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FOREST STEWARDSHIP SERIES 3

Forest Ecology

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A forest is more than trees. It is also the shrubs, wildflowers, and grasses; the animals that depend on and live among these plants; the soil in which the plants grow; the dead trees and plants; the stream that flows through it; the insects, fungi, bacteria, and organisms you cannot readily see; and the climate. In short, a forest is an ecosystem. An ecosystem is simply a specific area of the earth that includes all the living organisms and nonliving components of the environment that interact within its boundaries. An ecosystem can be any size, such as a log, pond, field, forest, or the whole earth's biosphere.

Objective

Understand the structure and functions of forested ecosystems in California.

Competencies

- *Identify the forest ecosystem(s) on your property.*
- *Appreciate the relationships between climatic and environmental conditions and vegetation.*
- *Understand the essential role of soil and soil conservation in preserving the productivity of the forest.*
- *Identify the trees, shrubs, and other plants that comprise the forest.*
- *Observe the many interactions between plants, animals, and other microorganisms in the forest.*
- *Understand energy, water, and nutrient cycling in forest ecosystems.*
- *Understand ecological succession and its relationship to natural disturbances and forest management.*
- *Manage the forest in an ecologically sustainable manner.*

Related Forest Stewardship Series Publications

- *Vegetation Management (ANR Publication 8236)*
- *Forest Regeneration (ANR Publication 8237)*
- *Forest Wildlife (ANR Publication 8238)*

It is useful to understand and manage your forest as an ecosystem because all the components influence one another: for example, if you want certain tree species in your forest, you may have to manage the competing vegetation. You cannot control certain aspects of the ecosystem such as climate; you must learn to live within its constraints of temperature and precipitation. In many cases the dates of last and first frost control the growing season, the types of plants you can grow, and the productivity of your forest. High temperatures and low precipitation limit the growing season at low elevations, as do cold temperatures and snow at higher elevations.

Much of what we do in forestry is based on an understanding of ecology. Ecological concepts provide a basis for predicting the effects of our actions on ecosystems. Timber harvesting, grazing, wildlife habitat improvement, even fire control intentionally or unintentionally change vegetation to favor or discourage certain ecological functions. For example, when we harvest a forest, we change the wildlife habitat in ways that are positive for some species and negative for others. Techniques such as thinning may be used to develop forest conditions suitable to grow bigger trees faster by reducing competition. When we use controlled burns to reduce dense fuel loads in shrub communities we are mimicking some natural disturbance processes.

Viewing our management activities in an ecological context provides a basis for understanding the effects of those activities on ecosystem processes. Altering vegetation can change many things beyond the obvious, immediate changes in plant cover. Taking an ecosystem approach would mean considering the effects of vegetation management on all comprehensible ecological functions and processes.

Most of our activities in the forest are aimed at improving the production of goods and services for human benefit. Evaluating those activities in an ecological context can provide insight into a larger picture, predict and avoid potential negative effects, and perhaps lead to a thoughtful weighing of human benefits versus ecological effects. An ecosystem orientation requires a broader vision and understanding, which includes not just the human community and its needs but the entire ecosystem and its processes.

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FOREST TYPES OF CALIFORNIA

California is a large state, 300 miles east to west and 800 miles north to south. It is very diverse geologically, topographically (mountains and valleys), and climatically (coastal, desert, and continental). This diversity of conditions conspire to create the many different California forest types.

California forest types vary in relation to climate and soils. In any of the mountain ranges, as one rises in elevation the temperature drops and annual precipitation increases. This same gradient occurs as one travels north in latitude. At lower elevations, oaks and pine tolerate the higher temperatures and low precipitation, while at higher elevations Douglas-fir, true fir, and hemlock respond to the cooler temperatures and increases in precipitation. These forest types are associations of trees, shrubs, and herbs. The species occur together in communities because they share some of the same environmental requirements and tolerances for light, water, nutrients, and other necessities of life. In some cases there is interdependence, for example, the trees create the shade necessary for understory plants to grow.

Careful observation of your forest will reveal some of the environmental conditions conducive to the occurrence of certain species. Which plants grow in full sunlight? Which prefer shade? Many plants are able to grow in conditions somewhere in between. For example, ponderosa pine grows best in full sunlight, and, though it can tolerate shade for years, it generally will not respond with more rapid growth to a thinning of competing trees. White fir, on the other hand, can grow slowly for many years in deep shade but will respond with increased growth if an opening in the forest canopy allows more sunlight to reach it. Plants differ in their tolerance to a number of other factors including moisture stress (drought), disease, air pollution, soil nutrients, frost and heat.

Coastal Redwood

Coastal redwoods (fig. 1) are the world's tallest tree. They grow along the north coast of the state in a fog belt strongly influenced by proximity to the Pacific Ocean. This maritime climate has heavy winter rains, frequent storms, and cool summers. Fog provides moisture year-round. Redwoods are able to grow rapidly and are adapted to survive periodic fires and flooding. It is a highly unusual conifer species because it can sprout following a disturbance and does not need to germinate from seed. Trees associated with the redwood include Douglas-fir, tanoak, grand fir, Pacific madrone, and California bay. The understory can consist of shrubs (hazelnut, salal, poison oak, huckleberry, and rhododendrons) along with numerous ferns and herbs such as sword fern, redwood sorrel, and Solomon's seal.

Figure 1. Coast redwood forest, Jedidiah Smith State Park. *Photo:* Gary Nakamura.

Riparian Forest

"Riparian forest" is a generic term for the communities that occur as narrow, often dense groves of broadleaf winter-deciduous trees along watercourses, rivers, streams, springs, seeps, and lakes. Black cottonwood, white alder, big leaf maple, dogwood, and willow are characteristic trees. Riparian forest has a very high value for many wildlife species, providing water, thermal cover for terrestrial animals as well as fish, migration corridors, and nesting and feeding opportunities. Riparian forests are given special protection by the Forest Practice Rules' Watercourse and Lake Protection regulations and by the California Department of Fish and Game (DFG) and Water Quality Control Board (WQCB) regulations.

Oak Woodland

The California foothills have hot, dry summers and mild, wet winters. Oaks and gray pines are the dominant trees in these woodlands, along with a number of associated chaparral shrub species such as manzanita, ceanothus, and mountain mahogany (fig. 2). Plants growing here have to be able to conserve water and tolerate drought during the long dry season. Some grasses avoid the drought by completing their life cycle and going to seed before the dry season. Manzanita has hairy or waxy leaves that minimize water loss during the dry season. Plants native to oak woodland are adapted to frequent low-intensity fires and may resprout or germinate from seed following fire. Non-native annual grasses have almost completely replaced the native perennials in these woodlands, resulting in poorer wildlife habitat and changes in the fire regime. Acorns, nuts, and berries support a rich wildlife fauna of over 300 species.

