of height over diameter the average height of each diameter class was obtained. The cubic-foot, International board-foot, and Scribner board-foot volumes for each diameter class were computed with the aid of volume tables. (Tables 12, 14, and 16.) Totals for each of the five items (number of trees, basal area, and the three volumes) were obtained for (1) the total stand, (2) the stand 7 inches in diameter and larger, and (3) the stand 12 inches in diameter and larger. The basal area of the average tree was obtained by dividing the total basal area of the composite plot by the total number of trees. The age of a composite plot and the average height of its dominant and codominant trees[18] were taken from the measurements of the tract represented by the composite plot.

TABLE 20.—*Check of yield tables against basic data (deviation of actual values from estimated values)*

Table	Deviation: Aggregate	Deviation: Average
TOTAL STAND		
	Per cent	*Per cent*
Number of trees	−0.27	19.5
Basal area	+.63	11.4
Cubic volume	+.69	13.05
Basal area of average tree	+1.97	21.4
STAND 7 INCHES OR MORE IN DIAMETER		
Number of trees	+0.74	
Basal area	+1.55	14.1
Cubic volume	+1.13	
International board-foot volume	+.06	16.6
STAND 12 INCHES OR MORE IN DIAMETER		
Number of trees	+0.55	
Basal area	+3.87	23.1
Cubic volume	+2.99	
International board-foot volume	+3.55	
Scribner board-foot volume	+2.65	23.1

[18] The height-diameter tallies of a tract showed specifically which of the trees measured for height were in the dominant and codominant crown classes. When the data for some of the earlier measured tracts were examined it was discovered that the height tally sheets showed only diameter and height, and had no note concerning crown classes. It would ordinarily have been impossible to determine the site quality of these tracts on the basis of the average height for dominant and codominant trees. Experimentation with data of tracts for which there was complete information showed a relationship between the dominant and codominant trees and the rest of the stand and thus permitted the use of some of the data which otherwise could not have been used. It was found that the dominant and codominant trees constituted 55 per cent of the entire range in diameter classes of a tract. In young stands this range included only a few sizes of trees because the entire range of diameters was small; old stands had a wide range in sizes and the dominant and codominant classes therefore included more diameter classes than the young stands. With this knowledge it was possible to determine the probable lower diameter limit of the dominant and codominant crown classes. Then from the height tally or from the height-diameter curve the average height of the trees in these classes was obtained. A somewhat different method of approach to this problem would be to compare the average diameter of all crown classes combined with the average diameter of the dominant and codominant classes.

From this point on, the composite plots were treated exactly as the single plots of the ordinary yield study. The method used is that developed by Donald Bruce for the yield study of southern yellow pine (1). Briefly, the procedure is as follows:

Prepare curves representing site index.

Construct preliminary curves of total basal area.

Reject plots which have erratic values for total basal area. (The application of two standard deviations centered on the mean resulted in the Douglas fir yield study in the elimination of 10 composite plots, representing 49 individual plots or 22 acres.)

Using the accepted data, construct four basic tables—total basal area, basal area of average tree, total number of trees, and cubic-foot volume.

Tables for the stand 7 inches in diameter and larger and for the stand 12 inches in diameter and larger are derived by means of conversion factors from the tables for the total stand.

The yield tables were checked against the data from which they were constructed. These checks are given in Table 20.

The final basis for the yield tables, when all data, for whatever cause, had been eliminated, was as follows:

Composite plots (tracts), 235.

Individual plots involved, 1,867.

Total area, acres, 1,252.29.

Stand tables were originally prepared by plotting on logarithmic-probability paper the percentage distribution of number of trees in each diameter class, as described by Bruce (1). The computation of these stand values is simplified by an alignment chart recently devised by L. H. Reineke and presented here as Figure 17.

