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A. E. Douglass

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EVIDENCE OF CLIMATIC EFFECTS IN THE ANNUAL RINGS OF TREES[1]

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The first substantial comparison between rings and rain with which the author is acquainted was made by the astronomer, J. C. Kapteyn of Holland, in 1880 and 1881 on oaks in the Rhine region. Professor Kapteyn has recently prepared and published a brief pamphlet on the subject.[2] A similar comparison between the growth of the great sequoia (*Sequoia gigantea*), and rainfall is shown in figure 1 in which the curve for rainfall is from Huntington,[3] from data at Fresno, 70 miles away and 5,000 feet lower in elevation. In spite of widely different conditions there is evident resem-

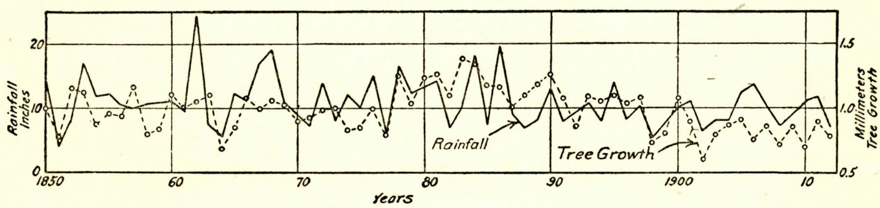

Fig. 1. Comparison of rainfall at Fresno, California, and growth of sequoias. (Rainfall after Huntington.)

blance at a number of places in this comparison. It is a great pity that no proper records can be obtained in the actual region of the sequoias nor are any but the most superficial observations being made at the present time.

The material here presented has emerged in the process of dating and measuring about 85,000 annual rings which had grown in some 275 different trees in the states of Oregon, California, Arizona, Colorado, and Vermont, as well as in England, Norway, Sweden, Germany, and Bohemia. The climatic evidence is of three kinds, of which the first is shown in figure 2. This is the direct correlation between the annual rings of yellow pine (*Pinus ponderosa*) and the rainfall at Prescott, Arizona. The trees grew within

[1] Presented before the St. Louis meeting of the Ecological Society of America January, 1920.

[2] Kapteyn, J. C., "The growth and meteorological factors," Rec. Trav. Bot. Neerland 11:70, 1914. Kapteyn found growth cycles of 12.4 years, being the same in different species.

[3] Huntington, Ellsworth, "The Climatic factor as illustrated in Arid America," 341 pp., plates and maps, Carnegie Inst. of Wash. Publ. 192, 1914.

one mile of the location of the weather records. Although the curve is based on only 10 trees, its accuracy is over-abundantly checked by nearly a

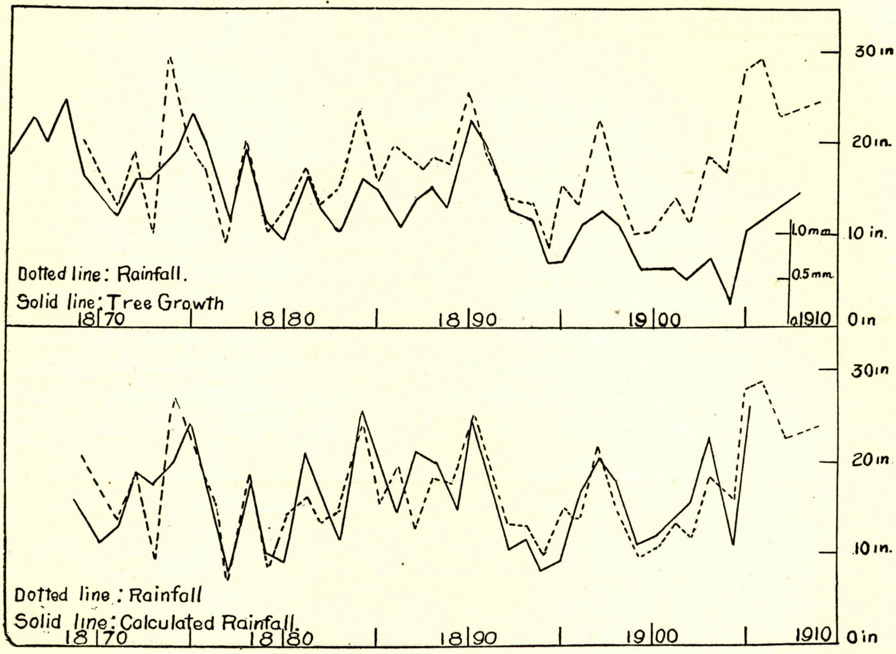

FIG. 2. Comparison of forty-three years of rainfall and tree growth at Prescott, Arizona.

