Tales Trees Tell

Story 3:
A Year in the Life of a Pine Tree

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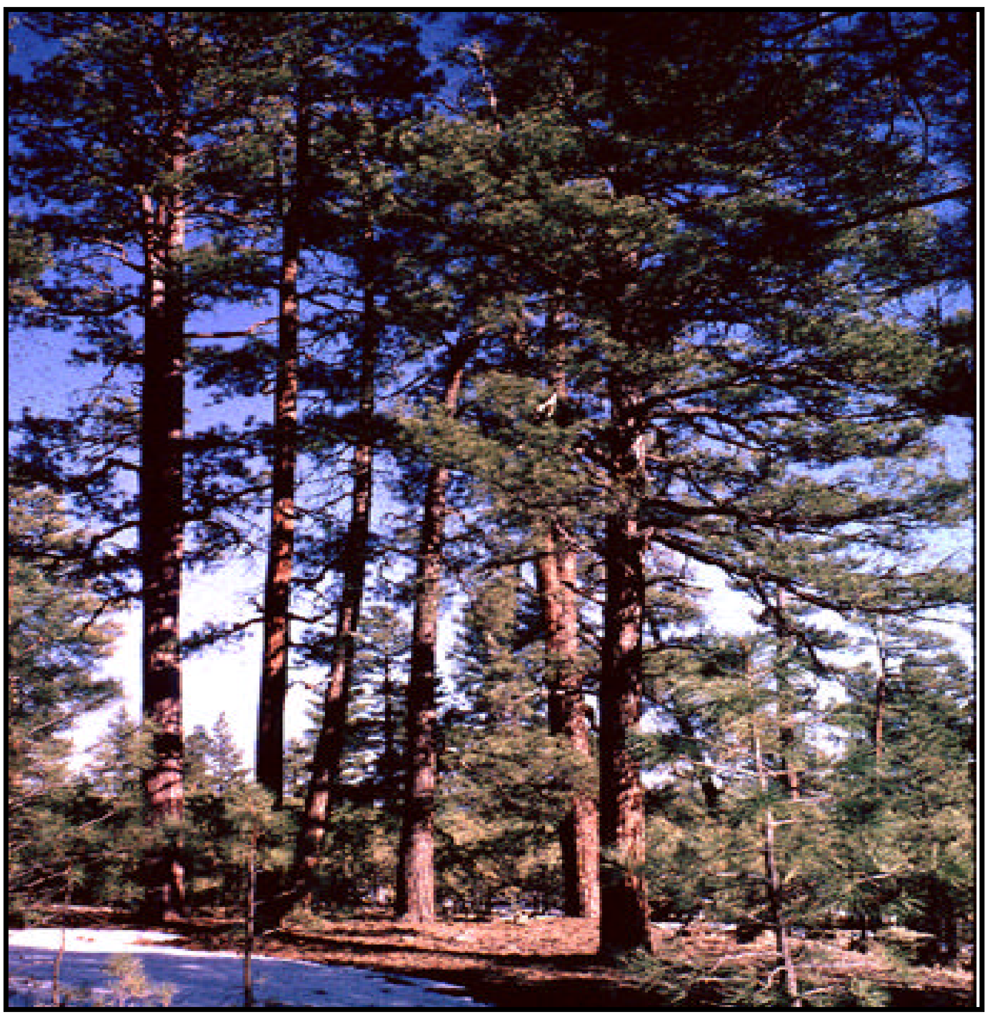
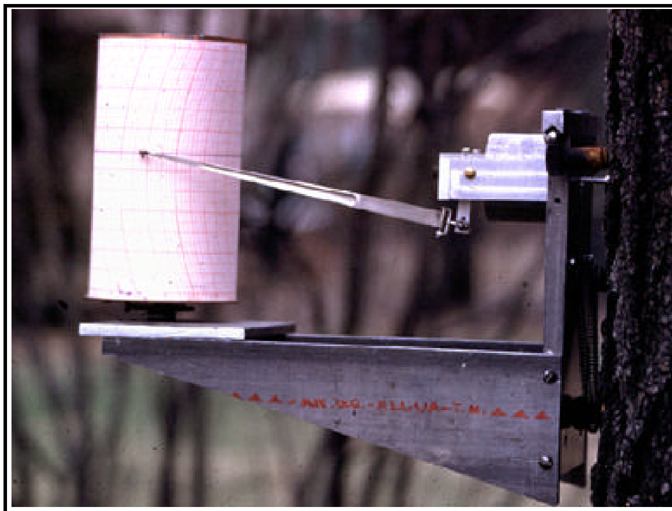


I have always enjoyed being among trees. My special love and joy is the ponderosa pine forests of western North America. They are an inspiration to me, and this tale is an attempt to share a bit of that joy with you. In order to fully appreciate how a tree can tell a story in its ring structure, it is necessary to understand life from the perspective of a tree along with how and when it grows. You and I dwell in our homes which creates a habitat in which we can live and thrive. The tree does not generate body heat as mammals like us do, nor can it construct a habitat around itself. It must be capable of living, growing and surviving outside exposed to the elements through all four seasons of the year.

It is beautiful how native trees, those that evolved in the forest they now live in, are so well tuned to their environment. In temperate forests, deciduous trees loose their leaves during winter but evergreen trees retain leaves all year long. During the winter when freezing temperatures can damage growing tissue, growth has ceased and the term for this is “dormant”. Trees, as well as animals and other plants, become more active and begin growth at about the right time in the spring. All native plants are adapted to flower, fruit and form seeds at the right time for them to succeed and reproduce. They seemingly anticipate winter by going into dormancy at about the right time. How does this come about? To understand this and the stories written in the annual growth rings of trees, it is necessary to learn more about the state and nature of the tree growth processes throughout the four seasons of the year.

Of course, we can never really be a tree. However, we can spend some time with the trees observing, measuring and describing the conditions a tree experiences, examining how it responds to those conditions and imagining what it is like to be a tree. Instruments such as thermometers, rain gauges, soil moisture meters and light recorders can be used to measure and record the environment and growth, so that we don't have to reside in the forest all of the time.



The dendrograph that my father and I developed to measure the size changes in the stem of a tree is mounted on three screws inserted into the dead wood. As the trunk grows, it expands and becomes closer to the instrument. A probe touching the outer bark measures this distance and any change, magnified 100 times, is recorded on the chart.

Some of my colleagues and I have measured the forest environment and observed a wide variety of trees growing in different places for intervals of several years. Sometimes we have to invent our own measuring devices. During one Christmas holiday, my father and I built an instrument, called a dendrograph, to measure and record the changes in trunk size, so that I could follow the growth in diameter of a tree trunk (technically called the main stem). By following the increase in trunk size, I could learn when the rings began to grow, when they grew most rapidly, what caused them to grow rapidly and when they stopped growing. The dendrographs were placed on tree trunks and a shelter was built around them to keep out the weather, mice and all kinds of things that like to hide or build nests in the dendrographs.

