Exploring Forests

What is a forest?

In essence, forests are large, continuous stands of trees. Throughout the world there are many different types of forests, but a common characteristic of forests is that trees are the dominant type of vegetation. The main factor that determines what type of forest will grow in any one region is climate, primarily the patterns of **precipitation** and the annual temperature range. Forest distribution is affected by humidity, cloud cover, snowfall, the number of frost-free days and wind. It is also affected by non-climatic factors such as **soil** type, fire frequency and the presence of animal species. Despite the fact that there are many different types of forests, the world's forests can be divided into two main groups: temperate and tropical.

Forest Structure

Temperate and tropical forests differ in many regards, including climate, density, degree of diversity, and plant types and animal species. However, in many other ways, all forests are also very similar. Forests are all dynamic communities made up of living and non-living components. All natural forest systems contain: small, non-woody plants; fallen branches; dead logs; and trees varying in age, size and type which overlap to form forest layers.

A forest can basically be described as having three different layers: the ground layer or **forest floor**, the shrub layer or **understory**, and the tree top layer or **canopy**. In some forests, such as tropical rain forests, there are a few trees that grow taller than all the rest and stick out above the canopy. These taller trees are referred to as the **emergent layer**. Each level of the forest has its own unique features as well as its own inhabitants. Although most forest animals nest, feed and carry out their other activities in only one or two layers of the forest, some are known to travel through and utilize all layers of the forest.

The forest floor is primarily comprised of soil; leaf litter; seedlings; and shade-tolerant, **herbaceous** (non-woody) plants. Large, heavy mammals make their homes on the forest floor. In addition to the larger ground-dwelling animals, there are many smaller animals living under fallen logs or in the leaf litter. Leaf litter is teeming with life as microscopic **organisms** break down all the dead material that falls to the forest floor. These crucial members of the forest community release **nutrients** back into the soil where they can then be absorbed by plants.

In both temperate and tropical rain forest, the soil is thick with **mycorrhizal** (mahy-kuh-RAHY-zuhl) **fungi**, which literally translates to "fungus roots." Trees form symbiotic relationships with these **fungi**, which increase the roots' water and nutrient gathering capacity by expanding the surface area of roots and by penetrating into smaller pores than is possible for plant roots. Mycorrhizal fungi can provide as much as ten times the absorptive surface as plants without the association and are essential in absorbing phosphorus, zinc, copper and other nutrients. In return, the fungi receive sugars made during **photosynthesis**, sometimes as much as 5 to 10 percent of the plant's total production (Brady and Weil, 1996). In temperate forests, mycorrhizal fungi are important in gathering water during dry summers and in obtaining nutrients in areas where soils are heavily leached.

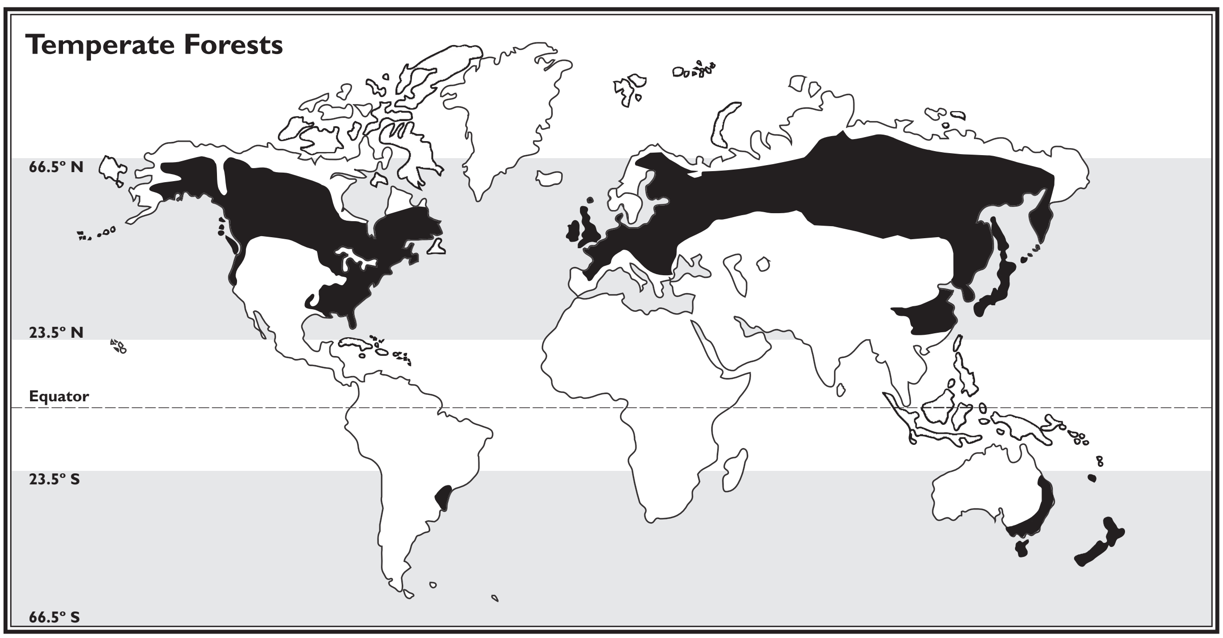
Above the forest floor, small and young trees, as well as shade-tolerant bushes, create the understory of the forest. The understory is home to many birds, reptiles, insects, amphibians and small mammals that travel up and down through the forest understory in search of food. In the tropics, **lianas** (woody vines) may extend from tree to tree and from the treetops to the ground.

These vines provide ample pathways for animals to move through the forest without ever coming down to the ground.

The canopy layer of the forest has the greatest exposure to the sun's energizing rays. Because of this, many other plants use these tall trees as a platform to grow closer to the sun. One characteristic of both temperate and tropical rain forests is the presence of **epiphytes**, or plants that grow on other plants instead of in the soil of the forest floor. Often called "air plants," epiphytes exist in temperate forests in the form of mosses, liverworts, **lichens** and some ferns. In the tropical rain forest, however, they explode in number, size and diversity. It's estimated that a quarter of all plant species that live in lowland rain forests are epiphytes. They can be as small as the algae, lichens and moss **epiphylls**, which colonize the surface of a leaf, or as large as full-grown trees.

Animals that make their home in the canopy must be hardy because, unlike species inhabiting lower levels of the forest, they are not as sheltered from wind, rain and sun.

When present, the emergent layer is made up of the crowns of a scattering of very tall trees that stick out above the canopy. In addition to providing food, these trees are often used by animals as temporary perches or lookout posts. The emergent layer is primarily found in tropical rain forests and is uncommon in temperate forests.



Temperate Forests of Washington

Temperate forests grow throughout the world at mid-latitudes in areas lying between the hot tropics and the cold polar regions (latitudes 23.5° and 66.5° North of the Equator and between latitudes 23.5° and 66.5° South of the Equator). Temperate forests grow where the climate is relatively mild year-round. Much of Washington is blanketed by low-elevation coniferous temperate forests. These include the drier forests of eastern Washington (the east slopes of the Cascades, southern arms of the Okanogan, Kettle, and Selkirk ranges, and the northern arm of the Blue Mountains), to the wetter west slopes of the Cascades and east slopes of the Olympics, to the wettest west slopes of the Olympics. For this curriculum, we have chosen to discuss temperate forests typical of the lowlands of western Washington. Remnants of these forests can be found in and around our urban and rural neighborhoods and may therefore be a familiar reference point for many students. *For more information on Temperate Rain Forests, please see the zoo's Washington Wildlife teacher packet.*

Temperate lowland forests of Washington are dominated by **needleleaf** (as opposed to **broadleaf**) trees, most of which are **evergreen conifers** such as cedars, hemlocks, Douglas firs and true firs. The conical shape of many conifers helps the trees to capture as much of the cloud-filtered light as possible, especially in winter when the sun is perpetually low in the sky. This shape and their flexible boughs also help trees shed heavy snow in winter. Most conifers are evergreen (they retain their needles year-round) which increases their capacity to photosynthesize throughout the year. This ability is especially important in the Pacific Northwest, where most precipitation falls in winter and droughts are common in the summer. The occurrence of summer droughts limits the distribution of **deciduous** trees because they need moisture during the summer, when they have leaves, to carry out photosynthesis. Thus, the Pacific Northwest climate favors needleleaved evergreen trees. **Riparian** areas (river corridors) are often dominated by broadleaf deciduous species such as vine maple, red alder and black cottonwood.

Weather in temperate forests is seasonal with distinct wet and dry periods and temperature variations. Because of this, the growth rate of plants varies with the seasons. The growth rings on trees are a result of this seasonal growth. Rapid spring growth produces a wide light ring. As growth slows down in summer a smaller, darker ring is formed. Thus we can tell a tree's age by counting the numbers of paired light and dark rings.

Temperate Forest Soil

Soil is formed when the bedrock, or parent material, breaks down into clay, silt and sand particles and mixes with organic matter. In temperate forests, insects, banana slugs, tiny microbes and other decomposers work to break down the thick layer of leaf litter that has fallen from trees above. As the organic material decomposes, nutrients are slowly released into the soil. Despite the work of decomposers, climate slows the decomposition of organic matter and, consequently, soil formation. Long, cold winters and short, relatively cool summers mean that it may take as long for a tree to decay as it did to grow in the first place; a 300-year old tree might take three centuries to decay. This means that on the temperate forest floor there is often a thick layer of duff—decomposing organic materials—found between the soil and the litter layer of freshly fallen twigs, needles, and leaves. Because of this, tree roots are extensive and may penetrate the soil three feet (one meter) or more in order to access water and nutrients deeper in the soil. These deep roots also help stabilize the tree during windstorms.

