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ANNUAL RINGS IN BIG SAGEBRUSH,
ARTEMISIA TRIDENTATA

by

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I hereby recommend that this dissertation prepared under my
direction by CHARLES WESLEY FERGUSON
entitled ANNUAL RINGS IN BIG SAGEBRUSH, ARTEMISIA
TRIDENTATA

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MEMORIAL DEDICATION

This volume is respectfully dedicated to the late Dr. Edmund Schulman of the Laboratory of Tree-Ring Research, University of Arizona, Tucson. It was his tutelage and direction, first as his student and later as his field and laboratory assistant, that made possible this application of the concepts and techniques of dendrochronology to a shrubby nonconiferous species.

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CHAPTER I

INTRODUCTION

Range management specialists have become increasingly concerned in the past few decades with the competition between species produced by the invasion of shrubby plants into grassland ranges. Big sagebrush, Artemisia tridentata Nutt., is a widespread shrub dominant over large areas of the western United States. It occurs primarily on sites that are capable of growing, or have grown, a grass cover (Hall and Clements, 1923, pp. 141, 148) and is thus an invading species. Complete evaluation of the ecological status of the species in terms of succession requires analysis of annual growth layers (the so-called "rings") to determine the age of a given plant and the growth potential of the site. The objective of this study has been to evaluate big sagebrush throughout the southern limit of its distribution with respect to structure and rate of annual lateral growth of the stems with a view to application to ecological problems of range management.

Review of Literature

Age of woody plants commonly has been determined by counting annual rings in a single radius. This is a valid method applicable to most conifers in the temperate zone. From the lower altitudinal limits and the southern border of the forest, through the shrub and desert zones, to the tropics, environmental conditions and growth responses become increasingly unfavorable for the formation of clearly delimited annual rings. Schulman (1953) stated

Deserving special mention among the species whose ring-growth is so erratic or complex as to be, in general, quite useless as an index of climate are the coast redwood (in contrast to the giant sequoia of the Sierra Nevada), Arizona cypress, the Southwestern junipers other than J. scopulorum, lodgepole pine, and, at present, all the semi-desert hardwoods of the Southwest.

And Schulman (1956) added

Hypersensitive records (of ponderosa pine), with quite undatable false annual rings and growth observed to be very erratic around the circuit of the stem, are occasionally found on outlier sites of the lower forest margin in central and southern Arizona and New Mexico and in northern Mexico. The woodland species similar to ponderosa pine in this region (Pinus leiophylla, P. engelmanni) are generally undatable, as are in general also all the brush hardwoods, intermingled with them or in the drier shrub zone below.

In his description of the stem structure of big sagebrush, Diettert (1938) terms the ring annual. In view of the general concept that northern hemisphere plant species south of the temperate forest

or altitudinally below it do not form clearly delimited annual rings, big sagebrush might be considered unique. The stem structure of big sagebrush does not lend itself to the "biotic", observational approach of the dendrometer (Daubenmire, 1945) or dendrograph (Fritts and Fritts, 1955). In this study, the approach will be that of the tree-ring analyst, or dendrochronologist (Schulman, 1956). Most of the concepts and techniques of tree-ring analysis can be applied to the study of big sagebrush and, when combined with seasonal observations, are adequate for the interpretation of ring structure.

References to the age of big sagebrush as determined by ring counts occur in ecological literature. Quinnild and Cosby (1958) made ring counts of the larger plants of big sagebrush and of fire-scarred living trees on Big Top Mesa in western North Dakota. The ring counts of big sagebrush indicated an age of 16 and 17 years and thus verified that a fire might have occurred about 1940 as was indicated by a study of the fire-scarred trees. On nearby Two-Top Mesa, one of the larger plants of big sagebrush appeared to be 47 years old. Large plants of big sagebrush that had been dead for several years were also found. The occurrence of a 47-year-old plant along with large dead plants on the same type of site indicated that the 16- and 17-year-old plants had become established following a fire and that these were not the maximum ages possible under the environmental conditions of the site.

Ellison (1954), in a study of vegetation of the Wasatch Plateau, Utah, counted a maximum of 38 rings in Artemisia rothrockii. He estimated a few bushes with rotten centers to be 50 years old or older. Mention is made of the relative age of A. tridentata, but this appears to be an estimate not based on ring counts. Cottam and Stewart (1940), in conjunction with an ecological study of the Mountain Meadows Valley in Washington County, Utah, counted rings of A. tridentata and found plants on a foothill site that were over 50 years old and still vigorous. They were aware that large, rapidly growing bushes reach an early maturity--perhaps man very early realized that the smaller plants of a species were slower growing than their better situated counterparts. Isaiah 17:5,6 reads that (Moffat translation) "...he is like some desert shrub that never thrives, set in a dry place in the steppes, in a salt, solitary land." Booth (1947-1948), in a study involving ring counts of 311 stems of big sagebrush, recorded one plant with a maximum count of 56 rings. Plants 101-110 years old are mentioned by Stewart, Cottam and Hutchings (1940). Blaisdell (1953) stated that "big sagebrush is typically a long-lived plant. Even-aged stands attain an age of 30 to 40 years, and individual plants may exceed 100 years." Unpublished data at the Dubois Sheep Experiment Station, Dubois, Idaho, mentioned several plants over 100 years old (Blaisdell, 1955), including one that reached an age of 118 years (Goodwin, 1955).

Discussion of Terms

Definitions of terms used in describing the concepts and techniques of dendrochronology, and specific applications of these and other terms to ring studies in big sagebrush, are an aid in understanding the text. A discussion of terms is given by Douglass (1946), but for convenience in the present instance, a brief definition and discussion of the terms used in this text follows.

Absent, or missing ring. See annual growth layer in this discussion.

Age class. An arbitrary grouping of plants of about the same age or, if so stated, about the same total length of ring series.

Annual growth layer. The secondary xylem formed in any given calendar year. This layer of xylem, as seen in a cross section of the stem, forms a ring, which implies a full circuit and a certain regularity about the circuit. The term "ring" as used in this study may apply to an arc of growth rather than to a continuous ring.

An annual ring, especially in conifers, may be reduced in size to only a few cells that maintain the same ring width completely about its circuit. The foregoing describes a microscopic ring. This term is often used in a relative sense, but serves to call attention to the highly significant smaller-than-average ring that provides a key in establishing the ring chronology. A microscopic ring may be small to the point of

being totally absent about some portion of its circuit. It is then referred to as being locally absent. When no growth was deposited in visible portion of the specimen in a given year, this year is recorded as an absent or missing ring.

A growth ring showing two surges of growth in one year is a double (or multiple) ring. The second layer in the double ring is a false ring (Record, 1943). In extreme cases, double rings resemble two growth rings, but can be delimited through crossdating.

Complacent. A ring series that does not vary appreciably in width from year to year, or a site with adequate moisture that produces such a ring series. Complacency and its antithesis, sensitivity, are illustrated and described by Bannister and Smiley (1955).

Crossdating. Douglass (1946) described crossdating as "the comparison together of like ring patterns in different trees and the selection of the exact place at which correspondence between them is found." Schulman (1956) stated

Locally absent rings, false rings, and other less important sources of potential error in dating a ring sequency may be completely eliminated if a sufficient degree of parallelism in year-to-year fluctuation in ring-width is present in comparative sequences.

A knowledge of these sequences and their inherent variability may involve the study of many hundreds of specimens and include other species, age classes within the species, sites and major geographical areas in relation to each other and to climatic and historic data.

Double, or multiple ring. See annual growth layer in this discussion.

Growth ring. See annual growth layer in this discussion.

Lobe. The form, when seen in cross section, of the outer portion of the cleft and irregular stem that is characteristic of big sagebrush, especially of the older plants. A lobe may terminate either in an area of living cambium or in a dead terminal lobe.

Locally absent ring. See annual growth layer in this discussion.

Microscopic ring. See annual growth layer in this discussion.

Missing or absent ring. See annual growth layer in this discussion.

Sensitive. A ring series that varies greatly in width from year to year in response to changes in precipitation (in southwestern United States) or a site "thoroughly protected from any imported water and obviously limited by nature to dependence on the precipitation immediately about it (Douglass, 1946)."

Signature. A short, easily identifiable ring sequence that matches a portion of the established chronology.

Species Characteristics of Big Sagebrush

General Description. Big sagebrush ranges from Lower California, southeastern California, and northern Arizona northward to the Pacific

Northwest, British Columbia, and the Dakotas (Kearney and Peebles, 1954). Dayton (1931) stated that it "has a wider distribution than most North American shrubs and is probably more abundant than any other." The species occurs on soils of igneous, metamorphic or sedimentary origin.

Big sagebrush, Artemisia tridentata Nutt. belongs to the Anthemideae or mayweed tribe of the Compositae (Rydberg, 1916; Rydberg, 1922; Hall and Clements, 1923; and Ward, 1953). Hall and Clements (1923) divided A. tridentata into subspecies. In the present investigation, no attempt has been made to differentiate between subspecies, and all material belonging to the species has been classed as A. tridentata.

Typically, big sagebrush is an evergreen shrub about one meter high with a single, multibranched stem and an irregular crown. According to Beetle (1957), the southern ecotype typically has a rounded crown, but the northern ecotype is flat-topped. In defining the form of the stem section collected for growth-ring analysis, the use of the word "shrub" with the above definition may lead to confusion. Ward (1953) described big sagebrush as "with a single short trunk or with few ascending branches from the base." This description encompasses both "arborescent" and "fruticose" (shrub) plant form as used by Benson (1957). Stating that big sagebrush often has a relatively short main trunk will aid in understanding

the description of the collection technique and of the analysis itself.

Stem as used in this text will encompass both a relatively short main trunk and a single unit of the shrub form where a number of branches arise from ground level. The short main trunk, or an overmature modification of it, was the type most frequently encountered in this study.

As Cottam and Stewart (1940) mentioned, extremes in size are not necessarily proportional to age. Big sagebrush 30 to 50 years old, but not over six inches tall, were collected by the author at the head of the Silver Canyon road in the White Mountains of California, while near Kanab, Utah, Pase (1956) recorded a plant 15 feet 7 inches high and an adjacent plant, shown to be 21 years old, 13 feet high.

Due to lack of winter buds, the stem tips have much the same appearance throughout the year. There are no bud scales; leaves arrested in development in the fall resume their growth in the spring (Diettert, 1938). Beetle (1957) is not of this opinion.

Big sagebrush has two types of branches: vegetative and reproductive. Formation of the reproductive, or flowering branches, and their death following the ripening of seed cause the death of local areas of the lateral stem cambium at the point of branch emergence. This results in the formation of numerous depressed areas that show clearly when the bark is removed. These, often with the nonself-pruning branch still in place, may be traced to the central pith (Figure 1).

Figure 1. Section through a stem of big sagebrush at point of emergence of a reproductive branch showing the lobes produced at this portion of the stem by the nonhealing scar.

Diettert (1938) mentioned the marked eccentricity of the older stems. He attributed this to three causes: death of flowering branches, which remain on the plant for one or more years; cambium death resulting from the removal of the bark by wind or other agencies; and unequal growth in different portions of the same ring. Diettert implied, but did not specifically state, that the cambium never expands laterally over a dead portion of the stem nor combines with adjacent living cambium to cover an injured area, as is common in the healing of fire and other scars in most trees.

The eccentricity of the stem in which there is a total lack of radial symmetry in the older plants produces two features that will be mentioned in the text and that should be described in detail. These are the lobe and the rosette-form. "Lobe", as the term is used here, describes one cross-section segment of the stem either in the incipient or detached form (as shown in the cross sections in A and B in Figure 2). In the diffuse-spreading or decumbent form of both overmature multiple-branched shrub types and single-stemmed plants from which the lowermost branches have split off, the branches spread radially outward and form what is herein termed a "rosette" or circular cluster.

The rosette-form of overmature big sagebrush is illustrated by a living plant and a dead plant (Figure 3) from the north fork of Trail Canyon, Nevada. The plants pictured were growing in the deep alluvium

Figure 2. Diagrammatic longitudinal and cross sections of (A) mature and (B) overmature growth forms of big sagebrush showing the position of the pith in the solid and detached stems and the detachment of branches in the older plants that forms the rosette.

Figure 3. A living plant (above) and a dead plant (below) showing the rosette-form of the branches. A 15-centimeter rule is used as a scale.

of a small valley and had grown more rapidly than specimens collected for ring sensitivity and maximum age. They serve to illustrate the decumbent form of older plants after the full-formed stage of thrifty growth has passed. The nature of the branching in the final stage of the rosette-form is more evident in dead than in living plants. In overmature plants, the pith typically is present only in the extreme basal section and in the branches above their juncture with the main stem (Figure 2). Because of the structural weakness of the interxylary cork, the branches may split away from the main stem. This exposes the pith area and the interior portion of the stem is subjected to additional weathering (Figure 3).

Stem Anatomy. The major anatomical characteristics of the stem as described by Diettert (1938) follow: The pith of the young stem is stellate in cross section and composed of rather large isodiametric parenchyma cells. With the initiation of secondary growth, the gaps between the bundles are gradually closed by production of vascular tissue from the interfascicular cambium and by differentiation of some of the outer pith cells into fibers.

The primary xylem consists of annular and spiral vessels and fibers; the latter develop slowly and may not reach maturity until the second summer. A considerable amount of secondary xylem is produced

before the end of the first year; this also consists solely of fibers and vessels, the walls of the latter being densely pitted.

The phloem, of which a comparatively small amount is produced the first year, is capped by strands of primary phloem fibers. These do not reach maturity in the older portions of the stem until near the end of the growing season. The cortex of the stem is comparatively thin and composed of a few layers each of collenchyma and parenchyma. Very little cork is produced the first year.

The wood is diffuse porous. Vessels are more numerous and have smaller diameters in the early wood than in the late wood. Fibers, on the other hand, are more numerous and thicker-walled in the late wood than in the early wood. Maturation of the vessels is rapid; that of the fibers is much slower, many of them not reaching maturity until the second year. For this reason, the latest annual ring has a lighter appearance than do the older rings, often appearing as a bright yellow zone that stands out in contrast to the light brown of the older xylem. This yellow layer is analogous to the sapwood of many trees and shrubs.

Saul (1955) stated

...vessel elements up to .056 millimeter in largest diameter, .033 to .112 millimeter long, in tangential wavy lines throughout the annual rings in cross section appearing to be more or less uniform in size, simple perforation plates transverse, oblique on narrow cells, tails usually absent or short, lateral walls with 8-10 vertical rows of round to scalariform bordered pits having long horizontal

apertures, spiral thickenings present on round, pitted or unpitted cells; fiber tracheids absent; libriform fibers, thick-walled, with small double spiral thickenings, uniform throughout annual rings; longitudinal parenchyma, paratracheal and terminal in the form of interxylary cork, usually in 2-3 rows of radially rectangular cells dividing the annual rings.

The conspicuous rays are multiseriate and vary from .05 to .092 millimeter in width and from .262 to 1.312 millimeters in height (Diettert, 1938). The comparable measurements by Saul (1955) are .084 to .126 millimeter for the width and .280 to .560 millimeter for the height. Saul (1955) describes the rays as

...conspicuous, not numerous, multiseriate only, in tangential section appearing short and broadly fusiform surrounded by vertically rectangular sheathing cells, heterogeneous, the cells chiefly rounded in tangential view, cross fields with 13-20 half-bordered pit pairs, some cross fields without pit visible.

The annual development of an interxylary cork layer is a striking feature of the stem of this plant. This layer is produced every year during the growing season between the new annual wood ring and that of the previous year. These cork layers are typically 2 to 18 cells wide and have a total thickness of .03 to .275 millimeter. With the beginning of growth in the spring a single layer of meristematic cells (interxylary cork cambium) remains between the last-formed xylem of the previous year and the newly forming xylem tissue. These initials may increase in number but remain relatively unspecialized until the onset of extremely

hot and dry weather. At the beginning of the hot period, the innermost layer of these cells becomes suberized; the other layers remain in various stages of development. Maturation and suberization of the cork initials are progressive in a centrifugal direction, until at the end of the growing season they all have become suberized and no longer possess living protoplasm. Scattered, isolated vessels occur in the cork layer. Development of the interxylary cork closely parallels that of the external periderm; the latter is more extensive, however, and always develops centripetally.

Development of the interxylary cork is accompanied by suberization of the rays in the previous annual ring, although this process also extends into the older portion of the latest-formed rings. Suberization of the rays begins with the innermost cells of a ray and progresses outward. The latest-formed annual ring is thus completely sealed off from the interior mass of wood which then contains no living cells.

The bark of the older stem is brown and shreddy; it is often quite loose and peels off readily in narrow strips. This feature appears to be due to layers of cork and sclerenchyma which alternate with weak, thin-walled phloem cells.

