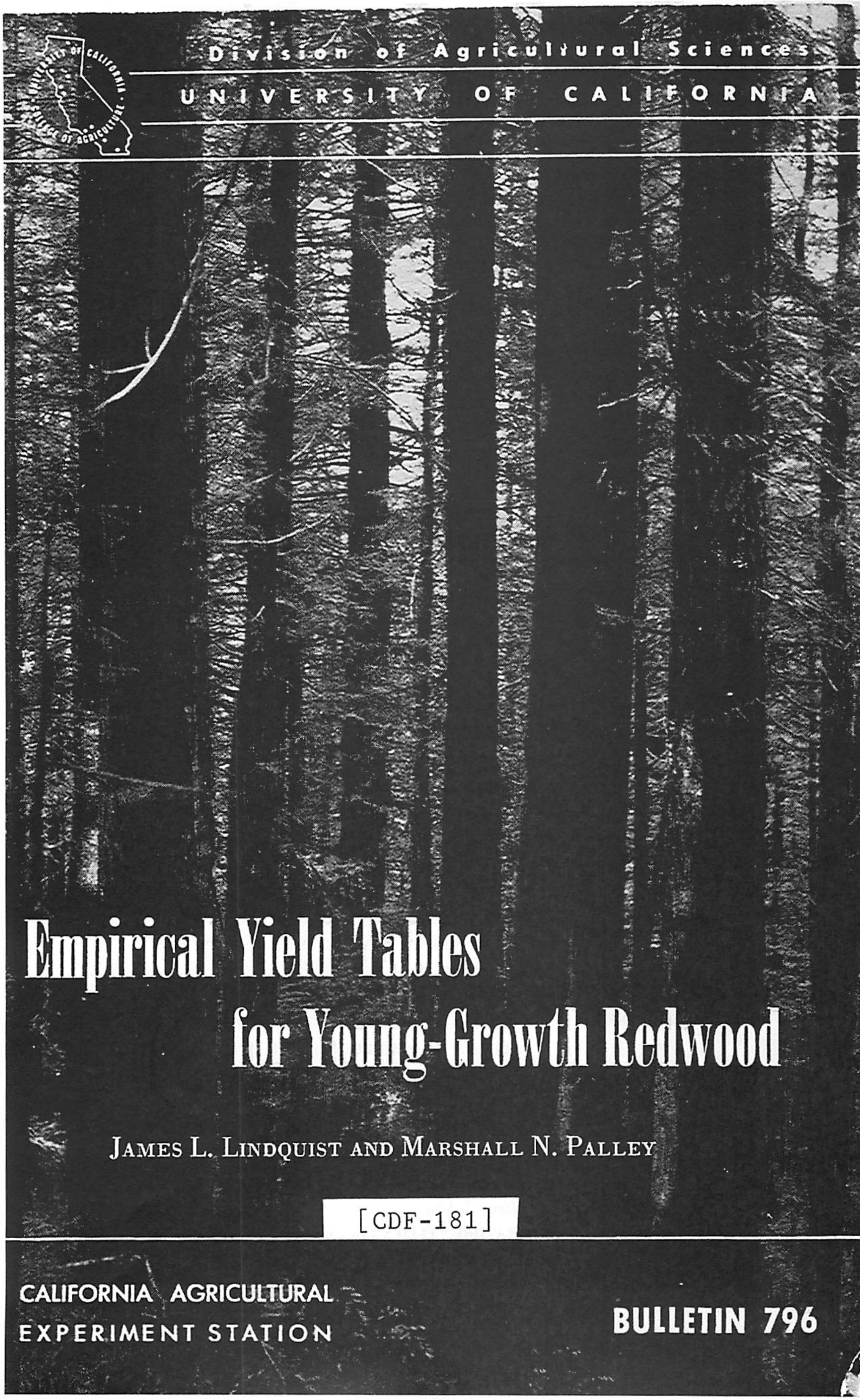

Division of Agricultural Sciences
UNIVERSITY OF CALIFORNIA

Empirical Yield Tables for Young-Growth Redwood

JAMES L. LINDQUIST AND MARSHALL N. PALLEY

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CALIFORNIA AGRICULTURAL EXPERIMENT STATION

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Empirical Yield Tables for

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[CDF-182]

James L. Lindquist and Marshall N. Palley

ing-Growth Redwood

This bulletin presents yield tables, up to age of 100 years, for stands of young-growth coastal redwood and associated species, as these occur in the commercial forest areas of northern California. Tables show expected annual growth and yields at 10-year intervals in terms of basal area, average diameter, number of trees per acre, and volume for portions of these stands exceeding 4.5 inches and 10.5 inches in DBH (diameter at breast height).

Growth and yield figures in this bulletin are keyed to stand age and site index. Stand age is measured by counting the annual rings of dominant trees at breast height. Site index is a measure of the expected height of dominant redwood trees in the stand at the age of 100 years.

The tables are recommended for use without adjustment where stand basal areas are 60 per cent or more of those given in the publication. They are not recommended for timber cruising, unless very approximate results are acceptable. Volume growth and yield are given in cubic feet and in board feet, International ¼-inch log rule. A graph is provided for converting volumes to the Spaulding log rule.

AUGUST, 1963

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LIST OF TABLES AND FIGURES

JAMES L. LINDQUIST AND MARSHALL N. PALLEY

Empirical Yield Tables for Young Growth Redwood[1]

STANDS OF YOUNG-GROWTH redwood (*Sequoia sempervirens* [d. Don] Endl.) occupy an increasing portion of the total commercial redwood forest land as the supply of old-growth redwood becomes more restricted through continued harvesting. Stands similar to the virgin redwood forests will never again be produced, on a commercial basis, under existing forest management practices. Thus the permanently established redwood-oriented timber industries of the northern California coast face the irreplaceable loss of their primary resource base, the virgin redwood.

Commercially stocked young-growth stands in 1948 totaled 727,000 acres, approximately 38 per cent of the total redwood acreage, which supported 6.4 billion board feet of living saw-timber (California Forest and Range Exp. Sta., 1953). These figures do not include young-growth redwood in mixed old and young stands. This tremendous source of redwood with great growth potential available now, coupled with the loss of virgin stands, indicates an increased utilization of these young stands in the future. For this reason, the timberland owners and managers need information concerning the growth and yield of this species to arrive at decisions on long range policies concerning physical plant, taxation, marketing, and similar areas of forest management. The yield tables offered in this bulletin will aid in making reasonable predictions of long-range stand development.

REDWOOD REGION

Redwood stands occur from the extreme southwestern corner of Oregon south along the Coast Ranges of California to southern Monterey County as a narrow band that seldom extends inland more than 30 miles (figure 1) (California Forest and Range Exp. Sta., 1953). This belt is not continuous but includes some large gaps, notably in southwestern Humboldt County and around San Francisco Bay. There are isolated stands in Marin and Alameda counties where climatic conditions are favorable for the species. The portion of the range north of Fort Bragg is characterized by large relatively unbroken tracts of redwood in association with other conifers. This portion of the range has the greatest remaining amount of old-growth timber. Throughout the southern part of the range redwood is typically found in smaller localized tracts that have environmental conditions favorable to this rather exacting species. There are few stands of commercial virgin redwood remaining south of Fort Bragg; where stands do occur commercially they are of low concentration or difficult of access.

Young-growth stands developed subsequent to the initiation of logging in the redwood region during the mid-nine-

[1] Submitted October 30, 1962.

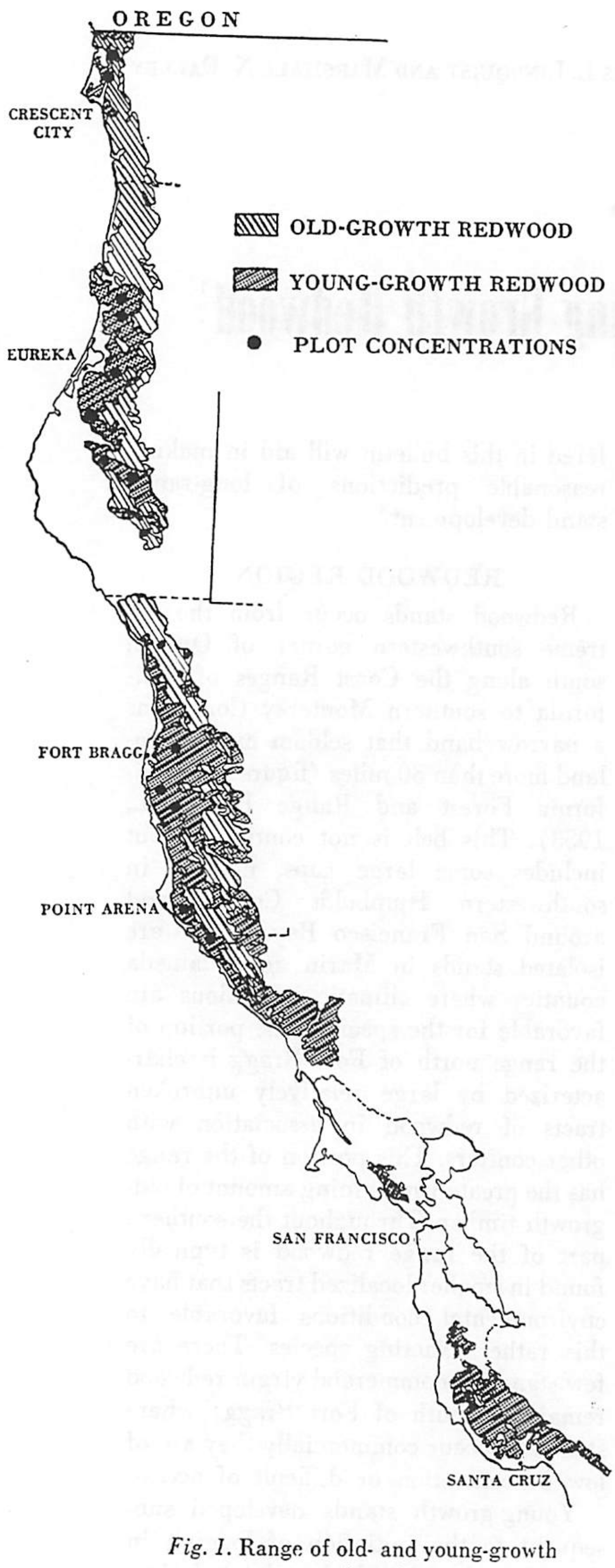

Fig. 1. Range of old- and young-growth redwood.

teenth century. Logging operations at this time were concentrated near the major rivers and bays of the coastal region. As these areas were cut operations spread into the adjacent uplands. The geographical distribution of the young-growth stands indicates major concentrations in the southern portion of the range and along the coast and rivers of the northern portion of the range. Changes in the logging operations brought about by the railroad, and later the truck and tractor, have altered the earlier logging patterns and subsequent distribution of the young-growth stands. Figure 1 indicates the range of the old- and young-growth redwood stands.

Redwood occurs in a region of moist cool climate with relatively high annual precipitation, especially north of San Francisco Bay. Long-range precipitation records of the United States Weather Bureau indicate a maximum of nearly 100 inches near the northern range limit dropping to approximately 20 inches near Monterey, with averages varying from 40 to 60 inches throughout the major portion of the range. Precipitation, mostly in the form of winter rain between November and March, is supplemented during the summer by frequent heavy coastal fogs. The high humidity of the fog-belt reduces the amount of water lost by transpiration and evaporation; also, condensation of this fog on the trees is often in such large amounts that the ground is kept damp. The temperature throughout most of the range is moderate with the extremes rarely greater than 100°F or less than 20°F. Frost and snow occur occasionally at the upper elevations over most of the range. The mean temperature varies between 50–60°F, with average January temperatures of 44–48°F, and average July temperatures of 56–64°F (United States Department of Agriculture, 1941).

The principal topographic features of the redwood region are the mountain ranges with narrow steep valleys along the coast. Some major drainages of the region are the Smith, Klamath, Mad, Eel, Noyo, Big, Navarro, Gualala, and Russian rivers. Most of these rivers have narrow alluvial flats. Redwood grows at elevations from sea level to nearly 3,000 feet. In the northern, more humid portion of its range it extends up the west slopes of the mountains over the summits to the east side. Further south, ideal conditions for growth become more restricted until near its southern limit redwood is found only in sheltered canyons where surface water is available through most of the year and summer fog is common. Topography may influence the distribution of the species by controlling the inland flow of the fog (Harlow and Harrar, 1950). An example of this topographic control is the Eel River Valley which permits heavy fogs to penetrate well inland behind the much higher coastal ridges of Cape Mendocino where redwood is not found.

The principal uplands soils associated with redwood have developed on heavily folded and faulted marine sandstone. These are typified by soils of the Hugo and Goldridge series groups (Storie and Weir, 1953), which are primarily brownish in color, sandy to clay loam in texture, acidic, and moderately deep even on slopes. These podzolic soils associated with coniferous forest types are rated as high-to-intermediate sites for conifers (Storie and Wieslander, 1952). Alluvial soils adjacent to the major rivers, which represent a small percentage of the range, support the best development of the redwood type. Young-growth stands are also found on soils of the sandy marine terraces of Del Norte and Humboldt counties.

Tree species commonly associated with redwood include: Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), Sitka spruce (*Picea sitchensis* [Bong.] Carr.), grand fir (*Abies grandis* [Dougl.] Lindl.), western hemlock (*Tsuga heterophylla* [Raf] Sarg.), tanoak (*Lithocarpus densiflorus* [Hook. and Arn.] Rehd.), Pacific Madrone (*Arbutus menziesii* Bursh), red alder (*Alnus rubra* Bong.), and California laurel (*Umbellularia californica* [Hook. and Arn.] Nutt.). On the narrow alluvial flats the stands are pure redwood with an occasional laurel or alder. Further up the slopes, on upland soils, the most common associate of redwood is Douglas-fir. Sitka spruce and western hemlock are found along the northern coastal portions of the range. Near the range limits of redwood, where environmental conditions due to lack of fog, adverse temperatures, and lower rainfall are less favorable for redwood, the less demanding species such as Douglas-fir, grand fir, oak and tanoak become more prevalent.