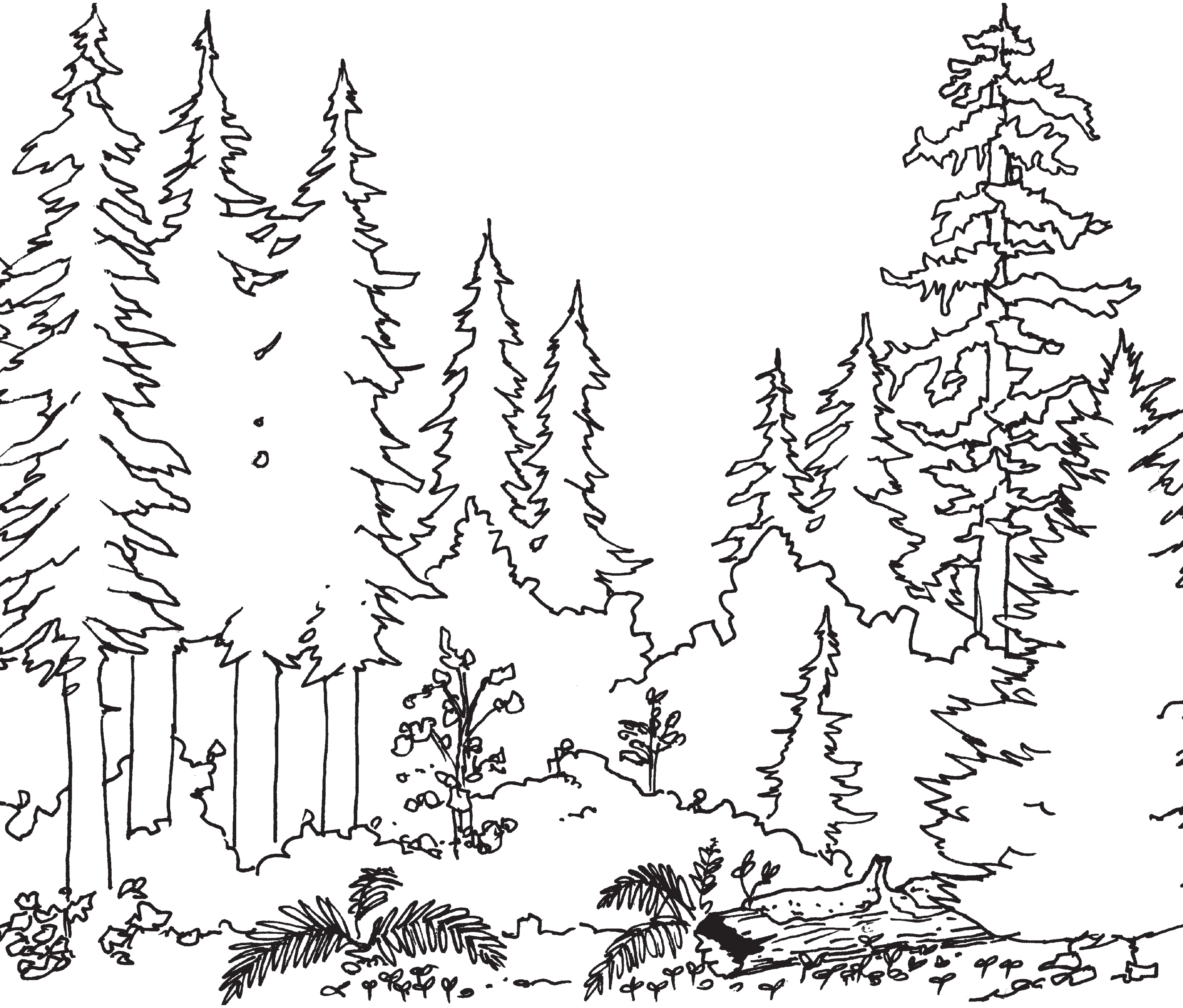
How is a Temperate Forest Born?

Forests are born through a process called forest succession. Natural clearings can be created by wind, fire, disease or other **disturbances**. Clearings are rapidly colonized by pioneer plant species, such as red alder, which enhance soil structure and fertility. Red alder have special bacteria living in nodules on their roots; these bacteria convert atmospheric nitrogen into a form of nitrogen that plants are able to use. Forest soil is further improved by fast-decomposing, nitrogen-rich alder leaves.

Douglas fir can also be considered a pioneer species. It grows well on mineral soil, such as that which forms after a volcanic eruption. Unlike western hemlock, which has tightly packed needles along its branches to capture light, Douglas fir has less densely packed needles on its branches. Capturing less light than the hemlock, it doesn't grow well in shade. Most pioneer plants can't compete in shady, closed habitats. With the passing of time, soil conditions improve and western hemlock eventually becomes the dominant tree species. If left undisturbed, hemlocks and other shade-tolerant plants will continually reseed themselves, forming what is called a climax forest.

Of course, change is the rule, not the exception in forest ecosystems. In most instances, forests will be exposed to a variety of disturbances long before a climax forest is formed, triggering the cycle of forest **succession** to begin again.

Temperate Forest Layers

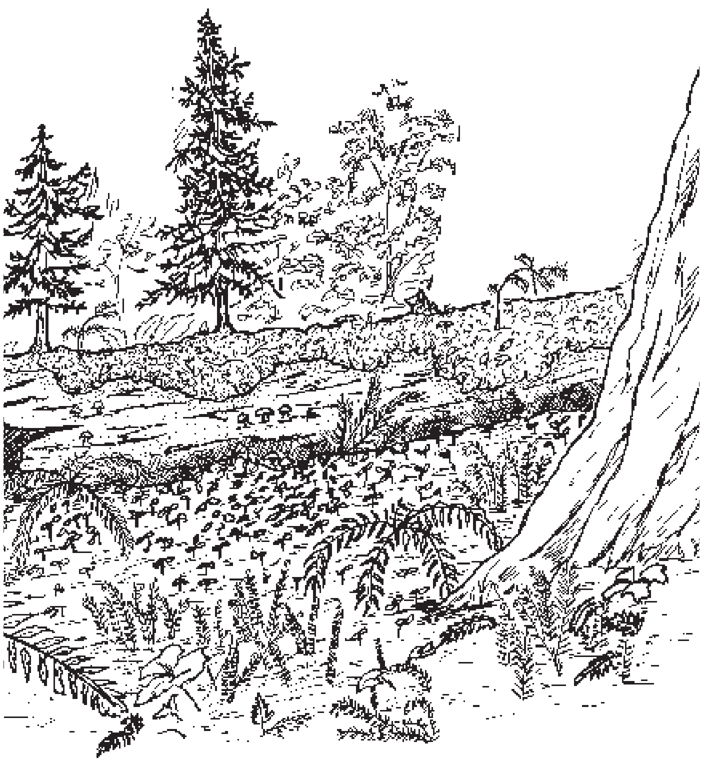


Forest layers are particularly well developed in old growth temperate forests. In addition to vertical layers, old growth forests are characterized by trees more than three hundred years old, an abundance of downed logs on the forest floor, and the presence of snags throughout the forest. These components add further structural diversity to old forests. Horizontal diversity is created when old trees fall and open up small areas of increased light that encourage young trees in the understory to grow and reach toward the canopy.

Forest Floor

Plants of the Forest Floor

The temperate forest floor is a green carpet of herbaceous plants and mosses, which grow vigorously on decaying wood and other organic material, aiding in the **decomposition** process. Ferns are widespread forest floor dwellers, with sword fern being the most abundant. False lily of the valley, queen's cup, and twinflower are among the other herbaceous plants that form extensive green patches. Numerous tiny tree seedlings can also be found, such as the shade-tolerant western hemlock.



The presence of a great number of downed logs on the forest floor may be one of the most important characteristics of mature temperate forests. Nearly all western hemlock tree seedlings in the Olympic rain forest, for example, are established on downed logs or decaying snags. These forest floor **"nurse logs"** and "mother snags" (in the understory) provide a constant supply of moisture and nutrients. The latter also boost the seedlings beyond the reach of browsing animals and up to the light that filters into the understory.

Animals of the Forest Floor

Invertebrates

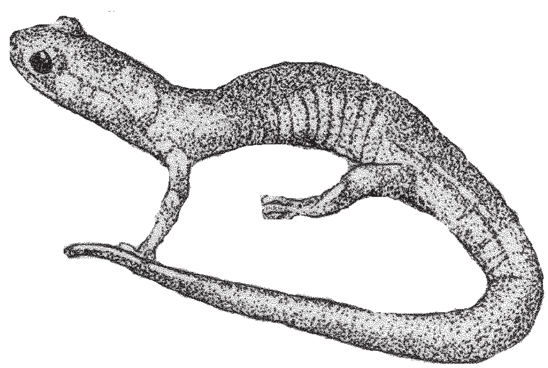
Many organisms, including insects (especially beetles) and fungi, invade downed logs soon after they fall. While a mature tree is alive, only 10 percent of its mass is actually living at any one time. The rest is dead wood which provides structural support. When the tree dies, it can attain a greater ratio of living matter to dead mass due to inhabitation by animals, fungi, and plant roots. Thus, it is aptly stated that a tree may be more dead when alive and more alive when dead. In logs on the forest floor, many insects and other **arthropods** find homes and food. These include bark beetles and wood-boring insects such as ambrosia beetles. Beetles are key species when it comes to the decomposition of logs because they bore tunnels into the wood, carrying with them **bacteria** and fungal spores that will continue the decaying process. Ambrosia beetles deposit fungal spores in holes they have bored and feed on the fungus that grows there. Once the beetles have started the process, the logs are further colonized by carpenter ants, termites, millipedes, mites, centipedes and other arthropods.

