Vertical growth in four species of pines in Indiana

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(1929-1964)

Edited by

Ray C. Friesner

The Butler University Botanical Studies journal was published by the Botany Department of Butler University, Indianapolis, Indiana, from 1929 to 1964. The scientific journal featured original papers primarily on plant ecology, taxonomy, and microbiology. The papers contain valuable historical studies, especially floristic surveys that document Indiana's vegetation in past decades. Authors were Butler faculty, current and former master's degree students and undergraduates, and other Indiana botanists. The journal was started by Stanley Cain, noted conservation biologist, and edited through most of its years of production by Ray C. Friesner, Butler’s first botanist and founder of the department in 1919. The journal was distributed to learned societies and libraries through exchange.

During the years of the journal's publication, the Butler University Botany Department had an active program of research and student training. 201 bachelor's degrees and 75 master's degrees in Botany were conferred during this period. Thirty-five of these graduates went on to earn doctorates at other institutions.

The Botany Department attracted many notable faculty members and students. Distinguished faculty, in addition to Cain and Friesner, included John E. Potzger, a forest ecologist and palynologist, Willard Nelson Clute, co-founder of the American Fern Society, Marion T. Hall, former director of the Morton Arboretum, C. Mervin Palmer, Rex Webster, and John Pelton. Some of the former undergraduate and master's students who made active contributions to the fields of botany and ecology include Dwight W. Billings, Fay Kenoyer Daily, William A. Daily, Rexford Daubenmire, Francis Hueber, Frank McCormick, Scott McCoy, Robert Petty, Potzger, Helene Starcs, and Theodore Sperry. Cain, Daubenmire, Potzger, and Billings served as Presidents of the Ecological Society of America.

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VERTICAL GROWTH IN FOUR SPECIES OF PINES IN INDIANA

By Ray C. Friesner

The time and character of height growth in conifers has been studied by several American investigators but, so far as is known to the writer, these studies have included only two species of pines and all have been done in New York or New England States. These previous studies have included the following areas and species: *Pinus resinosa*, New York, Baldwin (1), Cook (2), Tryon and Fimm (6); Connecticut, Kienholz (4); New Hampshire, Kienholz (3); *Pinus strobus*, Connecticut, Stevens (5). Since an opportunity was afforded on the author's own plantings in Brown County, Indiana, to study these two species and *Pinus sylvestris*, in addition, and to study an additional species, viz. *P. banksiana*, on the nearby plantings of Mr. Charles Youngman, it was thought worthwhile to present these data on these additional species and on species previously studied but from a different geographical area. The work of Cook (2) and Kienholz (4) were published several months after the present work was well under way and did not come to the writer's attention until after the present data were complete.

**METHODS**

On March 22, 1941, 50 specimens each of *Pinus strobus*, *P. resinosa*, *P. sylvestris* and *P. banksiana* were selected for study. The lengths of the terminal bud, the height, and the approximate age of each tree was noted and each was marked by a number inscribed with India ink on a linen tag. The approximate age of each species except *P. banksiana* was determined by counting the number of annual "internodes" of growth present. These trees showed from 3 to 8 "internodes" of growth. The individuals of *P. resinosa* and *P. sylvestris* were transplanted in April, 1936, while those of *P. strobus* were of two lots, one transplanted in April, 1936, and the other in April, 1938. The individuals of *P. banksiana* were transplanted in April, 1938. It is thus apparent that all specimens had become well established. At the beginning of the observation period the specimens of *P. strobus* showed a height range of 19-312 cm; the range for *P. resinosa* was 56-178 cm, that for *P. sylvestris* was 77-294 cm, and for *P. banksiana* it was 71-154 cm.
Measurements were made by sliding a short arm attached at right angles on a vertical millimeter scale, the bottom of the latter resting each time on a rust-proof pin which completely pierced the stem within the level of the topmost false whorl of lateral branches. The upper limit of measurement was the tip of the growing point of the twig and, as soon as it was formed, the tip of the terminal bud containing the next year's primordia. Measurements were taken weekly from March 31 to October 16 and a final one on December 4, 1941. All were made to the nearest mm.

All specimens except those of *P. banksiana* were on a hillside with gentle to moderate slope and with north, west, and northwest exposure. Those of the latter species were on a nearly level site on top of a ridge. The entire area belongs to the so-called Knobs area of Indiana. This area is characterized in its native condition by *Quercus alba*, *Q. velutina*, *Q. montana*, *Carya ovata*, *C. glabra* and *C. ovalis*.