STAND DEVELOPMENT

The initial stage in a young-growth stand following the harvesting of the virgin growth is marked by the numerous sprouts which develop on or near the stumps of old-growth trees (figure 2). These clumps of vegetative reproduction provide the earliest and principal means of redwood reoccupancy of a site. During the first years following logging, hardwoods and brush species often become well established in open areas between redwood clumps and provide an effective ground cover. Redwood and other coniferous seedlings may become established during these years, however, juvenile growth of seedlings is slow because of the heavy cover of brush. As the stems of the stump sprouts increase in size, quite rapidly during the first few years, mortality is simultaneously reducing the number of stems in the clumps quite heavily. However, tree height growth has an effect on the brush, which begins to die out as a result of the outward spread of the sprout clumps' canopy (figure 3). The seedlings which developed in the openings and were retarded by the brush begin their period of rapid growth. Douglas-fir and grand fir trees which have

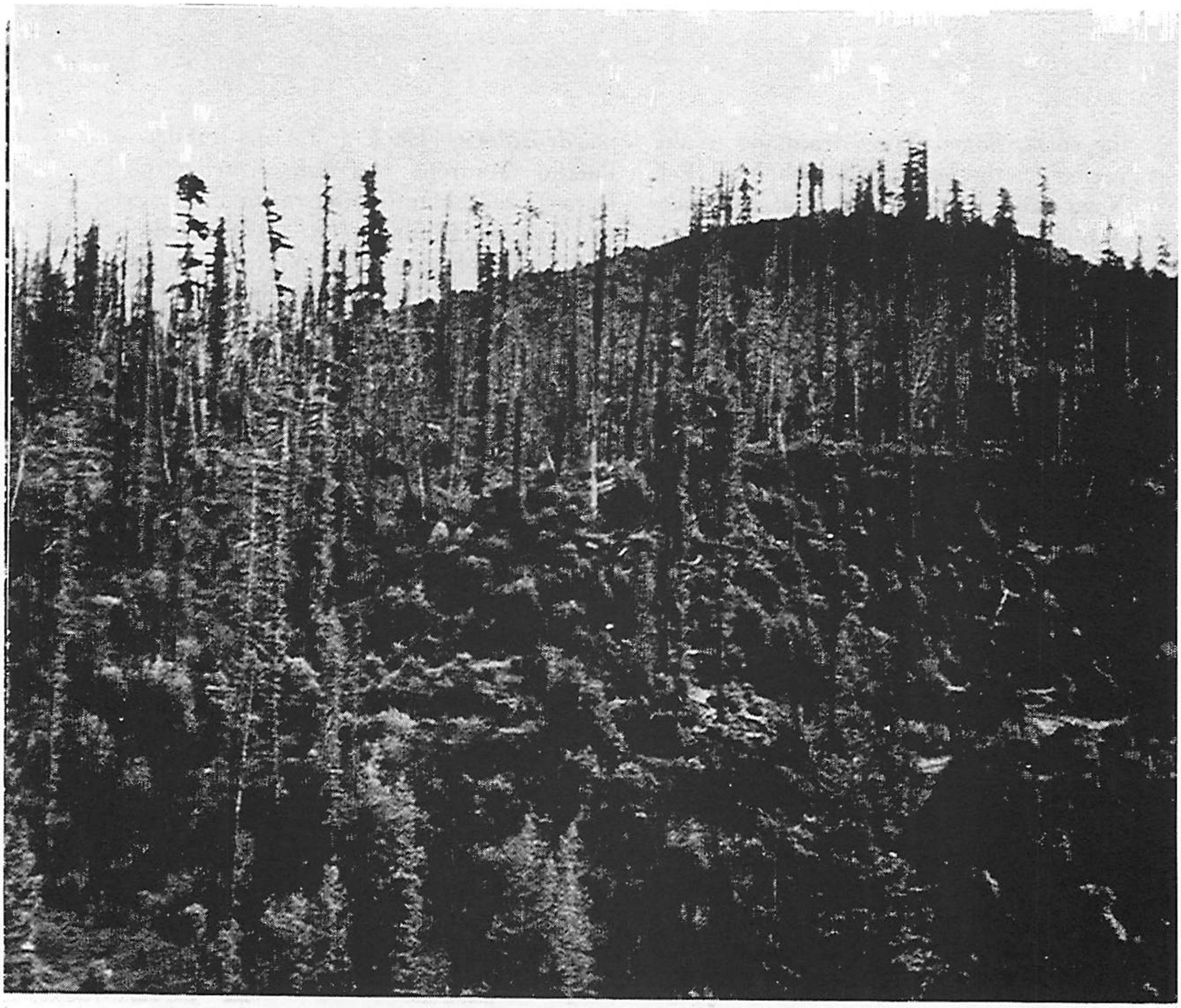

Fig. 2. Young-growth redwood sprout reproduction (1–4 years).

lagged behind sprouted redwood now begin to catch up and will surpass redwood in total height.

As the stand matures and the canopy closes other conifers maintain their height advantage over redwood for a period of years despite their apparent younger age when measured at breast-height. Redwoods eventually become the tallest trees of an old stand. Natural pruning of redwood branches is slow and dead branches may persist for many years. Within the redwood clumps the portion of the bole toward the center of the clump is often free of branches; most branch development is toward the outside of the clump. Stems about the old stump may be quite numerous and boles often coalesce as the diameters increase. Because redwood is tolerant of shade in moist conditions many suppressed trees within the clumps continue to live, often resulting in all crown classes being represented within a single clump. Resistance to this competition in the clumps may be due not only to inherent tolerance of the species but also to the use of the massive root system of the old-growth tree. The outreach of the branches of the clumps often effectively closes the canopy when stump spacing is not too wide. Thus these young-growth stands often retard the development of a second story of younger trees or brush. The more advanced young-growth stands, 80–100 years old, often resemble old-growth stands with

Fig. 3. Young-growth redwood stand (20–30 years).

their massive wide spread stand elements, a high single crown canopy, and the ground relatively free of brush or advance reproduction to obstruct the view in the stand (figure 4). However, in young-growth the stand elements are not individual trees but groups of trees closely associated with old-growth stumps.

The developmental histories of the young-growth stands have been influenced to a large degree by the various harvesting methods and topographic conditions of the redwood region. There is a close association between these two factors since, with the introduction of heavier more mobile handling and transportation equipment, the logging of old-growth redwood progressed into areas formerly inaccessible. Logging techniques associated with various types of equipment have fundamental differences in application and effects on the land. This has resulted in redwood re-establishment occurring under widely different conditions. Early logging operations were generally restricted to the alluvial river flats where oxen and the rivers provided the principal means of transportation. These logging operations, taking only the best quality trees, moved very slowly upstream in the narrow valleys leaving some residual trees and adjacent stands on the slopes as a source of seed for restocking the land. Subsequent introduction of heavy equipment and the railroad to the logging operations allowed an expansion

Fig. 4. Closed stand of young-growth redwood sprouts (80–100 years).

of operations onto the adjacent slopes. Yarding by donkey engines and the high cost of establishing rail lines resulted in a system of clear-cutting whereby most of the timber in a given locality was either harvested or destroyed by the logging operations. This resulted in vast areas of open land with few seed trees available. As a result, brush and redwood stump sprout clumps, the only remaining means of redwood regeneration, reoccupied the land. The introduction of tractors and trucks in the mid-1930's again caused a shift in the harvesting methods. This extremely mobile equipment and concern over the supply of old-growth timber brought about selective cutting methods which do not destroy the residual stands.

The oldest existing young-growth stands, 70–100 years old, resulted from the river logging, but constitute a very small percentage of the young-growth acreage. Stands resulting from various types of clear cutting range in age from 30 to 80 years and are by far the most prevalent stands. Stands regenerated following selective tractor logging, generally less than 20 years old, do not enter into consideration in this study since they are often uneven-aged mixtures of old- and young-growth trees.

YIELD STUDIES

Tables of growth and yield express in numerical form the stand development process which has been outlined in the preceding section and illustrated in the photographs. A distinction is made between short-term growth prediction, in which the increment for a period of less than 20 years is the desired result; and yield studies in which the total accumulated amounts of volume and other forest stand characteristics are shown at age intervals of the active useful life of a stand. This yield study forms part of a larger project which includes prediction of short-term growth as a second main objective. A separate publication will be devoted to short-term growth prediction.

A yield table traces the expected development of forest stands from their origin to some arbitrary age, showing changes in stand basal area, volume, average diameter, and number of trees associated with changes in site index and age. The value of yield table representations of idealized stand development is that they provide a standard against which stands may be compared and a basis for long range projections. Because values shown in yield tables represent an average of existing conditions of a sample of stands, application to actual stands must consider the character of the original sampled stands.

The yield tables of young-growth redwood presented in this study may be defined as empirical yield tables, which are tables developed from "average stand conditions as found in nature" (Bruce and Schumacher, 1935). Sampling carried out for compilation of the present tables sought stands that were typical of better stocked conditions occurring within this type. Expressing yields in terms of age and site index is desirable since it incorporates variables important in the management of growing stands. Stocking is not used as a predictive variable in these yield tables. Consequently some variability of yield controlled in other yield table methods by either selection of normally stocked stands or use of stocking as a predictive variable remains unexplained. Construction techniques resulted in tables that resemble normal yield tables; however, yield figures represent the average of stands which do not necessarily fully occupy the site.

SAMPLING

The objective of the data collection was to sample for growth of representative stands in the young-growth concentrations occurring throughout the commercial range of the type for development of short-term growth predictive equations. Reevaluation of the sample data for yield table presentation resulted in a measure by which long-range assessments of productivity could be made.

Sampling was carried out in the four North Coast counties of Del Norte, Humboldt, Mendocino, and Sonoma with special emphasis on securing a representative sample of the various sites, ages, and stand densities in each of the major areas visited. The pattern of the logging has influenced the distribution of ages and sites to some extent. Generally, as distance from the coast and elevation increase the site index and age decrease. Geographical distribution of plot concentrations are shown in figure 1.

Sampling was restricted to naturally occurring, essentially even-aged, young-growth stands that originated subsequent to logging of the virgin stands. Samples were not taken in stands that showed evidence of recent disturbances due either to logging or excessive windthrow. Also stands that were of two-storied canopy as a result of past cutting history were not sampled. Occasionally, scattered residuals of the virgin stand occurred in young-growth stands selected for sampling. In such cases samples were moved and did not include the residual tree or young-growth trees that might have been influenced by the residual. The majority (51 per cent) of the stands sampled were 100 per cent redwood, with 90 per cent of the stands exceeding 50 per cent redwood by basal area. Species composition of the samples, by basal area, showed the following averages: redwood, 83.7 per cent; other conifers, 13.6 per cent; and hardwoods, 2.7 per cent. On approximately 35 per cent of the sampled stands the trees selected by point sampling were entirely of sprout origin; over-all, the sprouts comprised 65 per cent of the redwood trees included in the samples. The mean basal area per acre of the samples was 374 square feet plus or minus 156 square feet.

Relative to basal area stocking density there was an attempt to sample stands that were stocked to such a degree that a manageable and useful crop could be expected. Seriously understocked stands, commonly depicted as brush fields, including widely scattered clumps of redwood were not utilized. Distribution of sample plots by site index for age, basal area, major soil groups, slope, and aspect are shown in the appendix. In brief, the stands sampled were even-aged, relatively pure, undisturbed representative stands occurring in young-growth redwood.

The point-sampling technique was used for defining the sampling units within the stands. This method proved an efficient way of estimating the stand characteristics needed for yield tables. In particular it was well-suited to selecting trees for boring for radial growth measurements required for short term growth predicting equations. In the point-sampling method trees are selected with probability proportional to their basal area. Thus, the larger trees which account for nearly all the growth of the stand are sampled more intensively than the smaller trees. The Spiegelrelaskop was used to define the trees to be included in the sample. Basal area factors of 10, 20, and 40 were used in establishing temporary growth sample points of 15 to 25 trees under varying stand conditions.

At each sample point, diameter at breast-height, past five- and ten-year radial growth, origin (seedling or sprout), and crown class were determined for each living tree over 4.5 inches DBH. Breast-high age and total height were determined on five to eight dominant trees of the sampling unit. Dead trees that exceeded 4.5 inches DBH were judged as to probable cause and time of death. Trees dead longer than ten years were not included in the sample. Other information recorded for each sample point included a stem map, verbal stand description, slope class, aspect, soil type, and geographical location.

Young-growth stands for sampling were located through the use of Soil and Vegetation Survey Maps, owner type maps where available, and discussions with land owners. A preliminary reconnaissance of an area, using this information, prior to establishing sample points was helpful in securing a better picture of existing stands of the area. The exact location of sample points within stands was left to the discretion of the crew leader. The principal aim of the point location within the stand was to secure a sample of trees representing uniform stand conditions. Several preliminary estimates of the stand basal area per acre were made, and the point selected was one from which the basal area estimate approximated the average of the preliminary estimates.

COMPUTATION OF STAND CHARACTERISTICS

Calculation of per-acre estimates of the stand characteristics, number of trees, basal area, volume, and average diameter at each sampling location was performed using an original program developed for the University of California IBM 704 computer. These characteristics were computed for the entire stand, defined as all trees over 4.5 inches in diameter, and for the sawtimber stand, those trees over 10.5 inches in diameter. Volumes for the entire stand were expressed in cubic feet and for the sawtimber stand in board-feet in terms of the International ¼-inch log rule. For convenience these two portions of the stand will be referred to as the cubic-foot and the board-foot stands, respectively. This computer program also developed stand characteristics for five years and for a whole decade earlier using borings and site curves to approximate the earlier states of the stand. However, these results were not used in the preparation of the yield tables, but were utilized instead in studies of short-term growth.