Field and Laboratory Procedure

Collection. In the initial stages of field work, all material collected as A. tridentata was identified by sight, and the stem was considered as the "herbarium specimen". As work progressed, the need for leaf and flower herbarium material became evident. Collections from August, 1956, included herbarium specimens labeled as cited material. One set was deposited at the Herbarium of the University of Arizona, Tucson, Arizona. A second set was collected for analysis and identification in conjunction with a study of the taxonomy of the woody species of Artemisia by Alan A. Beetle, University of Wyoming, Laramie. All stem sections and field notes have been deposited at the Laboratory of Tree-ring Research, University of Arizona.

Criteria for the selection of individual plants were apparent maximum age for the site and soundness of stem. Because of the initial difficulty in evaluating plant age during field collection, it was necessary to collect more than the desired number of stems (at least three sound stems of the maximum age). Many stems were not of direct value because (1) the plants were short-lived or the older plants had the inner wood weathered away and as a consequence the ring series were short, or (2) because of growth characteristics that made evaluation difficult. As the study progressed, it became possible to judge in advance the ages of plants on typical sites so that eventually selection of plants for study

was based first upon selection of a site, then upon plants within the site. It was found that sites with environmental stress, primarily that of drought, produced older, slower-growing plants. As the study required the use of mature and overmature plants, collections were largely restricted to this type of site. In successive field seasons, the criteria for selection of a site became more refined as a result of the analysis of previous collections, and it was possible to select better sites and older plants within the site.

In an area producing plants that were 100-or-more years old, dead plants were often collected when they appeared to have a total age equal to, or greater than, the living plants.

Stems of the older plants, rather than being a single trunk, often consist of connected lobes derived from the original stem. In an advanced stage of growth, the lobes separate and form a rosette-like, nearly prostrate collection of stem parts. A specimen collected for ring analysis in this study consists of a single stem or a single-lobed portion from any one plant, unless otherwise stated.

Initial field collections ideally consisted of the complete stem. Branches and dead material were removed by snapping the brittle wood. Because chopping shattered the inner portion of the stem, the plants often were sawed off at ground level. If too fragile to be sawed, the plant was dug out of the ground and later sectioned. Overmature plants, their dead

roots weakened by rot, usually could be pulled out of the ground. Care was taken not to damage the stem by twisting or bending it.

Increment borings were often taken from adjacent conifers to provide comparative tree-ring material.

Preparation. Outer layers of the stem are protected by a very resistant, shreddy bark up to one centimeter thick, but structural weakness within the stem, resulting from the included cork, causes the rings near the center to exfoliate when exposed to the elements. These inner layers, valuable in dendrochronologic analysis, are fragile and require care in cutting and surfacing. Preservation was found to be best achieved by mending with a plastic glue as soon after collecting as possible. Vinyl glue was found to be a very efficient binder, and, because it did not completely solidify, permitted cutting and sanding of the mended stem.

When gluing a relatively sound section preparatory to sanding, glue was first put in cracks and weak spots in the less desirable surface. When this area was dry, the specimen was turned over and the other side glued. This was repeated, perhaps turning the specimen on its side, until all weak areas were filled. When all critical inner and outer surfaces had been coated, the initially unmanageable specimen was converted into a solid unit sound enough for handling and storage.

As a dozen or more stems were often collected from each site, a collection, even from one site, soon became bulky. Excess stem material and the root area were sawed off before the stems were labeled and sacked. Final sectioning was done with a fine-tooth band saw in the laboratory, and the best portion was selected for study. Two or three saw-cuts, surfacings, and re-examinations were sometimes necessary before the surfaces finally used for analysis were selected. When recutting, the better of the secondary surfaces were saved as distribution material.

The full cross section must be surfaced to examine the complete circuit of annual growth in the irregular stem section characteristic of A. tridentata. A belt power-sander was found to be the best tool for surfacing these cross sections.

In preparing the smaller, hand-sized specimens, the sander was placed on its side or tilted slightly upward in a V-shaped brace formed by two small boards nailed to the workbench. This technique permitted the specimen to be held against the moving belt and the sanding process was easier to observe. Larger, thinner sections were sanded by placing them in the V-brace and using the sander in its normal, upright position. A 3 x 21-inch belt sander was used with a series of garnet papers from 80 to 120 grit and aluminum oxide papers from 150 to 320 or 400 grit. These, used in sequence from coarse to fine, quickly produced a smooth

surface suitable for examination with a ten-power hand lens. Handling and examination of the specimen was made easier by stripping off loose or excess bark and removing dirt and dust with a jet of compressed air.

Preparing the surface of a cross section by sanding left the large pores nearly filled with the fine wood particles removed in the sanding operation. Occasionally, it was necessary to improve a portion of a surface, as when attempting to locate an earlier pith year or terminal growth year on a dead plant. This resurfacing was done easily and quickly with a razor blade at the time the specimen was being examined. In contrast to the sanding, a razor-cut surface left the large pores completely empty and the wood appeared to have a very different structure.

The razor-blade technique of preparing a surface was useful in examining the sapwood when this yellow wood contained more than a single year's growth as often occurred in the root zone or in the stem of plants collected midway through the growing season. Layers of inter-xylary cork in the yellow wood are not evident on a sanded surface but are visible on a razor-cut surface.

Examination. Contrast between the dense xylem and the more porous layer of included cork was accentuated by the application, with a cotton swab, of a light coat of kerosene. Differentiation was further aided by examining with frontal light reflected at an angle from the polished surface. The cork layer, not having the high albedo of the

harder wood, would stand out under the reflected light that masked the color and permitted examination of structure alone.

All specimens collected from a given site were compared and analyzed collectively. The ring pattern in each specimen was evaluated in terms of others in the group, and a ring pattern, or chronology, was established for the site. The site chronology was then compared with that of other groups, with adjacent tree-ring chronologies, or was analyzed with respect to rainfall data. In this way, it was possible to memorize not only the chronology as a whole but also the character of individual years. This made it possible to determine the age of a plant by recognizing, for example, the 1900 signature, and to work inward from that period rather than from the outside ring. The same approach made it possible to identify a given ring sequence in dead plants and to determine the last growth year before the plant died, if this was within the known chronology.

When a specimen consisted of two or more parts, each was dated separately, even though the adjoining pieces fitted in a known position. This provided a control for the dating of short sequences, especially in detached inner portions. A 165-year-old specimen from Trail Canyon provides a good example of this. This specimen consisted of two pieces that had been forcibly separated by lateral expansion of the lobes. This distortion prevented joining them exactly, even though the growth layers

were in sequence. The living portion had an inner ring of 1857. The chronology of the detached inner piece was picked up on the 1822-1829 signature and was verified by following the series to an inner ring of 1794 and to an outer ring of 1856. This gave an uninterrupted sequence through the 1856-1857 break. The linking of chronology between two adjoining pieces was further verified by a close examination of the surfaces of the break where it could be seen that the two pieces once had fitted together. This fitting, whether in a fresh break or where two pieces have been forced apart by the growth of the lobes, is completely certain when substantiated by (1) the sequence in chronology, (2) the matching of the break in general contours, (3) the matching of branch stubs or branch scars within the surface of the break, and (4) the alignment of the rays in a continuous line across the break separating adjoining pieces.

In chronology building or in the dating of individual specimens, the innermost portion often may be undecipherable due to the occurrence of double rings, microscopic or locally absent rings, or shortness of the series in a detached portion. When other specimens in the same or nearby groups are dated, it often is possible to come back to an undated portion, and with the added information, date it.

Rings on one or more radii of both surfaces were identified on the specimen by marking the decade years with a needle point or with an

inked dot. When all radii on both surfaces had been examined, a radius containing the least distortion was marked for measurement if the specimen warranted further study. This radius followed the direction of the rays in the central portion of a lobe and was usually curvilinear, because direction of lobe growth was seldom straight.

Rings were measured in hundredths of a millimeter on a Craighead-Douglass Measuring Instrument (Douglass, 1943) and, after the spring of 1959, on a DeRouen Dendro-Chronograph. The dendro-chronograph utilizes a somewhat different method of recording the measured ring, but the absolute values recorded by the two instruments for the same ring series were identical within the limits of accuracy of the instruments. As the measurements were read on the dial of the measuring instrument, they were recorded on adding machine tape. This was then prepared for filing by mounting on standard 8 1/2 x 11 paper.

Measured ring series of individual specimens or group means were plotted on a vertical scale of 0.50 millimeter per centimeter, unless otherwise noted, and a horizontal scale of one year per two millimeters. Specimens of a single age class from one site were tabulated and averaged to form a group mean, thus minimizing random fluctuation of individual specimens caused by the growth-form of the lobes. An age class is comprised of a group of plants with essentially the same age and rate of growth. For example, three plants with pith years of 1894, 1896,

and 1897 and with comparable chronologies along a radial length of five to six centimeters would be considered to be in the same age class. After these three series were measured, they could be tabulated and averaged. To avoid the distortion near the pith and the unequal pith years, the averaging would be from 1899 or wherever the ring widths were of comparable magnitude.

All measured ring sequences were checked in one of two ways: (1) by visually checking the specimen as the measurements were read, or (2) by comparing the plotted measurements with other related plots.

In addition to checking the absolute values, the examiner could compare the relative ring widths of a greater area of the surface than could be seen under the microscope of the measuring instrument and could note any divergence of the measured ring sequence from the general pattern. Any gross error such as the recording of 0.35 millimeter for 1.35 millimeters easily could be detected; smaller errors could be detected by noting relative widths of adjacent or sequential rings.

With practice, one can judge by eye even the absolute width of a ring. If the examiner anticipates the numerical value of the width before it is read and the recorded figure is not within a narrow margin of the estimated width, a correction is made by remeasuring the ring.

Familiarity with the chronology enables the examiner to detect errors in measurement by observation of the plotted values. When a single plot is compared with others of plants in the same area or other related data, even relatively minor errors can be detected. A suspected error in measuring or plotting often turns out to be a true value and comparison with other plants or elsewhere about the circuit on the same plant indicates that the discrepancy is due solely to an extreme width within the natural variation of the annual growth.

It should be emphasized that any measurement is accurate within the limits of the machine and that corrections made are usually based upon the more general view obtainable when checking with a ten-power hand lens rather than upon errors in the measuring operation. With a minimum of practice, one can measure and plot with an accuracy approaching exactness. Due to the possibility of error, measurements or the resultant plots should be checked.

In the measurement of ring sequences, the emphasis was upon many specimens rather than on different radii (or lobes) or the same radius at different elevations in the stem. The total measurements or the derived mean for a site thus had the weight of a larger number of sampled specimens.

Special Techniques in Analysis

Microscopic, locally absent, and false rings in conifers were discussed by Schulman (1956). Big sagebrush on dry sites produces microscopic rings in years of very low rainfall and, very rarely, an interval about the circuit where a ring is locally absent. The latter may be either an anomaly caused by a local injury of the cambium or a physiological eccentricity occasioned by extreme drought. As yet, no instance of the complete absence of a seasonal growth-ring, or "missing ring," has been found in big sagebrush.

False rings, on the other hand, occur in big sagebrush at low elevations and in southern latitudes, but were not encountered by either Diettert (1938) or Moss (1949) in their work in more northern areas. In the drier southern areas, an extra layer of interxylary cork sometimes is included within one season's xylem growth and causes a double or multiple annual ring; one of these growth zones is known as a false annual ring (Record, 1934).

The false component may be identified by using two approaches: microscopic inspection of the ring structure and cross dating.

Microscopic Inspection. Frontal light reflected from the polished surface of a specimen accentuated the interxylary cork layer due to differences in texture which caused the light to be absorbed, rather than reflected by the cork. In contrast, when the polished surface was

examined under diffuse light from any point at right angles above it, differences in color, rather than in texture were noted. In a specimen uncomplicated by any double rings, one layer of interxylary cork would separate the two layers of xylem surrounding it. In some specimens, when examined under reflected light, a closely spaced double line could be seen between annual xylem layers instead of the usual, slightly broader line of interxylary cork. When examined from above under diffuse light, this double line was seen to be a single cork layer containing xylem elements and it was evident that the double line observed under reflected light was primarily the inner and outer limits of the cork layer. The cork layer had become so large and complex that the central portion contained some xylem elements and was hard enough to take a polish. Diettert (1938) reported occasional vessels in the cork but apparently had not observed a sufficient concentration of xylem elements to produce false rings. If growth of the xylem for one season is interrupted, a second layer of interxylary cork cambium is formed and deposits a second layer of interxylary cork as the xylem growth resumed. In typical double rings of big sagebrush, the false layer of cork is strongly defined and lies between distinct layers of xylem fibers and vessels. This extra layer of cork cambium may occur either as a partial or a complete meristematic layer. The resulting cork consequently follows the same complete or interrupted pattern about the circuit

and may vary in thickness. These second layers of cork in a double ring are usually more distinct near the center of the ring-arc and, as they are commonly thinner than the true cork layer, often fade out or merge with the cork of the bark near the edge of the lobe. The secondary layer, or false component, of the double ring often occurs as a lens rather than as a complete layer. This is most likely to occur in young, fast-growing plants of the sort shown in Figure 4. In Figure 5, one of the two lenses is shown in enlarged detail. If the lens were expanded along the arc of the ring bordering it on the inside, it would become a false ring. A single radius through the lens obviously would not be distinguishable from a radius through a false ring at any position about the circuit. In rare instances, a third component may be formed in a multiple ring.

If a suspected false layer cannot be verified by study of a single specimen, an analysis based upon crossdating is used.

Crossdating. When specimens exhibit a degree of sensitivity, all specimens in an area would be expected to show a similar pattern of variation in that all have been subjected to the same climatic stresses. This similarity in ring chronologies enabled the specimens to be crossdated. Because a false component in big sagebrush does not occur in every ring but is typical only of certain years, these "false rings" can be identified by crossdating; other lobes of the same plant or of other specimens serve as controls.

Figure 4. Lenses shown on a full cross section of a stem from a young, fast-growing plant. An enlargement of the section near the lower lens is shown in Figure 5. A five-centimeter rule is used as a scale.

Figure 5. Detail of the lower lens shown in Figure 4.

CHAPTER II

RING ANALYSIS DATA

Data will be presented in tabular form for individual sites within each major collection region. Site data summarized in tables include (1) collection date; (2) elevation in feet; (3) the pith year; i. e., the year in which the pith was formed, and (4) total length, in years, of the ring series. This last item represents the difference between the innermost ring and the collection date, plus one year when the current season's growth is present on the specimen. Discussion of dating problems and their interpretation are summarized at the end of each section. Because of their repetitive nature only representative specimens in each tabulated group are discussed. Dated ring chronologies on various portions of the collection were inspected by Bryant Bannister, Edmund Schulman, Terah L. Smiley, and Marvin A. Stokes of the Laboratory of Tree-Ring Research.

Major collection sites are shown in Figure 6. Data have been grouped in the following regional sequence: northwestern New Mexico;

Figure 6. Outline map of the southwestern United States showing the following numbered collection sites for big sagebrush: (1) northwestern New Mexico, (2) northeastern Arizona, (3) San Bernardino Mountains, (4) Panamint Mountains, (5) White Mountains.

northeastern Arizona; San Bernardino Mountains, California; Panamint Mountains, California; White Mountains, California and Nevada.

Navajo Reservoir Area, New Mexico

A stem collection of big sagebrush from six sites and a collection of increment borings from pinyon, Pinus edulis, and one-seed juniper, Juniperus monosperma, were made in the Navajo Reservoir area, near the confluence of the Los Pinos and San Juan Rivers, in northwestern New Mexico (Figure 7). This collection, made in cooperation with the Navajo Project (a salvage archaeology program under cooperative agreement between the National Park Service, Region Three, and the School of American Research, a research affiliate of the Museum of New Mexico) was undertaken in part to investigate the possibility of using big sagebrush as a tool in dating archaeological sites in the area (Ferguson, 1958). Three of the collection areas were on or near prehistoric dwelling sites (Sites 90, 95, and 149; Dittert, 1958) and retain their archaeological survey site classification in the discussion. Ring analysis data for the six sites are presented in Table I, but each site will be discussed separately.

Dam Mesa Site. Six specimens were collected on the northern part of the Dam Mesa. This level area was three-quarters of a mile in length and lay immediately north of the Navajo Reservoir Dam on the San

Figure 7. Location of collection sites in the Navajo Reservoir area at the junction of the Los Pinos and San Juan Rivers. Numbers on the map represent the following sites: 1. Dam Mesa; 2. Second Bench; 3. Site 95; 4. Site 149; 5. River Bank; and 6. Site 90. The area illustrated is the west-central portion of the Pine River Quadrangle in northwestern New Mexico (see insert on the map for quadrangle location). Scale is one mile to 2 5/8 inches. Contour interval is 20 feet.

