PRECISION MEASUREMENT OF RADIAL GROWTH AND DAILY RADIAL FLUCTUATIONS IN DOUGLAS FIR

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The dial indicator, one of industry's precision tools, has been tested over a period of two and a half years to ascertain its suitability as a dendrometer. This study cannot claim to be the first of its kind, nor to yield exhaustive information, and on this basis the instrument should therefore neither be condemned nor accepted in full. The experience gained may be crystallized in a warning. The dial indicator is unnecessarily precise for measurement of response of growth to thinning; too many sample trees are required to reduce the influence of biological variation so as to match instrumental precision. The dial indicator is technically inferior to the dendrograph as a recorder of daily fluctuations in stem diameter.

The experimental results were found to contribute significantly to a better understanding of the Douglas fir in its relation to environment and silvicultural management; but in evaluating the experiments as such it should be borne in mind that their original design has been restricted by their basic purpose, namely to test the dial indicator.

During the last four years, the Harvard Forest has employed the dial indicator to analyze the effects of various silvicultural treatments upon coniferous plantations. When this work was first reported (Brown, 1947), it was decided that a similar instrument might be useful at the Cowichan Lake Forest Experiment Station to evaluate the effect of thinnings, in terms of radial growth, within one or two years after the time of treatment¹. Accordingly, upon the successful completion of a preliminary study to determine a suitable adaptation of the dial indicator for measurement of radial growth, a series of readings have now been obtained with which it is possible:

1. to test the practicability of the method of measurement, and
2. to assess the importance of these measurements which seek to evaluate the silvicultural treatment of stands in a comparatively short time.

Concurrent with these measurements of growth response after thinning, a separate study sought to ascertain local climatic influences on daily radial fluctuations of individual trees, and hereunder, to compare two trees of similar age and each seven inches d.b.h., one situated in the open, the other in a fully-stocked stand. This latter data is also indicative of the march of seasonal diameter-growth.

All measurements were on Douglas fir trees on similar sites in a 40-year-old natural fir type during the period September, 1947, to November, 1949.

THE DIAL INDICATOR

Description, adaptation and precision

The growth-indicator gauge is an industrial tool, the Starrett No. 655F indicator. About three inches in diameter, the face is calibrated to 0.001 inches: the unit divisions are about 1/13 inch wide. The spindle will measure a travel of at least one inch. Although capable of fine measurement, the instrument is strongly housed and the mechanism gives satisfactory service.

As received from the manufacturer, the instrument has a lug drilled to form an eye on the back of its frame. This eye facilitates mounting for dendrometric use. The only description of a mounting available was the one given by Reineke (1932). In a modification of Reineke's method, the mounting found satisfactory was made from three pieces of steel plate rigidly welded

¹ The project and adaptation of the dial indicator to it were planned by E. H. Garman, B.C. Forest Service.

together to form a face-plate ($3\frac{3}{4}$ " x 2" x $\frac{1}{4}$ "') set normal to a mounting plate ($3\frac{3}{4}$ " x $2\frac{3}{4}$ " x $\frac{1}{16}$ "'). These two plates were made rigid by a triangular support set between them. A position-ring was welded to the face of the mounting plate which was equipped with drilled lugs adjacent to a hole drilled in the plate to take the lug on the back of the indicator. The indicator was firmly bolted to the plate through the holes aligned in the three lugs. In this position, the spindle activating the indicator projects beyond the common edge of the two plates. To obtain a constant reading when the instrument is in use the bearing surface of the face-plate and its two lips were milled and polished, then protected with a light film of oil.

Plate 1. Adaptation of the dial indicator as a dendrometer

Two views of the dial indicator as adapted for measurement of tree-growth are shown in Plates 1 and 2.

On the north side of the tree at 4.5' height flat-headed screws were used for three contact points. These screws were cadmium-plated with a smooth finish which facilitated screwing into the tree as well as a providing a satisfactory contact surface. The point of radial measurement was set-up by applying a small amount of stick-shellac heated in special applicator with spirit-lamp, to the point upon which the spindle of the instrument was to bear, on the smoothed bark. A warm glazier's point was then pressed upon the hot shellac

to form a contact surface for the point of the spindle.

Upon insertion of the screws, injury to the cambium is slight and the resulting stimulation of growth of wound tissue is limited to a narrow zone around the screws. Care was taken to position the screws at a distance greater than 0.4 inches from the glazier's point, since Reineke (1932) had pointed out that this was the maximum distance at which any measurable growth increase was due to the insertion of screws.

