

## Chapter 2

### The Science and Ecology of the Coast Redwood

#### What's so special about coast redwoods?

The coast redwood, *Sequoia sempervirens*, is a very special tree, scientifically, commercially, and aesthetically.

Coast redwoods grow to the greatest height of any tree.\* Like most records, the record for the tallest tree changes as new trees are discovered and measured and former champions die or are damaged. In 1963, a survey team from National Geographic Society found a group of trees in the Redwood Creek area of Humboldt County that were believed to be the tallest trees in the world. The Tall Tree or Libby Redwood, as it is called, was measured at 367.8 feet. Since then it has lost several feet of height due to dieback of its tip, and sediments from flooding have also raised the surrounding forest floor. Steve Sillett, an associate professor at Humboldt State University, has since measured a redwood in Humboldt State Redwoods Park at 370.1 feet tall. In the fall of 2006, three redwoods in Redwood National Park were measured at over 371 feet tall, with the tallest, called the Hyperion Tree, at 378.1 feet (Geniella, 2006). According to the Save-the-Redwoods League, the Hyperion Tree has subsequently been re-measured and found to be 379.1 feet tall!

\*There have been claims of taller Douglas-fir trees and eucalyptus, but the coast redwoods reach the greatest verified height among trees living today.

Many studies have been done to try to determine how water can reach the top of a redwood tree that is over 300 feet tall. The process isn't thoroughly understood, but the processes of **cohesion**, **adhesion**, and **capillary action** seem to play an important part. Essentially, water molecules "stick" together, so that when a water molecule evaporates from a needle, through a process called **transpiration**, it "pulls" the next molecule upward. That molecule of water, in turn, pulls the next one and so forth. These processes don't completely explain how the water reaches the top of such a tall tree, though. It may be that water-conducting tissues of redwoods are more efficient than those of most trees. More research needs to be done to understand this basic yet complex issue.

**See the activity "Let's Stick Together" in section IV.**

#### Teaching Idea



*When in a grove of redwoods, ask the students to state some ideas about how the trees can get water up to the top leaves. Record their ideas and follow up when you return to the classroom with the activity "Let's Stick Together!" from Section IV.*

Coast redwoods reach great diameters. The giant Sequoias of the western Sierra reach a larger circumference, over 40 feet at the base and 25-30 feet near the base, but the coast redwoods can reach great size, too. Coast redwoods can reach diameters over 30 feet at the base and 12-18 feet near the base, although most are much smaller.



Figure 5



Figure 6

(Photos courtesy of The Clarke Museum)

## Teaching Idea



When measuring the size of trees, foresters generally measure the circumference at "breast height" (4.5 feet), and use that to calculate the diameter at breast height (**dbh**). (Actually, they use a special tape measure that does that calculation for them. See the activity "Making a Forester's Diameter Tape" in Section IV.) This is especially important in the case of the coast redwood because the base often flares out significantly, resulting in a trunk that may be quite a bit smaller when measured several feet above ground level. Using the diameter of the tree or log and its height or length, foresters estimate the volume of lumber that the tree or log can provide.

Since circumference equals pi times the diameter, the diameter equals circumference divided by pi.

$$C = \pi \times d \qquad d = C \div \pi$$

Work with students to practice converting circumferences of circles to diameters. You can also work on rounding off and approximating. For example, have the students calculate the difference between using 3.14 for pi and using 3.1 or 3 when calculating the diameter of a tree with a given circumference. Is the error greater if the circumference is greater?

e.g.: If the circumference is 10 feet, using 3.14 gives a diameter of about 3.18 feet, while using 3 for pi yields a diameter of about 3.33 feet, a difference of 0.15 ft.

If the circumference is 20 feet, using 3.14 gives a diameter of about 6.37 feet, while using 3 for pi yields a diameter of about 6.67 feet, a difference of 0.3 ft.

**See the activities "Making a Forester's Diameter Tape" and "Redwood Pi" in Section IV.**

Coast redwoods can have a huge volume of wood. According to Noss (p. 92), the largest giant Sequoia has a trunk wood volume of almost 1,500 cubic meters. The largest coast redwood has a volume of over 1,000 cubic meters. The next largest tree, a western red cedar, has a volume of barely 500 cubic meters. Studies indicate that a healthy stand of redwoods may have more **biomass** than any other **ecosystem** on earth! The greatest known biomass of standing vegetation on earth occurs in a redwood forest stand, where there may be over 1,400 metric tons of biomass per acre (Veirs, 1996).

A single tree in Humboldt County has an estimated volume of 361,336 board feet, which is enough to build 22 five room houses!

**See the activity "How Big?" in Section IV.**

Coast redwoods can grow rapidly.

While trees living in the shade grow relatively slowly, redwoods growing in optimal conditions can grow quite rapidly. A stand of vigorously growing redwoods can grow up to 2000 board feet per acre per year between the ages of 40 and 60, which is enough wood to build an average-sized house every five years. They are the fastest growing **softwood** species in the United States (California Redwood Association, 1990).

Since redwood trees can be re-grown in a relatively short time, they are considered a renewable resource. Unlike iron, concrete, or plastics, new redwood trees can be grown where the original forest stands have been removed, but it should be noted that a **second-growth** forest is not the same as an ancient forest.

Coast redwoods can live a very long time. The oldest trees are probably the bristlecone pine trees of the Sierra, which have been measured to be over 4,000 years old. The giant Sequoias can live to be 3,500 years old. (Some earlier measurements indicated up to 4,000 years, but more current research indicates a lower age limit for the giant Sequoia.) The oldest coast redwoods are about 2,200 years old (Schneider, 1988).

It is interesting to note that the redwoods with the largest diameters are not necessarily the oldest. The largest specimens are usually found in alluvial flats or flood plains of coastal rivers. The access to sunlight, water, and nutrients provided by periodic flooding in these areas provides optimal growth conditions. While these trees are adapted to withstand the flooding, they usually succumb within a thousand years or so. Some trees in more protected areas can grow older, but they generally don't grow as large.

Coast redwoods can sprout new trees from stumps or damaged trees. While many kinds of **hardwood** trees will produce sprouts from stumps or damaged trunks, few softwood trees (**conifers**) do so. Redwood stumps sprout so prolifically that early homesteaders had trouble keeping new trees from growing in cleared fields, and stump sprouting is a major source of "new" trees in logged stands. Since a stump sprout already has a built-in root system, stump sprouts grow much more rapidly than seedlings. A stump sprouted sapling may grow as much in one year as a seedling grows in seven years. Occasionally, a falling redwood branch will impale itself into the ground, sprout roots and branches, and form a new tree. Logs awaiting milling will often sprout new branches as they sit at the sawmill.

An interesting question arises from the coast redwood's tendency to sprout new trees from stumps, roots, or even branches. If a tree is cut or is otherwise injured, coast redwoods often sprout new trees from the old stump. Is that sprout a new tree, or is it still the original tree? If it is still the original tree, and the sprouted tree subsequently sprouts new sprouts, are they still the original tree? If redwoods do this for several generations, and if the sprouted trees are considered to still be the original tree, some trees may be several thousand years old even though they don't have the growth rings to show it! (Other trees, such as quaking aspen, also stump sprout readily.)

The species name for the coast redwood is *sempervirens*, which means “ever living.” The stump sprouting and longevity of the trees make this an apt species name!

Coast redwoods resist fire, insects, and disease. Redwood's resistance to fire is due in part to its thick, fire-resistant bark. The bark will burn if thoroughly dry, but it is very absorbent and holds moisture. Also, as compared to fir and pine, the wood and bark of coast redwoods contain relatively little flammable pitch.

Chemicals called **tannins** give redwood its distinctive color and also provide resistance to insects and fungus-caused diseases. (Apparently the insects don't like the taste of the tannins.) This resistance to rot earned redwood a well-deserved reputation as a wood that could be used for such things as fence posts, grape stakes, and railroad ties where the wood is in contact with the ground.

Tannins accumulate in the wood over time, and older trees generally have more tannins than younger trees. Due to the accumulated tannins, the **heartwood** of old redwoods is generally darker than that of young redwoods, and young growth redwood lumber, with less accumulation of tannins, is generally not as decay resistant as old-growth redwood lumber.

Lumber from coast redwoods is superior to other kinds in many respects. When different kinds of wood are compared for their commercial properties, redwood has earned the highest ratings in such things as durability, resistance to fire, glue-holding ability (important when joining small pieces to make larger boards), capacity to accept paint or stains, dimensional stability (not shrinking or expanding too much when dry or wet), and resistance to termites and rot. These properties make it especially useful for exterior applications such as decking, siding, and fences. Most redwood is relatively lightweight when dry (Simpson Timber Company, 2003). When combined with its beauty and ability to grow rapidly, these properties have earned redwood the reputation as a commercial "wonder wood" (Adams, 1969?). Redwood doesn't do as well as some other woods such as Douglas-fir in "compression" tests, though, so it generally isn't used for wall studs.

When considering redwood as lumber, it is important to distinguish between wood coming from slow growing ancient trees and wood coming from rapidly growing trees such as "young-growth" forests typically produce. The close grained, clear, dark red wood with large amounts of insect- and rot-resistant tannins generally comes (or came) from large old redwoods such as those logged prior to the 1970s. Very few of these "**old-growth**" trees remain available to loggers, so most redwood found in lumber yards comes from young-growth trees which have not had the time to deposit large amounts of tannins, and generally have more knots.

**See the activity "Fence Post Studies" in section IV.**

Coast redwoods are the state tree...actually a state tree. In 1931, the "California Redwood" was named the official state tree. However, the bill did not distinguish between the giant Sequoia and the coast redwood. In 1951, it was decided that the state tree designation would be shared by the two species.

## General Ecological Principles

### What is Ecology?

**Ecology** is the study of an environment, the organisms that live in the environment, and their interactions. Some people use the term "ecology" to mean conservation or environmental protection. In *Redwood Ed*, we will use the scientific meaning...the study of interactions and interconnectedness of organisms and their environment, including such factors as light, soil, water, and air.

