GROWTH AND TEMPERATURE PROFILE
OF A DOUGLAS-FIR TREE

by

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For. Eng. University of Belgrade, 1964

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF FORESTRY

in the Faculty
of
FORESTRY

We accept this thesis as conforming to the
required standard

THE UNIVERSITY OF BRITISH COLUMBIA
MAY, 1973
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Date June 4, 1973
This thesis investigated the temperature and growth profile of one Douglas-fir tree. A series of thermocouples located at different heights and depths was connected to one multi-channeled recorder. Using systematic sampling, data were recorded for a period of two years. Temperatures were analyzed for one summer and one winter month.

Vertical distribution of the width of annual rings was analyzed for the period of the last 50 years for both earlywood and latewood as well as for total annual rings. Basic growth theories were outlined and the thesis suggests that none of these gives a completely satisfactory answer. Possible significance of temperature on the vertical growth distribution of annual rings was outlined.
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ACKNOWLEDGEMENT

I wish to thank Mr. L. Adamovich for encouragement and guidance in this study and Dr. J.H.G. Smith for his very valuable criticism, suggestions and encouragement, as well as for financial support. I would also like to express my appreciation to Dr. A. Kozak for his advice and assistance with statistical analyses, Dr. J. Worrall for his guidance and criticism, and Dr. V. Heger for his valuable suggestions. I would like to express my gratitude to Mr. J. Walters for his encouragement and guidance in the final stages of the study, to Mr. R. St. Jean for his help in collecting of data and to Miss B.A. Bilodeau for her patience with my handwriting.

Finally, I wish to thank my wife, Jelena for her patience and understanding.
INTRODUCTION

In recent years interest in the microclimate of the forest has been increasing. Through analysis of the energy budget of the forest, all forms of energy within the system can be traced and located. The main source of energy is solar radiation which takes the form of heat, chemical reactions, etc. Energy is transported within the system by conduction, or radiation and, at the same time, transformation of one type of energy to another takes place. The basic form of energy within the system, or within the tree as a unit of that system, is heat. When solar radiation falls upon a tree, the part of the tree exposed to this radiation becomes warmer than the surrounding air. Heat from exposed parts of the tree is conducted to the rest of the tree and radiated into the air. Air in return conducts the heat to the lower parts of the tree. The amount of energy stored in the tree, in a unit of time, depends on exposure of the tree to the energy source, solar radiation.

Temperature of the air does not have a direct effect on tree form or the structure of the tree but the action of heat is visible on physiological processes. Depending upon heat conditions, a tree can have an increase, retardation, or complete cessation of physiological activities.

First plant temperature measurements were recorded by Hunter in 1775. Since then a large number of measurements have been made on
different plants as well as on trees. Most measurements have been made on a short term basis and there is lack of data on temperature and heat distribution covering a period of more than two or three days.

In this thesis an attempt is made to relate the temperature measurements of one Douglas-fir tree near the Administration Building on the University of British Columbia Research Forest, Maple Ridge, B.C., to the growth of annual rings at different heights. Temperature measurements were recorded for two years, and growth distribution within the measured area was analysed. In a way it is a continuation of Heger's work (1965), who suggested that temperature of the different parts of a tree may be one of the important factors in bole formation.

LITERATURE REVIEW

VERTICAL PROFILE OF AIR AND TREE TEMPERATURE

Knowledge of the air temperature is essential in the explanation of many physiological activities such as the flushing of buds, flowering, beginning and ending of growth. In forestry, where we are dealing with complex plant communities, with different plant temperature requirements, knowledge of vertical air temperature profile is important.

The temperature of the air layer near the open ground is determined by the amount of heat which the surface of the ground absorbs (Geiger, 1950). Under the forest canopy is the body of air whose properties are conditioned by the stand. Basically we have the same case as in the
open ground but the point of exchange of heat is raised from the ground to the canopy of the stand. Consequently during the day, with incoming radiation, the highest temperature will be in the upper part of the crowns. During the night conditions are reversed, the highest temperature is under the canopy due to outgoing radiation streams.

This was confirmed by Walters (1960) who found that the average air temperature in a Douglas-fir - western hemlock forest at the height of 90 feet was 4°F higher as compared to one foot above the ground. The maximum difference occurred late in the afternoon.

In a deciduous forest, air temperature at the height of 25m is higher at all times as compared to 1m above the ground. On an average sunny day the least difference was 0.7°C and maximum was 3.1°C (Heckert 1959). The author concluded that the difference was caused by openings in the canopy of a deciduous forest. Due to these openings the forest floor becomes a secondary active surface of heat exchange between air and the solids.

The temperatures within the trees are closely related to air temperature because they are conditioned by the microclimate of the environment.

Heger (1965) found that the bark surface of Douglas-fir trees exposed to direct sun radiation reached a temperature as high as 102°F. At the same time air temperature was 65-67°F. Temperature of the trees grown within the stand was 1-2°F lower than air temperature.

Temperatures measured at heights of 0-86 cm. showed that plantation-grown red pine had uniform temperature at 0 cm. except during the night
when it dropped 3°C. Temperature at 86 cm. was a sinusoidal wave with the difference between two extremes of 5.5°C (Herrington, 1969).

In general there is a scarcity of research on temperatures of the living trees. Despite this scarcity, one can draw the following conclusions on the basis of previous research.

1. Amplitude and time of maximum and minimum temperature change from the surface to the interior of the tree. In the interior of the wood the amplitude is smaller and the occurrences of maximum and minimum temperatures is later than on the surface of the tree (Herrington, 1969).

2. Temperature of the tree stem varies with height. The crown of the tree is warmer in the spring and summer and colder in the fall and winter as compared to the base of the tree.

3. Response to temperature changes depends on the size of the tree or the parts of the tree.

VERTICAL GROWTH DISTRIBUTION

The amount of cambial growth, and the distribution of earlywood and latewood along the tree bole, varies. It was found by Hartig, Onaka, and others that variation in thickness of annual rings can be found not only in dominant but in suppressed and open grown trees (Farrar, 1961; Kozlowski, 1971). Suppressed trees have a maximum
growth of annual ring at the upper part of the crown. Along the bole the width of annual ring decreases and in some cases in the lower part of the bole it may be missing (Fig. 1, curve 1) (Farrar, 1961).

Dominant trees have a maximum width of annual ring in the upper part of the crown. Along the bole the width of annual ring decreases and then increases at the base of the tree (Fig. 1, curve 2).

The annual ring of an open grown tree has its maximum close to the ground (Fig. 1, curve 3).