On the forest floor, banana slugs spend their time feeding on fungi, lichen and leaves of plants. The banana slug is the most common **native** slug of Washington's temperate forests. Most other slugs in our region were introduced from Europe. When slugs eat fungi, the spores pass through their digestive systems undamaged but prepared to germinate. This digestive tract journey is necessary to initiate germination of many fungal spores.

Amphibians

Amphibians find prime **habitat** in Washington's temperate forests. Cope's giant salamanders are usually associated with flowing water. In fact, Cope's giant salamanders differ from other salamanders in that they usually do not complete metamorphosis to become terrestrial adults. Instead, Cope's salamanders remain as aquatic larvae that are capable of breeding. Larvae of other salamanders, such as ensatinas and western redbacks, become terrestrial adults and are often found in leaf litter or fallen logs on the forest floor. Salamanders eat aquatic invertebrates during their water life stages and terrestrial invertebrates during their land life stages. Salamanders and other amphibians help to control populations of invertebrates, such as insects, in temperate forests.

The tailed frog of the Pacific northwest is the only species of tailed frog in North America. The only other tailed frogs in the world are found in New Zealand, where there are three species. Tailed frogs are **nocturnal** and spend most of their time in cool,



clear, fast-flowing waters in forested areas, only foraging on land when humidity is very high. More common frogs of Washington's temperate forests include Pacific treefrogs and red-legged frogs. Pacific treefrogs are widespread across the state from sea level to high montane elevations, while red-legged frogs occur primarily west of the Cascades below 2,800 feet (850 m). Despite their common name, Pacific treefrogs spend most of their time moving along the ground or in low shrubs. Most frogs are herbivorous as tadpoles but eat small invertebrates as adults. Frogs are often preyed on by snakes and birds.

Reptiles

Northern alligator lizards can be found at the margins of forests and in logged areas under downed trees and rocks. Northern alligator lizards eat all kinds of arthropods and sometimes small vertebrates, but do not eat roughskin newts and most salamanders, due to the toxic skin secretions of these animals. Common and northwestern garter snakes also inhabit western Washington low-elevation forests, as do western fence lizards, painted turtles, rubber boas and western terrestrial garter snakes.

Mammals

One complex web of interactions that involves small mammals is also important for the giant trees of the forest. Some mycorrhizal fungi produce above-ground mushrooms, others produce below-ground truffles. It has been discovered that many small mammals regularly search for and eat truffles. Truffle-eaters include flying squirrels (also the only lichen-eating rodent), red-backed voles, deer mice, chickaree squirrels, chipmunks and hares. The spores of the truffles survive their passage through small mammal digestive systems and are dispersed when the animals move throughout the forest. The dispersed spores will grow their own **mycelia** and create new mycorrhizal relationships with the trees. Pacific northwest trees that are grown without a mycorrhizal association do not fare as well as trees with mycorrhizal help. Thus, small mammals are vital to the overall health of a forest.

Other forest floor inhabitants include shrews, which have extremely high energy needs and search non-stop for food. Terrestrial species of shrews burrow in the leaf litter of the forest floor looking for insects, while water shrews often prey on amphibians and other aquatic animals. Water shrews even eat salamanders, which most other animals find unpalatable.

Mountain beavers, the oldest known living rodents, are often referred to as "living fossils." Inappropriately named, mountain beavers are not actually beavers and they most commonly inhabit lowlands, not mountains. Mountain beavers are found mainly in western Washington but also inhabit the Okanogan Highlands. Mountain beavers are burrowing, voracious **herbivores** and prefer damp openings, such as ravines and deciduous tree groves, within coniferous lowland forests. Here, they harvest plants, mainly ferns and small flowering plants, to store over the winter.

Spotted and striped skunks are members of the weasel family that inhabit temperate forests. Skunks prefer damp lowland riparian areas with deciduous trees. They also frequent cleared areas. In the winter and spring, skunks prey mainly on small mammals, such as cottontail rabbits and mice, while in summer and fall they primarily eat insects (especially beetles), berries and other parts of plants in addition to mammals. Skunks will also eat **carrion** when available. Skunks may be preyed on by great horned owls. It has been noted that great horned owls sometimes have a slightly skunky smell about them! Great horned owls, like most other birds, do not have a well-developed sense of smell, so eating skunks is no problem for them. Skunks are fairly sociable animals and will often share their dens in rotting logs or stumps with several other skunks. Skunks will generally not spray unless persistently threatened.

Through grazing, browsing and trampling, Roosevelt elk often influence the composition of understory and forest floor vegetation. For example, the growth of ferns and shrubs is limited by elk, thus creating a more open understory and encouraging the vigorous

growth of herbaceous plants on the forest floor which in turn provide good grazing for the elk. As referred to earlier, seedlings growing on large logs or snags have a better chance of surviving because they are out of reach of the elk.

Black-tailed deer, due to their smaller size, have far less impact on forest vegetation than do elk, but are an important food source for several **predators**, such as cougars and coyotes. Deer are primarily **browsers** (eat woody vegetation), whereas elk are more often **grazers** (eats herbaceous vegetation).

Coyotes, **omnivores** in the the dog family, have become more widely distributed throughout their habitat since the extirpation (elimination from a certain area) of wolves from Washington state by the early 1900s. The diet of coyotes includes mammals as large as young deer, carrion, and seasonal fruits, such as blackberries and salal berries. Coyotes will hunt in forest thickets and forested riparian areas but they prefer running down their **prey** in open areas. For this reason, coyotes have actually benefited from the increase of open areas due to logging. Coyotes in western Washington generally hunt at night. When they are not hunting, coyotes may find shelter among fallen logs and other logging debris in clearcuts or in underground dens.

Bobcats range across Washington state and utilize a variety of habitats at various elevations. A small-sized cat with thick, light gray fur, the bobcat may have been named for its extremely short tail. Mainly active at night, bobcats hunt their prey by ambush, the “sit-and-wait” technique. Bobcats prey on hares, birds and rodents such as mountain beavers and mice. In winter, bobcats will eat carrion of deer and elk, though they may occasionally hunt and kill young deer and elk. In the forest, marks of bobcats can be seen on trees where they sharpen their claws about two to five feet (60 to 150 cm) up the trunks. Bobcats often travel in brushy areas, but they are fairly adaptable, utilizing logged land and second growth. During the day, when they are not hunting, bobcats rest out in open areas or in brush, but in bad weather they may use dens in hollow trees, stumps, or logs for shelter.

Cougars, also known as mountain lions, pumas, or catamounts, are **carnivores** in forest regions of Washington. By stalking and then pouncing, cougars prey mainly on deer and elk. Cougars occasionally eat other animals from insects to hares to coyotes and will also scavenge. Cougars are beneficial to forest **ecosystems** because they cause redistribution of elk and deer, preventing damaging overgrazing, overbrowsing, and trampling of any particular region.

Black bears are the largest predator found in low-elevation forests of Washington, but they have an extremely varied **omnivorous** diet. Bears eat lots of plants in spring, berries found in forest edges to fatten up in fall, and insects, fish and small mammals whenever they can be found. Bears often rip open rotting logs to find beetles and other insects, thus aiding in the decomposition process. Though they are mostly ground-dwelling, black bears are good climbers. They climb trees to find bee hives and to take refuge when in danger.

Understory

Plants of the Understory

The understory of a temperate forest hosts a number of different small trees and shrubs. Plants that grow in the understory must be tolerant of very shady conditions due to the dense canopy overhead. Understory plants often have their leaves spread flat and wide to catch the maximum amount of available light.

Western yew is a small, slow-growing, shade-tolerant conifer. With the right conditions, as found in canyons and river bottoms, yews can grow to a height of 60 feet (18 m). The bark of western yew has been found to contain high concentrations of a compound called taxine that is effective in combating certain cancers. Other understory plants of these temperate forests include evergreen huckleberry and red huckleberry as well as red elderberry, devil's club and salal.

Animals of the Understory

Invertebrates

Temperate forest understories also contain a number of flowering trees and shrubs such as the Pacific dogwood and rhododendron that host a number of pollinators including butterflies and bees. Like all butterflies, the Pacific fritillary begins life as an egg which hatches into a caterpillar (larva). Feeding on violet leaves—its larval food plant, a specific plant needed by the caterpillar for food—the caterpillar grows and periodically sheds its skin through a process called molting. After the final molt, a hard covering, called a pupa or chrysalis, forms around the larva inside. Inside the pupal case, the pupa makes the transformation to emerge as a winged butterfly. Like most adult butterflies, Pacific fritillaries feed on the nectar of flowers, which they find in moist forests, wet meadows and streamsides. Males spend their time eating and searching for mates in woods and meadows. Females lay eggs on the leaves of a larval food plant, and the life cycle begins again.