Within two years of setting-up the glazier tips, twelve per cent had fallen off or altered position due to bark-fissuring or resin-flow. Perhaps more satisfactory than stick-shellac would be the waterproof ambroid cement used in the Black Rock Forest (Tryon, 1949).

Plate 2. Dial indicator in use.

The precision of the instrument and the method of measurement were tested under laboratory and field conditions. In the laboratory three sets of readings by three observers were analyzed to show that there was a significant difference between the observations of a single observer and the readings of all three observers. Further, a precision of ± 2.6 ten-thousandths of an inch at a 5 per cent level might be expected when one observer was employed. An analysis of 360 readings taken in the field on a control tree which had a $5\frac{1}{2}$ inch lag-screw set into the heartwood indicated a precision of ± 5 ten-thous-

andths of an inch at the 5 per cent level. This field precision might be considered conservative as shading of the lag-screw undoubtedly would have caused improvement, the extent of which cannot be determined by the data available at present.

The reliability of the dendrometer in measuring radial growth was tested by Fowells (1941). He compared core measurements with dendrometer measurements at the end of a growing season and upon the evidence of this data he states: "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 were also highly significant, the dendrometer measurement of radial growth apparently is reliable even though the measurements include more than growth of the xylem."

A similar test of reliability, performed for the dendrometer used at Cowichan Lake, substantiated the findings of Fowells. The width of the growth ring in 1948 was measured microscopically on 50 cores bored in separate trees each of which had dendrometer measurements of radial growth at a point two inches above or below the place of boring. In a comparison of these two sets of measurements the correlation coefficient was $+ .908$. This value was highly significant. Apparently, because of this good correlation the dendrometer measure of radial growth may be considered reliable. Further analysis made it evident that there was a significant difference between measurements by the dendrometer and measurements on the core, and that these differences were all positive with an average value of $+ 0.002$ inches. Therefore, in a forty-year Douglas fir stand a truer measure of the actual average growth of a group of trees may be obtained by subtracting 0.002 inches from the average of the dendrometer readings.

RADIAL GROWTH

as affected by thinning

Precise measurements of radial growth using the dial indicator as a growth-gauge were studied to evaluate the amount and period of response following a crown thinning in a natural fir stand. Ten trees in each of four one-tenth acre circular plots were set-up for dial indicator readings. With one plot as a control, the other three were thinned by removing 38 per cent of the volume prior to treatment. The time of thinning varied. The first thinning was conducted in the middle of the growing season (June), the second after the end of the growing season (mid-November) and the third before the start of the growing season (mid-March). The tree-readings for radial response were recorded every ten days from the beginning of the 1948 growing season until the end of the 1949 growing season. The aim was to discover if any difference existed in the radial response between the group of ten trees in each sample.

For analysis of the radial response in the two plots thinned in the dormant season, the assumption was made that since the mean rate of growth of the control trees was identical in the year prior to treatment and the year after treatment, the mean rate of growth of the sample trees in the thinned plot would have been the same in the two years, and hence the relative rate of growth of the two samples would have remained constant, had no thinning taken place. On this basis, the expected rate of growth for the two samples was ascertained as in Table 1 below:

Table 1—Dormant Season Thinning—Comparison of pre-treatment and post-treatment radial growth

Time of Thinning	Stand Natural 40-year Douglas fir	Average cumulative radial growth				Percent increase in rate of growth of thinned stand
		Pre-treatment 21/4/48 - 1/12/48		Post-treatment 18/4/49 - 31/10/49		
		in .001"	as percent of control	in .001"	as percent of control	
November	Control Thinned	71.9 66.8	100 92.9 (expected	72.1 81.6 67.0*)	100 113	21.8
March	Control Thinned	71.9 74.8	100 104 (expected	72.1 78.3 75.0)	100 108.5	4.4

* Expected growth of November thinned plot in 1949 was calculated as 92.9 per cent of 72.1 units of control plot.

If the assumption be considered valid, these percentages indicate a significant difference in the change of radial growth following a thinning in different months of the dormant season. In the year following treatment in two similarly treated plots, the sample trees in the November thinned plot showed greater response than those in the March thinned plot. Apparently, although the reason is at present obscure due to lack of plot replication, a thinning at the start of the dormant season so conditioned the trees as to permit more favourable response than a cut applied just before radial growth dormancy was broken.