Table I. Ring analysis data for the Navajo Reservoir area, New Mexico.

Site name and collection date	Elevation, feet	Pith year or (*) inner- most ring	Length of series, years
Dam Mesa 8-19-58	6,330	1906 1906* 1890* 1875* 1867* 1866	53 53 69 84 92 93
Second Bench 8-19-58	5,940	1905 1903 1890 1887* 1859	54 56 69 72 100
Site 95 8-20-58	5,850	1916* 1905* 1886 <u>1/</u> 1882 1882 1882 1882* 1878 1876* <u>2/</u> 1877 1861* 1855 1838* —	43 54 (58) 77 77 77 77 81 (55) 82 98 104 121
Site 149 8-19-58	5,840	1909* 1906 1905 1905* 1902* 1899	50 53 54 54 57 60

Table I. (cont'd) Ring analysis data for the Navajo Reservoir area,
New Mexico.

Site name and collection date	Elevation, feet	Pith year or (*) inner- most ring	Length of series, years
River Bank	5,820	1937	22
8-19-58		1913	46
Site 90			
6-17-58	5,775	1905	54
		1899	60
		1893	66
		1888	71
		1880	79

^{1/} Dead when collected. Terminal ring in 1943.

^{2/} Dead when collected. Terminal ring in 1930.

Juan River about 2.5 miles, by river, south of its confluence with the Los Pinos River. Here, an open stand of big sagebrush, on a sandy clay soil, contained plants with from 53 to 93 rings (Table I). The innermost ring on the 92-year series was apparently very near the pith and the plant appeared to be only a few years older than was indicated by the total number of rings. Characteristics of the innermost rings of the 84-year series indicated an age several years in excess of the recorded 84, perhaps as old or older than the 92- and 93-year-old plants. Although three of the six plants from this mesa were only slightly over 50 years old, the age of the stand itself was in excess of 90 years.

These plants exhibited a strong tendency to form false layers. These occurred either as small rings that were regular about the circuit, or as lenses.

Second Bench Site. Five plants were collected on the second bench west of the Los Pinos River at its junction with the San Juan River (Table I). The soil at this site was a well-drained sandy loam derived from sandstone. Most of the older plants were badly weathered and had eroded centers. Four of the five plants collected still retained a pith, but three of these were of only moderate age, ranging from 54 to 69 years. One 72-year series was obtained from a plant with the pith missing and, although the plant was older than was indicated by the total rings, it probably was not much in excess of the recorded age.

The fifth specimen was composed of two pieces, the outer of which was comparable in cross section to many stems from which the pre-1900 portion had been eroded. The innermost ring was laid down in 1905. In position when the plant was collected was a second detached piece that constituted the inner core. The pith was present in this piece and the ring series, from 1859 to 1900, contained an excellent chronology, especially the small rings for 1861, 1864, 1870, 1876, 1885, 1887, 1894, and 1896. Where the contours of the two pieces fitted together, the adjacent surfaces were eroded and the rings for 1901, 1902, 1903, and 1904 had been lost. Had it not been for the excellent 42-year series on this inner piece, the noncontinuous ring series could not have been positively tied to the outer piece and this would have prevented its use in determining the age of the plant. On the other hand, had the relation of this inner core to the 1905-1958 series on the outer piece not been known, it could have been dated by comparison with the area chronology represented by the single measurement plotted in Figure 9.

The five specimens from this site were almost devoid of false rings. This may have been due to their slower growth rate and to their occurrence on a protected site; i. e., neither on the mesa top nor on the main drainage. On these specimens, only the ring for 1947 consistently developed a false layer.

Site 95. The Site 95 collections were made in a pure stand of big sagebrush found on a bench on the west side of the Los Pinos River a few hundred yards above its confluence with the San Juan River. Thirteen specimens, two of which were dead, were collected (Table I). The range in ages indicated that the site supported an uneven-aged stand with the maximum ages of from 100 to 150 years. In general, the specimens exhibited an excellent chronology, although there were many double rings. The ring for 1947 was always double; the other double rings; i. e., 1887, 1902, 1911, and 1929, varied in their occurrence from specimen to specimen, and in their ease of recognition.

Three of the oldest plants from this site were over 100 years old; the 98-year series appeared to have a considerable number of the inner rings missing. The plant with the 121-year count had a 50-year inner portion that consisted of a single lobe about one centimeter wide. This is characteristic of the older, slower-growing plants. With this evidence, it was estimated that the pith for this specimen was formed about 1800 or even earlier.

Age at time of death of each of the two dead plants was 55 and 58 years. The younger plant dated to an 1876 pith and, because the chronology was much earlier in time than in the 58-year series, aided in establishing the chronology for the pre-1900 interval.

Site 149. The collections from Site 149 were made from a pure stand of big sagebrush on a long, low bench extending south from the mesa between the Los Pinos and San Juan Rivers and immediately above their junction. This site is just above and slightly left of center in Figure 8.

The length of series for the first five specimens, which were from the top of the bench, ranged from 50 to 57 years (Table I). Although three of the specimens had eroded centers, the count apparently would not have been much greater had the pith been present. The specimens from this site indicated a faster growth rate and earlier maturity than for Site 90 immediately across the Los Pinos River to the south.

Although the growth layers in the first five specimens (with pith years 1909-1902) from Site 149 were double in about one year out of ten, the double rings were easily recognized. The false layer for 1947, however, which usually was very regular in width about the circuit, was difficult to distinguish from a true annual ring.

The 60-year series was from a plant growing near the upper slope at the eastern edge of the bench, under different site conditions than were the other five specimens from Site 149. Except for the extreme center, the inner portion of the ring series was complacent; the outer portion, on the other hand, had an excellent chronology. This specimen was the only one in the Navajo Reservoir collections that showed no evidence of

Figure 8. View to the north showing Site 149, the sagebrush-covered point in the center of the picture, at the junction of the Los Pinos River, coming in from the left, and the San Juan River, from the upper center. Site 90 occurs on the bench in the foreground just to the right of the area shown in the photograph. See the topographic map in Figure 7.

a double ring for 1947. This, combined with the crossdating between specimens, verified the typical double nature of the 1947 ring.

River-bank Site. Two specimens were collected near the west bank of the San Juan River about a half mile above Site 149 (Table I). One 22-year-old stem was selected as an example of the large (estimated height 12 feet), fast-growing plants from alluvial soil near the river. The stem of this specimen, illustrated in Figures 4 and 5, had large, complacent rings. An interruption of the growth on a portion of the ring caused the formation of lenses, one of which is shown in detail in Figure 5.

The second specimen was from the same immediate area, but was growing on a well-drained, sandy-loam slope above the road. Growth rate and ring character of this plant contrasted markedly with these characters as exhibited by the plant from the more favorable site. Although 46 years old, the second plant had a total cross-sectional area about half that of the 22-year-old specimen. Even this rate of growth was rapid, however, when compared with 100-year-old plants on the adjacent benches. The ring chronology was difficult to interpret because of at least one false layer in each annual ring; some rings even had a third component. This specimen, as an isolated collection, would have been difficult to date without adequate comparison material.

Site 90. Five specimens (Table I) were collected by A. E. Dittert, Jr. at Site 90 (to the right of the stand shown in the foreground in Figure 8), prior to collection in the area by the author. All five specimens contained a pith and the various plants ranged in age from 54 to 79 years. This collection was analyzed at the same time as the others in the Reservoir area, but it alone would have been adequate to establish the area chronology for big sagebrush and to show the relationship of this chronology to that of the pinyon, Pinus edulis.

In contrast to the type of plants collected later by the author on other sites in the same general area, those collected by Dittert had larger and sounder stems and were slightly shorter lived.

Discussion; Ring chronology. Stem sections of thirty-seven plants, representing the range of growth types in the Navajo Reservoir area of northwestern New Mexico, were collected and examined. Plants near the stream bottom and on moister sites were up to 12 feet in height and fast-growing. In contrast, those on the benches and mesa tops were low and slow-growing. Some specimens with an age of over 100 years were found on the more protected middle and upper benches. The central portion of the older plants was typically eroded and lost, thus making difficult the collection of long ring series. Both types produced growth rings which occasionally contained an extra growth layer (false ring). These were readily defined and, rather than complicate the identification

of the growth layers as to the year in which they were formed, added to the character of the ring and facilitated dating of the specimen.

Discussion; Comparison with conifer chronologies. Increment borings were taken from twelve pinyons, Pinus edulis, and two exploratory borings were taken from one-seed junipers, Juniperus monosperma, to provide a local tree-ring chronology. Four of the pinyons had pith dates in the mid-1600's. The relatively slow-growing pinyon is characterized by many missing rings; the juniper by both missing rings and false rings; both, however, were datable.

The plotted ring chronologies shown in Figure 9 illustrate the close correlation between (1) a single plant of big sagebrush, the inner rings of which are lost; (2) a mean of four pinyons from the immediate area, representing the local tree-ring chronology; and (3) the mean of seven Douglas-firs from Mesa Verde (Schulman, 1956) 45 miles to the west-northwest, representing an established area chronology. Because of differences in species and area, some year-to-year differences in chronology were noted, but the essential features; i. e., the small rings, followed the same pattern. Note especially the minimum ring widths recorded for the years 1847, 1851, 1861, 1864, 1870, 1876, 1883, 1886, 1896, 1902, 1904, 1913, 1918, and 1943.

Figure 9. Plots of measured ring width of one big sagebrush; the mean of four pinyons, expressed in hundredths of a millimeter, and the mean growth departures for seven Douglas-firs, expressed as a per cent.

Northeastern Arizona

Forty-nine plants of big sagebrush were collected from three sites in northeastern Arizona. Two of the sites were on the Navajo Indian Reservation: one north of Ft. Defiance, the other south of the Canyon de Chelly National Monument near the junction leading to Spider Rock Campground. The third site was in the Betatakin unit of the Navajo National Monument. In the interest of brevity, these are referred to hereinafter as the Ft. Defiance, Spider Rock, and Betatakin sites, respectively.

The longest ring series from each area were measured and the mean for each site was plotted to show graphically the comparative ring chronologies (Figure 11).

Ft. Defiance Site. The Ft. Defiance collection site (Figure 10) was eight miles north of Ft. Defiance on the road towards Sawmill and 0.1 mile east of the road. At this site, big sagebrush occupied an upper valley slope on a red sandstone soil and extended to the border of the pinyon and ponderosa pine growing on a slight rise above the upper slope. Big sagebrush in this area was about one meter high and occurred as an open stand with a grass understory. There was a greater number of plants per unit area on the upper slope near the timber than elsewhere in the valley. Observation, substantiated later by the ring analysis, was that

Figure 10. Ft. Defiance Site. Big sagebrush in the foreground was 50 to 60 years old. Ponderosa pine and pinyon occur in the background.

the stand was not very old. This was indicated by thrifty, full-formed plants and a lack of prostrate branches and dead wood.

The length of series for the 13 plants from this site ranged from 44 to 61 years (Table II). The actual ages probably were only one to five years in excess of these figures because the pith was present on all stems collected and the lowermost surface of the stem section was within a few centimeters of the ground line. The stems were solid and relatively unlobed. Height growth was rapid; annual height growth of four centimeters or more was common in the 40- to 50-year-old plants. The year 1955 was used as the outer year in calculating the length of series even though it occurred on only three specimens. Because of the earliness of the collection date (April 16), growth for 1955 was present only on these three plants from this site and these were the more vigorous specimens. Three of the slower-growing plants were nearly dead, perhaps as a result of the drought of the previous few years. The years 1946 and 1947 showed as double rings on four of the specimens. The rapid growth, the range in age of the 13 plants, and the presence of young plants in the area indicated a rapidly-maturing, uneven-aged stand of big sagebrush at this site.

Spider Rock Site. The Spider Rock collection site was on the road between Chinle and Sawmill along the south rim of Canyon de Chelly and four miles southwest of the Spider Rock Campground. Eighteen stems

Table II. Ring analysis data for big sagebrush from the Ft. Defiance and Spider Rock sites in northeastern Arizona.

Site name and collection date	Elevation, feet	Pith year or (*) inner- most ring	Length of series, years
Ft. Defiance 4-16-55	7,560	1912	44
		1911	45
		1908	48
		1907	49
		1907	49
		1905	51
		1905	51
		1903	53
		1903	53
		1901	55
		1897	59
		1897	59
		1895	61
Spider Rock 4-15-55	6,700	1905*	51
		1904*	52
		1902*	54
		1902*	54
		1901	55
		1893*	63
		1889*	67
		1879*	77
		1879*	77
		1876 *	80
		1875*	81
		1870*	86
		1868*	88
		1864	92
		1864*	92
		1862	94
		1862*	94
		1859	97

of big sagebrush were collected immediately southwest of the junction of the road leading to the campground in an open stand of pinyon and juniper on a gentle slope of loose, deep, red sandstone soil.

The length of the ring series for the 18 specimens ranged in an even progression from 51 to 97 years (Table II). These figures did not in all cases indicate actual plant ages because 14 of the 18 specimens lacked a pith-area core. A severe drought during the period from 1894-1904 resulted in death of portions of the stem cambium and the consequent formation of many lobes. These lobes were differentiated in 1905 or occasionally two or three years earlier, as in the four specimens with the shortest length of series. The severity of this drought was commented on by Schulman (1956) as follows

During the period 1897-1904 and for several years earlier, deficient growth and such intensity of drought as have been rarely approached in the centuries of growth records prevailed in both the Colorado River Basin and southern California.

In contrast to the lobes of older, slower-growing plants that maintained a constant width for 40 to 50 years, some specimens showed a remarkable increase in the total circuit of active cambium over a period of time through a given cross section. One lobe showed an arc of 0.2 centimeter at the base of the innermost ring, that for 1905. By 1949, the stem at this section showed only one break in the cambium, and the total arc of the two resultant lobes measured 9.5 centimeters. In this

specimen, as in many others from this site, the rings for 1950 and 1951 were small and the cambium became interrupted at intervals about its circuit with the result that lateral stem growth was broken into many units. This break in the continuity of the cambium resulted in the formation of 14 lobes with a total arc of 10.5 centimeters prior to the 1955 ring. Thus, during a period of 50 years, this section showed a lateral expansion of the active cambium from 0.2 to 10.5 centimeters.

Double rings occurred frequently at this site, especially in the faster-growing stems. The small ring for 1904 was double in about half of the specimens. Other years that were represented by double rings in one or more of the 18 specimens were 1878, 1881, 1909, 1911, 1914, 1929, 1930, 1934, 1936, 1940, 1946, and 1947. Some variation occurred in the form of the false layer; in one specimen it appeared as a wedge (1911) and in others as a lens (1881).

The presence of three specimens with pith years of 1864, 1862, and 1859 indicate a maximum age of at least 97 years for the site. The 10 specimens with an inner ring antedating 1900 all had the narrowed stem characteristic of lobes formed on a solid core of 15 to 20 rings. Because of this, it is assumed that some of the plants lacking a pith were a few years older than the oldest recorded for the site.

Betatakin Site. The Betatakin collection was represented by two sites: (Site I) a group of three specimens from an open pinyon-juniper

stand near the campground and (Site II) a group of 15 from a small valley about 0.5 mile south of the headquarters. These two sites were somewhat distinct and are reported separately in Table III. The three plants from the pinyon-juniper stand all lacked a pith and indicated a maximum age for the area ten-or-more years greater than that of the valley site.

In this area, 1899, 1930, and 1947 were represented by double rings. The ring for 1956 was present but incomplete. The oldest of the plants collected indicated a maximum age for the site of about 90 years.

Discussion. Double rings, occurring in big sagebrush from each of the three sites in northeastern Arizona, were present in certain years frequently enough to show some crossdating in this feature of ring growth. The most frequent occurrence of double rings was in the years 1904, 1930, 1946, and 1947.

Specimens within each of the three sites had ring chronologies with crossdating that was evident upon visual examination. This crossdating within the sites was easily extended to crossdating between the three major areas represented in the northeastern Arizona collections. To illustrate this similarity in ring pattern, the longest ring series were measured and a mean for each area was plotted. These comparative ring

Table III. Ring analysis data for big sagebrush from the Betatakin sites in northeastern Arizona.