The area receives an average-expected annual rainfall of 40.46 inches. That for the year during which the measurements were taken was 32.80 inches which is 81.07% of the normal-expected for this area. From table I it will be seen that rainfall for the first 5 months of the year 1941 was much below the normal-expected. Not until June, when most of the growth in most of the specimens was over, did rainfall exceed the usual. The site is approximately 1,100 feet above sea level.

**RESULTS**

**CHARACTER OF ELONGATION CURVES**

Vertical growth was begun by all species during the week ending April 13. From table II it will be seen that every individual of *P. banksiana*, 82% of *P. sylvestris*, 96% of *P. resinosa* and 30% of *P. strobus* began growth during this week. The majority (66%) of individuals of *P. strobus* and 16% of *P. sylvestris* began the following week while two individuals of *P. strobus* and one of *P. sylvestris* were delayed until the third week.

Individual curves were plotted showing the course of the growth activity for each of the 200 trees studied. A careful survey of these curves showed that they fall into 9 different types, one each of which is shown in curves A to I inclusive in figure 1. These curve types may be characterized as follows:

Curves of type A (fig. 1) are essentially symmetrical, i.e., after one or two weeks of slower growth they rise steeply to a maximum
an arm attached at right
end of the latter resting
entirely pierced the stem
lateral branches. The
growing point of the
of the terminal bud con-
ents were taken weekly
on December 4, 1941.
were on a hillside with
and northwest expo-
early level site on top
called Knobs area of
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. plana and C. ovata.
annual rainfall of 40.46
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. sylvestris
the course of the growth
careful survey of these
types, one each of which
1. These curve types
symmetrical, i.e., after
steeply to a maximum
and then decrease in a very similar, except inverse, order to the midsummer zero. All curves of all types show somewhat oscillating small amounts of elongation for a number of weeks following the midsummer zero period. This will be discussed after the character of the main growth has been disposed of. Curves of type A are not frequent. Table III gives the frequency of the various types of growth curves exhibited by these four species of pines and there it will be noted that curves of type A occur in 6 individuals of *P. resinosa*, 3 of *P. sylvestris*, 1 of *P. banksiana* and none of *P. strobos*

This makes a total of but 5% of all of the curves.

Curves of type B (fig. 1) differ from those of type A primarily in that there is a less conspicuous initial drag, the curve rises more steeply to the peak and descends less rapidly and over a longer period of time to the midsummer zero point. Curves of type B are thus steeper on the left than on the right. This type of curve is somewhat more frequent than type A and occurs (table III) in 3 individuals of *P. strobos*, none of *P. resinosa*, 7 of *P. sylvestris*, and 9 of *P. banksiana* making a total of 9.5% of all individuals measured. It is worthy of note that, while this is the type of curve shown for *P. resinosa* by Kienholz (4), it is not exhibited by a single individual of this species in the present study. The curve shown by Kienholz, however, is not one for a particular individual but a curve obtained by averaging a number of individuals over a period of years.

Curves of type C (fig. 1) are similar to those of type B except that they are the reverse of each other, i.e. those of type C present a much more rapid decline from the peak of most rapid elongation to the midsummer zero than the rise from initiation of growth to the peak. Curves of type C are thus much steeper on the right while those of type B were steeper on the left. Curves of type C are much more frequent in *P. strobos* and *P. resinosa* than in any other species and are also more frequent in these two species than any other types of curves are in these same species. In table III it will be seen that curves of type C occur in 15 (30%) individuals of *P. strobos*, 22 (44%) of *P. resinosa*, 3 (6%) of *P. sylvestris* and none of *P. banksiana*. This makes a total of 20% of all individuals of all four species. Apparently this same type of curve was exhibited by *P. resinosa* in the results of Cook (2).

In curves of type D (fig. 1) the peak of elongation is maintained at a nearly uniform rate for 2 or, in some cases, 3 weeks, thus giving the curve a flat top. These curves are similar to those of type C in that they are of a type which is frequently used to indicate that there is an increasing rate of elongation for several weeks preceding the peak of elongation which is reached at the middle of the growth period or at the end of the period on which the growth measurements were made.

Curves of type E (fig. 1) differ in that the peak of elongation is reached more rapidly and the slope of the curve continues to decrease until it decreases to a minimum. This type occurs in 6 of 64 individuals of *P. banksiana* and 6 of 104 individuals of *P. strobos*. Curves of type E are steeper on the right than on the left in all cases and the slope continues to decrease to a minimum (table III) in slightly more than half of all individuals measured.
that they are steeper on the right than on the left. This type of curve is found most frequently in the same species where the preceding one is found, viz. *P. strobus* (12 individuals) and *P. resinosa* (10 individuals, table III). In spite of the fact that these individuals show a sustained peak they do not, on the average, show a greater total growth than individuals exhibiting other types of curves.