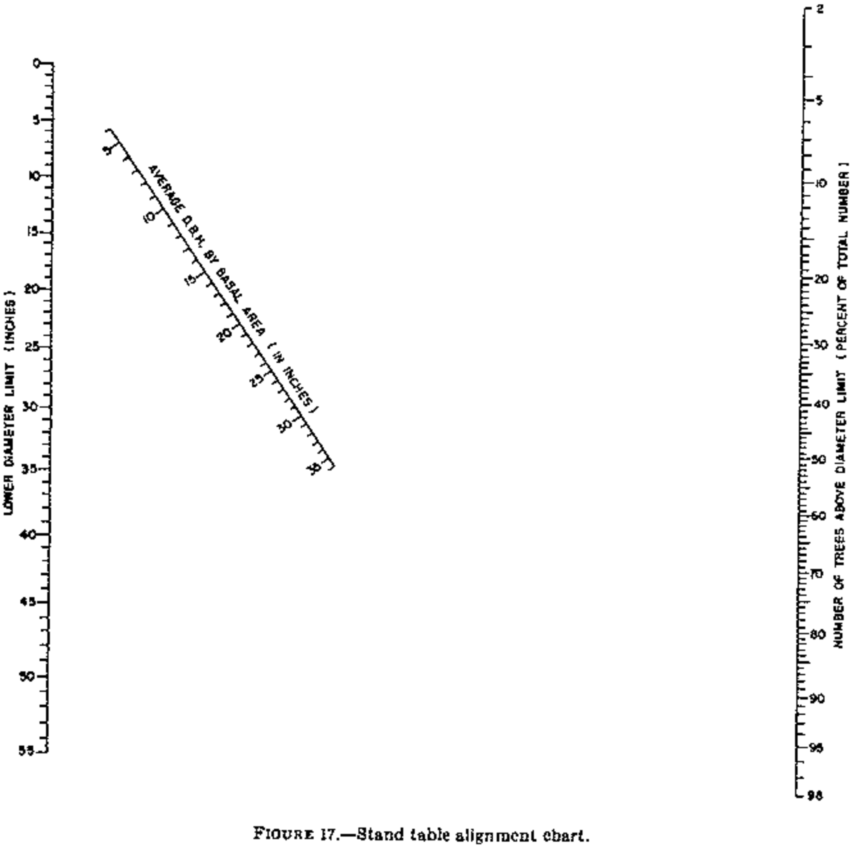

FIGURE 17.—Stand table alignment chart.

To use this chart a straightedge is laid across the three graduated scales, intersecting the scale for lower diameter limit at the desired figure. and the scale for average diameter at the figure corresponding to the diameter of the average tree of the total stand. (Table 2.) The stand of trees above the selected lower diameter limit is then read on the scale at the extreme right, in percentage of total number of trees. After computing the number of trees above successive lower diameter limits the number of trees in each diameter group is subtracted from the number in the group immediately preceding to obtain the number of trees in each group. The sample computation given in Table 21 will make this clear.

TABLE 21.—*Sample computation of stand table*

Diameter-class group	Lower diameter limit	Trees above lower limit		Trees in group
Inches	*Inches*	*Percent*	*Number*	*Number*
4-5	3.5	100.0	337	22
6-7	5.5	93.5	315	54
8-9	7.5	77.5	261	67
10-11	9.5	57.5	194	73
12-13	11.5	36.0	121	55
14-15	13.5	19.5	65	39
16-17	15.5	8.0	27	18
18 and over	17.5	2.7	9	9
Total				337

Age, 60 years; site index, 140; diameter of average tree, 11.1 inches (from Table 2); total number of trees, 337 (from Table 2).

A REVISED YIELD TABLE FOR DOUGLAS FIR

A primary purpose of the yield table is to predict the future condition of given stands of second growth. It seems self-evident that such prediction is possible only when the yield table well describes such stands as they are today. The conventional normal yield table described in the body of this bulletin does not meet this requirement. Its failure is widely recognized in the case of partially stocked stands that have fewer and larger trees than a normal stand. This leads to a confused definition of normality or normal stand density. Normality percentage by numbers of trees may not be closely related to timber volume, and normalities by basal area, cubic-foot volume, and board-foot volume, are often grotesquely different.

The conventional table also fails frequently in the case of stands that may be considered normal in terms of one but not all standards of measurement. This is because subnormal stands may become normal with the passage of time. A stand having normal board-foot volume, for example, may have been normal for many years or for only a few If the stand has been normal for many years, it will consist of considerably more smaller trees than a stand that has been normal only a few years. In other words, the difficulties in defining normality will persist even after normality has been attained.

Preliminary yield tables for Douglas fir that are free from most of these difficulties are presented here. They should be more applicable than conventional tables to subnormal stands, and in many cases to normal stands as well. No claim is made, however, that they are accurate for use with all types of subnormal stands or with extreme cases of understocking. They must be thoroughly tested before their applicability can be clearly determined. Thus, the new tables are presented to permit actual tests against typical stands.

A further advantage of the new tables is that the independent variables used for predicting stand volumes can be more easily and accurately measured. Site index is eliminated completely, and age assumes a minor role. The important independent variables are average diameter, number of trees per acre, and a height relationship based on a small number of measured samples.