Once installed, I had to return weekly to rewind the clocks, change the charts and make other measurements. Later we added batteries and electric clocks so during the winter the instruments continued to record without rewinding, unless the ink dried out, a spider built a web pulling the pen away from the recording paper or a curious bear broke into the shelter. Once we had a flash flood and lost one dendrograph which is probably still buried underneath the boulder rubble carried by the torrent from the brief but severe mountain storm.

The beech-maple forest in Ohio that I first studied. Note the green shelter that covers a dendrograph mounted on the trunk of a beech tree.

Although this discussion will not be confined to just one kind of tree, I have spent the most time studying the growth of ponderosa pine (Pinus ponderosa) on relatively dry sites about 8000 feet (2625m) high on top of a mountain near Tucson in southern Arizona. Other species I have studied are American beech (Fagus grandifolia) growing in Ohio, white oak (Quercus alba), red oak (Quercus rubra) and sugar maple (Acer saccharum) growing in Illinois, pinion pine (Pinus edulis), Douglas-fir (

Pseudotsuga menziesii) and ponderosa pine growing in Mesa Verde National Park, Colorado, and bristlecone pine (Pinus longaeva) in the white mountains of California (see Tales Trees Tell: Tale 1.)

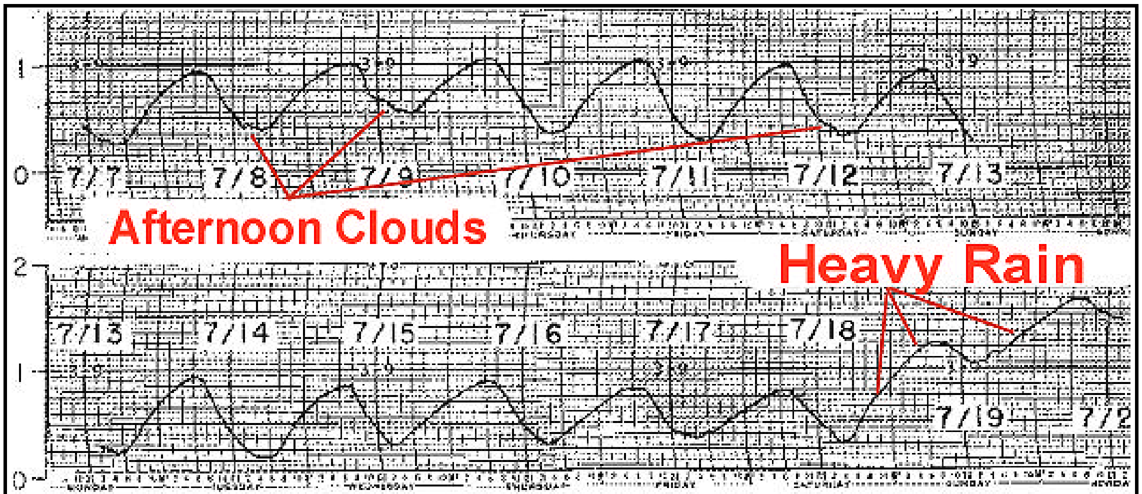
Winter

Winter starts for earnest by late November in the mountains of Arizona when temperatures may drop below freezing almost any night and sometimes for several days in a row. During very cold spells ice can form inside the living tissues except where dissolved sugar and other substances act like antifreeze and prevent ice formation.

The Mesa Verde site in southwestern Colorado in winter. Photosynthesis can occur even with snow on the ground if the living needles are warmed, exposed to light and moisture is available from the stem.

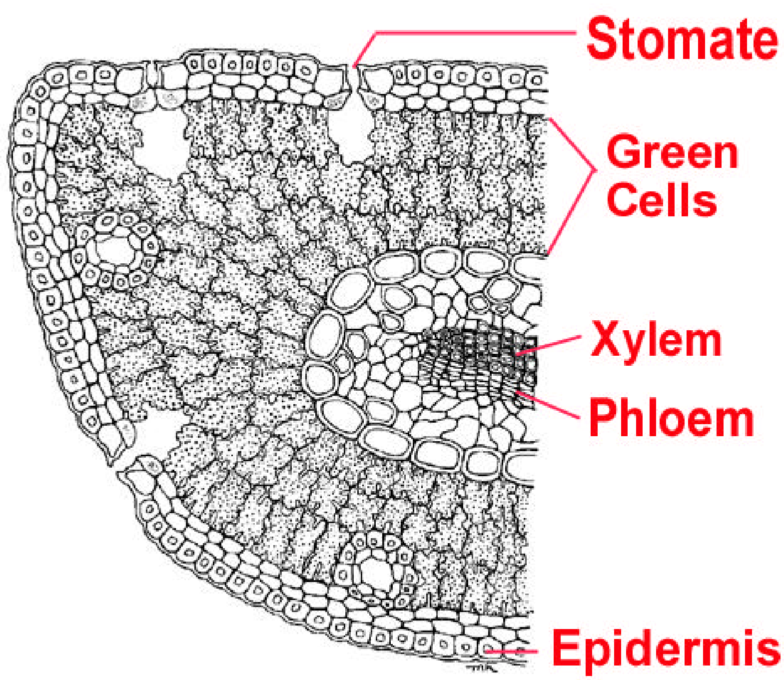
If the trees are growing when winter begins, they could be injured. Natural selection has removed those trees in the past that had continued growing into the winter so all that remain today are dormant except possibly in their roots which we rarely observe. But just because they are dormant does not mean they are inactive. Dormancy refers only to the absence of growth. The leaves (needles) of pines remain green and alive for a number of years so they are called evergreen trees. These green needles can carry on photosynthesis whenever temperatures and conditions inside them are favorable and there is light. As mentioned in Tale 2, photosynthesis is the process of making sugar from carbon dioxide and water using the energy from light. Some deciduous trees that lose their leaves in winter have green tissue in their bark, especially in the small stems, so they are capable of some winter-time photosynthesis.

Temperatures of the air around a pine can range from below freezing to as high as 70 0 F (21 0 C). There may be snow on the ground, but in sunny weather the snow on the south-facing slopes may melt or simply evaporate if the air is dry. In the sun, the trees can become quite warm even if the snow is deep and covers the ground. Early snow can



Dendrograph records show trunk swelling during the night when more water is absorbed than is lost from the tree and shrinkage during the day when more water is lost by transpiration. This particular record from ponderosa pine was made during July 1966 after the first early rains occurred. The pulse of daytime shrinking and swelling at night is large at this time of year because temperatures are high, lots of water is lost by transpiration and similar amounts are absorbed by the roots. Note that there was a heavy rain on the 19 th when summer growth began with trunk swelling and rapid expansion.

insulate the ground and prevent the roots from freezing all winter long. At night the air temperatures at moderate altitudes often drop below freezing as do the temperatures of the needles, branches and bark. During very cold weather, the trunk can freeze but the dormant growth layers have an internal antifreeze that protects them. The trees usually thaw out fully during the day. They lose water through transpiration and can carry on photosynthesis. The tree trunks actually shrink a bit during the day as more water is lost from the tops of the trees than is absorbed by the roots.



