The Period of Seasonal Growth of Ponderosa Pine and Associated Species

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The period of seasonal growth of trees is not only an interesting natural phenomenon, but also may be an important factor in the execution of certain field studies. The data presented indicate some significant differences among the periods of growth of certain coniferous species and in the period of growth of ponderosa pine at different locations.

THE seasonal growth of six coniferous species in one area and of ponderosa pine at five elevations has been measured for a number of years in a working center in the Sierra Nevada. These data have been taken in order to provide a basis for pro-rating the time interval between periodic measurements of trees in yield studies. It is the purpose of this paper to present some of the observations on seasonal growth.

Although the literature abounds with reports of observations on the seasonal growth of trees, there is little knowledge of the seasonal distribution of growth of some of the principal coniferous species of the Sierra Nevada of California. MacDougal (*10, 11*) has reported exhaustively on the period of growth of Monterey pine on the central coast of California. He indicated that the period of diameter growth varied from 2 to 8 months and that height growth lasted for 10 months. Glock (*6*) reported that the maximum growth of juniper in the high Sierra occurred within two weeks after winter snows had melted. Pearson (*12*) found the period of diameter growth of ponderosa pine in Arizona varied from 87 to 117 days.

In other regions many investigators have studied the period and progress of seasonal growth and have found variability associated with species, with years, and with place. Baldwin (*1*), studying the height growth of white pine, balsam fir, white spruce, red spruce, and black spruce, found differences in the time and the rate of growth among the species but noted consistency in the performance of any one species in a given location. Tryon and Finn (*17*) found that the culmination of height growth occurred three to four weeks earlier in Norway spruce, white spruce, and Norway pine than in European larch. Ninety percent of the growth of pine and spruce occurred in about 7 weeks, whereas that amount of growth of the larch required about 15 weeks. In Pennsylvania, Illick (*8*) noted that 80 percent of the height growth of white pine was completed in 30 days. Kienholz (*9*) concluded that white pine, pitch pine, and Norway pine behaved similarly but differed from white spruce and balsam fir in the time of inception and cessation of height growth. Reed (*13*) determined that loblolly pine began its shoot growth 2 weeks before shortleaf pine and also ceased growing before shortleaf pine. Gustafson (*7*) observed that the height growth of Scotch pine was completed by the end of June and that diameter growth was completed by the end of August. Rees (*14*), studying radial growth of red spruce in the Adirondacks, found that the period of growth on four sites varied from 6 weeks to 14 weeks. He observed also that the growth of shoots ceased about the time that the spring wood was completed. Brown (*2, 3*), studying the radial growth of pitch pine and white pine, observed after the first surge of growth a rest period followed by a second period of growth.

Procedure

Sample trees and locations.—The six species studied were ponderosa pine (*Pinus ponderosa* Law.), sugar pine (*P. lambertiana* Dougl.), lodgepole pine (*P. contorta latifolia* Engelm.), Jeffrey pine (*P. jeffreyi* "Oreg. Com."), white fir (*Abies concolor* Lindl. and Gord.) and California incense-cedar (*Libocedrus decurrens* Torrey). Ten trees of each of the six species, 3 to 6 feet high, were selected for height measurements and an additional ten trees each of only four species, ponderosa pine, sugar pine, white fir, and incense-cedar, 5 to 25 inches in diameter, were selected for radial measurements. Radial growth measurements were not made on lodgepole pine and Jeffrey pine because enough trees of this size did not occur in the area. The trees

[1]Maintained in cooperation with the University of California, at Berkeley, Calif.

used for radial growth measurements were isolated, dominant, or codominant and were classed as 1, 2, or 3 according to the Dunning (5) tree classification.

Trees of the six species measured for height growth were contained in an area of about ten acres, located on the west slope of the Sierra Nevada along the South Fork of the Stanislaus River in the Stanislaus National Forest. The elevation is about 5,200 feet. The trees of the four species measured for radial growth were scattered over about 60 acres in the same locality at an elevation of about 5,300 feet. The site quality of the general area is very good, being quality I in the common scale of site classification.