The computer program developed stand estimates for each of three species groups, redwood, whitewood (all other conifers) and hardwood, and for all species groups combined. Each tree measurement was divided by the square of its diameter (an alternative to dividing by the basal area) and all such weighted tree measurements were accumulated over the plot. The following formulas were applied to the weighted sums to obtain per acre figures for basal area, number of trees, and diameter of the tree of average basal area:

To compute stand volumes, a separate set of local volume equations was generated for each plot, using the redwood and other conifers whose total height was measured. First, the volume of each of these site trees was computed in cubic feet and in board feet by substituting its diameter and height in tree volume equations for that species and unit of measurement. The equations in the appendix (tables 26 and 27) were used for redwood. For the whitewood tree volumes, equations were fitted to standard Douglas-fir volume tables (Pacific Northwest Forest and Range Exp. Sta., 1955). Then, regressions of volume on diameter squared were solved for redwood and for whitewoods, yielding equations of the form

$$\text{volume} = a + bD^2$$

where "a" was the intercept and "b" the slope of the local volume equation. The local volume equations for hardwoods did not vary from plot to plot. Coefficients a and b were computed from U. S. Forest Service local volume tables for tanoak and red alder[2] for both the cubic-foot and board-foot units and these values were used uniformly for all the plots.

Once the local volume table coefficients were available, per-acre volumes for each species group and volume measurement unit were computed for each plot by the

[2] Data on file with the Pacific Forest and Range Experiment Staton.

$$\text{BASAL AREA PER ACRE} = \text{BAF} \times N \tag{1}$$

$$\text{NUMBER OF TREES PER ACRE} = \frac{\text{BAF}}{0.005454} \times \sum \frac{1}{D^2} \tag{2}$$

$$\text{AVERAGE DIAMETER} = \sqrt{\frac{\text{Basal area per acre}}{\text{No. Trees per acre}} \times \frac{1}{0.005454}} \tag{3}$$

where:

BAF = basal area factor

N = number of trees at the sampling point

D = diameter at breast height of a tree

0.005454 = constant linking basal area (sq. ft.) to squared diameter (sq. in.)

following formula (Palley, 1963):

$$\text{VOLUME PER ACRE} = \frac{\text{BAF}}{0.005454}\left(a \sum \frac{1}{D^2} + bN\right) \qquad (4)$$

SITE INDEX

A site index classification was prepared for the various classes of forest land occupied by young-growth redwood in terms of average total height of dominant redwood at a base age of 100 years, ages being determined at breast-height (Lindquist and Palley, 1961). Average breast-high stand age and average total height of dominants (Hornibrook, 1942) of data collected in 161 stand samples were graphically curved to develop the site index values represented in table 1 and figure 5. Site indices from 100 to 240 by increments of 20 site units, and ages ranging from 10 to 100 years are included in these tables. For convenience the site index may be grouped in classes of 20 units that are defined by the curves, i.e., site class I, greater than 201; site class II, 181–200; and so forth to class VI, 101–120. Extension of the site index values to 240 provides an upper limit for the curves, since seldom will stands reach this figure. Values of site index estimated from the curves for the sample plots used in the yield table study ranged from 100 to 232, with but three exceeding 220.

Evaluation of the stand site index made from a sub-sample of trees may be accomplished by means of either a fixed area plot or a point sample to define a group of trees representative of a localized segment of the stand. Average stand breast-high age and total height are estimated from measurements of five to eight dominant redwood included in the group of trees at each location. Application of these averages to the site index curves or tables gives the site index of the plot. As an example, if average breast-high age is 45 years, and the average total height of dominants is 100 feet, by interpolation in table 1 or figure 5 a site index of 161 is indicated. Realignment of the site-height data shown in the appendix (table 24 and figure 12) provides

TABLE 1
AVERAGE TOTAL HEIGHTS OF DOMINANT REDWOOD BY BREAST-HIGH AGE AND SITE INDEX

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

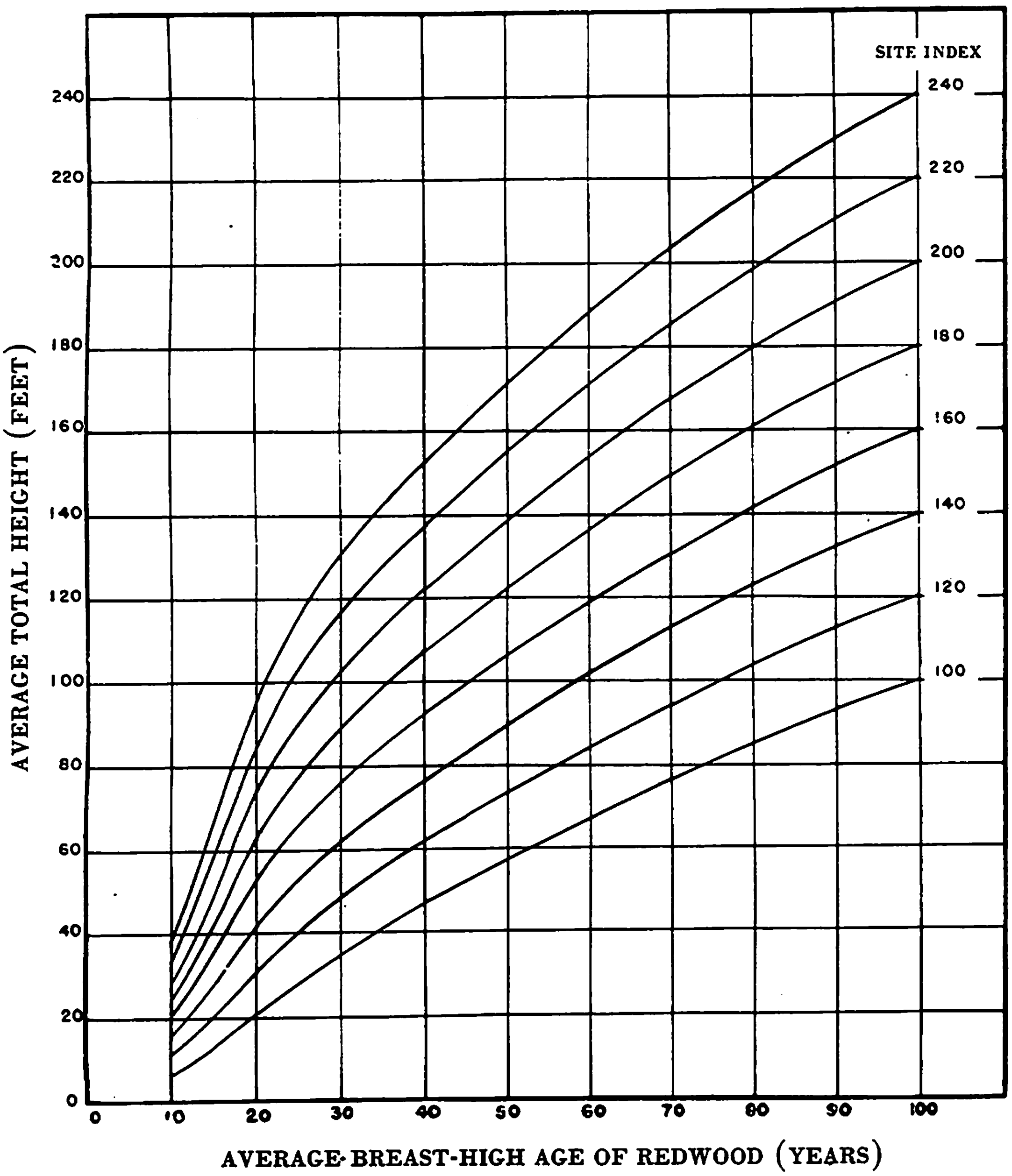

Fig. 5. Site index values of dominant redwood by height and breast-high age class.

a more convenient means of estimating site index.

Breast-high expression of the average stand age of young-growth redwood is appropriate because stump-sprouts show extremely rapid juvenile height growth and often exceed breast-height (4.5 feet) during the first growing season. Sprout-origin trees often develop as the dominant trees of the maturing stand. In this way, breast-high and total age are often the same. Restriction of the total height measurement to dominant trees makes estimates of average stand total height more clearly defined. There is less room for subjective factors to operate when only dominants are used as site-indicator trees.

YIELD TABLE CONSTRUCTION

Procedures for graphical development of the yield tables and curves followed, in general, recommendations made for the construction of normal yield tables (Bruce and Schumacher, 1935). Departure from this prescribed plan was necessary for elimination of the abnormally stocked stands. Bruce and Schumacher recommend that elimination of these plots be made on the basis of deviations from a curve of the logarithm of number of trees per acre over average stand diameter. Estimates of number of trees per acre made from point sampling procedures have been shown to be more variable than are estimates of the total basal area (Palley and O'Regan, 1961). Consequently estimates of frequency of these stands were assumed to be less reliable than estimates of basal area. Therefore, rejection of plots was based on the deviations of the actual basal area from the estimate of basal area from preliminary basal area curves (Chapman and Demeritt, 1936). The basic principle underlying the technique for developing these yield tables is the recognition of the variability of stand characteristics that may be associated with stand age. This variability, if inherent in the data, is made apparent through the calculation of the standard deviation and the coefficient of variation for each age class. If curves of these two statistics are dependent on age, yield tables which incorporate this technique result in more accurate estimates than those made from anamorphic harmonized curves. A further requirement for the appropriate use of this method is that the independent variables, age and site index, be not correlated. This data reveals no correlation between these two independent variables.

The first step in the reduction of the sample data to yield tables is the assignment of a site index to each sampled stand. The site index provides a relative measure of the yield capacity of each area and functions as the basis, along with age, for the classification of the samples. Preliminary basal area per acre curves, based on age and site class, were constructed for elimination of the abnormally stocked samples. Samples whose total actual basal area per acre differed from the curve estimate by more than two standard errors of estimate, computed for each site class, were rejected from consideration in the final set of curves. Seven of the 161 stand samples used in the preparation of site index tables were rejected on this basis, and two samples slightly older than 100 years were also eliminated. Distribution of the stands by basal area and site index are shown in appendix table 20.

Yield tables for the portion of the stand 4.5 inches and larger in diameter at breast-height were made by direct graphical curving of the sample plot data. Selection of the minimum tree diameter of 4.5 inches at breast-height as the basis for defining the cubic-foot volume stand was a decision made to restrict the sampling and calculation to the more economically valuable trees. Trees smaller than this diameter limit contribute little to the overall stand volumes and under most circumstances are not of commercial importance. Tables relative to the stand larger than 10.5 inches in diameter were constructed through the application of ratio conversions, associated with average diameter, to the table values of the cubic-foot stand. Values of stand characteristics represented in the tables are the expected gross per acre yields including all species, and do not consider loss factors such as decay, defect, and breakage. Adjustments of the gross yields must be made based on individual situations if estimates of net yield are required.

YIELDS OF STANDS LARGER THAN 4.5 INCHES IN DIAMETER

Basal area per acre (table 2, figure 6) displays a continuing growth throughout

TABLE 2

TOTAL BASAL AREA PER ACRE (SQUARE FEET), TREES OF ALL SPECIES OVER 4.5 INCHES DBH

Age (years)	Site index 100	120	140	160	180	200	220	240
20........	50	75	103	140	191	246	300	356
30........	86	122	162	216	288	367	444	525
40........	127	169	217	280	365	458	549	644
50........	176	218	266	330	416	509	600	696
60........	224	267	315	379	466	559	652	748
70........	264	307	355	419	506	599	692	788
80........	299	342	390	454	541	634	727	823
90........	334	377	425	489	576	669	762	858
100........	364	407	455	519	606	699	792	888

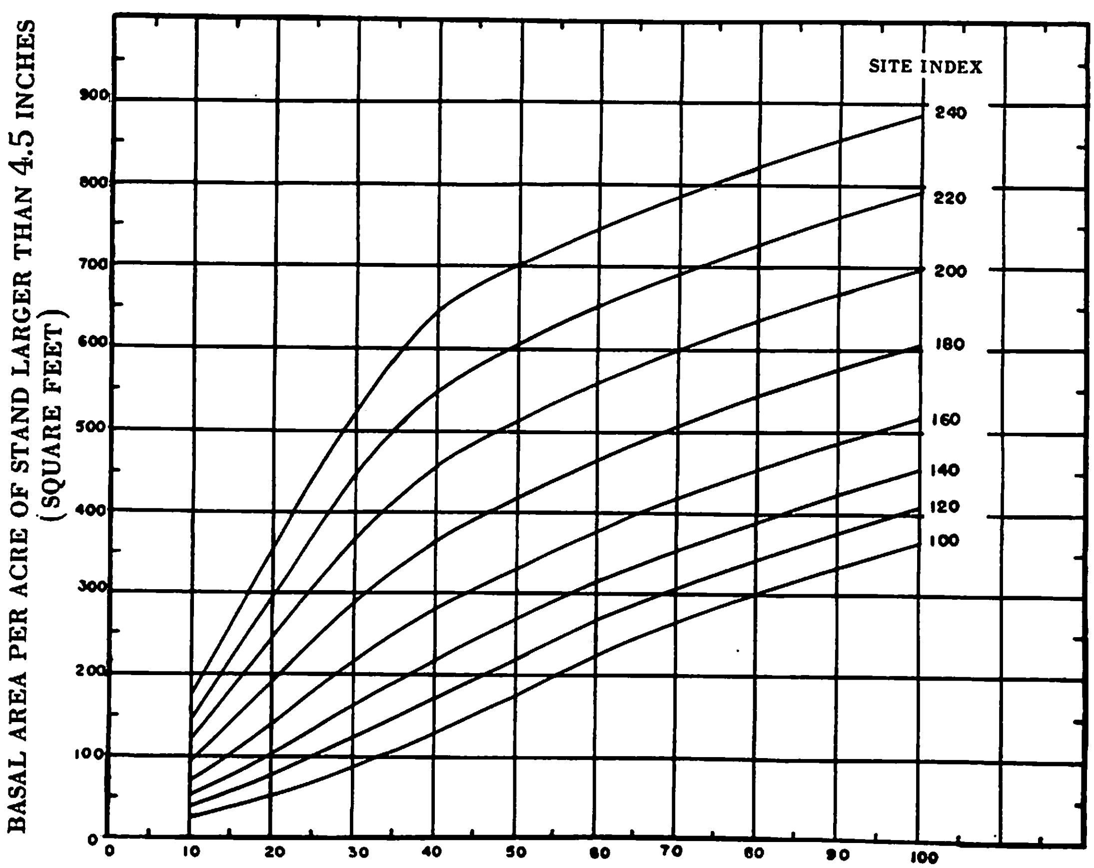

Fig. 6. Basal area per acre of young-growth redwood stands, trees of all species more than 4.5 DBH (diameter at breast height).

