Evolution of Plants from the Paleozoic to the Present

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Abstract

In an effort to present well-understood mechanisms of adaptation and selection in a simple format, we have developed an introductory laboratory script based on adaptive history and change in the plant kingdom. The exercise is designed as a "tree-walk through time," using trees and plants available on campus to illustrate adaptive traits of different plant groups developed during different points in geologic history. Beginning with discussions of the ancient spore-bearing plants and the gymnosperms, the fieldtrip continues through a total of 15 representative plants and their botanical stories, including: ferns, cycads, pine, ginkgo, hemlock, dawn redwood, magnolia, tulip tree, oak, elm, maple, apple, birch, bamboo, and orchids. Each of these is discussed in its evolutionary, morphologic, environmental and/or geologic context. The evolutionary pressures of hemlock

wooley adelgid and Dutch Elm Disease are also discussed. This laboratory script has been used with excellent success in General (non-majors) Biology at both Virginia Tech and at Roanoke College.

Introduction

In this laboratory exercise we focus on trees, looking at the changes in particular groups or lineages over time. Because plants are virtually non-motile, their adaptation strategies tend to be expressed in their form, rather than in active "behavior." Thus, the morphological differences between groups can be examined as potential reflections of changes in environmental conditions. An attribute of plants is that there are still many species representatives of the ancient lineages alive today. We recognize, and point out here, that it is indeed difficult to scientifically "prove" how or why any particular morphology or trait was introduced, adapted, became widespread, or was selected for or against. It is not the intent of this lab to do so, but rather to introduce the introductory student to the observation of the natural history, and to provoke him or her with specific possibilities as to how environmental events or changes may have provided evolutionary pressures. We recognize that some of the material within this lab is simplified somewhat for the sake of presentation to a lay audience. And we also recognize that the plants referred to in this lab are representative descendents of plants from other time periods, and not necessarily the same species as are found in the fossil record. Having stated these caveats, we will proceed.

The tour begins in the classroom, looking at plants from divisions of the most ancient plants, including ferns and cycads, with a description of each plant in its heyday. We then go outside and walk around campus describing the trees from the earliest to the most modern tree groups and their characteristics as they relate to the environment at the time of the emergence of that type of tree.

Background

Evolution is defined here as the process whereby populations of organisms undergo change in gene frequencies over extended periods of time. Natural selection is the mechanism by which populations of organisms undergo change. Natural selection is evoked by some aspect of the environment that puts pressure on a population of organisms. Organisms are successful if they can survive to reproduce. There are various environmental selection pressures, which either allow the organism to reproduce, or inhibit the reproduction of that organism.

These pressures select for traits already inherent in the organism's genetic structure. They are NOT acquired as a result of the pressure. The successful traits survive to reproduce more of the same kind, so the population will tend to have more of that trait in future generations of a specific population. A population is a group of individuals of a species living in the same area.

There are at least five mechanisms of natural evolution: mutation, virally- and/or bacterially-vectored DNA, transpollination, genetic drift, and natural selection -- which includes selection for, and selection against a trait. Eventually, significantly differing species or lineages may be produced.

Seeing Possible Evolutionary Trends in Plants Around us Today

Roughly, the great ages of plants can be broken into three periods. The Paleophytic, the Mesophytic, and the more modern Cenophytic (these correspond to the terms Paleozoic, Mesozoic, and Cenozoic when one is discussing fossil animals).

Station 1 - Ferns The Paleophytic plants include the spore-bearers. These represent the old coal swamp floras, these being "ferns" (including seed ferns), lycopods, and horsetails. These nonwoody plants, some of them 50-100 feet high, ruled the moist coastal swamplands some 250 million years ago. One of the trademarks of these ancient spore-bearers is their marked alternation of generations. Today the spore-producers aren't nearly so huge and impressive as they were in ages past. If you go to the tropics--or to the indoor mall, which may be closer--you may still see living tree ferns, which reach good, tree-sized proportions.

Next come the Mesophytic plants. About 150 million years ago, the world changed. Continents collided to form Pangea, an extremely large landmass or "super-continent." With the resulting large land area and uplift, climate changed, and the coal swamps began to dry up. In a stressed environment, plant and animal populations are vulnerable to natural selection pressures. That is, in times of change, a population or species can be selected along three paths. First, it may simply die out. Second, it may be selected for forms that can survive in refugia (these may be small and/or obscure forms). Or, third, the group may be selected for adaptive traits, which allow it to change with the environment, and to survive. Many coal plants indeed became extinct, while others became smaller and more obscure. Some lineages, however, adapted to dry conditions and a different life.