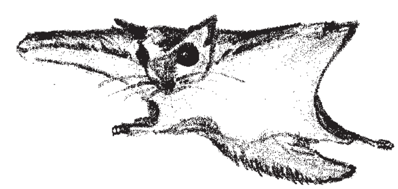
Birds

The winter wren is a secretive, insect-eating forest bird. In order to hide their eggs and young and to confuse possible predators, winter wrens build several nests, but utilize only one. The others serve as decoys. The real nest even has a false, dead-end entrance, bigger and more prominent than the real entrance. Nests are usually built in or near decaying downed logs. An oversized replica of a winter wren nest with eggs can be explored in the Habitat Discovery Loop at Woodland Park Zoo.

Mammals

Unlike some squirrels and chipmunks, chickaree squirrels, flying squirrels, and voles do not hibernate. Chickaree squirrels store large amounts of food, such as conifer seeds and truffles, for the winter. Flying squirrels depend on truffles in the summer but obtain most of their nourishment from lichens in the winter. Flying squirrels cannot actually fly. They have a well-developed gliding ability aided by flaps of skin that stretch between their fore and hind legs on each side of the body. Gapper's red-backed voles, which also feed heavily on truffles, are highly dependent on dense forest, preferring little ground vegetation and a lot of rotting logs.

Martens, members of the weasel family, are small

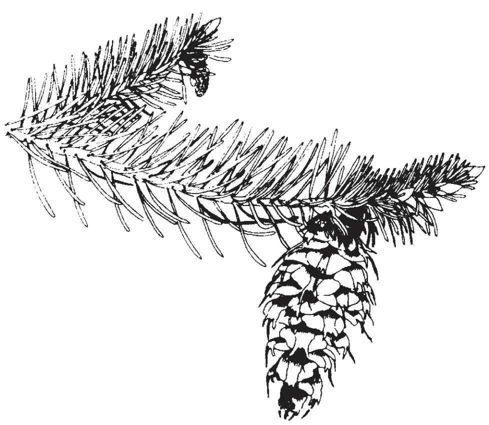


but vicious predators. Martens are very **arboreal** and can hunt as adeptly in tree branches as on the ground, eating small mammals, insects and birds. Martens can easily run down squirrels and red tree voles in the forest canopy. It has been proposed that the gliding ability of flying squirrels is an **adaptation** for escaping from arboreal predators such as martens. Martens also eat berries when they are available, and during winter they hunt on the ground for voles and hares. Cavities high up in trees are important to martens as nesting sites, though they may also find winter refuge in downed logs on the forest floor. Martens are quite solitary except during their breeding season in the summer months.

Canopy

Plants of the Canopy

Temperate forests in the Pacific Northwest contain trees that are long-lived and reach exceptional heights. The Douglas fir, one of the largest canopy trees in Washington's forests growing up to 350 feet (106 m), dominates more Northwest forests than any other tree. Douglas firs, which are taxonomically not true firs, are fast-growing, light-loving, long-lived, and relatively drought-tolerant trees. These trees are a "pioneer" species which means they can readily colonize a light-filled area following disturbance and will remain the dominant tree for hundreds of years. However, western hemlock and western red cedar are the climax species of these forests. Young hemlock and red cedar trees can grow slowly in the shaded understory for many years but will quickly take advantage of increased light made available when large trees fall. If the forest were to continue its development without major disturbance it would begin to reach its climax stage after 800 years. Hemlocks and red cedars would grow up to form the canopy, gradually replacing the Douglas firs, and become the dominant forest species.



Lichens are important inhabitants of older forest canopies. Lichens are a close partnership (another symbiotic relationship) between certain fungi and algae. Some lichens also incorporate cyanobacteria (blue-green algae). The fungus provides the structure of the lichen, and the algae provides the carbohydrates needed for growth through photosynthesis. The cyanobacteria enable certain lichens to absorb nitrogen from the air and convert it to a form usable by plants and animals. Lichens often fall to the forest floor, usually during wind storms, where they serve as built-in fertilizer for plants and winter food for foraging animals.

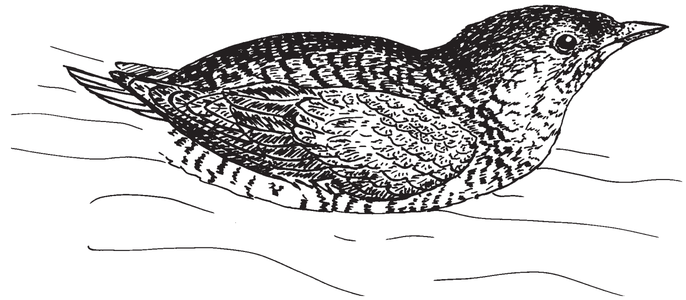
Animals in the Canopy

Invertebrates

Canopy tree needles, particularly of older forests, are colonized by an assortment of tiny organisms. Taken together, these organisms—fungi, algae, yeasts and bacteria—are called "scuzz." Some scuzz organisms grow on the insides of needles, others cover the outside. Scuzz aids trees by warding off needle-eating insects and by passing on nitrogen taken from the air. Tiny invertebrates, such as mites, springtails and amoebae, feed on the scuzz and are in turn eaten by spiders and predatory insects. Spiders and predatory insects offer great protection to the forest canopy by capturing and consuming needle-eating insects that invade the trees during summer. This greatly reduces the loss of needles to insect infestation. Birds, bats and other larger animals feed on the insects and spiders and are thus dependent on this **food web**.

Birds

Vaux's swifts are extremely fast flyers, up to five times as fast as the quickest similar-sized songbirds. They also have a high metabolism and must eat a steady supply of insects. Large, hollow, dead trees are important for their nesting sites.



Marbled murrelets are seabirds that can be spotted flying low over waves or diving under water in search of prey, primarily small fish. But unlike other seabirds, murrelets fly from the sea into the forests to build their nests, usually on broad branches covered with a thick layer of epiphytes high up in old trees. Because of the unusual and inaccessible locations of their nests, information about marbled murrelet nesting habits was unknown until relatively recently. In fact, Bent (1919) considered the nesting of marbled murrelets to be "one of the unsolved mysteries in American ornithology."

Pileated woodpeckers, Washington's largest woodpecker, eat carpenter ants which they find when they are chipping out rectangular-shaped nest holes in decaying snags. Woodpeckers excavate new nest holes each year, abandoning the nest holes of the previous year. Saw-whet owls, bats, flying squirrels and martens, among many other animals, rely on abandoned woodpecker holes for nesting sites.

Spotted owls primarily prey on small mammals, especially flying squirrels. Due to their dependence on flying squirrels and the large home range required by a pair of spotted owls (estimated up to 3,000 acres [1,200 hectares]), spotted owls are most successful in old growth stands. Recently, spotted owls have had to compete for habitat with barred owls, which have been expanding their natural range further south and west into Washington's forests. Barred owls, which are better adapted to second growth forests, have displaced many spotted owls from younger forests to older forests, contributing to spotted owls' dependence on old growth forests.

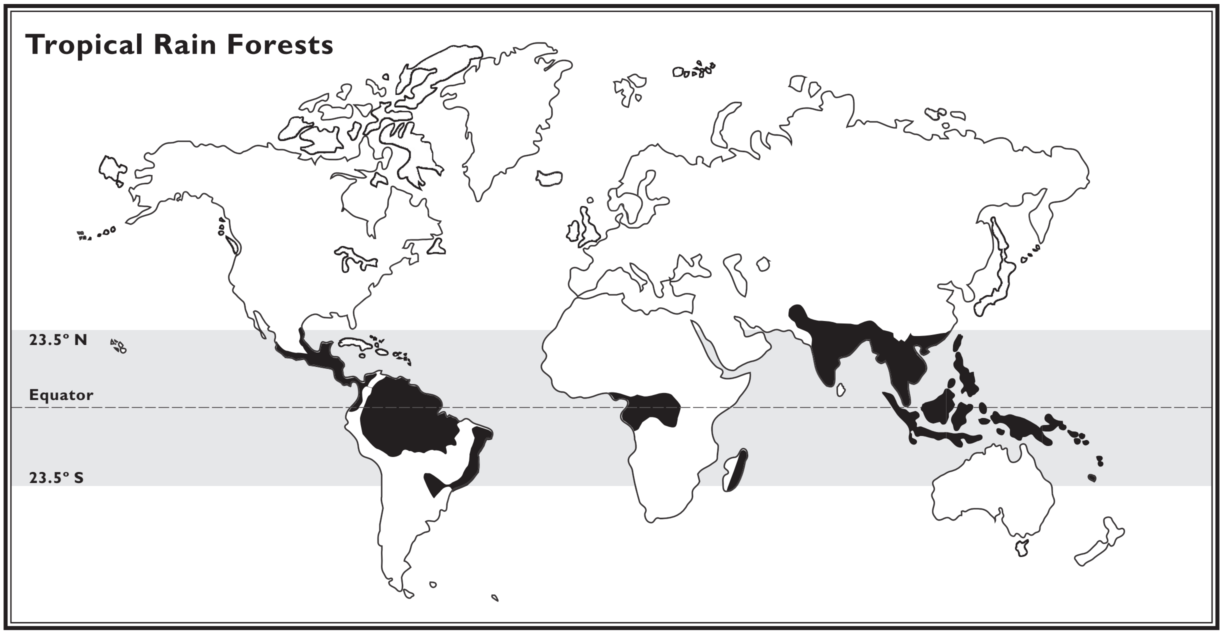
Goshawks are **raptors** that are superbly adapted to forest life with their short wings for powerful flight and long tails for maneuverability among trees. Goshawks prey on a variety of small mammals and birds. They primarily inhabit dense forest, often perching on downed logs when cleaning fur or feathers off prey.