Figure 1. Form of the annual rings for suppressed (1), dominant (2), and open grown tree (3). (From Farrar, 1961).
This was confirmed for Douglas-fir where dominant trees had maximum width of annual layers in the crown and equal width below the crown. Xylem production in the case of suppressed trees diminished toward the stem base (Kozlowski, 1971). In a dominant Douglas-fir tree, open grown, with live crown 94% of the total height it was found that the width of the annual rings was uniform except at the top where it decreased. A Douglas-fir tree grown in crowded conditions with the live crown 39% of the total height had uneven width of the annual layers. Thickness of annual rings from the butt decreased and in the upper part of the stem increased, with a sharp decrease at the top of the tree (Walters, 1962; Heger, 1965). Furthermore, it is possible to find two types of vertical xylem distribution within the same tree (Farrar, 1961).

Figure 2. Variation in thickness of annual rings at various ages on one plantation grown tree (From Farrar, 1961).
Change in distribution of the width of annual layers can be attributed to stand development and silvicultural treatment such as thinning and pruning (Farrar, 1961).

BOLE FORMATION THEORIES

This phenomena was explained by many scientists who developed several theories. In the 19th century Theodor Hartig proposed a nutritional theory. This theory explained uneven distribution of radial increment along the bole by availability of food within the tree. It was assumed that the quantity of food is directly related to the quantity of foliage above the point in question. In other words, maximum radial growth is achieved close to the base of the live crown and it diminishes above and below that point.

The conductive theory is based on the uniform flow of water from the root to the live crown. Jaccard found that dead branches reduce the cross-sectional area and the flow of water in to the crown. Increasing growth in the area of dead branches occurs in order to maintain a uniform flow of water because the cross-sectional area is increased at the same rate at which it was reduced by the dead branch.

The hormonal theory was developed in 1930 by F.W. Went who isolated a substance which was physiologically active in a very small concentration (Farrar, 1961). The evidence was obtained that the buds and leaves are the only producers of that substance which is phytohormone, known as auxin. Theodor Hartig in 1853 first made the observation that
cambial activity started at the base of expanding buds and spread along the branches and bole of the tree (Zimmerman, 1971). This was attributed to the presence of auxin which stimulates the division of cambial cells. Auxin moves downward from the buds towards the stem and into it, activating the cambium in the spring. This downward movement through the phloem may last for a few weeks. It has been proved by experiments that buds need not be present in order to activate the cambium. Debudded Pinus silvestris were able to produce auxin and activate the cambium in the presence of needles (Zimmerman, 1971). Once the cambium is activated it can produce its own auxin which will stimulate the division of cambial cells. Only simultaneous debudding and defoliation of Pinus strobus prevented activation of the cambium (Zimmerman, 1971).

The mechanistic theory developed in the last century by Schwendener and Metzger, is based on the force of the wind against the crown as a basic factor for uneven distribution in the size of annual rings at different heights. By this theory the force of wind causes bending stress within the tree, which is uniformly distributed along the branchless part of the tree. The amount of radial growth is proportional to the bending stress developed at various points of the bole.

Growth distribution shown in Figure 2 can not be explained by any of the existing theories. The nutritional theory which is based on amount of foliage above some point within the tree cannot explain the change in pattern of growth after thinning. As shown in Figure 2, a tree at age 21, in the first year after thinning, has vertical growth
distribution similar to the open grown tree. The size of the crown and amount of the foliage is the same as in the previous year prior to thinning when thickness of the annual layer at different heights is typical for stand grown trees.

The conductive theory failed to explain the same phenomenon. The number of dead branches within any cross section is the same as prior to thinning, which means that conductivity is not improved.

The hormonal theory is not able to give a satisfactory explanation of growth distribution within a live crown. Assuming that movement of auxin through the branches has uniform speed, then time of beginning and length of time of cambial activity within the trunk is a function of distance from the auxin producing bud to the trunk of the tree. Consequently, the maximum size of the annual ring must be at the top of the tree, which is not the case.

The most significant change after thinning is in environmental conditions such as exposure of residual trees to the sunlight and different microclimate. The residual trees will have an open grown tree vertical growth distribution until the crowns close again.

None of the theories describe fully the differences that appear within trees in distribution of earlywood, latewood, and whole rings. The analyses which will be described in this thesis document decadal and annual elements of ring growth and demonstrate substantial differences in temperature patterns within one tree. Much more work is needed, however, to evaluate fully the effects of temperature gradients and to relate existing partial explanations to a comprehensive theory of tree growth.
DESCRIPTION OF THE AREA

Locality of the Investigation

The study area lies at the southern part of the University of British Columbia Research Forest which is located about 35 miles east of Vancouver and 4 miles north of Haney.

The area was burned in 1868 and reforested to mixed forest of Douglas-fir, western hemlock and western redcedar. The Douglas-fir trees were first established after the fire providing the shade for younger western hemlock and western redcedar (Griffith, 1960). The area is within the Coastal Western Hemlock Zone, Wet Sub-zone. Vegetation at the sampling site is Moss type on Glacial outwash, Pseudotsugeto-Tsugetum Heterophylla Eurynchietosum Oregani (Krajina, 1959).

Estimated site index of the area is 150 (Douglas-fir) at age 100 years. At the present time average height of the stand is 130 feet.

Climate of the area

The climate of the area is the same as for the rest of the lower Fraser Valley, maritime and influenced by the mountains on the northern part of the Forest. Polar Pacific air is quite common, causing long rainy periods in fall and winter. Due to the influence of the Pacific Ocean the winters are warm but very wet for the latitude and the summers are usually hot and dry (Kendrew, 1955).
Precipitation

Precipitation on the Forest is similar to the rest of the Littoral Climatic Zone of British Columbia. Two periods can be distinguished; October to March is moist with an average monthly precipitation of 10.23 inches, and April to September with an average monthly precipitation of 4.27 inches.

Figure 3. Average precipitation for period 1958-1970 at Administration Building Weather Station.
Dry periods occur in June, July, and August with a 12 year average at the Administration Building area of 3.17, 2.40, and 3.76 inches of precipitation respectively. The maximum precipitation is in December and January with a 12 year average of 12.33 and 11.86 inches respectively.

Temperature

Temperature is featured with very mild winters and cool summers. Average temperature for the winter period is 39.33°F and for the summer period 61.60°F. Average maximum temperature is highest in July, 73.23°F, and lowest in January, 40.44°F. Average minimum temperature is lowest in January, 31.12°F and highest in July 53.29°F. (see Fig. 4).