Seasonal height and radial growth of ponderosa pine was measured also at elevations of 1,800, 3,000, 4,000, 5,000, and 6,000 feet. At each elevation height growth was measured on ten trees 2 to 6 feet high, and radial growth on ten other trees 5 to 30 inches in diameter of tree classes 1, 2, 3, or 6. The group of trees measured at 1,800 feet grew on a northwest slope; the groups measured at the other elevations grew on slopes varying from southeast to southwest. The group of trees at 1,800 feet grew at about the lower edge of the Transition life-zone, which includes ponderosa pine and associated species. The group of trees at 6,000 feet was approximately 25 miles distant from the group at 1,800 feet and was about at the upper edge of the Transition life-zone.

Height and radial growth measurements of the different species extended over a period of 8 and 7 years, respectively, from 1932 and 1933 to 1939, inclusive. Height and radial growth measurements of ponderosa pine at different elevations extended over a period of 6 years, from 1933 to 1938, inclusive. The first measurements each year were made in February or March at elevations of 5,000 feet and below, and in March or April at elevations above 5,000 feet. Each tree was measured at intervals of 10 days, or nearly so, until the middle of November.

Methods of measurement.—Height growth was measured from a pin placed in the stem below the last node to the tip of the terminal bud with a steel rule, notched at zero to fit the pin. Measurements were made to the nearest five-hundredth of an inch. This method is essentially the same as that used by Kienholz (*9*) and Reed (*13*), or by Tryon and Finn (*17*), who marked the tip of the terminal each period on a stick fastened along the stem. No deformities of the stem were caused by the pin. At the end of the season, the pins were placed below the node just formed, and a measurement was made to serve as the base for the next season. Thus any growth occurring before the first examination in the spring was measured. The date of emergence of the needles from the fascicle sheath was noted and the needle length was observed concurrently with height measurements.

Measurements of radial growth were obtained by use of the Reineke (*15*) dendrometer. This device consists of three parts: a hook screwed into the wood of the tree until about half an inch of space remained between the point of the hook and the smoothed bark; a small, round-headed screw imbedded in the bark directly beneath the hook; and a dial gauge to measure the distance between the hook and the screw. The dendrometer is so constructed that the measurement of growth includes growth of both xylem and phloem and expansion or contraction of the hook and screw and of the ½-inch of bark in which the screw is imbedded. Two or more sets of hook and screw were affixed to each tree. Changes in the distance from the hook to the screw were gauged to one thousandth of an inch. The dendrometer was selected from other devices such as the dendrograph (*10, 11*) or various growth bands (*10*) to measure radial growth because of its cheapness, simplicity, and apparent accuracy.

The reliability of the dendrometer in measuring radial growth was verified by two tests in which the dendrometer measurement of growth was compared with the width of the actual growth ring. In the first test increment cores were taken under the small screws of the dendrometers on 32 trees at the end of a growing season and the cores were preserved in solution to prevent shrinkage. The width of the last growth ring of each core was measured microscopically to the nearest thousandth of an inch. The measurements of ring width were compared with the corresponding dendrometer measurements by the "t-test" and by linear correlation. In the second test 25 dendrometers were installed 3 inches apart around the periphery of one tree. One dendrometer was removed each week and an increment core was taken under the small screw. The measurements of ring width were compared with those by the dendrometer as in the first test.

In the first test, the mean difference resulting from the subtraction of the core measurement from the dendrometer measurement was +0.0184 inches, with a standard error of ±0.0043 inches. The correlation coefficient was +0.936, a highly significant value explaining 88 percent of the variation. In the second test the mean difference, resulting from the same order of subtraction, was +0.0234 inches with a standard error of ±0.0043 inches. The correlation coefficient was +0.886, a highly significant value explaining 78 percent of the variation. Since the differences between the measurements by the dendrometer and the measurements from the increment cores were positive and highly significant in both tests, and since the correlation coefficients also were highly significant, the dendrometer measurement of radial growth apparently is reliable even though the measurement includes more than growth of the xylem.

Methods of analysis.—The study of differences in the distribution of seasonal growth of the six species and of ponderosa pine at five elevations was based on comparisons of the time at which growth started in the spring, the length of the growing period, and the relative rapidity of growth during the period of greatest growth rate or the "grand period of seasonal growth" referred to by Büsgen (*4*). These data were extracted from seasonal growth curves, of the logistic or S-shaped type, constructed from the periodic measurements. The average amount of growth of each set of 10 trees for each 10-day period was accumulated for the season. The average cumulative growth, by periods, was divided by the average total growth of the group of trees and the dividend converted to a percentage. The conversion to a percentage basis was expedient because the rate of growth of all the trees was thereby reduced to a comparable basis and because time and relative rapidity of growth, and not actual amount, were being studied. The accumulated percentages were plotted over time, forming the curves mentioned above. Examples of the growth curves of the 4 sets of data are shown in Figures 1, 2, 3, and 4.