TABLE 3

BASAL AREA PER ACRE PERIODIC ANNUAL INCREMENT (SQUARE FEET), TREES OF ALL SPECIES OVER 4.5 INCHES DBH

Age period (years)	Site index							
	100	120	140	160	180	200	220	240
20–30	3.6	4.7	5.9	7.6	9.7	12.1	14.4	16.9
30–40	4.1	4.7	5.5	6.4	7.7	9.1	10.5	11.9
40–50	4.9	4.9	4.9	5.0	5.1	5.1	5.1	5.2
50–60	4.8	4.9	4.9	4.9	5.0	5.0	5.2	5.2
60–70	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
70–80	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
80–90	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
90–100	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

TABLE 4

DIAMETER (INCHES) OF TREE OF AVERAGE BASAL AREA, TREES OF ALL SPECIES OVER 4.5 INCHES DBH

Age (years)	Site index							
	100	120	140	160	180	200	220	240
20	7.6	8.7	9.3	10.1	10.8	11.5	12.1	12.6
30	9.6	11.1	12.4	13.7	14.8	15.8	16.7	17.4
40	11.3	13.0	14.6	16.2	17.6	18.8	19.8	20.7
50	12.7	14.6	16.4	18.2	19.7	21.0	22.2	23.2
60	14.1	16.2	18.0	19.9	21.6	23.0	24.2	25.3
70	15.5	17.6	19.4	21.4	23.1	24.5	25.9	27.0
80	16.8	18.9	20.8	22.8	24.5	26.0	27.4	28.5
90	18.1	20.2	22.2	24.1	25.8	27.3	28.7	29.8
100	19.4	21.5	23.3	25.2	27.0	28.4	29.8	31.0

TABLE 5

NUMBER OF TREES PER ACRE OVER 4.5 INCHES DBH, TREES OF ALL SPECIES

Age (years)	Site index							
	100	120	140	160	180	200	220	240
20	159	180	219	251	298	342	377	414
30	170	182	194	211	240	269	291	316
40	182	184	186	195	216	238	257	275
50	200	187	181	182	196	212	223	237
60	207	186	178	175	183	194	204	214
70	202	182	173	168	174	183	189	198
80	194	175	165	160	165	172	177	186
90	186	169	158	154	159	164	170	177
100	177	162	153	149	152	159	164	169

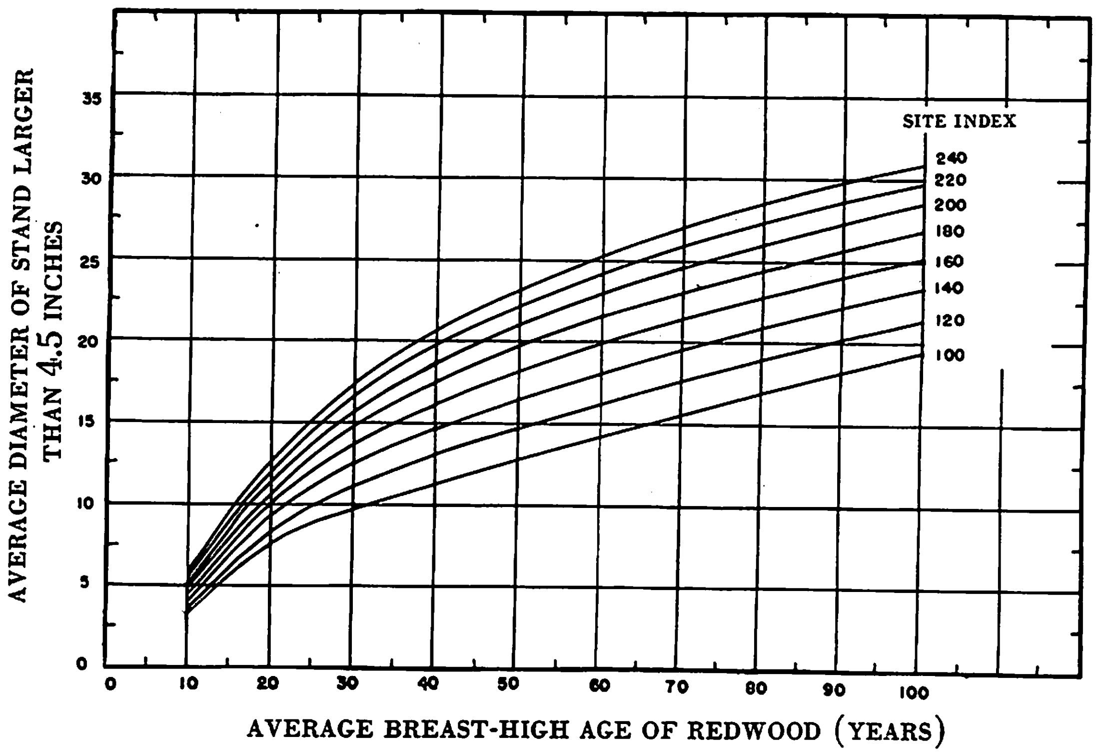

Fig. 7. Diameter of tree of average basal area, trees of all species more than 4.5 inches DBH.

the entire age range of these tables. This is in contrast to previous yield-table studies (Bruce, 1923) which show that basal area yield is nearly at a maximum at 60 years of age. The present curves of basal area, for all site-index classes, reach a uniform growth rate at 60 years resulting in parallel yield curves and uniform periodic annual growth rate beyond that age for all site indices (table 3). Indications from these curves are that redwood stands attain higher basal area per acre yields and sustain a larger growth rate for longer periods of time than formerly believed for young-growth stands.

Average diameter for an age-site class (table 4, figure 7) reflects the diameter of the tree of average basal area. Calculation of this stand characteristic depends on estimates of the basal area and number of trees per acre. Because of the variability associated with estimates of number of trees per acre made from point samples, errors in estimates of frequency may be reflected in the estimates of average diameter. The curves are steep up to 20 years of age, due in part to the use of only trees larger than 4.5 inches, the most vigorous trees of a young stand. Between 20 and 30 years the radial growth begins to drop off rapidly in the higher sites. The lower sites sustain a more gradual and uniform reduction in growth rate up to 100 years of age.

Numbers of trees per acre exceeding 4.5 inches in diameter (table 5) were developed from the yield tables of total basal area and average diameter. Calculation of number of trees for each age-site class in this manner has resulted in these three tables being compatible in that two of the tables will define the third. The configuration of these curves indicates that number of trees does not respond to age and site as do the other stand characteristics which increase with site and age. This is due to reduction, by mortality, as the age increases, of the large number of stems established initially in the stands. The restriction to a minimum diameter limit introduces ingrowth as an influence on the number of trees occurring in the earlier years of the stand development.

Rapid radial growth in the site classes greater than 120 has resulted in most trees exceeding 4.5 inches by 20 years, thus there is a continuing reduction in number of trees for these site classes over the entire age range of the tables. Maximum frequency is not reached in site classes 120 and below until 50 to 60 years, indicating that ingrowth of trees beyond the minimum diameter exceeds the mortality on these lower sites. At 100 years the drop in number of trees per acre, as site index increases, is reversed above site index 160 showing number of trees increasing with site index. This reversal in trend is undoubtedly due to improvement of environmental conditions which allows the suppressed trees to continue in the stand.

Yield volumes of cubic-foot volume (table 6 and figure 8) of the stand exceeding 4.5 inches in diameter have a uniform shape, with no abrupt change in slope apparent except for the lower site classes below 40 years of age. This uni-

TABLE 6

CUBIC-FOOT VOLUME PER ACRE YIELDS, TREES OF ALL SPECIES OVER 4.5 INCHES DBH, TO A 4 INCH TOP INSIDE BARK ABOVE A 1.5 FOOT STUMP

Age (years)	Site index							
	100	120	140	160	180	200	220	240
20	200	450	1,000	2,270	3,990	5,910	7,860	9,940
30	500	1,050	2,500	4,400	7,040	10,000	13,000	16,200
40	1,000	2,300	4,500	7,250	10,550	14,250	18,000	22,000
50	2,100	3,800	6,800	10,100	14,060	18,500	23,000	27,800
60	3,600	5,820	9,220	12,960	17,450	22,480	27,580	33,020
70	5,200	8,000	11,750	15,880	20,820	26,380	32,000	38,000
80	6,900	10,140	14,190	18,640	23,990	29,980	36,060	42,540
90	8,800	12,260	16,580	21,340	27,050	33,450	39,940	46,860
100	10,600	14,280	18,880	23,940	30,010	36,820	43,720	51,080

TABLE 7

CUBIC-FOOT PERIODIC ANNUAL INCREMENT, TREES OF ALL SPECIES OVER 4.5 INCHES DBH

Age period (years)	Site index							
	100	120	140	160	180	200	220	240
20–30	30	60	150	213	305	409	514	626
30–40	50	125	200	285	351	425	500	580
40–50	110	150	230	285	351	425	500	580
50–60	150	202	242	286	339	398	458	522
60–70	160	218	253	292	337	390	442	498
70–80	170	214	244	276	317	360	406	454
80–90	190	212	239	270	306	347	388	432
90–100	180	202	230	260	296	337	378	422

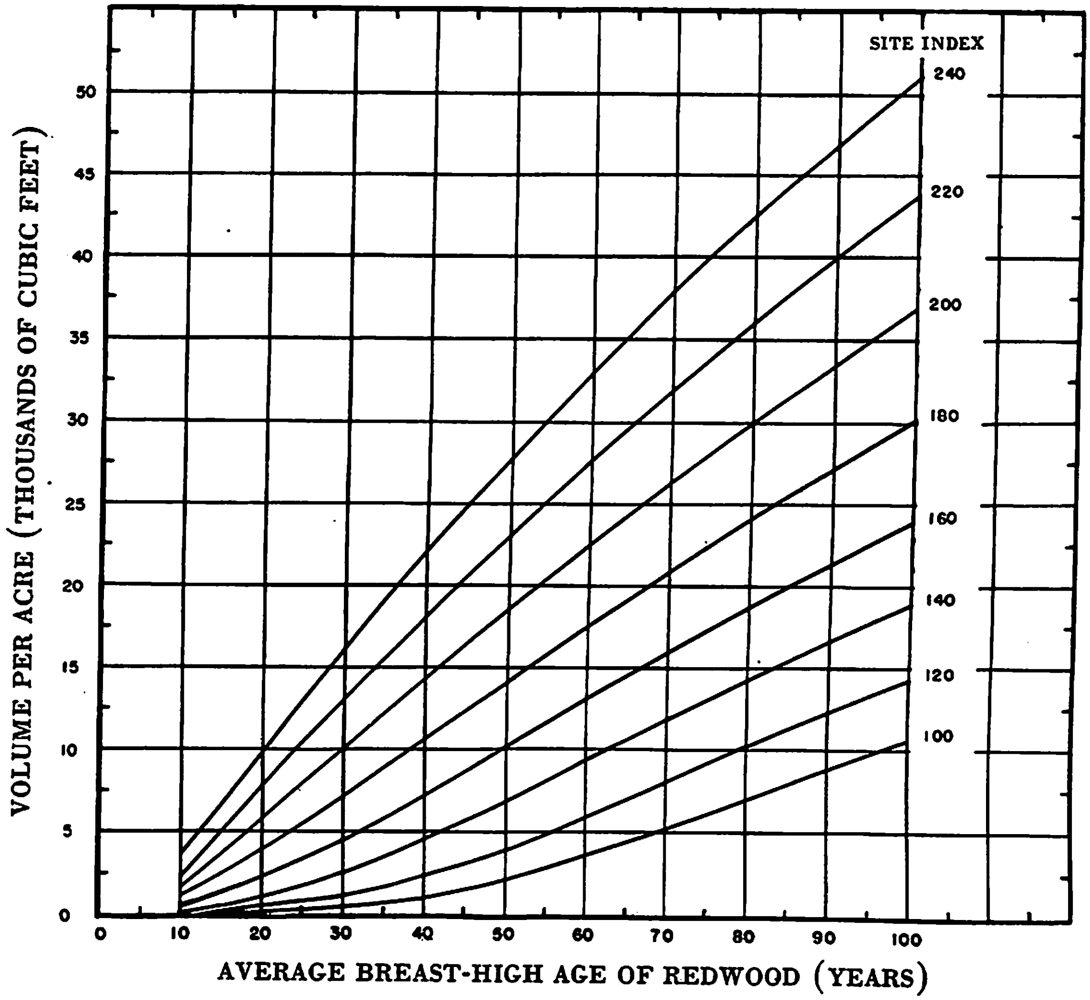

Fig. 8. Cubic-foot volume per acre of young-growth redwood stands, trees of all species more than 4.5 inches DBH.