### Teaching idea



*When introducing the term "ecology," it might be useful to discuss the word roots of the term. "Eco-" comes from the Greek term for home, and "-ology" means "the study of." So, ecology is, literally, the study of our home. Looking at the earth as our home can be very helpful when discussing environmental concerns. Introducing the word roots can also be helpful when discussing other "ologies" such as biology, geology, zoology, etc. It is also good to encourage the proper and specific use of terms. People sometimes say they're "protecting the ecology." Do they really mean that they're protecting the study of the environment? Or do they mean that they're protecting the environment?*

The physical parts of the environment are called the **abiotic factors**. These include such things as temperature, light, humidity, soil nutrients, and substrate type. **Biotic factors** are those that result from living things and their interactions with each other. Some specific abiotic and biotic factors of the coast redwood forests will be discussed in the later part of this chapter, but let us first review some basic ecological principles and vocabulary.

### Teaching Idea



*An important part of ecological studies deals with how organisms meet their needs for energy, materials, water, etc. Have students list their own needs and how they are met. Discuss true "needs," which are few, as distinguished from "wants," which are usually many. Also discuss the prices that we pay, not just in terms of money, for satisfying our needs and wants.*

## Cycles

There are many **cycles** in nature, and they are important to all organisms in all places, including people. Described below are some simplified versions of some of the important natural cycles.

Unlike energy, matter (chemical substances...the "stuff" of which everything is made) remains in the environment. It is neither created nor destroyed except in very unusual (on Earth) circumstances. This "**Law of Conservation of Matter**" is a basic law of nature, and warrants discussion with the students. It gives us the basis for the need to recycle, explains why we can't just create new stuff from nothing, and also explains why pollutants don't just "go away."

One place where the Law of Conservation of Matter plays a role in the redwood forest is in the **decomposition** of dead material. Bacteria, fungi, and other organisms "recycle" dead limbs, leaves, and organisms through the process of decomposition. Branches, tree tops, and other woody debris from logging are also decomposed or burned. Burning simply changes the wood into smoke and ash, recycling the materials in another way.

### Teaching Idea



*One way to help students to remember the main organisms involved with decomposition is "F.B.I."...fungi, bacteria, and invertebrates.*

### Teaching Idea



*Ask a student to throw away a piece of trash (or to tell how he or she would throw away a piece of trash). The student will doubtless throw it into the trash can. Point out that the trash can isn't really "away." It is just a different place, and the custodian will put it into a dumpster after school. The dumpster, of course, isn't really away either. The contents of the dumpster will go into a garbage truck, which will take it to a landfill – it's still not really gone! Also point out that where there is now a landfill, there was once a field, forest, or some other natural environment. There is no "away!" Whether we like it or not, the matter that we have on Earth, including our pollution, will stay with us, and we can't create more matter. We can, however, change it, from useful matter to trash, or, sometimes, from trash to useful matter.*

## The Water Cycle

Energy from the sun causes water from the Earth's surface to evaporate and enter the air as water vapor. As water vapor cools, it forms clouds. Further cooling results in precipitation as rain, snow, or hail. Fog is formed when moist air near the ground cools, and "fog drip" is a very important source of water for the coast redwoods.

### Teaching Idea



*Have students tell what happens when they exhale their warm, moist breath on a cold day, either into the air or onto a mirror or window. This condensed water is similar to a cloud of fog.*

Depending on where precipitation falls, it may re-enter surface water systems such as lakes, streams, and oceans, or it may fall onto the ground. Surface water may flow downhill as runoff in a stream, soak into the ground, or evaporate, starting the cycle again. A healthy forest has a rich soil with an abundance of organic material that absorbs and holds a lot of moisture.

**See the activity "Water Cycle in a Jar (or Two)" and "Have a Foggy Idea" in Section IV.**

If water enters the ground, it may be absorbed by plants, join the underground water system (**aquifer**), or it may re-emerge as a spring.

Plants move water through their **vascular systems**, consisting primarily of xylem and phloem cells produced by the **cambium** layer. The **xylem** moves water and minerals upward from the roots, while the **phloem** brings carbohydrates produced by the leaves to the other cells throughout the plant.

Some of the water taken up by the roots is used in **photosynthesis** and some is expelled through their leaves by a process called transpiration. Transpiration is water loss through the leaves of a plant, and it plays a very important role in the redwood forest. Warm, dry air increases water loss through transpiration. Fog decreases transpiration and is a major factor in determining where coast redwoods can (or cannot) grow.



**Teaching Idea**



*When discussing transpiration, compare it to perspiration.*

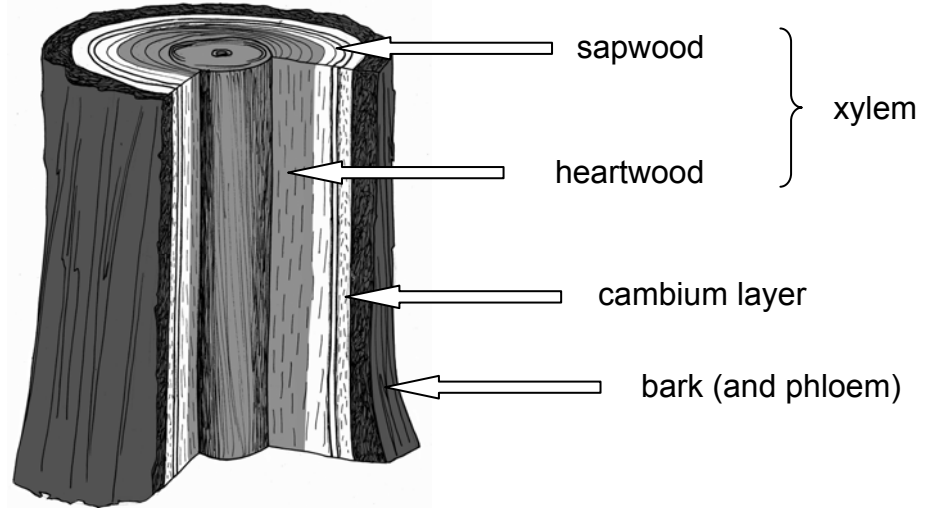


Figure 7

The living, active sapwood and the inactive heartwood make up the xylem, while the phloem is just beneath the bark, and is sometimes considered to be part of the bark.

***See the activity "Transpiration" in Section IV.***

Students are often interested to find out that every bit of water that they drink has been used by thousands of other organisms during its existence on Earth. The water that they drink today, for example, was probably once part of a dinosaur. The same holds true for the other substances in our bodies.

Water and the water cycle are extremely important to the coast redwoods and are further discussed below.

The Oxygen/Carbon Dioxide Cycle, and Photosynthesis

Oxygen enters the air primarily through the process of photosynthesis. In photosynthesis, plants use carbon dioxide and water to produce complex molecules of sugars. In the process, oxygen is released into the environment as a byproduct. On land, this oxygen "waste product" enters the air. In aquatic environments it may be dissolved into the water as it is released by plants or it may be released as tiny bubbles.

## Teaching Idea



*Place a sprig of a leafy plant, or an aquatic plant such as Elodea from an aquarium/fish supply store, in some water. Have students closely observe the small bubbles that form on the leaves. Then place the plant (still in the water) in the sun or under a bright light. Look for more bubbles of oxygen as the plant's photosynthesis increases. (Because gases dissolve more readily in cool water, some of the bubbles will be due to air coming out of the solution. This property of cool water to hold more dissolved air/oxygen is important to fish such as salmon and trout. They require cool water. Removal of shade cover over streams can reduce their ability to support trout or salmon populations. See the activity "Fantastic Photosynthesis" in Section IV.)*

Plants and other organisms use the sugars produced in photosynthesis as an energy source through the process of **respiration**. Respiration is a chemical process in which cells use oxygen and food such as sugars to release energy from the food, producing carbon dioxide and water in the process. (Students often confuse respiration, which is a chemical process, with breathing, which is the physical act of taking air in (inhaling) and exhaling waste from the lungs.)

As cells use oxygen in respiration, they produce **carbon dioxide** (CO<sub>2</sub>). Carbon dioxide is a waste product which must be expelled into the environment. During the daytime, carbon dioxide is removed from the environment by plants and some one-celled organisms in the process of photosynthesis, for which carbon dioxide is a raw material.

Forests play a very important role in the production of the oxygen on which we all depend. When trees (or other plants) are replaced by buildings or pavement, less oxygen is produced. A vigorously growing forest produces a lot of oxygen. Not only does photosynthesis produce oxygen, but it also takes carbon dioxide out of the air. Carbon dioxide is a major **greenhouse gas** that is a significant factor in **global warming**, or the **greenhouse effect**. Forests, therefore, not only replenish oxygen, but they also help remove excess carbon dioxide.

**See the activity "Global Warming" in Section IV.**

### The Nitrogen Cycle:

The element nitrogen makes up about 78% of the air. Nitrogen is an important raw material for many chemicals that organisms need to produce, including amino acids, which are building blocks for proteins, and nucleic acids, which form DNA. Most organisms, however, cannot use the nitrogen found in the air.

Some organisms, especially certain bacteria and some lichens, are able to use atmospheric nitrogen to form simple compounds such as nitrates. Plants, in turn, use the nitrates to form various more complex nitrogen-containing compounds. Animals, including people, get nitrogen from their foods.

Nitrogen compounds form an important part of animals' waste products. They provide fertilizer that is used by plants both on land and in the water. Nitrogen is also important because it is a necessary component of proteins, which are such an essential group of chemicals that they are sometimes referred to as the building blocks of life.

When organisms die, the nitrogenous compounds, as well as the other chemicals found in their bodies, are returned to the environment through the process of decomposition. Decomposition is accomplished through the action of various bacteria, fungi, and insects.

### Teaching Idea



*It is interesting to discuss what would happen if we didn't have bacteria and fungi to decompose dead organisms. Students will quickly understand that un-decomposed bodies would accumulate. More importantly, perhaps, chemicals needed by living things would be tied up in the un-decomposed bodies, depriving living organisms of the nutrients that they need.*

**See the activity "Duff Dwellers" in Section IV.**

### Energy

Most of the Earth's energy comes from the sun. Some of the sun's energy is reflected back into space by the atmosphere even before it reaches the Earth's surface. Other solar energy is absorbed by the atmosphere, oceans, and land, and is re-radiated into space as heat.

Of the energy that does reach the Earth's surface, some is reflected, some is absorbed as heat energy, and some is used by plants in the process of photosynthesis. Most of the energy that is absorbed is radiated back out to space at night. The energy stored in chemicals by photosynthesis is returned to the environment when the organisms use the sugars produced by photosynthesis in the process of respiration.