These groups re-invented themselves as the gymnosperms. (Notice that these forms were really "selected for" particular traits, and did not "decide" specifically to make particular changes by conscious choice). These can loosely be thought of as the original "plastic" plants; that is, they have tough waxy spiky stems, and slow metabolism.

Station 2 - Cycads The cycads (*Cycas* and *Encephalartos*) are really good extant examples representative of early gymnosperms. If you look closely at a cycad you will first notice the heavy trunk or bole; from this, the leathery leaf fronds extend. Modern cycads are tropical, being found both in temperate jungles and harsh desert-like environments. They have airborne pollen.

We know from studying coprolites (fossil dinosaur manure) that the cycads were also "dinosaur fodder." This is largely what grazers such as Triceratops ate. Cycads have root nodules with symbiotic nitrogen-fixing bacteria, much like the more modern legumes. Cycad saps are also usually very toxic with alkaloid poisons. Don't eat the cycads! Notice that the cycad has a large woody cone-like structure.

Station 3 - Pine The pine tree (*Pinus pungens, Pinus strobus, etc.*) is also an excellent representative of gymnosperm "plastic plants." Look at the small surface area of the pine needle. Observe the waxy surface of the needles. This decreases water loss in harsh and dry environments. They produce airborne pollen in vast quantities. (Ever park your car under a pine tree?) Notice the typical woody structure of the female cone, with the seeds borne naked between the bracts of the cone. The female cones usually take two years to mature, while the smaller, more numerous male cones are borne annually. These plants have no flowers. The sap of the pine tree is perhaps not as poisonous as that of the cycad, but it is still strong and contains resinous and volatile oils.

Station 4 – Ginkgo Next comes the Ginkgo (*Ginkgo biloba*). This is another gymnosperm, and is one of the original "living fossils." Ginkgo leaves and stems, as fossils, were long known to European botanists, but the plant was also known to be extinct. When the European botanists began to explore China in the 1600s, they found live ginkgo trees in the gardens of Buddhist temples! The Ginkgo was the Buddhist sacred tree in a small province of Chekiang in Eastern China. The large temple trees had long life-spans of many hundreds of years, and had apparently been kept and raised as sacred temple trees by the Buddhists, possibly for as long as 10 to 12 thousand years. As close as the Europeans could tell, there were NONE existing in the wild by the time of their discovery. The point has been debated that wild ginkgo trees may indeed have been known and described in the early scientific literature of China, but that neither the trees nor the literature were accessible to the Europeans. Be that as it may….The Europeans took Ginkgo back to Europe where they were studied and propagated. The male Ginkgo tree produces motile "sperm" like many of the old coal plants, and the female produces an "egg." Eggs of female trees contain huge amounts of butyric acid, which is why, at times in the city, the streets really reek of ginkgo (it smells of vomit).

Station 5 - Hemlock Now stop briefly at a Hemlock tree (*Tsuga canadensis*). Once again, this is a gymnosperm, and its leaf structure is needle-like. These have small individual needles and smaller cones, but are structurally similar to pine trees. Hemlocks grow well in cold and miserable conditions here in the Appalachians, such as those up around Mountain Lake. Presently, we are in the middle of a tragic, but still important botanical history. If you look at this or other hemlock trees on campus you will see they are covered with a white fuzzy material. This white material is an aphid-like insect pest called the Wooley Adelgid. The microscopic insects feed at the bases of the individual hemlock needles, weakening, and usually killing an adult tree within 3-4 years. The Adelgid is transferred from tree to tree by the wind, or on the feet and bodies of insects, birds and mammals.

Station 6 – Dawn Redwood Going a bit further, here we come to yet another conifer. This one is *Metasequoya glyptostroboides*--or the "dawn redwood." This is not exactly one of the West Coast "big trees"--it is far smaller, but similar, and related. Again, notice the needles and cones. This tree however is deciduous; it loses its needles over the winter. *Metasequoya* is another excellent example of a tree that was known only from fossils; that is, until a single tiny grove of them was discovered in 1944 in a small out-of-the-way canyon in the "Valley of the Tigers" in Szechwan, China. It also was known to be "extinct" to Western Science—except, it turns out, for these very few trees in one location. Seeds of the trees were sent to the United States just after World War II, and were propagated.