Mammals

Due to their appetite for insects, bats of temperate forests are essentially the shrews of the air! Unlike shrews, however, bats are generally active only at night and spend their days in a deep sleep called torpor. Temperate forest bats hunt insects using their sense of hearing. Bats emit high-pitched sounds that reflect off surrounding objects giving them a "sound map" of their environment. This technique is called echolocation. Bats may catch insects directly with their mouths or scoop them up into a space inside their bent wings and pick them out with their mouths while momentarily free-falling. Some bats, including little brown bats and long-eared bats common in temperate forests of Washington, use membranes on either side of the tail to scoop up insects so that they can eat on the fly. Silver-haired bats are migratory bats that occur in Washington's forests in spring and fall. Silver-haired bats typically roost during the daytime in the spaces created when loose bark separates from the trunks of trees.

Tropical Rain Forests

The word tropical refers to the constantly warm and humid climate characteristic of the regions of the world between latitudes 23.5° North and 23.5° South of the Equator. In these regions, temperatures are relatively warm and constant and precipitation is high. Within the tropical zones, regional biotic (living) and abiotic (non-living) factors, especially the annual patterns of precipitation, have resulted in the presence of several types of forests. We have chosen to focus on the main type of forest found in Costa Rica: tropical rain forests.



According to the U.S. National Academy of Scientists, a typical four square-mile (10.4 km^2) patch of tropical rain forest contains:

- 1,500 flowering plant species
- 750 tree species
- 125 mammal species
- 400 bird species
- 100 reptile species
- 60 amphibian species
- 150 butterfly species

(Rainforest Action Network, 2001)

Tropical rain forests are the warm, wet, lush forests that grow around the equatorial regions of the earth. These forests consist of broadleaf, evergreen trees and are consistently warm and wet throughout the year. Annual precipitation in tropical rain forests usually exceeds 80 inches (2,000 mm) per year. Although tropical rain forests can experience a wet and a dry season, rainfall is generally spread throughout the year so that even during the driest months, these forests still receive at least four inches (10 cm) of rainfall. Compare that number with Seattle, which receives about five inches (13 cm) of rainfall per month during the wet season and a total average of 38 inches (96.5 cm) per year. Some tropical rain forests receive extreme amounts of rainfall; the Choco region of Colombia can receive up to 324 inches (8,230 mm) of rain per year.

Humidity hovers around 80 to 90 percent, therefore, even when it is not raining, the vegetation is enshrouded in water vapor. Temperatures also remain relatively constant in tropical rain forests, rarely ranging lower than 70 degrees Fahrenheit or higher than 85 degrees Fahrenheit (21 to 29 degrees Celsius). In Costa Rica, the monthly average high temperature only varies from 70 to 80 degrees Fahrenheit.

Tropical forests contain a staggeringly high number of plant and animal species. To date, only a fraction of the forests have been studied; however, some scientists estimate that, based on current research, 50 to 90 percent of the world's living species may occur in tropical forests. Furthermore, many scientists theorize that the more than one million species identified and named worldwide is only a small fraction of the number of existing species and that millions of plant and animal species living in the tropical rain forests have yet to be discovered.

Why are Tropical Rain Forests So Diverse?

The factors contributing to the high level of **biodiversity** in the tropical rain forests are many and varied:

- Optimal growing conditions for plants: Abundant precipitation, high humidity and year-round warmth make tropical rain forests ideal places for plants to live. Temperate forests in Washington state, on the other hand, receive most of their precipitation during the cold winter months, when many plants are dormant. Also, much of this precipitation is in the form of snow, which plants can't use. During the warm summers, these temperate forest plants must endure drought.
- A highly developed nutrient cycle: Warm, moist conditions encourage rapid decomposition of dead plants and animals. The nutrients released by this process, which are essential to plant growth, are either immediately absorbed by plants or are leached out by the high amount of rainfall. This creates a patchy distribution of nutrients, to which plants have had to adapt to meet their nutrient needs.
- Plant and animal interactions: Tropical plants and animals coevolved, forming complex, specialized interconnections. Some of these relationships ensure the survival of both the plants and animals involved; other relationships foster the evolution of new adaptations in both plants and animals.
- Forest structure: The optimal growing conditions have created unique layering opportunities for plants. All forests can be described as consisting of three layers—forest floor, understory, and canopy—but the tropical rain forest is distinct in the vast numbers of different plants growing in each layer, especially the canopy, which is filled with vines and epiphytes. The tropical rain forest is also unique in that it contains a fourth layer of tall trees, the emergent layer, that grow higher than the canopy layer.
- Light limitations and disturbance: Despite year-round sunshine, light is a limiting factor in lower layers of tropical forests. Only 1 to 2 percent of available light reaches the understory and the forest floor. Therefore, plants have evolved a variety of ways to either reach light or adapt to low light conditions. The lower layers aren't always shrouded in darkness, however. When a canopy tree falls, due to old age, wind, lightning or other natural causes, a light gap is created. As with all ecosystems, a small-scale disturbance increases diversity by allowing new species to grow or fill a created **niche**. In this case, small trees suppressed by low light levels are able to move into the canopy layer, bringing along new vines and epiphytes, along with new food and shelter spaces for animals.
- Millions of years of stable conditions: The majority of the world's tropical forests have not experienced dramatic climatic or geologic change since falling sea levels allowed for an exchange of species between North and South America five million years ago. This relative period of stability allowed for the evolution of symbiotic relationships between plants and animals, as well as the formation of a complex nutrient cycling system.

Tropical Rain Forest Soil

The majority of soils on which tropical rain forests grow are extremely nutrient poor, due to a combination of factors:

- Soil is formed when the bedrock, or parent material, breaks down into clay, silt and sand particles and mixes with organic matter. Most tropical soils develop from an infertile clay layer called laterite, a general term for clay that has high levels of aluminum and iron.
- Millions of years of relatively stable conditions, with no recent geologic activity, translate into millions of years of soil weathering. As the parent material wears away, nutrients are taken up by plants or washed away. Only a small percentage of tropical forests were formed on younger soils created by volcanic activity or alluvial deposits, which are sand, silt or clay particles deposited by running water.
- The large amount of steady rainfall leaches, or washes away, nutrients from the soil. Due to leaching, infertile parent material, and weathering, tropical forest soils tend to be deficient in phosphorus, potassium, calcium, magnesium, sulfur, and nitrogen, all of which are macronutrients required by plants for growth and survival.
- The majority of nutrients in the tropical rain forest are held in the biomass, not in the soil (see chart). Biomass is the total dry weight of all organic matter (living and dead organisms) in a particular area. When tropical rain forests are cut and burned, some nutrients remain in the ash on the top of the soil, but most nutrients are either hauled away as timber or leached from the soil during the burning. Those nutrients that remain in the soil allow for short-term farming, but without the inflow of nutrients from decomposition, the soil is rendered infertile in a few years.
- The high rate of decomposition in the warm, moist tropical rain forest means that most soils are lacking in organic matter, which, in other forests, helps hold nutrients in the soil for plants to use.

A study in Brazil of the presence of nutrients in soil and biomass determined the following percentages:

Element	% in biomass	% in soil
Potassium	89.6	10.3
Calcium	100.0	0.0
Magnesium	92.3	7.7
Phosphorus	31.9	68.1
(the majority of phosphorus in soil is immobilized by iron and aluminum and is unavailable for uptake by plants)		
Nitrogen	26.9	73.1
(the majority of nitrogen in soil is present as nitrites or ammonium, which can't be used by plants)		

(Brady and Weil, 1996)

To combat these nutrient limitations, tropical plants have evolved a highly complex nutrient cycle. Decomposition quickly recycles nutrients in the rain forest. Leaf litter that has been shed by plants, as well as dead animals, feces and skin sheds, decay rapidly through the interactions of decomposers, which primarily consist of fungi and bacteria but also include worms, termites and other insects. Nutrients released from decomposing organic materials are immediately taken up by plants through a thick tangled mat of roots at or near the surface of the soil. This rapid uptake helps prevent nutrients from being lost through leaching or volatilization (conversion to a gas or a vapor).

In tropical rain forests, roots aren't able to grow deep because of the shallow soil, but instead spread out to form a wide net with which to catch nutrients. This often occurs in the form of buttress roots, which are woody flanges that extend from fifteen to twenty feet (4.5 to 6 m) up the trunk, down to the base. These roots then spread out great distances from the tree and send down fine rootlets, increasing a tree's nutrient-gathering capacity. These buttress roots also serve to support the tree during windstorms and hold soil in place, thereby preventing erosion.

Tropical Rain Forest Layers

Tropical rain forests are characterized by four layers of overlapping vegetation, but the height of the layers and the inhabitants within each layer vary due to location, climate, altitude and geologic history, among other factors. Most animals use more than one layer for eating, drinking, sleeping, and finding shelter and many plants can be found in more than one layer as they strive to reach the sunlight in the canopy. The following sections describe general characteristics of tropical rain forest layers and provide some examples of what types of plants and animals inhabit each layer.

Forest Floor

Plants of the Forest Floor

The darkest layer of the tropical rain forest is the forest floor; in forests where the canopy above is very dense, the forest floor may receive less than one percent of available light. Plants on the forest floor are well adapted to life in a dark and humid microclimate. The shade tolerant plants of the forest floor typically have large leaves to capture as much sunlight as possible. These leaves often have narrow tips that point down, which allows water to run off the leaves. These drip tips prevent leaves from having a constant film of water on their surface. Constantly wet leaves would be vulnerable to colonization by algae, mosses and lichens, which would block necessary light for photosynthesis and interfere with the leaves' gas exchange abilities.