As a result of all of these processes, energy is said to "flow through" the environment, constantly coming to Earth and being re-radiated back out into space. This is in contrast to matter, which is constantly recycled on earth through natural processes. The vast majority of organisms on Earth depend on the sun for a constant supply of energy.

An important aspect of energy in an ecosystem is the temperature range produced by sunlight. The coast redwood has a fairly narrow range of temperature tolerances. Unlike the giant Sequoias and dawn redwoods, the coast redwoods do not do well where the ground freezes in the winter. While the presence of fog, especially in the summer, is a major reason that the coast redwoods live near the coast, the temperature moderating influence of the Pacific Ocean is another.

## Niches and Trophic Levels

Human communities have people who fill various roles, such as growing food, producing various products, cleaning up the waste, and providing a variety of other services. Natural communities also have a variety of organisms that fulfill a variety of roles. The roles or jobs of organisms are called their **niches**. A redwood tree, for example provides food for some organisms. It also provides shade. Some animals, and even plants, live in redwood trees. All such roles combine to describe an organism's niche. One important part of an organism's role is its **trophic level**, or the place it has in a **food chain**.

The basic group of organisms on which all others depend is the **producers**. It is the producers that use the process of photosynthesis to produce complex chemicals upon which life depends. The most obvious producers in the redwood forest are the trees, but others, such as the ferns, mosses, and flowering plants, are also important.

Organisms that don't photosynthesize, such as animals, are called **consumers** because they obtain their energy from the food that they eat or consume. Consumers are often further divided into three or four groups:

**Herbivores** mostly eat plants. Examples include deer, squirrels, and hummingbirds.

**Carnivores** mostly feed on animals. Frogs, owls, and ticks are carnivores.

**Omnivores** eat both plants and animals. The raccoon is an example. As a species, humans are also considered to be omnivores.

**Scavengers (detritivores)** feed on dead animals or plants. Examples include turkey vultures and California condors.

Another important group of consumers is the **decomposers**. These organisms, mostly bacteria and fungi, consume dead organic matter and return the nutrients to the soil where the nutrients can then be used by plants again.

It is important to remind students that all consumers, including people, depend on the plants (producers) that form the basis of the food chain. (See below for a discussion of food chains and **food webs**.)

## Teaching Idea



*Have students compare their human community to a natural community such as a redwood forest. Compare the niches of organisms to the roles that people play in their community.*

## Food Chains and Food Webs

A "food chain" is a concept that ecologists find useful when studying ecosystems such as the redwood forest. Basically, a food chain is intended to show which organisms feed on which other organisms. For example, an insect might feed on a fern in the forest. A frog might eat the insect, and the frog might be eaten by a garter snake. The garter snake might, in turn, be eaten by a hawk. When the hawk dies, its body would be consumed by bacteria and fungi as well as a variety of insects and worms. Each of these steps is considered to be a trophic level.

Food chains are useful because they provide a simple illustration of the relationships between various organisms. However, food chains are almost always oversimplifications. The fern might have been fed upon by other types of insects, or deer, or other animals. The frog would eat a variety of insects, and the garter snake would eat other organisms, too. Although they are oversimplified, food chains can be useful in studying organisms.

A more realistic, but more complex, concept is that of the "food web." A food web shows that most organisms eat, and are eaten by, a variety of organisms.

When people discuss or teach about food chains and food webs, they often don't emphasize the critical role of the decomposers. Without the decomposers, the raw materials needed by the producers would soon be locked up, or sequestered, in the bodies of dead organisms.

While not technically part of food chains and food webs, the physical parts of the environment, such as water, sunlight, and minerals, are also important in food chains and food webs.

The next page shows examples of food chains and a food web such as might be found in a redwood forest.

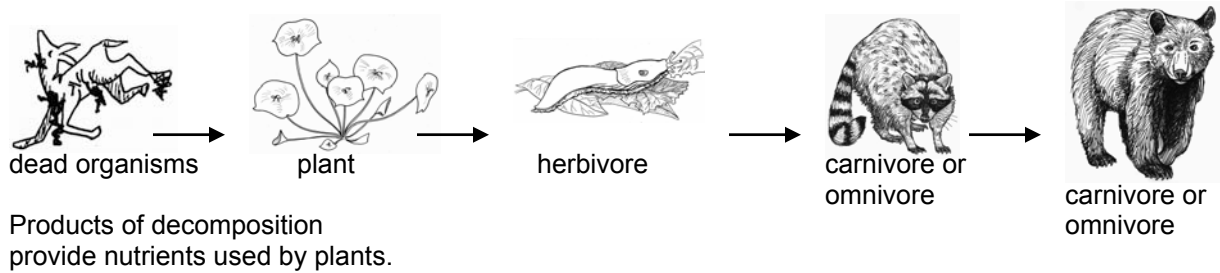
### **Teaching Idea**



*Use a transparency of the Food Chain/Food Web diagram when teaching about those concepts.*

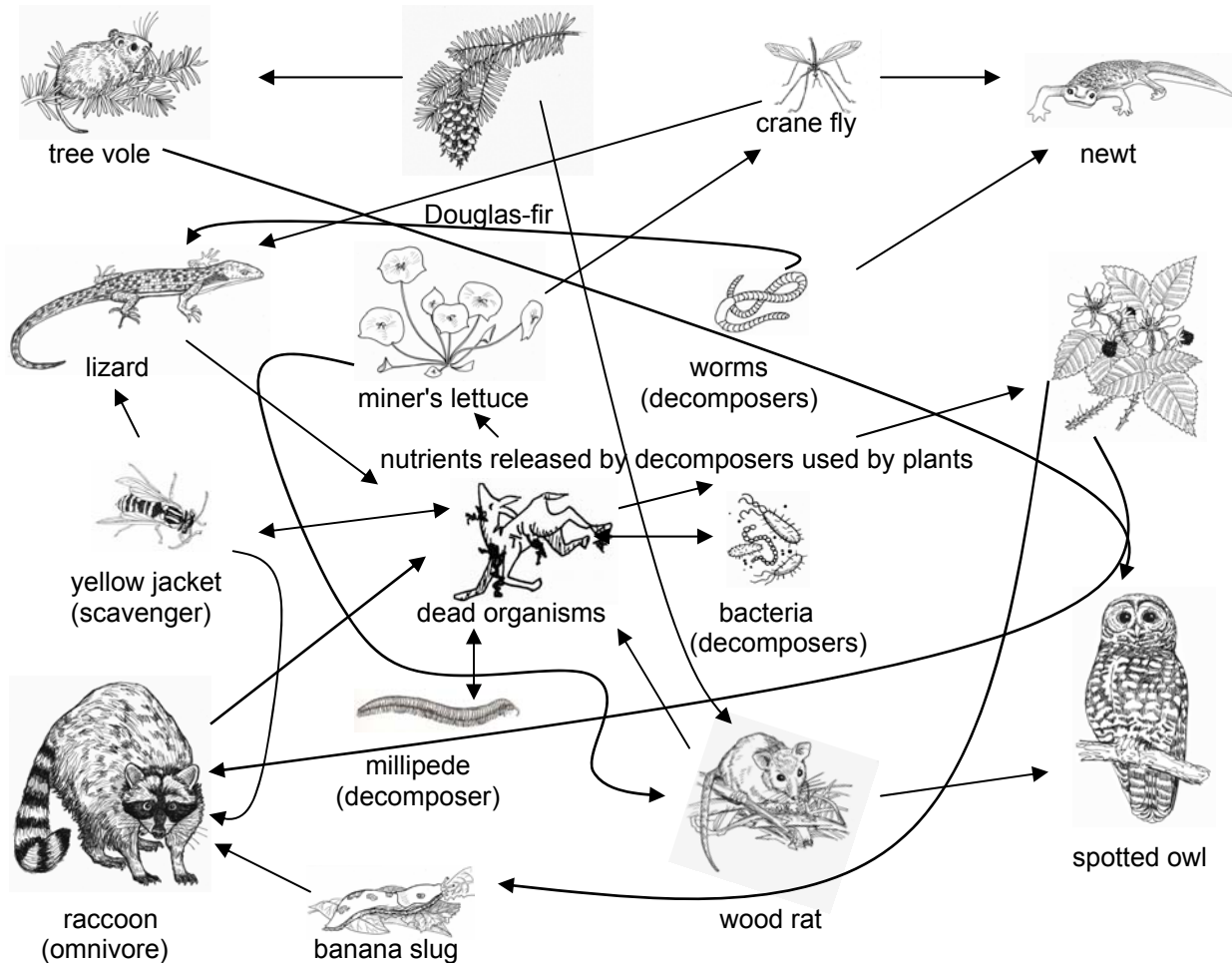
**Figure 8. A Redwood Forest Food Chain**

An arrow indicates that an organism is eaten by another.  
 For example, grass  $\longrightarrow$  deer  
 (is eaten by)



**Figure 9. A Simplified Redwood Forest Food Web**

Remember that the organisms depend on light (energy) from the sun, minerals and water. Even in this simplified food web, not all organisms or connections are drawn.



**See the activities "We're All in This Together" and "Who's for dinner?" in Section IV.**

### Populations

In the science of ecology, a group of individual organisms of the same species living in a defined area is considered to be a **population**. When an ecologist discusses a population, he or she will identify both the organism and the place. One might study the population of banana slugs on a fallen redwood log, deer in and around a meadow, or coast redwoods in a **watershed**.

The number of individuals in a population is limited by one or more factors in the environment. Depending on the organism, the factor might be available soil nutrients, water, sunlight, food, temperature, predators, or any of a number of other factors. Whatever limits a population is called the **limiting factor**. Thus, sunlight reaching the forest floor might be the limiting factor for low-growing plants, while moisture available in the summer might be a limiting factor for coast redwood trees. Available nesting places might be a limiting factor for birds such as the marbled murrelet. Suitable food or shelter might be a limiting factor for deer or the northern spotted owl.

The number of a type of organism that can thrive in a habitat is determined by one or more limiting factors. **Carrying capacity** refers to how many of a particular organism can live in a place over a long period of time without causing damage to the environment. One could place several deer in a small meadow, but they may not do well if there were too many, i.e., if the number exceeded the carrying capacity of the meadow. The carrying capacity for deer in a meadow is much lower than the same meadow's carrying capacity for mice or grasshoppers. If there are too many of an organism for the environment to sustain, the organisms are said to have exceeded the carrying capacity of that place.