Within the period 1958-1970 the coldest month was January, 1970 with a mean minimum temperature of 19.8°F and mean maximum temperature of 30.4°F, recorded at the Administration Building Weather Station.

In the same period the warmest month was August 1967 with a mean maximum temperature of 81.35°F and a mean minimum temperature of 54.85°F.
Figure 4. Maximum, minimum, and average temperature for period 1958-1970 at Administration Building Weather Station.

**Hours of bright sunshine**

Within the Research Forest the number of hours of bright sunshine is recorded only at the weather station on Spur 17, located 1.89 miles northeast of the Administration Building Weather Station. The number of rainy days at Spur 17 is the same as at the Administration Building and the total rainfall exceeds that of the Administration Building by only 9%.
Considering the proximity of Spur 17 to the Administration Building, and the similar climatological parameters, it is probable that the number of hours of bright sunshine would be similar.

The minimum number of hours of bright sunshine is in December, being 30.47 hours and the maximum is in July, being 240.80 hours (Fig. 5).

Figure 5. Monthly average of hours of bright sunshine recorded at Spur 17.
Climographs of the area

The two most important climate parameters, temperature and precipitation, were used in the construction of the climographs. Relationship between these two parameters determines the type of climate at any time of the year, gives the variability between the years (Appendix No. 1.), and climatic differences between different locations (Figs. 6 and 7).

Four types of climate can explain the variations within the year and they are determined on the following relationship between temperature and precipitation (Weiss, 1972).

AR. - Arid Climate is in the period of the year when the monthly precipitation (measured in mm) is less than double of the mean monthly temperature (measured in °C).

AR: Precipitation 2 x (monthly mean temperature)

SA. - Semi-arid Climate is within the period of the year when the monthly precipitation (measured in mm) is less than three times the monthly mean temperature (measured in °C).

SA: Precipitation 3 x (monthly mean temperature)

H. - Humid Climate is within the period of the year when the precipitation exceeds three times the mean monthly temperature, but it is less than 100 mm.

H: 100 mm precipitation 3 x (monthly mean temperature)
Climagraph
University of British Columbia Research Forest
Administration Weather Station

Elevation 470 feet
Yearly Average Temperature 49.23° F. (9.57° C.)
Yearly Average Precipitation 87.08 inches (2211.83 mm.)

Fig. 6. Climagraph for period 1958-1970. Administration Weather Station.
Climagraph
University of British Columbia Research Forest
Spur 17 Weather Station

Elevation 1285 feet
Yearly Average Temperature 48.06°F (8.92°C.)
Yearly Average Precipitation 95.67 inches (2430.01 mm.)

Fig. 7. Climagraph for period 1958-1970. Spur 17 Weather Station.
PH. - Perhumid Climate is within the period of the year when precipitation (measured in mm) exceeds double the value of the mean monthly temperature and is over 100 mm.

PH: Precipitation 100 mm and 2 x (monthly mean temperature)

From the climagraphs (Figs. 6 and 7) it can be seen that within the summer the climate is humid. Due to difference in the elevation, the humid period is longer at the Administration Building Weather Station (May-August) than at the Spur 17 Weather Station (June-August).

Within the rest of the year the climate is perhumid for both weather stations.

All climatic data indicate that the climate within the University of British Columbia Research Forest, as well as on the sampling site, is littoral with all the features which describe this type of climate.
EQUIPMENT AND SAMPLING

Equipment

The temperature measurements were recorded on charts for two years using a 24-channel Multi/riter recorder. The recording temperature range was 0 to 300F with accurate chart reading of 5F. Overall accuracy was better than 0.25 percent of the full scale, that is, the maximum error due to the recorder was 0.75F.

Temperatures were measured at four locations vertically and three or five locations horizontally with "Ceramo" metal sheeted, ceramic insulated thermocouple elements. Depending upon the place of application and installation requirements, four types of thermocouples were used:

1) For soil temperature measurements, protected thermocouples were used. This type of thermocouple is designed for application where the measuring environment would be detrimental to an exposed thermocouple element, such as corrosive liquids and gasses. In this construction, the magnesium oxide insulation is completely sealed from contamination and the measuring junction becomes an integral part of the tip of the thermocouple. Response time for change in temperature approaches that of an exposed thermocouple.

2) For temperature measurements in sapwood and heartwood, spring-loaded thermocouples were used. These are designed
for application where the sensing tip must maintain positive contact with the point of measurement. In this type the thermocouple conductors are welded together to form a junction which is insulated with magnesium oxide. The response time due to the insulators is slightly longer than that of the ceramic insulated thermocouples.

3) Shielded thermocouples were used for air temperature measurements. These have an exposed loop junction for a faster thermal response than the previous types described. An open, "T"-shaped, stainless steel shield over the measuring junction reduces the effect of radiant heat transfer between the bark and the exposed thermocouple.

4) For temperature measurements on the bark surface and in the inner bark, gasket thermocouples were used. A gasket thermocouple consists of insulated thermocouple wires, silver soldered to a circular metal gasket which then becomes the measuring junction. The thermocouples are supplied with a stainless steel support between the gasket and the thermocouple wire to relieve stress at the measuring junction. These thermocouple wires are insulated with fiberglass (Anon. 1966).
Sampling

Sampling was started at the end of July 1968 and was continued to the end of July 1970. Within this period, systematic sampling was used and temperatures were recorded every weekend starting Friday afternoon and continuing until Monday morning. In this way, temperatures for two continuous 24-hour periods were recorded. This kind of sampling was used throughout that period with the exception of the last week of August 1968, when temperatures were recorded for a full week in order to gain more information and to make up for time lost in the middle of August due to lack of recording charts.

This research was designed to gain information on the temperature of the tree by placing various types of thermocouples in different parts of the tree and in different environments.

The first set of thermocouples was placed at the root level, measuring the temperature of the soil, bark, and wood of the root. The root, 4 inches in diameter, was 10 inches below the surface of the soil. The soil temperature was measured with a protected thermocouple probe 6 inches long and 0.25 inches in diameter. This thermocouple was waterproofed by an extension fiberglass wire and the plastic covering of the connector above the ground.

For temperature measurements under the bark of the root, a standard gasket thermocouple was used. This was placed tangentially under the bark in order to cut down conduction of heat toward or away from the point of measurement. In the case of the radial bole, heat flow takes place and the probe is positioned to take heat away from
or towards the point of measurement. The magnitude of error caused by radial insertion of the probe would increase with the diameter of the probe and decrease with the depth of the point of measurement (Herrington, 1969).