Curves of type E (fig. 1) show a temporary pause in the rate of acceleration of elongation and thus exhibit a flat place (plateau) somewhere near the peak on the left side. In these individuals some unknown internal factors result in a temporary failure of the regular weekly increase in growth rate after which the rate speeds up and continues to the maximum rate. Curves of this type are found (table III) in 4 individuals of *P. strobus*, 2 of *P. resinosa*, 3 of *P. sylvestris* and are absent in *P. banksiana*.

Curves of type F (fig. 1) differ from those of type E in that the flat place or plateau is on the right or descending side of the curve. These curves result from a temporary holding of a rate of growth for a second week at a higher point for this second week than would have been expected in the light of what this individual had been doing. This type of curve is found (table III) in 3 individuals of *P. strobus*, 1 each of *P. resinosa* and *P. sylvestris* and 2 of *P. banksiana*.

Curves of type G (fig. 1) exhibit a double peak in elongation rate, the 2 peaks being of about equal intensity. Such a curve is an indication that the individual had elongated at a rate which temporarily exceeded the ability of internal factors to support it but after a period (usually 1 week) of deceleration these factors gained new momentum sufficiently to restore the elongation to a rate equal in intensity to that of the first peak. These curves are rare, occurring (table III) in only one individual each of *P. strobus*, *P. resinosa*, and *P. sylvestris*.

Curves of type H (fig. 1) also show two peaks of elongation but differ in that they are not of equal intensity. After the first peak is reached there is a temporary slowing followed by a new acceleration which continues to a peak higher than that previously reached. This type of curve was found (table III) in 6 individuals of *P. strobus*, 6 of *P. resinosa*, and 4 of *P. sylvestris* but was absent from *P. banksiana*; thus occurring in 8% of all individuals studied.

Curves of type I (fig. 1) are similar to the last 2 mentioned in that they exhibit double peaks of elongation rate but differ in that
the higher peak is reached first and the lower peak occurs as a temporary increase during the time of decelerating growth. This is the predominating type of curve in both 
P. sylvestris and P. banksiana, occurring (table III) in 27 individuals of the former and 38 of the latter species. It thus occurs in 54% and 76% respectively of the individuals studied in these species. This type of curve was also found in 6 individuals of 
P. strobus and 2 of 
P. resinosa.

**TIME OF MAXIMUM ELONGATION**

Table IV presents the data regarding the time of the peak in elongation rate. Individuals exhibiting more than one peak are shown for the date upon which the highest peak occurred. It will be noted that every one of the individuals of 
P. banksiana reached their highest peak during the week ending May 4 which, in every case, is 4 weeks after elongation began (cf. tables II and IV). While these trees all reached their peak in growth rate within 4 weeks it should also be noted that 76% of them (table III) exhibited a second but somewhat lower peak after the first one occurred.

The majority of 
P. sylvestris (74%, table IV) also reached their peak of elongation rate during the week ending May 4 which was, for most of them, 4 weeks after initiation. Initiation of elongation occurred in 82% of the individuals (table II) during the week ending April 13, but only 74% reached their peak in rate within the 4-week period. The majority of individuals showing this 4-week period of acceleration (27 out of 37) showed a second but lower peak following the primary one. While the majority of the individuals showed the short (4-week) period of acceleration of elongation, 18% showed a longer period reaching their peak during the week ending May 26. These were for the most part individuals which began elongating during the week ending April 20 (table II and IV) and hence have used 6 weeks in reaching their peak in rate.


**Pinus resinosa** in every instance used a longer period of time for its acceleration of elongation. In table IV it is noted that 60% of the individuals reached their maximum rate during the week ending May 26 and 28% reached it during the preceding week. It is thus apparent that 6-7 weeks elapsed for most of these individuals, and even 8 weeks for some, between initiation and maximum rate of elongation since 96% of them (table II) began during the week ending April 13. Kienholz (4) shows 6 weeks in his "average" curve for this species. Kienholz found the peak in elongation rate for this species to occur late in the growing season or even during the following year. 

*Note:* The text contains a typographical error with the year 1930 repeated in place of May 30, indicating the possibility of a typographical error or a reference to a previous study. The context suggests a reference to a study from 1930, but the year is not clearly stated in the text.
peak occurs as a terminal growth. This is the case with *P. banksiana*, 38 of the 47 species of which were found at Keene in May, and *P. resinosa*. 