Montane Chaparral

The term "chaparral" is derived from *chaparro*, Spanish for "scrub oak." Chaparral is the most extensive vegetation type in California, comprising 10 million acres, and the dominant species varying with annual precipitation, elevation, and climate (coastal, mountain, or desert). Though not technically a forest type, chaparral vegetation is often part of the oak woodland and lower-elevation mixed conifer forest. Manzanita and ceanothus species are usually principal components of montane chaparral. Wildfire plays an important role in montane chaparral ecology; dominant plants are adapted to fire and usually resprout or germinate quickly following a wildfire. Though drought resistant, chaparral plants are not conservative of water. They consume available soil moisture in the early spring, set seed, and go dormant during the summer drought. Rapid regeneration of chaparral shrubs may serve to stabilize soils following fire, but it also creates intense competition for moisture with germinating or planted tree seedlings.

Montane chaparral provides habitat for a wide variety of wildlife, such as rodents, which serve as food for birds nesting in adjacent conifer forest. Deer and other herbivores make extensive use of chaparral for summer browse, escape cover, and fawning habitat. Chaparral shrubs provide seeds, fruits, insects, and protection from predators for birds, as well as roosting and nesting sites.

Figure 2. Oak woodland. Blue oak, Shasta County. *Photo:* Gary Nakamura.

Mixed Conifer

Mixed conifer forests are found in the middle elevations of the Sierra Nevada and the Cascade and Klamath mountain ranges from about 3,000 to 6,000 feet (fig. 3). Summers are warm and dry; winters are cool, and most of the precipitation, with some snow, occurs during this time. Soil moisture is a critical factor in determining where and how well species grow. Conifers grow here in various combinations. In fact, these forests claim the greatest diversity of coniferous trees in the world, including ponderosa (yellow) pine, Jeffrey pine, sugar pine, incense cedar, white fir, and Douglas-fir, as well as black oaks and many other trees. Shrubs such as manzanita, ceanothus, bitter cherry, and mountain misery are prominent in the understory. Periodic fires are an essential part of the mixed conifer forest ecosystem. Fire suppression over the last century has changed the density and species composition of mixed conifer and other California forests.

Douglas-fir–Mixed Evergreen Forests

Douglas-fir is a dominant tree in much of the Pacific Northwest and in several forest types in California from the Oregon border down through the Coast Ranges and inland to the northern Sierra Nevada (fig. 4). It is often associated with mixed evergreen hardwood species, including California bay, coast and canyon live oaks, tanoak, and Pacific madrone. A wide variety of plants and animals are found in Douglas-fir forests.

Red Fir Forests

The red fir forests are found along a belt in the Sierra Nevada at elevations of approximately 6,000 to 8,000 feet, between the mixed conifer and subalpine forests (fig. 5). This area receives heavy snowfall each year. Red fir forests do well on deep, rocky soils with good soil aeration such as glacial moraines. Other trees associated with red fir in much of their range include white fir, Jeffrey pine, lodgepole pine, and juniper.

Subalpine Forests

The subalpine forests are found at roughly 8,000 to 11,000 feet elevation, just below the timberline of the central and southern Sierra Nevada as well as the Cascades and

Figure 3. Sierra Nevada mixed conifer forest. Overstory of ponderosa and sugar pine, Douglas-fir, incense cedar, and black oak and an understory of incense cedar and white fir. UC Blodgett Forest Research Station, Georgetown, CA. *Photo:* Gary Nakamura.

Figure 4. Douglas-fir forest, Trinity County. *Photo:* Gary Nakamura.

Figure 5. True fir forest. White fir, Klamath Mountains. *Photo:* Gary Nakamura.

Figure 6. Subalpine forest. Mountain hemlock and red fir; Lassen Volcanic National Park. *Photo:* Gary Nakamura.

Warner and Klamath Mountains (fig. 6). Southern California has a drier subalpine habitat. This is a challenging environment: winter conditions of snow and frost may prevail much of the year, the wind is harsh, and solar radiation intense. The soil is generally shallow and has minimal water-holding capacity, creating droughty growing conditions for plants. Whitebark pine, mountain hemlock, lodgepole pine, and junipers are the characteristic tree species.

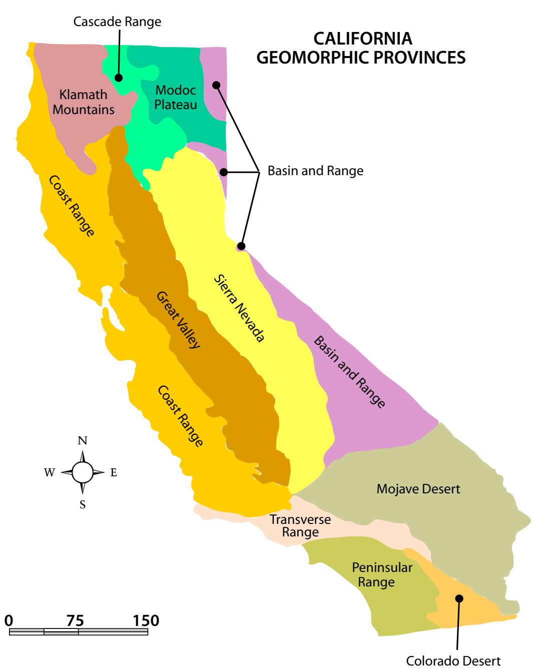

Figure 7. Map of the geomorphic units of California. *Source:* California Department of Conservation, California Geological Survey, 2002.

PHYSICAL FACTORS THAT INFLUENCE YOUR FOREST

The physical environment determines the conditions for the living components of the ecosystem. Physical factors include topography, climate (temperature, precipitation amount and pattern, humidity), the physiochemical nature of the soil and water (nutrients and acidity), underlying geological material, and human influences such as air pollution.

The topography of the land—mountains, valleys, rivers, and so on—affects the climate, soils, and water. California has an incredibly diverse topography. Elevation ranges from 282 feet below sea level in Death Valley to 14,496 feet at Mt. Whitney. Interestingly, these two locations are only about 50 miles apart. Mountain ranges include the Coast Ranges, which extend the length of the state along the Pacific Ocean; the Sierra Nevada; the Klamath Mountains in the northwest corner of the state; and the Transverse Range, which extends east to west, separating southern California from the Central Valley and Sierra Nevada (fig. 7).