A spring-loaded thermocouple without a lead was used for temperature measurements of the wood. The probe was 0.125 inches in diameter with the minimum length 1.5 inches and the maximum length 2.125 inches. In order to utilize the full length of the thermocouple, the probe was inserted into the wood through a radial hole 0.125 inches in diameter. As the depth of the hole was 2 inches and the probe was designed to give maximum protection from detrimental environmental conditions, the error due to radial insertion was negligible.

During sampling the position of the thermocouple was maintained by a hexagonal nut adaptor.

At 4.5 feet above the ground the temperature was measured at several locations.

Air temperature was measured with a shielded thermocouple, the measuring point being located 0.5 inches from the bark surface. The metal shield protected the exposed thermocouple wires from the radiation of the bark surface.

For measurements on the bark surface and under the bark, gasket thermocouples were inserted in the same way as in the root.

An increment borer sample was used to determine the depth of the sapwood. For sapwood measurements a spring-loaded thermocouple was used as described for the root measurements.
Heartwood temperatures were measured with a spring-loaded thermocouple 0.125 inches in diameter and a length range of 3.000-3.625 inches.

The same arrangement of thermocouples was used at 45 feet and 85 feet above the ground (Fig. 8).

Data were collected in full only for the first two months because the complete set of thermocouples at the 85-foot level was lost during a 45 m.p.h. gale on the night of Sept. 17, 1968. Due to lack of funds the lost probes were not replaced. The sampling done following this date was only for the root, the 4.5 foot, and the 45 foot levels.

Due to the excessive amount of data, it was felt that analyses covering a two month period would be most practical.

Block No. I represents the period of July 31 to August 25, 1968, the warm period of the year; and Block No. II represents the period from Dec. 1 to Dec. 29, 1968, the cold period of the year.

Two thermocouples, the air temperature probe and the probe located within the bark at the 45-foot level were damaged prior to the Block II period, and all records originating from these locations were discarded.
Fig. 8. Relative positions of sensors in bark, sapwood, and heartwood.
RESULTS

VERTICAL GROWTH DISTRIBUTION

In order to test theoretical growth distribution, and to fit a tree on which research was done into one of the known patterns, the amount of growth of earlywood, latewood, and complete annual rings was measured for a period of the last fifty years. Increments were taken at 1.0, 4.5, 15.0, 25.0, and every ten feet thereafter to the height of 85.0 feet. In order to minimize growth variation from year to year, average width of annual rings for a period of ten years is considered sufficient to provide a picture of tree development. Increments for the last eleven years, for which accurate meteorological data are available, are shown separately in order to illustrate variation from year to year.

From Figure 9, one can see that in the early stage of development, 1921-1930, vertical distribution of the width of annual rings resembles the growth pattern of a suppressed tree. This possibility was confirmed with aerial photographs of the area taken prior to major development in recent years. West of this sampled tree, two probably old growth Douglas-fir trees provided a sufficient amount of shade to cause such growth distribution. The most striking feature in growth distribution in this stage of tree development is the amount of earlywood at the height of 85 feet. Earlywood at that height exceeds latewood by 3.8 times and can account for 79.3 percent of the total annual
Fig. 9. Average widths and vertical distribution of earlywood, latewood, and total annual rings for period 1921–30, 1931–40, 1941–50 and 1951–60.
Fig. 10. Average width and vertical distribution of earlywood, latewood, and total annual rings for period 1961-70.

ring. Minimum width of the annual rings occurs at a height of ten feet above the ground, and it is exceeded by 4.4 times at the maximum at 85 feet. The place of maximum width of annual rings at that height shows that for Douglas-fir, maximum width is not below the crown but somewhere in the upper half of the crown. This is confirmed by Smith (1973) who found that the maximum width of earlywood occurs at the base of the full crown where needles persist to the bole of the tree. Maximum width of latewood occurs below the live crown. Maximum width of annual ring is close but below the place of maximum width of earlywood.

The period 1931-1940 indicates dominance of the sampled Douglas-fir
tree within the stand. Minimum width of the annual rings is still at the height of 15 feet. The new features within the sample height are two maximums of width of annual rings. The first maximum is close to the ground and the second is at 85 feet with strong indications that the true maximum is above this height. From Figure 9 one can see that the maximum width in the upper part of the tree is due to the width of earlywood which at 85 feet exceeds latewood by 3.2 times as compared with 1.7 at 15 feet. Width of latewood from 15 feet to 85 feet is the same. In contrast, earlywood increases. Width of latewood at 85 feet exceeds that at 25 feet by 14 percent as compared with earlywood which exceeds by 118 percent. This is confirmed by Heger (1965) and Smith et al. (1966) who found that earlywood and latewood are distributed differently and controlled by different factors.

Growth distribution of the width of annual rings in the period 1941-1950 is very close to the pattern described as a typical open-grown tree pattern. The maximum width of the annual rings is close to the ground. From the height of 15 to 65 feet, size of annual rings is uniform, except for small variations, and it reaches its minimum at 85 feet. This distribution of width of annual rings is conditioned by latewood since earlywood has uniform width. This pattern of growth distribution cannot be explained by any existing theories because growth conditions were similar in the previous period. One possible explanation which can be offered is that Douglas-fir, in certain stages of development, does not fit a pattern of growth development
by the stand. In this case a stand grown tree is producing growth typical of an open grown tree.

A similar growth pattern is seen in the next period, 1951-1960 in which the area was opened and the tree more exposed to an open grown environment.

Vertical growth distribution in the period 1961-1970 again resembles that of a suppressed tree, despite the fact that further clearing of the environs opened the area west of the tree. Due to this development one would expect growth distribution to be similar to that of an open grown tree, or a stand grown tree, assuming that the opening was not sufficient for a significant change in the growth pattern. The minimum width of annual rings is at ground level and its maximum is at 85 feet.

Investigation of the 1961-1970 period on a year to year basis shows three groups of vertical growth patterns. In 1960 and 1961, it is an open grown pattern, 1962 to 1968, a suppressed tree growth pattern, and 1968 to 1971 a pattern which does not resemble any of the basic patterns previously described (Figs. 11-16). In 1969 and 1970 the maximum width of annual rings as well as of earlywood and latewood moves from the crown area into the middle of the trunk well below the live crown. Assuming that the size of the annual rings is the function of the length of the growing season, and the maximum length of the growing season is within the crown due to early presence of auxin, this is quite unexpected. Instead of an expected maximum within the crown at its lower part, we have a minimum. The maximum
Fig. 11. Width of earlywood, latewood, and annual ring 1960 and 1961.