A measure of the response in the plot thinned in the middle of the growing season was not so easy to obtain since indicator-readings of a complete growing season prior to treatment were not available. These readings had only been recorded from the start of the growing season until the time of thinning. Therefore, increment borings were taken from the trees under trial for response, together with thirty more, to provide data for two purposes. The first was to procure a measure of the relative rate of growth of the two groups of ten trees in the thinned and control plots in 1947, the year prior to treatment. The second was to test the reliability of the assumption that the *relative* rates of radial growth of two groups of trees would remain constant in consecutive years. The analysis of these increment borings was enlightening yet disturbing. It was inferred from its result, that, only by good fortune, did so small a sample serve as a reliable measure of radial response in the dormant season thinning (Table I). Certainly this was not to be the case in the mid-growing-season sample of ten trees which, in the consecutive years of 1946-47,

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diameter-class. No such foresight was available at the initiation of the experiment and the assumption was proven untenable after measurements had been recorded for this thinning. Therefore, another method of analysis was attempted to derive a measure of thinning response for the plot thinned in the middle of the growing season.

This method involved the preparation of a graph (Figure I) showing the cumulative radial change of the control plot and the thinned plot as measured with the dial indicator throughout the 1948 growing season. Thinning was done on the 24th of June. After that date an extrapolated curve was drawn through five points to indicate the expected rate of growth of the plot had it not been thinned. The method of fixing these points is exemplified by the point of expected growth on September 26th, which was determined as follows:

1. In the control and the thinning plot the arithmetic mean of the period 6/5 to 19/6 was marked $\oplus$. (Fig. I).
2. In the control a line, drawn from the initial reading of the period through the mean and produced, cut the growth-curve on 26/9. Then a perpendicular was erected at this date.
3. In the thinning plot a line, drawn from the initial reading of the period through the mean and produced, cut the perpendicular at 26/9 — the point of expected growth.
4. Other points were secured by similar extrapolation on different periods of pre-treatment growth.

The difference between the actual and the extrapolated curve provided a measure of response at the end of each month following day of treatment. Read off the graph (Figure I) and expressed as a per cent (Table II) these values indicate a response of 7.9 per cent at thirty days after thinning increased slowly to a maximum of 10.9 per cent by the end of the growing season.

Table II — Growing Season Thinning

Treatment Date	Radial response as per cent difference between actual and expected rate of growth of 10 sample trees					
	30	60	90	120	150	days after treatment
June 24, 1948	7.9	9.1	10.3	10.9	10.8	

Thereafter, this increase of 10.9 per cent in the rate of growth of the plot was exceeded slightly throughout the 1949 growing season, since a response per cent of 12.1 was recorded in that year. This is a value intermediate to the response percent of 21.8 and 4.4, over the same year, to thinning in the previous dormant season (Table I). Therefore, in a comparison of the increase in the rate of growth of these three plots as related to the same control, the superiority of the response to a cut at the end of the growing-season (mid-November) seems well established.

A second experiment sought to determine the radial response following crown and low thinnings. As the dial indicator did not arrive in time to provide a year of readings prior to treatment, it was hoped to ascertain whether there was a real difference in the current annual increment of the differently treated plots as measured by the dial indicator in the year after thinning. However, upon statistical treatment of the sample data the variance due to sampling error invalidated any variance due to treatment although cursory examination of growth-curves indicated a superiority in the response to the crown thinning. It is interesting to note, on the basis of the ten trees used, that theoretical calculation of the number of trees required to provide an adequate sample of the spread in radial growth would have necessitated measurements on over 80 trees. This is a number in excess of what might be considered practical in an experiment determining response after thinning by dial indicator.

A probe of the growth trends of individual trees served to disclose that:

1. intermediate and co-dominant trees exhibited a more vivid response than dominant, and
2. by the third year after a 25 per cent cut the radial response of all trees had declined to a point where, in order to maintain an appreciable response, a thinning rotation of four years might be a happy choice silviculturally.

DAILY FLUCTUATIONS OF RADIUS

as related to environmental factors

As early as the last quarter of the nineteenth century caliper measurements revealed that diameter growth did not follow a continuous curve throughout the year. By repeated measurements during the day German investigators were able to disclose daily oscillations of the tree diameter about the conventional harmonic curve. In confirmation of these early findings numerous observers have analysed the complex causes of this phenomenon by means of very sensitive and often costly apparatus, such as continuously recording diameter tapes, dendrographs and recently the dial indicator. Unlike the first two, the latter instrument does not give continuous readings.

Two check trees, established as a means of control in conjunction with the thinning experiments at Cowichan Lake, were meant to furnish additional information as to the nature of relationship between radial fluctuations and concurrent meteorological observations². The growth data collected twice daily (0800 and 1700 hours) were also expected to render needed information of the exact duration and placement of the growing season of Douglas fir under local conditions.