The weather patterns in California result primarily from influences of the Pacific Ocean, the Central Valley, and the various mountain ranges. Moist air from the ocean moves up the mountains, cooling and condensing as it rises. This causes rain to fall on the west slopes of the Coast Range and Sierra Nevada, and on the south side of the Transverse Range. As a result, these

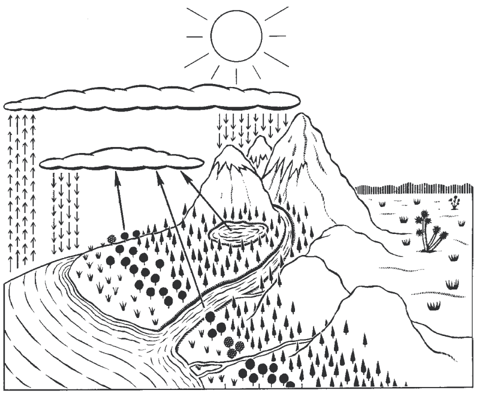

Figure 8. Mountains produce “rain shadows.” A portion of the West Coast in California showing the water cycle west of the mountains and the desert east of the mountains. *Source:* Redrawn from Buchsbaum and Buchsbaum 1972.

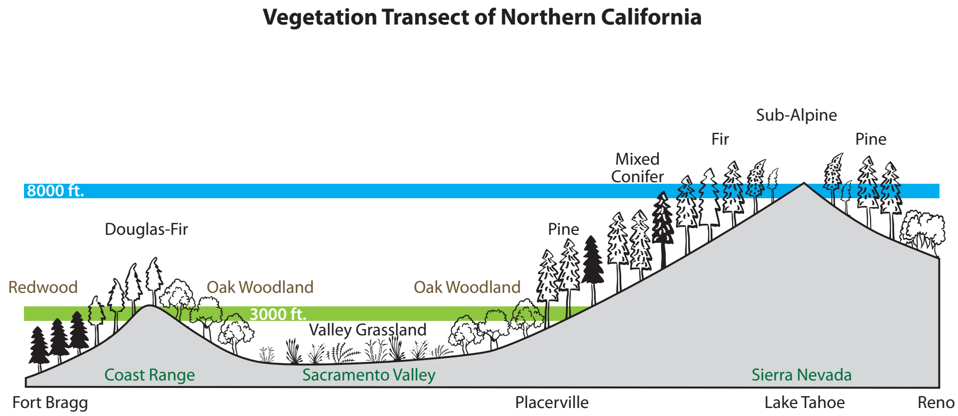

Figure 9. Vegetation transect from the ocean across the Coast Range mountains, Central Valley, and the Sierra Nevada mountains. Moisture-laden storms from the west drop most of their precipitation on the western slopes of the Coast Range and Sierra Nevada. The eastern slope of these mountains are in a droughty rain shadow.

areas have the most extensive forests in California. By the time the air gets to the lee side of the mountains it is depleted of moisture, resulting in a rain shadow—the dry San Joaquin Valley, Great Basin, and the Mojave Desert (fig. 8). Many plants tolerate only limited, specific ranges in temperature and moisture. The extremes of temperature (usually first frost in the fall) and moisture (the length of dry season) are two of the major factors that determine which plant and animal communities can survive. In California's Mediterranean climate most of the state receives little or no precipitation from April to October. However, because of its diverse topography and wide span in latitude there is a great variety of local climates and microclimates. California temperatures can reach 130ºF in the desert or go below –50ºF in the mountains (fig. 9).

The amount, timing, and form of precipitation (rain, snow, or fog) are the major determinants of what vegetation will grow in an area. California forests receive a wide range of precipitation—from as much as 200 inches per year on the North Coast to less than 10 inches in the desert (fig. 10). Snowfall occurs at higher elevations, and the snowpack represents an important source of water for the summer growing season. The unique North Coast redwood forests exist because of the fog belt and year-round temperate growing season along the coast.

Within the dominant climate of an area there are local climates (e.g., the cooler and moister environment of a riparian area along a stream or the difference in temperature between south- and north-facing slopes). At an even smaller scale, plants and animals may find microclimates that meet their special needs. Examples include burrowing animals that live underground where climate and temperature conditions remain very constant, or mosses that find adequate moisture around a spring or seep. On your land you may recognize different microclimates and notice they support different species.

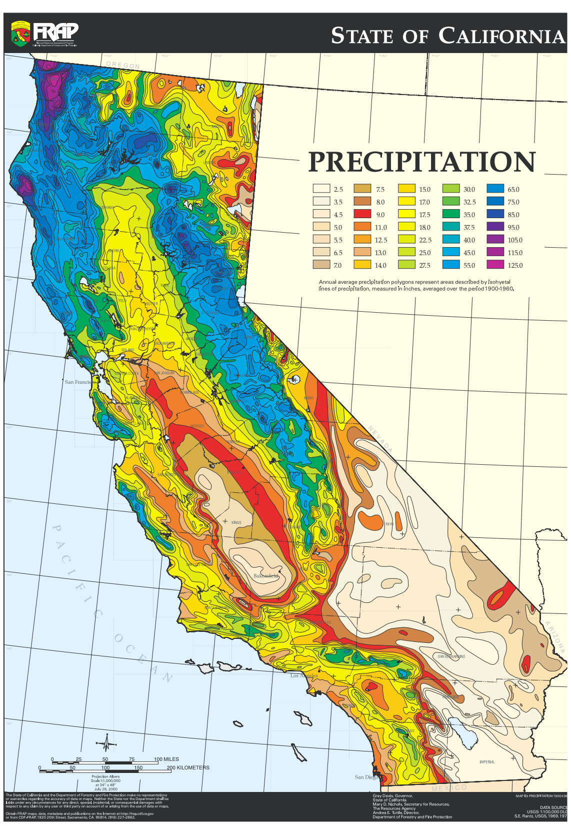

Figure 10. Precipitation map of California; mean zones, 1900–1960. *Source:* California Department of Forestry and Fire Protection.

FOREST SOILS

Soil is the substrate upon which plants grow and from which they get their nutrients and water. Your forest's soil determines what plants can and cannot grow there, and how fast and how much biomass those plants can produce. Keeping the soil healthy and in place protects your land.

Soil is derived from decomposed and weathered parent rock. In the Sierra Nevada and Transverse Range soils develop mainly from granitic rocks. Volcanic materials form most soils in the Cascades. Sedimentary rocks that have been broken down, moved, and deposited by water form the typical North Coast soils. Soils include varying amounts of organic matter, depending on their age and location. The soil's chemical and physical properties, which include texture, structure, organic matter content, nutrients and soil acidity (pH), determine its capacity to grow plants, its susceptibility to erosion and water transmission, and its suitability for construction of roads, septic tank leach fields, and building foundations.