Basic data for the new tables are from the same plots used in preparing the main part of this publication. Permanent sample plots established and periodi-

TABLE 22.—*Yield*[1] *of Douglas fir on fully stocked acre, trees larger than 5.0 inches d. b. h. (Forest Survey standard)*[2]

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
	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.*
20	50	50	100	200	300	400	500	650	800	950	1,100	1,300	1,450	1,650
30	400	550	800	1,050	1,350	1,700	2,100	2,500	2,900	3,250	3,600	3,950	4,200	4,400
40	1,050	1,350	1,800	2,350	3,000	3,700	4,300	4,900	5,500	6,000	6,400	6,750	7,050	7,250
50	1,900	2,350	3,000	3,800	4,800	5,600	6,350	7,050	7,700	8,300	8,850	9,300	9,700	10,000
60	2,800	3,500	4,300	5,200	6,250	7,200	8,150	9,000	9,750	10,400	11,050	11,600	12,050	12,400
70	3,700	4,400	5,300	6,350	7,500	8,600	9,650	10,550	11,400	12,150	12,850	13,500	14,050	14,500
80	4,300	5,200	6,200	7,300	8,550	9,700	10,850	11,900	12,850	13,700	14,500	15,200	15,850	16,350
90	4,750	5,700	6,800	8,050	9,400	10,700	11,900	13,050	14,100	15,050	15,900	16,650	17,300	17,800
100	5,100	6,150	7,300	8,650	10,100	11,500	12,800	14,000	15,150	16,150	17,100	17,900	18,550	19,050
110	5,400	6,550	7,800	9,200	10,700	12,150	13,550	14,800	16,000	17,050	18,000	18,800	19,550	20,100
120	5,700	6,850	8,150	9,600	11,200	12,700	14,150	15,450	16,650	17,750	18,800	19,700	20,450	21,150
130	5,950	7,150	8,450	10,000	11,650	13,200	14,700	16,000	17,250	18,400	19,450	20,400	21,200	21,900
140	6,150	7,350	8,750	10,300	12,000	13,600	15,150	16,500	17,850	19,000	20,100	21,050	21,850	22,550
150	6,300	7,550	9,000	10,600	12,300	14,000	15,600	16,950	18,300	19,500	20,650	21,600	22,500	23,200
160	6,450	7,700	9,200	10,850	12,650	14,400	16,000	17,400	18,750	20,000	21,150	22,150	23,050	23,800

[1] Rounded to nearest 50.

[2] This table was derived from cubic foot volume and yield tables presented in the body of this publication. Volumes are stem volumes, exclusive of bark and limbs, between stump and 4-inch top d. i. b. Stump height equals d. b. h. for trees up to 24 inches d. b. h.; for trees 24 or more inches d. b. h. a stump height of 2 feet is assumed. The table was compiled by P. A. Briegleb, Pacific Northwest Forest and Range Experiment Station, March 15, 1941.

TABLE 23.—*Yield of Douglas fir on fully stocked acre, trees 12 inches in diameter and larger, to an 8-inch top, International rule (one-fourth inch kerf)* [1]

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
	Bd. ft.	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*
30	-----	-----	-----	-----	-----	-----	400	1,100	1,800	3,100	4,800	7,100	9,500	12,400
40	-----	-----	-----	200	1,400	3,100	5,400	7,700	10,600	14,000	18,200	22,900	28,300	33,800
50	40	200	1,900	3,900	6,500	9,900	14,600	20,000	26,000	31,800	37,700	43,900	50,100	56,400
60	1,300	3,100	5,700	9,600	14,700	21,100	27,800	34,300	41,700	49,000	56,000	63,100	69,300	75,700
70	2,900	6,300	10,600	16,500	24,100	32,400	40,600	48,700	57,000	64,600	72,500	79,600	86,400	93,300
80	5,200	10,200	16,300	23,500	33,100	42,600	52,200	61,600	70,000	78,400	86,700	94,200	101,500	108,600
90	8,200	14,100	21,800	30,200	41,000	51,600	62,300	72,100	81,500	89,900	98,400	106,600	114,100	121,400
100	11,300	18,000	26,500	36,200	48,000	59,400	70,600	80,900	90,800	99,800	108,500	116,700	124,500	132,100
110	14,300	22,000	30,900	41,600	54,000	65,900	77,600	88,200	98,500	107,900	116,800	124,900	133,200	140,300
120	17,200	25,300	35,000	46,400	59,200	71,600	83,500	94,600	105,000	115,000	124,000	132,200	140,500	147,900
130	19,800	28,400	38,700	50,700	63,800	76,700	88,600	100,300	110,800	121,000	129,800	138,600	147,100	154,900
140	22,300	31,300	42,000	54,600	67,900	81,100	93,300	105,300	116,000	126,200	135,300	144,000	152,700	160,800
150	24,700	33,900	45,100	58,200	71,400	84,900	97,500	109,800	120,800	131,000	140,500	149,000	157,800	166,000
160	26,900	36,500	47,800	61,300	74,700	88,500	101,500	113,900	125,200	135,500	145,000	153,600	162,400	170,100

[1] Derived by adjustment of Scribner volumes in table 4, p. 27, by P. A. Briegleb, December 1948.