TABLE 8

CUBIC-FOOT MEAN ANNUAL INCREMENT, TREES OF ALL SPECIES OVER 4.5 INCHES DBH

Age (years)	Site index							
	100	120	140	160	180	200	220	240
20........	10.0	22.5	50.0	113.5	199.5	295.5	393.0	497.0
30........	16.6	35.0	83.2	146.2	234.4	333.0	432.9	539.5
40........	25.0	57.5	112.5	181.2	263.7	356.2	450.0	550.0
50........	42.0	76.0	136.0	202.0	281.2	370.0	460.0	556.0
60........	59.8	96.6	153.0	215.1	289.7	373.2	459.8	548.1
70........	74.4	114.4	168.0	227.1	297.7	377.2	457.6	543.4
80........	86.2	126.8	177.4	233.0	299.9	374.8	450.8	531.8
90........	97.7	136.1	184.0	236.9	300.2	371.3	443.3	520.1
100........	106.0	142.8	188.8	239.4	300.1	368.2	437.2	510.8

formity of slope, of a given site class, on either side of the age of the culmination of the periodic annual increment indicates a broad range of ages from which rotation age could be selected if viewed exclusively from the point of yield and growth. Periodic annual increment (table 7) has culminated for all site classes prior to 100 years, this age occurring earlier as site index increases. Mean annual increment (table 8) does not culminate for site indices below 180 until after 100 years; in the higher classes this age varies from approximately 45 years (site 240) to 95 years (site 180). The period of time until culmination and the flatness of the curves of mean annual increment suggest the possibility of longer rotations for this species if they are desired.

YIELDS OF STANDS LARGER THAN 10.5 INCHES IN DIAMETER

Tables for the stand 10.5 inches and larger in diameter represent the stand characteristics describing the board-foot stand. Utilization standards dictate an interest in the larger trees since they represent the portion of the stands that can be most economically harvested. Development of this series of tables and curves was based on the tables of the corresponding characteristics of the stand larger than 4.5 inches in diameter, the cubic-foot stand, rather than on an independent curving of the plot data using this larger diameter limit. The technique for developing tables of segments of stands (Bruce, 1926) was used to create average diameter and basal area tables for the board-foot stand. This procedure utilizes the ratio of the measurements of the board-foot stand to cubic foot stand, expressed as a percentage, plotted over the average diameter of the cubic-foot stand. This curve expresses the percentage by which the smaller diameter values at each age-site class are corrected to give board-foot stand values. The shape of the curves expressing this percentage is usually sigmoid, reaching 100 per cent at the larger diameters where the characteristics of the two stands are the same. This identity was found in the larger average diameter classes when all trees had exceeded the 10.5-inch diameter limit and both stand structures contained the same trees. Yield table values of stand characteristics of the two stand segments became progressively closer as the age of the stand increased.

TABLE 9

BASAL AREA PER ACRE (SQUARE FEET), TREES OF ALL SPECIES OVER 10.5 INCHES DBH

Age (years)	Site index							
	100	120	140	160	180	200	220	240
20........	11	31	57	90	135	192	243	299
30........	51	91	134	190	262	341	420	503
40........	97	145	196	262	350	445	538	634
50........	148	198	250	318	407	503	595	692
60........	199	250	303	371	461	556	651	748
70........	244	295	347	414	503	598	692	788
80........	283	333	384	451	540	634	727	823
90........	322	371	421	487	576	669	762	858
100........	356	402	453	519	606	699	792	888

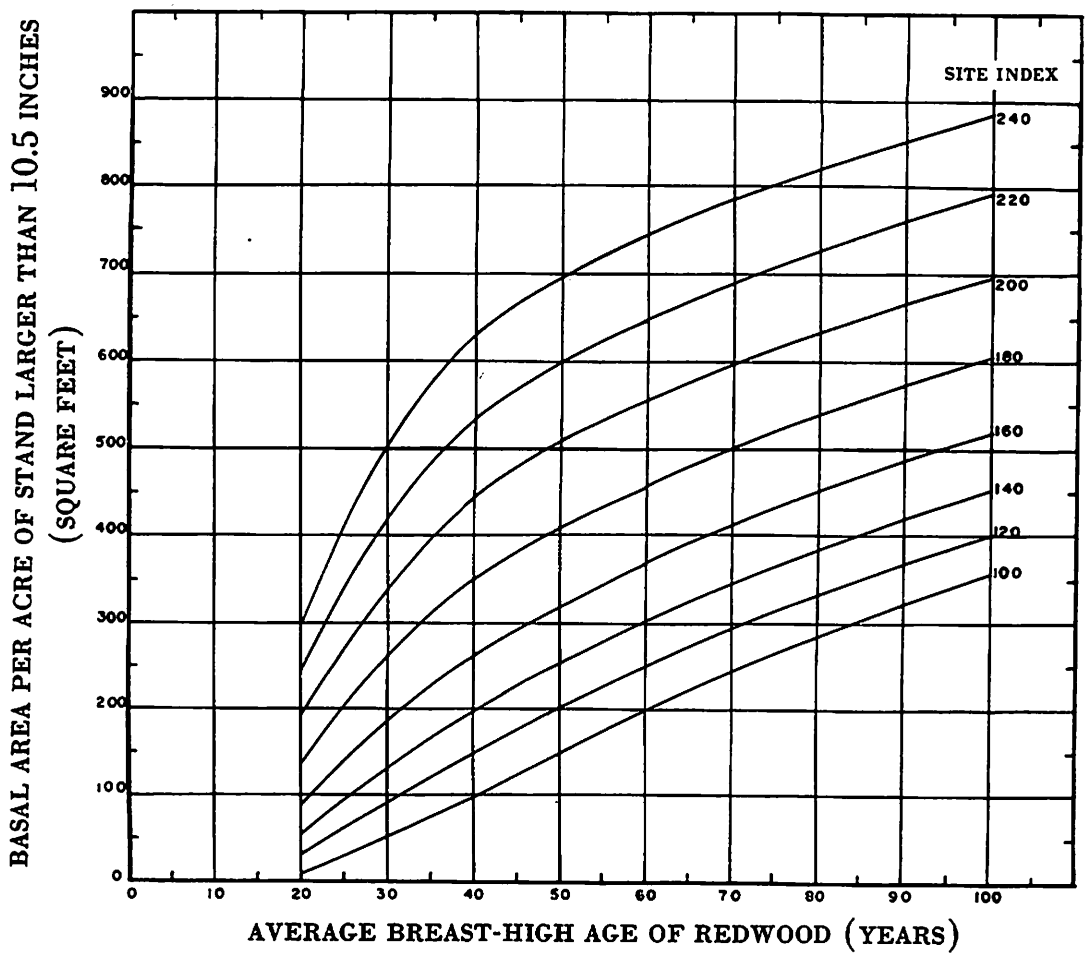

Fig. 9. Basal area per acre of young-growth redwood stands, trees of all species more than 10.5 inches DBH.

Basal area curves of the board-foot stand (table 9, figure 9) have a shape similar to those of the whole stand. The principal difference lies in the younger age classes for which basal area of this portion of the stand is less than for the stand defined by the smaller diameter limit. This difference, for a given site class, becomes less as the age increases. As site index increases, the age at which the two stands have equal basal areas is reduced; i.e., site index 160, 100 years; site index 200, 80 years; and site index 240, 60 years. Periodic annual growth (table 10) of this portion of the stand experiences more rapid growth during the earlier years; this growth rate gradually drops and finally equals that of the cubic-foot stand.

Since average diameter of the board-foot stand is derived from trees which have exceeded 10.5 inches in diameter, average diameter at a given age-site class is larger than that of the cubic-foot stand during the years where ingrowth is occurring. From the age at which all trees of the stand have exceeded the board-foot diameter limit the two stand segments have similar average diameter curves. As in the basal area curves the age at which the two average diameter curves of a given site index coincide becomes less as site increases. The result of this larger diameter limit on the configuration of the

TABLE 10

BASAL AREA PER ACRE PERIODIC ANNUAL INCREMENT, TREES OF ALL SPECIES OVER 10.5 INCHES DBH

Age period (years)	Site index							
	100	120	140	160	180	200	220	240
20–30......	4.0	6.0	7.7	10.0	12.7	14.9	17.7	20.4
30–40......	4.6	5.4	6.2	7.2	8.8	10.4	11.8	13.1
40–50......	5.1	5.3	5.4	5.6	5.7	5.8	5.7	5.8
50–60......	5.1	5.2	5.3	5.3	5.4	5.3	5.6	5.6
60–70......	4.5	4.5	4.4	4.3	4.2	4.2	4.1	4.0
70–80......	3.9	3.8	3.7	3.7	3.7	3.6	3.5	3.5
80–90......	3.9	3.8	3.7	3.6	3.6	3.5	3.5	3.5
90–100.....	3.4	3.1	3.2	3.2	3.0	3.0	3.0	3.0

yield curves of board-foot average diameter is much flatter curves, and consequently smaller growth rates than for curves of the cubic-foot stand during the early years of the stand development (table 11).

The number of trees per acre larger than 10.5 inches (table 12) for each age-site class was derived from the yield table values of total basal area and average diameter of the board-foot stand, and reflects the number of trees of average tree basal area. Similarity of the frequencies for the older-age and higher-site classes of the board- and cubic-foot stands has resulted from the development of the basal area and average diameter values of the board-foot stand from similar tables of the cubic-foot stand. This agreement in tree numbers occurs at such time as all the trees of the stand have exceeded 10.5 inches. Increased site index results in a younger age at which the two stand segments correspond. The longer period

TABLE 11

DIAMETER (INCHES) OF TREE OF AVERAGE BASAL AREA, TREES OF ALL SPECIES OVER 10.5 INCHES DBH

Age (years)	Site index							
	100	120	140	160	180	200	220	240
20...............	12.2	13.1	13.8	14.4	14.9	15.4	15.8	16.1
30...............	14.0	15.1	16.0	16.8	17.5	18.1	18.8	19.4
40...............	15.2	16.4	17.3	18.4	19.5	20.4	21.2	21.9
50...............	16.1	17.3	18.6	20.0	21.1	22.1	23.1	23.8
60...............	17.1	18.4	19.8	21.3	22.6	23.6	24.6	25.4
70...............	17.9	19.5	20.8	22.4	23.7	24.8	25.9	27.0
80...............	18.9	20.5	22.0	23.5	25.0	26.0	27.4	28.5
90...............	19.9	21.5	23.1	24.5	25.8	27.3	28.7	29.8
100..............	20.8	22.5	23.9	25.3	27.0	28.4	29.8	31.0

Table 12

NUMBER OF TREES PER ACRE, OVER 10.5 INCHES DBH, TREES OF ALL SPECIES

Age (years)	Site index							
	100	120	140	160	180	200	220	240
20........	14	33	55	80	112	148	178	211
30........	48	73	96	123	156	191	218	245
40........	77	99	120	142	169	196	220	242
50........	105	121	132	146	168	189	204	224
60........	126	135	142	150	166	183	197	213
70........	140	142	147	151	164	178	189	198
80........	145	145	145	150	158	172	177	186
90........	149	147	145	149	158	164	170	177
100........	151	146	145	149	152	159	164	169

of time necessary for trees to exceed the larger diameter limit causes the point of maximum number of trees to occur at an older age than for the cubic-foot stand, where for most site classes this maximum is reached prior to 20 years of age. The number of trees per acre prior to the age of culmination reflects changes in the stand in which ingrowth beyond the diameter limit exceeds loss, subsequent to this age the pattern is reversed and mortality is predominant.

Yield table values of board-foot volume for trees over 10.5 inches show gross stand volumes of all species by International ¼ inch rule to an 8 inch top DIB and a 1.5 foot stump. The board-foot volumes, as calculated from the original plot data, were not plotted and curved directly to develop these tables. Instead the board-foot to cubic-foot volume ratio, computed for each stand sample, was tabulated by diameter class and plotted over the average diameter of the cubic-foot stand to develop volume ratio site index curves (table 13). Average diameter curves, which depend on age and site-index classes, were used to determine the volume ratio at a given diameter-site class; this is the volume ratio conversion factor of the corresponding age-site class. Board-foot volumes were computed by applying the conversion factor of each age-site class to the corresponding volumes of the cubic-foot stand. The board-foot volume yield tables represent a collation of information from yield curves of cubic-foot volumes, average diameter, and volume ratio; and are only indirectly related to the computed board-foot volumes of the stand samples.