As to the influence of environmental factors on tree-diameter variations, most aspects of the problem have been covered and thoroughly analysed by previous workers. Two authors, D. T. MacDougal (1924) and F. W. Haasis (1934), have treated almost every imaginable phase of the subject. This study may at first glance appear to be overshadowed by these intensive and far reaching investigations and thus be confined merely

² Observed at Cowichan Lake Forest Experiment Station by Mr. E. A. Roberts.

to a repetition for corroboration of evidence gained from work with other species. It is believed, however, that now the Thorntwaite method⁸ of climatic classification is available for use in basic studies the comparative analysis of the reactions of a stand tree and those of a tree growing in the open is throwing light on an unexplored facet of the problem.

Preceding investigations of related phases of the subject are of a quality to provide established conclusions acceptable as a factual background for this study. It has thus been shown that temperature has little, if any, direct influence on daily fluctuations of stem diameter. Indirectly, however, it must be considered one of the main factors as temperature is intimately linked with moisture relationships of the entire nature complex.

Daily fluctuations are caused by continuously alternating dehydration and rehydration of cell tissues. Thus water may be considered the main regulating factor on which all attention should be focused. The problem may be further simplified by eliminating every form of molecularly bound water, leaving free water only with which to deal. The water balance in a tree may be expressed as a hydrostatic tension between water supply and water consumption. If the tree demands more water for transpiration and growth than is available through the roots from the soil a water deficit and shrinkage occurs, usually during the daytime. Any subsequent rehydration will cause swelling and increase of diameter and is found to take place during the night when relative humidity is high. Reduced to essentials, the daily fluctuations seem to be governed by the two factors: amount of water available in the soil, and evaporativity of the environment.

This approach simplifies the problem but it is still by no means simple and readily understood. Haasis (1934) thus states: "The evaporativity of the environment is determined by the temperature, the humidity and the rate of movement of the air, and the intensity of solar radiation (cp. Livingston and Haasis, 1929). The effects upon tree diameters of variations in these several factors are extremely difficult to separate from one another." The same author found, however, that, on the whole, his dendrographic studies made it evident that for the most part any increase in the integrated evaporating power is reflected in an increased shrinkage in tree trunks, and vice versa. MacDougal reached the conclusion, based on established facts, that daily variations are intimately linked with the stomatal program and the course of transpiration.

This study could contribute no more than a confirmation of these statements. It could never shake the conclusions by disagreement, because the dial indicator is inferior to the dendrograph; it is not so sensitive and it does not record continuously.

The second factor, the water supplying power of the soil, obviously plays a most significant role in controlling the water conditions within the tree and so influences the diametral fluctuations to a material extent (Haasis, 1934). Soil moisture is controlled also by water supply and consumption, respectively precipitation and the combination of evaporation and

⁸ The method is presented in detail in the *Geographical Review*, Jan. 1948, vol. XXXVIII, No. 1, p. 55-94: "An approach toward a rational classification of climate" by C. W. Thorntwaite.

transpiration (evapotranspiration). The above-mentioned Thornthwaite classification of climate includes an expression of the water balance in the soil, derived from comparison between the two determining factors: precipitation and potential evapotranspiration. The latter is defined as the amount of water which in a given situation would be transferred to the atmosphere provided

FIG. II: MARCH OF PRECIPITATION AND POTENTIAL EVAPOTRANSPIRATION IN 1948 AT COWICHAN LAKE FOREST EXPERIMENT STATION.

sufficient water were available and all other circumstances equal; thus potential evapotranspiration is equal to actual evapotranspiration under ideal conditions of soil moisture and vegetation. The method employs annual and monthly values of local temperature and precipitation but does not reflect daily variations in the soil moisture condition. Thornthwaite emphasizes that the method is open to improvement, especially with regard to the employed constants of the formulae; but even so it shows logical trends when applied to local and controllable conditions. The march of potential evapotranspiration through the year is found to follow a uniform pattern in most of the

United States, whereas the march of precipitation is highly variable. If indicative of soil moisture condition throughout the year the Thorntwaite method should serve as a clearly reflecting background against which the relationship between precipitation and the daily diameter-fluctuations could be analysed.