TABLE 24.—*Yield of Douglas fir on fully stocked acre, trees 15.6 inches in diameter and larger, to a 12-inch top, Scribner rule* [1]

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
	Bd. ft.	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*
30	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	500	1,000	2,000
40	--------	--------	--------	--------	--------	--------	--------	--------	500	2,000	3,000	5,000	8,500	12,000
50	--------	--------	--------	--------	--------	--------	1,000	2,800	5,000	9,000	13,000	19,000	25,000	32,000
60	--------	--------	--------	800	1,500	3,000	6,500	10,000	14,500	19,500	26,000	33,000	42,500	54,000
70	--------	--------	--------	2,900	5,000	9,000	14,000	19,500	26,000	33,000	41,000	49,000	58,500	68,000
80	--------	--------	--------	5,500	9,500	15,000	22,000	29,000	37,000	46,000	55,000	64,000	73,000	83,000
90	800	1,500	4,500	8,500	14,000	21,000	30,000	38,500	47,000	57,000	66,000	76,000	86,000	98,000
100	1,700	4,000	7,000	12,000	19,500	28,000	38,000	48,000	58,000	67,500	78,000	87,000	97,000	107,000
110	2,700	5,600	10,000	16,000	25,000	36,000	46,000	56,500	66,500	76,000	86,500	96,500	106,000	115,000
120	3,700	7,000	12,000	20,000	31,000	42,000	52,500	63,000	73,500	84,000	94,000	104,000	114,000	124,000
130	5,000	9,500	16,000	24,000	36,000	47,500	58,500	69,000	80,000	90,500	101,000	111,000	121,000	131,000
140	6,500	12,000	19,000	27,500	39,000	52,000	63,500	75,000	86,000	96,500	107,000	117,500	127,500	137,000
150	8,000	13,500	21,000	31,000	43,500	56,000	68,000	80,000	91,000	102,000	113,000	123,500	133,500	143,000
160	9,500	16,000	24,000	34,000	47,000	59,500	72,000	84,000	96,000	107,000	118,000	128,500	139,000	149,000

[1] These values were derived from board foot volume and yield tables presented in the body of this publication. Trees scaled by 32-foot logs. Allowance was made for a 2-foot stump. Volumes are gross scale and no deductions have been made for breakage or defect. They were read from curves prepared by W. H. Meyer, January 1933, at Pacific Northwest Forest and Range Experiment Station, October 1946.

cally remeasured by the Pacific Northwest Forest and Range Experiment Station were used for checking the tables. Other auxiliary data were taken from W. H. Meyer's study, Height Curves for Even-Aged Stands of Douglas Fir, reported in a processed paper in 1936, and his Journal of Agricultural Research article, A Study of the Relation Between Actual and Normal Yields of Immature Douglas Fir Forest, issued in 1930. Auxiliary data from an article entitled New Methods and Results of Growth Measurement in Douglas Fir, by P. A. Briegleb and J. W. Girard, issued in the Journal of Forestry in March 1943, were also used.

AVERAGE DIAMETER AS A BASIS FOR YIELD TABLES

Over 20 years ago it was found that some of the more difficult problems of normal yield table construction were easily solved by using average stand diameter (regardless of site and age) as the independent variable. This led G. H. Barnes to suggest in an article published by the British Columbia Forest Service in 1931, The Importance of Average Stand Diameters as a Factor in Forecasting Timber Yields, that a similar treatment might profitably be applied to the entire process. Further studies confirmed the impression that stands of the same average diameter breast high were much more nearly alike in every way than were stands of the same site and age class. Meyer in United States Department of Agriculture Technical Bulletin 544, Yield of Even-Aged Stands of Sitka Spruce and Western Hemlock, issued in 1937, presented partial yield tables based on average diameter at breast height as well as the complete yield tables based on site and age. The tables given here are an extension of this same principle.