Fig. 12. Width of earlywood, latewood and annual ring 1962 and 1963.
Fig. 13. Width of earlywood, latewood, and annual ring 1964 and 1965.

Fig. 14. Width of earlywood, latewood, and annual ring 1966 and 1967.
Fig. 15. Width of earlywood, latewood, and annual ring 1968 and 1969.

Fig. 16. Width of earlywood, latewood, and annual ring 1970.
is at a height of 45 feet and it exceeds the minimum by 201 percent. A possible explanation is that in 1967 a steel tower was erected and some branches of the sampled tree and one suppressed hemlock tree were removed in order to accommodate the tower. Furthermore, in 1968 and 1969 measurements for several projects were made at all three levels and for these measurements a number of instruments were attached to the tree which further complicates the problem. The climate of the area within the period can be ruled out because climagraphs for these years do not show any unusual features. The climate was humid and perhumid with the exception of August 1970 when there was a short period of arid climate which is not an unusual feature in summer.

The lowest increment within the last eleven years was in 1962, the year in which the area west of the tree was cleared. A possible explanation for such an increment is the shock due to change of environment. The same change is a possible reason for increased production of earlywood and latewood in the upper part of the trunk. In the period 1962-1967, vertical distribution of the widths of annual rings resembled that of a suppressed tree. Growth in the lower part of the trunk was similar to that of the previous period. The increase was in the upper part of the tree, in the earlywood as well as in the latewood, due to the change of light and microclimate.

Ten year averages show different stages in development of a Douglas-fir and a period of stabilized distribution up to 1960. The period 1960-1970 is featured by significant and frequent changes which
most likely can be attributed to the change in the environment. From the graphs representing distribution of earlywood, latewood, and complete annual rings, one can see that the significance of each part of the annual ring is not the same. This is in agreement with Heger (1965) who found that the form of earlywood layers differed from that of latewood. Smith et al. (1966) found that variation in thickness of earlywood and total annual rings is most significantly associated with the number of rings from the pith or reciprocal of number of rings from the pith.

Since the number of annual rings within the same tree is a function of the height one can say that the most important influence on the width of annual rings, earlywood, and latewood is the height at which the annual ring and its components are measured.

TEMPERATURE PROFILE OF THE TREE

Temperature measurements recorded during 1968 are divided into two periods. Period one consists of recordings made at the end of July and during August and it represents the temperature profile of the tree within the growing season. Temperature profile of the dormant period of the tree is represented by the measurements made in December 1968 and it is considered as period number two.

The first period is more interesting, not only because it represents the productive period of the year, but also because the data are more complete. Within the period due to daily macroclimatic differences, one can distinguish two sub-periods. The first sub-period
consists of recordings made on July 30, 31, and August 1 and 2, 1968. The common denominator for these four days is that the maximum temperature recorded at the Administration Building weather station was in the eighties, minimum temperature in the fifties, precipitation nil, and there was 10.5 - 13.3 hours of bright sunshine (Table 1).

Temperatures of the trees representing the second sub-period was recorded on August 22, 23, 24, and 25, 1968. This sub-period represents the rainy period of the summer. Meteorological statistics recorded at the Administration Building are: maximum 58 to 68F, minimum 54 to 50F, precipitation 0.03 to 0.74 inches and 0.0 to 4.5 hours of bright sunshine (Table 1).

Macroclimatic data recorded at the Administration Building in December 1968 are given in Table 2.

The temperature data were analysed on an IBM 360, Model 67 computer using analysis of variance programme described by Dempster and Starkey, 1970. Three way classification was used having the model:

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>D.F:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical temperature</td>
<td>(V-1)</td>
</tr>
<tr>
<td>Block</td>
<td>(B-1)</td>
</tr>
<tr>
<td>Horizontal temperature</td>
<td>(H-1)</td>
</tr>
<tr>
<td>Interaction vert. x block</td>
<td>(V-1) (B-1)</td>
</tr>
<tr>
<td>Interaction block x horizontal</td>
<td>(B-1) (H-1)</td>
</tr>
<tr>
<td>Interaction vert. x block x hor.</td>
<td>(V-1) (B-1) (H-1)</td>
</tr>
<tr>
<td>Experimental error</td>
<td>V H B (Q-1)</td>
</tr>
<tr>
<td>Total</td>
<td>VHB Q</td>
</tr>
</tbody>
</table>
Table 1. Macroclimatic statistics July 30 to August 25, 1968 (Period 1) recorded at Administration Building.

<table>
<thead>
<tr>
<th>Day</th>
<th>Date</th>
<th>Maximum Temperature °F</th>
<th>Minimum Temperature °F</th>
<th>Precipitation Inches</th>
<th>Sunshine Hours</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>July 30</td>
<td>84</td>
<td>54</td>
<td>0</td>
<td>12.9</td>
<td>Tenth day without rain</td>
</tr>
<tr>
<td>2</td>
<td>July 31</td>
<td>86</td>
<td>54</td>
<td>0</td>
<td>13.3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Aug. 1</td>
<td>84</td>
<td>58</td>
<td>0</td>
<td>13.1</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Aug. 6</td>
<td>71</td>
<td>47</td>
<td>0</td>
<td>10.5</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Aug. 22</td>
<td>60</td>
<td>53</td>
<td>.74</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Aug. 23</td>
<td>61</td>
<td>54</td>
<td>.69</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Aug. 24</td>
<td>68</td>
<td>51</td>
<td>.03</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Aug. 25</td>
<td>58</td>
<td>53</td>
<td>.66</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
Table 2. Macroclimatic statistics Dec. 1 to Dec. 29, 1968 (Period 2) recorded at Administration Building.

<table>
<thead>
<tr>
<th>Day</th>
<th>Date</th>
<th>Maximum Temperature °F</th>
<th>Minimum Temperature °F</th>
<th>Precipitation Inches</th>
<th>Sunshine Hours</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dec. 1</td>
<td>40</td>
<td>32</td>
<td>.27</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Dec. 7</td>
<td>46</td>
<td>33</td>
<td>1.27</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Dec. 14</td>
<td>54</td>
<td>40</td>
<td>.09</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Dec. 15</td>
<td>46</td>
<td>42</td>
<td>.46</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Dec. 21</td>
<td>34</td>
<td>25</td>
<td>.40</td>
<td>.1</td>
<td>4 inches of snow</td>
</tr>
<tr>
<td>6</td>
<td>Dec. 22</td>
<td>41</td>
<td>29</td>
<td>1.01</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Dec. 28</td>
<td>6</td>
<td>1</td>
<td>0.0</td>
<td>6.5</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Dec. 29</td>
<td>9</td>
<td>-4</td>
<td>0.0</td>
<td>6.8</td>
<td></td>
</tr>
</tbody>
</table>
The significance of differences between various points of measurements is given in Table 3. In this table, points of measurement are within the trunk of the tree. Table 4 represents the results for the same period but taking into account root temperature as a fourth level of sampling.