Site name and collection date	Elevation, feet	Pith year or (*) inner- most ring	Length of series, years
Betatakin I 5-28-56	7,200	1899*	58
		1888*	69
		1870*	87
Betatakin II 5-28-56	7,200	1911	46
		1909	48
		1909	48
		1908	49
		1905*	52
		1904*	53
		1898	59
		1889*	68
		1888*	69
		1887*	70
		1887*	70
		1880	77
		1880	77
		1876	81
		1875	82

chronologies and an adjacent Douglas-fir chronology are shown in Figure 11. The measurements are for a mean of three plants of big sagebrush from north of Ft. Defiance, eight from the Spider Rock area, and five from the Betatakin area (one from Site I and four from Site II). About 30 miles separate the first two sites; 80 miles the last two. The bottom curve, shown for comparison, is a mean of five Douglas-fir from Tsegi Canyon (Schulman, 1949) with an eight-year extension. The Douglas-firs were all growing within a few hundred meters of the big sagebrush plants from which the Betatakin mean of five was derived. The break, represented by paired vertical lines, in the three curves for big sagebrush represent the earliest year reached by all the plants comprising the group mean. Measured ring widths for the oldest specimen in each group is plotted to the left of the break to provide an extension for each of the mean chronologies. These extensions are of value in that they, through crossdating, provide a control for the innermost portion of the mean chronology. The minimum ring widths for the year 1896 in the Ft. Defiance extension, and hence, the early portion of the mean of three, is substantiated by the occurrence of a ring of comparable width in the mean chronology for the Spider Rock and Betatakin big sagebrush and for the Tsegi Douglas-fir. The Douglas-fir chronology is the only available control for the Spider Rock extension and the dating in the big sagebrush is verified by the minimum ring widths for 1861 and 1864 in both series.

Figure 11. Mean ring measurements for three big sagebrush plants from north of Ft. Defiance, eight from the Spider Rock area and five from Betatakin, and growth departures for five Douglas-fir (DF) from Tsegi Canyon. Mean ring widths for the big sagebrush are expressed in hundredths of a millimeter; mean growth departure for the Douglas-fir as a per cent.

Strong similarity will be noted in ring chronology between the three areas and between the two species. Small rings, which are critical in dating a specimen, are the key rings to use in visually cross-dating a plotted ring chronology. In this regard, note the minimum ring widths for 1861, 1864, 1887, 1894, 1896, 1902, 1904, 1918, 1934, 1936, and 1951.

The dominant climatic factor--winter rainfall--responsible for the crossdating within the specimen itself is reflected in the similarity of ring pattern in all plants in the same site and between major areas, as shown in Figure 11. In other areas within the broad west to east path of the winter storms, then, could be expected to be found the same general chronology. In Figure 11, note the 1900 interval, especially 1902 and 1904, as well as the increased ring width for 1952 following the minimum for 1950 and 1951 and then compare these ring sequences with the chronologies for the Navajo Reservoir area (Figure 9), for the Panamint Mountains (Figure 24), and for the White Mountains (Figure 34).

San Bernardino Mountains, California

Forty-four plants of big sagebrush were collected at various sites north and east of Big Bear Lake in the San Bernardino Mountains of California (Figure 12). Ring analysis data for Furnace Canyon and Belleville are presented in Table IV and for the sites east of Baldwin Lake

Figure 12. Location of collection sites for big sagebrush in the San Bernardino Mountains of southern California. Numbers on the map represent the following sites: (1) Furnace Canyon, (2) Belleville, (3) Site I east of Baldwin Lake, and (4) Site II east of Baldwin Lake. The area illustrated is the southeastern portion of the Lucerne Valley quadrangle. Scale is one mile to one inch. Contour interval is 50 feet.

in Tables V and VI. A brief description accompanies each tabular presentation and two major aspects of the ring study in this area, namely, dead plants and height growth are presented in the discussion.

Furnace Canyon, California. The Furnace Canyon site was north of the Greenlead Road between Holcomb Valley and Big Pine Flats and 0.1 mile west of Furnace Canyon. Big sagebrush constituted a scattered understory on a dry south slope, on limestone soil, covered with pinyon, juniper, and mountain mahogany, Cercocarpus sp.. The four specimens ranged from 59 to 71 years in length of series, and the pith was present on both surfaces of the stem section (Table IV). These ages indicated the maximum potential age of big sagebrush on the site to be slightly over 70 years. In two of the four specimens, 1952 was a double ring. In the youngest of the four, the ring for 1915 was missing in a localized portion of its circuit. This was the only instance where such an effect was observed in big sagebrush, and it is presumed to be an anomaly that may have been due to local injury of the cambium.

Belleville, California. The two Belleville specimens (Table IV) were growing on soil that was assumed to have been disturbed during the time of the town's occupancy (ca. 1860-1870). The pith on the 43-year specimen was estimated to have been formed five to ten years earlier than the innermost remaining ring. This, with allowance for at least one year for height growth on the second specimen, would mean that both

specimens had ages slightly in excess of 45 years. This age would be in keeping with the possible invasion of the plants into the abandoned townsite. Both specimens were fast-growing and were not collected for their age but because of their historical significance.

Table IV. Ring analysis data for big sagebrush from Furnace Canyon and Belleville, California.

Site name and collection date	Elevation, feet	Pith year or (*) inner- most ring	Length of series, years
Furnace Canyon 9-10-57	7,350	1899 1897 1888 1887	59 61 70 71
Belleville 9-10-57	7,350	1915* 1914	43 44

The 44-year specimen had large, well-developed roots exposed on the eroded soil surface. These exposed roots had produced many small adventitious roots.

Area east of Baldwin Lake, California. Collections in the area east of Baldwin Lake were made on two distinct sites. Both were along the road to Arrastre Creek east of its junction with the road around Baldwin Lake. Site I was 0.9 mile east of the junction; Site II, 0.1 mile. Material from both sites was collected in 1956. Site I was revisited on two consecutive days in 1957. Material from the three collections on Site I are tabulated in Table V as a single group, but with the collection dates given for each specimen as a control for the length of series.

Collections at Site I were made on deep granitic alluvium about midslope, south of the road, in a small valley of big sagebrush surrounded with low hills covered with pinyon and juniper (Figure 13). Plants associated with big sagebrush were Bouteloua sp. and Chrysothamnus sp. The valley site was composed of an uneven-aged stand of big sagebrush with a noticeable amount of reproduction and many old and dead plants. The older plants, those in the 80-to-100 year age class, contained much dead wood as is shown in the site photograph.

The pith on the 52-year series was estimated to have been formed between 1901 and 1903. These dates would extend the age only one to three years beyond the innermost remaining ring. The 56-year series, on the other hand, had an estimated 20 to 30 rings lost and indicated the care necessary to interpret the character of the innermost portion of a stem with an eroded center if an estimate of total age is desired.

Table V. Ring analysis data for Site I east of Baldwin Lake, California.

Collection date	Elevation, feet	Pith year or (*) inner-most ring	Length of series, years
9-10-57	7,280	1913	45
12-23-56		1904*	52
9-10-57		1905	53
12-23-56		1901	56
9- 9-57		1900*	58
9- 9-57		1894*	64
9- 9-57		1861	(69) ^{1/}
9- 9-57		1885*	73
12-23-56		1883	74
9-10-57		1875	(76)
12-23-56		1881*	76
9- 9-57		1880*	78
12-23-56		1874	83
12-23-56		1873	84
9- 9-57		1868	(84)
12-23-56		1872	85
9- 9-57		1853	(85)
9- 9-57		1873*	85
9- 9-57		1863	(88)
9- 9-57		1869	89
12-23-56		1868	89
12-23-56		1868	89
9- 9-57		1868	(89)
12-23-56		1868*	89
9- 9-57		1868	90
9-10-57		1868	90
12-23-56		1859	(92)
9- 9-57		1866*	92
9- 9-57		1865	93
12-23-56		1864	93
12-23-56		1862	95
9-10-57		1862	96
12-23-56		1860	97
9- 9-57		1858*	100

^{1/} Dead when collected. Outermost bark ring for the seven plants in parentheses are given in Table VIII.

Figure 13. Site I for the big sagebrush collections east of Baldwin Lake, California; rabbitbrush, Chrysothamnus sp., along the road; single-leaf pinyon, Pinus monophylla, in the background; view to the northeast.

The earliest ring in each specimen is recorded. Sometimes, this is an innermost ring on the lower surface of a specimen which retains a pith of a slightly later date on the upper surface. This situation facilitates the estimation of the pith year on the lower surface and makes it possible for the estimate to be within one or two years of the correct date. Three specimens from Site I were in this category: the specimen with an innermost ring of 1866 had a pith year of 1867 on the upper surface; that of 1868, 1870; and that of 1873, 1873. This and the form of the innermost rings constitute evidence that the pith year on the lower surface would have been only one to three years earlier than that for the innermost ring. The three specimens with 73-, 76-, and 78-year length of series had many rings lost and were in the 80- to 100-year age class. The direct and indirect evidence makes possible a relatively sound age estimate for all 34 specimens.

The 34 specimens tabulated in Table V included seven that were dead when collected. Certain aspects of the ring studies of dead plants warrant special attention and these are described in detail in the discussion of this area. All of the seven dead plants still retained the pith. In one of these the pith year predated by five years the innermost ring of 1858 in the oldest of the living plants and thus extended the chronology provided by the living plants. Two other dead specimens had pith years

of 1859 and 1861 which, with some of the other older dead plants, aided in verifying the early portions of the chronology for the site.

Series lengths for the 34 plants were evenly distributed over a time period of from 45 to 100 years. This, in view of the fact that only the older specimens were collected, indicated an uneven-aged stand for this area at the time of collection. The plant with the 100-year ring series had lost a considerable portion of its center, perhaps as much as 50 years. The age of this plant, substantiated by that of the dead plant with the 1853 pith, indicated a maximum age for the stand of well over 100 years. The abundance of overmature plants on the site and the evidence provided by the seven dead plants indicated that the area had not been subjected to an extensive fire for well over 100 years. An occasional plant might escape in a general burn, but the likelihood of so many being bypassed is extremely small.

The ring chronologies, especially in the older, slower-growing plants, were relatively sensitive. There was some tendency towards the production of false rings. The ring for 1904 was often double and, to a lesser extent, so were the rings for 1873 and 1898.

The large living lobes in plants established prior to about 1885 had their beginning in the growth following the 1900-1904 interval. In a few cases, the specimen consisted of the pre-1900 core with only a single

lobe still attached and the rest obviously detached. Cambium death about portions of the stem during this period caused localized growth in the remaining areas and resulted in a mushroom appearance of the newly formed lobes as they became established.

The 85-year specimen collected December 23, 1956, is an extreme example of a recurved lobe (Figure 14). At the portion of the stem shown, the specimen was essentially a single lobe during its whole life as evidenced by the short-lived nature of the branch lobes. During the 82 years of this growth period, the 5.6 centimeters of curved radius brought the active cambium to within 0.5 centimeter of the original pith. The growing tip of the lobe in an adjacent section had exerted enough pressure to displace the inner portion and place the active cambium in the area formerly occupied by the pith and the few years of growth surrounding it.

Stem collections at Site II were made north of the road on a south slope with a granitic soil and outcropping metamorphosed schist. The four specimens were from slightly different sites on the slope and differed somewhat in growth rates and sensitivity of ring pattern (Table VI). The 59-year specimen had some evidence of false layers, especially in 1936 and 1946. Ages ranged from 57 to 67 years. With the allowance of a few years for height growth to the point of sectioning, most of the older plants on the slope were probably only a little more than 70 to 80

Figure 14. Recurved lobe in a stem of big sagebrush in which the radius has made nearly a 360° turn in 82 years and has placed a portion of the active cambium very near the pith. Dots mark decade rings; the three dots mark the year 1900. A one-centimeter rule is used for scale.

years old. Growth rates on the three specimens in which the pith was present on both ends of the section were 1.1, 1.8, and 2.8 centimeters per year for periods of four, five, and five years, respectively.

Table VI. Ring analysis data for big sagebrush from Site II east of Baldwin Lake, California.

Collection date	Elevation, feet	Pith year	Length of series, years
12-23-56	6,800	1900	57
		1898	59
		1889	67
		1889	67

The 59-year-old specimen contained a scar from a reproductive branch (Figure 1) and showed the lobes produced at this portion of the stem by the nonhealing scar. In this specimen, the inked dots mark the years 1910 and 1920. The large ring near the center is for 1905.

Discussion; Dead plants from Site II east of Baldwin Lake, California. The seven dead specimens presented in Table VII were in the near-maximum age class for the area (Table V), and all had both pith and bark rings present. The 69-year series had no bark attached to the outermost ring (1929), but bark was present on another lobe that had a

terminal ring of 1928. The fact that the seven plants had been dead over a wide range of years, from 1 to 28 years, yet still retained both their bark and their stem characteristics is of value in two respects: Chronology building and ecological interpretation.

The potential value of dead plants in chronology building is illustrated by the 85-year-old plant that had been dead for 20 years (Table V). This specimen contained the rings for the years 1853-1857 and thus extended the chronology five years back beyond the innermost ring of 1858 for the oldest living plant.

Ecological interpretation of the site was aided by the dating of long-dead plants of maximum age for the site. As an idealized example, if only living plants were considered and 100 years was shown to be the maximum age for the site, then the statement could be made that the species had been in the area for 100 years. But if 100-year-old plants are found that have been dead for 20 years, the species has been in the area for 120 years, thus extending the known period of occupation by the length of time that plants of maximum age have been dead or, more explicitly, by the period of years that the early chronology in the dead plants extends back past that of the oldest living plant. As a greater number of dead plants are collected and studied, additional light is thrown on this relationship between dead plants and the length of time they have been dead. It is realized that many of the dead plants would lack the central

portion; but, again, with many plants collected, the approximate, if not the exact age could be determined and compared with the maximum age of the living plants on the same site. Ultimately, these data could be incorporated into tabular form such as the proposed deterioration classes for big sagebrush presented in Table VIII. The designation of class of dead plants is arbitrary, but the use of six classes seems to fit very well the conditions encountered in this study. The limits on the number of years since death of the plant in each class have a high degree of flexibility. In practice, these limits should be based upon as extensive a collection as possible. The character of plant parts for each class would hold, in general; but it is to be realized that these are arbitrary classes and that in nature they would form a continuous gradient. It is conceivable that sound plants of the maximum age for any given site could be found for the first four or possibly five classes; but that the sixth and most likely the fifth class would be solely an extrapolation of the data from the first four or five.

With data such as are presented here as a guide, the ecologist could evaluate more fully the longevity of a community of big sagebrush. Because this species, especially the dead plants, is very susceptible to complete removal by fire, the presence of long-dead plants of maximum age for the site would serve as an indication of at least the minimum time since the area had been swept by fire.

Table VII. Pith and bark years for seven big sagebrush plants from Site I east of Baldwin Lake that were dead when collected.

Pith year	Bark year	Length of series, years	Years since death of plant
1875	1950	76	7
1868	1956	89	1
1868	1951	84	6
1863	1950	88	7
1861	1929	69	28
1859	1950	92	6
1853	1937	85	20

Discussion; Early height growth of big sagebrush in the San Bernardino Mountains, California. To illustrate the use of growth-ring interpretation in height-growth studies and the relation of rate of height growth to site, 21 of the 44 plants of big sagebrush from the San Bernardino Mountain collections which had a stem section with pith dates on opposite ends of the section that differed by one or more years were analyzed for annual height increment. By dividing the length of the section by the difference in pith dates, a figure was derived for the average annual height growth for that interval (Table IX).

The specimens representing the Furnace Canyon and Baldwin Lake Site II collections were too few in number to serve as more than an

Table VIII. Plant deterioration classes for big sagebrush.

Deterio- ration class	I	II	III	IV	V	VI
Years since death	0	1-5	5-15	15-30	30-50	50-plus
Descrip- tion	Living	Leaves lost	Branchlets lost	Some main branches prostrate	Branches prostrate	Decomposed fragments

Table IX. Average early height growth based upon length of stem section when pith dates differ by one or more years.

Collection site	Length of section in cm.	Pith year of lower surface	Pith year of upper surface	Difference in years	Average annual ht. growth in cm.
Furnace Canyon	4.8	1887	1889	2	2.4
	12.5	1897	1901	4	3.1
	5.7	1888	1889	1	5.7
Baldwin Lake, east, Site II	4.5	1889	1893	4	1.1
	9.0	1901	1906	5	1.8
	14.0	1898	1903	5	2.8
Baldwin Lake, east, Site I	12.4	1868	1878	10	1.2
	2.6	1876	1874	2	1.3
	9.0	1868	1874	6	1.5
	15.0	1868	1860	8	1.9
	7.0	1871	1868	3	2.3
	14.0	1861	1866	5	2.8
	8.5	1875	1872	3	2.8
	6.0	1861	1859	2	3.0
	6.1	1868	1870	2	3.1
	3.5	1868	1869	1	3.5
	5.5	1869	1868	1	5.5
	6.5	1884	1883	1	6.5
	7.0	1875	1876	1	7.0
	7.6	1862	1863	1	7.6
	8.5	1853	1854	1	8.5

approximation of height growth on these sites. Site I, on the other hand, was represented by 15 specimens and these provided some points for discussion. No pith dates more recent than 1883 occur. This was due to the fact that only older plants were collected and because those specimens with a short length of series represented old plants with eroded centers rather than younger plants with only a few years of growth lost. As shown in the last two columns of Table IX, the average annual height growth varies inversely with the number of years in the stem section even though the lengths vary somewhat. If the stem sections were all of a given length, the plants with a greater rate of height growth would, of course, be represented by correspondingly fewer years.