The leaves of the saplings on the forest floor are different from those of full-grown trees in the canopy, even among the same species. Leaves in the canopy and emergent layers are smaller and more leathery in order to conserve water. In the shade of the forest floor, the leaves are larger and softer in order to catch as much light as possible. Sapling leaves also have drip tips similar to those on the other forest floor plants.

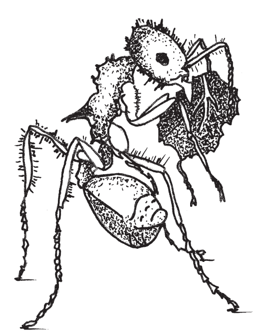
Animals of the Forest Floor

Invertebrates

Invertebrates, animals without backbones, dominate animal life in the tropical rain forest. It's estimated that of the total weight of the animal biomass in the forest, 50 percent comes from invertebrates in the top four inches (10 cm) of the soil (Myers, 1993). In addition to sheer numbers, diversity of invertebrates on the rain forest floor is high as well. These animals range in size from microscopic to enormous. Centipedes, which average one to two inches (2.5 to 5 cm) in length in temperate zones, can reach eight inches (20 cm) long in tropical forests.

Millipedes are also extremely large in the tropical rain forest; giant millipedes can reach ten inches (25 cm) compared to one to two inches (2.5 to 5 cm) in the temperate forest.

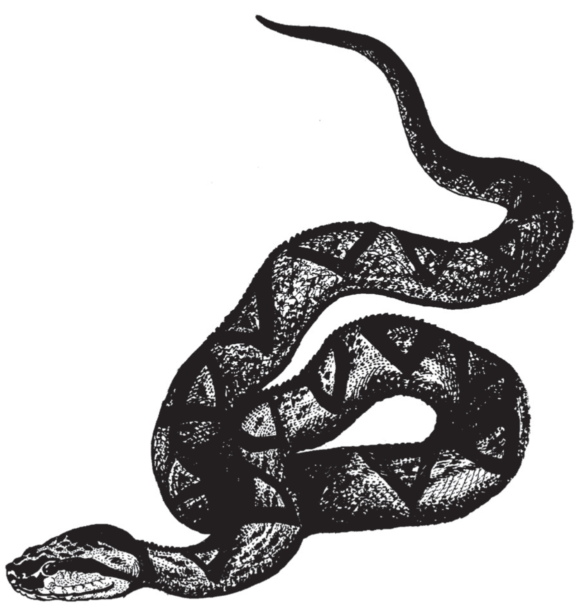
Another important group of decomposers is termites. Termites process huge amounts of organic matter and are often important sources of food for many animals and plants. Also found on the forest floor—or more precisely under the forest floor—are the leaf-cutting ants, found in the Neotropics. With their scissor-like mandibles, leaf-cutting ants clip sections of leaves from specific trees in the canopy and carry them down into their underground nests, which can be as much as 20 to 25 feet (6 to 7.5 m) below the surface. Then, they chew up the leaf, add fecal fluid, and apply the paste to the walls of the fungus garden. The ants then eat the fungus.



Another group of ants having a large impact on their surroundings are army ants of the Neotropics. These ants live in colonies with as many as one million individuals. By night, the ants form camps up to 35 cubic feet (1 m^3) in volume around the queen and her brood. By day, they march through the forest floor, raiding the nests of termites, wasps or other ants. They will even capture and eat larger insects, scorpions, small snakes and lizards.

Reptiles and Amphibians

Snakes are common forest floor predators, eating a wide range of food, from frogs to terrestrial birds to small mammals. Most of these snakes use camouflage and lie-in-wait strategies to catch their prey. The green anaconda, the largest snake in the world, is found in South America in swamps and in and along streams. This snake, also called a water boa, kills with constriction and can reach lengths of more than 30 feet (9 m).



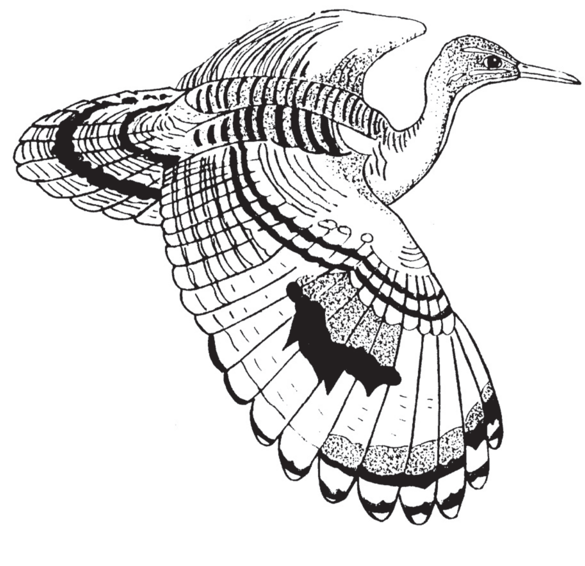
At lengths of eight to twelve feet (2.5 to 3.5 m), the bushmaster is the largest venomous snake in the New World and the longest viper in the world. This nocturnal snake is a pit viper meaning it has heat sensitive pits on each side of its head, which help it locate prey. The venom of a bushmaster is not as toxic as other venomous snakes, but is produced in enormous quantities and kills by causing internal bleeding. Despite this, however, and because of their elusive nature, there have been very few human fatalities from bushmasters.

The snake that is considered much more of a threat than the bushmaster is the fer-de-lance. The fer-de-lance is responsible for more human fatalities than any other Neotropical snake. If startled or provoked by larger animals, including humans, the snake will attack aggressively with repeated bites.

Other inhabitants of the forest floor include frogs. Some forest floor frogs are dull in color, which helps them camouflage against the soil and leaf litter. Others, such as the poison dart frogs of the Neotropics, are brightly colored to warn predators of their toxicity. Poison dart frogs secrete poisons through their skin, which affects the nervous system and muscles of predators such as birds and snakes. Some native people of the tropical rain forest put this poison on the tip of their darts when hunting. (See "Plants of the Understory" in this packet for more information about poison dart frogs.)

Birds

The birds of the forest floor tend to fall into two categories: larger, heavier birds that are primarily foraging on the forest floor, and those that nest on the forest floor, but which may venture into the upper layers to find food or to make communication calls. Sunbitterns are New World forest floor dwellers. Both male and female birds use coloration for camouflage and defense. Sunbitterns have stripes of dark brown and chestnut-orange that blend in well with the sun-flecked forest floor. When spread out, the tail feathers resemble eyes, which can scare off potential predators.



Curassows are also large birds found on South American forest floors. Due to their size and heavy weight, these birds tend to be poor fliers. Some curassows have evolved adaptations allowing them to eat the hard nuts and tough seeds produced by some tropical rain forest trees. These nuts and seeds are often too tough for many animals to eat. However, to help in digestion, some species of curassow will swallow stones along with their food. The stones help to grind up the nuts and seeds in the bird's crop, which is the extended area of the foregut that stores food.

Many tropical rain forest birds can be found in many layers, but make their nests on the ground. One example is the motmots, which make their nests in existing holes in riverbanks or in burrows that they dig themselves. They hunt insects and lizards and crush their prey with their large, powerful, serrated bills. Motmots are found throughout Central and South American rain forests.

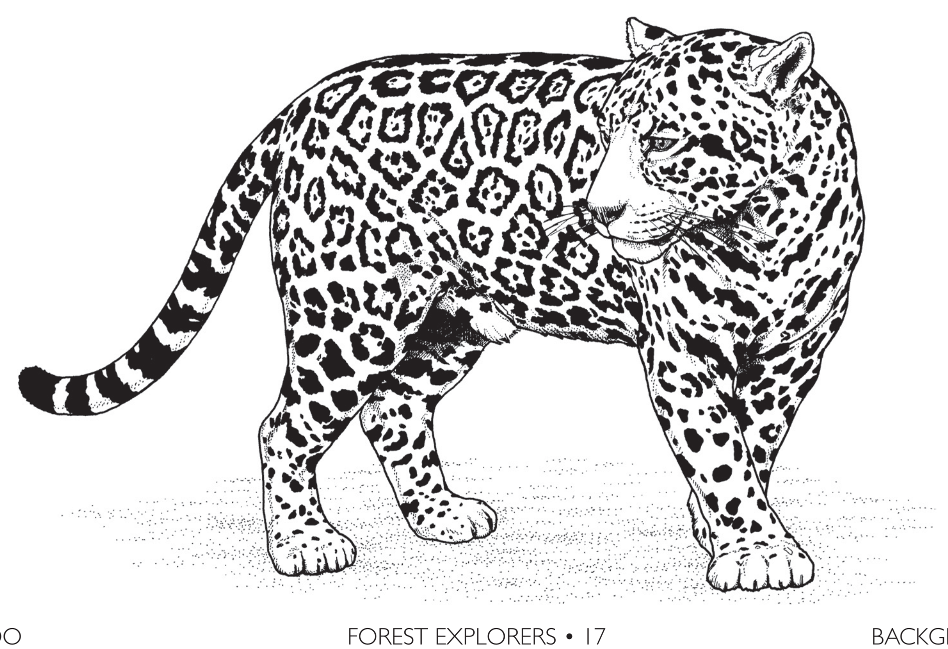
Mammals

The tropical rain forest floor is also home to a diverse number of mammals, most of which are much larger than similar animals in other habitats. This is particularly evident with the rodent populations. In the tropical rain forest, rodents can weigh as much as 100 pounds (45 kg). Most, such as tropical America's agoutis and pacas, have a huge impact on their environment, from their importance as seed distributors to their availability as prey for forest floor predators.