Many students have heard of **overpopulation**. To an ecologist, "overpopulation" means exceeding the carrying capacity of a place, or exceeding the number of individuals that a place can support without harm to the environment. With regards to human population, one must consider not only how many people a place (a house, a town, a state, a continent, or the Earth) can support, but also the quality of life for the people (or other organisms). Of course, the Earth can support many more people living at a subsistence level than it can support at the level of resource use that we have in the United States. Even within the United States, some people use many more resources than others. It might be useful to discuss the quality of life vs. quantity and whether we should be willing to consume less so that others can have enough to survive.

A discussion of carrying capacity can help students understand the importance of trying to minimize their negative impact on natural environments. It can also help them to understand that they can have positive impacts.

**Teaching Idea**

*Discuss "wants" vs. "needs." Many things that most of us consider almost necessities (telephones, cars, televisions, soda pop, meat, etc.) would be considered luxuries by much of the world's population. Discuss the idea of "living simply so that others may simply live."*

**The Pyramid of Numbers or Pyramid of Biomass**

As one goes "up" a food chain, there is a decrease in both numbers and the total mass of the organisms (biomass). This is because organisms are not 100% efficient in converting food to body mass. Some of the food is converted to body mass, but much of it is lost as waste. A single grasshopper, mouse, deer, bear, or human will eat many times its weight in its lifetime.

**Teaching Idea**

*Discuss with the students what would happen if this inefficiency were not true. Ask a student to estimate how much he or she eats in a day. If they were 100 percent efficient, they would gain that amount of weight each day! Have the students calculate (and, perhaps, graph) how much weight they would gain in a week if their body added all of their food to itself. Point out that eventually all potential food matter would be "tied up" in living organisms.*

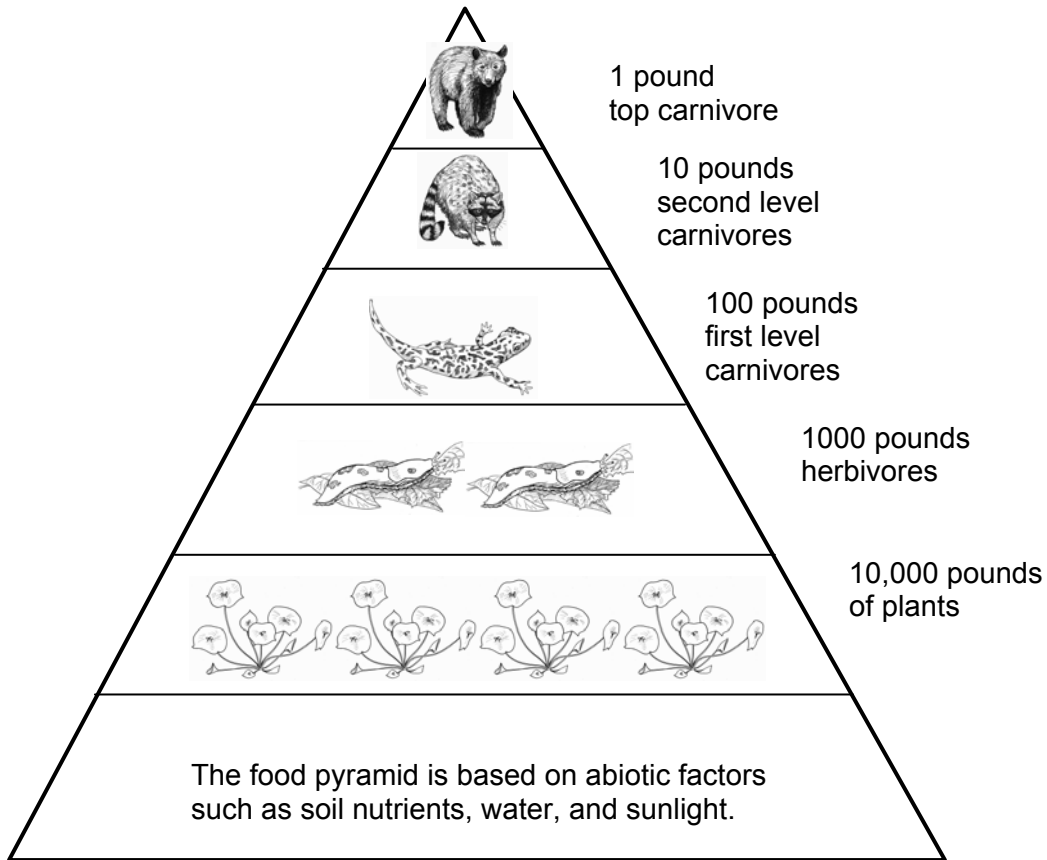
In reality, of course, most of the food that we eat is not added to our bodies, even though it may seem like it as we approach middle age! Most of the food that we take in is expelled from our bodies as solid waste (feces), liquid waste (urine and perspiration), or gaseous waste (CO<sub>2</sub> and water vapor in our breath). While the efficiency of conversion varies among organisms, an often-used approximation is 10%. Using that estimate we can create a hypothetical **pyramid of numbers** or biomass like the one below.

An important consequence of this inefficiency is that more steps in a food chain result in fewer top consumers (such as people). A given amount of land can support more people if they eat plants such as corn, wheat, or rice than if the same amount of land is used to raise cattle for people to eat. Basically, the Earth can support more vegetarians than carnivores. For example, a field can support more mice or grasshoppers than lizards or foxes.

**See the activity "The Higher the Fewer" in Section IV.**



Figure 10. **A Redwood Forest Food Pyramid**



### Habitat, Community, and Ecosystem

A **habitat** is a place where an organism lives. A stand of redwoods is a habitat, as is a clearing in the forest or a decomposing log. The redwood forest is not a homogeneous environment. There are various **microhabitats** such as the shaded forest floor, rotting logs, streamside (**riparian**), sunny openings, dead trees (**snags**), and others. Studies of redwood soil organisms reveal some of the highest known diversities of soil organisms of any type of ecosystem (*Redwood, 1969?*). Even a redwood tree itself has microhabitats ranging from the bark at the base of the tree, to the crotches of branches, to the forest **canopy**. Each microhabitat will have its own set of organisms filling the various niches.

**See the activity "Microhabitats" in Section IV.**

The forest itself can be viewed as having different vertical layers. The soil and the organisms that live in it provide the foundation on which the forest grows. On top of the soil is the **humus**, where leaves and other organic materials are decomposing. The top

part of the humus is the **duff**, consisting of more recently fallen leaves and twigs that have begun to decompose but are still recognizable as leaves. On top of the duff is the recently fallen **litter**.

Beneath the litter, duff, and humus is, of course, the soil. The nature of the soil is an important factor for all plants, including the coast redwoods. One indication of the importance of soil is the growth rates of redwoods growing in alluvial flats as compared to those growing in different soil types "upslope." In conjunction with the greater availability of water, the deeper, richer soils of the alluvial floodplains result in growth rates as much as 20 times that of the trees growing in the thinner, drier soils on some hillsides.

Growing near the ground are the ground cover plants. Shrubs are larger. Small trees form the **understory**. The canopy consists of the top branches of the taller trees.

The lower branches of a single tree or group of trees will sometimes hang down nearly to the ground, creating sort of a tent-like effect around the trunk(s). This "tent" may reduce the light and water so much that no green plants can grow underneath it. While fog drip and water from light rains may be reduced, the tent-like enclosure may actually have fairly high humidity due to transpiration. Such redwood tents are another type of microhabitat.

Forests can also be subdivided horizontally or laterally. Some organisms do best in the interior core of the forest, while others need to be near forest openings. The edge of the forest, between forest and grassland, or between redwood forest and hardwood forest, provides a greater diversity of microhabitats and, therefore, has a greater diversity of organisms. The same is true for the edge of a stream, lake, or rocky outcropping.

In an old-growth forest, there are normally gaps in the canopy due to **treefall**. Treefall can be caused by many things such as wind, a landslide above a tree, slumping of soil down slope, root rot, or erosion of the bank of a stream. These gaps provide microhabitats that allow a greater diversity of both plants and animals than one would find in an even-aged forest. Similarly, streams not only provide habitat for the aquatic and riparian organisms, but also provide access for sunlight into the nearby forest. If timber lands are managed to maintain a diversity of microhabitats, they can maintain some of the species diversity found in a natural forest. Studies have shown that pure stands of redwoods, whether in a naturally "pure" redwood forest or an area managed so that redwoods predominate, have less diversity and abundance of wildlife than stands that include a variety of types of trees (Diller, 1996).

**See the activities "Creek Studies," "Duff Dwellers," and "Microhiking" in Section IV.**

Each type of habitat is defined by a set of abiotic (non-living) and biotic (living) factors.

All of the organisms that live together in a habitat can be referred to as a **community**. A community is a group of interacting populations in a given geographic area. Just as our human communities have people that do different jobs, natural communities include organisms that make their living in different ways and depend on each other. A redwood community would include the redwood trees and the various other plants, animals, fungi, lichens, and bacteria that live with them. Each member of the community has a particular role or niche. Any natural community will have a diversity of organisms, *i.e.*, it will have **biodiversity**. A community with the organisms that naturally occur there is said to have **biological integrity**, *i.e.*, it is a "natural" community.

Another thing to consider regarding redwood forest communities and habitats is the spatial arrangement. One factor is the size of the "patch" of habitat. Some species will do fine if they have some logs under which to live. Others, however, require large areas. Ten 1-acre stands or patches may not support any of a particular species of bird, while one ten-acre stand may support many. Fragmentation of habitat is an important concern as forest land is developed for other uses such as houses, shopping centers, and roads.

Three types of redwood forest communities are often described. The **alluvial-flat** forest type exists along the rivers and creeks where a deep soil has been built up by periodic flooding. The temperatures are mild, summer fog persists, the soils are rich, deep, and well-drained, and moisture is plentiful. It is in the alluvial-flat redwood **stands** that the largest and most magnificent trees are usually found. Alluvial-flat stands may be almost pure redwoods, which form a dense shade-producing **overstory** or canopy, or they may include a variety of shade-tolerant species (Barbour *et al.*, 2001).