It will be noted in the case of the species of curve was also shown in the table (II) that the maximum rate of elongation occurred for 30% during the week ending April 13, for 66% during the following week and for the remaining 4% another week later. Maximum rate occurred for the entire period of 3 weeks with 6% reaching it during the week ending May 4 (table IV) and 18, 14, 38 and 24% reaching it for successive following weeks. The time elapsed thus varied from 4 to 7 weeks. Stevens (5) found the maximum in rate of elongation for this species to come about June 10 for 1928, '29 and '30 at Keene.

Comparison of these data (table IV) with rainfall for the months preceding and during the period of accelerating growth (table I) may throw some light upon both the elapsed time and the double peaks shown in curves of type I (table III). It will be noted in table I that rainfall throughout the first 5 months of the year 1941 was far below the normal-expected for this area. Only during the months of April and May did the rainfall approach even 50%. The total rainfall for the 5-month period was only 35.94% of the normal-expected. Abundance of rain came in June when 181.23% of the normal-expected fell but this was after both primary and secondary maxima in elongation rate were reached in every individual. These June rains had no part in the secondary maximum reached by 54% of the individuals of *P. sylvestris*, and 76% of those of *P. banksiana* (table III) since all were over before the rains came. The small amount of rainfall during April and, more particularly during May, may have brought the maxima in elongation rate earlier than would have been the case if more water had been available but it is more probable that its effect had more to do with the total amount of elongation.

**THE MIDSUMMER PAUSE**

Elongation rate in all individuals declined from the maximum to zero or near-zero. This zero-point was reached for the majority of all species during the 2-week period ending June 23 (table V). It was reached during the week ending June 16 by more individuals than during the following week but the total time-spread necessary to reach for the majority
for all individuals to reach it was 7 weeks. The time elapsed between
the maximum in elongation rate and the midsummer zero-point was
4-9 weeks for P. banksiana, 4-7 for P. sylvestris, 3-7 for P. resinosa
and 3-6 for P. strobus. By comparing table IV and V it will be seen
that the first individuals to reach the midsummer zero are doing so
by the time the latest ones reach their peak in elongation rate. It
should also be noted that the zero point is reached by the majority of
individuals at the very time when available water is the most
abundant.

The time elapsed between initiation of elongation and the mid­
summer pause is shown in table VI where the number of individuals
showing each elapsed amount of time is shown in relation to starting
height of the tree. It will be noted that from 7 to 12 weeks elapsed
between initiation and midsummer pause in P. strobus with the ma­
jority of the individuals continuing elongation 8-10 weeks. In P.
resinosa the time is 8-10 weeks with the majority using 9 weeks.
Kienholz (4) found this time to average 60 days at Keene, N. H.,
and Baldwin (1) found it to be 69 days at Ithaca, N. Y., while Cook
(2) found it to vary from 45 to 63 days over a 5-year period near
Stephentown, N. Y. In P. sylvestris the elongation period varied
from 8 to 12 weeks with the majority using 8-9 weeks while in
P. banksiana the time is 7-12 weeks with the majority using 8-10.
Table VI shows no detectable relation between amount of time used
for elongation and height-classes of trees nor is there any apparent
correlation between the time of initiation of elongation and the length
of time during which it will continue.

ELONGATION FOLLOWING THE MIDSUMMER PAUSE

After a midsummer pause of 1-4 weeks (usually 1 week) all
species showed small increments of renewed elongation activity vary­
ing from zero up to 13 mm in any one week and totalling from 2 to
74 mm for the entire post-midsummer season. This range was 2-24
mm in P. strobus; 16-40 mm in P. resinosa; 6-41 mm in P. sylvestris;
and 10-74 mm in P. banksiana. In 21 individuals out of the 200
measured the total elongation occurring after the midsummer pause
was appreciably greater in amount than the original length of the
winter buds at the beginning of the observations. It is reasonably
certain that except for these 21 individuals the post-midsummer
elongation observed is due to new bud elongation. Of the 21 indi­
viduals one was P. strobus and attained a post-midsummer elongation
of 14 mm in entire season. The other 20 were P. sylvestris all
were P. banksiana, and one was P. strobus. It is reasonable to
elongation after

Two instances of the terminal branch node of growth occurred
an additional 2 months after the midsummer pause. His measure­
ments show this part of the branch to have elongated 30 additional
mm. His measurements were read to the nearest 1 mm but the
were not made continuous during the season.