Soil texture is the size and proportions of the mineral particles that make up the soil. It determines how well the soil will retain water and nutrients. The three major soil texture categories are sand, silt, and clay. The relative proportions of these determine the soil texture and physical properties. Sandy soils are coarse textured, clay soils fine textured, and silty soils are intermediate in texture. Loam is a soil texture consisting of nearly equal amounts of sand, silt, and clay. Textures between these classifications can also be used to describe soil types, e.g., sandy loam or clay loam.

Clays are the smallest particles. When wet, they are sticky and plastic, easily deformed, and unable to bear great weight (they make a poor road base). They become hard and strong when dry. Clay soils have tiny spaces between soil particles that hold water for a long time. Clay particles also have large surface areas that hold important plant nutrients. Silt is smooth and slippery when wet. The individual particles are much smaller than those of sand, though larger than clay. Sand is gritty to the touch. It is the largest of the three size classes of soil particles, and the individual grains or particles can be seen with the naked eye. Sand has large spaces between the grains and gives up water to plants easily but also loses water quickly as water drains through the porous grain structure.

Soil structure refers to the horizontal layers, or horizons, of soil, starting with the humus on top, then topsoil, subsoil, and on down to the parent material on the bottom (fig. 11). Organic matter (the decomposed remains of plants and animals) holds soil particles together and provides the phosphorus, sulfur, and nitrogen that are essential for plant growth. Darker-colored soil usually means a relatively high level of organic matter is present. In the inland forests of California where all of the precipitation occurs in the winter, moisture is the most limiting plant growth factor. The soil must hold all the water a plant will require during the rainless growing season. Soils that have a medium or loam texture and are 2 to 4 feet deep to bedrock hold sufficient moisture to sustain and grow conifer forest trees.

Soils supply all the nutrients necessary for plant growth except carbon, which is supplied by

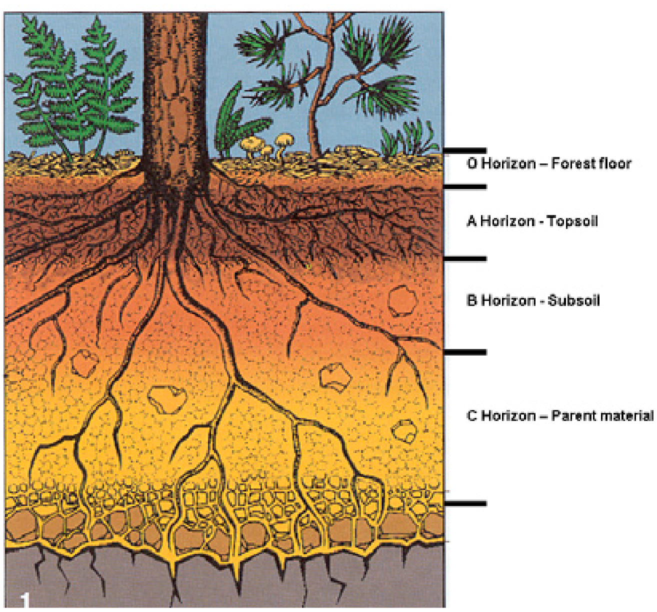

Figure 11. Soil profile. Soil horizons develop like cake layers in response to geology, climate, plants and animals, and time, creating organic matter and nutrient-rich topsoil (A horizon) and clay-accumulating, moisture-holding subsoil (B horizon). Forest soils have a litter (leaves, branches) layer and an organic matter horizon (O horizon) that distinguish them from valley agricultural soils with very little surface organic matter. *Source:* Powers 1990, p. 14.

the atmosphere as carbon dioxide. Soil nutrients include six macronutrients required in relatively large amounts (pounds per acre per year) and eleven micronutrients required in small amounts (ounces or grams per acre per year). The three most important macronutrients are nitrogen (N), phosphorus (P), and potassium (K). Forest soils are typically low in nitrogen content compared with agricultural soils, with less than 1 percent available nitrogen. However, this naturally low level does not result in poor tree growth or health because trees have many years to accumulate the nitrogen necessary for healthy growth (unlike corn or annual crops that must complete their growth in a few months), and trees internally recycle nitrogen and other elements and are not dependent upon decomposition of leaves on the forest floor for nutrients every year. While conifers will respond to nitrogen and other fertilizers, they are unnecessary for normal, healthy tree growth and development. As noted above, growing season moisture is usually the growth limiting factor in California forests.

Mineral deficiencies and imbalances can be seen in plants. A few unique soils, such as those derived from serpentine (California's state rock), have compositions that are toxic to many plants. Specially adapted plant communities have evolved in these areas, including plants that can tolerate the high nickel, copper, and magnesium concentrations.

The concern is often raised that tree harvest will deplete the forest of essential nutrients. In California's temperate forest ecosystems 90 percent or more of a forest ecosystem's nitrogen (and other essential nutrients) is in the soil. The forest floor, with its leaves, needles, and decomposing organic matter, contains another 5 percent of the nitrogen, and all the standing vegetation the remaining 5 percent. Thus, removing all the standing vegetation completely would remove 5 percent of the ecosystem's plant nutrients. Nitrogen is replenished at a rate of a few pounds per acre per year in precipitation (air polluted with nitrous oxides yields even more nitrogen in the precipitation). In contrast, tropical rain forests that have climates suitable for year-round growth have most of their plant nutrients in the vegetation. The soil is relatively sterile, and most plant nutrients are derived from decomposing and recycled plant matter that falls to the forest floor. Tree harvesting in tropical forests can remove significant amounts of nutrients if the nutrient-rich leaves and bark are not left on-site (wood has relatively low nutrient concentrations, which is why wood is not a particularly palatable food except for termites, fungi, and wood borers).

Soil acidity, measured as pH, influences the availability of essential and toxic elements as well as the ability of a plant to take up certain essential nutrients. The acidity of a soil also affects soil microorganisms, whose decomposition activity affects the amount and availability of essential nutrients like nitrogen, phosphorus, and calcium and of toxic elements like boron. Forest soils are generally slightly acidic, a condition to which conifers are well adapted. Highly acidic soils are often associated with iron, copper, or gold mine tailings. Highly alkaline soils are rare in California forests except in serpentine rock areas.

Productivity of the soil in terms of plant growth, or biomass, can increase over time as organic matter increases and more rock weathers into soil, but these changes do not occur within the scale of a human lifetime. Productivity can be improved by management practices such as adding organic matter, fertilizing, and tilling, but these activities are generally too expensive to carry out over large areas of forestland. Although it is difficult to improve the productivity of forestland, productivity can definitely be reduced through poor management. Once reduced, it is difficult to restore. Threats to the soil's productivity include soil compaction, nutrient depletion, and soil erosion. Good forest management practices can minimize these threats.