Wild pigs offer further examples of adaptations to forest inhabitation. The evolutionary response of the peccary, a seed eater found in the tropical Americas, to the rock-like seed coat on the seeds of some tropical trees is a set of large, flat molars, which crush the hard seeds. The body shape of the peccary also helps them push through the undergrowth.

The tropical rain forest floor is also inhabited with powerful predators, including the jaguar. Jaguars play a significant role in the ecosystem of the tropical rain forests of the Americas. Though their spotted coats give them a similar appearance to the leopards of Asia and Africa, jaguars generally are larger and heavier, with broader heads and shorter, thicker legs and tails. In fact, jaguars are the largest cats in the Western Hemisphere and the third largest cats in the world, after lions and tigers.

Jaguars are excellent hunters, employing their sharp teeth and claws as well as their stealthy and powerful bodies. Jaguars tend to be solitary, nocturnal hunters that feed on a wide variety of prey. In fact, as many as 85 different species have been linked to the diets of jaguars, everything from larger forest floor mammals such as tapirs and peccaries to lizards, frogs, caimans and fish. Jaguars are excellent swimmers and will even pursue prey into the water.



Understory

Plants of the Understory

The understory of the tropical rain forest receives two to 15 percent of the sunlight reaching the forest and is characterized by small trees and shrubs. Many of these small trees are saplings of canopy and emergent trees that are living in a state of arrested development until a gap in the canopy occurs. When this happens, these saplings experience a rapid surge of growth, allowing some to move into the canopy and close the gap.

Many of these small trees and shrubs are covered in vines and epiphytes. Some of these vines, which, when woody, are called lianas, began life as small shrubs and later, using curling tendrils or hooks, climbed up into the understory in search of light. Most end up winding around the treetops of the canopy, but many remain in the understory.

One successful example of tropical epiphytes is the orchid, of which almost 30,000 species have been identified worldwide, the majority of which are located in the tropics. These tropical orchids are primarily epiphytic and are found in the understory and canopy layers. Many orchids have complex relationships with specific insect pollinators. Some bear flowers that resemble female insects in appearance and smell. These flowers attract male insects looking for mates, tricking the males into transferring pollen from one flower to another. Others produce tiny flowers that smell of rot and mildew, which attracts tiny flies. The seeds produced by orchids are some of the smallest seeds of any flowering plant. As fine as powder, they are wind dispersed and have no food reserves. To germinate, seeds form a relationship with nutrient-providing fungi. Once germinated, orchids grow slowly and take years to flower.

Because the roots of epiphytes don't penetrate the tissues of the host plant, they're not considered **parasites**. They do, however, compete with the host plant for light and nutrients, and often cause branches of the host plant to collapse under their combined weight. Some trees have adapted to these problems by periodically shedding their bark and ridding themselves of the load of epiphytes. Others have smooth bark, which is difficult for epiphytes to colonize.

Epiphytes do sometimes benefit their host species, however. Moisture laden, nutrient rich debris collects in and around the leaves and roots of epiphytes. Some trees sprout adventitious roots, which are roots that sprout from unexpected places, in this case, from the trunk or branches. These roots tap into this debris to collect nutrients. This phenomenon also occurs in temperate forests. Other species benefit from the presence of epiphytes as well. Many frogs, insects and earthworms live in or feed on the debris collected around the epiphytes. Some epiphytes are colonized by ants, which pack organic matter around the plant to make their nests. As the debris decomposes, it nourishes both the ants and the epiphyte.

Bromeliads, which are a type of epiphyte, are especially beneficial to the animals around them. The leaves of the bromeliad form a cup at the base of the plant. This cup collects water and serves as a watering hole, feeding area, and breeding ground for many animals, such as the poison dart frog.

Most frogs around the world require pools of water in which to lay their eggs, but in the tropical rain forest, the high humidity of the forest floor provides enough moisture for the developing eggs. Poison dart frogs lay their eggs on leaves on the forest floor. When the eggs hatch, the attending parent—either the male or the female depending on the species—climbs high into the understory or canopy and deposits each tadpole into a different bromeliad. This ensures that all are not lost if a bromeliad is attacked by predators such as the giant damselfly larvae, which hatch in bromeliad pools and feed on tadpoles. Tadpoles primarily feed on algae and mosquito larvae, but in some species, the mother returns each day and deposits a single, nutrient-rich, unfertilized egg for the tadpole to feed on. The tadpole stays in the bromeliad during its entire metamorphosis to adult frog.

Animals of the Understory

Like the poison dart frog, many animals use the understory on a temporary basis, while others use it as their primary habitat.

Invertebrates

Many invertebrates have close associations with specific understory plants. Along with damselflies, invertebrates such as mosquitoes, beetles and cockroaches utilize bromeliad pools as breeding areas. Others, such as one species of crab, make the bromeliad watering cups their permanent home. Some species find food and shelter in the litter that collects in and around bromeliads. These include spiders, snails, ants, scorpions, crickets and millipedes. Some invertebrates, such as the euglossine bee, are the sole pollinators for many orchid species. Other rain forest plants are pollinated at night by moths. These plants usually have white flowers with an intense scent.

The pendulous, bright red and yellow flowers of the *Heliconia* species, found in the Neotropics, are a common sight in light gaps in the tropical rain forest understory. The numerous upturned bracts of each flower hold water, which provides a breeding pool for flies and mosquitoes. Many insects, including katydids, beetles, and spiders, find shelter in the furled *Heliconia* leaves. The tawny owl butterfly lays its eggs on the leaves of the *Heliconia*, which is then a food source for the hatching larvae. This butterfly is known for the large eyespots on the underside of its wings, which are thought to help deter predators.

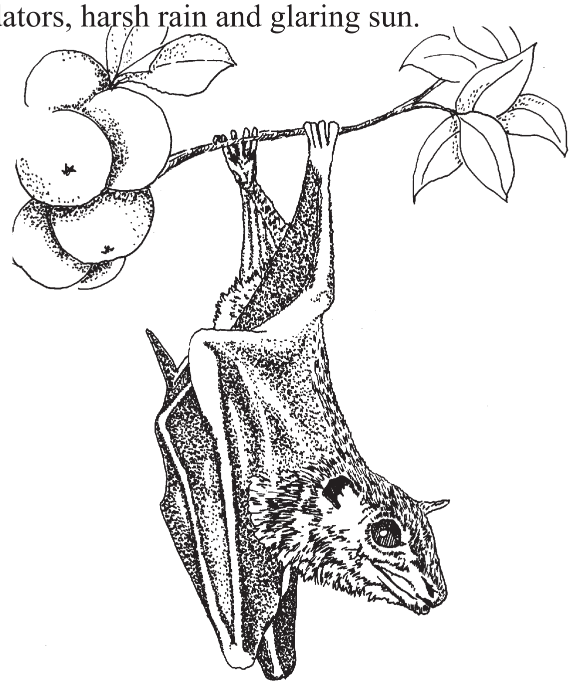
Birds

As the primary pollinators of *Heliconia* species, hummingbirds are often seen in the understory of tropical America. They hover over flowers and use their long bills to feed on nectar. Because of their small size and almost constant movement, hummingbirds need large amounts of high-calorie nectar, supplemented with protein-packed insects, to survive. They can get both from *Heliconia* flowers.

Some hummingbirds have longer, more specialized bills that fit specific flowers. Many different species of hummingbirds feed on the nectar of the *Heliconia*, in part because it produces copious amounts of nectar, but it's the sicklebill's long, curved bill that perfectly fits the flower bracts of the *Heliconia*. Passionflowers are well adapted for pollination by most hummingbirds. To sip nectar, the hummingbird has to wedge its head into a tight fit below the flower's stamens. While the bird is feeding, pollen is deposited on the back of its head. When it visits the next passionflower, the pollen is transferred.

Mammals

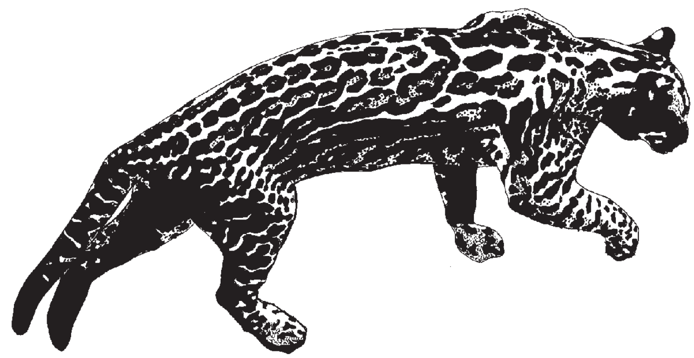
Bats can also be found around the versatile *Heliconia*. Tent-building bats, found in New and Old World tropical forests, collapse leaves of the Heliconia to form "tents" by biting through the midribs of the leaves. These tents then protect the bats from predators, harsh rain and glaring sun.