F values for the winter period of the year are listed in Table 5 showing the differences between root, 4.5, and 45.0 feet above the ground.

A graphical presentation of actual measurements of one hot summer day is shown in Figures 17, 18, and 19. Figure 17 shows the cooling and heating process at breast height which is quite slow and reaches maximum temperature at 5 p.m. The graph showing temperatures at 85.0 feet is another extreme, Figure 19. After the cooling process is finished, from 6 to 10 a.m. temperature of the bark is raised by 17.2°F as compared to the height of 4.5 feet above the ground. From the same figures, one can see that the times of occurrence of maximum and minimum temperatures at different points of measurement within the same vertical level are different. With the increased depth in the wood, maximum and minimum temperatures occur later as compared to the place of energy exchange. Regression lines which can describe expected time of maximum temperature are different for different heights and dependent on diameter at the measuring point. Regression equations for period one which give a time of occurrence of maximum temperature are:

\[ Y = 15.67 + 1.06 X \quad \text{at breast height (1)} \]
\[ Y = 14.56 + 1.20 X \quad \text{at 45 feet (2)} \]
Table 3. F values for measurements above the ground, Period 1.

Vertical levels: 4.5, 45.0, and 85.0 feet.

<table>
<thead>
<tr>
<th>Day</th>
<th>Vertical</th>
<th>Block</th>
<th>Horizontal</th>
<th>V x B</th>
<th>V x H</th>
<th>B x H</th>
<th>V x B x H</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>62.18**</td>
<td>276.57**</td>
<td>1.42</td>
<td>2.38</td>
<td>0.72</td>
<td>18.91**</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>63.46**</td>
<td>163.75**</td>
<td>0.40</td>
<td>1.00</td>
<td>0.84</td>
<td>14.02**</td>
<td>0.51</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>66.16**</td>
<td>159.43**</td>
<td>1.01</td>
<td>1.45</td>
<td>0.98</td>
<td>15.53**</td>
<td>0.67</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>22.46**</td>
<td>198.18**</td>
<td>1.02</td>
<td>2.60</td>
<td>0.13</td>
<td>16.38**</td>
<td>0.74</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>57.94**</td>
<td>212.12**</td>
<td>6.26**</td>
<td>2.37</td>
<td>0.40</td>
<td>13.39**</td>
<td>0.88</td>
<td>Horizontal levels 1,2,4,5</td>
</tr>
<tr>
<td>6</td>
<td>88.72**</td>
<td>185.22**</td>
<td>0.10</td>
<td>5.31**</td>
<td>0.18</td>
<td>10.22**</td>
<td>0.88</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>57.62**</td>
<td>184.77**</td>
<td>0.26</td>
<td>6.76**</td>
<td>0.41</td>
<td>20.31**</td>
<td>1.32</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>158.87**</td>
<td>41.36**</td>
<td>63.57**</td>
<td>5.42**</td>
<td>4.14**</td>
<td>13.66**</td>
<td>1.30</td>
<td></td>
</tr>
</tbody>
</table>

** Highly significant - level of significance 0.5%
Table 4. F values for all measurements, Period 1.

Vertical levels: root, 4.5, 45.0, and 85.0 feet.

<table>
<thead>
<tr>
<th>Day</th>
<th>Vertical</th>
<th>Block</th>
<th>Horizontal</th>
<th>V x B</th>
<th>V x H</th>
<th>B x H</th>
<th>V x B x H</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>125.36**</td>
<td>215.87**</td>
<td>3.88</td>
<td>10.98**</td>
<td>0.50</td>
<td>13.89**</td>
<td>1.24</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>128.39**</td>
<td>131.44**</td>
<td>2.05</td>
<td>6.79**</td>
<td>0.60</td>
<td>10.91**</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>120.76**</td>
<td>121.64**</td>
<td>0.53</td>
<td>6.24**</td>
<td>1.64</td>
<td>10.02**</td>
<td>1.30</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>23.08**</td>
<td>161.05**</td>
<td>0.70</td>
<td>7.79**</td>
<td>0.17</td>
<td>11.77**</td>
<td>1.02</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>23.34**</td>
<td>158.25**</td>
<td>0.68</td>
<td>4.77**</td>
<td>0.04</td>
<td>0.18</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>40.92**</td>
<td>123.04**</td>
<td>0.11</td>
<td>5.49**</td>
<td>0.11</td>
<td>0.26</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>22.91**</td>
<td>146.96**</td>
<td>0.01</td>
<td>7.65**</td>
<td>0.27</td>
<td>0.34</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>36.39**</td>
<td>49.35**</td>
<td>1.29</td>
<td>3.97**</td>
<td>0.40</td>
<td>0.16</td>
<td>0.13</td>
<td></td>
</tr>
</tbody>
</table>

** Highly significant - level of significance 0.5%
Table 5. *F* values for Period 2.

Vertical levels: root, 4.5, and 45 feet.

<table>
<thead>
<tr>
<th>Day</th>
<th>Vertical</th>
<th>Block</th>
<th>Horizontal</th>
<th>V x B</th>
<th>V x H</th>
<th>B x H</th>
<th>V x B x H</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>36.53**</td>
<td>40.09**</td>
<td>14.46**</td>
<td>4.62</td>
<td>14.20**</td>
<td>8.94**</td>
<td>1.94</td>
<td>Mild</td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>346.51**</td>
<td>25.43**</td>
<td>120.69**</td>
<td>10.13**</td>
<td>99.78**</td>
<td>30.27**</td>
<td>9.74**</td>
<td>Cold</td>
</tr>
<tr>
<td>6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>7808.21**</td>
<td>92.80**</td>
<td>639.14**</td>
<td>16.48**</td>
<td>69.67**</td>
<td>37.73**</td>
<td>10.85**</td>
<td>Very cold</td>
</tr>
<tr>
<td>8</td>
<td>9720.06**</td>
<td>68.42**</td>
<td>133.70**</td>
<td>29.62**</td>
<td>136.51**</td>
<td>4.18</td>
<td>3.36</td>
<td>Very cold</td>
</tr>
</tbody>
</table>

** Highly significant - level of significance 0.5%
\[ Y = 15.80 + 0.79 \, X \] at 85 feet (3)

In the equations \( X \) value for bark surface is 1 and range of data is from bark surface to 3.5 inches into the wood.