Yield table values of board-foot volumes indicate a relatively uniform progression, with stand volumes rising uniformly up to and beyond the age of growth culmination (table 14, figure 10). Periodic annual increment has not culminated for site classes 100 and 120 by 100 years, but has clearly done so for the higher site classes (table 15). The reduction in the growth rate is slight subsequent to the age of maximum periodic annual growth. Mean annual increment of the board-foot volume (table 16) does not culminate prior to 100 years except for site index classes exceeding 200. The earliest age of culmination of volume growth is approximately 70 years for site class 240. As in the case of the cubic-foot volume there is here an indication of the possibility of longer rotations for maximization of volume yields since

TABLE 13

BOARD-FOOT/CUBIC FOOT VOLUME RATIO, (BOARD-FOOT VOLUMES BY INT. ¼" RULE FOR TREES OVER 10.5 INCHES, CUBIC FOOT VOLUME FOR TREES OVER 4.5 INCHES IN DIAMETER)

Ave. diameter (inches)	Site index							
	100	120	140	160	180	200	220	240
8	.46	.80	1.19	1.54	1.85	2.02	2.30	2.45
10	2.11	2.40	2.72	3.02	3.28	3.43	3.66	3.79
12	3.12	3.64	3.64	3.89	4.11	4.24	4.43	4.54
14	3.98	4.16	4.36	4.55	4.71	4.80	4.95	5.03
16	4.53	4.69	3.87	5.04	5.19	5.27	5.40	5.47
18	4.99	5.14	5.31	5.46	5.59	5.67	5.78	5.85
20	5.34	5.48	5.63	5.77	5.89	5.96	6.07	6.12
22	5.60	5.74	5.88	6.02	6.14	6.20	6.31	6.37
24	5.88	6.01	6.15	6.27	6.39	6.45	6.55	6.60
26	6.07	6.19	6.32	6.45	6.56	6.62	6.71	6.77
28	6.22	6.34	6.46	6.58	6.68	6.74	6.83	6.88
30	6.34	6.45	6.57	6.68	6.78	6.84	6.92	6.97
32	6.45	6.56	6.68	6.78	6.88	6.93	7.02	7.07
34	6.56	6.66	6.78	6.89	6.98	7.03	7.12	7.16
36	6.67	6.77	6.88	6.99	7.08	7.13	7.21	7.26

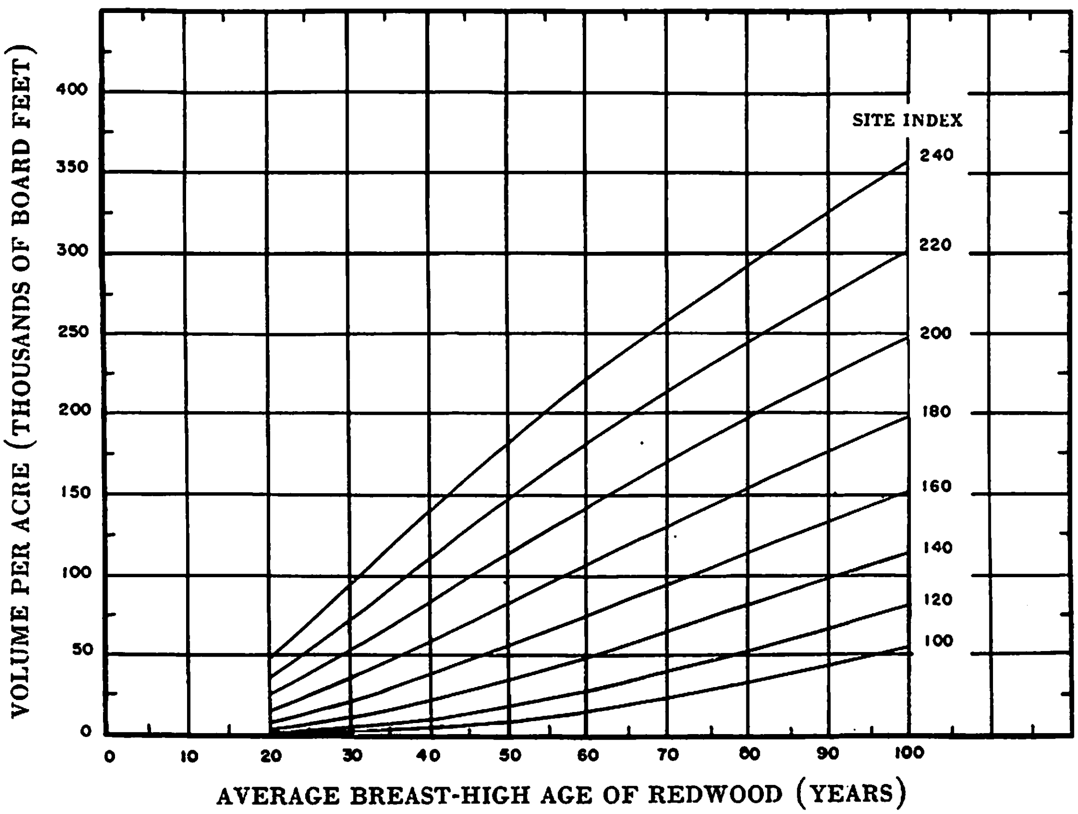

Fig. 10. Board-foot volume per acre of young-growth redwood stands, trees of all species more than 10.5 inches DBH, International ¼ rule.

TABLE 14

BOARD-FOOT VOLUME PER ACRE YIELDS, TREES OF ALL SPECIES OVER 10.5 INCHES DBH (INT. ¼" RULE), TO 8 INCH TOP INSIDE BARK ABOVE 1.5 FOOT STUMP

Age (years)	Site index (feet)							
	100	120	140	160	180	200	220	240
20	...	600	2,300	7,000	14,500	23,900	35,000	46,500
30	900	3,100	9,500	19,600	34,500	52,300	71,600	93,200
40	2,800	8,800	20,400	36,900	57,900	82,100	108,700	137,500
50	7,300	16,500	33,700	55,300	82,000	112,700	146,000	181,300
60	14,400	27,400	48,900	74,500	106,100	142,100	180,900	221,900
70	22,800	40,400	65,000	94,500	130,400	170,900	214,400	259,500
80	32,400	53,700	81,500	114,300	153,500	198,200	244,800	293,500
90	44,000	67,400	98,300	133,800	176,400	224,100	273,600	325,700
100	55,760	81,300	114,600	152,300	198,100	248,500	301,700	357,600

TABLE 15

BOARD-FOOT PERIODIC ANNUAL INCREMENT, TREES OF ALL SPECIES, OVER 10.5 INCHES DBH

Age period (years)	Site index							
	100	120	140	160	180	200	220	240
20–30	...	250	720	1,260	2,000	2,840	3,660	4,670
30–40	190	570	1,090	1,730	2,340	2,980	3,710	4,430
40–50	450	770	1,330	1,840	2,410	3,060	3,730	4,380
50–60	710	1,090	1,520	1,920	2,410	2,940	3,490	4,060
60–70	840	1,300	1,610	2,000	2,430	2,880	3,350	3,760
70–80	960	1,330	1,650	1,980	2,310	2,730	3,040	3,400
80–90	1,160	1,370	1,680	1,950	2,290	2,590	2,880	3,220
90–100	1,176	1,390	1,630	1,850	2,170	2,440	2,819	3,190

TABLE 16

BOARD-FOOT MEAN ANNUAL INCREMENT, TREES OF ALL SPECIES OVER 10.5 INCHES DBH

Age (years)	Site index							
	100	120	140	160	180	200	220	240
20	..	30	115	350	725	1,195	1,750	2,325
30	30	103	316	653	1,149	1,742	2,384	3,104
40	70	220	510	922	1,448	2,052	2,718	3,438
50	146	330	674	1,106	1,640	2,254	2,920	3,626
60	239	455	812	1,237	1,761	2,359	3,003	3,684
70	326	578	929	1,351	1,865	2,444	3,066	3,711
80	405	671	1,019	1,429	1,919	2,478	3,060	3,669
90	488	748	1,091	1,485	1,958	2,487	3,037	3,615
100	556	813	1,146	1,523	1,981	2,485	3,017	3,576

growth is not grossly affected by increasing age. In addition, because the mean annual and periodic annual growth rates are maintained at a high and relatively uniform level over an extended period of time the selection of rotation age may be exercised over a number of years. This makes consideration of factors other than those strictly associated with volume productivity of the site more feasible.

APPLICATION OF YIELD TABLES

Some general observations on these yield tables relative to the prediction of future yields are appropriate for pointing out important features of their application to actual stands. Of particular importance to bear in mind is that the basis for these tables were undisturbed, even-aged, unmanaged young-growth redwood stands. Consequently these tables are representative of stands within the range of conditions found in the sample data. It is not deemed appropriate to adjust estimates of the future yield on the basis of current basal area. Attempts to use the tables on stands which show evidence of disturbance or mixed old- and young-growth might result in errors in estimated yields. Estimation of current stand volumes from these tables is not recommended as a cruising aid because of the inherent variability of the yields used to make these tables. The tables may be applied to mixed stands provided that redwood comprises more than 50 per cent of the stand by basal area, the user must assume that species composition will remain the same as at present.

Yield values for the various stand characteristics, shown by age and site classes in the tables, are to be estimated from actual stand conditions using an estimate of mean stand site index at a given future age. It is therefore appropriate to consider the estimate of the stand site index in terms of the average of several such stand observations. A single estimate within the stand would not likely be an adequate definition of the average stand site index. The stand sample to estimate site index may be established by means of either fixed boundary plots or point samples, since they are used only as a device to define a group of trees in a localized segment of the stand. Estimates of the average stand breast-high age and total height should be made from measurements of five to eight dominant redwood included in each sample plot. The site index estimate is made from the average age and total height observations by application to the site index curves. When using these tables one should bear in mind that the yield values are in terms of average breast-high age of dominant trees, not total age, thus no correction in age is necessary for stump height, also, the tables show per-acre gross yields including all species.

When assessing future productivity of young-growth redwood land it is necessary to consider the size and stand complexity of the forest property. Sampling units should be distributed in a manner to secure several site index estimates that are representative of the entire property. This may be done by a plan that distributes the sample plots over the property. Where the property acreage is large, or age and site cover a wide variety of conditions, total productivity may best be estimated by sampling within several defined strata. Delineation of the strata on type maps or aerial photographs is helpful in planning the sampling system for each stratum and provides necessary estimates of strata acreages. For example, it may be desirable to base these site index classes on soil and topographic conditions, with two or three broad age classes in each site class. Where the acreage is small, or if the stands of the property are homogeneous in terms of age and site index, stratification of the property is not necessary.

Recommendation of the optimum number of sample plots necessary for an adequate representation of the mean site index of an entire property or stratum is difficult because of the variability that occurs within these young-growth stands. However, as a guiding principle the sampling should attempt to define the mean population site index with a high degree of precision since site index represents the sole basis for the prediction of the future yields from these tables. Site index is not sensitive to variations in stocking, except in cases of extreme over- or understocking, and therefore may function as a unit which combines the stands of various stocking densities associated within broad site classes. Assuming that the stands of the property have been stratified into relatively homogeneous tracts, site index samples within these strata should not define a wide range of values. This sample should be evaluated to determine the mean, standard deviation, and coefficient of variation of the observed site indices. These provide an estimate of the population mean, the dispersion of the observations about this mean, and the relative value of the standard deviation to the estimated mean. From this analysis it is possible to determine the number of plots necessary to meet requirements of a mean site index estimate plus or minus limits of acceptable error at a given level of confidence. The dependence on mean site index for the estimates of future yield makes it advisable to base the estimates of this value on a sufficient number of site index observations to insure estimates that are within 5 per cent of the population parameter at the 95 per cent level of confidence.

An example of the application of the yield tables presented in this bulletin, based on data taken from ten one-fifth acre permanent plots in a relatively homogeneous tract of young-growth redwood is summarized in table 17. The average breast-high age and average total height of each plot are based on measure-

TABLE 17

EXAMPLE OF PREDICTED PER ACRE STAND YIELDS AT 100 YEARS BREAST-HIGH AGE

Plot	Age	Ave. ht. dom.	Site index	Predicted plot values at 100 years			
				Basal area	Cubic ft volume	Ave. dia.	Board ft volume
	yrs	*ft*		*sq. ft*	*cu. ft*	*inches*	*int. ¼-inch*
1	37	92	166	545	25,761	25.7	166,040
2	34	83	160	519	23,940	25.2	152,300
3	19	43	150	487	21,410	24.7	133,450
4	17	40	156	506	24,446	24.8	144,600
5	33	88	170	562	26,975	26.1	275,200
6	30	92	176	588	28,802	26.6	188,940
7	20	56	166	545	25,761	25.7	166,040
8	35	72	143	465	19,639	23.6	120,250
9	34	86	165	541	25,457	25.6	163,750
10	35	95	175	584	28,497	26.5	186,700
Total	297	747	1,627	5,342	250,688	254.5	1,597,270
Average	29.7	74.7	162.7	534.2	25,068.8	25.45	159,727
Values using average site index			163	532	24,850	25.5	159,140

ments of five to eight dominant redwood. Estimates of site index, for each plot, were made by interpolation from either table 1 or figure 5 using average breast-high age and total height. Prediction of yield table values of each stand characteristic at 100 years was made under the assumption that site index does not change over the extended growth period. These predictions required only the estimate of current site index to interpolate the yield values at the terminal age. Making predictions on the basis of individual plots requires a considerable amount of interpolation to determine per acre average tract values at the future age. However, prediction of average tract values may be simplified by determining the mean site index of the plots, and applying this estimate to the yield table values at 100 years (see bottom line of table 17). Comparison of the average stand per acre estimates arrived at by the two procedures indicates little difference between the methods.

Calculation of the number of site index observations necessary for an estimate within plus or minus 5 per cent of the population mean at the 95 per cent degree of confidence from the ten site index values of table 17 indicates that nine plots would have been sufficient to meet these requirements. The coefficient of variation is the percentage ratio of the standard deviation to the mean of the site index observations. These values are determined as follows:

$$SD = \sqrt{\frac{\sum (X-\bar{X})^2}{N-1}}$$

$$= \sqrt{\frac{1010.10}{10-1}} = 10.58 \qquad (5)$$

$$CV = \frac{10.58}{162.7} \times 100.0\% = 6.5\% \qquad (6)$$

where:

X = Site index observations
SD = Standard deviation of site index observations
N = Number of observations
CV = Coefficient of variation

The required number of site observations have been derived from the formula:

$$n = \frac{CV^2 \times t^2}{d^2} = \frac{(6.5)^2 \times (2.26)^2}{(5)^2}$$

$$= 8.63 \text{ or } 9 \text{ plots} \qquad (7)$$

where:

t = the number of standard deviation for 95 per cent confidence and 9 degrees of freedom (2.26)
d = allowable error, as per cent of the mean (5 per cent)
n = calculated number of required observations

It should be pointed out that the application of these tables is different from that of normal yield tables. The use of normal yield tables for the prediction of future yields of stands requires an adjustment of the predicted values, often based on the percentage of the actual to the tabled value of basal area for that age and site index class. The present tables do not require adjustment of the estimates of the future volume yields. They are predicated on the increasingly prevalent idea that well-stocked stands over a fairly wide range of basal area densities produce about the same amount of volume growth (Johnson, 1955; Spurr, 1952).

In approximately one-third of the stands of young-growth sampled the redwood originated entirely from stump sprouts following the logging of the virgin stands. The spatial distribution of the redwood in these stands is concentrated near the old stumps causing localized areas of dense stocking, while the intervening areas between the stumps are unoccupied. While it is possible to attain very high basal area per acre figures, due to the many trees in these clumps, there is not the equitable distribution of stems that is implied in the definition of a fully stocked stand. For this reason the usual concept of normality does not fully satisfy the requirements of the expression of stocking in the undisturbed and unmanaged stands of this timber type. As a result it is appropriate to consider the basal area measurements as being representative of better stocked stands, and the yield table values as the average of those stands expressed in terms of age and site index.