Most of the parks with which people are familiar were formed around alluvial flat groves. Since those groves contain most of the superlative trees, it was those groves that were first protected. Trees in the lowlands are typically much larger than those growing on the slopes and uplands. Alluvial flat groves, however, make up only a small fraction of the total redwood forests. The vast majority of the redwoods are found on the hillsides above the flats.

Away from the stream bottomland, redwoods often grow mixed with Douglas-fir trees. North-facing slopes may have more available moisture and may retain it longer than the south-facing slopes, which are typically shallower and retain less moisture. Tanoak and madrone may form understories, especially where the slope is more exposed. Since these upland stands of trees don't have the optimal growth conditions of the alluvial flats, the trees are generally smaller. There are exceptions, though, as the tallest known tree, the Hyperion Tree in Redwood National Park, is "upslope." These slope forest stands are, however, important in the protection of the downhill and downstream groves and watersheds.

At higher elevations, above 1000 feet, the slopes are often even steeper and the soils shallower, so even less soil is retained. In the northern part of the redwood region, redwood may dominate the overstory, but Douglas-fir or other conifers may grow with it,

forming a mixed evergreen forest type. Tanoak, madrone, huckleberry, and rhododendrons may form a dense understory and shrub layer. In the southern region, a **subcanopy** layer is often formed by the tanoak.

When we combine the community of organisms with the habitat in which they live, we have an **ecosystem**. Within the ecosystem, the organisms interact with each other and with their physical environment. A community can be large, like a redwood forest covering hundreds of acres and including many ridges and valleys, or smaller, like a particular stand of redwoods on a hillside or on an alluvial flat along a river, or even very small, such as the community of organisms living in and on a fallen log, or in the upper branches of a redwood tree.

Communities are not static; they continually change over time. The sequence of change from one community to another is sometimes called **succession**. The idea of succession involves a series of progressive changes in the species structure of the community. Many textbooks describe succession as a gradual and continuous replacement of one group of plants and animals with another. It is, however, rarely as simple and linear as that. Changes in the physical environment tend to favor different species, so different species dominate at different times. Species from previous or later successional stages will usually be present at several stages.

**See the activity "The Only Constant is Change: Succession in Action" in Section IV.**

Succession on newly formed land (primary succession), such as a lava flow or bare rock, might proceed through successional stages like this: bare rock...lichens on the rock breaking it down and trapping nutrients...mosses or small grasses growing among the lichens...small herbaceous plants growing in the accumulating soil...small grasses...bushes and shrubs...shade intolerant trees...shade tolerant trees...forest.

A common textbook example of succession occurs as a lake fills with sediments and becomes first a shallow pond and then a marshy area. As sediments continue to accumulate, the marsh may become a grassy field. Bushes and shrubs may invade the field, eventually being replaced by forest trees.

In the redwood forest, anything that creates bare soil can start a new successional process. Bare soil is commonly produced by landslides, falling trees, silt from floods, fires, clearing of land for homes or roads, or logging. The first plants that grow on the bare soil are called the **pioneer species**, and in the redwood area may include many other species, including grasses, blackberries, poison oak, coyote brush, or others, including **exotic** (non-native) species. Redwood seedlings or sprouts may be among the first plants to begin growing. In the redwoods, succession isn't so much a sequence of different plants as a change in which plants dominate.

The series of communities in a successional sequence is called a **serie**, and each of the temporary communities is called a seral stage. Eventually, succession may slow down

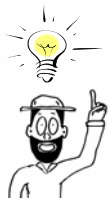
and a more or less steady state may be achieved. The "final" community is stable, tolerant of the environmental conditions that it imposes upon itself. This "final" stage has been called the **climax community**, but it is rarely, if ever, truly a final stage. While the late stages of succession are relatively stable and may last for a long time (hundreds or even thousands of years), they are not permanent. Nutrients may be tied up in vegetation, or fire, flood, landslide, or other event may set succession back. A more modern concept is that of a community reaching a state of dynamic equilibrium in which individual plants and animals are constantly dying and being replaced, resulting in a constantly changing community.

The redwood community is now considered to be a "late seral stage," but some ecologists feel that it may not be the climax community for the area. Unless something disrupts succession, the redwood forest may be replaced by a variety of other forest types including hardwoods, western hemlock, Douglas-fir, and other species. Some believe that we owe the existence of the coast redwood forests to periodic fires and floods that kill these other species. Others maintain that, since fire and flood are natural occurrences in the redwood region, redwoods should be considered the climax community type.

A 1969 study done on the Redwood National Park indicated that, if fire is kept out of the park and other methods of removing competing species aren't introduced, succession would probably result in change in the constitution of the forest, especially in the alluvial flats. It suggested that over the next 500 years, many redwoods would be replaced by hardwoods, Douglas-fir, and other species, and that the redwoods might disappear from Redwood National Park in 2000 years (Lowell, 1990).

In some areas, old-growth forests of even-aged trees suggest that natural phenomena such as fires and landslides cleared swaths of the natural forest much like **clear-cut** logging does. Clear-cutting has been compared to natural processes such as fires, landslides, and treefall, but natural disturbances rarely occur over areas as large as clear-cut areas, and the type, scale, and severity of the disturbance is usually different.

### Teaching idea



*Have students compare and contrast clear-cutting with fire with regards to their effect on the forest. How are they similar and how are they different? What happens to the materials in the tree when it is cut? When it is burned? What is the impact on other plants and animals? On the water and soil? How long does it take for the forest to recover?*

### People

The role of people in the redwood region is discussed in Section II, with emphasis on the timber industry. Conservation and environmental concerns are discussed in Chapter

3 of this section. Today, all but about 5% of the original coast redwood forests have been logged. Most of that 5% is in parks and reserves. Almost all logging by timber companies is done on privately-owned land that has already been logged once, or even twice, producing **second-growth** and **third-growth** redwood.

Not only has the timber industry shifted from cutting **old-growth** trees, but its methods have changed. When timber land was cheap, regulations essentially non-existent, and the redwood forests seemed infinite, an exploitative attitude of "cut out and get out" prevailed in the redwood timber industry. Today, land is relatively expensive, regulations abound, and timber companies generally manage their holdings as a long-term investment.

As California's population has increased, more people want to move into the redwood region, especially in the southern and central parts where there is less rain and fog. In those areas, an important threat to the redwood forests is from fragmentation as people purchase small parcels on which to build homes. Of course, to build homes, people cut trees for the building site, roads, and to open up the area so that they can have sun for their swimming pool, deck, and lawn. This fragmentation has a great impact on the redwood forest wildlife.

In the northern redwood region, there has been less of a population boom, but towns and cities have grown, and building has had an impact on some redwood stands. A major impact in Humboldt and Del Norte counties, where the timber industry was (and still is) most important, has been a shift from the dominance of the timber industry to a more diversified economy. This shift has been accelerated by the increase in redwood acreage protected in parks, by some population influx, as well as by mechanization, regulations, economic, attitudinal, and other changes within the timber industry.

Controversy still exists in the redwood region, though, as people seek to preserve the remaining old-growth trees, streams, and wildlife in the redwood forests and stands, even if they are owned by timber companies. Timber companies seek ways to remain profitable while managing their lands for the long term and complying with regulations.

While Section II deals with the human history of the redwoods, it might be useful to discuss here some terminology as it relates to the ongoing concern about environmental issues in the redwoods.

Even some of the terminology used to describe caring for the environment can be confusing. What is the difference between conservation, preservation, management, and stewardship of the land? In this guide, I will use the terms as follows with regards to the redwoods:

**Preservation:** Managing the land so that it remains, as much as possible, in a more or less natural state as it was before Europeans came to California. (It should be noted that keeping fire and flood out of redwood forests will not preserve the forests in a natural state, as both fire and flood are

natural in redwood forests. How to maintain a redwood forest in its current condition – or the condition that a park was in when the park was created – is an important issue.)

**Conservation:** The wise use of resources so that they provide the most good for the most people. Sometimes preservation might be the best use; sometimes harvesting of lumber might be the best use. (The dictionary definition of conservation is to "preserve from loss, waste, etc.; preservation." The definition that I am using is more commonly used in resource management fields such as forestry.)

**Stewardship:** Caring for the land or environment, protecting it from damage.

**Management:** Making choices as to what happens to the forest, with specific goals in mind. A forest might be managed for recreational use, as an example of a pre-European old-growth forest, for research, or as a lumber-producing resource. A stand of trees might be managed to produce the maximum amount of timber in the short term, or to continue to produce timber over a long period of time. Management implies steps taken towards a goal, and usually includes aspects of preservation, conservation, and stewardship.

**Environmentalism:** Environmentalism is another term that means different things to different people. What is an "environmentalist?" The foresters and scientists of the forest products industry would consider themselves to be environmentalists, as their job is to manage the forest lands so that they can grow more trees while complying with forest practice regulations.

Preservationists would consider themselves to be environmentalists because they are trying to preserve and protect the forest environment from human impact. Some use the term "environmentalist" in a negative manner, referring to those who have interfered with business interests or who have taken actions that threaten their livelihoods. In *Redwood Ed*, I will use the term "environmentalism" to refer to concern for the environment and to environmentalists as those who have that concern.

### Teaching Idea



*Have the students first discuss the meanings of the terms conservation, preservation, stewardship, and management. Then have them look up the dictionary definitions. Have them try to agree on definitions that will show the differences. Discuss word roots.*

A few words about "old-growth" and related terms:

Terminology can be important and confusing, as is the case with the term "old-growth." To some, old-growth redwoods are those in an area that has never been logged. To others, the term implies a certain type of forest ecosystem, while others use the term to describe trees of a certain size or age. To many, old-growth redwood forests are revered as places for spiritual renewal, while others see them as a potential but unavailable source of increasingly valuable lumber. One must also consider the difference between a stand of old-growth trees and an old-growth forest, which includes trees of varying species and ages.

Would a group of trees in an area where Native Americans felled trees using fire be considered old-growth? What about trees that are 170 years old, but growing in an area that was logged in 1830? And what about trees in a forest that has never been logged, but are only 10 years old and growing in an opening created by a fallen forest giant, root rot, fire, undercutting, flood or other causes? Are they old-growth?