A cross-section of a pine needle showing the outer epidedrmis layer, which is covered with a waxy layer on the outside so most of the moisture leaving the needle and carbon dioxide entering the needle must pass through the holes called stomates. Photosynthesis occurs in the green cells, water moves from the stem through the xylem, the green cells and out the stomates during the day when they are open. Sugar from photosynthesis is transported out of the needle and down the stem through the phloem.

At night, without light, photosynthesis stops. The stomates in the needles, through which the water vapor must pass, close. Little water is lost through the leaves and the trunk swells as water is absorbed through the roots at a faster rate than it is lost through the leaves. The dendrographs, can measure these changes in trunk size, like a pulse from our heart beat but there is only one beat per day. Irregularities in this beat do occur when clouds block the sun, closing the stomates and reducing the loss of water.

On rare occasions when the ground is frozen at these moderate elevations, the tree tops may loose much water if it is windy and warm while the frozen roots cannot absorb water. On these occasions the leaves may dry out and die. In the spring or summer after the snows have gone you may have walked through such a forest and seen the brown needles or branches that have been killed this way. This is called “winter kill” by foresters, but brown needles are not always an indicator of winter kill. Insect damage, stem breakage or other factors also can cause the needles to dry out, turn brown and die. After needle death, a corky layer is formed at its base, the dead needles become detached (abscise) and eventually fall to the ground.

The dendrograph shelter mounted on a sugar maple in central Illinois in early spring when the buds were just beginning to open and the leaves were emerging.

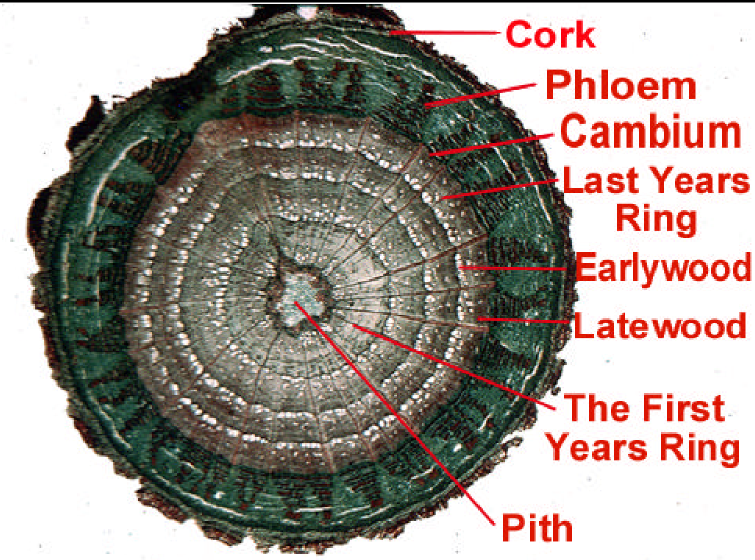
Many of the forest animals such as bears, lizards and insects hibernate in winter. Many insects live through the winter as eggs, pupa or larva in the ground, on decaying wood or simply attached to branches in the trees. Squirrels will wake up at times trying to find the cones they have buried in their caches during the warmer seasons. Winter birds that are active on sunny days include the chickadee, woodpeckers, nutcrackers, some sparrows and a variety of other species depending upon the location of the forest. Rabbits, mice, owls and foxes may appear under the cover of night.

SPRING

As spring approaches, daytime temperatures begin to rise and the trees are not frozen as frequently, more photosynthesis occurs and more water is lost from the tops of the trees. Animals begin to stir and become more active. In the deciduous forests of eastern North America, spring is the time the flowers cover the forest floor before the leaves of the trees expand and close the forest canopy cutting out the sunlight that is so important for the spring flowers to photosynthesize, grow, bloom and form seed.

This is also the time when many birds begin their migrations to northern regions. Some summer residents such as the robin, thrushes, vireos and bluebirds establish territories and begin building nests. Insects, particularly the ever present gnats and mosquitoes begin to buzz around our heads and deer, turkey, coati and other animals may appear with their young.

On the arid sites in the Arizona mountains, if there is plenty of water in the soil, the day is sunny and temperatures are warm, photosynthesis occurs rapidly and much water is drawn into the roots, passes up the stem and is lost by transpiration through the needles of the tree. If and when it turns cold, both photosynthesis and water loss decrease. Thus, the amount of food made by photosynthesis is highly correlated with how much water fell as snow or rain, was retained by the soil and was absorbed and transpired from the tree.



The tissues in the young stem or twig of a pawpaw tree (Asimina triloba). The outside protective cork surrounds the phloem (the food and growth regulator conducting system) and together they form the bark. The cambium lies between the phloem and the wood or xylem (the water conducting tissue). Annual rings are produced in the xylem with large thin-walled cells in the earlywood and small thick-walled cells in the latewood. The first ring surrounds the pith made up of thin-walled cells that have little function but can serve as temporary food storage for the young twig.

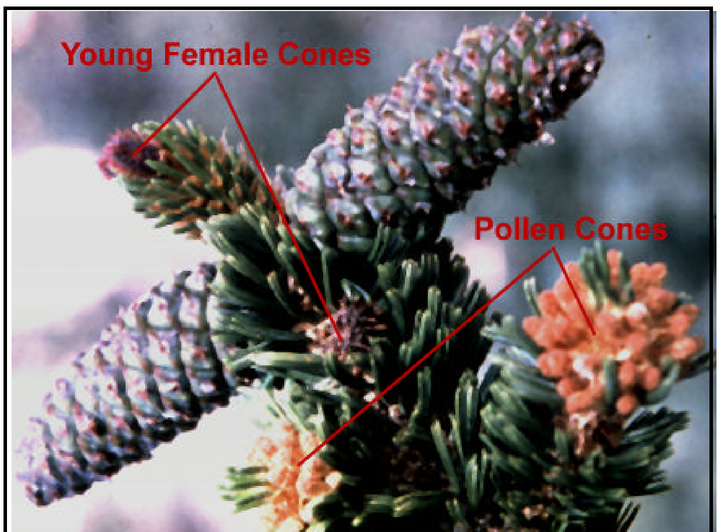
When day lengths are longer and temperatures become warm enough so that severe freezing and frost are unlikely (late March or April in the mountains of southern Arizona), the pine buds begin to swell and produce chemicals called growth regulators. The growth regulator amount (concentration) increases as the buds continue to swell, and the chemicals are carried down the stem in a transporting tissue called the phloem that lies within the living inner portion of the bark.