PLANT IDENTIFICATION

To really know your forest, identify the major species of plants and animals living there. Many good resources are available for doing this, including published and Internet guides and the input of knowledgeable neighbors or professionals. When identifying plants, take care to note any that may be listed as threatened or endangered, as well as those considered to be pests. Also, it is important to know the scientific name of a plant because the common name is sometimes given to two or more different plants, for example, "red fir" has been used for *Pseudotsuga menziesii* (Douglas-fir) as well as for *Abies magnifica*. For scientific names of common forest plants, see table 1.

A tree is a woody perennial (living more than one season) plant that usually has a single trunk. Trees are identified primarily by their leaves, bark, flowers, and shape. They can be categorized as softwoods, conifers, or evergreen versus hardwoods, deciduous, or broadleaf. Conifers are cone-bearing trees with needle-shaped or scalelike leaves. Their cone characteristics, the number and length of needles in a bundle, and their bark texture and pattern can be used to identify them. Broadleaf trees can be deciduous or evergreen; in California all native broadleaf trees are hardwoods such as oak, alder, madrone and tanoak. Broadleaf trees are most readily identified by their leaf shapes and acorns or fruits.

A shrub is a perennial woody plant that usually has multiple stems. Some plant species can grow as either shrubs or small trees depending on environmental conditions. Shrubs are most easily identified by their leaf shapes and fruits. Several California shrub genera such as the *Ceanothus* and *Manzanita* have many species that are difficult to distinguish from each other.

Many annual and perennial herbaceous plants grow in California forests. Common favorites tend to be the showy wildflowers we all love to see in the spring. These plants are best identified when the flowers are blooming. There are many excellent flower guides; it is best to find one written for your region.

Ferns are an ancient group of plants that lack flowers and seeds. They have fronds (leaves), rhizomes (roots), and a rachis (central stalk) (fig. 12). At certain times of year the underside of the fronds bear sori, the reproductive bodies containing spores. The pattern of sori as well as frond shape are identifying features of the ferns.

Although often overlooked, lichens and mosses are important members of forest ecosystems. Lichens, found on the surface of rocks and trees, are often confused with mosses. Lichens consist of a fungus and an alga that live together in a mutually beneficial arrangement called symbiosis. The fungus provides shelter and moisture for the alga, while the alga manufactures food through photosynthesis. Lichens are very hardy and can withstand extreme cold, drought, and sunlight. Some lichens can live on bare rock, where they produce acids that break down the rock, aiding in soil formation. Some lichens are very sensitive to air pollution; the presence or

Table 1. Common and scientific names of plants

Common name	Scientific name
big leaf maple	*Acer macrophyllum*
bitter cherry	*Prunus emarginata*
black cottonwood	*Populus trichocarpa*
black oak	*Quercus kelloggii*
California bay	*Umbellularia californica*
canyon live oak	*Quercus chrysolepis*
ceanothus	*Ceanothus spp.*
coast live oak	*Quercus agrifolia*
coast redwood	*Sequoia sempervirens*
dogwood	*Cornus nuttallii*
Douglas-fir	*Pseudotsuga menziesii*
grand fir	*Abies grandis*
gray pine	*Pinus sabiniana*
hazelnut	*Corylus cornuta*
huckleberry	*Vaccinium ovatum*
incense cedar	*Calocedrus decurrens*
Jeffrey pine	*Pinus jeffreyi*
juniper	*Juniperus occidentalis*
lodgepole pine	*Pinus contorta*
manzanita	*Arctostaphylos spp.*
mountain hemlock	*Tsuga mertensiana*
mountain mahogany	*Cercocarpus betuloides*
mountain misery	*Chamaebatia foliolosa*
oaks	*Quercus spp.*
Pacific madrone	*Arbutus menziesii*
poison oak	*Toxicodendron diversilobum*
ponderosa pine	*Pinus ponderosa*
red fir	*Abies magnifica*
rhododendron	*Rhododendron macrophyllum*
salal	*Gaultheria shallon*
sugar pine	*Pinus lambertiana*
tanoak	*Lithocarpus densiflorus*
white alder	*Alnus rhombifolia*
white fir	*Abies concolor*
whitebark pine	*Pinus albicaulis*
willow	*Salix* spp.

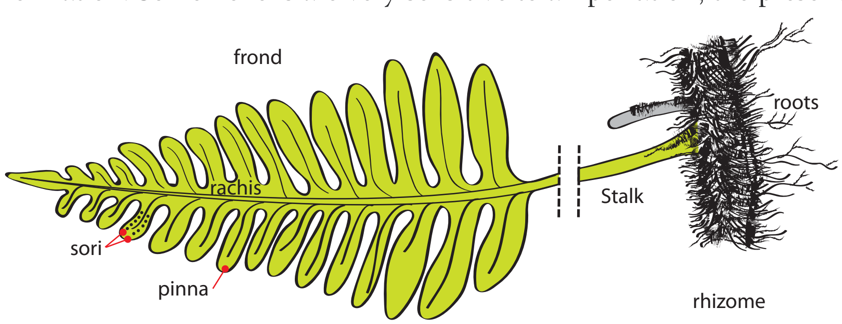

Figure 12. Fern frond.

absence of these sensitive species can help you determine your air quality. Some lichens have a third symbiont, a nitrogen-fixing bacteria that can transform atmospheric nitrogen from an inorganic compound to an organic one useable by plants . Lichens are identified by their forms, colors, and habitat. Mosses are primitive green plants that grow primarily in moist habitats, in riparian areas, or in the shady understory of forest trees. Species identification is difficult and requires some expertise.

Neither lichens nor mosses injure the trees or plants on which they grow. They have neither roots nor vascular systems that invade the plants. They are merely attached to the plants (epiphytes), not parasitic on them as mistletoe or some fungi can be. Neither moss nor lichen grow only on the north side of trees.

A number of common plants do not fit easily into the above categories. These include horsetail, cattail, grasses, sedges, and rushes. Learning to identify these plants, when they flower, and which habitats they prefer can be challenging, but generally is a fun and rewarding experience.

ANIMALS IN THE ECOSYSTEM

Wildlife is an especially fascinating component of the forest, one that many landowners are eager to encourage, or in some cases discourage. Animals depend on plants for their food, shelter, nesting places, refuge, and other elements necessary for survival. Therefore, the composition and structure of the plant community largely determine which animals can be found there. The place where a plant or animal lives is its habitat; what it does in that habitat, its role or function in the community, is its niche. Complex plant communities tend to have more habitats and niches available to support more types of animals. Most animals are associated with specific plant communities and habitats that provide food, water, hiding cover and protection from weather, and nesting or reproductive areas. The best way to manage forestland for these wildlife species is to provide the type of habitat they require.

Most natural forests contain a variety of habitat types: wetlands, meadows, trees of different ages and sizes, snags and fallen logs, various plant communities, and physical features. These provide a mosaic of habitats that can be used by different animals. Each species requires a variety of habitat elements to survive.