In this guide, I will use the term "old-growth" to refer to redwoods that are in areas:

- a. that have not been logged, other than the occasional tree felled by Native Americans...relatively undisturbed by humans
- b. that are in a stand of trees or forest with diverse ages, spacing, and sizes of trees, with a multi-level canopy...structurally complex
- c. with large (for the site) and/or old (for the species) trees
- d. with most of the understory consisting of shade-tolerant species
- e. with downed logs on the floor and some "snags," or standing dead trees

While some species can do fine in even-aged forests, the downed logs, snags, and canopies of old-growth redwood communities provide habitats for many species that do not thrive in even-aged forests. Some timber companies intentionally leave snags and other woody debris to provide old-growth-like habitats; in fact, timber management plans may require that snags and other "wildlife trees" be left during logging operations.

I will use "second-growth" to refer to trees growing in an area where the old-growth forest has been logged once, and "third-growth" to refer to trees growing where second growth forests have been logged. The term **young-growth** refers to any trees growing after the first cutting.

## Coast Redwood Ecology

Factors that affect organisms are often divided into two categories—physical, or abiotic, and biological or biotic factors. These divisions are not mutually exclusive, because the physical factors affect the biological and *vice-versa*.



## Physical (Abiotic) Factors

Moisture is the main limiting factor for the coast redwood. They grow best where annual precipitation is in the range of 140 inches, including **fog drip**. The climate of the redwood region can be broadly described as Mediterranean, with the majority of the rain falling in the winter, and both winter and summer temperatures being moderate.

The presence of summer fog may be the most important limiting factor, especially in the southern redwood region. Not only does fog reduce evaporation of water from the ground and reduce transpiration, but it condenses on the leaves and drips to the ground where it can soak into the soil. This fog drip is used not only by the redwoods, but by the other plants and animals in the community. In the summer, some understory plants may get nearly 100% of their moisture from fog drip, and 22-46% of the moisture available to the ecosystem may come from fog drip (Dawson, 1996). Measurements have shown that fog drip can add four or more inches of water to the soil around a tree in a single foggy summer day, and may provide up to 40% of the water that a redwood uses in the summer, and over 25% of its annual water input (Noss, 2000).

Studies have shown that redwoods, as well as other plants, can absorb water (as fog) directly through their needles. This seems to be particularly important for young trees, especially in years in which there is less rainfall than normal.

The correlation of the coast redwood's range with the fog belt of northern and central California is apparent. The coast redwood's natural range is along the coast, seldom extending beyond 35-40 miles inland. In drier areas, such as the southern range, or farther inland, the redwoods are often confined to the fog-containing valleys.

***See the activity "Have a Foggy Idea" in Section IV.***

Temperatures in the coast redwood region are relatively mild when compared to the areas where the other species of redwood grow. Coast redwoods grow best where the range between high and low temperatures is not very great. Temperatures rarely reach freezing or 100 degrees Fahrenheit. Not only is the annual temperature range small, but coast redwoods grow best where there is little difference between the daytime and nighttime lows. Both air and soil temperatures are important.

Light is important, of course, for photosynthesis. Different plants have different tolerances for shade, and the coast redwood is considered shade-tolerant or very shade-tolerant. While light may not be a limiting factor for survival, it is extremely important because of its effect on the growth rate of redwoods. A redwood tree growing in optimal conditions of light, moisture, and soil may add as much as 1.5-2 inches to its diameter in a year. A tree of the same age growing in the reduced light of a dense redwood forest might add less than 0.2 inches to its diameter in a year. A one-year-old sapling may grow to be two meters tall in a well-lit area, while a 100-year-old tree growing in the shade may be only 10 meters tall. Even a redwood, however, will

eventually succumb if it doesn't have access to adequate light. As noted elsewhere, the redwoods with the largest diameters usually grow along rivers where they have ample light and moisture.

Anything that opens up the forest canopy can prompt a growth spurt. A large tree falling may open the forest, as might a landslide, strong wind, or even a chainsaw. A study of tree rings can show when the tree's growth was **released**, resulting in more widely spaced rings. The added light also allows trees that are less shade-tolerant species to grow. As a tree falls, it may move down slope, clearing a swath of vegetation and bringing debris to lower ground or creeks.

When a forest canopy closes in, more shade results in slower growth or suppression. In order to grow in the reduced light of a redwood forest, plants must be shade-tolerant.

***See the activities "Fence Post Studies," "The Great Tree Cookie Mystery," and "Slow Growth or Fast Growth?" in Section IV.***

As a tree grows taller, the lower branches receive less light. Eventually, the lower branches die and break off, a process called **natural pruning**. One consequence of natural pruning is the absence of knots in wood formed after the branch falls. Knots are formed where limbs grow from trees and are surrounded by subsequent growth. Lumber without knots is called "clear," and it is much more valuable than wood with knots. Older trees generally have much more clear wood than do young-growth trees.

The tops of most plants tend to grow towards the light. This growth towards something is called a positive **tropism**, so redwood branches and tops tend to have a strong positive **phototropism**, or grow towards light. The roots of most plants, similarly, have a strong positive **geotropism**. (Negative tropisms would, of course, be growing away from something.) Sometimes trees growing in shady areas bend towards an open space such as a creek or other clearing.

Wind is a factor in redwood ecology for a variety of reasons. Redwoods have shallow root systems for trees their size. When redwoods live in fairly dense forest situations, the trees tend to shelter each other from the strong winds that sometimes come with winter storms. If some trees are removed by logging, landslide, or other means, the remaining trees may be susceptible to being knocked down by subsequent winds. This **windthrow** or **blowdown** can have a snowball effect as the fallen trees expose the remaining trees to the winds.

While proximity to the coast provides the coast redwood with necessary moisture in the form of rain and fog, the trees don't tolerate wind-carried salt. Redwoods may live near the coast, but seldom on the coast. On the cliffs high above the ocean, however, the redwoods may grow near the water if the salt spray doesn't reach them.

Not only does wind bring salt and blow trees down, but it can remove fog, resulting in desiccation. Drying wind not only removes moisture from the leaves, increasing transpiration, but it also removes moisture from the soil.

Soil is an extremely important abiotic factor in any terrestrial community. Soil provides mineral nutrients, holds moisture, and anchors the plants. The roots of the coast redwood are relatively shallow for a tree of its size, often only 6-10 feet deep on a 200-300 foot tall tree. The roots do spread out laterally for a large distance and may even intertwine with those of neighboring trees, which can provide extra support.

The largest redwoods grow on the alluvial flats along rivers and creeks. Periodic flooding deposits silt around the trees. A coast redwood has the ability to sprout a new layer of roots from the base of its trunk when it is buried in silt. If the newly deposited sediments consist of coarse gravel, though, the roots may die because the coarse sediments don't hold moisture well.

Soil texture is important because it can facilitate or hinder absorption and retention of moisture. Redwoods do well in a wide range of soil types, but do best where the soil is continuously moist and well aerated.

For successful redwood reproduction by seeds, the soil needs to be disturbed. On an undisturbed forest floor, the layer of needles, leaves, and twigs is often too thick for the tiny seed to produce a root that can reach the soil, and the air spaces between the needles on the floor allow the developing young root to dry out. In nature, landslides, treefall, flooding, and fire prepare the soil for redwood seeds. Logging, with its concomitant soil disruption, can actually enhance the sprouting of redwood seedlings.

Sometimes a portion of a hillside slides or "slumps" downhill, resulting in a relatively flat-topped area where the slumping soil stops. This disturbed area, sometimes called a **slump-jumble** often provides a place where redwood seedlings can gain a start, along with other colonizing early-successional plants.

When a tree falls, of course, the roots pull some of the soil with them, thus creating what is called a **root-pull pit**. This pit provides exposed soil for pioneer species or redwood seedlings, as does the wad of soil attached to the root.

Flooding can be a major environmental factor, especially in the rainy north coast region. Redwoods often live on the alluvial flats, and they are more resistant to flood damage than other species such as Douglas-fir, alder, tanoak and others. Redwoods surviving a flood may eventually die, however, if the roots are unable to obtain oxygen because they are buried too deeply in sediments. As discussed above, though, many redwoods have the ability to send up new shoots into the newly deposited sediments.

Fire is a very important factor in the redwood forests. Redwood trees are relatively resistant to damage by fire, but many of the plants competing with them are more

susceptible to fire damage. The trees' thick, fire resistant bark protects the living inner parts, and the wood has little resin.

The actively living part of a tree trunk is the cambium layer, which lies directly under the bark. As long as the cambium is protected, damage to the surface of the bark or the center of the trunk may not significantly hurt the tree.

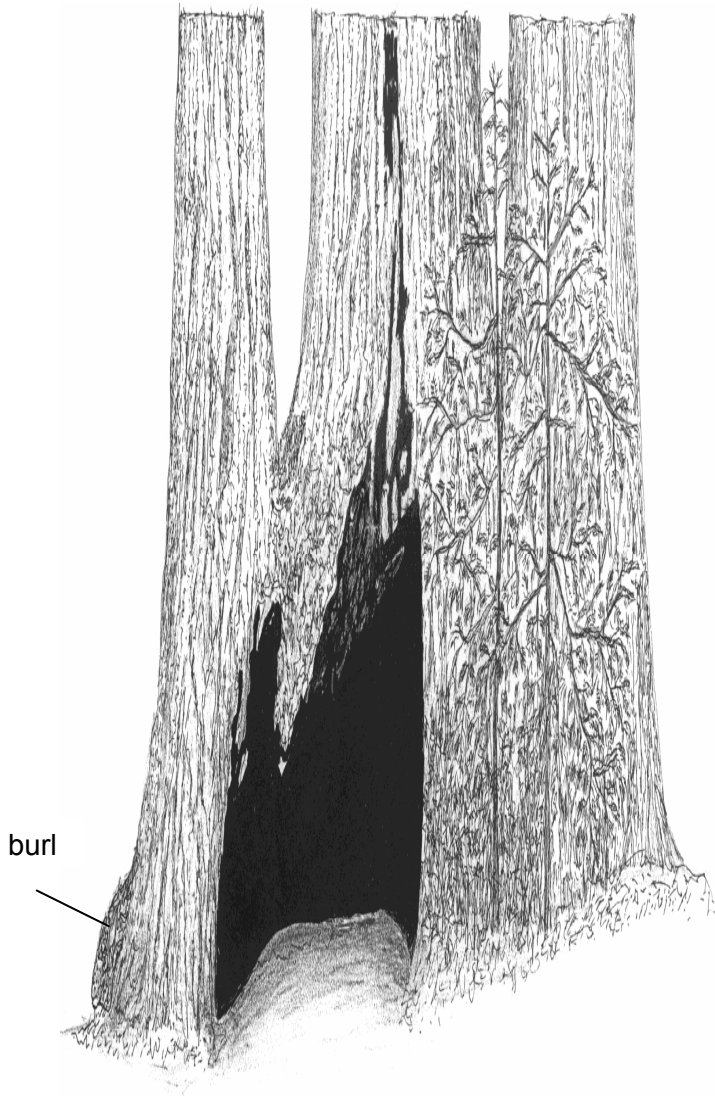
***See the activity "The Anatomy of a Giant" in Section IV.***

In the alluvial flat stands, fires tend to burn with low intensity. The generally moist conditions, flat terrain, and the nature of the plants near the ground all work together to reduce the intensity of the fire. The redwood's bark is resistant to fire, and even the wood itself is fire resistant because of its lack of pitch and its high water content. In a mature redwood stand, the lowest branches may be a hundred feet or more above the ground, further reducing the damage caused by fire.