Table VI shows the total elongation occurring after the midsummer
pause in 21 individuals of the species of P. banksiana, P. sylves­
tris, P. resinosa, and P. strobus. The elongation is shown in millimeter
markings on the trees with the symbol ++ indicating the amount of
elongation occurring after the midsummer pause. The following are
examples of the symbols used in Table VI:

1. P. banksiana: ++
2. P. sylvestris: ++
3. P. resinosa: ++
4. P. strobus: ++

In Table VII the average seasonal elongation is shown for all four
species. The total increase is 258 mm for the season. This is
than the class average.
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P. sylvestris; 

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It is reasonably 

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Of the 21 mid­ 

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of 14 mm in excess of the length of the terminal bud at the beginning 
of the season: 3 were P. resinosa attaining an excess of elongation 
over original length of bud of 12, 10 and 10 mm respectively; 1 was 
P. sylvestris and attained an excess of elongation of 21 mm; and 16 
were P. borealis in which the elongation excess ranged from 10-49 
mm. It is reasonably certain that these 21 cases represent real stem 
elongation after midsummer pause.

Two instances not included in the above were observed where 
the terminal bud awakened and gave rise to a short additional "inter­ 
node" of growth. These were both in P. strobus and each one added 
an additional 33 mm of primary growth to that formed before the 
pause. The curve for P. resinosa in Kienholz's (4) paper apparently 
shows this post-midsummer-pause elongation but Cook's (2) data 
do not show it. This is no doubt due to his method of measurement. 
His measurements were taken weekly using a wooden yardstick and 
were read to the nearest one-quarter inch from a starting point 
marked with paint or wax crayon. The individual weekly increments 
following the midsummer pause were almost always too small to be 
detected by measurements of this type.

Table VII gives a picture of the time during which this extra 
elongation occurred. From the table it will be noted that 18% of the 
individuals of P. strobus continued the extra growth until and includ­ 
ing the week ending September 11, 36% stopped after the following 
week and 8% showed some elongation between October 16 and 
December 4. The majority of the individuals of P. resinosa showed 
no further elongation after October 9, but 20% still showed elonga­ 
tion between October 16 and December 4. In P. sylvestris elongation 
entirely ceased in the majority of the individuals by October 2; and 
in P. borealis the majority ceased by October 9. These dates ap­ 
pear late but they must be taken along with the fact that the rainfall 
for October was 232.40% (table I) of the normal-expected while 
the temperature continued unusually mild well into December.

TOTAL SEASONAL ELONGATION

In table VI the individuals are divided into height-classes and the 
average seasonal increment for individuals of each class is given. In 
all four species it will be noted that there is a definite relation between 
total increment and height of the individuals at the beginning of the 
season. Thus in P. strobus each succeeding taller class grew more 
than the class below it. The average ranged from 132 mm for the
height-class below 50 cm to 518 mm per individual for the height-class above 300 cm. In *P. resinosa* the average elongation per individual was 339 mm for individuals initially 100 cm or less high, 432 mm for individuals in the 101-150 cm height-class, and 505 mm for those in the 151-178 cm height-class. The average total seasonal increment for *P. resinosa* reported by Cook (2) ranged from approximately 275 mm to 513 mm. In *P. sylvestris* the data show increasing average elongation with increase in height-class up to the 201-250-cm class but decreased elongation in one individual above that class. Average total increment varies from 303 to 787 mm. In *P. banksiana* the average increment per individual is 567 mm for 18 individuals of 100 cm or less initial height and 606 mm for 32 individuals initially between 101 and 139 cm high. It will be noted that *P. banksiana* shows the greatest average increment in relation to initial height with *P. sylvestris* second and *P. resinosa* third.

The present data do not deal with the question of relation between total growth and rainfall. There is no certain effect of rainfall upon the periodicity of growth or the type of curve exhibited.

**DISCUSSION**

From the practical standpoint of forestry the differences in the various types of curves exhibited by these pines is of little significance since they bear little or no relation to total amount of elongation for the season. It is true that the average elongation per individual is higher in *P. sylvestris* and *P. banksiana* (table V) where curves of type I (table III) predominate but this difference is more likely a species difference rather than an elongation-type difference. On the other hand, from the standpoint of theoretical internal physiology, they are of considerable significance. All of the curves illustrate a grand-period type of behavior which results in a periodicity of elongation, the essential character of which is not obviously affected by external factors. The time when the elongation begins, the height of its peak, and the total amount of elongation are undoubtedly affected by external factors of the present season and indirectly, through amount of food reserves, by external factors of the past season. The effect of the total amount of elongation in one season upon that of the following season and their relation to external factors of the environment will be presented in a subsequent paper.