The beginning of growth was defined for comparative purposes in this study as the date by which 5 percent of the total seasonal growth had been completed. This time was measured from January 1 each year. The end of seasonal growth was defined as the date by which 95 percent of

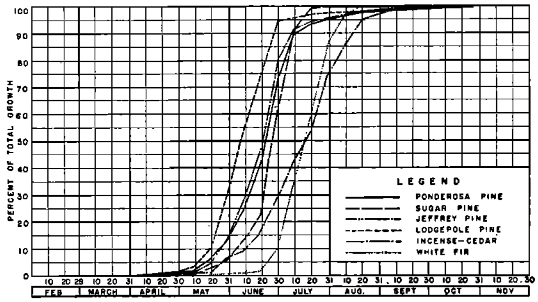

Fig. 1.—Progress of seasonal height growth of different species, 1937.

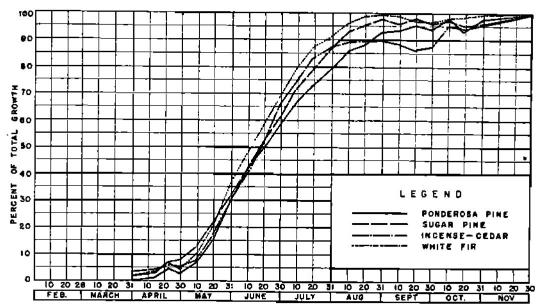

Fig. 2.—Progress of seasonal radial growth of different species, 1937.

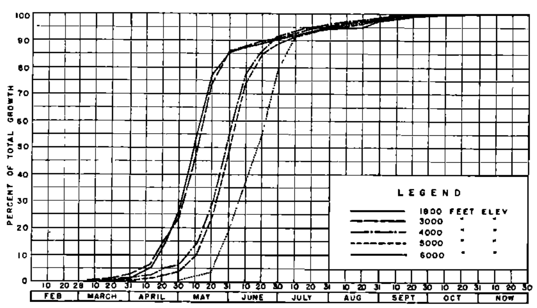

Fig. 3.—Progress of seasonal height growth of ponderosa pine at different elevations, 1937.

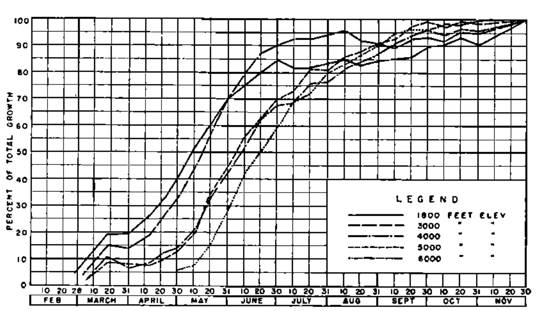

Fig. 4.—Progress of seasonal radial growth of ponderosa pine at different elevations, 1937.

the seasonal growth had occurred. The time interval between these two dates was used as the length of the growing period. These arbitrary limits were established to avoid the employment of personal judgment in determining the date on which growth actually started or stopped. The selection of the 5 percent point as the beginning of growth largely avoided the necessity of extending the curve toward the datum established the previous fall whenever the initial spring measurement did not precede growth inception. These artificial limits, it is believed, are not in disagreement with the practical purpose of the study and do not change the positions of the species or elevations in their time or rate relationships.

The minimum number of days required to complete 50 percent of the total growth was selected as a measure of the rapidity of growth during the period of greatest growth rate. The minimum number of days required to complete 50 percent of the growth was always included between the points of curvature of the growth curve. To extract these data from the curves, a celluloid grid, calibrated with abscissa in days and with a fixed ordinate equal to 50 percent, was moved along each growth curve until the abscissa, or number of days, became a minimum. This process resulted, in effect, in the determining of the minimum base of a right-angled triangle whose altitude, parallel to the ordinate of the growth curve, was equal to 50 percent and whose hypotenuse was represented by a segment of the growth curve.