A diverse wildlife population is essential to a healthy forest. Wildlife provides vital functions for the forest—they control insect populations, pollinate plants, and aid in seed dispersal. Predators keep the herbivore population in check, protecting the forest from overgrazing. Burrowing animals such as rodents and earthworms aerate the soil and recycle nutrients. Squirrels bury acorns, in effect planting oak trees. Plants and animals in a forest community have evolved complex interdependent relationships that are mutually beneficial and necessary for a healthy forest ecosystem.

Interactions between and among Species

The complex interactions between and among plants and animals in an ecosystem can be positive, negative, or neutral depending upon our management goals, what we are trying to create or achieve. An example of a positive interaction is that of trees and mycorrhizae (fungus root). Mycorrhizae are fungi that bond with plant roots and assist host plants in obtaining water and nutrients by growing faster and into a larger soil volume than the roots can alone. Mycorrhizae also provide host plant roots with antibiotic defense from soilborne diseases. In exchange, the fungi receive carbohydrates from the tree's photosynthesis. This type of mutually beneficial association is called symbiosis. Negative interactions are also important in defining the forest ecosystem. One important example is competition. Competition occurs in nature for any factor that is in limited supply, including space, sunlight, water, nutrients, food, mates, habitat, and so on. The

Two Survival Strategies: Specialist versus Generalist

Giant sequoia is something of a specialist ecologically. Limited to a small number of groves, it requires specific conditions to grow and reproduce successfully. Its shallow but extensive fibrous root system grows best in deep, well-drained sandy loams. It prefers moderate climate sites, such as drainage bottoms and meadow edges. Adequate soil moisture throughout the dry growing season is critical for successful regeneration of giant sequoia, although seedlings do not survive in wet soils. Regeneration depends on an occasional intense, large-scale fire to open the cones and create a seedbed for the young seedlings to survive. Light intensity, frequent fires are also necessary to thin out the more shade-tolerant but fire-intolerant white firs that compete with young sequoia seedlings for light and soil moisture.

Douglas-fir is something of a generalist. Widespread throughout the West, it thrives in a variety of habitats, soil types, and environmental conditions. Its moderate shade tolerance allows it to grow in the understory and respond well when light and moisture become available by thinning or the death of competing trees. Older trees develop a thick, fire-resistant bark.

ability to outcompete others for the necessary life requirements is a key to survival for plants and animals. The forest practice of thinning young trees decreases competition for sunlight, water, and nutrients and increases the remaining trees' survival and growth, as well as their resistance to insect and disease attack.

Species can be highly adapted for very specific conditions (specialists) or can tolerate a wide range of conditions (generalists). Specialists have an advantage when conditions are stable; they can often outcompete the generalists in their limited habitat. However, when conditions change, specialists may have trouble surviving and adapting to the new conditions.

DECOMPOSERS

Bacteria, mold, fungi, some insects, and other small and often overlooked organisms play an extremely vital role in any ecosystem. They are the recyclers, responsible for breaking down the bodies of plants and animals into their nutrient elements, making them available to plants. As these tissues decay, they become dispersed into fragments called organic detritus. Organic detritus is a food source, improves soil texture, and provides nutrients to the community. Nutrient-rich leaves decay more quickly than nutrient-poor wood.

In forests in the western United States, wildfire is an important decomposer of plants. In tropical rain forests and eastern hardwood forests with year-round moisture, biological decomposition plays a large role in reducing plant and animal material to nutrient elements that return to the soil for uptake by plants. Many western forests have extended dry seasons when it is too dry or too hot for biological decomposition to proceed rapidly. Biomass accumulates to the point where it will carry a fire. Human fire suppression efforts in the twentieth century have limited the extent of frequent, low-intensity wildfires and have allowed forest fuel to build up to the point where large, intense, catastrophic wildfires are occurring that cannot be easily suppressed.

BIODIVERSITY

Biological diversity, or biodiversity, is the variety and abundance of life forms, processes, functions, and structures of plants, animals, and other living organisms in an ecosystem. Biodiversity can be assessed at the level of the gene pool, species, community, ecosystem, or region or landscape (multiple ecosystems). Each level of biodiversity has three components: compositional diversity, or the number of elements within the system at that scale; structural diversity, or the variety of patterns or organizations within a system; and functional diversity, or the number of ecological processes within a system. The effects of changes in biodiversity thus depend on the scale and the aspect of biodiversity being considered. Changes in species diversity and habitats are often used as indicators of the health of an ecosystem.

Young forests usually have a greater number of individual species—often generalists and weeds—than do mature forests. As a consequence, they may have a higher level of biodiversity as measured by the number of species. But older forests support some species that cannot survive in younger forests due to the species' more complex habitat requirements. Older forest characteristics include decaying logs, shrubs, a variety of tree species, snags, and often a multilayered canopy that supports a community of canopy dwellers. Some wildlife species such as northern spotted owl and Pacific fisher are highly dependent on old-forest habitat and have been reduced in numbers because this habitat has become increasingly scarce. In the case of the northern spotted owl, it has effectively become an emblem for old forests, even though in California it has been shown to survive in younger forests as well.

The example of the northern spotted owl illustrates the problem inherent in the concept of biodiversity. Biodiversity must be understood in the context of scale and level of biological organization. In some circumstances, managing to maximize one aspect of biodiversity, such as species diversity, may take a tremendous toll on certain plant or wildlife species. As a general rule, managing for biodiversity at the landscape level is most feasible and sustainable, that is, creating a diversity of different habitats over a relatively large geographic area will provide the most ecological benefits over the long term.

ENERGY FLOW THROUGH AN ECOSYSTEM

All living things need energy to survive. Solar radiation from the sun is the source of energy that supports most natural ecosystems. Through photosynthesis, green plants convert light into chemical energy (carbohydrates) that supports the production of wood, leaves, branches, fruit, seed, and so on. Herbivores get their energy by eating plants, carnivores by eating other animals, and decomposers though the breakdown of plants and animals. Through decomposition, nutrients are made available to the soil flora and fauna and energy (in the form of heat) is released to the environment. Each step in this chain is called a trophic level. In natural communities this complex chain is often called the food web. As energy flows from the sun through an ecosystem, at each step some of the energy is lost to the environment in the form of heat during metabolism and decomposition.