Table 25 is the basic description of second-growth Douglas fir stands when average stand diameter is the independent variable. This was derived from the

TABLE 25.—*Revised Douglas fir yield table, based on average diameter instead of site and age*

Average d. b. h.[1] of stand (inches)	Normal number[2] of trees per acre	Normal height of trees of average d. b. h.	Volume per tree				Volume per tree, 12 inches d. b. h. and over	
			Total stand[2] and entire stand	5 inches d. b. h. and over to 4-inch top	7 inches d. b. h. and over to 4-inch top	12 inches d. b. h. and over to 4-inch top	International ⅛-inch rule[3]	Scribner[4] rule
		Feet	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Board feet*	*Board feet*
2	4,466	22						
3	2,387	31						
4	1,530	39	1.8	0.9	0.2			
5	1,084	47	3.2	2.1	1.1			
6	818	55	5.1	3.8	2.6	0.3		
7	644	62	7.6	6.2	4.9	1.1	5	3
8	524	69	10.9	9.4	8.0	2.5	18	11
9	437	76	14.9	13.4	12.1	5.3	35	23
10	371	83	19.6	18.0	16.7	9.5	66	43
11	320	90	25.2	23.6	22.7	15.1	102	67
12	280	97	31.5	29.8	28.3	21.7	148	99
13	248	104	38.5	36.6	36.5	29.5	224	149
14	221	110	46.6	44.3	44.3	38.3	274	184
15	198	117	55.5	52.8	52.8	48.0	347	236
16	180	123	65	62	62	58	432	296
17	164	130	76	72	72	69	521	359
18	150	135	87	83	83	81	618	429
19	138	141	99	95	95	93	724	510
20	127	147	112	108	108	106	836	593
21	118	152	126	121	121	119	956	683
22	110	157	142	136	136	134	1,075	779
23	102	162	158	152	152	150	1,205	886
24	96	167	175	169	160	168	1,339	999
25	91	171	193	186	186	185	1,485	1,125
26	85	176	213	205	205	204	1,653	1,262
27	80	180	234	227	227	227	1,826	1,405
28	76	185	256	249	249	249	2,031	1,582
29	72	189	279	271	271	271	2,249	1,730
30	68	194	302	293	293	293	2,476	1,905

[1] Weighted by basal area.
[2] Total stand; i. e., trees over 1.5 inches in d. b. h.
[3] To 5-inch top.
[4] To 8-inch top.

same plot data that were used to compile the yield tables in the main body of this publication. The method of derivation is simple, involving merely sorting the plots by diameter-breast-high classes and summarizing, averaging, and curving the corresponding number of trees per acre, normal height, and the various expressions of volume shown in table 25. Because some of these items had not been worked out for the individual plots, ratios based on other available studies were used to derive them to save time. Obviously, additional columns (such as the number of trees per acre more than 12 inches in diameter) could readily be added to this table if desired, thus covering all the standards of measurement presented in the normal yield table.

Table 25 may be applied to any given second-growth Douglas fir stand for which average diameter and number of trees per acre have been determined. Volume per acre, as defined in the heading of any of the last six columns, is obtained merely by multiplying the volume per tree by the number of trees per acre as determined by field sampling. This use of the table is, in effect, a short-cut method of cruising second-growth stands.

CORRECTIONS FOR HEIGHT

The short-cut method described above has been checked for accuracy by using it to estimate the volume in cubic feet of the basic temporary plots and also of the permanent sample plots. The standard error of estimate for individual plots was found to be 6.5 percent, even when average diameters were interpolated to the nearest 0.1 inch.

The cause of this rather high error was found to be associated with variations in height. It is, then, clear that stands of the same average diameter at breast height may vary in the height-diameter relation. This variation was in turn found to be loosely correlated with site. The looseness of this correlation suggested a correction based directly on the height-diameter relation rather than indirectly on the site index.

It was found that, if the estimates of volume in cubic feet on each plot were adjusted in proportion to the ratio between (1) the average height of the trees of average diameter at breast height on the individual plots and (2) the corresponding normal height given in table 25, column 3, the standard error of estimate was reduced to 2.6 percent, a very satisfactory figure. The maximum error discovered in stands 10 inches or more in average diameter breast high was 4 percent.

In 1936 Meyer prepared a series of standard Douglas fir height-diameter curves, referred to on page 68, for each combination of site and age (Height Curves for Even-Aged Stands of Douglas Fir). Table 26 was taken from his work sheets and represents a similar series of curves based on average stand diameters.