Based upon the limited evidence, it can be said that the rate of height growth was greater at the Furnace Canyon site than at the two sites east of Baldwin Lake. The variation within the 15 specimens from Site I is probably due to slight differences in site conditions for the individual plant. Some plants were collected about midslope (in the foreground in Figure 13) and some on the upper slope near the pinyon-juniper stand.

The surface on either end of a stem section may be through a point either early or late in the growing season. This purely random surface introduces a slight error in the length of the stem between pith years in contrast to the situation if it were possible to select a surface at a standardized point. This error is minimized when the length of the

stem contains many years of growth. Consideration of this factor, combined with the short length of most of the sections, makes the figure for the average height growth per year a very rough estimate. Because rate of height growth serves as an indication of site conditions, it does have a value in determination of age-site relationships. This approach, in contrast to the observational approach of measuring height growth as it occurs, has the advantage of working from the present back into the past.

When there was a difference of a single year in the two opposing pith dates, the height-growth figure could be the minimum for that year (diagram A in Figure 15) or more than the maximum (diagram B in Figure 15). This same concept applies to stems with any number of years represented. If the two surfaces of a stem section both intersected the pith for the same year, then the length could represent anything from a minimum to a maximum growth for that year.

In the diagrams of Figure 15, the growth layers are represented as equal in width. This would make the height growth constant from year to year, but it is apparent that this is not the case. The rate of height growth for a given length of time, five years for example, may vary within a single plant, depending upon where the five-year period falls. If it fell within a dry period, such as the 1900 interval, the rate of height growth presumably would be less than if it had fallen in a more favorable period.

Figure 15. Annual height increment as shown by succeeding pith years. Diagrams A and B represent a longitudinal section through a diameter showing the pith (the heavy vertical line) and the superimposed cones of four annual growth layers. Sections 1 and 2 in diagram A span a minimum length of stem which includes the pith for two years. Sections 3 and 4 in diagram B span a maximum length of stem without including a third year. This maximum length, as indicated by the dotted lines delimiting the actual height growth, is more than the terminal increment for one year.

If a height-growth study, per se, were to be made on stems of big sagebrush or any other species, the greater the length of the stem being studied, the greater would be the accuracy; i. e., the less the error due to the position of the section within the year's terminal stem growth and to the larger number of full-year growth in the stem between end cuts. Ideally, a stem could be dissected and the terminal increment for each year plotted. It is assumed, on the basis of the evidence at hand, that the year-to-year pattern of terminal growth rate would parallel that of the ring width for the corresponding year.

Discussion; General. The area surrounding Big Bear Lake in the San Bernardino Mountains was ideal for the study of big sagebrush for a variety of reasons. It represents, as far as known, a southern limit of the sites which produce big sagebrush 100-or-more years in age. Collections in Riverside and San Diego Counties and in Lower California indicated that plants in these areas tended toward a shorter-lived form. Throughout these areas there are no large, open stands of big sagebrush. Rather, it occurs to the south of the San Bernardino Mountains, as the elevation decreases, beneath open stands of ponderosa pine, as fringes around upper valley slopes and as a roadside weed in chaparral. It is suspected that at elevations of 9,000 to 10,000 feet in the Sierra San Pedro Martir in the northern part of Lower California that big sagebrush sites would approximate those of the Big Bear Lake area.

The Big Bear Lake area represents a potential for a study of the relationship of ring chronologies in A. tridentata to those in A. nova and A. rothrockii, which are common in localized areas and occur admixed with big sagebrush. Big sagebrush in the San Bernardino Mountains and to the south in southern California is termed A. tridentata var. angustifolia by Munz (1935).

A majority of the 44 big sagebrush specimens collected in the San Bernardino Mountains, when grouped in 10-year age classes, fall in the 70- to 99-year range (Table X). These ages probably represent a near-maximum age for the plants at this species for the collection sites. As big sagebrush is readily killed by fire, living plants of these ages and the presence of many overmature and dead plants and plant remains indicate that the stands have not been swept by fire within this period.

Table X. Representation of the 44 plants in the San Bernardino Mountain collections in ten-year age classes based upon total length of series.

Ten-year age class	Number of specimens
40 - 49	3
50 - 59	6
60 - 69	4
70 - 79	9
80 - 89	12
90 - 99	9
100 - plus	1

Panamint Mountains, California

Stems of big sagebrush were collected from two major areas in the Panamint Mountains, Death Valley National Monument, California (Figure 16). The upper-elevation area was at Arcane Meadows and on the adjoining south slope to the east. The lower-elevation areas were in Wildrose Canyon at the Charcoal Kilns and at Thorndike Camp.

Arcane Meadows Area. In 1955, 1956, and 1958, stems of big sagebrush were collected along the Mahogany Flat-Telescope Peak trail about three and a half miles south-southwest of the Charcoal Kilns (Figure 17). The site was at an elevation of 9,600 feet and about a hundred feet below and a few hundred yards east of Arcane Meadows on the upper side of the trail. The collection site was above the pinyon-juniper zone and below the limber pine and bristlecone pine.

The Arcane Meadow site was a steep south slope composed of coarse dolomitic talus. Deposits of plant litter occurred under the dense stringers of vegetation, vertical to the slope (Figure 18); there was some soil formation in the stringers but little or none between. The soil and litter of the stringers, on which big sagebrush predominates, permitted the retention of some moisture, in direct contrast to the dry talus rubble immediately adjacent.

The small, single plants of the Kilns site showed no resemblance in form to the plants of the south slope below Arcane Meadows. At this

Figure 16. Collection sites at Charcoal Kilns, Thorndike Camp and Arcane Meadows as shown on the U.S.G.S. Telescope Peak Quadrangle, Inyo County, California, 15 minute series. Scale is one mile to one inch. Contour interval is 80 feet.

Figure 17. Big sagebrush site below Arcane Meadows. Stems of three plants over 200 years old were collected from the south slope above the Mahogany Flat-Telescope Peak Trail shown in the foreground.

Figure 18. View up the slope of the big sagebrush site below Arcane Meadows. The big sagebrush occurs in stringers of vegetation, which lie vertically along the slope between the talus rubble.

latter site, the stems were complex and massive, often 20 centimeters or more in diameter. Even though the vegetation in the stringers was only one meter high, the prostrate stems overlapped each other much like shingles on a roof and single stems often reached three or four meters in length (Figure 19). Collecting, by sawing the stem, was difficult because of the dense profusion of living and dead branches, the steep slope, and the piling of talus rocks over the basal portion of the stem (Figure 20). Once exposed, the older plants could be pulled up; but sawing was less likely to damage the stem.

The collection of three specimens in 1955 at the Arcane Meadow site (Table XI) was important enough in terms of longevity of big sagebrush that the site was later revisited. The first three specimens were old and, as is common in the old plants, two were lacking the pith. Neither of these two stems contained any indications to provide a basis for estimating the number of growth years lost, but because of the relatively fast growth rate, it is presumed that their age did not approach that of the third specimen. The third stem contained a pith year of 1740. The 216 years of growth that this represented constituted the oldest known plant of big sagebrush at the time of collection (Figure 21). Two additional plants over 200 years old were collected later at slightly higher elevations on this site and provided additional evidence of the great age of big sagebrush in this area. The rings on two radii of the

Figure 19. Stem of a plant of big sagebrush, dead for many years, showing the prostrate form of a four-meter long stem. A white, 15-centimeter ruler is placed in the center of the stem for scale.

Figure 20. Natural occurrence of an old plant (upper photograph) of big sagebrush at 9,200 feet in the Panamint Mountains in a tangle of talus rock with overlying living and dead vegetation. Same plant (lower photograph) after removal of dead wood and talus rock from the basal portion of the plant. A white 15-centimeter ruler is used as a scale.

Table XI. Ring analysis data for big sagebrush from the Panamint Mountain, California, sites.

Site name and collection date	Elevation, feet	Pith year or (*) inner- most ring	Length of series, years
Arcane Meadows			
6-27-56	9,300	1865	92
6-27-56	9,300	1858*	99
6- 3-55	9,400	1857*	99
6- 3-55	9,400	1856*	100
6-27-56	9,300	1835	122
6-14-58	9,675	1755*	204
6- 3-55	9,400	1740	216
6-14-58	9,500	1743	216
Thorndike Camp			
6-12-58	7,400	1902*	57
		1894*	65
		1871	88
		1867	92
Charcoal Kilns			
6- 4-55	6,900	1925*	31
		1899*	57
		1899*	57
		1898*	58
		1898*	58
		1873* ^{1/}	(71)
		1874	82
		1868*	88
		1860*	96

^{1/} Dead when collected; bark year is 1943.

Figure 21. Cross section of a stem of big sagebrush with 216 annual rings from the site below Arcane Meadows. A five-centimeter rule is used as a scale.

plant with the 216 annual rings, pictured in cross section in Figure 21 were measured. The radius from the pith, below the five-centimeter mark on the scale, to the terminal lobe at the extreme right was measured and plotted as "Arcane 1" in Figure 22. On a comparable section, six centimeters above the surface shown, the radius from 1760 (the pith area was missing at this section) to the terminal lobe at the top of the picture was measured and plotted as "Arcane 3". These measurements were plotted to show the similarity in chronology between two radii of a single old plant of big sagebrush and between these and a regional mean, represented by the southern California bigcone spruce chronology (Schulman, 1956) based upon about 50 trees collected over a large area. The small rings, which are the keys to crossdating, identify the rings for any given year of minimum growth in each of the three plots. Note especially the minimum widths recorded for 1765, 1782, 1829, 1857, and 1904. Even though the chronology in the big sagebrush is not always parallel in the two radii, there is no doubt that the growth layers are annual because of the sharpness with which the minimum years represented by 1765 and 1782 occur in both the big sagebrush and the southern California bigcone spruce chronologies.

Prior to the identification of the chronology in the Arcane Meadows specimens, the highly rain-sensitive bigcone spruce of southern California and the especially sensitive ponderosa pine, Pinus ponderosa, from the

Figure 22. Plotted ring measurements, in hundredths of a millimeter, of two radii, labeled Arcane 1 and Arcane 3, of a 216-year-old plant of big sagebrush from the site below Arcane Meadow. At the bottom, for comparison, tree-ring growth departures, expressed as per cent deviation, of approximately 50 measured increment borings of bigcone spruce from southern California. The number of trees on which the bigcone spruce growth-curve for various time intervals is based is noted above the curve.

Spring Mountains near Las Vegas, Nevada (Schulman, 1956), were compared. From these two chronologies on opposite sides of the Panamint Mountains, the rings for 12 years that were extremely critical--minimal--in each area were selected to form a 200-year master chronology. The relatively complacent chronology of the 216-year-old stem of big sagebrush from the Arcane Meadows site contained some growth layers that were smaller than average. The derived master chronology, consisting of only 12 rings for a 200-year period, was duplicated in the smaller rings in the big sagebrush. This crossdating showed that there were no double or microscopic rings at this elevation and that the rings were annual and occurred in their proper sequence.

Schulman (1956) commented on the parallelism of the Spring Mountain chronology with that of the southern California bigcone spruce and suggested that trees of the White Mountains of California are good sources of rainfall history. Schulman stated that in these areas, as in all other comparisons of conifer growth vs temperature in western United States, no significant relation to this element is found.

Stem characteristics of the plants with the 92- and 99-year-long ring series collected at the 9,300-foot elevation were much the same and it is assumed that the latter contained a pith only a few years prior to the innermost ring of 1858. Many new lobes were formed at the 1900 interval in the 99-year-old stem. These two specimens, from the lowest

elevation in the Arcane Meadows site, contained double rings in the growth layers for 1904, 1916, and 1925. This elevation is apparently the upper limit of the false rings common in the Wildrose Canyon sites.

Thorndike Camp Area. The Thorndike Camp collection site, at an elevation of 7,440 feet, was a mile south of the Charcoal Kilns in Wildrose Canyon. Collections were made on a ridge, upon which was a water tank, across the road and immediately west of the camp (Figure 16). The plants collected were growing on the bare shoulder of the ridge and on slight benches above rocky outcrops. Of the four plants collected (Table XI), the two with eroded centers contained 57 and 65 annual rings, respectively. The other two, with the pith areas intact, had total ages of 88 and 92 years.

Charcoal Kilns Area. Stem material was collected in 1955 on the valley side of the road about a hundred yards below the Charcoal Kilns. The site is located at an elevation of 6,800 feet one mile north of Thorndike Camp (7,440 feet) and between the summer headquarters of Death Valley National Monument, in Wildrose Canyon, and Mahogany Flat (8,133 feet).

The Charcoal Kilns site lies in a small valley (Figure 23). The soil is a coarse alluvium, subject to flash floods but with extremely low moisture retention. It is highly improbable that there is ground-water within reach of the sagebrush roots.

Figure 23. Charcoal Kilns area, Death Valley National Monument, California.

Here, the big sagebrush grows near its lower elevational limit at the lower edge of the pinyon-juniper type. The big sagebrush occurs in the bottom of the small valley, not as a pure stand but admixed with an open stand of pinyon-juniper. The single stems of many plants consist solely of detached lobes with the inner portions weathered away.

The exact time and length of occupancy of the charcoal kilns would have a bearing on changes in the plant community of the area because of the timber cutting, human occupancy, and the possibility of fire due to the activity of the kilns or the carelessness of man. The ten large charcoal kilns were used in the late 1860's or early 1870's to make charcoal from the pines that grew there. The charcoal was freighted across Panamint Valley to the Modoc Mine for use in smelting ore. (Anonymous, 1939).

Stem sections of nine plants were collected near the Charcoal Kilns (Table XI). Five of the stems were lobes that had become detached from pre1900 cores. The core and the resultant formation of many lobes as a result of the drought of the 1900 interval were strikingly evident on the four longer-lived specimens. The plant with the 96-year ring series predates the supposed occupation of the area in the late 1860's or early 1870's.

All specimens were very sensitive and had a good chronology. Double rings, characteristic of the site chronology, occurred in the years

1894, 1896, 1902, 1904, and 1925 in nearly all specimens containing these years.

To show the crossdating between individual specimens within a site, the ring chronologies in seven sections collected at the Charcoal Kilns site were measured, and plotted in Figure 24. The mean of seven, from 1901 on, is plotted below the seven measurements to show the relationship of any of the individuals to the mean. The early portion, consisting of a single specimen, is plotted to the left of the paired vertical lines. The bottom plot, shown for comparison, is a 13-specimen tree-ring chronology (Schulman, unpublished) composed of four pinyon, Pinus monophylla, four bristlecone pine, Pinus aristata, and two limber pine, Pinus flexilis, from the Panamint Mountains; and two bristlecone pine and one limber pine from the White Mountains, 120 miles to the northwest.

Discussion; Climatic Analysis. Rainfall records were not available for the immediate areas, but three nearby weather stations provided comparison data: Greenland Ranch and Cow Creek, both about 25 miles northeast in Death Valley proper; and Trona, at 1,623 feet and about 40 miles southwest of the Panamint Mountains. Greenland Ranch has the lowest mean annual precipitation recorded for an official United States Weather Bureau station: 1.66 inches for a 44-year record through 1954 (Seamon and Bartlett, 1956). The amount of rainfall in Wildrose Canyon

Figure 24. Plotted ring measurements of seven big sagebrush from the Charcoal Kilns site shown in comparison with their mean and with an adjacent tree-ring chronology. Ring measurements for big sagebrush are expressed in hundredths of a millimeter and the tree-ring growth departures are expressed as per cent deviation.

is probably midway between that of Greenland Ranch and Trona; that of Arcane Meadows, slightly higher because of increased elevation. Seasonal pattern is that of general winter precipitation and occasional summer storms.

The relationship between the big sagebrush growth-curve from the Charcoal Kilns area, July-June (12 months) rainfall for Greenland Ranch and Trona, and the growth departures for the southern California bigcone spruce, Pseudotsuga macrocarpa, is shown in Figure 25. The number of years of overlap in these four plots is not great, but examination of the curves shows crossdating that is very good considering the biotic, climatic, and geographic units involved. Note especially the minimum points for 1921, 1923, 1925, 1929, 1933, 1934, 1936, 1942, 1949, and 1953. It is suspected that the correlation of growth rings with rainfall data would be more positive if the summer months, with their occasional heavy storms, were removed from the 12-month totals used here for comparison.