In forests on hillsides, especially where other species, such as Douglas-fir and tanoak, grow along with the redwoods, fires often are much more intense. More flammable trees may even provide a ladder-like effect, allowing the fire to reach the redwood overstory. Fire is also important in maintaining the grasslands known as **prairies**. In Redwood National Park, park managers are using fire to rid the prairies of invading native and non-native species. Due to their natural resistance to fire, however, mature redwoods are seldom killed by fires.

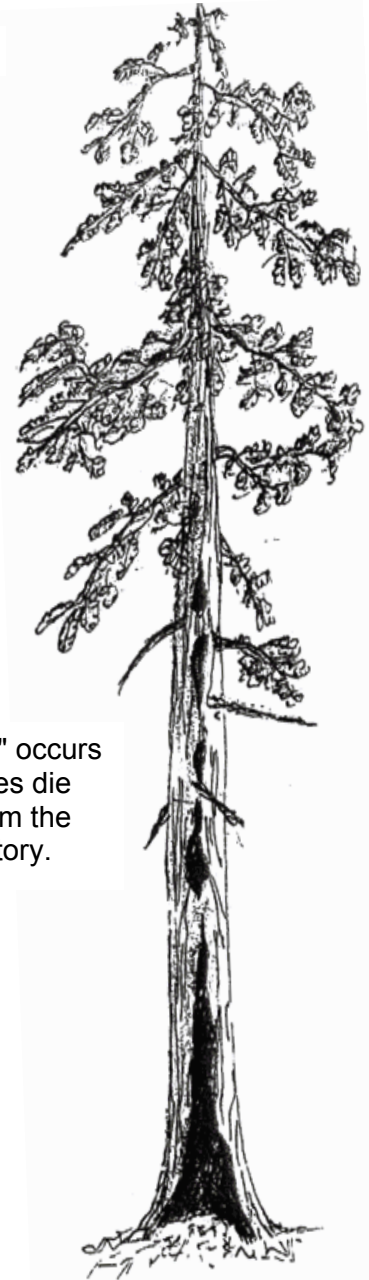
Occasionally, fire may actually penetrate the bark of a redwood and damage the wood beneath. This is most common on the upslope side of a tree where branches and litter have accumulated. Subsequent fires, along with fungal infections, may repeatedly attack the tree, resulting in a hollowed-out cavern, called a fire cavity, in the base of the tree. If enough of the sapwood is burned, the tree may be killed, but redwoods often continue to grow even if a significant portion of their base or heartwood is burned out. Early settlers supposedly used these tree-caves as pens for animals, or even living quarters, and they are often called **goosepens**. Sometimes these hollows extend well up the tree, forming a **chimney tree**. Such fire cavities provide shelter for such animals as hibernating bears and roosting bats.

Figure 11



A goosepen with a burl at the base to the left.

Figure 12



"Natural pruning" occurs as lower branches die due to shade from the canopy or overstory.

Sometimes fires will penetrate the bark and burn the heartwood, creating a "chimney tree." If the cambium and sapwood survive, the tree may continue to live for years, providing habitat for many types of organisms.

Drawings from *Life History and Ecological Guide to the Coast Redwood, Sequoia sempervirens*, by Daniel J. Miller.

Sometimes a redwood may have its branches burned off by a large fire. While the tree may be killed, sometimes the branchless **bole** (trunk) will sprout hundreds of branches, forming a "**fire column**" tree, sometimes called a **Christmas tree**, that may look like a bottle brush or pipe cleaner.

Figure 13



Figure 14



Crown fires sometimes burn off the limbs without killing the tree or the dormant buds beneath the bark. The buds may then sprout new branches, forming a fire column tree or "Christmas Tree."

Various factors such as salt spray or lack of water may kill the top of the tree, resulting in a "spike top."

Drawings from *Life History and Ecological Guide to the Coast Redwood, Sequoia sempervirens*, by Daniel J. Miller.

Fire is a natural part of the redwood forest ecosystem, and may be necessary for the survival of the redwood forest. Fires kill other species that compete with the redwoods for light and nutrients, and also return nutrients to the soil. As noted elsewhere, some studies indicate that, over the course of several centuries, a lack of fire may result in the replacement of redwoods by other species. Fires, especially large ones, are more common in the drier southern and inland parts of the redwood region. Native Americans used fire to maintain clearings in the redwood forest so that desired plants and animals would have suitable habitat. (This is discussed more thoroughly in Section II.)

In the northern redwood region, evidence of fires in moist coastal areas indicates a frequency of up to once in 500 years, while in drier inland areas significant fires occurred naturally about once in 100-200 years (Veirs, 1996). In drier southern areas, the natural fire interval was much shorter, perhaps as low as 30 to 50 years (Lanner, 1999). Native Americans may have started fires to encourage the growth of desired plants every 2-10 years.

**See the activities "Fence Post Studies," "The Great Tree Cookie Mystery, and "Slow Growth or Fast Growth" in Section IV.**

### **Biological (Biotic) Factors**

Reproduction in the coast redwoods occurs in three ways: seeds, sprouting from stumps or injured trees, and sprouting from fallen branches.

Redwood trees have both male and female cones on the same tree. During the winter, the male cones produce pollen, which settles on young female cones and fertilizes the ovules within. In about six months, each  $\frac{3}{4}$ -inch-long female cone may develop 60 to 120 seeds. The seeds of the huge tree are tiny...it takes over 100,000 of them to weigh a pound. After the seeds and cone mature, the cone opens and sheds the seeds, usually between November and February. Most of the 10 million or so seeds produced by each tree per year are not viable, but 5% to 10% are (Barbour et al., 2001).

The production of cones and seeds varies with the health of the tree and its age. Seed production begins when trees are only 5-15 years old, but trees aged 250 to 1000 years seem to produce not only the most cones, but the most viable seeds. Some trees produce few or no cones for many years. There is some evidence that this may be due to lack of stress, as stressed trees seem to produce more cones.

As noted above, if the seeds fall on accumulated forest leaf litter or duff, they are likely to dry out and die before they can extend their developing roots to the soil. Seeds falling on leaf litter are also very susceptible to infection by **damping-off** fungi. Seeds are also fed on by banana slugs and brush rabbits, as well as nematodes (round worms).

Seeds that fall on mineral soil, however, have a much better chance of germinating and surviving. Soil exposed by wildfire or deposited by flooding is often covered by forests of miniature redwoods. The soil exposed by a fallen tree's roots, a small landslide, or logging operations can provide a seed bed that also has ample sunlight.

If a quantity of redwood seedlings starts to grow, on an area of disturbed soil on a slumping hillside for example, a dense cluster of trees may form. As the trees grow, the interior portion of the cluster receives increasing amounts of shade, and the trees at the center may lose the battle for sunlight and die back. This is one way that a circle of redwoods may form.

Coast redwoods are among the fastest growing trees in the world. A 20-year-old tree may be 30 feet tall and 10 inches in diameter with a shallow network of roots extending 20 to 30 feet out. A young tree may grow two to six feet in height and an inch or more in diameter each year. A 50-year-old redwood may be 100 feet tall, and it may reach a height of 200 to 300 feet by the time it is 200 years of age. This rapid upward growth is important if the tree is to compete successfully with its shade-producing neighbors.

After reaching the sunlight at the height of the forest canopy, the tree slows its vertical growth and adds more wood to its trunk or bole. Thus, a 200-year-old tree may be 250 feet tall with a diameter of five feet, while a 400-year-old tree may be 275 feet with a diameter of only seven feet. By the time the tree is 700 years old and 300 feet tall, its diameter may be 15 feet. Timber companies seek an optimal growth rate and harvest cycle that produces the most wood in the shortest time.

An important form of reproduction in redwoods is its ability to sprout from its **bud collar** or **burls**. A tree may also form burls high up the side of the bole. Burls contain dormant buds, sometimes numbering in the thousands. If the tip of a seedling or tree is damaged, the dormant buds are released from dormancy and rapidly grow into shoots that are extremely vigorous in their growth. Such a sprout may grow 8 to 10 feet in its first year, and may produce a 30-inch diameter, 150-foot tall tree in 50 years. These vigorous sprouts may number more than 200 around a single stump, but competition thins them out over time. Seedlings as young as six months old have the ability to send up new sprouts if their tops are damaged. A Division of Forestry study found that within two years of logging, 90% of the stumps may sprout new saplings.



Figure 15. Burls. Note the small trees sprouting from burls at the left. (Photo courtesy of Michael Roa.)

Since the sprouts from a stump or fallen redwood have the same genetic makeup as the original tree, they are **clones** of the parent tree. Clonal rings are common in redwood stands that have been logged, as the sprouts from the cut stump often grow into a circle



of trees. In fact, since the sprouts have the benefit of the original tree's extensive root system, they have a great advantage over seedlings and are an important source of "new" trees in logged areas. (These circles are sometimes called "fairy rings," but that term is probably better saved for circles of mushrooms that develop as nutrients are used up in the center of the circle.) In some areas where fires are frequent, whole groves of redwoods may consist of clusters of short, multi-trunked trees produced by stump sprouting.