A discussion of the internal factors responsible for the grand-period type of growth behavior would be out of place here but it should be pointed out that these pines except *P. strobus* show simple grand-period type curves. In *P. strobus* elongation accelerates with increase in height-class up to the 301-350-cm class followed by complete deceleration for the remainder of the season. *P. sylvestris* shows intermediate behavior with the majority of the individuals of this type having the grand-period type curve. *P. banksiana* shows more rapid deceleration and *P. resinosa* decelerates with the same vigor as *P. sylvestris* after the peak is reached (table V) the very time when the growing season ends.
should be pointed out clearly that every type of curve exhibited by these pines except types A, B, and C present a modification of the simple grand-period behavior wherein a life process begins slowly, accelerates with increased tempo to a maximum then decelerates in somewhat the same, except inverse, order to a dragging minimum followed by complete cessation. When a modification of the simple grand-period type of behavior occurs on the left or accelerating side of the curve (curve-types E and H) the internal factors are more likely to involve modification of enzyme action in rendering food reserves available, assimilation reactions and water conduction problems than a matter of dwindling amount of food reserves. When a curve shows a flat top (curve D, table III, fig. 1), it is possible that the maximum amount of enzymes has been reached while the food reserves are still high and elongation rate is conditioned by rate of enzyme activity in rendering reserves available for assimilation and respiration. When the modification in the curve occurs on the right or decelerating side (curve types F and I), amount of enzymes can hardly be a factor since the total amounts are already greater than necessary, in view of the fact that they are not used up in the chemical reactions they promote. Such modifications are more likely related to dwindling supply of reserves. That they are due almost entirely to internal factors seems to be further indicated by the fact that, even though available water supply was greatly increased by excessive rainfall in early June this had no effect in modifying an already rapidly-declining elongation rate. The midsummer zero period was reached (table V) by the majority of individuals of all species at the very time when available soil water was at its highest for the season.

SUMMARY

1. Elongation was measured in 50 individuals each of Pinus strobus, P. resinosa, P. sylvestris and P. banksiana weekly from March 31 to October 16 with a final reading on December 4.

2. Elongation began for the majority of the individuals of the last three named species during the week ending April 13 and for the majority of P. strobus during the following week.

3. All individuals show a grand-period type of elongation behavior with the curves falling into 9 different curve-types.

4. The maximum in elongation rate was reached by all of the individuals of _P. banksiana_ and the majority of those of _P. sylvestris_.

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during the week ending May 4 which was 4 weeks after initiation. In *P. resinosa*, the time thus elapsed was 6-7 weeks and in *P. strobus* it showed a spread of 4-7 weeks.

5. Abundant rains coming in June when all individuals were rapidly decelerating in elongation had no measurable effect in stopping the declining rate.

6. A midsummer zero-point in elongation rate is reached by all individuals. It is reached during the week ending June 16 by more individuals than during any other one week and by the majority of individuals of all species during the 2-week period ending June 23.

7. All species show a period of post-midsummer activity after a midsummer-zero point has been reached. In most of the individuals this extra elongation is due to bud activity but in some it is undoubtedly true axial elongation.

8. Total average seasonal increment per individual increases with increased initial height. This increment is 132-518 mm in *P. strobus*; 339-505 mm in *P. resinosa*; 303-787 mm in *P. sylvestris*; and 567-606 mm in *P. banksiana*.

ACKNOWLEDGMENT

The writer wishes to take this opportunity to express his sincere thanks for the courtesies shown by Mr. Charles Youngman in permitting study of all the individuals of *P. banksiana* and 17 specimens of *P. sylvestris* from the planting on his estate.

LITERATURE CITED

TABLE I

Rainfall for the year 1941 as determined by the U. S. Weather Bureau at Columbus 17 miles from the site under observation.