Haasis (1934) found that as the soil becomes progressively drier during a period of rainless weather the amplitude of daily fluctuations in Monterey pine situated on a dry site gradually grows smaller until, at the end of a protracted drought, the dendrographic pen may be tracing a near-

FIG. III: NUMERICAL VALUES OF DAILY AND NIGHTLY RADIAL FLUCTUATIONS, BY TEN-DAY PERIODS

ly straight line. The same author explains this reduction of amplitude by assuming that the water in the conducting tissues of the tree is so firmly attached to the cell walls that little or no further loss can occur and that shrinkage, therefore, takes place to only a limited extent, if at all.

A glance at Figures II and III makes it evident beyond all shadow of doubt that this does not apply to the two Douglas firs at Cowichan Lake; on the contrary, the fluctuations reach their greatest values in the dry season (July-August) and thereafter they gradually taper off to be almost negligible when water is supplied in abundance. This divergence is fatal to neither of the two studies, simply because the explanation is found in

the difference between the two localities. The study of Monterey pine was carried out at Carmel in California where the trees under observation were growing on a fixed sand dune. The summer at Carmel is rainless and dry, but comparatively cool because of the fogginess. The two Douglas firs at Cowichan Lake are growing under somewhat different conditions. The soil is classified as stony, sandy loam with a water retaining power of about twice that of sand, and the evaporativity of the environment is high during the daytime in the warm and dry summer months.

These differences in environmental conditions provide the explanation of the diverging reactions of the trees at the two localities, because: "A reduced amplitude of diurnal fluctuations may be due either to a reduction of the amount of water in the tree or a reduction in the evaporativity of the environment" (Haasis, 1934). Both causes are probably effective at Carmel, their relative proportion being unknown, whereas the apparent soil water deficiency at Cowichan Lake (Figure II) does not reach as far as to reduce the amount of water in the tissues to the point where no further dehydration and shrinkage can occur. Furthermore, as the evaporating power of the air is not restricted appreciably by extreme cloudiness or fogs, violent fluctuations are to be expected in the dry season.

In comparing Figure II to Figure III it becomes evident that the period of greatest fluctuations does not coincide with the period of highest potential evapotranspiration. The fluctuations culminated about one and a half months later than did the potential evapotranspiration, i.e., by the end of July and the middle of June respectively. This pattern for 1948 was followed also in 1949 with the exception that both culmination points were delayed two to three weeks due to different weather conditions.

It is characteristic, however, that in both years the fluctuations seemed to reach their highest values in the middle of the period of water deficiency, which strongly supports the belief that a combination of the two soil moisture controlling factors, respectively potential evapotranspiration and precipitation, is a reliable measure by means of which the influence of various climatic components on daily fluctuations may be effectively analysed.

Both trees follow the same general pattern throughout the season. Even small amounts of rain in the dry season, July and particularly August, are strongly reflected in the fluctuations, often to such a degree that a normally expected shrinkage during the day is not only eliminated but even converted to swelling and probably actual growth.

Conversely, heavy rains in the wet months, September-November, cause progressively smaller and often no traceable reactions at all. It is characteristic, aside from the periods when fluctuations fall within or close to the experimental error, that the daily fluctuations of the stand tree are smaller than those of the open grown tree (Figure III). The shrinkage during the daytime is smaller, the following swelling at night is correspondingly smaller and the response to precipitation or lack of precipitation is smaller.

That a stand tree should show more moderate radial fluctuations than an open grown tree can hardly be considered a revolutionizing and unexpected discovery as a little ecological thinking will lead to the same conclusion. The microclimate established in a closed stand tends to level and delay the influence of sudden changes in macroclimatic factors. The evaporation from the soil is less in the stand and so is the transpiration from the individual tree, taken as a function of wind velocity. The canopy retains a certain amount of rain and the water is evaporated directly from the crown without ever reaching the ground and the roots.

Potential evapotranspiration may appear to be discredited as a means of analysis by such incomparable conditions, which to a certain extent is true, as far as details are concerned. The Thorntwaite classification, however, does not pretend to offer more than rough measures and as such it is still safe to use it.

The transpiration capacity of the open grown tree is several times that of the stand tree; the capacity assumed to be a simple function of dry weight of foliage. The possibility that such difference in transpiration capacity might have appreciable influence on the respective amplitudes⁴ of fluctuations cannot be excluded. It is most probable even that various degrees of transpiration capacity would show positive correlation with corresponding degrees of daily fluctuations, and it might clarify the problem even more if transpiration capacity were expressed on a relative basis, as a ratio between weight of foliage and volume of solid wood.