### Teaching Idea



*Gift shops in the redwood region sometimes sell living redwood burls that can be grown in the classroom. These burls are sometimes collected legally on private land, or from trees that have been cut for lumber. Too often, however, they are cut illegally on private land or even in parks. Thieves have been known to cut down trees in order to get at burls high up on the trunk. Caution students not to injure trees by collecting burls on their own. If you live in the redwood region, perhaps you can obtain burls from a logging company.*

*A discussion of burl harvesting can lead to a discussion of killing or injuring organisms for such things as fur coats, feathers, shells, and other non-essential uses. Discuss how purchasing such items supports the killing of plants and animals, often illegally. Discuss the poaching of animals in parks, not only in the U.S.A., but also elsewhere, such as Africa.*

A less common form of cloning occurs when a fallen branch or tree sprouts roots from the buds on the downward side and branches or trunks on the upward side, sometimes producing a line of "new" trees along the fallen trunk. Sprouts have even emerged from harvested logs months after they were cut.

A rare type of sprout forms an "albino redwood." These trees grow from sprout burls on otherwise normal redwood trees. They don't live to be large trees, but are an interesting phenomenon. If you visit a park, you might ask the naturalist or interpreter if there are any albino trees that can be seen. Don't be surprised if they won't tell you of the location, though, as albino trees are rare and fragile.

### Teaching Idea



*When discussing the large number of seeds produced by a single redwood cone or tree each year, also discuss how many seeds would be produced by a tree in its lifetime. (Seed production is not constant throughout a tree's life, but it is easy to see that a tree producing 10 million seeds per year may produce a billion or more seeds in a lifetime of several hundred years.) For the species to survive in its current numbers, each tree only needs to successfully produce one other tree that reaches maturity.*

*Discuss the idea that some seeds may produce seedlings or young trees that are more likely to survive. Help the students come up with some characteristics or adaptations that may give some seedlings an advantage in the struggle for survival. Some adaptations might include faster growing roots, faster growing stems, chemicals that make them more resistant to fungus or distasteful to animals, or better resistance to drying out. This can lead to a discussion of natural selection.*

### Teaching Idea



*Many students have heard of **cloning**. Discuss its advantages and disadvantages.*

*Since the redwood ovum may be fertilized by pollen from another tree, reproduction from seeds provides the opportunity for a new mixture of genetic information. This results in variation, which results in the possibility of new adaptations that may give the new seedling a competitive advantage (or disadvantage). For example it has been found that trees from the southern redwood region often do not grow well in the north, and vice versa. Apparently trees in different areas have evolved somewhat different and specialized genes.*

*When a stump or fallen log grows a new sprout, that sprout is genetically identical to the original tree. It is a clone. It will have the same genetic characteristics, good and bad, of its "parent." Tree nurseries often take cuttings from trees with desired characteristics and use them to produce hundreds of clones with those desired genetic characteristics.*

*Discuss with the students what characteristics timber companies might desire. Examples include fast growth, straight trunks, horizontal branches (resulting in smaller knots), resistance to disease or insects, the ability to withstand drought, or others.*

*Discuss with students the dangers of having a "crop" of trees all with the same characteristics, i.e., a **monoculture**. (All of the trees—or corn or wheat or cotton—will have the same good characteristics, but they will also all have the same "bad" characteristics; they will all be susceptible to the same diseases, environmental changes, predators, etc.)*

*Discuss how nature deals with this issue...mixing of genes through sexual reproduction, natural selection, "survival of the fittest."*

*Then discuss how timber managers might deal with the problems of monoculture... leaving seed trees, stump sprouting producing a portion of the trees, planting a variety of clones, or using selective harvesting.*

Tree growth and form are important to the redwood's survival. Much of the redwood's shape comes from adaptations that enable it to compete for the light needed for photosynthesis. Rapid growth in height, as described above, enables it to out-compete

other trees when a clearing becomes available. Once a canopy forms, most other trees can't thrive in the shady understory, so competition for water and minerals is reduced.

As the tree grows taller and the canopy forms, the lower branches lose their usefulness. In a process called **natural pruning** these lower branches die and fall off. As noted elsewhere, the subsequent wood growth below the level of the branches will be free of knots, which are caused by the growth of wood around a branch. This "clear" wood produces very valuable lumber, but the young-growth trees that provide most of the lumber today produce relatively little clear wood. Conversely, the huge trees cut in the early days of logging had a lot of clear wood, so much so that the tops of the trees, which contained branches and therefore knots, were often left in the woods.

In their quest for light, trees sometimes grow **reiterated trunks** at or near the canopy level. These may grow out from the main trunk or may grow upwards from a horizontal branch. These **reiterations** are essentially like tree trunks growing from the upper parts of the tree. They can be quite large. A 307-foot tall tree in Del Norte County, aptly called the Del Norte Titan, has a diameter at breast height of about 24 feet. It sports a reiteration that grows from its trunk more than 150 feet above the ground and has a base diameter of more than five feet. That single tree has 43 reiterated trunks growing in its crown. Another tree, called the Redwood Creek Giant, has 148 reiterated trunks (Noss, 2000). (See figure 16.)

These reiterated trunks, along with "regular" branches, provide a complex canopy that supports a rich collection of other plants and animals. Plants that live on other plants are called **epiphytes**, and over a dozen species of epiphytes have been found in the coast redwood canopy. Although not truly an epiphytic species, a western hemlock tree 40 feet tall has been found growing in a pocket of canopy soil. (*Coast Redwood*, by Barbour *et al.*, has a nice section on the forest canopy, including photographs of reiterations.)

Sometimes when trees are under stress, the top of the tree may die, resulting in a "**spike top**" tree. (See Figure 14.) This stress may be caused by lack of water, salt spray, or other environmental factors. Such trees can often be seen along freeways.

If a redwood starts to lean, or grows on a hillside, it may develop asymmetrical growth, with the downhill or side towards which the tree leans growing faster, forming a buttress that supports the tree. Sometimes these trees are called "flatiron" trees because of their cross-sectional shape.

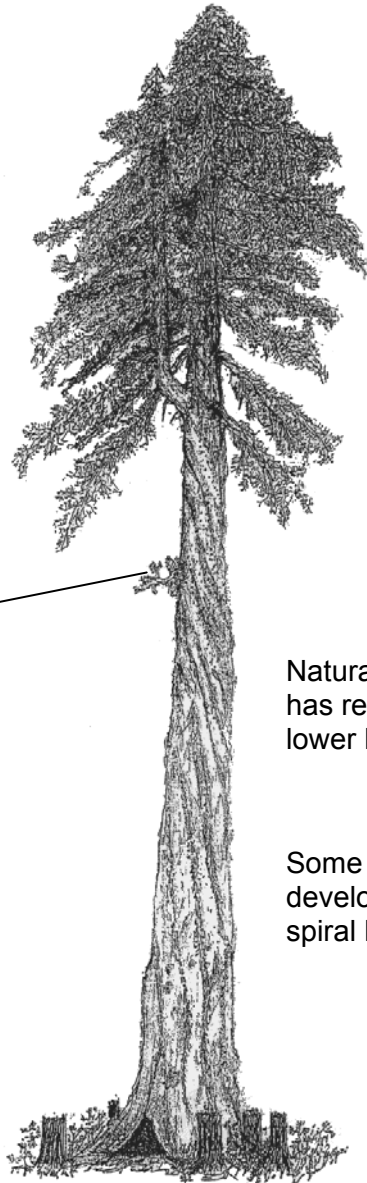
Figure 16.

An injury to the trunk or a limb may result in the growth of a tree-like reiteration.

Most burls form at the base of the tree, but they may also form high up on the trunk.

Woodrats may build their nests in goosepens.

Stump sprout rings are common around cut redwoods, but they also form after other types of disturbance such as a fire. This tree has a ring of several living trees, shown here as stumps.



Natural pruning has removed the lower branches.

Some coast redwoods develop twisted or spiral bark.

Drawing from *Life History and Ecological Guide to the Coast Redwood, Sequoia sempervirens*, by Daniel J. Miller.

The root system of the coast redwood is also adapted to its environment. The coast redwood lacks a large **tap root**; rather, its roots extend more than 50 feet laterally and have a depth of 12 feet or less. The roots may interlock with those of neighboring trees, which provides additional stability during wind storms or floods. The roots may produce many small rootlets in the top three feet or so of soil.

Most plants have very fine **root hairs** that greatly increase the surface area of the root system and facilitate the absorption of water and minerals. The coast redwood, however, lacks root hairs. Rather, coast redwoods have a variety of strand-like fungi that grow on the roots and actually extend into the root cells. These fungi absorb water and nutrients and pass them on to the redwood cells. In turn, the fungi receive nutrients from the tree. This mutualistic association is called mycorrhizae.

**See the activity "The Root of the Matter" in Section IV.**

As layers of soil build up around the base of a redwood, or as the base is covered by silt from a flood, the root crown may send out new layers of roots, or the lower roots may send shoots upward. Studying these layers of roots enables biologists to study the frequency of floods. A study of root layers in the Bull Creek area of Humboldt County indicated that there were about 15 major floods in the last 1000 years, and that the floodplain was raised by more than 30 feet. (Barbour et al., 2001)

### Teaching Idea



*The Save-the-Redwoods League has published a very interesting booklet titled Story Told by a Fallen Redwood, by Emanuel Fritz (1995). If possible, obtain a couple of copies of this booklet for students to study, and if you are in the Richardson Grove area, visit the actual log about which the booklet is written.*

Animal associations with the redwoods are important, but, other than man, it is generally the redwoods that affect the animals, as opposed to the animals affecting the redwoods. As noted above, the tannins and thick bark of the coast redwood make it unpalatable to most insects. For example, hundreds of insect species consume Douglas-fir, but only about 50 species feed on redwood. So effective are the redwood's defenses that no insect species causes economically significant damage to redwood trees.

A few mammals feed on the redwoods. Some, like woodrats, mice, deer, and elk feed on young seedlings. Elk and deer feeding on the terminal shoots of young trees or spouts can suppress the trees' growth or even kill them. Various animals, such as woodrats, squirrels, porcupines, and black bears, feed on the cambium layer beneath the bark. Black bears sometimes cause significant damage to stump sprouts or seedlings planted in logged areas as they strip the bark and feed on the cambium layer, especially in the early spring when the sap is flowing. Bears seem to prefer saplings ranging from 6-12 inches in diameter, so they are of particular concern to timber companies. A tree can be killed if a foraging bear or porcupine eats so much of the vascular tissue that the tree cannot transport materials to and from the leaves, a process called **girdling**. A variety of rodents and birds feed on redwood seeds.