<table>
<thead>
<tr>
<th>Month</th>
<th>Rainfall</th>
<th>Normal-Expected</th>
<th>% of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>1.25 in.</td>
<td>3.69 in.</td>
<td>33.87</td>
</tr>
<tr>
<td>February</td>
<td>0.95</td>
<td>2.45</td>
<td>38.77</td>
</tr>
<tr>
<td>March</td>
<td>0.47</td>
<td>3.97</td>
<td>11.84</td>
</tr>
<tr>
<td>April</td>
<td>2.02</td>
<td>3.72</td>
<td>54.30</td>
</tr>
<tr>
<td>May</td>
<td>1.68</td>
<td>3.49</td>
<td>48.25</td>
</tr>
<tr>
<td>June</td>
<td>6.58</td>
<td>3.63</td>
<td>181.23</td>
</tr>
<tr>
<td>July</td>
<td>0.48</td>
<td>2.87</td>
<td>16.72</td>
</tr>
<tr>
<td>August</td>
<td>3.45</td>
<td>3.72</td>
<td>92.74</td>
</tr>
<tr>
<td>September</td>
<td>3.20</td>
<td>3.71</td>
<td>86.25</td>
</tr>
<tr>
<td>October</td>
<td>7.46</td>
<td>3.21</td>
<td>232.40</td>
</tr>
<tr>
<td>November</td>
<td>2.35</td>
<td>2.78</td>
<td>84.53</td>
</tr>
<tr>
<td>December</td>
<td>2.91</td>
<td>3.22</td>
<td>90.37</td>
</tr>
<tr>
<td>Total</td>
<td>32.80</td>
<td>40.66</td>
<td>81.07</td>
</tr>
<tr>
<td>Jan.-May</td>
<td>6.37</td>
<td>17.32</td>
<td>35.94</td>
</tr>
<tr>
<td>Aug.-Oct.</td>
<td>14.11</td>
<td>10.64</td>
<td>132.62</td>
</tr>
</tbody>
</table>

TABLE II

Initiation of vertical growth. Percentage of trees beginning growth during weeks shown.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>April 13</td>
<td>30%</td>
<td>90%</td>
<td>82%</td>
<td>100%</td>
</tr>
<tr>
<td>April 20</td>
<td>66%</td>
<td>4%</td>
<td>16%</td>
<td>0%</td>
</tr>
<tr>
<td>April 27</td>
<td>4%</td>
<td>0%</td>
<td>2%</td>
<td>0%</td>
</tr>
</tbody>
</table>

TABLE III

Distribution of curve types among the species studied. Figures indicate the number of individuals of each species exhibiting each type of curve.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Slopes of curve about uniform</td>
<td>0</td>
<td>6</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>B. Slope steeper on left</td>
<td>3</td>
<td>0</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>C. Slope steeper on right</td>
<td>15</td>
<td>22</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>D. Flat top—mostly steeper on right</td>
<td>12</td>
<td>10</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>E. Plateau on left</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>F. Plateau on right</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>G. Double peak—about equal</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>H. Double peak—lower on left</td>
<td>6</td>
<td>6</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>I. Double peak—lower on right</td>
<td>6</td>
<td>2</td>
<td>27</td>
<td>38</td>
</tr>
</tbody>
</table>
TABLE IV
Time of peak in rate of elongation. Percentage of trees showing peak each week.

<table>
<thead>
<tr>
<th>Week Ending</th>
<th>P. strobus</th>
<th>P. resinosa</th>
<th>P. sylvestris</th>
<th>P. banksiana</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 4</td>
<td>6%</td>
<td>0%</td>
<td>74%</td>
<td>100%</td>
</tr>
<tr>
<td>May 11</td>
<td>18%</td>
<td>2%</td>
<td>6%</td>
<td>0%</td>
</tr>
<tr>
<td>May 19</td>
<td>24%</td>
<td>2%</td>
<td>4%</td>
<td>0%</td>
</tr>
<tr>
<td>May 26</td>
<td>38%</td>
<td>64%</td>
<td>11%</td>
<td>0%</td>
</tr>
<tr>
<td>June 2</td>
<td>24%</td>
<td>0%</td>
<td>2%</td>
<td>0%</td>
</tr>
</tbody>
</table>

TABLE V
Time of midsummer zero period. Percentage of trees reaching zero period each week.

<table>
<thead>
<tr>
<th>Week Ending</th>
<th>P. strobus</th>
<th>P. resinosa</th>
<th>P. sylvestris</th>
<th>P. banksiana</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 2</td>
<td>0%</td>
<td>0%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>June 9</td>
<td>4%</td>
<td>2%</td>
<td>14%</td>
<td>16%</td>
</tr>
<tr>
<td>June 16</td>
<td>44%</td>
<td>66%</td>
<td>54%</td>
<td>44%</td>
</tr>
<tr>
<td>June 23</td>
<td>32%</td>
<td>8%</td>
<td>18%</td>
<td>20%</td>
</tr>
<tr>
<td>June 30</td>
<td>12%</td>
<td>8%</td>
<td>6%</td>
<td>16%</td>
</tr>
<tr>
<td>July 10</td>
<td>4%</td>
<td>6%</td>
<td>4%</td>
<td>2%</td>
</tr>
<tr>
<td>July 17</td>
<td>4%</td>
<td>10%</td>
<td>2%</td>
<td>0%</td>
</tr>
</tbody>
</table>

TABLE VI
Showing relation of height classes to time of initiation of growth, time elapsed between initiation of growth and midsummer pause, and total seasonal growth.