Station 7 – Southern Magnolia In the mid-Cretaceous period a new development—that of flowering plants, occurred. These were the forerunners of today's angiosperms. The Magnolias are one of these representative lineages, as are the water lilies. Our traditional southern magnolia, with its huge heavy waxy leaves, and its bracted flowers and cone-like seedpods, is yet another living fossil. The flower here is a true flower but it is very primitive in structure, more-or-less simply adding a set of large fleshy petals to the older cone structure. Look carefully at the cone and its bright red seeds. Once again, trees in this lineage were also "dinosaur fodder." The sap of the southern magnolia is again heavy and resinous, not particularly appetizing.

Station 8 – Tulip Tree Somewhat more "advanced" along this lineage is the Tulip-tree *Liriodendron tulipfera*. Here we see a much more modern-looking tree form, with almost modern-looking leaves. It is still a very large tree, and very long-lived. Notice the "cone" structure of the flower and seeds. When the tree blooms, the petals around the cone-like structure are quite similar to the Magnolia, although not nearly so showy. In the tulip tree, instead of seeds on individual bracts, the seeds themselves compose the structure. It is also worth mentioning that the leaves are still very waxy and heavy, although the tree does lose them each winter. The body chemistry of the tree, like many of the older plants we've seen, is rather toxic.

Station 9 – Bur Oak Here we will mark as the turning point from the Mesophytic trees to the current age of Cenophytic trees.

We continue the tour with a new development, the NUT. Here we will look at a bur oak tree (*Quercus macrocarpa*). Notice the similarities and differences with the plants that we have seen before. The new "strategy" here among some groups seems to be to package the offspring seeds with more energy and food--to abandon the cone altogether, and produce a "fruit"--in this case an acorn. (The acorn is not a nut in the true botanical sense). As the nut trees were arriving on the scene, the rise of the mammals was also occurring. If you look closely you may see squirrels in the branches above us. While the squirrels eat a certain number of the nuts and acorns they gather, at the same time they bury an even larger number, which they promptly forget. These well-planted seeds survive to germinate, producing more trees for squirrels.

Station 10 - American Elm If you had traveled in many American towns a hundred years ago, you would have found the streets lined with huge, high arching trees; these were the American Elms. The unique angle of the high arched branches always made a grove or line of Elm trees resemble a high Gothic cathedral. In the middle of the 20th Century, however, almost all of the great ancient elms of the United States were lost to a fungal disease called Dutch Elm Disease. This fungus invades the xylem and phloem of the tree, clogging them up, and cutting off the supply of sap to the leaves and branches. The disease first kills individual branches, and then the whole tree. The disease was accidentally brought into New England from Europe, and quickly spread southward, destroying the elms as it went. Only a few of our original Elms remain—this is one of them. The seed of the Elm is quite small, and winged –the seeds together look a bit like breakfast cereal flakes.

Station 11 - Maple Maple (*Acer*) trees have responded to more uncertain climatic conditions of more recent times. In general, one might loosely associate maple trees with, say, the age of sabre-tooth tigers. Maple seeds, like those of the Elm, have less energy invested in them than the nuts of oak trees. They are smaller winged structures. Notice too that the leaves of the maple are thinner and more expendable. They are brightly-colored in the fall, with many accessory pigments. Also worth noticing is that the sap of these newer trees is not nearly as toxic as the older style ones. We make maple syrup out of the sap of maple trees. Another apparent trend is toward shortened lifespan. When climatic conditions change a lot, it may be a good strategy for a tree to invest energy in reproduction, and not live for hundreds of years as an individual. The life span of a typical maple tree is about 75 to 100 years

Station 12 - Apple (Alternative-Bradford Pear) **Not** all newer tree lineages have given up the concept of a fruit or nut in favor of smaller, winged seeds. The alternative equivalent is a larger fleshy fruit, such as we see in fruit trees of the family Roscoe: apple (*Mauls domestics*), pear, (*Pyres communes*), sweet cherry (*Prunes avian*), plum (*Prunus subcordata*), peach (*Prunus persica*), etc. The reproductive advantage of a large, sweet fruit is obvious—a mammal eats the fruit. The seeds then pass unharmed through the digestive tract, and are planted and fertilized at the same time! In several of the fruit-producing trees, human domestication has served as an extremely strong selection pressure for the past 1 to 2 thousand years. There are presently about 600 named varieties of domesticated apple. These trees also are relatively short-lived: 50 to 75 years. Apples themselves are not a native American species. The folklore you have heard about "Johnny Appleseed" is true—John Chapman actually lived, born in 1774—and did actually introduce apple trees virtually single-handedly across much of America. He collected his apple seeds from only one or two sources, cider mills along the Allegheny River valley above Pittsburgh. Because of this, the genetic pool of the original Johnny Appleseed trees was very small.