To correct volume estimates for variations in height, one need only measure a small number of mechanically selected trees that are near the stand average in diameter. (In practice, they would be measured before stand diameter was precisely determined.) The sum of the total heights of the measured trees divided by the sum of the corresponding total heights taken from table 26 will give a correction factor that should be applied to the volume. For instance, if the actual trees are 5 percent higher on an average than is indicated by table 26, volume estimates from table 25 should be raised 5 percent, etc.

For board-foot volumes, greater errors were found, particularly by the Scribner rule. The standard error of estimate in Scribner volume for individual plots was 10.8 percent. It was found, however, that the large errors were concentrated in the stands of small average diameter. For stands with an average diameter breast high of 12 inches and over the standard error was only 4.1 percent.

Many may believe that errors in determining board-foot volume of a stand with small average diameter are of little concern, since the volume is in scattered trees of merchantable size and the stand as a whole is unmerchantable. Moreover, such errors tend to diminish as the stand grows older. If this opinion is accepted, the present tables appear to meet the requirement of adequately describing typical second-growth stands as they are today. It remains to supply a means of predicting future volumes.

NORMALITY

Attention should first be called, however, to the simplification introduced into the concept of normality. When tables 25 and 26 are used, normality by number of trees and by volume, however expressed, are identical. Normality may, therefore, be defined as the ratio between the actual number of trees per acre and

TABLE 26.—*Standard height for well-stocked second-growth Douglas fir, based on average diameter of stands* [1]

Tree d. b. h. (*inches*)	Total height when average d. b. h. of stand is—												
	6	8	10	12	14	16	18	20	22	24	26	28	30
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
2	32	32	29										
4	44	46	47	56	43	38							
6	55	59	63	65	66	65	63	60					
8	64	69	74	79	81	82	82	81	77	73	69		
10	72	77	83	89	94	96	97	98	96	94	90	85	
12	77	83	90	97	103	107	111	113	111	110	107	105	
14	81	90	97	104	110	116	120	123	124	125	123	123	122
16	85	94	103	111	117	123	127	132	133	135	136	135	134
18	88	99	107	115	122	129	135	140	142	144	146	145	145
20		103	112	120	128	135	142	147	151	154	155	155	157
22		106	116	125	132	139	146	153	157	161	164	166	167
24			119	129	136	144	151	157	162	167	170	172	175
26				132	140	148	155	162	166	172	176	178	182
28				134	143	151	158	166	171	176	181	185	188
30				137	146	155	162	169	176	180	185	190	194
32					149	159	166	173	179	184	188	193	198
34					152	162	169	177	182	187	192	196	201
36					154	165	171	180	185	190	195	200	204
38								183	188	192	198	203	206
40								185	190	195	202	205	211
42									193	197	204	208	213
44									195	199	206	211	215

[1] Derived from Walter H. Meyer's Height Curves for Even-Aged Stands of Douglas Fir and from his work sheets.

that shown in table 25 for the corresponding average diameter breast high (interpolated to the nearest 0.1 inch). The similarity between this expression and that found in Perfecting a Stand-Density Index for Even-Aged Forests, by L. H. Reineke (published in the Journal of Agricultural Research in 1933) is self-evident. The percentage form is more easily understood and leads to simpler computations.

PREDICTED DESCRIPTIONS OF FUTURE STANDS

If tables 25 and 26 are to be used for future stands, a method must be provided for predicting the future average stand diameter, the future number of trees per acre, and the future height correction.

Diameter will be considered first. Conventional yield tables rely on age and site as the sole basis for determining tree diameter, even though these two variables usually lead to erroneous estimates of the present diameters. Table 27 provides for predicting the diameter growth (10-year) directly on the basis of the present diameter and the age. These two variables are an expression of preceding diameter growth, so that, in effect, estimated future growth is related to that of the past. As figures in table 27 indicate, however, future diameter-breast-high growth is not assumed to equal that of the past. Allowance is made for normal decline in growth as age advances.

Table 27 is merely a transformation of the information contained in the conventional table showing the relation between average diameter breast high and site and age. (See p. 14.) Some technical objections may be raised to the indirect graphical method used in deriving the table, but it appears to be an acceptable first approximation easily extracted from the available data.

It seems probable that better estimates might be obtained by use of current diameter growth determined by increment borings, but here the additional problem arises of estimating the "false growth" resulting from the death of smaller trees. Pending further research the present table seems reasonably satisfactory.

A conservative estimate of the future number of trees may be obtained by calculating the present normality and multiplying the normal number of trees for the predicted average diameter breast high (table 25) by this percentage. This ignores the tendency of understocked stands to approach normality. To allow for that tendency, table 28 has been derived from a study by Briegleb and Girard (see p. 68) of understocked stands. When data obtained in that study were plotted in the form indicated by table 28, a straight regression line was fairly well defined. By use of this table a corrected future normality can be predicted, and presumably a more accurate forecast of the future number of trees can be made.