The increase in concentration of this growth regulator causes a change in the cambium, a one celled layer along with a few associated growing cells lying just inside the phloem and outside the wood. The protoplasm (the living portion of a cell) in the cambium becomes less dense and the cells begin to swell and eventually divide. A division towards the outside will produce new phloem cells, one towards the inside will produce new wood cells, called xylem. The first cells formed in the xylem will become the innermost and largest cells of the annual ring. This is the time that the bark becomes loosely attached to the wood; and with trees such as willow you can make whistles from the twigs because the bark will slip off the wood. After notching the bark and shaving a slot in the wood, slip the bark back on the twig and blow.

The initiation of growth gradually progresses down the branches and trunk taking about a week or so to reach the base.

Growth at the branch tips.

New branches begin to emerge from the buds. As the buds continue expanding, little purple green bumps (female cones) appear along the new stem from the buds near the tree top and orange yellow bumps (pollen cones) appear, usually on side branches. The pollen cones expand, the pollen is shed and it floats in the wind as fine golden dust.

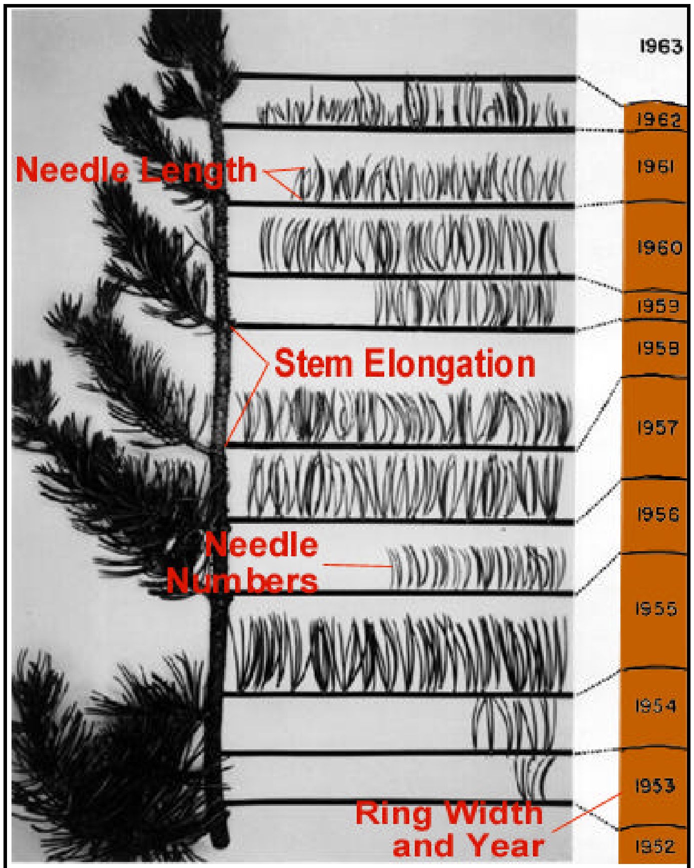


The young female cones, pollen cones and larger one-year-old cones of bristlecone pine.

As the pollen is carried off in the wind, some lands on the female cones at the branch tips. A little tube with the protoplasm of the pollen grain grows out of the pollen, down through one of the female flower cone scales to the base where it penetrates the ovule eventually fertilizing the oosphere (the egg). The pollen may land on the female cone in June but may not reach the egg until the next spring. During the next year the fertilized egg grows into the embryo of the new tree contained in the seed. It takes two and a half years from the time the pollen is shed before the cone ripens and the seed is shed from ponderosa pine.

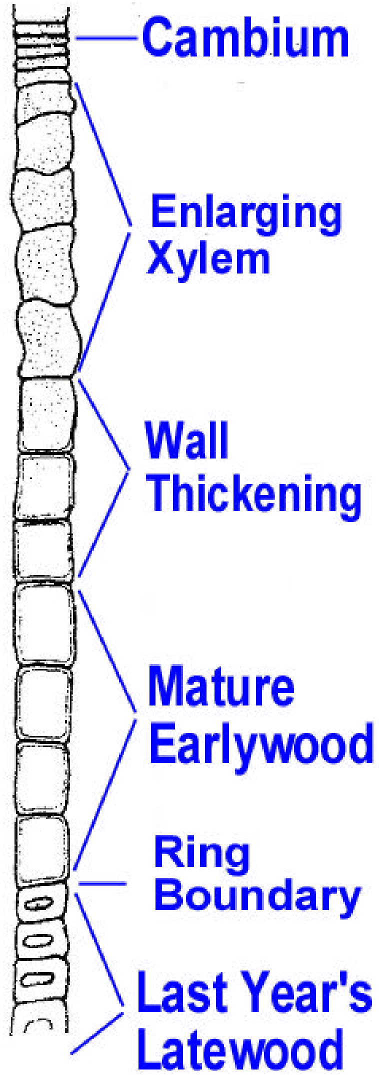
Several weeks after the young cones appear on the branch tips, very short needles emerge on the stem behind the bud and elongate slowly as more needles emerge from the expanding bud. The lengthening of the stem, emergence of needles and their elongation will continue until late August.

A new bud will appear from the old growing bud and the number of needles for next years growth are influenced by how favorable conditions are at the time the buds are produced. However, the length of the needles are not determined until the next growing season. The elongating needles may be short if winter, spring and summer moisture and photosynthesis is low. They are longer if there is abundant moisture, stored food and favorable temperatures. You can see that stem growth is a complex process. The numbers of buds, cones, needles, and maximum branch lengths can be reduced by unfavorable conditions in the year prior to current elongation while the needle lengths, final branch lengths and ring widths can be reduced by unfavorable conditions during the year of stem and needle elongation as in the illustration.



Needle lengths, stem lengths, needle numbers and ring widths on a branch of pinyon pine from Mesa Verde, CO, for years 1952-1962. Except for 1952-1954 where many of the needles have abscised, the numbers of needles and stem lengths appear to be determined by conditions during the end of the prior years' growing season. However, the ring widths and needle lengths are mostly influenced by the current year's growing conditions.