Follow the Energy through an Ecosystem

Energy flows through an ecosystem by many pathways. A tree absorbs sunlight through its leaves and converts it to chemical energy (i.e., carbohydrates and plant tissues) through the process of photosynthesis. Some of that energy is stored as cellulose and carbohydrates in the trunk, roots, fruit, and leaves for the tree's later use or is used to support the process of gathering more sunlight. The tree respires, burning sugar to produce energy for cell functions. An animal, such as a deer, browses the foliage for its energy needs. When leaves or branches fall to the ground, decomposers—worms, insects, and fungi—take over, breaking the leaves down to smaller and smaller components that can eventually be taken up by the roots again as nutrients. A robin might eat the worm that helped decompose the leaves; a hawk could then feed on the robin. The fungus that grew on the worm's castings could form a mushroom, which is eaten by a squirrel that is eaten by a fox. When the fox dies, its body feeds scavenger insects and fungi.

CHEMICAL CYCLES

While energy flows one way through the system requiring constant input from the sun, other processes cycle elements around and around with no net gain or loss of the element, just transformation or change in its form.

Nitrogen, an essential element for life, is an important example. The atmosphere is approximately 78 percent nitrogen. Despite its abundance, gaseous nitrogen (N_2) cannot be used by plants and animals directly. It must be transformed, or fixed, into ammonium (NH_4). Nitrogen fixation occurs naturally in two ways: a small amount is produced by lightning, but much more is produced on land by special types of bacteria. Nitrogen-fixing bacteria are found in soil or water or in swollen tissues, called nodules, on the roots of some plants (such as legumes and ceanothus) or in some species of lichens. These plants and bacteria have formed a mutually beneficial (symbiotic) relationship where the bacteria gets water, nutrients, and protection from the plant in return for supplying the plant with a source of fixed and biologically available nitrogen.

Once nitrogen enters a plant it is transformed into proteins and other compounds necessary for plant tissues and functions. When animals eat the plants, they incorporate the nitrogen into their own tissues. Eventually, the nitrogen in proteins and tissues is released by decomposers, where it can go through a decomposition process called denitrification that turns the usable nitrogen back into nitrogen gas, which then returns to the atmosphere.

Low natural rates of fixation often make nitrogen the limiting factor in plant growth. This limitation can be overcome with the use of nitrogen fertilizers, but application of too much fertilizer can cause water quality problems. Nitrogen fertilizers are highly soluble and may run off into rivers, lakes, and streams, causing pollution. Nitrogen oxides, a product of automobile exhaust and burning fossil fuel, can create smog and can fall as acid rain. In Southern California, such nitrogen-rich rain is fertilizing some ecosystems and changing their composition and productivity, often to the detriment of the native plants that tolerate naturally low levels of nitrogen. On the North Coast there is increasing evidence that the returning spawning salmon are an important source of nutrients for those ecosystems, bringing nitrogen and other elements harvested from the ocean back to terrestrial watersheds, where they spawn and die along the river banks to decompose or be eaten by other animals.

Other chemical elements are cycled through ecosystems in similar ways. These include carbon, hydrogen, oxygen, nitrogen, phosphorus, calcium, and potassium. These chemicals are absorbed by plants from the soil or air; the plants are then eaten by animals, and eventually decomposers break them down, returning the elements to the soil or water and carbon dioxide to the air.

Any element in short supply may be the limiting growth factor for a plant or animal. For example, calcium is often deficient in serpentine soils, which limits the species of plants that can grow there. Some plants and animals have evolved the ability to survive in these otherwise “hostile” environments.

WATER CYCLE

In California, with its Mediterranean climate and annual drought period, water is the most important factor limiting plant growth and ecosystem productivity. The water (hydrologic) cycle dramatically shapes the environment (fig. 13). It begins when water evaporates from oceans, lakes, rivers, and other water bodies. In addition, water moves from the soil through roots and stems to the leaves and then to the atmosphere, a process called transpiration. Water in gaseous form (water vapor) in the atmosphere con-

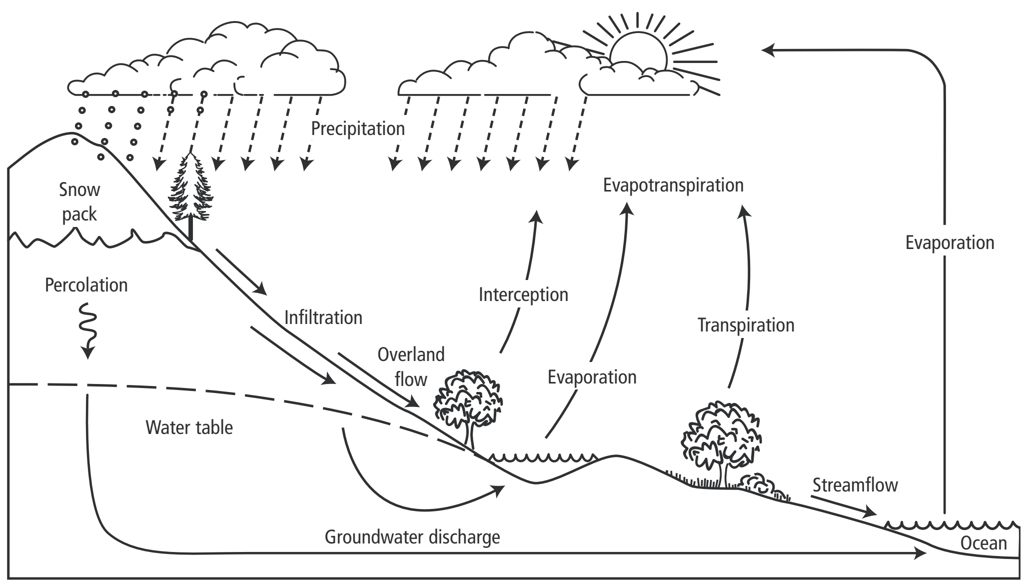

Figure 13. The water, or hydrologic, cycle.

denses into clouds as it rises and cools, eventually falling as precipitation. When precipitation reaches the ground as rain or snow, most of the water that is not absorbed by the soil and plants returns to streams and lakes and eventually reaches the ocean. Some is stored as groundwater.

SUCCESSION

In studying forest communities, patterns of plant development emerge. One of these is known as succession, the somewhat predictable and often lengthy sequence in which one community replaces another, ending in a climax community that is self-perpetuating. For example, after a fire or other large-scale disturbance, the first plants to reestablish themselves tend to be grasses and various herbaceous species that grow quickly in direct sunlight. These give way to larger shrubs (e.g., chaparral species such as manzanita) that grow more slowly but eventually shade out the grasses. The chaparral plants may grow so densely they exclude other species for a long time, perhaps decades. Trees such as pines need sunlight to grow. If there is an opening in the chaparral the trees can get above it in a few years, shading out the chaparral, which requires sunlight. The reforestation technique of removing brush for the first few years after planting to “release” young seedlings is actually a practice to speed the successional process along to the next stage.