The relative importance of environmental factors and transpiration capacity, and possibly other individual characteristics, as to influence on the magnitude of daily fluctuations is a complicated matter and it is far beyond reach of this study to attempt a solution. This, however, should not prevent one from concluding at present that the open grown tree as a general rule shows greater radial fluctuations than does the stand tree, partly because it is growing in the open where it does not enjoy the protection offered under stand conditions, and partly because the open grown tree has developed certain physical characteristics according to its environment.

DURATION AND PLACEMENT OF THE GROWING SEASON

The material now collected does not indicate definitely what is the beginning and end of the growing season. The data merely reveal that in the years 1948 and 1949 the two Douglas firs at Cowichan Lake began radial enlargement in the first week of April and that no appreciable increase of diameter took place after the last week of September, giving a growing season of about 170 days. It will be noted from Figure IV that fastest growth occurred from the middle of May until the middle of June, i.e., after one-third of the entire growing season had elapsed. The stand tree consistently showed less growth than the open grown tree. This difference was most

⁴ The expression "amplitude of fluctuations" is borrowed from the terminology of dendro-graphic investigations. In dealing with dial indicator readings (0800 and 1700 hours) it should be borne in mind that these do not necessarily represent the true amplitudes, or in other words, the true maximum and minimum of radius within 24 hours. The hours of reading were experimentally determined in 1947 by dial indicator measurements taken at two and a half hours intervals. A slight deviation from the true amplitude does not deduct from the value of the observations as comparative measures as long as they are taken simultaneously on both trees.

apparent during and shortly after the period of fastest growth, but apart from this no significant difference between the two trees could be detected.

The forty trees measured at ten-day intervals in conjunction with the thinning experiment showed no divergence from the above observations.

SUMMARY

The Cowichan Lake Forest Experiment Station, British Columbia, has tested the dial indicator as a dendrometer by conducting a number of experiments in Douglas fir where precise measurement of radial changes was involved. A modification of Reineke's method of adapting the instrument was successfully applied to measurements on single trees. Upon analysis of means from several sample trees, however, the experimentally determined precision of measurement (± 0.0005 inches) was eclipsed by the biological variation, unless an excessive number of samples were employed. When core measurements were compared to dendrometer measurements a correlation coefficient of $+0.908$ indicated the instrument to be a reliable means of measuring radial growth.

FIG. IV: DAILY NET INCREASE OF RADIUS IN TWENTY-FOUR HOURS, BY TEN-DAY PERIODS.

The study of radial growth response to thinnings by various methods and at various times during the year failed to give significant results in every case, due to inadequate sampling. The use of the assumption that the *relative* rates of growth of two groups of trees would remain constant in consecutive years did not always appear tenable. Therefore, at the Cowichan Lake Forest it is felt that the application of this instrument should be restricted to young stands, evenly stocked and at the age when canopy closure is just complete. These would provide a better population for a small but adequate sample. Relative rates of growth of groups of trees would stand a better chance of being constant since the spread in rate of growth within a group might be much less erratic. Certainly the employed sample in a forty-year-old natural Douglas fir stand was not adequate and, of the phases of the thinning practices studied, only the experiment measuring the response to thinning in different months of the year gave a reliable result.

Daily radial variations other than actual growth, were studied on two Douglas firs, of which one was growing in a fully stocked stand, the other

one in the open, throughout the growing seasons of 1948 and 1949. The fluctuations, and sudden changes in these, were found to be consistently smaller for the stand tree than for the tree growing in the open, but apart from this no other difference in behaviour was significantly revealed. A combination of monthly values of potential evapotranspiration and precipitation appeared to be a reliable background upon which the relationships between daily fluctuations of radius and various climatic factors, rainfall in particular, may be effectively analysed. A study of the degree and nature of the relationship between precipitation and daily radial fluctuations led to the conclusion that the fluctuations reach their highest values in the middle of the dry period, the period of water deficiency (in July-August in 1948), and that even small amounts of rain in this period have a striking effect on the fluctuations; i.e., greatly increased radial enlargement during the night and often full elimination of the shrinkage during the day. Conversely, large amounts of rain during the wet season had but little or no immediate effect on the fluctuation. The dial indicator is fundamentally inferior to the dendrograph as a means of measuring daily fluctuations, firstly, because the hour of measurement is predetermined whereby the readings may not record the actual amplitudes of fluctuations and, secondly, because the actual readings are not preserved by the instrument itself but have to be transferred in the field from instrument to notebook by more or less reliable and often different observers.

The growing season for Douglas fir commenced in 1948 and 1949 in the first week of April and continued 170 days to the last week of September.

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