The recommended procedure of using a group of site index observations of a homogeneous tract does not require estimates of stand basal area. Since adjustment of the yield table figures is not warranted it is not necessary to compare the actual and table estimates of stand basal area.

CONVERSION OF YIELD TABLE BOARD-FOOT VOLUMES TO SPAULDING RULE

Measurements of the total board-foot stand volume have been made using volume tables based on the International ¼ inch rule. This formula rule, which allows for taper within a four foot log segment, is most often used for work associated with growth studies. Customarily within the redwood region the board-foot volumes are in terms of the Spaulding log rule for young-growth trees or the Humboldt rule, which deducts 30 per cent of the Spaulding, for the old-growth timber. Consequently the board-foot volumes of the yield tables will often be converted to the log rules most commonly used in this region.

Recent volume tables for young-growth redwood give tree volumes for both the International ¼ rule and the Spaulding rule (appendix tables 27 and 28). These tables indicate that tree volumes by the Spaulding rule are less than by the International rule. Spaulding tree volumes when expressed as a percentage of the larger volume estimate become proportionally larger as the diameter of the tree increases, reaching approximately 100 per cent at a diameter of 50 inches, shown in figure 11. When dealing with stand-volumes, conversions based on this tree-volume curve are not entirely appropriate since stands are composed of trees covering a range of diameters.

The effect of diameter distribution occurring within a stand structure on the stand volume relationship of the two log rules is shown in figure 11. The curve of stand volume ratio was made from individual ratios of 27 remeasured permanent plots, whose board-foot volumes were calculated using both International and Spaulding volume tables. The average volume ratios of the stands have been plotted over the average diameter of the stand inventory of trees exceeding 10.5 inches. The difference between the stand- and tree-volume ratios which is most apparent in the smaller diameter classes is due to the range of diameters, and consequently tree ratios, within a stand structure. To

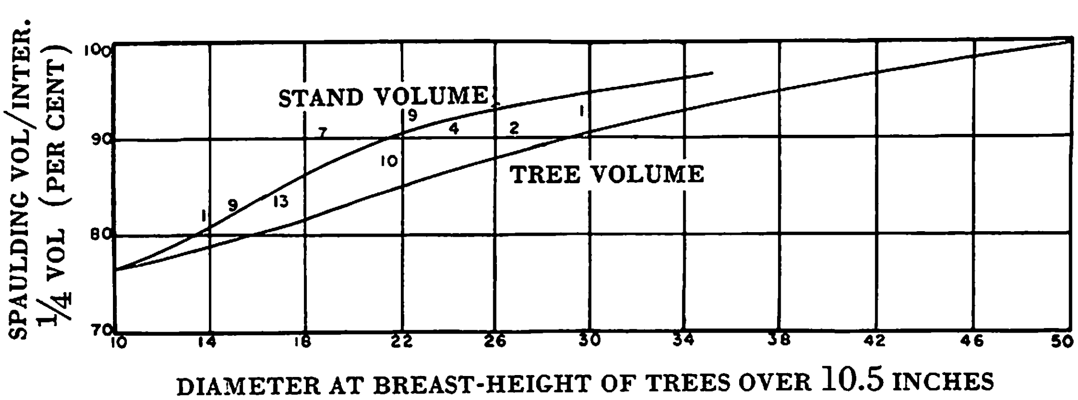

Fig. 11. Conversion of International ¼ rule volumes to Spaulding rule, volumes for trees and stands.

convert board-foot volumes of the yield tables to Spaulding rule it is necessary to determine the future average stand diameter of the stand over 10.5 inches. Application of this future stand diameter to the curve of stand volume ratios will estimate the percentage by which the yield table board-foot volumes must be adjusted. For example, the average diameter of trees over 10.5 inches at 100 years for site index 163 is 25.55 inches This diameter when applied to the stand volume ratio curve indicates that the Spaulding stand volume is approximately 92.7 per cent of the International stand volume. The average volume per acre (Spaulding Rule) at age 100 in the example of table 17 is: (.927) (159,140) = 147,523 board feet.

COMPARISON TO PREVIOUS STUDY

Reference has been made previously to the yield study of young-growth redwood made by Bruce in 1923 since it represents the only other existing yield investigation of this species. This early work was described as preliminary because of the limited age range, 60 years, and the lack of data from the poorer site index classes. Yield tables were developed from fully-stocked normal stands as a standard typical of yields that could be expected under management of this species. This management would include planting, or some other means of securing the full stocking of the stands, and proper care of the stands until maturity. Bruce found that this ideal condition rarely existed except in small restricted stands, and suggested artificial regeneration of the stands to realize maximum utilization of land productivity. During the intervening years since 1923 very little of the second-growth acreage has been put under any form of management and it is still necessary to deal with unmanaged naturally regenerated young-growth stands (Fritz, 1959).

It is difficult to make comparisons with the Bruce yield tables and draw conclusions because of the basic difference in the type of stands utilized as the basis for the studies. Furthermore, there are differences in the minimum size of tree included, volume tables and log rules, and construction techniques. The most apparent and important differences are the trends of yield and growth curves which begin to show at about 50 years of age. These trends indicate, in the Bruce study, that the stands experience a sharp decline in yield and growth, as in the case of basal area per acre which has nearly reached a maximum by 60 years. The trends of the present tables correspond closely with the Bruce results up to age 50, but from that point the present tables indicate a much higher growth rate. This difference in volume yields has importance when considered from the standpoint of culmination of mean annual growth, which often serves as the basis for determining the rotation age. The Bruce curves of mean annual board-foot increment reach their maximum at approximately 45 years. Culmination in this unit for the present study does not occur until at least 70 years of age, and in site index values less than 200 not before 100 years.

The range of basal area per acre values between Bruce's site class I and III is narrow relative to the present curves; this is also true for the cubic and board-foot volume yield curves. This would seem to indicate that the differences in yields of these stand characteristics does not depend on site index as strongly when dealing with fully-stocked stands as is the case with stands of the present study.

APPENDIX

Sample Data

DATA FOR THE CONSTRUCTION of the empirical yield tables presented in this study were obtained from measurements of the current inventory of 172 temporary point samples of young-growth redwood collected during the summers of 1958 and 1959. The selection of stands to sample was guided by a desire to encompass the conditions that occur in young-growth redwood stands.

Not all samples established were utilized for development of the yield tables, 20 of the 172 established samples were rejected. The rejection was accomplished in two stages: the first involved reasons related to the defined stand description; the second based on basal area deviations relative to the standard error of the basal area per acre deviations computed for each of the six site index classes. Basis for plot rejection and number of plots rejected are summarized as follows:

CAUSE OF REJECTION	NO. OF PLOTS
1. Residual old growth	4
2. Per cent of redwood (Less than 20%)	2
3. Missing data	3
4. Older than 100 yrs.	4
5. Abnormal stocking	7
TOTAL	20

Frequency distributions of the samples by the principal characteristics of site and stand show the result of the sampling plan and range of conditions encountered. Tables 18, 19, and 20 indicate the frequency distributions of the plots relative to the stand characteristics: basal area, age, and site index. Distribution of the samples by environmental factors of aspect, slope class, and soil parent material by site index classes is shown in tables 21, 22, and 23. Since site index is dependent on a variety of edaphic, climatic, and stand factors it is difficult to understand clearly the function and importance of each set of factors in determining the site index. The distributions in the tables show general trends of sample occurrence within the site index classes.

TABLE 18

FREQUENCY DISTRIBUTION OF SAMPLE POINTS BY BREAST-HIGH AGE AND SITE INDEX

Age at b. h. (years)	Site index						
	Over 200	181–200	161–180	141–160	121–140	101–120	Total
0–10	..	..	..	..	..	..	0
11–20	..	1	3	1	..	..	5
21–30	3	5	6	2	2	..	18
31–40	7	11	10	6	1	..	35
41–50	5	8	15	3	3	1	35
51–60	2	11	9	6	2	..	30
61–70	2	3	4	4	2	1	16
71–80	2	1	4	..	1	..	8
81–90	1	1	..	..	..	..	2
91–100	1	1	..	1	..	..	3
Total	23	42	51	23	11	2	152

TABLE 19

FREQUENCY DISTRIBUTION OF SAMPLE POINTS BY AGE CLASS AND BASAL AREA

Basal area (sq. ft.)	Age class										
	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-81	81-90	91-100	Total
0–100........	..	..	1	..	2	..	..	..	..	..	3
101–200........	..	5	8	7	3	1	1	..	..	..	25
201–300........	..	..	4	8	5	3	2	..	..	..	22
301–400........	..	..	3	12	9	11	7	3	..	..	45
401–500........	..	..	1	4	9	12	3	2	..	1	32
501–600........	..	..	1	3	5	..	2	2	1	1	15
601–700........	..	..	..	..	1	2	1	..	1	..	5
701–800........	..	..	..	1	..	1	..	1	..	1	4
over 800........	..	..	..	..	1	..	..	..	..	..	1
Total......	..	5	18	35	35	30	16	8	2	3	152

TABLE 20

FREQUENCY DISTRIBUTION OF SAMPLE POINTS BY BASAL AREA AND SITE INDEX CLASS

Basal area (sq. ft)	Site index class						
	Over 200	181-200	161-180	141-160	121-140	101-120	Total
0–100......	..	..	2	..	1	..	3
101–200......	1	3	10	7	3	1	25
201–300......	1	7	7	5	2	..	22
301–400......	5	12	17	6	4	1	45
401–500......	3	14	9	5	1	..	32
501–600......	6	4	5	..	..	..	15
601–700......	3	1	1	..	..	..	5
701–800......	3	1	..	..	..	..	4
over 800	1	..	..	..	..	..	1
Total....	23	42	51	23	11	2	152

TABLE 21

FREQUENCY DISTRIBUTION OF SAMPLE PLOTS BY ASPECT (CARDINAL DIRECTION) AND SITE INDEX CLASS

Site class	Aspect					Total
	North	East	South	West	Level	
1........	3	..	1	2	17	23
2........	6	4	11	9	12	42
3........	7	7	14	12	11	51
4........	4	4	6	4	5	23
5........	2	1	6	2	..	11
6........	1	..	..	1	..	2
Total.	23	16	38	30	45	152

TABLE 22

FREQUENCY DISTRIBUTION OF SAMPLE PLOTS BY SLOPE CLASS AND SITE INDEX CLASS

Site class	Slope class			Total
	0–10%	11–30%	Over 31%	
1.......	19	2	2	23
2.......	15	17	10	42
3.......	15	14	22	51
4.......	5	6	12	23
5.......	..	4	7	11
6.......	..	1	1	2
Total.	54	44	54	152

TABLE 23

FREQUENCY DISTRIBUTION OF SAMPLE PLOTS BY SOIL GROUPS AND SITE INDEX

Site class	Soil group			Total
	200	800	900	
1..	14	3	6	23
2..	7	18	17	42
3..	3	25	23	51
4..	1	14	8	23
5..	..	10	1	11
6..	..	1	1	2
Total....................................	25	71	56	152

Where 200 = Alluvial soils.
800 = Consolidated sandstone.
900 = Weakly consolidated material.

Site Index

Yield site index curves are designed to display changes of total height with age for selected site index classes which are represented as curved lines. This type of representation is valuable because it shows visually the development of total height and height growth with age. Despite the fact that the nature of this arrangement of the variables is one more appropriately suited for the estimation of height the most common application of these curves is for the estimation of site index from measurements of total height and age. Through a realignment of the axes the data shown in table 1 and figure 5 may be displayed in a manner that facilitates direct estimation of site index. The conversion of the data with site index as the dependent variable shows

Yield Table Checks

The efficiency of the tables to estimate stand characteristics was checked by testing the fit of the curves to the actual data from the field samples. This was accomplished by computing the aggregate differences and average deviations for each of four major stand characteristics (table 25). The aggregate differences express the difference between the total estimated and actual values of all plots as a percentage of the total actual value. This measure indicates how well the yield curves fit the sample from which the curves were constructed. Average deviations indicate the difference between the actual and estimated values of each individual plot expressed as a percentage of the estimated value, and is the sum of all individual deviations divided by the number of observations. The relatively close agreement between the estimated and the actual total values of the 152 sampled stands is shown by the small aggregate differences. Only in the case of board-foot volume does the aggregate difference exceed one per cent. The average deviations are high and in effect are a reflection of the variability of the original field measurements. Considering the broad field criteria of selecting stands and the leniency of plot rejection relative to the stocking, the high average deviations were not unexpected.

TABLE 25

AGGREGATE DIFFERENCES AND AVERAGE DEVIATIONS OF YIELD TABLE FROM THE ACTUAL PLOT DATA

Stand variable	Aggregate difference (per cent)	Average deviation (per cent)
Basal area (cubic-foot stand)	+ .48	28.4
Cubic-foot volume	+ .23	30.3
Board-foot volume	+2.11	31.4
Average diameter (cubic-foot stand)	− .70	37.5

Volume Tables

Stand volumes of young-growth redwood were computed using as the basis standard volume tables shown in tables 26 and 27. These tables were prepared as a separate study (Palley, 1959, 1961) from weighted multiple regression analysis of total height, diameter at breast height, and combinations and powers of the measurements as the independent variables. Scaled volumes of logs in terms of cubic-foot, International ¼ inch rule, and the Spaulding rule were the dependent variables for the least square solution of the formulas shown in the footnote of each volume table. The Spaulding volume table (table 28), not used for the calculation of the sample data, is shown here because of the widespread use of this rule in the redwood region.