hundred trees at greater distances. The upper pair of curves representing the original values shows a very substantial agreement. In the lower pair of curves a simple conservation formula has been applied, producing a more marked agreement. The corrected values of tree growth represent the rainfall with an accuracy of about 85 percent. These pines grow at as low, and therefore at as dry an elevation as they can survive. Their rings show certain characters which seem to be dependent on the way in which the precipitation is distributed throughout the year. Much material along this line has been accumulated, and, when it is worked out will certainly increase the accuracy with which these trees represent the local rainfall.

The second form of evidence is the marked resemblance found in certain individual rings over a wide extent of the country in which climate is the only common factor. This is illustrated in figure 3 showing the years 1840 to 1864 in western trees. There are many points of resemblance and some interesting points of difference, but the figure is arranged especially to show the small ring for 1851. The three sequoias at the top cover 50 miles in California. Then there is a gap of 450 miles to the yellow pines of Arizona.

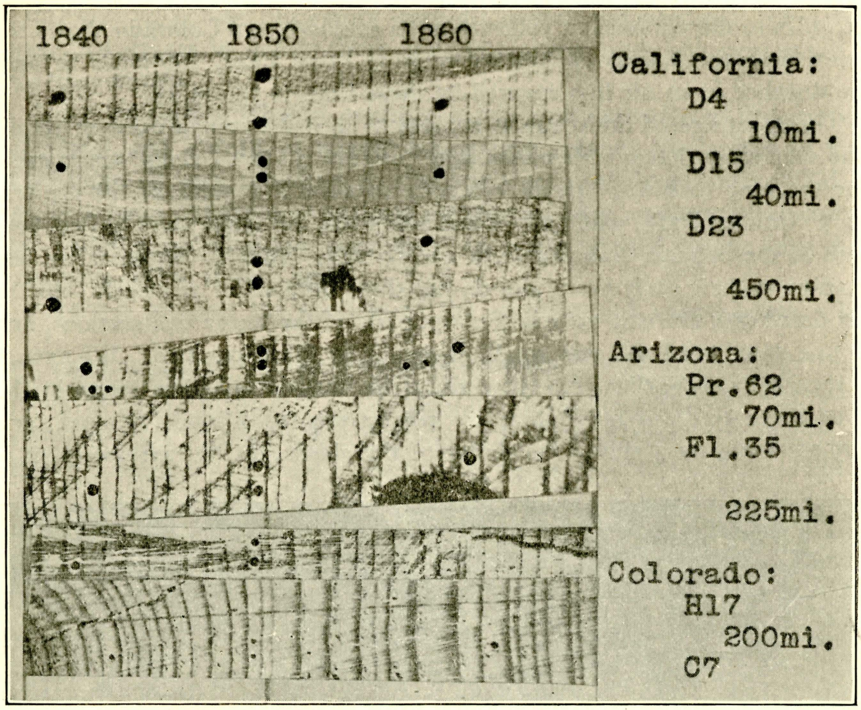

FIG. 3. Similarity in the ring of 1851 and others across 750 miles of country.

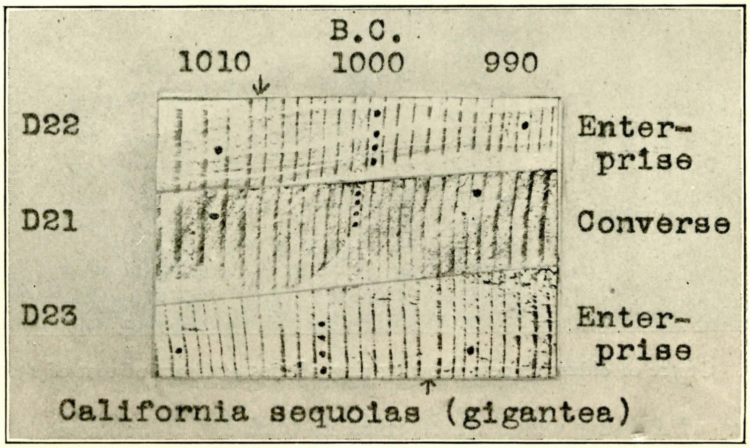

FIG. 4. Similarity in young sequoias across fifty miles of country. Note especially the rings for the years 993 and 1008 B.C.