Discussion; General. The Charcoal Kilns area and the Arcane Meadows area, two contrasting sites in the same geographical area, provided ideal growing conditions and material for study. The Charcoal Kilns site typified the lower altitudinal range of big sagebrush in the area and, although the species does occur near the top of Telescope Peak (11,049 feet), the Arcane Meadows site represents an upper altitudinal

Figure 25. Comparative plots for big sagebrush, July-June rainfall and bigcone spruce. The big sagebrush growth curve, from the Charcoal Kilns area in the Panamint Mountains, is represented by mean measurements, expressed in hundredths of a millimeter, of three specimens from 1875 to 1900 and of seven from 1901 to 1955. The break between the two means is indicated by paired vertical lines at 1900 and 1901. July-June rainfall, in inches, is plotted for Greenland Ranch and Trona. The bottom plot is of tree-ring growth departures, expressed as per cent deviation from a trend line, of bigcone spruce from southern California. This curve is based on 54 trees from 1875 to 1899 and on 51 trees from 1900 to 1944, as noted by the figures above the curve, with an extension (dotted) to 1950.

form, though certainly not the upper extreme. Physiographically, the Arcane Meadows area is more exposed than the Kilns site, but this exposure is compensated for by increased moisture.

White Mountains, California and Nevada

The White Mountains provide ideal conditions for the study of drought-type ring chronologies at high elevations because they lie to the east, and in the rain shadow of the Sierra Nevada range. Bishop, at 4,108 feet in the intervening valley, has an average annual precipitation of about six inches. No weather stations are available in the areas where collections of big sagebrush were made, but short-term data at the Naval Research Station, at 10,150 feet, about 7.5 miles due north of the collection sites near Reed Flat and the Mexican Mine indicated an annual average of about 10 inches for these areas.

Stems of big sagebrush were collected in the White Mountains from a series of sites that provided an altitudinal range from 6,350 feet at Westgard Pass, and 7,350 feet at Cedar Flat to over 10,000 feet near Reed Flat. Collections were made at seven locations, Trail Canyon, Wyman Canyon, Silver Canyon, Reed Flat, Mexican Mine, Cedar Flat, and Westgard Pass.

Trail Canyon Area. Collections of big sagebrush from the Trail Canyon area, 4.0 miles east-northeast of Boundary Peak (Figure 26),

Figure 26. Collection sites for big sagebrush in the Trail Canyon, Nevada, area. Numbers on the map represent collection sites at the following elevations: (1) 8,500 feet, (2) 8,300 feet, (3) 8,100 feet, and (4) 6,450 feet. Area shown on the topographic map is the upper-central portion of the U.S. G.S. Quadrangle for White Mountain, California-Nevada. Scale is two miles to one inch. Contour interval is 100 feet.

consisted of 18 specimens from four sites (Table XII). The uppermost site was represented by a single specimen collected by Schulman a half mile above the end of the road in Trail Canyon. The second two sites at the 8,300- and 8,100-foot elevations were comparable to the first in elevation but differed in site character. The 8,300-foot site was located on the east slope of a knoll dominated by big sagebrush. The 8,100-foot site was on the west slope of a large canyon (an unnamed canyon leading to Gold Hit) in which big sagebrush occurred in openings in a stand of pinyon and juniper (Figure 27) and in a small canyon bottom. The 184-year specimen, as indicated by its age and sensitivity, was from a site more nearly comparable to the 8,100-foot than to the 8,300-foot site. The fourth site, at 6,450 feet, was in the valley below the mouth of the canyon and 2.0 miles from the base of the mountains.

In terms of both sensitivity and age, the 8,100-foot site in the north fork of Trail Canyon was by far the best. Here, the nine plants collected ranged from 80 to 217 years in length of ring series; seven of the nine were in the 150- to 200-year age class.

The six plants collected at the 8,300-foot site ranged in age from 65 to 165 years. Apparently the plants on this knoll do not reach the 200-year age class as do those of the north fork site.

Table XII. Ring analysis data for big sagebrush from the Trail Canyon, Nevada, sites.

Collection date	Elevation, feet	Pith year or (*) inner-most ring	Length of series, years
6-26-57	8,500	1774	184
6-22-58	8,300	1894	65
		1875	83
		1854*	105
		1814*	145
		1810	149
		1794	165
6-23-58	8,100	1879	80
		1872*	87
		1814*	145
		1810	149
		1810*	149
		1809	150
		1798*	161
		1796*	163
		1742	217
6-23-58	6,450	1863*	96
		1860*	99

Figure 27. Trail Canyon, 8,100-foot collection site. The nine plants collected here ranged in age from 80 to 217 years.

Dating of the first specimen collected in the Trail Canyon area was verified by Schulman who also commented that it had essentially the local bristlecone pine chronology. At the time, this specimen was the second oldest of the species. A 217-year-old specimen from a subsequent collection markedly increased the known maximum age for the area. This 217-year-old plant thus added a third major area to the list of sites producing 200-year ring series. The first two were the area below Arcane Meadows in the Panamint Mountains and the Mexican Mine-Reed Flat area of the White Mountains.

The two specimens collected below the mouth of Trail Canyon at the 6,450-foot elevation displayed a sensitivity and tendency to form double rings that is characteristic of low elevations. These two plants were collected within a hundred yards of the road, yet both were in the 100-year class. One had a pith year of 1860; the other an inner ring of 1863. This dating is based upon the assumption that 1863 is a microscopic ring; a small false layer at this point could be misleading as there is no earlier material on the specimen with which to verify the interpretation. Longer series at higher elevations, especially in the specimen collected by Schulman, show 1863 as a small ring. However, there is no local control for the inner portions of these two ring series; i. e., no plants of greater age from the same site. Crossdating in ring

sequences earlier than the critical 1863 ring would verify or reject its interpretation as a microscopic ring.

Doubles occurred in 1873, 1899, 1904, 1931, 1950, and 1955 in both specimens from the 6,450-foot elevation. The years 1873 and 1950 were represented by rings that were both double and microscopic. The clear-cut form and the crossdatability of the double rings, combined with the extreme sensitivity of the site, indicate that seasonal distribution of precipitation was a determinant in the production of double rings. If the growing season at lower elevations generally terminates prior to the advent of summer rains, then earlier-than-usual summer rains might come within the growing season of the species and cause an extra layer to be added to the growth ring for that year. Hence, these low-elevation plants would be sensitive indicators of rainfall for perhaps a greater portion of the year than the plants of higher elevations.

Wyman Canyon Sites. The seven plants collected in the Wyman Canyon area (Figure 28) did not in themselves provide material for a separate study, but they did substantiate data from the other collections in the White Mountains. These seven plants were from four sites each of which differed in elevation and in general environmental conditions (Table XIII).

The highest site, at an elevation of 10,160 feet, was on a slight easterly slope 100-200 yards west of the White Mountain road at its

Figure 28. Collection sites for big sagebrush in the White Mountain, California, area. Numbers on the map represent the following collection sites: (1) Wyman Canyon, (2) Silver Canyon, (3) Reed Flat, (4) Mexican Mine, (5) Cedar Flat, and (6) Westgard Pass. Area shown is the central portion of the U.S. G.S. Quadrangle for Blanco Mountain, California. Scale is one mile to one inch. Contour interval is 80 feet.

Table XIII. Ring analysis data for big sagebrush from the Wyman Canyon, California, sites.

Collection date	Elevation, feet	Pith year or (*) inner-most ring	Length of series, years
6-20-56	10,160	1876	81
		1874	83
6-21-58	9,150	1907	52
6-21-58	8,840	1882	77
		1877	82
		1872	87
6-21-58	8,800	1865*	94

junction with the Wyman Canyon road. The two plants from this site differed greatly in ring characteristics despite their nearly identical ages. The 81-year specimen had a more sensitive chronology than did the second plant. This was in keeping with a slightly slower growth rate as evidenced by a shorter radius (5.2 centimeters vs 8.4 centimeters in the second stem for the period 1876 on) and a slower height increment (5.6 centimeters in seven years vs 8.0 centimeters or more in one year). Initial growth on the 52-year plant was rapid as indicated by an identical pith date on two surfaces separated by a vertical distance of 5.5 centimeters. Similarly, the 77-year specimen had a pith date differing by only one year in 8.0 centimeters of height growth.

The single plant collected at the 9,150-foot elevation was a fast-growing 52-year-old specimen with clearly defined false rings in 1929, 1931, and 1936. In the four plants from the lower elevations, the rings for these years were small and showed no evidence of doubling. The three plants from the 8,840-foot elevation were growing on alluvium forming a small flat on the canyon floor.

The 94-year ring series was from a plant on a south slope where the big sagebrush formed stringers of vegetation on a talus slope. Moisture conditions were good as evidenced by lush green grass near some seeps and by the vigorous growth of the big sagebrush and the lack of dead wood in the older plants. This plant showed a slower growth rate

than any of the five plants from the lower elevations and the character of the innermost rings indicated that much of the central portion had been eroded.

All seven specimens contained a good ring chronology in spite of their relatively rapid growth. This limited sampling was not sufficient to provide an estimate of maximum ages for the four sites, but did show that the sites in the canyon were protected from severe climatic conditions, and the plants as a class were not as old as those on more exposed sites at the same or higher elevations.

Silver Canyon Area. Plants were collected from two distinct sites at the head of the Silver Canyon road (Figure 28). Thirteen specimens were obtained in 1956 and 1958 from the windswept saddle (elevation 10,490 feet) at the head of the road. Six specimens, which were collected in 1958, were from the west slope at the edge of a bristlecone-pine stand (elevation 10,400 feet) about 500 yards northwest of the saddle. Ring data for these 19 specimens are tabulated in Table XIV, but the two sites will be discussed separately.

The Silver Canyon site at 10,490 feet, a wind-swept saddle at the head of the Silver Canyon road, had plants that were composed of prostrate branches extending outward less than 60 centimeters and with little living material over 15 centimeters high. A typical plant of this form is shown in comparison with a 30-centimeter rule in Figure 29.

Table XIV. Ring analysis data for big sagebrush from the Silver Canyon, California, sites.

Collection date	Elevation, feet	Pith year or (*) inner-most ring	Length of series, years
6- 7-56	10,490	1933	24
6- 7-56		1921*	36
6- 7-56		1920	37
6- 7-56		1915	42
6- 7-56		1915	42
6- 7-56		1911	46
6- 7-56		1910	47
6- 7-56		1908	49
6- 7-56		1906*	51
6-18-58		1905	54
6-18-58		1903	56
6-18-58		1885*	74
6-18-58		1875*	84
6-18-58	10,400	1882*	77
6-25-58		1839*	120
6-18-58		1834	125
6-18-58		1831*	128
6-18-58		1825*	134
6-25-58		1816*	143

Figure 29. A small, prostrate plant of big sagebrush in the saddle at the head of the Silver Canyon road. This plant had prostrate branches extending outward less than 60 centimeters and had little living material over 15 centimeters high. A 30-centimeter rule is used as a vertical scale.

The oldest specimen from this site was a narrow-stemmed lobe with 84 rings, but with much of the inner portion missing. An estimated age for this plant of at least 90 years, combined with the record from the other 12 plants, indicated that this site produced plants at the time of collection with maximum ages from 50 to 100 years. Although these ages are not exceptional when compared with maximum ages recorded for other sites, they do suggest the maximum age that the conditions of this type of site may produce.

In the 1956 collection, lateral stem growth for 1956 was only faintly indicated and there was no line of separation formed by the inter-xylary cork cambium for 1956. In all nine specimens, the 1955 ring was completely yellow and this sapwood color had not begun to fade. The character of the innermost portion indicated that the two specimens in which the pith area had been eroded had lost from 20 to 30 rings.

The years 1948 and 1950 were represented by small rings in the specimens from both collections; in two of the specimens collected in 1956, the ring for 1950 was sufficiently smaller than that for 1948 to be termed microscopic.

The four plants collected in 1958 were taken eleven days later in the growing season than were the plants in the 1956 group, assuming the same date for the beginning of the season in both years. These four had stem growth for 1958 clearly differentiated from that of 1957 by a

layer of interxylary cork and already had a ring width approximately one-third that of the 1957 ring. Any evidence of a growth layer is sufficient to add a year to the length of a series; whereas a plant collected before growth started in the spring would have a record of one year less. A partial ring is of no value in chronology building but does provide a terminal-growth year; i. e., the last growth year of the plant; it is to be realized, of course, that the plant may have been collected or have died naturally in the following calendar year. A partial ring does provide at least a minimum width for that year. These partial growth-years can be evaluated later in terms of more recent comparative material collected from the same site.

The chronologies in the six specimens from the Silver Canyon site at 10,400 feet were very complacent, but the small rings necessary for defining the chronology occur in their proper sequence. For example, relatively dry winters were indicated by the small rings for 1836, 1842, 1863, 1865, 1896, 1904, 1929, 1948, and 1950 in the three measured series plotted in Figure 30.

In curves A and B in Figure 30, 1842 and 1845 are years of minimum growth; in curve C, 1842 is a minimum growth year, but the following low point is in 1844 rather than 1845. This apparent difference for 1845 is of little consequence in identifying the ring series because the chronology is substantiated by the small rings for 1836 and 1842, which

Figure 30. Plotted ring measurements, expressed in hundredths of a millimeter, for three big sagebrush plants from the 10,000-foot site northwest of the saddle at the head of the Silver Canyon road.

occurred in their proper sequence in all three specimens. Other slight differences in pattern occurred; but the general crossdating of critical years held, especially when the specimen itself was examined. It is this actual dating on the specimen that establishes the chronology, not the plotted representation of a single measured radius.

Five of the six specimens lacked a pith and it was apparent that much of the early growth had been lost. Maximum age for the site, however, was probably well in excess of the 143 years recorded on the longest ring series.

Reed Flat Area. The four plants listed in Table XV were from the bristlecone-pine area immediately east of Reed Flat (Figure 28) and represented three local areas each with slightly different site conditions. As might be expected of such a small diverse collection, the plants varied greatly in age.

The 70-year specimen showed a rapid growth rate, but because of its eroded center had a total age greater than suggested by the 70-year ring count. In this specimen, the 1956 ring was well-defined and equaled in width about one-third of the 1955 ring. As was mentioned earlier, a partial terminal growth ring can be evaluated in terms of later collections which serve as controls. It was seen from later collections that 1955 was of less-than-average width; hence, a ring for 1956 that was

one-third of the width of the 1955 ring had obtained approximately one-fourth of its growth at the time of collection.

The two plants in the 1956 collection were growing on a bench a few hundred yards east of the 197-year specimen. One of the two specimens was dead when collected, but was readily dated. This plant had a ring series from 1813 to 1933, but was estimated to be about 30 years older than its 121-year record would indicate.

The 136-year specimen from the 10,100-foot elevation was from the slope below Pine Alpha, the first bristlecone pine shown to be over 4,000 years old (Schulman and Ferguson, 1956 and Schulman, 1958). Although the specimen of big sagebrush had retained only 136 annual rings, the pith and inner rings had weathered away in a manner that indicated a probable age slightly in excess of 150 years.

Table XV. Ring analysis data for big sagebrush from the Reed Flat area.

Collection date	Elevation, feet	Pith year or (*) inner-most ring	Length of series, years
6-21-56	10,000	1887*	70
6-17-58	10,100	1823*	136
6-21-56	10,100	1813* ^{1/}	(121)
6-19-58	10,000	1762*	197

^{1/} Dead when collected. Bark year was 1933.

The 197-year series was found at the head of the south fork of Birch Creek, a hundred yards down the trail toward Methuselah Walk from the Edmund Schulman Campground. Four pieces of this plant were collected that had inner rings for the years 1788, 1764, 1762, and 1762. In all cases it was apparent that much of the inner wood was missing and the plant undoubtedly was much older than the 197 rings indicated.

Mexican Mine Area. Fifteen plants (Table XVI) were collected from three different elevational sites in the area from one to two miles south of Mexican Mine on the White Mountain road (Figure 28). The lowest site collection consisted of 12 specimens from a single general area but with the individual plants growing under somewhat different site conditions.

The ring chronology in the 77-year-old specimen at the 9,600-foot site was not evident by inspection with a ten-power hand lens and was recognizable only when two radii, one at each end of the specimen, were measured and plotted. Although it contained some double rings, such as typically occur in sensitive ring series, this specimen was complacent and was of no value in chronology building.

The 83-year series was obtained from a small rosette growing on an open, very dry, southwest slope of a large ridge-knoll.