Figures 21 to 30 represent graphical presentations of actual temperature measurements at the same depth but at the different levels. From the Figures 21 to 25 one can see that under clear sky conditions the temperatures are higher with the height of sampling point at any time of the day or night. In cloudy conditions the mean temperatures are higher with the height of sampling point but they overlap each other due to small differences between the temperatures, Figures 26 to 30.
DISCUSSION

As expected, results of the analyses of variance show highly significant differences between different vertical levels. Duncan's Multiple Range Test shows that any of the two means differ significantly and the highest temperatures are at 85 feet above the ground. This high temperature at the upper part of the trees may be one of the significant influences on the width of annual rings.

The difference between the blocks, where each block represents a period of six hours, is also highly significant. This difference is not only due to different means but also because of different temperature trends in each of the blocks. For the first six hours the temperature trend is downward due to the cooling process. For the next two periods the trend is upward due to the heating process, and this is succeeded by the cooling process and downward trend, Figures 17 to 20. The temperature trend within each block depends on the depth of the point of measurement and with increased depth and diameter at the point of measurement a shift to the right occurs, as in the case of heartwood at 4.5 feet, Figure 17. The expected shift to the right due to depth and diameter is given by regression equations 1, 2, and 3.

Differences between temperatures at the horizontal levels are not significant in the summer period due to the very small differences between the means, Tables 3 and 4.

Table 3 shows highly significant interaction between the blocks
<table>
<thead>
<tr>
<th>Location of thermocouple</th>
<th>Maximum Temperature</th>
<th>Minimum Temperature</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>81.0</td>
<td>61.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Bark surface</td>
<td>79.5</td>
<td>62.0</td>
<td>17.5</td>
</tr>
<tr>
<td>Inside of bark</td>
<td>76.7</td>
<td>62.5</td>
<td>14.2</td>
</tr>
<tr>
<td>Sapwood</td>
<td>73.5</td>
<td>65.0</td>
<td>8.5</td>
</tr>
<tr>
<td>Heartwood</td>
<td>71.0</td>
<td>66.5</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Figure 17. Stem temperature changes on August 1, 1968 at 4.5 ft. above the ground.
Location of thermocouple | Maximum Temperature | Minimum Temperature | Range
--- | --- | --- | ---
Air | 85.3 | 62.0 | 23.3
Bark surface | 82.0 | 62.7 | 19.3
Inside of bark | 82.0 | 62.7 | 19.3
Sapwood | 79.8 | 66.5 | 13.3
Heartwood | 78.0 | 70.3 | 7.7

Figure 18. Stem temperature changes on August 1, 1968 at 45.0 ft. above the ground.
Figure 19. Stem temperature changes on August 1, 1968 at 85.0 ft. above the ground.
Figure 20. Stem temperature changes on August 22, 1968 at 4.5 ft. above the ground.
and horizontal temperatures. The significance of this interaction can be attributed to the shift of sapwood and heartwood temperature waves to the right, Figure 17. The other factor which may be contributing to the significance of this interaction is the difference in the speed of heating, depending upon the depth of wood. This is causing a difference in temperature slopes within the blocks.

In Table 4 horizontal temperatures are only for the environment in which measurements are taken, the barkwood and the sapwood. It shows significant interaction between blocks and horizontal temperatures only on sunny days. In cloudy conditions interaction is not significant because of the minimal shift and the minimal daily temperature change within any point of measurement. At the same time interaction between vertical gradients and blocks is significant which was not the case in Table 3. It is obvious that this significance of interaction is due to root temperatures which are more stable than the temperatures of the stem. In some of the blocks temperature changes of the root within the block are insignificant as compared with temperature changes in the stem or in the air, Figures 21, 22, 24, 26, 27, and 29.

The high significance for blocks and significance of differences between vertical levels in Table 4 can be explained in the same way as in Table 3.

Table 5 shows results of analyses of variance for data collected in December 1968. On the majority of these days there is a high significance of each of the sources of variation. These significances are due to measurements in the soil and open air environment and the
Figure 21. Temperature of the environment on August 1, 1968.

Figure 22. Temperature of the bark surface at different vertical levels on August 1, 1968.
Figure 23. Temperature inside of the bark at different vertical levels on August 1, 1968.

Figure 24. Temperature of the sapwood at different vertical levels on August 1, 1968.
Figure 25. Temperature of the heartwood at different vertical levels on August 1, 1968.
Figure 26. Temperature of the environment on August 22, 1968.

Figure 27. Temperature of the bark surface at different vertical levels on August 22, 1968.
Figure 28. Temperature inside of the bark at different vertical levels on August 22, 1968.

Figure 29. Temperature of the sapwood at different vertical levels on August 22, 1968.
Figure 30. Temperature of the heartwood at different vertical levels on August 22, 1968.
differences between the two. At the same time the test was extremely sensitive and minimal differences were picked up due to the large degree of freedom for experimental error. Temperature differences within this period do not have the same importance to the annual ring formation as temperatures within the growing season. It should be noted that root temperature is higher than stem temperature. This temperature difference could explain the early beginning of root cambial activity.

Temperature differences within the growing season are more important and can be offered as part of the explanation for the different size of annual rings at different heights.

Temperature, as well as light, is one of the important environmental factors in tree growth and development. Temperature influences physiological activities of the plant through its effect on the rate of metabolism (Zimmerman, 1971). Plant requirements in regard to temperature are expressed in terms of optimum temperature and upper and lower temperature limits. Plant exposure to temperatures above or below optimum temperature will produce lengthening of time of development and plant growth (Lowry, 1970). Cytoplasmic streaming in the cambium is an important indicator of cambial activity and can be affected by the temperature and the time of year. At the temperature of -1°C there is no streaming. Between 5°C and 34°C there is a linear increase in rate of streaming followed by a sharp drop between 34°C and 42°C. Exposure of the cambial cells of Pinus silvestris to a temperature of 40-42°C for two or three minutes was lethal (Thimann et al., 1957). The optimum
temperature and limits are not well defined because of different species and the change of temperature requirements for the same species through the development stages.