Station 13 – European White Birch The rise of the birch (*Betula)* coincides with the time of the ice ages, and the 'ephemeral' and temporary tree forms that one might expect along a glacial margin. In these smallish trees you see exceedingly short lifespans—sometimes 10-30 years. In addition, notice the very small seeds, and recognize the tree's ability to colonize and reproduce quickly. The leaves are hardly waxy at all, but rather are described as "fuzzy." Besides the small size of the tree, the wood is also very soft and structurally quite weak; therefore, there is not much investment in large trunks or long-lasting wood. It is worth considering that it is through this most recent portion of time in which we also see the growth and development of other 'ephemeral' groups such as the grasses and composite flowers and weeds. These are all forms that live well in disturbed areas. They represent a particular set of niches.

Station 14 - Bamboo The development of the grasses (during the Oligocene, about 30 million years ago) along with the other monocots, represents the beginning of a new and very intriguing plant chapter. Within a very short time, the monocot grasses have already moved into tree-like niches, with the palm trees, and with bamboo. The grasses tend to be extremely aggressive and productive. As these forms spread out quickly over the earth, they changed the look of it greatly, producing prairies and savannah. It is important to recognize that with the new plants of that time, also came new mutualistic animals—the grazers, such as the horses and cows and bison and camels. Humans are also primarily grain-eaters. The grasses are extremely efficient primary producers, and there is no way at all that we could support a human population on this planet of 6 billion people without the grains as a food-source for us all.

Station 15 - Orchid The final relatively recent group that we will consider is the Orchid. The orchids are a very large plant group that we know to be evolving rapidly at the present. Orchids evolve into many niches, often with startling traits and apparent "strategies." Here we see that many orchids are epiphytic tree dwellers, like the bromeliads. We see them adapting their aerial roots to catch and hold water in jungle rainstorms. We see orchids enticing pollinating insects in ever-increasingly complex ways. Some orchid flowers are constructed to mimic female wasps—more startling yet, the flower smells of female wasp pheromones—inducing visiting males to attempt to mate!

Evolutionary Tree Walk Quiz

1. Two of the trees we saw during the Evolution walk were on the verge of extinction. Which two were these?
2. Name one change over time that trees have demonstrated in their leaf structure.
3. What is one way a tree may decrease water loss in harsh and dry environments?
4. One tree was hand-pollinated by Buddhist monks to insure its continued survival. Which tree was this?
5. Name one angiosperm tree that has a seedpod that closely resembles the pine cone.
6. What might be an advantage of a nut over a cone during the Cenozoic times during the rise of the mammals?
7. How many types of pinecones are from the white pine? What types are they?
8. Name a deciduous gymnosperm we saw during the Evolution Walk.
9. We see evolutionary trends in angiosperm trees over time. Identify two of the trends.
10. Cycads have defensive mechanisms against being eaten. Name one.

References (Reading List Only)

Andrews, Henry N. Jr. 1947. Ancient Plants—And the World They Lived In. Comstock Publishing Co., Inc., Ithaca, NY, 279 pages.

Beck, Charles B. 1976. Origin and Early Evolution of Angiosperms. Columbia University Press, New York, NY, 341 pages.

Forsline, P.L. 1995. Adding Diversity to the National Apple Germplasm Collection; Collecting Wild Apple in Kazakhstan. New York Fruit Quarterly 3:3-6.

Ibberson, J.E. *et.al.* 1968. Common Trees of Pennsylvania. Commonwealth of Pennsylvania, Department of Forests and Waters. Harrisburg, PA, n.p.

Leavitt, Robert Greenleaf. 1933. The Forest Trees of New England. The Arnold Arboretum of Harvard University, Jamaica Plain, MA, 179 pages.

Ley, Willy. 1951. Dragons in Amber: Further Adventures of a Romantic Naturalist. Viking Press, New York, NY, 328 pages.

Owen-Smith, Norman. 1989. Megafaunal Extinctions: The Conservation Message from 11,000 Years B.P. Conservation Biology, Vol. 3, No. 4: 405-408.