Growth in diameter



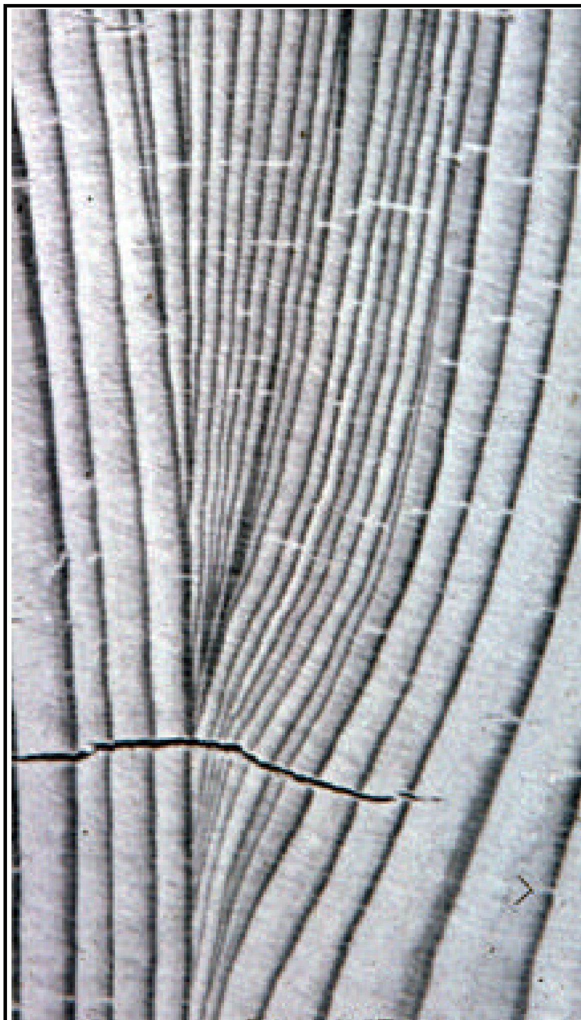
The growing region of the xylem showing the cambium cells that are dividing, young xylem cells that are enlarging and older xylem cells in which the walls are thickening. Four cells have fully matured into earlywood. The ring boundary and four of the last years thick-walled latewood cells are visible.

of the trunk.

Returning to the cambium under the bark which is just starting to grow in April , the cells in the cambium begin to divide more and more rapidly as temperatures rise reaching fastest rates of division around the middle of May. With the production of new phloem and xylem cells, the trunks still expand at night and contract during the day, but each day the trunk expands a little further than it did the previous day. After several divisions, the outer and inner-most cells in the cambium loose their ability to divide but they continue to enlarge. In a few days, to one or more weeks, the enlarging cells that will become xylem (the water conducting wood cells) attain their maximum size and begin to form thicker walls of wood-like substances called cellulose and lignin. The first formed cells of the earlywood remain in the wall thickening stage for only a few days. They then die, loose their protoplasm and water begins to move through them. Each xylem cell is connected to xylem cells above and below them by tiny holes in the cell wall called pits, forming a continuous column of water from the roots through the stem to the needles in the crown of the tree.

If there was little moisture for lack of winter snow or rain, the rate of cell division and enlargement will be slower because there will be less water and stored food from the previous year and from winter and spring photosynthesis. As the water lost by transpiration becomes greater than the water absorbed by the roots, the trunk expansion slows and then begins to shrink. In severe drought there are fewer cells produced; they do not expand as much and may remain in the wall-thickening layer longer. Thus they are smaller and have thicker walls. Cell division may even stop, followed by the cessation of cell enlargement and later the termination of wall thickening.

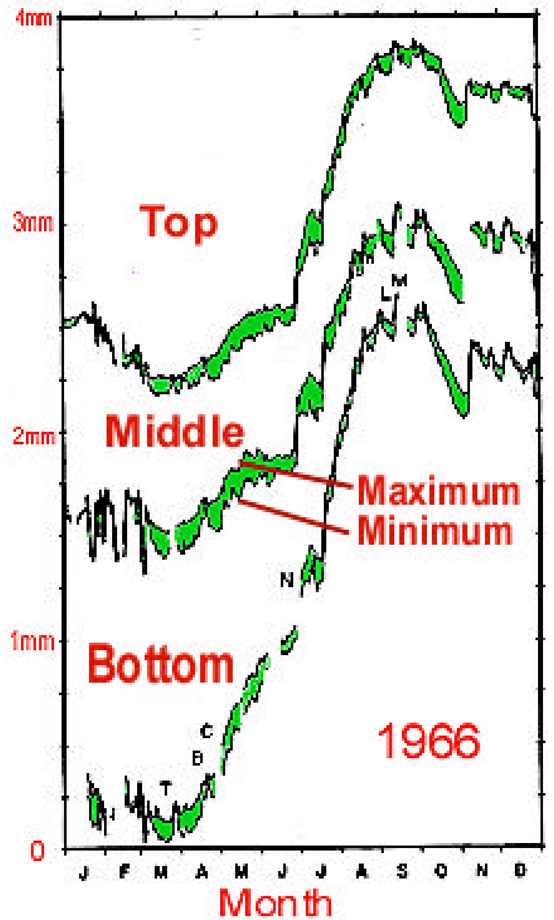
If the summer rains fail to arrive and there has been little snow and rainfall to replenish the soil moisture, only a few cells will be produced and the ring will be narrow. In extreme years, there may be so little moisture and stored food, that the growth regulator concentrations may be too low to initiate growth by the time they reach the lower levels of the trunk. Growth may begin only in the crown or in the upper portions of the trunk. In such cases when a ring forms only in the upper part of the tree, it is missing near the trunk base where dendrochronologists usually sample the rings. A simple count of the rings will be off by one year at the base. To avoid such errors due to counting when a ring is missing, dendrochronologists use a more complicated procedure called cross-dating. This procedure is explained more fully in other Tales Trees Tell.



It is difficult to show a missing ring but at the bottom of the picture there are many rings that are missing. This is an extreme case as usually only an occasional ring is missing and its location can be identified using cross-dating. A missing ring in the trunk is usually present somewhere else in the tree.

When there is abundant soil moisture from winter snow or rain, and lots of food reserves, the rates of both cell division and cell enlargement will be greater than if the soils are dry. Even during moist years the growth rates begin to decrease after the optimum growth period in May because little rain falls at this time, soil moisture levels decline and the growth controlling processes signal a gradual decline in growth rate. With less water absorption the trunk expands more slowly at night and the shrinkage during the day is greater. The balance between water absorbed and water lost is dependent upon how much moisture is stored in the soil and how extensive and hot the dry period is before the onset of summer rains. In 1966 growth did not stop completely in late June like it could in an extremely dry year.

In Arizona we have two marked rainy seasons, one during late fall, winter and early spring and the other starting around the first week in July and ending in early September. The driest and often the hottest month is June,