The beginning of cambial activities is not only dependent on air temperature but even more on soil temperature. In independently controlled soil and air environment, at the constant soil temperature of 40F and air temperature of 80F during the day and 60F during the night, the growth of the Douglas-fir seedlings was nil. The first sign of new growth was noticed when the soil temperature was raised above 40F (Hocking, 1972). Significance of temperature on root growth was demonstrated in controlled environmental conditions, where the root medium was maintained at three temperature levels. The root temperature was controlled at 1.7, 4.4, and 7.2°C, and the dormant shoots were maintained at 15°C at day time and 10°C at night. Cambial activity of the shoots was not recorded for any combination of temperatures, but significant root growth was recorded for Taxus and Forsythia plants maintained at 4.4°C and 7.2°C (Meyer, 1967). The diameter growth of roots commences before the growth of any other part of the plant because the minimum temperature requirement for root growth is lower than that of the stem or the branches (Amilon, 1910).

Before any diameter growth can take place the cambium must reach a temperature which is above a minimum required for the start of cambial activity. Since the temperature of the trees is conditioned by the environment, thickness of bark, which has a very low heat conductivity, is one of the significant factors on the time of initial diameter growth.
The investigation shows that thin-barked species had started diameter growth earlier than thick-barked species (Amilon, 1910). Favourable temperature conditions in the beginning of the growing season can cause a faster diameter growth due to the number of cell layers which is higher than in a cold year. In cold periods there is little or no wood formation (Zumer, 1969). The production of lammas shoots and false annual rings was influenced more by environmental than genetic factors (Walters, 1961). Smith (1973) found that climate influenced growth more than any other factor including fertilization. Sudden and severe temperature changes such as a frost reduced the growth. High spring and summer temperatures promoted the growth of earlywood but curtailed the growth of latewood.

Temperature is not only related to the rate of cambial division, but also to the length of tracheids. Increased night temperature up to 25°C caused an increased diameter growth and tracheid length as compared to control plots in one-year-old *Sequoia sempervirens* and Douglas-fir seedlings. A temperature bridge which maintained a temperature 5°C above the ambient showed the effect of temperature on the tracheid length of Sitka spruce seedlings. After a period of six weeks, tracheid lengths were measured within the bridge and below it. It was found that cells within the bridge were significantly longer than below the bridge where the temperature was lower (Brown, 1970).

All these examples indicate the significance of temperature on
tree growth. It also indicates that temperature may be one of the factors in the bole formation.
CONCLUSION

Tree ring analysis of the sampled dominant Douglas-fir tree shows that Douglas-fir may fit theoretical diameter growth distribution only in the early stages of development. In the thrifty stage, growth below the crown shows small variations. This is not the case with other species. It also shows the extreme sensitivity of Douglas-fir growth to environmental changes and as a reaction a shift of maximum width of annual rings below the crown. In early stages of development, the maximum width of the annual rings is in the middle or in the upper part of the crown which may be attributed to temperature requirements and actual temperatures within the crown.

Temperature measurements indicate that the highest temperatures are expected to be in the upper part of the tree. Direct temperature correlation with the amount of growth of annual rings is difficult to prove. By comparison of actual data for growth and temperature, one can conclude that there is a very good chance that temperature may be one of the significant variables on amount of growth in various parts of the tree. Perhaps a similar experiment should be repeated with temperature measurements taken on several dominant, codominant, and suppressed trees. At the same time one could maintain the temperature of one part of the trunk at a lower limit of cambial activity and compare the growth within that part with the rest of the
Recognizing the fact that temperature requirements are different for various species and even for the same species, and that they vary with the stage of development, one can say that cambial activity will not start until the temperature of the cambium reaches the lower temperature limit. This lower temperature limit will be reached at different times in different parts of the tree. It will be reached first within the crown and last within the lower part of the tree. Because of this difference, length of growing season is different in various parts of the tree.

The other variable is optimum growth temperature, its length, and the time of the year when it occurs. If optimum temperature is reached early in the year and stays for some length of time, it will cause a larger annual ring within the part affected. If that temperature is reached during the dry season, the temperature advantage is lost due to the unsatisfactory conditions of other variables on which the growth depends.

In order to determine the significance of temperature as a factor influencing distribution of radial growth in tree boles, further research is needed.
BIBLIOGRAPHY


APPENDIX

Climagraphs of the area for period 1960-1970.
Climagraph 1960
University of British Columbia Research Forest Administration Weather Station

Elevation 470 feet
Monthly Average Temperature 9.40°C.
Monthly Average Precipitation 164.80 mm.
Climagraph 1961
University of British Columbia Research Forest Administration Weather Station

Elevation 470 feet
Monthly Average Temperature 9.60°C
Monthly Average Precipitation 208.89 mm.
Climagraph 1962
University of British Columbia Research Forest Administration Weather Station

Elevation 470 feet
Monthly Average Temperature 9.37°C
Monthly Average Precipitation 186.79 mm.
Climagraph 1963
University of British Columbia Research Forest Administration Weather Station

Elevation 470 feet.
Monthly Average Temperature \(9.75^\circ C\)
Monthly Average Precipitation 174.41 mm.
Climagraph 1964
University of British Columbia Research Forest
Administration Weather Station.

Elevation 470 feet
Monthly Average Temperature 8.70°C
Monthly Average Precipitation 201.37 mm.
Climagraph 1965
University of British Columbia Research Forest
Administration Weather Station

Elevation 470 feet
Monthly Average Temperature 9.46°C
Monthly Average Precipitation 161.38 mm.
Climagraph 1966
University of British Columbia Research Forest
Administration Weather Station

Elevation 470 feet
Monthly Average Temperature 9.45°C.
Monthly Average Precipitation 199.91 mm.
Climagraph 1967
University of British Columbia Research Forest
Administration Weather Station

Elevation 470 feet
Monthly Average Temperature 10.26°C.
Monthly Average Precipitation 196.35 mm.
Climagraph 1968
University of British Columbia Research Forest Administration Weather Station

Elevation 470 feet.
Monthly Average Temperature 9.49°C.
Monthly Average Precipitation 216.17 mm.
Climagraph 1969
University of British Columbia Research Forest
Administration Weather Station

Elevation 470 feet
Monthly Average Temperature 9.22°C.
Monthly Average Precipitation 154.70 mm.
Climagraph 1970
University of British Columbia Research Forest Administration Weather Station

Elevation 470 feet
Monthly Average Temperature 9.25°C
Monthly Average Precipitation 162.62 mm