Significant variations in start of growth, length of the growing period, and rapidity of growth among species or elevations and from year to year were determined by analysis of variance (*16*). The form of analysis used distributed the total variation to years, to species or elevations, and to error. The significance of a difference between species or between elevations with respect to the start, length of period, or rapidity of growth was established by the *t*-test, in which the standard error was derived from the appropriate variance analysis.

The adequacy of a sample of only 10 trees of each species or at each elevation was indicated by analysis of variance for one season of the individual periodic growth measurements converted to percentages of total seasonal growth. These analyses revealed significant differences in the proportionate amount of total growth completed in 10-day periods by different species or by ponderosa pine at different elevations. The use of the average of 10 trees in the main analysis has not distorted, apparently, the differences between species or between elevations.

Results

Tables 1 to 4 give average values of the date of start of growth (Start), the length of the growing period (Length), and the minimum number of days required to complete 50 percent of the total growth (Rapidity) together with the magnitude of differences which are significant at the 5-percent and 1-percent levels.

Table 1.—Height Growth of Different Species, 8-year Average

	Species						Significant difference	
Variable	Lodgepole pine	Jeffrey pine	Ponderosa pine	Sugar pine	Incense-cedar	White fir	5 percent level	1 percent level
Start, days[1]	127	136	133	146	144	175	5	7
Start, date	May 7	May 16	May 13	May 26	May 24	June 24	----	----
Length, days	69	78	81	51	91	46	6	8
Rapidity, days	21	21	22	15	37	20	3	4

[1]Number of days from January 1.

Table 2.—Radial Growth of Different Species, 7-Year Average

	Species				Significant difference	
Variable	Ponderosa pine	Sugar pine	Incense-cedar	White fir	5 percent level	1 percent level
Start, days[1]	105	107	105	121	12	16
Start, date	April 15	April 17	April 15	May 1	----	----
Length, days	147	129	136	108	23	32
Rapidity, days	47	46	39	44	5	7

[1]Number of days from January 1.

The start of growth, length of the growing period, and minimum number of days required to complete 50 percent of growth also varied with years in most of the variance analyses. Years were unimportant statistically in only three analyses: the length of the period of radial growth of different species, the length of the period of height growth of ponderosa pine at different elevations, and the minimum number of days required to complete 50 percent of the height growth of ponderosa pine at different elevations. Undoubtedly the variation from year to year is the result of climatic conditions during these years. No attempt was made to correlate the phases of seasonal growth with climatic conditions.

Discussion of Results

The date at which seasonal growth started, the length of the growing period, and the minimum number of days required to complete one-half the total growth were found to vary for different species. Lodgepole pine began seasonal height growth first each year. White fir began seasonal height growth one month to one and one-half months later than the other species. By the time height growth of white fir started, lodgepole pine, ponderosa pine, Jeffrey pine, sugar pine, and incense-cedar had completed 88, 63, 67, 45, and 25 percent of their seasonal growth, respectively.

White fir and sugar pine completed their total height growth in the shortest period of time. The difference in the length of growing period between these two species was not significant but the difference in time between either of these species and any other species was highly significant. The length of the growing period of lodgepole pine was less than that of ponderosa pine, Jeffrey pine, or incense-cedar. The length of the growing period of incense-cedar was greater by a highly significant number of days than that of the other species. In order of cessation of growth, lodgepole pine was first, followed by sugar pine, Jeffrey pine, ponderosa pine, white fir, and incense-cedar.

The minimum length of time required to complete 50 percent of the height growth was found to be surprisingly short for sugar pine and very long for incense-cedar. The 15-day period required for sugar pine was significantly shorter than the period required for the other species. The very rapid growth of sugar pine may be related to the fact that needle elongation of sugar pine does not occur until after the period of rapid height growth. Brown (*2*, *3*) and Kienholz (*9*) have suggested that there is competition within the plant for food materials for different growing points. Lodgepole pine, Jeffrey pine, ponderosa pine, and white fir did not differ from each other with respect to the length of this period of rapid growth. Incense-cedar required almost twice as much time to complete the most rapid 50 percent of growth as the other species. The slow relative rate of growth of incense-cedar may be due to the fact that, having no large over-wintering bud as the pines have, its growth is the result of a continual cell differentiation and elongation. In pine and in fir the sudden

Table 3.—Height Growth of Ponderosa Pine at Different Elevations, 6-year Average

	Elevations					Significant difference	
Variable	1800 feet	3000 feet	4000 feet	5000 feet	6000 feet	5 percent level	1 percent level
Start, days[1]	88	92	105	116	128	11	16
Start, date	March 29	April 2	April 15	April 26	May 8	----	----
Length, days	122	108	105	97	89	17	24
Rapidity, days	24	22	25	21	26	5	6

[1]Number of days from January 1.