Here two individuals 70 miles apart are given. Two hundred and twenty-five miles to the northeast a yellow pine in southwestern Colorado shows the same effect, checked by a Douglas fir from Pikes Peak, 200 miles beyond. The distance in an air line covered by these trees is 750 miles.

The great age of the sequoias enables us to make comparisons of conditions that existed two milleniums ago. Figure 4 shows rings which grew near the year 1000 B.C. In the center is shown a tree north of the General Grant National Park, while above and below are the same years in two trees south of the Sequoia National Park and 50 miles distant. Sequoias are less sensitive in their early years and do not show differences as clearly, but the ring dated 993 B.C. was very large, especially in the lower two sections, and the one dated 1008 B.C. was small, especially in the upper two. We cannot as yet go much earlier than that since the earliest complete rings in the oldest three trees so far found, are respectively 1087 B.C., 1122 B.C., and 1305 B.C. Figure 5 shows the center of the oldest; at the extreme point is

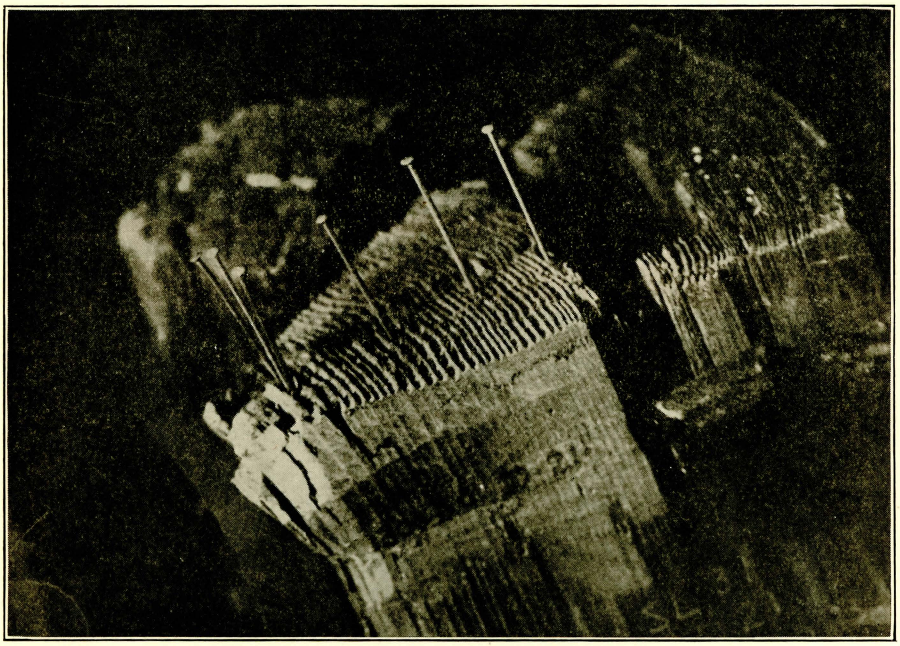

FIG. 5. Centre of oldest sequoia showing ring of 1305 and part of that of 1306 B.C.

a portion of the ring which was formed in 1306 B.C. The dating of those ancient rings has been a process very far from mere ring counting, for unchecked counting in these old trees (and many others) is very treacherous. These dates have meant the study of nearly 55,000 different rings and repeated minute comparison of those for each year as found in the 35 different trees. This has taken years of time and several trips to the sequoia forests. In this way omissions and errors were discovered and verified. Thus it is hoped that errors in dating these very interesting trees are very small or altogether absent.

The third type of climatic evidence is really an extension of the one just described. But instead of merely taking into account similarities in individual rings, it uses similarity in ring variation over large areas. This is done by a form of harmonic analysis for which I have constructed an instrument called a periodograph capable of analyzing plotted curves into their component cycles, if such exist.