Table XVI. Ring analysis data for big sagebrush from the Mexican Mine, California, sites.

Collection date	Elevation, feet	Pith year or (*) inner-most ring	Length of series, years
6-13-56	9,600	1880	77
6-21-58	9,100	1828* 1767*	131 192
6-10-56	8,880	1900*	57
6-24-56		1877*	80
6-19-58		1876*	83
6-10-56		1870*	87
6-24-56		1859*	98
6-18-58		1838*	121
6-24-56		1831*	126
6-19-58		1827*	132
6-13-56		1799	158
6-18-58		1752 ^{1/}	(161)
6-13-56		1779*	178
6-19-58		1759*	200

^{1/} Dead when collected. Bark year was 1912.

The 132-year series was obtained from a plant growing under an open stand of pinyon, Pinus monophylla, east of a saddle and about 60 feet below the 8,880 feet for the collection in general. The specimen consisted of a single, elongated lobe with much of the inner portion lost.

The ring series in the 158- and 178-year series from the 8,880-foot site were measured and plotted for use in checking the chronologies in adjacent plants. Ring measurements for the 178-year series are plotted in Figure 34.

The dead specimen with a 161-year ring series consisted of three pieces that comprised the full cross section, and it is suggested that these represented a main stem and two branches of a plant with a short trunk rather than three branches arising from the ground line. Each piece had a good chronology and crossdated without difficulty. The pith years on the three pieces were 1752, 1759, and 1764. The presence of a pith on each piece indicated that the sectioning was in the lower branch region rather than in the basal stem and that a section taken from lower in the stem would have had a pith year prior to 1752. Inner and outer years of the three pieces follow:

Pith year	Bark year
1764	1848
1759	1912
1752	1876

The interior portion; i. e. , 1752-on, of this plant was equal in age to the innermost portion of a ring series from a 200-year-old plant. This added information on the early portion of the 200-year chronology illustrates the applicability of collecting dead plants when indications are that they have an age that will be of value in establishing the ring chronology.

In the piece with the 1848 bark ring, one lobe, which terminated in an enclosed area where pressure from adjoining lobes compressed and preserved the bark, still retained the yellow color of the sapwood in the last three rings, 1836, 1837, and 1838. This was the earliest date at which the yellow sapwood was observed in a dead terminal lobe.

Only three of the 15 specimens from the area south of the Mexican Mine still retained a pith at the time of collection. Eroded centers of 12 of the specimens and ages of over 121 years for nine of the 15 plants substantiated the evidence of the 200-year ring series and indicated that the maximum age for plants on extreme sites in the 9,000-foot zone was in excess of 200 years.

Because of the wide variety of sites from which plants in this group were collected, the environmental conditions were slightly different from plant to plant. As a consequence, the character of the ring sequences varied greatly. This perhaps was indicative of the fact that this combination of elevation and site conditions is critical in the balance

between the relatively shorter-lived plants and sensitive chronologies of the lower elevations and the longer-lived plants and relatively com-
placent chronologies of the upper elevations.

Mexican Mine Area; Analysis of stem characteristics and chron-
ology of the full cross section of a 200-year-old plant. One specimen
from the Mexican Mine area, collected June 21, 1958, was judged in the
field to be in the 200-year age class and an effort was made to save
every piece of the basal portion of this nearly dead plant for a study of
the lobe-form of a large and extremely old stem and of the chronology
it contained. The plant was massive in total cross section and had a
large number of dead terminal lobes and only a few living terminal lobes;
i. e., lobes with active cambium. A terminal lobe, as used here, refers
to the outermost portion of lateral stem growth as seen in a cross
section through that position in the stem. Seventeen pieces, only five of
which could be reassembled in relation to each other with any degree of
confidence, comprised the total cross section. The pieces varied in
length from 4 to 14 centimeters and the lowermost surface probably was
within five centimeters of the root-crown transition; i. e., the ground
line. A count was made of all terminal lobes on the top and on the
bottom surfaces of the 17 pieces. The top surface had a total of 405
terminal lobes; the bottom 399. The lobes, as seen in cross section,
never coalesce; they will continue as a single segment or they will branch,

forming additional terminal portions. Most of the dead terminal lobes still had bark attached. On terminal lobes without bark, the break probably occurred more often between xylem layers than between the outermost layer and the bark because of the structural weakness of the interxylary cork. It thus was assumed that the count would have been slightly greater had the missing portion of the bark-free terminal lobes been present. This possibly greater number, combined with the 405 and 399 counts, made it certain that this plant, estimated to be well over 200 years old, had about 400 terminal lobes in any given cross section in the basal portion of the stem. Of this number, only three terminal lobes on a single detached piece were living at the time the plant was collected.

Each of the 17 pieces comprising the total cross section was grouped into three major parts based upon the real or assumed relation to each other in the original stem and the ring chronology was established for each piece (Table XVII). Terminal dates on the outermost lobes of the 16 dead pieces ranged from 1845 to 1951. Dates of the innermost ring year ranged from 1767 to 1905.

The 11 pieces in Part I formed no discernible pattern of relationship to each other when collected, but probably were lobes on the original central stem. Four pieces of Part II were clustered in a semicircle about the fifth and oldest piece and appeared to be lobes that had become

Table XVII. Inner and outer ring years for 17 pieces comprising the stem of an old plant of big sagebrush.

Major parts	Innermost ring year	Terminal ring year, bark attached	Length of series, years
Part I	1854	1939	86
	1847	1920	74
	1829	1943	115
	1812	1858	47
	1812	1924	113
	1802	1948	147
	1801	1870 ^{1/}	70
	1798	1871	73
	1797	1907	111
	1794	1873	80
	1767	1845	79
Part II	1876	1946	71
	1865	1948	84
	1863	1950	88
	1863	1948	86
	1814	1951	138
Part III	1905	1958	54

^{1/} No bark attached.

detached from it. The whole of Part II apparently constituted a single large lobe similar to the pieces in Part I. The single piece designated as Part III contained the only living portion of the whole plant.

The inner ring of many pieces in Part I was in the 1794-1814 period, indicating that they became detached from a central portion at about the same time. This possibly was due to the effects of a drought and would be comparable to the death of the stem cambium in many portions about the circuit as occurred in the 1900 interval in the Panamint Mountain collections.

Because of the nature of their occurrence and their time relationship, there was no doubt that these pieces constituted a single plant. A continuous chronology from 1767 to 1958 was provided on an overlapping series rather than on a single radius. The earliest date was an inner ring at 1767 in a piece from which much of the pith area had been eroded. The form of the inner portion indicated that this plant was much older than the 192-year ring series would suggest. Any estimate of the pith date would be tenuous because of the lack of evidence as to the number of rings that might have been present. The oldest plants found in a given area would serve as indications of the possible maximum age of plants with an eroded center. Age data for this site and three other areas in the White Mountains have indicated that an age of 200

years is not a rarity and that an estimated age of well over the recorded 192 years would not be out of line with the evidence.

Cedar Flat Area. The nine specimens from Cedar Flat (Table XVIII) were growing in openings in a stand of pinyon-juniper (Figure 31). The chronologies were extremely sensitive and only the large fast-growing plants showed a tendency to produce false layers.

Only one specimen was collected at the 7,800-foot elevation. This has been included in the Cedar Flat tabulation even though it was growing in the altitudinal and linear transition between Cedar Flat and Mexican Mine to the north. The specimen had a very sensitive chronology with no double rings and appeared to be much older than was indicated by the 91-year series.

Table XVIII. Ring analysis data for big sagebrush from the Cedar Flat area.

Collection date	Elevation, feet	Pith year or (*) inner-most ring	Length of series, years
6-17-56	7,800	1868*	91
6- 7-56	7,350	1887	70
6-17-58		1883*	76
6- 7-56		1877*	80
6-17-58		1877*	82
6- 7-56		1861	96
6-17-58		1862	97
6-13-56		1860	97
6-17-58		1861	98
6-13-56		1856*	101

Figure 31. Cedar Flat site at 7,350 feet in the White Mountains.

In all four specimens, the ring for the collection year of 1958 was equal to or greater than that for 1957, indicating that the growth for the year had started much earlier than the collection date. This was in contrast to less growth for 1958 by the same time at higher elevations in the White Mountains.

Four of the five specimens in the 1956 collections were large, thick-stemmed plants. The ring for 1956 was larger at time of collection than the 1955 ring. The 1956 ring had almost reached its maximum width, as indicated by the relative width of the ring for this year in the four specimens in the 1958 collection. The inner ring of the 101-year specimen appeared to be within one or two years of the pith.

The maximum age for the site was slightly in excess of 101 years as indicated by five plants with ages from 92 to over 101 years. The plants with eroded centers, as illustrated by the specimen with 76 rings (Figure 32), were much older than suggested by the length of ring series. Analysis of three of the larger specimens that contained pith rings at each end of the stem section indicated a height growth of from 2.5 to 8.0 centimeters per year.

Westgard Pass Area. The Westgard Pass site was 4.1 miles west of the summit (7,276 feet) of Westgard Pass at an elevation of approximately 6,350 feet (Figure 33). The site was situated on a north-facing slope south of the road and, in general appearance, was

Figure 32. A plant of big sagebrush, in the Cedar Flat site, with a 76-year ring series and an eroded center. The area of the plant near the 15-centimeter rule shows exfoliation of the inner rings. Note the low density of the big sagebrush.

Figure 33. Big sagebrush site west of Westgard Pass showing the rocky ridge where the 200-year-old plant was found.

similar to the Arcane Meadows site (Figure 17) in that the plants occur in stringers on a talus slope composed of granitic and metamorphic rock. The Westgard Pass site contrasted with the Arcane Meadows site, however, in respect to both insolation and elevation. The Westgard Pass site was the lower of the two by nearly 3,000 feet. The difference in elevation was compensated for by a difference in insolation and plants of extreme age occurred on both sites.

The youngest of the three specimens collected at this site (Table XIX) showed a 105-year ring series with a pith year of 1854. The plant was growing on a steep, loose talus slope about 15 feet above the bottom of a wash. Even on this relatively favorable site, growth had been slow and the chronology was very sensitive and without even a trace of false rings.

Table XIX. Ring analysis data for big sagebrush from the area west of Westgard Pass, California.

Collection date	Elevation, feet	Pith year or (*) inner-most ring	Length of series, years
6-16-58	6,350	1854	105
		1795*	164
		1745	214

The 164-year specimen consisted of three pieces, two of which were enlarged lobes that had been attached to an inner core. This third piece was extremely fragile and distorted, but the chronology was excellent and the outermost ring year formed a continuous sequence with the innermost ring year of the outer two pieces. This faster-growing specimen contained some false layers that the slower-growing 105-year series served to identify.

The stem section of the 214-year-old specimen consisted of three pieces, only one of which was still living at the time the plant was collected. Although the ring series was discontinuous, the inner portion had an excellent chronology and was readily dated.

This plant was outstanding in two respects. First, and the more obvious, was its age of 214 years. This, when combined with an elevation of below 7,000 feet for the site, provided an added record not only to the geographical range of the 200-year-old plants, but also to their altitudinal range. The plants of the 200-year age class previously recorded had been in the 9,000- to 10,000-foot zone in the Panamint and White Mountains. The tendency of this site to produce old plants was substantiated by the fact that the second of three plants collected from this area was 164-or-more years old.

In all three specimens, the ring for 1931 was double with some indications that the false layer might have been in the early wood of

1932 rather than in the latewood of 1931. In all three specimens, the rings for 1898 and 1899 were very small and occasionally microscopic.

Discussion. The White Mountain area offered a wide variety of environmental site conditions and an elevational range of several thousand feet for big sagebrush. The 76 plants herein reported provide some insight into age-site relationships and to the maximum ages possible for the various sites. One typical aspect of ring analysis is variation in chronology associated with environmental differences and changes in elevation. To provide data for the correlation of altitudinal or regional chronologies, a mass of data should be collected from which solid, continuous chronologies of maximum length could be selected for comparison studies. The present collection represented only a cursory sampling in contrast to the type of intense site and altitudinal studies that could be undertaken in this area now that the potential has been disclosed.

It appeared even from this limited sampling that big sagebrush in the White Mountain area reaches a maximum or near-maximum age for the species. Many environmental factors in the causal complex, primarily those affecting moisture relationships, responsible for this longevity possibly also occur in the environment of the bristlecone pine. This coniferous species reaches an age of well over 4,000 years on the dry sites in the 10,000-foot zone in the White Mountains (Schulman and Ferguson, 1956; Schulman, 1958). Ring series in many of the bristlecone

pinos are extremely sensitive and the chronology parallels that of low-level drought-recording conifers. The ring pattern in big sagebrush very closely follows that of both the bristlecone pine and the relatively low-level pinyon.

The durability of the wood when protected from the elements by bark and by being encompassed by other portions of the same stem is in contrast to the tendency of growth layers to exfoliate when exposed to the effects of moisture and wind. On very old plants where the stem is protected, the bark may remain on terminal lobes that have been dead for 100-150 years. The stem of the dead plant with the 161-year ring series (Table XVI) was composed of three pieces, one of which died in 1848, a second in 1878, and the third in 1912. Since the death of these segments, they had remained exposed to the elements without any of the bark, or of the pith-to-bark, sequence being removed. In the case of the piece with 1848 as a bark year, this sequence covered a time span of 110 years. Some bark rings in the pre-1800 period still retained their covering of bark and were of sound wood. Many plants in the 200-year age class had portions of the stem in the first 50 years of growth that terminated in a dead lobe.

The durability of dead plants of big sagebrush under dry conditions may enable the chronology to be extended back into time many more years than would be possible with living plants alone, a factor of no little value

in dendrochronological studies. The dead plant mentioned above had only 161 annual rings, but the ring chronology it contained went back to 1752, a date 27 years earlier than any recorded for living plants collected from the Mexican Mine area.

At the higher elevations in the White Mountains, the number of trees per unit area is low and there is no understory--the average annual precipitation at the 10,000-foot elevation is approximately 10 inches per year--and the vegetation is thus protected from a ground fire or a crown fire. Many stands of bristlecone pine have survived for three or four thousand years without damage by fire other than that sustained by an occasional isolated tree struck by lightning. Even big sagebrush, especially on the rocky outcrops, is safe from a running fire. Thus, it is apparent that the maximum age of a big sagebrush community on a given site where fires do not occur is determined by a combination of genetic and environmental factors other than fire.

To provide an adjacent tree-ring control for the ring chronology in the big sagebrush from the White Mountain area, two species of conifers were studied. Increment borings from 12 or more bristlecone pine in the Reed Flat area were dated using as a control the bristlecone pine plots from 1850 on and the southern California bigcone spruce indices from 1700 on (Schulman, 1956). Three cores of comparable length of radius for the 250-year period were measured, averaged, and plotted to

provide a chronology from 1700 on for the 10,000-foot zone in which many of the older big sagebrush plants were found.

In the same manner, six cores of single-leaf pinyon from the Cedar Flat area were dated, measured, averaged, and plotted to form a control at the 7,350-foot elevation ten miles south of the Reed Flat area. In both instances, the measurements for the individual cores were plotted and studied in relation to their derived mean. All specimens were highly sensitive and correlated very closely with the means.

In Figure 34, the bristlecone pine mean of three is plotted at the top and the pinyon mean of six at the bottom to provide, in effect, the control at the altitudinal limits of the big sagebrush. Ring measurements of five individual plants of big sagebrush from the intervening elevations are plotted in their appropriate altitudinal sequence between the two conifer means.

The first two plots of big sagebrush are of plants from an elevation of 8,100 feet in the Trail Canyon area (Table XII), 34 miles north of Reed Flat. The third plot is of a plant from an elevation 10,000 feet in the Reed Flat area (Table XV). The last two are from an elevation of 8,880 feet two miles south of Mexican Mine (Table XVI).

All five big sagebrush are plotted on the same vertical scale. The first feature evident upon visual examination is the complacency of the specimen from the 10,000-foot elevation as indicated by the smaller

Figure 34. Plotted ring measurements, expressed in hundredths of a millimeter, for a mean of three bristlecone pines from the Reed Flat area; for five individual plants of big sagebrush from three sites in the White Mountains; and for a mean of six pinyons from Cedar Flat.

ring widths from 1800 on and by the relatively less variation in widths from the mean. This complacency is a common feature of the upper elevation plants and makes them more difficult to date when the outer-ring-year is not known.

A mean of two-or-more radii in a complacent specimen would provide a truer picture of the chronology. The fifth big sagebrush is the most sensitive as indicated by the wide range in ring widths from year to year. Crossdating between the bristlecone pine and the pinyon is better than between any one of the big sagebrush and either of the conifer means, because random fluctuations have been averaged out.