TABLE 27.—*Estimated diameter growth per decade in normal stands of second-growth Douglas fir* [1]

Average d. b. h. of stand (in.)	Diameter growth when age of stand in years is —													
	20	30	40	50	60	70	80	90	100	110	120	130	140	150
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
2	1.6	1.1												
3	2.0	1.4	0.9											
4	2.4	1.6	1.1	0.9										
5	2.8	1.9	1.4	1.1										
6	3.2	2.2	1.6	1.3	1.0									
7	3.7	2.5	1.8	1.4	1.1	0.8								
8		2.7	2.1	1.6	1.3	1.0	0.7	0.6	0.6					
9		3.0	2.3	1.8	1.4	1.1	.8	.7	.6	0.6				
10		3.3	2.6	1.9	1.5	1.2	.9	.8	.7	.6	0.5	0.5		
11		3.6	2.8	2.1	1.7	1.3	1.0	.9	.8	.7	.6	.5	0.4	0.4
12			3.0	2.3	1.8	1.4	1.1	.9	.8	.7	.6	.6	.5	.4
13			3.3	2.5	2.0	1.5	1.2	1.0	.9	.8	.7	.6	.5	.5
14			3.5	2.6	2.1	1.6	1.3	1.1	1.0	.8	.7	.7	.6	.5
15			3.7	2.8	2.2	1.8	1.4	1.2	1.0	.9	.8	.7	.6	.6
16			4.0	3.0	2.4	1.9	1.5	1.3	1.1	1.0	.8	.7	.7	.6
17				3.1	2.5	2.0	1.6	1.3	1.2	1.0	.9	.8	.7	.7
18				3.3	2.7	2.1	1.7	1.4	1.2	1.1	.9	.8	.7	.7
19					2.8	2.2	1.8	1.5	1.3	1.1	1.0	.9	.8	.7
20					3.0	2.3	1.9	1.6	1.4	1.2	1.0	.9	.8	.8
21					3.1	2.4	2.0	1.7	1.5	1.3	1.1	1.0	.9	.8
22						2.5	2.1	1.7	1.5	1.3	1.1	1.0	.9	.8
23						2.7	2.2	1.8	1.6	1.4	1.2	1.1	1.0	.9
24						2.8	2.3	1.9	1.7	1.4	1.2	1.1	1.0	.9
25						2.9	2.4	2.0	1.7	1.5	1.3	1.1	1.0	1.0
26							2.5	2.1	1.8	1.5	1.3	1.2	1.1	1.0
27							2.6	2.1	1.9	1.6	1.4	1.2	1.1	1.1
28							2.7	2.2	1.9	1.7	1.5	1.3	1.2	1.1
29								2.3	2.0	1.7	1.5	1.3	1.2	1.1
30								2.4	2.1	1.8	1.6	1.4	1.3	1.2

[1] Figures derived from yield tables on page 14. Above figures include "false growth" resulting from death of smaller trees and hence will not agree with actual diameter growth of surviving trees as determined by borings.

TABLE 28.—*Estimated increase in normality in a 10-year period*

Normality	10 years' increase in normality	Normality after 10 years	Normality	10 years' increase in normality	Normality after 10 years
0.30	0.08	0.38	0.95	0.02	0.97
.35	.07	.42	1.00	.02	1.02
.40	.07	.47	1.05	.01	1.06
.45	.06	.51	1.10	.01	1.11
.50	.06	.56	1.15	.00	1.15
.55	.06	.61	1.20	.00	1.20
.60	.05	.65	1.25	.00	1.25
.65	.05	.70	1.30	-.01	1.29
.70	.04	.74	1.35	-.01	1.34
.75	.04	.79	1.40	-.02	1.38
.80	.03	.83	1.45	-.02	1.43
.85	.03	.88	1.50	-.03	1.47
.90	.02	.92			

Variations of heights from those in table 26 will presumably persist for many years. A careful search of all available permanent sample plot information failed to reveal any definite tendency for the ratios of actual to standard heights either to increase or decrease. The present height ratios may, therefore, be used for future stands without change.

EXAMPLE OF USE OF THE TABLES

The following calculations will clarify the manner in which tables 25 to 28 may be used.

Assume that the data collected give the following information:

Average number of trees per acre (number) 151
Average diameter (inches) 14.5

Sample trees

Diameter breast high (inches)	*Height (feet)*	*Diameter breast high (inches)*	*Height (feet)*
13	103	15	111
14	106	14	99
12	100	16	114

Average age, 70 years.