Figure 6 presents the analysis of the sequoias and yellow pines. The

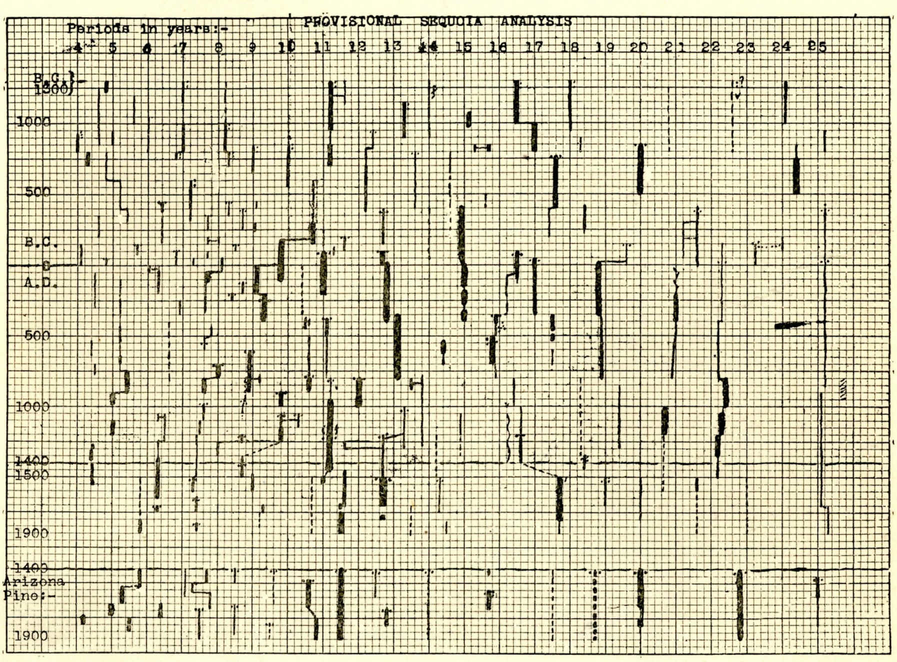

FIG. 6. Short period cycles in sequoia and yellow pine.

various possible periods in years are marked at the tops and bottom; dates are at the left. The various short vertical lines show the duration of the respective cycles found. The last 500 years of the sequoia analysis fall just below the black line, and at the bottom is the analysis of the same period in the yellow pines. Though 450 miles separate these two groups there is considerable resemblance between them. Similar periods occur at 25 years, 23.9, 20.0, 18.9, 17.7, 14.1, 12.7, 11.6, 10.7, 7.4 and 5.8 years with varying intensities. The sequoia alone shows a period at 21.6 and the pines alone show one at 15.7 years. The strong one in each at 11.6 is the well known sunspot period. It is interesting to note that the only part of the sequoia with which the pine analysis shows good agreement is just where it should be, namely in the last 500 years. This evidence encourages one to believe in the reality of this kind of analysis and at the same time to regard climate as a very important if not controlling factor. This analytical method is entirely new but seems very promising.

In order to improve this analysis I am trying at the present time to produce from the 35 sequoias now represented in my laboratory collection, the best possible record of sequoia growth for 3,200 years. This means selecting the best parts of the best trees. The parts wanted of course are those which respond most closely to climatic influence. For this purpose I have proposed and am testing out a certain characteristic in the trees which I have called mean sensitivity. This may be described as the difference between each two successive rings divided by their mean. The quotients are arranged in groups of ten or some other number of years, and listed as the mean sensitivity of that period. Figure 7 shows the appearance of rings of

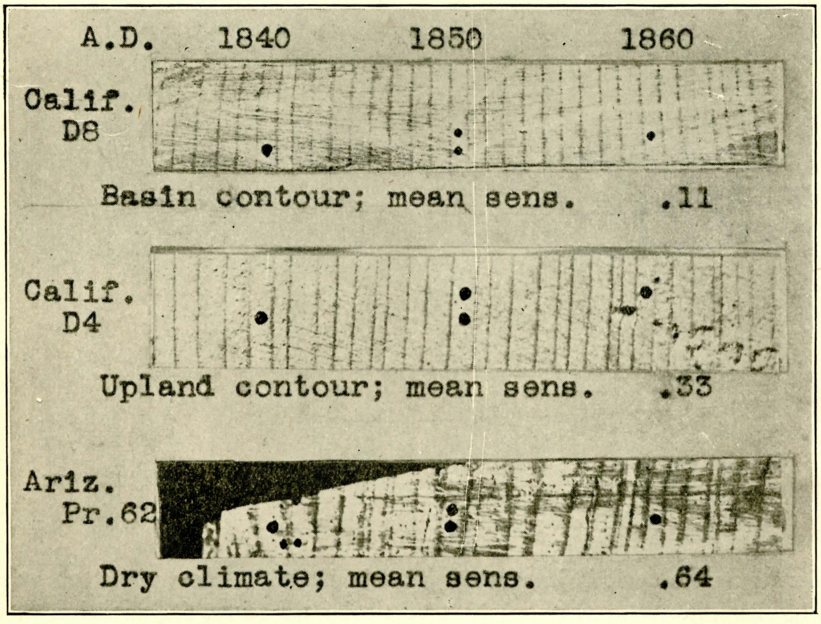

FIG. 7. Appearance of rings showing different degrees of sensitivity.