Succession may include changes in soil chemistry as well as species composition. After a fire, when nitrogen in the soil may be deficient, plants that can grow in low-nitrogen conditions have an advantage. Plants such as lupines or alder, which contain nitrogen-fixing bacteria in their roots, are often pioneer species. As these first pioneer plants in an open, cleared site grow and die they decompose, releasing their organic matter and nitrogen to the soil. This allows species that require more nitrogen to grow in that place.

While succession is often thought of as a well-ordered process, in looking at the total ecosystem you may find many variations in the pattern. Variations in succession occur for a number of reasons, including special soil conditions, microclimate, disturbance, and random chance. The size, severity, and timing of disturbances can vary a great deal. For example, a wildfire burns with varying severity depending on the time of day, wind speed, and air temperature and humidity, creating some areas where trees are killed by a high-intensity fire and plant succession starts over and other areas where many trees survive a lower-intensity fire and the forest does not start anew. Or, insects or disease may attack and kill a particular tree species (bark beetles, root diseases, and dwarf mistletoe are often tree-species-specific), naturally thinning the forest to the advantage of the trees and plants that are unaffected by the disturbance. Consequently, in any forest landscape we may see a mixture of vegetation, including nonforest stages of succession. This mosaic of habitats occurs in any natural ecosystem.

DYNAMIC ECOSYSTEMS

Ecosystems are constantly changing. Forest succession is the more or less orderly change over time as plants grow larger, taller, and more extensive and out-compete other plants for light, water, and nutrients, suppressing or killing them. Disturbance is an expected though usually unpredictable part of any ecosystem that occurs naturally in the form of fire, flood, insect and disease damage, wind throw, and other natural events. Many common forest practices mimic natural disturbance to some extent. For example, prescribed burns introduce fire into the ecosystem in a controlled manner, and timber harvest opens up the forest floor to sunlight.

Fire is a significant form of disturbance in California forest ecosystems. Many California forests are adapted to fire and have trees, plants, and animals with structures and reproductive cycles that tolerate fire of a certain frequency and severity. In the Sierra Nevada, mixed conifer forests have adapted to frequent (every 10 to 20 years), low-intensity surface fires that tend to kill small trees, grass, and brush but do not kill the larger, thicker barked trees. Some fire-adapted brush species resprout following fire, giving them an advantage over species that grow from seed and take a few years to become established. Fire also releases the seeds of trees and plants that need fire to germinate, cleans the forest floor of accumulated duff and litter, destroys insects and disease-causing organisms, thins smaller trees, releases nutrients from plant tissue into the soil, and produces mosaics of habitat in the forest.

Disturbance opens up the forest canopy, allowing the establishment of new plants, in effect setting succession back to an earlier state. However, in many of our forests disturbance size and severity has increased beyond the historic natural range due to human influence. Roads, dams, logging, fire suppression, and prescribed burning can have a negative effect on the forest. In particular, wildfires have become larger and more severe since 1900, when we began to successfully suppress small fires. A forest that historically would have burned with relatively low intensity every 20 years has built up 100 years' worth of fuel and now burns with great intensity and rapid spread.

Although disturbance is natural and necessary, there is a matter of scale. Humans perceive as "natural" (and prefer) disturbance that occurs on a small scale, in patches in the forest. When disturbance occurs over vast areas of the forest, more time is required for recovery. Intense fire, for example, may change the soil chemistry or make the soil impermeable to water, which can cause erosion. If all the seed trees are killed over a large area, it takes longer for new trees to become established and longer for the associated wildlife to return.

ECOLOGICAL FUNCTIONS

The forest ecosystem is more than the sum of its parts. As a whole, the ecosystem performs a number of functions, or services, with benefits far beyond its borders. Through photosynthesis, forests release oxygen to the atmosphere and store carbon in wood, producing the oxygen we breathe and ameliorating some of the causes of global warming. Forests can moderate local and regional temperatures. Water is filtered and purified through the soil and litter of forests. The rate of water runoff is decreased, preventing floods and increasing the amount of water that percolates through the soil to underground aquifers. Forest vegetation protects soil from erosion. Forests support the organisms that keep the food web intact. They stabilize stream banks and provide cooling cover, large woody debris, and food sources for fish. These and other functions are part of the life support system of our planet.

USING ECOLOGICAL CONCEPTS FOR MANAGEMENT

To manage the forest as an ecosystem that provides services and life support functions consider the following management strategies.

- Reduce soil disturbance in all your activities.
- Recruit and retain some logs, snags (standing dead trees), and debris in the forest to provide habitat and nutrients to the soil.
- Protect riparian areas by providing functional habitat buffers along streams.
- Arrange harvest units so as to provide corridors for animal use.
- Provide structural diversity appropriate to your forest type.
- Reintroduce fire where practical.

RESOURCES

Most private forestland has a National Forest in its vicinity. The Forest Service has a wealth of information on forest ecology, soils, climate, and other environmental conditions that you may find relevant to your forest and its management. It is best to visit local Forest Service offices to find out what is available; for the location of your local office, visit the Forest Service's Pacific Southwest Region Web site at http://www.fs.fed.us/r5/.

Numerous texts and popular books and articles focus on California forest ecology. These can be accessed through university libraries or through in Internet search for "California forest ecology."

The California Native Plant Society (http://www.cnps.org) has many publications that will assist you in identifying plants on your property.

The Natural Resources Conservation Service may have soil maps that include your property; see http://www.ca.nrcs.usda.gov/ and http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx.

Visit the California Biodiversity Council Web site at http://ceres.ca.gov/biodiv/ to find out more about challenges of protecting and preserving California's natural heritage.

Finally, your local California Department of Forestry and Fire Protection (CAL FIRE) (http://www.fire.ca.gov) and Department of Fish and Game (DFG) (http://www.dfg.ca.gov) staff will be well-informed about forest ecology, timber harvest impacts, and related matters. The CAL FIRE Forest and Resource Assessment Program (FRAP) has a tremendous amount of mapped and published information; find them at http://www.fire.ca.gov.

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What tree is that? A guide to the more common trees found in the Western U.S. Nebraska City, NE: National Arbor Day Foundation. Order from the National Arbor Day Web site, www.arborday.org.

Online Guides

Calflora, California wildland plants Web site, http://www.calflora.org/index0.html.

CalPhotos: Plants, UC Berkeley CalPhotos Web site, http://calphotos.berkeley.edu/flora/.

Natural Resources Conservation Service Plants Database, http://plants.usda.gov/.

What Tree Is That? Online tree identification database, National Arbor Day Foundation Web site, http://www.arborday.org/trees/treeID.cfm.

ENGLISH–METRIC CONVERSIONS

English	Conversion factor for English to Metric	Conversion factor for Metric to English	Metric
Length			
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