In a long series such as the 200-year plots in Figure 34, the dating can be quickly verified by checking the crossdating in the very small rings. The alternating sequence in the 1760's, especially the years 1763 and 1765, provides a good signature. A sequence used in dating detached inner portions of old plants consisted of the small rings for 1795, 1807, 1812, 1813, 1822, and 1829. These are followed by the small rings for 1836, 1856, 1857, 1863, 1865, 1873, and 1883. The 1900 signature, common in other areas, is represented in the White Mountains by 1894, 1896, 1899, 1904, 1910, and 1912. The small rings for 1929, 1931, 1934, 1936, 1948, 1950, 1951, and 1953 complete the series.

CHAPTER III

DISCUSSION

Rays

Structural weakness of the rays occasionally is responsible for a slight readjustment of the position of portions of the xylem wedges between rays. One or more, usually a series of growth layers between adjacent rays, may move as block units. Slippage occurs primarily in the central portions of older plants because of stress caused by the recurved lobes. The amount of displacement is usually only a fraction of a ring width and the direction of displacement alternates between rays rather than being progressive in a continuous direction. In this study, analysis of the ring pattern was not hindered by this slippage because relative width of the growth layers was not changed, but inspection was confined to the pattern of the growth layers between adjacent rays rather than on greater proportions of the circuit.

Stem Growth as Affected by Drought

Examination of cross sections of stems of very old big sagebrush plants indicated that severe drought during the years from 1894 to 1901 or 1904 produced a recognizable pattern of stem growth. This was due to complete cessation of activity in large areas of the stem cambium in apparent response to lack of moisture. This effect had a widespread geographic distribution, occurring from northwestern New Mexico to the San Bernardino, Panamint and White Mountains of California, and was associated with the drought conditions from 1894 to 1901 or 1904. In the California area, drought and its effect on growth were particularly marked in 1899. On the basis of observed defoliation and death of big sagebrush in the area east of Baldwin Lake in the San Bernardino Mountains in 1957, it seems probable that the drought conditions prevailing in the 1900 interval probably produced an extensive leaf fall in big sagebrush and caused the death of many branches or branch parts. Rootlets became suberized and ephemeral root hairs doubtlessly disappeared.

When normal growth was resumed, as in 1901 in the Panamint Mountains or 1905 elsewhere, the total active stem cambium in many stems appeared to have been reduced by as much as 75 per cent with the result that subsequent growth was concentrated in the remaining cambium. With the resumption of average, or above-average rainfall,

the theorized relatively greater proportion of roots to stems would produce exaggerated growth in the remaining stem cambium. The same effect might, of course, occur as a result of reduced competition caused by death or weakening of neighboring plants of the same or different species. The accentuation of growth shows up quite obviously in the plotted measurements for 1905, 1906, and 1907 in the mean of five plants from the Betatakin area (Figure 11). A maximum also occurred at this interval in rainfall records and in long tree-ring series but was more pronounced in the big sagebrush due to effects of the lobed growth-form of the stem.

Subsequent lateral expansion of the remaining cambium minimized the aftereffects of dry years such as 1902 and 1904 in the Panamint Mountains until growth about the stem circuit became somewhat stabilized. This nonclimatic effect must be considered if a big sagebrush chronology is to be interpreted as a precipitation index, bearing in mind that ring chronologies reflect relative rather than absolute changes in winter precipitation. The initial cause of the stem eccentricity (or lobed growth of the stem as seen in cross section) is the scar produced on the stem cambium by the death of fruiting branches. This effect is compounded by cambium death due to drought.

Following the death of the cambium in portions of the stem, there is an expansion in ring width in the remaining area during favorable years.

Continued over a period of 10 to 20 years, this localized growth causes a mushroomed appearance in any given cross section of the stem. Even this enlarged area soon stabilizes its lateral limits and a single lobe only one centimeter wide may continue for 50 or more years. Maintenance of a uniform lobe width requires consistently favorable conditions for growth. Any marked detriment to growth would cause a decrease in cambial activity, which, if continued, could eventually result in death of the plant.

Interpretation of growth rings in the terminal portion of elongated lobes depends upon the relative size and shape of the lobe in comparison to the annual rainfall during the interval involved. The normal lobe, the one best suited for analysis, is broad, regular in width, and essentially straight (A in Figure 35). Lobe B has divided and one or both lobes may decline in vigor. The decreasing growth in dying or nearly dead plants is illustrated in the pointed lobes (C and D in Figure 35) where each successive ring is of less lateral extent than the one before. This decrease in growth is climatic in origin; but because of the accentuated trend, the growth rings cannot be interpreted as a climatic equivalent. If, in dating a ring sequence for measurement, the best radius terminates in a pointed lobe, yet a round terminal of another lobe, otherwise unusable, is available, the dating is transferred to the rounded lobe with enough overlap to show the transition. The measurements and resultant plots thus incorporate two or more radii.

Figure 35. Idealized cross section of a portion of a stem showing terminal lobes. Lobe A is thrifty; the two lobes at B are declining in vigor and the growth layer for each succeeding year is of less lateral extent than the one preceding it. Lobes C and D are dead terminal lobes. The radius measured would be a curvilinear line through the center of the figures marking five-year growth periods.

Climatic Relationships

Crossdating within a species such as big sagebrush, and between species as between big sagebrush and conifers, implies a dominant environmental factor that is active over a wide geographical area. For conifers in the semiarid portion of southwestern United States, this has been shown to be winter precipitation (Schulman, 1956). The high degree of crossdating possible between big sagebrush and conifer chronologies showed that the big sagebrush similarly relies on winter moisture.

To show graphically this relationship between rainfall and growth, a single specimen of big sagebrush in an area having nearly equal winter and summer precipitation was compared with seasonal rainfall data (Ferguson and Humphrey, 1959). This specimen was from near the Grand View entrance to the Grand Canyon National Park, Arizona. In one lobe of a cross section of this plant, a straight-line segment of a curvilinear radius, represented by the heavy line over the picture in Figure 36, was selected for comparison with precipitation data. In Figure 37, the ring series for the years 1908 through 1932 is compared with winter rainfall and with summer rainfall from the Park headquarters 20 miles to the west. The amount of rain in both periods for each year is tabulated in Table XX and is indicated in the diagram by the width of the space bounded by two lines.

Figure 36. Single lobe of a cross section from a stem of big sagebrush growing near Grand View entrance to Grand Canyon National Park. The heavy radial line covers the 1908-1932 segment compared with rainfall data in Figure 37.

Figure 37. Winter rainfall (above) and summer rainfall (below) compared with the 1908-1932 period of plant growth illustrated in Figure 36.

Table XX. Rainfall, in Inches, at Grand Canyon National Park Headquarters, 1908-1932.

Year	Winter	Summer
	November-April	May-October
	<u>inches</u>	<u>inches</u>
1908	9.14	10.27
1909	9.96	6.40
1910	7.85	4.43
1911	10.39	9.95
1912	4.65	7.15
1913	6.86	5.32
1914	9.52	6.34
1915	7.36	4.96
1916	9.62	7.28
1917	6.02	5.25
1918	5.73	10.33
1919	9.50	8.30
1920	10.89	4.20
1921	4.48	10.02
1922	9.19	6.96
1923	9.28	8.15
1924	9.14	6.78
1925	6.85	12.14
1926	8.79	7.40
1927	10.19	12.98
1928	8.08	6.12
1929	6.07	6.93
1930	4.49	8.85
1931	5.14	6.45
1932	10.84	5.25
25-year total	200.03	188.21

The stronger correlations of growth rate to winter rainfall is shown by the fact that as winter rainfall increases or decreases, so too does the width of the growth ring for the corresponding year. It will be seen that a similar relation between growth and summer rainfall occurs less often.

In 1912, 1918, 1921, and 1925 when summer rainfall totals were nearly twice that in the winter, the ring for each year corresponds in relative size to the winter precipitation. In these years, as in the average, the heavy portion of the May-October rains came in July, August, and September, well after the plant had completed its growth. In contrast, the ring for 1930 more nearly represents the much heavier summer rainfall.

This is explained by an analysis of the monthly data which show that May, June, and July rains were substantially above the average and occurred in time to be utilized by the plant during its growing season. In 1920 and 1932, the winter rains were more than twice that of the summer rains; here again, the ring widths parallel the winter rains.

Climatological Applications

In studies of growth rings in big sagebrush or other species, determination of age may not be the primary objective; it may, however,

be a means to an end. Thus, a dendrochronologist, attempting to derive a precipitation-, river runoff-, or temperature-equivalent chronology from either a coniferous or a nonconiferous species in an unexplored area, is looking for trees with long-term ring records that correlate with climatic data within the interval of overlap. The initial approach in a previously uninvestigated shrubby species would be a study of the stem anatomy in an effort to delimit a given unit of the stem as being an annually deposited structure. If the deposition-year of a given annual ring is determined by starting with the present and delving into the past, correlation with climatic data, as precipitation in the southwestern United States, is the starting point. If the age of the species exceeds the length of the weather records, it may be possible to extrapolate the recorded weather data within the degree of correlation with growth rings. This is indicated diagrammatically below:

The use of additional growth ring records permits a further extension of the climatic record. With the correlation established between the climatic data and species "A", then the climatic data plus species "A" becomes a basis for correlation with species "B"; these, in turn, become a basis for correlation with "C", etc., as illustrated below:

In the above diagram, A, B, and C could represent a single species in one area or in three different areas. In either case, the mean of three might provide a more reliable rainfall index for the period of record than would a single weather station, especially if the station were at some distance or at a different elevation. Similarly, a mean of two or more stations surrounding the study area would provide a better index for correlation with a plant species growing in the intermediate

area than would any single station. Conversely, it is possible that a mean of the growth records of three species or of a single species from three areas would actually provide a better rainfall index for their immediate area than would any single station or stations outside of this area.

Growth rings may be correlated with climatic records by using the 12-month July-June totals in a winter rainfall regime or by using the standard monthly records regrouped on a basis of specific seasons of growth. Correlation coefficients between tree growth and rainfall have been worked out for 16 monthly combinations, encompassing such units as short winter, long winter, and winter plus the previous summer, by Schulman (1956).

A light rain is ineffective for growth of woody plants because of the high percentage of moisture lost through interception by foliage and through evaporation. A higher correlation, therefore, may be achieved by using only storm totals above specified minima. A closer correlation may also be obtained by the use of plants growing near the weather station (this would be especially necessary if spotty summer storms affected the growth rings) or by the use or establishment of weather stations near the species being studied.

An even better correlation of growth rings with various moisture units might be obtained by the use of soil moisture of the root zone

rather than precipitation. The correlation should be closer, inasmuch as soil moisture represents the effective rainfall that is available to the plant, and excludes evaporation and runoff losses. Additional growth-ring studies are needed to determine the relative merits of these methods of recording effective rainfall. Big sagebrush and other shrubs would have their place in this type of study in that they grow altitudinally below and latitudinally south of the forest border.

Ecological Applications

Dendrochronological dating of woody species that have definite annual rings is not difficult when the outermost ring is present and the year when this ring was laid down is known. Many woody species, on the other hand, do not possess growth layers that can be identified as annual. Others require intensive study before the annual character of the rings can be determined. Still others, of which big sagebrush is an example, may be deciphered with relative ease. With any species, however, determination of a complete and accurate chronology requires extensive crossdating of many specimens from a given site. Crossdating for any given species is then strengthened by extension of the chronology from site to site, and eventually from one geographical region to another. The chronology for succeeding species may be determined with greater ease after the ring pattern has been established for the first species

studied. Chronology building for a second species may proceed concomitantly with work on the initial species, but the main emphasis should be on expanding the number of sites for the original species rather than on crossdating from species to species within a limited area.

In ecological studies, especially those based on random sampling, the length and sensitivity of the ring sequence may not always be adequate for dendrochronological dating of the specimens. In such cases, plant age can be determined by a count of the growth layers if they can be, or have been shown to be annual in the species being studied.

When ring width is used as a criterion of growing conditions as affected by precipitation, it is essential that sites be carefully selected to assure that the plants have received no moisture to supplement that falling directly on the site. Dendrochronological studies have shown that maximum ages tend to be reached on sites subjected to environmental stress. Big sagebrush is no exception in this regard. On sites that were steep and rocky, thus allowing little retention of soil moisture, big sagebrush was found to be slow-growing and to reach a maximum age. In contrast, the fast-growing, short-lived plants occurred in valley sites, often on fine alluvial soil, and with access to relatively unlimited soil moisture. In terms of forage production, sites with a stand of young, fast-growing big sagebrush would offer the best possibilities for conversion to perennial grasses.

The maximum age reached by perennial woody plants is highly variable. Ages may range from more than 4,000 years, as in the case of bristlecone pine, to probably as few as 5 to 20 with such suffrutescent species as burroweed, Aplopappus tenuisectus, or snakeweed, Gutierrezia sarothrae. Were ages known more generally, they could be included in ecological or taxonomic descriptions of the species. Such information in many instances would be as valuable as a statement of maximum height growth, type of branching, or other features. In addition to species age, concomitant information on gross stem anatomy could also be included to advantage. The stem anatomy previously worked out for big sagebrush by Dittert (1938) and Saul (1955) was available for the present study.

Many possibilities exist for the application of age determinations by ring counts in big sagebrush or other shrubs once the annual nature of the rings has been determined. These include determination of maximum or less-than-maximum ages of plants in an area; variations in age between different ecological, altitudinal, or geographic sites; even or uneven age nature of the plants in a community; or correlation of age with documented or derived knowledge of an area with reference to fire or land-use practices such as plowing. If, for example, a collection along a transect showed significant differences in age, it might be possible to determine the cause; i. e., whether the age difference occurred

along an abandoned fence line, at an old plow line, or at the boundary of a burn. Or the application might be reversed, the limits of a known disturbance being determined by a study of plant ages.

Certain relationships between maximum age and altitude, and both latitude and longitude became evident as the study progressed. In general, there tended to be an increase in maximum age from the lower limits of the species to the 9,000- to 10,000-foot zone followed by a rather rapid decrease to the upper altitudinal limits. Geographically, within the area of study, big sagebrush was found to increase in maximum age from northwestern New Mexico west to the Panamint and White Mountains of California. From these areas there was a rapid decrease in maximum age toward the Pacific coast and south into Lower California. These observations open interesting fields for speculation and for further study not only with big sagebrush but with many other woody plants. As one or more factors become limiting, the maximum attainable age may be expected to decrease. This effect, however, may be dissimilar as one ascends toward the upper altitudinal limits of a species where temperature may be limiting or as one descends into hot, arid areas where moisture is limiting. A great deal of supporting data for these generalizations is needed and can be obtained only by dendro-chronological studies of a variety of species.

Archaeological Applications

Solid stems of big sagebrush found in prehistoric sites may offer a means of dating the archaeological structure or feature in which the material is found. Twenty-five or more archaeological specimens of big sagebrush have been collected in northwestern New Mexico by workers on the Navajo Project. Growth rings in some of these specimens showed sensitivity and some had ring series of over 50 years, but a datable combination of both sensitivity and length has not been found (Ferguson, 1959).

Ring chronologies in big sagebrush have been shown to crossdate with adjacent conifer chronologies and with regional means some distance away. A master chronology for big sagebrush, therefore, is not a requisite for dating archaeological material. However, material thus far found in prehistoric dwellings in northwestern New Mexico and on Wetherill Mesa, Mesa Verde National Park, Colorado, does not contain records of sufficient length to permit dating of the individual specimens. Specimens have been shown to crossdate within the site and thus could form a floating chronology. This type of chronology building is aided by identifiable false rings that add character to the chronology of big sagebrush and strengthen the shorter ring series. A composite chronology of this sort is more datable than that of the component specimens. The

floating chronology, if not datable by the master chronology, might crossdate with datable structural timbers and thus provide additional interpretation of construction practices.

CHAPTER IV

SUMMARY

A collection of approximately 700 stem sections of big sagebrush, Artemisia tridentata, Nutt., from seven western states and Lower California, Mexico, has shown that this shrubby plant has the same ring character as do many forest trees.

This study has shown that big sagebrush produces a growth ring that is sensitive to changes in annual precipitation and in some areas reaches an age of slightly more than 200 years. The ring chronologies of big sagebrush show essentially the same pattern as adjacent tree-ring chronologies. At lower altitudes and southern latitudes, false annual rings are occasionally formed by an extra layer of interxylary cork produced when growth is interrupted.

Because big sagebrush does have a definite annual ring, the rings can be counted to determine the age of any given plant or plant community. The oldest plants found indicate the maximum age reached by the species in that area; or they may indicate the time that has elapsed

since some catastrophe such as fire, plowing, or flooding had occurred. The use of shrubs in this way thus provides an avenue for climatic and ecologic interpretation outside of the forested areas.

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