different sensitivity. The first section came from a sequoia which grew in a swampy basin about 15 miles east of the General Grant National Park. The tree has a "complacent" growth, with rings all of nearly the same size. Its mean sensitivity is .11. The second is a sensitive sequoia which grew high up on the mountain side with a limited water supply and depended

FIG. 8. Forest on moist uplands with little or no running water; the site of sequoias of good sensitivity (see Fig. 10).

FIG. 9. Dry climate forest of western yellow pine in northern Arizona; site of trees of high sensitivity (see Fig. 10).

This is in Flag. back of Obsy on malpais. The lower tree in Fig 7 is from Prescott on decomposed granite much more on the moisture of each year as it came. Its rings have more character and individuality, and the changes from ring to ring are much more evident. The mean sensitivity is .33. The third is a hyper-sensitive dry climate yellow pine near Prescott, one of the 10 used in the curves of Prescott tree growth already described. It grew near the lowest limit of the yellow pine. Some of its rings, such as 1841 and 1857, are so small as to be found with difficulty. Its variations from year to year are extremely large, and its mean sensitivity is .64. The character of the sites of the last two trees may be seen in figures 8 and 9. Figure 8 shows the site of the sensitive sequoia, in the moist uplands. The sample given is from the high stump in the left foreground. This location is about 800 feet higher in elevation than that of the tree with low sensitivity, and is near the top of the mountain. There is a small spring higher up and a small trickle of water near this tree, but, with the other trees near it, it shows a greatly increased sensitivity. Figure 9 is a typical view in the yellow pine forest in the dry climate of northern Arizona. One notices the isolation of the trees and the lack of competing vegetation so that the trees' chief struggle is against the dryness of the climate.

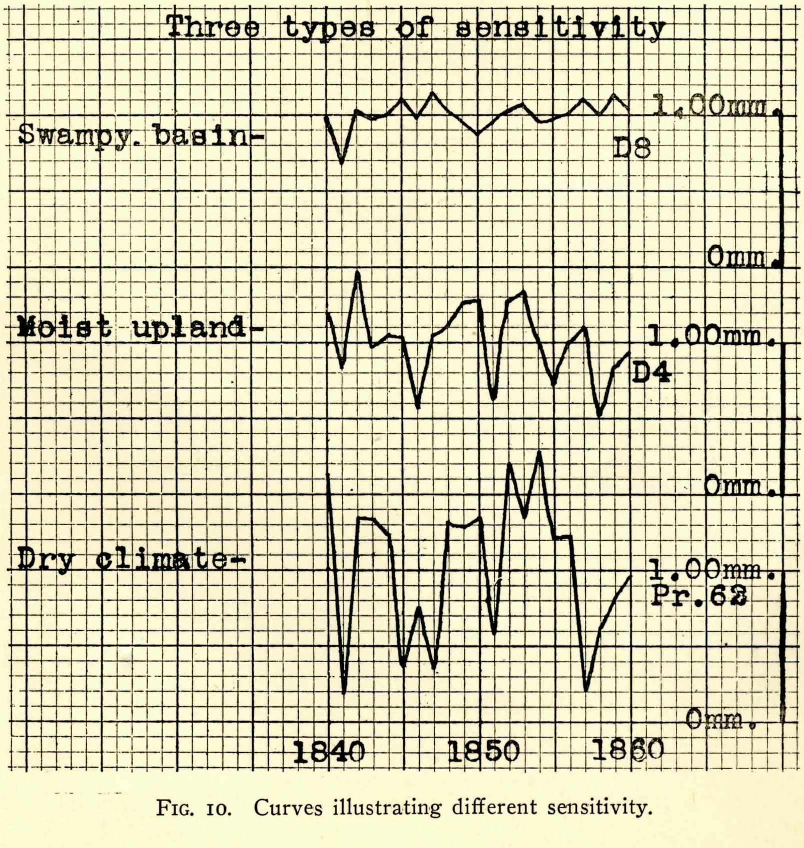

FIG. 10. Curves illustrating different sensitivity.