<table>
<thead>
<tr>
<th>Height Classes</th>
<th>No of Individuals beginning growth in each class</th>
<th>No of individuals beginning growth during week ending</th>
<th>Weeks elapsed between initiation of growth and midsummer pause</th>
<th>Average total growth for season</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pinus strobus</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19-50 cm</td>
<td>6</td>
<td>3 3 3</td>
<td>2 3 1</td>
<td>132 mm</td>
</tr>
<tr>
<td>51-100</td>
<td>6</td>
<td>3 3 3</td>
<td>3 2 1</td>
<td>213</td>
</tr>
<tr>
<td>101-150</td>
<td>11</td>
<td>2 9</td>
<td>1 2 5</td>
<td>313</td>
</tr>
<tr>
<td>151-200</td>
<td>21</td>
<td>9 11 1</td>
<td>7 4 7</td>
<td>437</td>
</tr>
<tr>
<td>201-250</td>
<td>5</td>
<td>2 2 1</td>
<td>1 1 3</td>
<td>367</td>
</tr>
<tr>
<td>301-312</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>518</td>
</tr>
<tr>
<td><strong>Pinus resinosa</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>56-100</td>
<td>12</td>
<td>11 1</td>
<td>2 8 2</td>
<td>339</td>
</tr>
<tr>
<td>101-150</td>
<td>27</td>
<td>26 1</td>
<td>1 22 4</td>
<td>432</td>
</tr>
<tr>
<td>151-178</td>
<td>11</td>
<td>11</td>
<td>1 8 2</td>
<td>565</td>
</tr>
<tr>
<td>Height Classes</td>
<td>No. of Individuals in #1 Class</td>
<td>No. of Individuals in #2 Class</td>
<td>Weeks elapsed between initiation of growth and midseason pause</td>
<td>Average total Growth for season</td>
</tr>
<tr>
<td>---------------</td>
<td>-------------------------------</td>
<td>-------------------------------</td>
<td>---------------------------------------------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td><em>P. sylvestris</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>77-100</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>303</td>
</tr>
<tr>
<td>101-150</td>
<td>21</td>
<td>17</td>
<td>4</td>
<td>524</td>
</tr>
<tr>
<td>151-200</td>
<td>22</td>
<td>18</td>
<td>7</td>
<td>605</td>
</tr>
<tr>
<td>201-250</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>787</td>
</tr>
<tr>
<td>251-300</td>
<td>1</td>
<td>1</td>
<td>8</td>
<td>589</td>
</tr>
<tr>
<td><em>P. banksiana</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>71-100</td>
<td>18</td>
<td>18</td>
<td>3</td>
<td>567</td>
</tr>
<tr>
<td>101-139</td>
<td>32</td>
<td>32</td>
<td>5</td>
<td>606</td>
</tr>
</tbody>
</table>

**TABLE VII**

Time of cessation of elongation. Percentage of trees showing no elongation after the weeks shown below.

<table>
<thead>
<tr>
<th>Week Ending</th>
<th><em>P. sitchensis</em></th>
<th><em>P. resinosa</em></th>
<th><em>P. sylvestris</em></th>
<th><em>P. banksiana</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>July 17</td>
<td>4%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>August 7</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>14</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>21</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>28</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Sept. 4</td>
<td>2%</td>
<td>8</td>
<td>4%</td>
<td>4</td>
</tr>
<tr>
<td>11</td>
<td>18</td>
<td>10</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>18</td>
<td>36</td>
<td>14</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>25</td>
<td>14</td>
<td>14</td>
<td>28</td>
<td>14</td>
</tr>
<tr>
<td>Oct. 2</td>
<td>6</td>
<td>20</td>
<td>10</td>
<td>24</td>
</tr>
<tr>
<td>9</td>
<td>4</td>
<td>14</td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td>16</td>
<td>4</td>
<td>6</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Elongation after 10-16</td>
<td>8</td>
<td>20</td>
<td>4</td>
<td>10</td>
</tr>
</tbody>
</table>