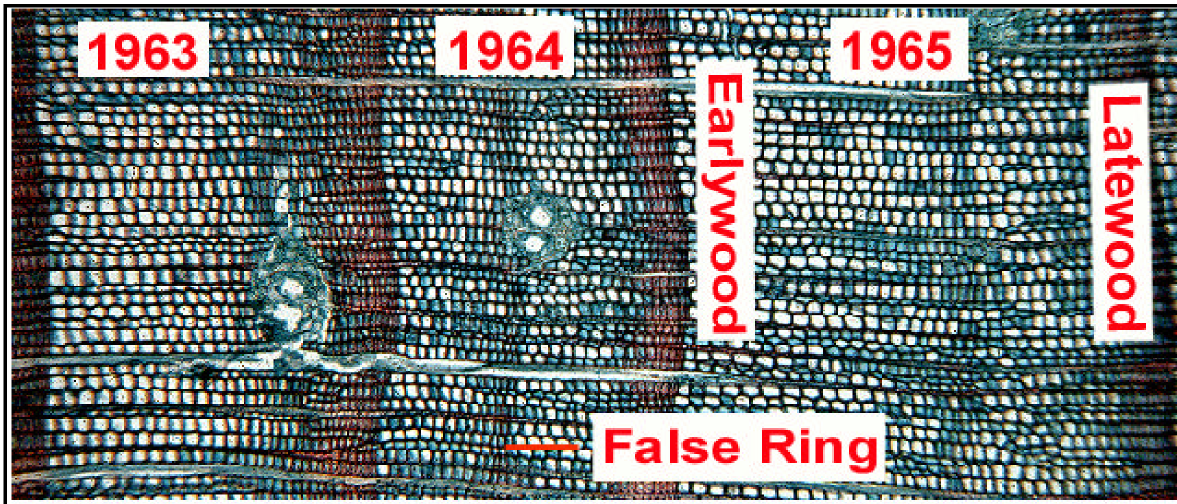
The annual growth curve can be seen by plotting the daily max-imum and minimum trunk size measured by the dendrographs. Growth as measured by trunk size began in April soon after the buds began to swell. After the optimum growth period in May the trunk expanded more slowly. Expansion increased in July with the beginning of the summer rains. By early September expansion had stopped but wall thickening continued for at least another month. T-buds begin to swell, B-buds opening, C-cambial division begins, N-needles emerging from buds, L-latewood cell walls thicken and M-needles reach full lengths.

which is right in the middle of the growing season and immediately follows the month of optimum growth.

When the summer rains begin, usually with magnificent lightning bolts and booming thunder, soil moisture is replenished, first in the upper soil levels. If the rains continue, moisture reaches deeper soil levels. The roots absorb much more water than is lost by transpiration, so the trunk begins filling up like a balloon until it reaches its maximum size. This size will be dependent upon how many new cells have been produced and how much they have expanded. The photosynthesis rates also rise abruptly, more food is made and cell division along with cell enlargement rates again begin to increase.

As the season progresses, the growth of the buds and lengthening of the needles begins to decline even if conditions are favorable for growth. The growth regulator concentrations diminish or a different regulator becomes dominant; we are not certain what exactly occurs. In any case there is a change in the growth regulators, the cambium division begins to decline, the cells remain in the enlargement zone for a shorter period of time but they are in the wall thickening zone for a longer time and/or may be thickening at a faster rate.

The last-formed cells are smaller and they have thicker



The structure of the rings formed in the tree for 1963-1965 from left to right. Note the smaller cells forming a false ring in the middle of the 1964 ring when growth slowed down and the trunk shrank during the June-July dry period. A similar but less pronounced feature is visible in the 1965 ring on the right. The larger cells on the inner (left) boundary form the earlywood. The darker smaller cells on the outer (right) boundary form the latewood. The smallest ring with the fewest cells was formed during 1964 telling us this was a relatively dry year. More precipitation fell in 1965 and the ring was much wider.

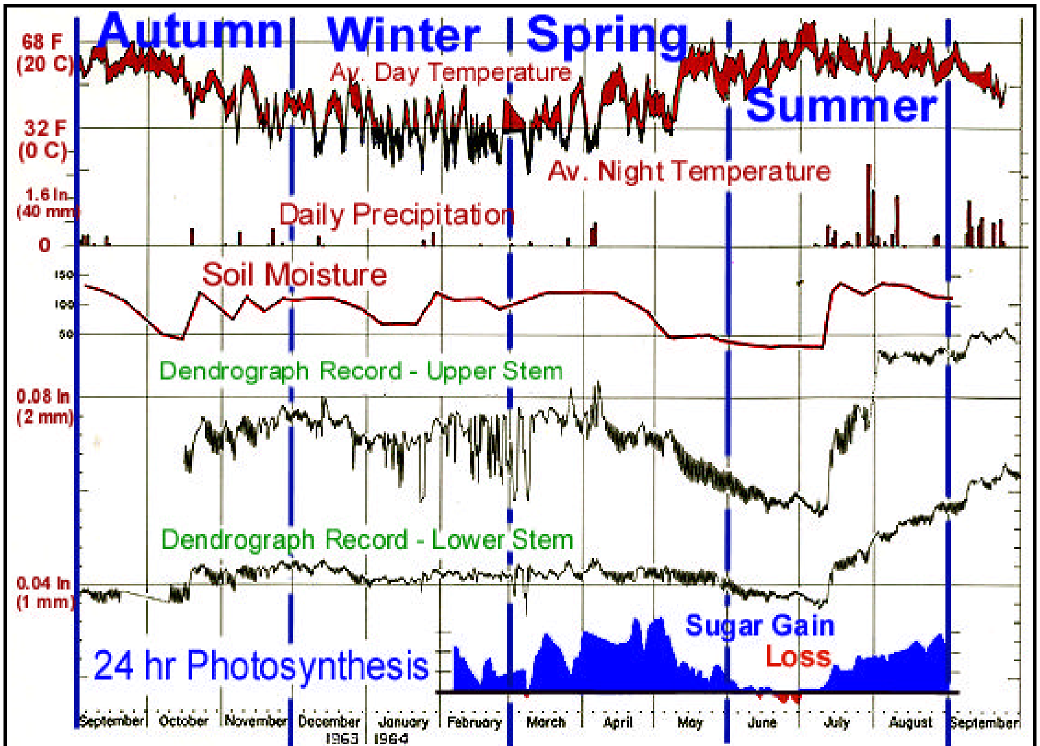
walls. They form the latewood which is darker in color. The sharp boundary between the dark last-formed latewood of one ring and the light first-formed earlywood of the next ring mark the abrupt boundary between annual rings.

AUTUMN

There is no clear change that can be recognized as the beginning of autumn. Cell division will slow until it stops in August or September if it has not stopped earlier. In some years when there is plenty of summer rain and the cambium has temporarily stopped growth in June, cambial division may begin again so that two rings are formed in one year in certain places of the tree trunk. Since these double rings do occur, as well as missing rings, dendrochronologists cannot rely on simple ring counting. They must use the more involved procedure of cross-dating to identify where double or missing rings occur. The rigor of the cross-dating procedure assures that each ring is identified as to the exact year in which it grew.

Photosynthesis and transpiration are measured throughout the year by enclosing branches in plastic bags and measuring the carbon dioxide uptake and moisture loss from the branch.

Sometimes a plastic tent was inflated around an entire tree and the minute by minute details of photosynthesis, transpiration as well as stomatal opening and closure were measured during several days and nights.