Douglas-fir volume tables (table 5, cubic-feet; table 9, board-feet of Agriculture Handbook No. 92) were reduced to formulas by linear multiple regression analysis. Volumes from these tables of selected whitewood trees within the stand samples, and the dimensions of these trees provided the dependent and independent variables for the calculation of the following formulas;

Cubic-foot volume = $.00194D^2H + 1.37294D - .05245D^2 - 6.7903$

Board-foot volume = $.02467D^2H + 55.0921D - 1.9123H - 3.0057D^2 - 248.2895$
(Int. ¼ rule)

where: D = Diameter at breast-height
H = Total height

These formulas for whitewood and the redwood volume table formulas were the basis for the computation of tree volumes used for the development of local volume tables for each species group in each stand sample.

Local volume table constants for the calculation of the per acre hardwood volumes for all samples are as follows:

Cubic-foot volume = $.1354D^2 - 2.16$

Board-foot volume = $.698D^2 - 69.8$
(Int. ¼ rule)

(Tables 26, 27, 28 on following pages)

Table 26

MERCHANTABLE CUBIC-FOOT VOLUME TABLE FOR YOUNG-GROWTH REDWOOD

(*Sequoia sempervirens* (D. Don) Endl.)

Cubic foot Volume to a 4-inch Top Inside Bark

D.B.H. (inches)	Total height (feet) 20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	No. of trees
4		.3	.7	1.0	1.3														2
5	.4	.9	1.4	1.8	2.3														6
6	.9	1.6	2.2	2.9	3.6	4.2													2
7		2.3	3.1	4.0	4.9	5.7													4
8		3.0	4.1	5.2	6.3	7.4	8.5												9
9		3.9	5.2	6.6	7.9	9.3	11												6
10		4.7	6.4	8.1	9.8	11	13												4
11		5.6	7.6	9.6	12	14	16	18	20	22									9
12		6.6	8.9	11	14	16	18	21	23	25									9
13		7.7	10	13	16	18	21	24	27	29	32	35							8
14		8.7	12	15	18	21	24	28	31	34	37	40							16
15		10	13	17	21	24	28	31	35	38	42	46							13
16		11	15	19	23	27	31	35	39	43	48	52	56						20
17		12	17	22	26	30	35	40	44	49	53	58	62						16
18		14	19	24	29	34	39	44	49	54	59	64	69	74					20
19		15	21	26	32	38	43	49	54	60	66	71	77	82					21
20		16	23	29	35	42	47	54	60	66	72	78	85	91					22
21		18	25	32	38	45	52	59	66	72	79	86	93	100					14
22		19	27	34	42	49	57	64	72	79	87	94	102	109					19
23		21	29	37	45	54	62	70	78	86	94	102	110	119	127	135			14
24		23	32	40	49	58	67	76	84	93	102	111	120	129	138	146			31
25		24	34	43	53	62	72	82	91	101	110	120	130	139	149	158			21
26		26	36	47	57	67	78	88	98	109	119	129	140	150	160	171	181		27

[CDF-220]

29		44	57	70	82	95	108	121	134	146	159	172	185	198	210	223		18
30		47	61	74	88	102	115	129	143	156	170	184	197	211	224	238	252	24
31			64	79	94	108	123	137	152	166	181	196	210	225	239	254	268	17
32			68	84	99	115	130	146	161	177	192	208	223	239	254	270	285	32
33			72	89	105	122	138	154	171	188	204	220	237	253	270	286	303	16
34			76	94	111	129	146	164	181	199	216	233	251	268	286	303	321	24
35			81	99	118	136	154	173	191	210	228	247	265	284	302	321	339	16
36			85	104	124	144	163	182	202	222	241	261	280	300	319	339	358	13
37				110	130	151	172	192	213	234	254	275	295	316	336	357	378	8
38				116	137	159	181	202	224	246	267	289	311	332	354	376	398	14
39				121	144	167	190	213	236	258	281	304	327	350	373	395	418	1
40				127	151	175	199	223	247	271	295	319	343	367	391	415	439	4
41				133	158	184	209	234	259	284	310	335	360	385	410	436	461	2
42				139	166	192	219	245	271	298	324	351	377	404	430	456	483	4
43					173	201	229	256	284	312	339	367	394	422	450	478	505	3
44					181	210	239	268	297	326	355	384	412	442	470	499	528	4
45					189	219	249	280	310	340	370	400	431	461	491	522	552	4
46					197	228	260	292	323	355	386	418	450	481	513	544	576	4
47					205	238	271	304	337	370	403	436	468	502	534	568	600	1
48					213	247	282	316	350	385	419	454	488	522	557	591	626	2
49					221	257	293	329	365	400	436	472	508	544	579	615	651	1
50					230	267	305	342	379	416	454	491	528	565	603	640	677	7
No. of trees	5	10	13	19	41	32	20	69	90	122	94	45	13	13	6	1		593

NOTE: Table adapted from table 1 of Palley (1961) by deducting the volume of a 1.5-foot stump and a top taken as 17 feet in length. Table entries may be approximated by the equation:

$$V = -1.380326 + 0.267097\,D + 0.001675\,H + 0.001956\,DH - 0.016521\,D^2 + 0.0014505\,D^2H,$$

where V is the volume of solid wood (in cubic feet) between stump and top, D is d.b.h. (in inches) on the uphill side, and H is height (in feet) from ground level on uphill side to tip.

Log rule: butt logs cubed by Newton's formula, upper logs by Samalian's.
Scaling length: mostly 16 feet.
Trim allowance: none.
Stump height: 1.5 feet, uphill side.
Top diameter: 4.0 inches, inside bark.
Basis: 593 trees.
Data gathered in Sonoma, Mendocino, Humboldt, and Del Norte counties, California.

TABLE 27

TOTAL HEIGHT VOLUME TABLE FOR YOUNG GROWTH REDWOOD

(*Sequoia sempervirens* (D. Don) Endl.)

Board Feet to an 8-inch Top—International ¼-inch Rule

D.B.H. (inches)	Volume by total height in feet 40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	No. of trees
11	25	25	30	35	40	40	45	50									9
12	30	40	45	50	60	65	75	80									9
13	40	50	60	70	80	95	105	115	125								8
14	45	60	75	90	105	120	135	150	165								16
15	55	70	90	110	130	150	165	185	205	225							13
16	60	85	105	130	155	175	200	225	250	270							20
17	65	95	125	150	180	210	235	265	290	320	350						16
18	75	105	140	170	205	240	270	305	340	370	405						20
19	80	120	155	195	230	270	310	345	385	425	460						21
20	85	130	175	215	260	305	345	390	435	475	520						22
21		140	190	240	290	335	385	435	485	535	585	630					14
22		150	205	260	315	370	425	480	535	590	645	700					19
23		165	225	285	345	405	470	530	590	650	710	775					14
24		175	240	310	375	445	510	580	645	715	780	850					31
25		185	260	335	410	480	555	630	705	775	850	925	1000				21
26			280	360	440	520	600	680	760	840	925	1005	1085				27
27			295	385	470	560	645	735	820	910	995	1085	1170				25
28			315	410	505	600	695	790	885	980	1075	1170	1265				36
29			335	435	540	640	745	845	945	1050	1150	1255	1355	1460			18
30			355	465	575	685	795	905	1010	1120	1230	1340	1450	1560			24

31				490	610	725	845	960	1080	1195	1315	1430	1550	1670	1785	1905	17
32				520	645	770	895	1020	1150	1275	1400	1525	1650	1775	1905	2030	32
33				545	680	815	950	1085	1220	1350	1485	1620	1755	1890	2025	2160	16
34				575	720	860	1005	1145	1290	1430	1575	1720	1860	2005	2145	2290	24
35				605	755	905	1060	1210	1365	1515	1665	1820	1970	2120	2275	2425	16
36					795	955	1115	1275	1440	1600	1760	1920	2080	2240	2400	2565	13
37					835	1005	1175	1345	1515	1685	1855	2025	2195	2365	2535	2705	8
38					875	1055	1235	1415	1590	1770	1950	2130	2310	2490	2670	2850	14
39					915	1105	1295	1485	1670	1860	2050	2240	2430	2620	2810	3000	1
40					955	1155	1355	1555	1755	1955	2150	2350	2550	2750	2950	3150	4
41						1210	1415	1625	1835	2045	2255	2465	2675	2885	3095	3305	2
42						1260	1480	1700	1920	2140	2360	2580	2800	3020	3240	3460	4
43						1315	1545	1775	2005	2240	2470	2700	2930	3160	3390	3620	3
44						1370	1610	1855	2095	2335	2580	2820	3060	3305	3545	3785	4
45						1425	1680	1930	2185	2440	2690	2945	3195	3450	3700	3955	4
46							1750	2010	2275	2540	2805	3070	3335	3595	3860	4125	4
47							1820	2095	2370	2645	2920	3195	3470	3750	4025	4300	1
48							1890	2175	2465	2750	3040	3325	3615	3900	4190	4475	2
49							1960	2260	2560	2860	3160	3460	3760	4060	4360	4660	1
50							2035	2345	2655	2970	3280	3595	3905	4215	4530	4840	7
No. of trees	2	4	10	39	32	20	69	90	122	94	45	13	13	6	1		560

Table prepared by weighted multiple regression. Table entries computed from the equation:

$$V = 7.0914\,D - 1.9081\,H + 0.08436\,DH - 0.57075\,D^2 + 0.01158\,D^2H,$$

where D is D.b.h. on the uphill side and H is height in feet from ground level on uphill side to tip.

Log rule—International ¼-inch.

Scaling length—16 feet.

Trim allowance—0.3 feet.
Stump height—1.5 feet, uphill side.
Top diameter—8.0 inches, inside bark.
Basis—560 trees.
Data gathered in Sonoma, Mendocino, Humboldt, and Del Norte counties, California.
Aggregate Difference—Table is 0.06 per cent low.
Average Deviation—14.72 per cent.

[CDF-223]

TABLE 28

TOTAL HEIGHT VOLUME TABLE FOR YOUNG GROWTH REDWOOD

(*Sequoia sempervirens* (D. Don) Endl.)

Board Feet to an 8-inch Top—Spaulding Rule

D.B.H. (inches)	Volume by total height in feet															No. of trees
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	
11	20	22	25	27	29	32	34	36									9
12	25	31	36	41	46	51	56	61									9
13	31	39	47	55	64	72	80	88	96								8
14	36	48	59	71	82	94	105	117	128								16
15	42	57	72	87	102	117	132	147	162	177							13
16	47	66	85	104	123	142	160	179	198	217							20
17	52	75	98	121	144	167	190	213	236	259	283						16
18	57	85	112	139	167	194	222	249	277	304	331						20
19	62	94	126	159	191	223	255	287	319	351	383						21
20	67	104	141	178	215	252	289	326	363	400	437						22
21		115	157	199	241	283	325	367	409	452	494	536					14
22		125	172	220	268	315	363	410	458	505	553	601					19
23		136	189	242	295	349	402	455	508	562	615	668					14
24		146	206	265	324	383	442	502	561	620	679	739					31
25		157	223	288	354	419	485	550	616	681	746	812	877				21
26			241	313	384	456	528	600	672	744	816	888	960				27
27			259	337	416	495	574	652	731	810	888	967	1046				25
28			277	363	449	535	620	706	792	877	963	1049	1134				36
29			297	390	483	576	669	762	855	948	1040	1133	1226	1319			18
30			316	417	517	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]

[CDF-224]

31				445	553	661	770	878	986	1095	1203	1311	1420	1528	1636	1745	17
32				474	590	706	823	939	1056	1172	1288	1405	1521	1637	1754	1870	32
33				503	628	752	877	1002	1127	1251	1376	1501	1626	1750	1875	2000	16
34				533	666	800	933	1066	1200	1333	1466	1600	1733	1866	2000	2133	24
35				564	706	848	991	1133	1275	1417	1559	1702	1844	1986	2128	2270	16
36					747	898	1050	1201	1352	1504	1655	1806	1958	2109	2260	2412	13
37					789	949	1110	1271	1432	1592	1753	1914	2075	2235	2396	2557	8
38					832	1002	1172	1343	1513	1683	1854	2024	2195	2365	2535	2706	14
39					875	1056	1236	1416	1597	1777	1957	2137	2318	2498	2678	2859	1
40					920	1111	1301	1492	1682	1873	2063	2254	2444	2634	2825	3015	4
41						1167	1368	1569	1770	1971	2172	2373	2573	2774	2975	3176	2
42						1224	1436	1648	1859	2071	2283	2494	2706	2917	3129	3341	4
43						1282	1505	1728	1940	2173	2396	2618	2841	3063	3286	3509	3
44						1343	1577	1811	2045	2279	2513	2746	2980	3214	3448	3682	4
45						1405	1650	1895	2141	2386	2631	2877	3122	3367	3613	3858	4
46							1724	1982	2239	2496	2753	3010	3267	3524	3781	4039	4
47							1800	2070	2339	2608	2877	3146	3415	3684	3954	4223	1
48							1878	2159	2441	2722	3004	3285	3567	3848	4129	4411	2
49							1957	2251	2545	2839	3133	3427	3721	4015	4309	4603	1
50							2037	2344	2651	2958	3265	3572	3878	4185	4492	4799	7
No. of trees	2	4	10	39	32	20	69	90	122	94	45	13	13	6	1		560

Table prepared by weighted multiple regression. Table entries computed from the equation:

$$V = 7.0015\,D - 1.0930\,H - 0.02451\,DH - 0.55260\,D^2 + 0.01320\,D^2H,$$

where D is D.b.h. on the uphill side and H is height in feet from ground level on uphill side to tip.

Log rule—Spaulding. (Scribner values used for 8- and 9-inch logs.)

Scaling length—16 feet.

Trim allowance—0.3 feet.
Stump height—1.5 feet, uphill side.
Top diameter—8.0 inches, inside bark.
Basis—560 trees.
Data gathered in Sonoma, Mendocino, Humboldt, and Del Norte counties, California.
Aggregate Difference—Table is 0.11 per cent high.
Average deviation—15.59 per cent.

[CDF-225]

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