Table 4.—Radial Growth of Ponderosa Pine at Different Elevations, 6-Year Average

	Elevation					Significant difference	
Variable	1800 feet	3000 feet	4000 feet	5000 feet	6000 feet	5 percent level	1 percent level
Start, days[1]	47	55	70	82	107	17	23
Start, date	Feb. 17	Feb. 25	March 11	March 23	April 17	----	----
Length, days	241	148	183	177	143	26	36
Rapidity, days	58	49	59	57	48	12	16

[1]Number of days from January 1.

spurt of growth may be the elongation of cells differentiated in the large bud. Büsgen and Munch (*4*) have indicated that the difference in the rapidity of seasonal height growth between beech and ash is due to the fact that beech has a large overwintering bud in which the cells for the shoot growth are laid down and ash has not.

In the study of the seasonal radial growth of the four species, the only differences in the start of growth were between the tardy white fir and the other three species. The length of the growing period of white fir was significantly shorter than that of ponderosa pine and incense-cedar but the other differences among species were not significant. The minimum number of days required to complete 50 percent of the growth was less for incense-cedar than for ponderosa pine or sugar pine. There is no apparent explanation of the fact that incense-cedar required the least number of days to complete 50 percent of its radial growth but the greatest number of days to complete 50 percent of its height growth.

The start of seasonal height growth of ponderosa pine was later with each rise of 1,000 feet in elevation, except between 1,800 feet and 3,000 feet. An increase of 2,000 feet in elevation caused a very significant delay in the inception of height growth. Table 3 indicates that growth started over a month later at 6,000 feet than it did at 1,800 feet or 3,000 feet. At the time growth started at 6,000 feet (5 percent completed), 15 percent, 25 percent, 52 percent, and 56 percent of the seasonal growth had occurred at 5,000, 4,000, 3,000, and 1,800 feet, respectively.

There was a decrease in the length of the period of height growth with increase in altitude, but the decrease in number of days was significant only when the increase in altitude was 3,000 feet. Although the length of the growing period was shown to vary with elevation, the cessation of growth did not. The minimum number of days required to complete 50 percent of the growth did not vary with altitude. These facts indicate that differences in the length of the growing period were largely the result of the differences in the time at which growth started.

The beginning of radial growth was significantly later with each additional 2,000 feet of elevation, with the exception that there was a significant delay between 5,000 feet and 6,000 feet. The shortest period in which 50 percent of the radial growth occurred did not change with elevation, a finding in agreement with the height growth findings. No regularity associated with changes in elevation was apparent in the length of the period of radial growth. The statistical reason for this irregularity was obvious when the growth curves were examined. Each year the seasonal growth curve of the trees at 1,800 feet leveled off at about 90 percent of total growth for a period of about two months and then gradually increased. The curve of the trees at 3,000 feet, however, leveled off at about 95 percent for a similar period and then also gradually rose. Obviously, the 95 percent level arbitrarily chosen as the end of growth intercepted the curve of 3,000 feet at an early date and intercepted the curve of 1,800 feet at a late date.

A comparison of Tables 1 and 2 and of Tables 3 and 4 indicates that the beginning of radial growth precedes the beginning of height growth. Only in the pines did radial growth continue for any appreciable period after the cessation of height growth. At the time height growth of ponderosa pine ended, 84 percent of the radial growth had occurred. At the cessation of height growth of sugar pine, 80 percent of the radial growth had occurred.

The stage of seasonal growth may be estimated roughly by the development of the needles. At the time of needle emergence from the fascicle sheath, lodgepole pine, Jeffrey pine, ponderosa pine, sugar pine, and white fir had completed 59 percent, 50 percent, 54 percent, 80 percent, and 18 percent, respectively, of their seasonal growth. These observations are not in agreement with the general statement by Reed (*13*) that height growth begins with the appearance of the season's needles. Possibly differences of interpretation exist as to what constitutes appearance of needles, the presence of the fascicle sheath, or the emergence of the needle from it. Other investigators (*3, 9, 14*) have reported that the needles of pines do not appear until after height growth has started and that the foliar buds of spruce break a week after height growth has started. In this study all height growth was completed by the time needle growth was completed.