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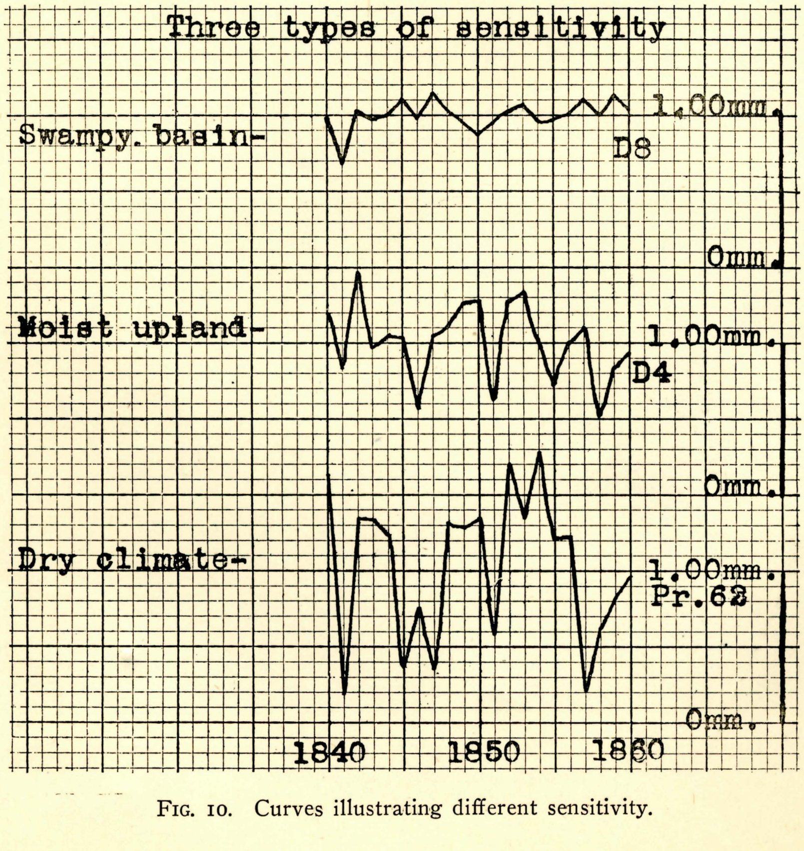

FIG. 10. Curves illustrating different sensitivity.

The way these variations in sensitiousness look in plotted curves is shown in figure 10 in which the curves of growth of these three trees show percentage departures, each from its own mean. The different character resulting from the different environment is at once apparent to the eye.

In conclusion I would say:

1. Trees probably integrate, and may be made to disclose to us, climatic combinations advantageous to certain types of vegetation.

2. The study of this subject promises to enable us to outline what might be called agro-meteorological districts, that is areas over which exist similar advantageous combinations of weather elements.

3. The application of the criterion of mean sensitivity promises to make possible the proper selection of sequoia records, which in turn will give us much climatic information about the last 3,200 years.

4. Information regarding suitable forests for similar study, located in central and other parts of North America, will be greatly appreciated by the writer.

[*Note.*—The foregoing paper presents an entirely new viewpoint toward the relation between climate and tree growth in that it recognizes that factors other than the seasonal rainfall influence the size of the trees' annual rings. Dr. Douglass' development of the idea of "mean sensitivity" represents a marked step forward in this important line of research. Foresters have been a little skeptical of direct correlations between climate and annual rings because their work has thrown them into direct contact with the intricacies of tree growth. In the forests of humid regions competition for light seems to play a more important part than variations in precipitation from year to year. A crowded tree will have smaller rings in a favorable season than a dominant tree in a poor season. Nevertheless, even in such forests it should be possible, with knowledge and care, to learn something of the past climate from tree rings. For example, in red spruce (*Picea rubens*) the period of suppression is indicated by an inner core of very narrow rings. If this period, and the later period of semi-suppression, is rejected the study of the dominant period should afford fairly reliable results. The difficulty is of course to decide what to use and what to reject. We believe that this difficulty is not insuperable. Even trees in the forests of semi-arid regions, such as the western yellow pine of the southwest, are not entirely free from crowding because they tend to grow in groups. Here, however, the problem is less difficult because yellow pine requires light and does not persist long in shade. As a general rule it would probably be fairly safe to say that the more light demanding the tree, the easier and safer will be the correlation with climated. EDITOR.]