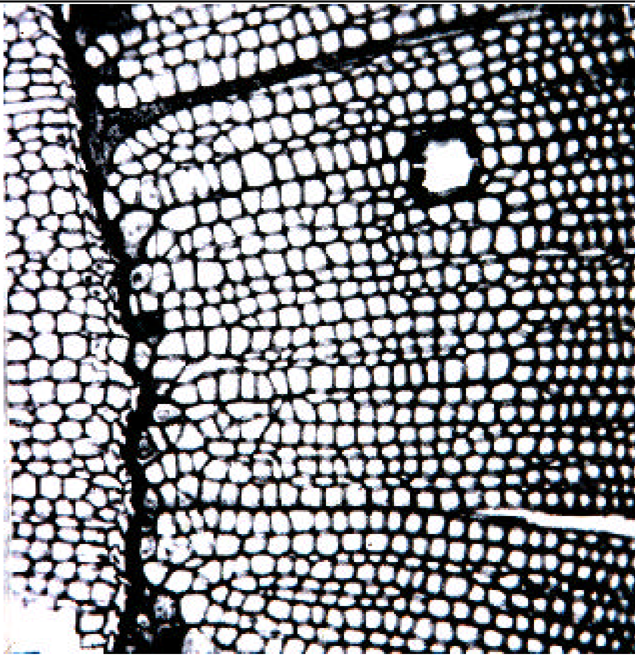
The results of our measurements for each day from September 1963 - September 1964, a relatively dry interval of time. Soil moisture levels were only moderate during the autumn and winter and no rain fell from early April - early July. During this hot dry period, the trunk stopped expanding and began to shrink especially in the upper stem. Little photosynthesis occurred (blue) at the beginning of summer and carbon dioxide-was lost (red) from respiration in the tree until early July. Little moisture and food was retained by the stem and growth was suspended until moisture and food were replenished by the July rains. In the middle of July trunks expanded and summer growth began.

However, the cambium will eventually stop, usually well before the end of September. Cell enlargement inside the cambium may cease shortly after cambial division stops, but the wall thickening can continue into October and even November, if temperatures remain favorable and nights remain mild. Eventually wall thickening stops, the tree becomes dormant again, and the protoplasm in the cell changes so that it can endure the low temperatures of winter without damage to the cells.

Sometimes, if growth begins too early or continues into the autumn too late, a sudden sever cold period may freeze and kill the cambial or enlarging cells, producing a wound, called a frost ring, that is easily identified by the presence of crushed cells. If the frost is not too severe, the cambium reorganizes itself after the freeze forming new cells on the inside of the crushed cell fragments. A very severe frost may kill a large part of the cambium in young stems or in exposed places where the insulating bark is thin; and the stem may take a number of years to grow back over the damaged area similar to the healing of a fire scar. Of course, some trees may be so severely frozen that they will die.

Any trees that start growth too early or remain growing too late in the year are likely to be killed by a sudden drop in temperatures below freezing. This is an example of natural selection. Only those trees that will delay their growth late enough in the year to avoid early frost and stop early enough in the year to avoid severe damage from late frost are the trees that survive today. That is why the trees are so well tuned to their environments. This natural selection is always occurring and keeps most trees within the bounds of natural variability in climate.

What if man causes an increase in temperature through over production of carbon dioxide, resulting in global warming of the earth? Gradually, through long periods of time, some seedlings that would not have survived previously will survive and some young trees will start growing earlier in the spring or stop growing later in the autumn. When and if the world’s climate returns to a colder state like it is today, those trees would then be killed by the return of spring and autumn frosts.



When a frost occurs during the growing season, it kills the actively dividing cells that collapse into a layer of cell fragments called a frost ring. If the frost is near the beginning of growth, the frost ring is in earlywood near the inner ring boundary as in this picture and if it is near the end of growth it is in the latewood near the outer ring boundary.

If climate becomes more extreme with long cold periods followed by long warm periods, many more trees could die along with some of the animal life that depend upon them. Eventually life capable of surviving these new extremes would evolve, but such a process takes a very long time and may span many generations of trees. You, your children's children and their children will see the damaged trees but will not see the evolutionary change because it occurs too slowly for us to detect by simple observation. Observations of fossils and on how animals and plants behave today provide the evidence for evolution. We put this evidence together, draw what seems to be the best inference to come to the conclusion that evolution is a real process and is at work today.

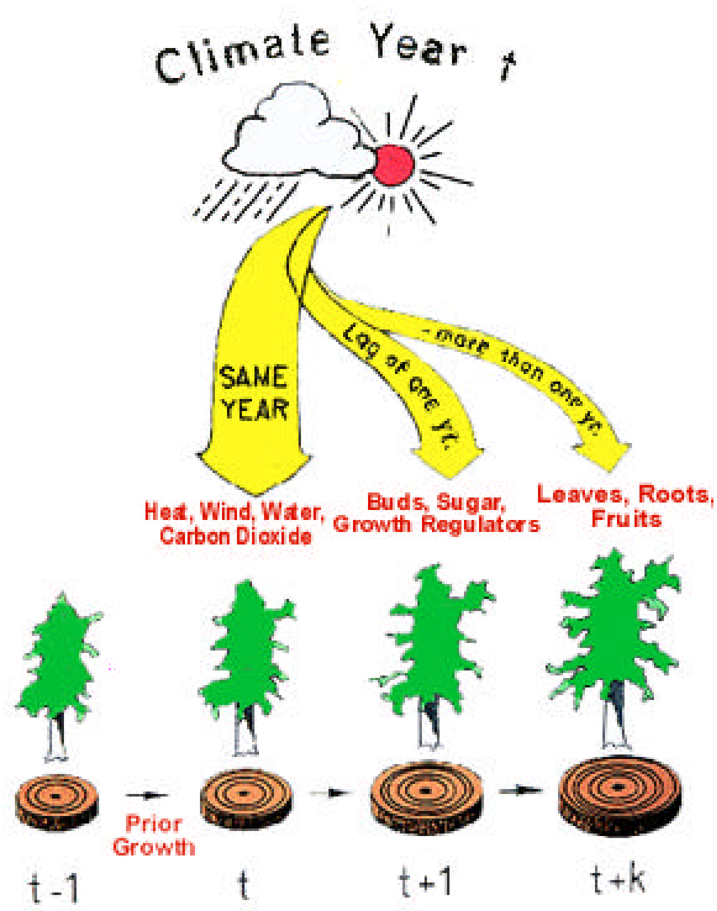
My colleagues, Dave Stahle from Arkansas and Valmore LaMarche and K. Hirschboeck from Arizona, have used the occurrences of frost rings, which are common on certain sites, to reconstruct years of extreme cold weather outbreaks in the western United States and studied the unusual weather patterns that caused them. Many of the unusual cold snaps were associated with crop failures. Some were associated with extreme El Nino events or explosive volcanic eruptions, sometimes on the other side of the world, that had ejected great dust clouds high in the atmosphere which were carried in the jet stream around the world. The dust particles weaken the suns rays, temperatures are lower and cold air may be carried south out of the arctic causing unusual cold periods and frosts after the growing season has started or before it has stopped. LaMarche and Hirschboeck created quite a stir in the archeological community when they dated the ancient eruption of Santorini, in the Agean Sea, at 1628-1626 BC from frost rings in bristlecone pine in California.