The results presented indicate that there are great enough differences in the period of seasonal growth among species to warrant consideration of these differences in the schedules for examination of field plots. A further complication is that changes in the period of seasonal growth are caused by place differences. Exact comparisons of growth rates or yields over periods of a few years between species or between areas climatically different can be made only if growth measurements are taken before or after the period of seasonal growth. For example, the average annual increase in total height of seedlings and saplings is used often as a measurement of the effect of stand improvement. These data may be the result of measurements made after a 5-year interval. But unless the calendar years include growth years, the actual growing period during 5 calendar years might be 4½ years for ponderosa pine and only 4 years for white fir. Such discrepancies might be introduced also in the comparison of measurements taken during a short period of time in areas differing by several thousand feet in elevation. These discrepancies could be avoided if measurements taken during the growing season excluded current growth. However, the recognition of current height growth of some species, as incense-cedar, is difficult; and the exclusion of current radial growth in measurements of tree diameter is, of course, impossible. It appears necessary then that there be a continuous record of the seasonal growth of some key species at each working center after the relationships among species have been established. This record should facilitate the adjustment of the time interval in growth studies.

Summary

A comparison of the seasonal height growth of six conifers over a period of 8 years has revealed differences in time of start of growth, length of growing period, and the minimum number of days required to complete 50 percent of the growth. The first species to start growth was lodgepole pine and the last was white fir. White fir had the shortest growing period and incense-cedar the longest. Sugar pine required the least number of days to complete 50 percent of its growth and incense-cedar the most.

A comparison of the seasonal radial growth of four conifers revealed that white fir was the last to start seasonal growth and had the shortest growing period.

Height growth of ponderosa pine started very significantly later with each rise of 2,000 feet in elevation. The length of the growing period was shortened significantly with an increase of 3,000 feet in elevation.

Radial growth of ponderosa pine started significantly later with an increase of 2,000 feet in elevation.

The rate of height and radial growth of ponderosa pine during the grand period of growth did not vary with elevation.

Needles of the pines did not emerge from the fascicle sheath until 50 percent or more of the growth had occurred.

Because of the differences apparent in the period of seasonal growth among species, among areas, and from year to year, the use of calendar years without regard to the period of seasonal growth in the calculation of average annual growth in short time studies may give biased results.

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National Defense—A Drain on the Timber Supply

Nearly 3,000 sawmills, including over a hundred new mills set up since 1939, are now operating at full capacity throughout the Tennessee Valley. Total production of these mills increased nearly 12 percent from 1938 through 1940. Because of defense activities, the National Lumber Manufacturers Association predicts a further increase of 21 percent in national lumber production.

This increased timber consumption, stimulated by national defense, presents a serious problem when present timber growth and drain are compared. Forest inventory and drain data show that the 2½ billion feet of pine sawtimber reserve in the Valley is being cut about two and one-half times faster than it is growing, and depletion of the Valley's 10 billion feet of pine and hardwood sawtimber is at least 70 percent greater than the increment.

The problem is less serious when all species and sizes of trees are combined. Considering trees under as well as over sawlog size, present drain exceeds growth only lightly. This balance can, however, rapidly swing toward the depletion side by the introduction of new wood-using industries and pulp mills.

Increased demand for timber products is also reflected in rising stumpage and lumber prices. Local lumber prices have increased $5 to $10 per thousand board feet within the past year. Stumpage prices, in the same period, have just about doubled. A recent timber sale on T.V.A. lands adjacent to the Pickwick Reservoir illustrates very well the increased demand for pine sawtimber and the resulting higher stumpage prices. On this operation, pine trees as small as 6 inches in diameter breast high are being cut as thinnings and sawed into "roofers." Furthermore, he bid $6.05 per thousand International rule. A year ago, the same stumpage would probably have brought no more than $3.05 per thousand, and it would have been next to impossible to sell the small, less desirable trees needing removal to improve the stand.

Notwithstanding the profits accruing to timber operators and the opportunities to practice closer utilization in managed stands, as a result of increased lumber demands, the net effect of national defense on timber consumption in the Valley will inevitably be detrimental to the long-time public interests unless strenuous efforts are made to direct the impetus into constructive channels.—*T.V.A. Forest Log, April 1941.*