Wanted:

(1) Estimated cubic foot volume today in trees 7 inches and over diameter breast high to 4-inch top.

(2) Estimated volume today in Scribner board feet 12 inches and over diameter breast high.

(3) Estimated volumes 10 years hence as above.

Present cubic foot volume is 151×48.55 (from table 25, by interpolation), or 7,311 cubic feet per acre.

Present Scribner volume is 151×210 (from table 25, by interpolation), or 31,710 board feet per acre.

Height correction

Diameter breast high	*Actual height*		*Tabular height (from table 26)*
12	100		104
13	103		108
14	106		112
14	99		111
15	111		115
16	114		118
Total	633	÷	668=0. 95

Adjusted volume per acre=0.95×7,331=6,964 cubic feet,

or=0.95×31,710=30,124 board feet.

Growth of average diameter breast high=1.7 inches (from table 27, interpolated).

Estimated average diameter 10 years hence=14.5 inches+1.7 inches=16.2 inches.

Present normality=151÷210 (table 25)=72 percent; predicted normality=76 percent (table 28).

Number trees 10 years hence=178 (table 25)×0.76=135.

Volume=135×64 (table 25)×0.95=8,208 cubic feet,

or=135×309 (table 25)×0.95=39,629 board feet.

$$\text{Growth per year}=\frac{8,208-6,964}{10}=124.4 \text{ cubic feet per acre per year}$$

$$\text{or } \frac{39,629-30,124}{10}=950 \text{ board feet per acre per year.}$$

PREDICTIONS FOR PERIOD OVER 10 YEARS

Predictions for two or more decades may be made by successive 10-year steps, the final stand at the end of the first period being taken as the starting point for the prediction for the second period. Intermediate periods can be derived by interpolation.

ACCURACY OF ESTIMATES OF FUTURE VOLUME

The accuracy of predictions of future volumes depends on the accuracy of predictions of three factors: The future average stand diameters, the number of trees per acre, and the height ratios. The resulting errors will be augmented by any errors that arise in computing volumes from these data.

A study of the Douglas fir permanent sample plots permits a preliminary appraisal of the accuracy with which future volumes can be predicted. The permanent sample plots were all at least fairly well stocked. The best figures now available for the permanent sample-plot study are 2.9 percent standard error of estimate for 10-year future average stand diameters; 5.1 percent for 10-year future density; and 3.4 percent for 10-year future height ratio. Predictions for moderately understocked stands should be nearly as accurate, provided that the density of the stands is not so heterogeneous as to cause very abnormal diameter distributions.

The standard error of estimate of 10-year future volume in cubic feet will reflect the combined result of these errors, plus that of calculating the cubic volume in the simple way herein proposed (2.6 percent). Theoretically, if the errors are not intercorrelated, this should be for the permanent sample plots

$$\sqrt{2.9^2+5.1^2+3.4^2+2.6^2}=7.3 \text{ percent.}$$

A direct calculation shows a value of 7.6 percent for the same plots, which is a remarkably close check.

The similar standard error for volumes based on the Scribner log rule and for stands larger than 12 inches in average diameter breast high should correspondingly be

$$\sqrt{2.9^2+5.1^2+3.4^2+4.1^2}=7.9 \text{ percent.}$$

A direct calculation shows only 6.6 percent.

If predictions are carried further into the future, the theoretical standard errors should be (if the errors of the later decades are not correlated with those of the earlier) the foregoing figures multiplied by $\sqrt{2}=1.4$ for 2 decades, by $\sqrt{3}=1.7$ for 3 decades, etc. Available data confirm this theory reasonably well, although the actual errors are about 18 percent higher, which suggests that surplus or deficient growth rates have a slight tendency to recur.

Again, it must be remembered that these figures apply to plots of 1 acre or smaller, and that estimates of future volume on such small areas are very fallible because of the erratic occurrence of tree mortality. Better results should be obtained for large tracts of land, although even then it must be recognized that abnormal conditions such as disease, insect infestation, and sleet damage, may invalidate the predictions. Such occurrences, of course, will upset calculations based on the conventional yield table as well.

IN CONCLUSION

This is not an argument for the complete abandonment of the conventional form of yield table. Such tables are useful for making general determinations of the growth capacity of forest land as distinct from the growing stock that happens to be thereon. Most of the problems of forest management, however, are concerned with actual growing stock that is seldom normal. For these problems the new tables seem to have decided advantages. Their limitations can be determined only by further testing.

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