By late November, all growth has stopped; the cambial cells have become resistant to freezing (winter hardening); and they remain this way until the next spring. Transpiration and photosynthesis will occur if day-time temperatures are above freezing, the roots and trunk are not frozen, and adequate light and soil moisture are available.

Therefore, if the winter is mild with plenty of soil moisture, transpiration and photosynthesis will be greater with a buildup of stored food, the tree ring for the next year will be large. The dryer the conditions for trees in Arizona, the less the food buildup even with plenty of sun, the less the growth rate and the narrower the ring for that year.

In more northern localities, or at higher elevations, the winters are longer and the summers shorter. In these localities both low moisture and low temperatures can produce changes in the processes of transpiration, photosynthesis and growth. As one goes further north or higher in the mountains, temperatures become more limiting to the rates of photosynthesis and cell growth than does the lack of moisture. The growing seasons are usually shorter, and the number of cells produced and their sizes reflect temperature rather than moisture. Here the trees tell different tales. You may wish to review Tale 1, The Grandpa Trees, as in this story, the trees at different elevations tell different tales about past climate.

You can see that the needles and numbers of branches on a tree are determined by what the climate has been in prior years. Food made in one year can be carried over as storage to the next year. Therefore, if we try to read the story in the tree rings, it is necessary to recognize that climate in one year can be the primary influence on what the tree ring looks like, but the climate in other years is also important as is the amount of growth in previous years. If a large number of cones are fertilized and grow, some of the food reserves will be used for reproduction (seeds) and there will be less for subsequent ring growth.



Climate not only limits ring growth in year (t), but it influences ring growth in subsequent years (t+1 and t+k) where k can vary for different species in different sites. The growth in the prior year (t-1) can also have an affect on how much sugar is left for the next years growth.

What else have I learned from observing how the trees grow over a number of years? While I believe I understand a little bit about how tree-ring growth responds to its environment, I am convinced that a larger part of the total knowledge about tree growth is still shrouded in mystery, remaining largely unknown.

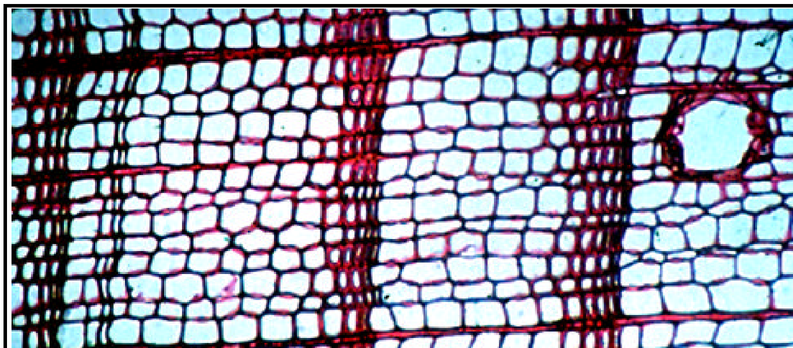
While they impact all of our lives in diverse ways, when I walk among these magnificent beings, I experience a oneness with them, a spiritual companionship. Some are solitary, perched on lonely dry outcrops with outstanding views over the landscape, which I can share. Others are more gregarious in dense cool forests where I can enjoy the shade and the fresh aroma of the decaying forest litter. If I take the time to walk or sit among them, contemplating my life and my genuine relationship to the earth and all life that dwells upon it, the mystery becomes a little more focused. I am at peace with myself and God of the universe in which I have been fortunate to live for a brief moment in time.

An ancient juniper (Juniperus osteosperma) with a magnificent outlook on life over northern Arizona.

The trees are living evidence that the “seasons” of life will change but each season offers unique opportunities to grow. Each season is important and provides a training ground for the next season that will inevitably follow. It is easy to mourn for what is past and gone, but it is also necessary and important to look forward to what the future can bring. We can work toward a bright or a dark future. We have free choice.

The mystery and unknown does not keep me from attempting to describe in these pages what little I do know of the tree response to its environment. I also enjoy trying to construct models of how the trees grow. The drawing on page 23 is a simple model expressing how the growth response works through time. It is even possible to express some of these relationships in very complex mathematical models to depict the linkages between the tree processes and ring growth. For example, to calculate when growth begins in the spring, an existing model for ponderosa pine examines day-time temperatures and starts cambial activity when the temperatures average 12.2 C $_0$ (54 F $_0$) for a period of 10 days. Many other values and equations are used to calculate other processes and changes. For the present, the mathematical modeling work is too complex to be described here. Every now and then I will slip in more complicated ideas which will be useful for understanding tree growth. After enough of these points are covered sufficiently, perhaps I can describe more detail about modeling how trees grow and produce the cells of the annual ring.

My greatest joy, love, respect and reverence for the trees and the many other plants and animals that make up the forest have grown over the more than 60 years that I have been living and observing these magnificent and complex beings, which play such an important role in our world. Perhaps now is the beginning of my autumn. Although I have less energy than when I was younger, I still can create a healthful productive environment for writing. I hope to do that, so I can share more of my joy, love and respect for trees along with a little bit of experience with trees, their rings and what they can tell us.



The widths, cell structure, density and chemical composition of wood in tree rings all tell marvelous tales that can help us understand, appreciate and better manage our lives. They can enable us to plan for a bright future that embraces joy with abundant opportunities within the limits of a healthy, diverse and balanced natural world.

Tree rings do and can tell marvelous tales that we can “hear” from no other beings on this earth. When we understand how the rings grow, we can observe the differences in rings and the structure of their cells from one year to the next and read the tales they tell. These tales can enhance the already rich history of our own past. If we truly understand and use this history wisely, with imagination, courage and a pinch of passion, I believe we can build a brighter future with greater abundance for all life on our planet including human kind. This would create a truly better life for you and me.

More information in books and on the World Wide Web:

Baillie, M. G. L. 1995. *A Slice Through Time: Dendrochronology and Precision Dating*. B. T. Batsford, London. 176 pp.

Fritts, H. C. 1976. *Tree Rings and Climate*. Academic Press, NY. Bound photocopies available from DendroPower Press, 5703 North Lady Lane, Tucson, AZ 85704-3905, USA.

Schweingruber, F. H. 1988. *Tree Rings: Basics and Applications of Dendrochronology.* D. Reidel Publishing, Dordrecht /Boston / Lancaster / Tokyo. 276 pp.

Schweingruber, F. H. 1996. *Tree Rings and Environment: Dendroecology*. Paul Haupt Publishers Bern, Stuttgart, Vienna. 609 pp.

Stahle, D. W. 1990. *The Tree-Ring Record of False Spring in the Southcentral USA*. Ph.D. dissertation, Arizona State University. 272 pp.

LaMarche, V. C. Jr and K. K. Hirschboeck. 1984. Frost rings in trees as records of major volcanic eruptions. *Nature* 307:121- 126.

The Ultimate Tree-Ring Web Page: http://web.utk.edu/~grissino/