Bats are incredibly diverse forest-dwelling species. With almost 1,000 species worldwide, bats have adapted to numerous niches and feed on a wide variety of food sources. Bats pollinate many understory plants. The flowers of these plants, such as the calabash tree found in tropical America, are often pale and have strong odors to attract bats. These flowers open at dusk and have sticky nectar, which is easier for the bat to lick. Many bat-pollinated trees have cauliflorous flowers that bud from the trunk of the tree instead of the branches. These flowers are easier for bats to access, since many larger bats fly below the dense canopy rather than through it.

Tropical rain forest bats are not only important pollinators, but many species are also vital seed dispersers as well. These fruit eating bats are attracted to fruits with strong scents, such as ripe bananas.

Some small primates, such as the marmosets, Goeldi's monkeys and golden lion tamarins of Central and South America, have strong hind legs that allow them to leap from tree to tree. They also have claws, instead of nails, in order to grasp tree trunks. Many of these small primates occasionally include sap in their diet, but pygmy marmosets—the smallest monkeys in the world—are primarily sap eaters. With their large front teeth, they chew holes in a number of trees in their range. Then, they periodically visit each tree to lap up the flowing sap.



Ocelots, found in the tropical Americas, are well adapted for both life in the understory and life on the forest floor. Small cats with black spots on yellowish fur, ocelots blend in well with the dappled light conditions in these layers. On the forest floor, they hunt peccaries, small deer, rabbits and small rodents. Ocelots are also excellent swimmers and include plenty of fish in their diet. In the understory, ocelots can use their exceptional climbing skills in hunting birds, reptiles and monkeys. Ocelots are also versatile in their habitat choice and inhabit several different kinds of habitats, from tropical rain forests to dry scrub and chaparral zones.

Canopy

The canopy layer of the tropical rain forest has the largest amount of biomass and the greatest number of plant and animal species due to abundant light, moisture, food and shelter.

Plants of the Canopy

This layer is composed of the crowns of the canopy trees and is the primary region of photosynthesis for the tropical rain forest. Within these crowns are countless epiphytes, vines, and lianas. In fact, the leaves of lianas comprise as much as 20 to 40 percent of all leaves in the canopy (Myers, 1993). The plants in the canopy receive the full glare of the sun, and experience temperatures of 90 degrees Fahrenheit and higher and 60 percent humidity.

The trees of the canopy can be between 100 and 200 feet (30 to 60 m) in height, depending on location, and often branches don't occur until 65 feet (20 m) up. The crowns of these trees usually don't interlock, but maintain a distance of approximately three feet (one meter). This phenomenon is called crown shyness. It's unknown why it occurs, but researchers theorize that crown shyness might prevent damage to other trees in high winds or stop the spread of leaf-eating insect larvae.

Trees that colonize light gaps are called pioneer species. These plants typically flower and fruit quickly and profusely. Energy is put towards rapid growth, thus leaves are less well defended than long-lived canopy trees and are magnets for herbivores. Fruits are typically small-seeded and sweet in order to attract an abundance and variety of seed dispersers.

Cecropia is one example of a New World pioneer species. *Cecropia* trees rapidly colonize large light gaps, providing invaluable services such as offering shelter for animals, and quickly shading the forest floor, which provides suitable conditions for slower growing canopy seedlings and protects the vulnerable root mat from desiccation. The fruits of Cecropia trees are reportedly eaten by eight monkey species, 12 bat species and 76 bird species (Myers, 1993). *Cecropia* trees also have an intricate symbiotic relationship with Aztec ants, which will be discussed in the "Animals of the Canopy" section of this packet.

Most canopy trees rely on animals as pollinators and seed dispersers. These trees have coevolved with specific pollinators to ensure pollination. Many canopy species are pollinated by bees and have evolved plant parts that deposit pollen in specific places on a bee's body. Each bee in the tropical rain forest might be carrying pollen from four or five different tree species, deposited on a particular part of the head, thorax, abdomen or legs. This ensures that a receiving flower only obtains the pollen from its species.

Flowers from tropical rain forest trees are also adapted to the specific needs of their animal pollinators. Moth-pollinated flowers are generally white in order to be more visible for night-flying moths. Bat-pollinated flowers are usually large and tough in order to provide a landing stage for the bats. These flowers are also often white and produce copious amounts of nectar and pollen to suit the bat's large appetite.

Canopy trees employ different strategies for seed dispersal. Some, such as many fig species, produce large volumes of small seeds packaged in easily consumed fruit. These fruits attract a large variety of

frugivores, which are animals that primarily eat fruit. The seeds are most often swallowed whole and, if they survive digestion, are deposited in feces far from their parent plant. Once deposited, these small seeds need to germinate quickly because their size does not allow for a large food reserve. The majority of seeds do not germinate, but because the seeds are produced in such a large volume and are spread so far, figs are common in tropical rain forests.

There are over 900 species of fig in tropical forests around the world and each species of strangler fig is pollinated by a specific wasp species. The sweet fruits of strangler figs are numerous and are dispersed by a large number of primates, small mammals and birds. The seeds germinate when deposited on a branch with enough debris to support the nutrient needs of a seedling.

Vines and lianas reach the canopy through a variety of means. In addition to the barbed hooks and curling tendrils discussed in the “Plants of the Understory” section of this packet, some vines are twiners that coil their entire stems around the trunks of smaller trees. Others have different forms in the understory than in the canopy layer. One example is the *Monstera* species in Central America. Seedlings on the forest floor reach a tree trunk and begin the climb up, laying their leaves flat like shingles against the trunk. Upon reaching the canopy, the leaves change to large leaves held horizontally away from the trunk.

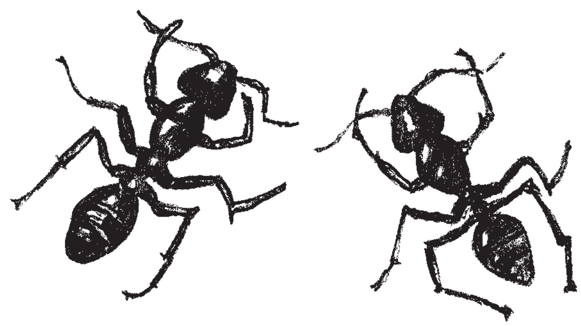
Animals of the Canopy

Invertebrates

The canopy layer supports a large number of invertebrate species. In Peru, one 17,500-cubic-foot (500 m) area of foliage, which is roughly equal to a two-car garage, may contain as many as 100,000 individual insects, including 50 species of ants and 1,000 species of beetles (Myers, 1993).

Leaves are the most abundant and constant food source in the canopy and are good sources of nutrients and protein. Many invertebrates, such as caterpillars and katydids, are primarily leaf eaters. The abundance of insects in the canopy attracts many animals in search of food, including predatory insects. These insects, such as praying mantises and assassin bugs, are found in an array of colors, sizes and shapes. Praying mantises use their front legs, which are equipped with sharp spines to grab their prey.

To combat these and other predators, many insects accumulate toxins and are then themselves poisonous. Other insects attempt to fool predators by employing mimicry, in which they resemble poisonous individuals in appearance, but are not themselves toxic. Insects also use camouflage to blend in with parts of plants or have false eyespots on their wings to scare off predators.



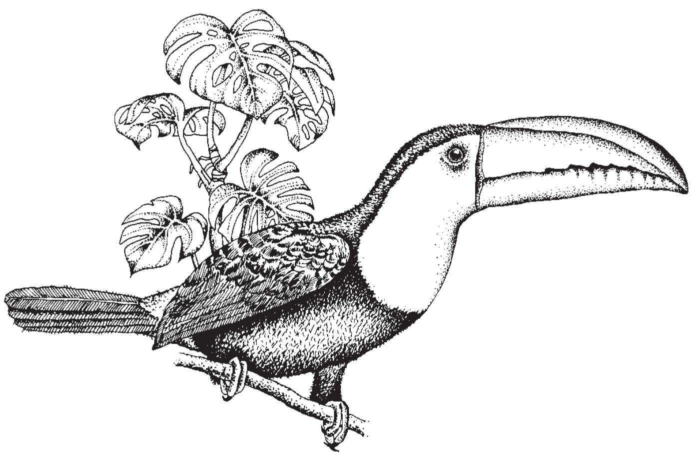
Aztec ants live in the hollow chambers in the trunk of *Cecropia* trees, where they keep mealybugs in the hollow chambers of *Cecropia* trees. These bugs are “milked” for the sugary nectar they produce; in return, the ants protect the defenseless mealybugs. In exchange for food and shelter, Aztec ants also protect the *Cecropia* trees from attack by leaf and fruit eaters. They will cover an intruder within moments, delivering vicious bites in the process. Even encroaching vegetation is attacked and ripped to shreds, giving *Cecropia* a competitive advantage that allows it to grow eight feet (2.5 m) a year (Collins, 1990).

One of the few animals able to dine on *Cecropia* leaves is the sloth, which is protected from ant bites by its thick, coarse fur. This New World leaf eater has a large, multi-chambered stomach containing bacteria, which digest the cellulose in leaves. Sloths move extremely slowly. Their main defense from predators is the green algae that grows in their fur and helps them blend in with their surroundings.

Birds

The main predator of sloths, as well as monkeys, is the harpy eagle. Harpy eagles sit on the tops of emergent trees searching for sloths and other prey. Upon locating a sloth, a harpy eagle will dive below the sloth and roll in-flight to grab it from below (Grambo, 1999).

Many of the birds in the canopy are insect eaters that will often form mixed species groups for foraging. Many birds, including the gray-headed tanager, form groups that follow army ants as they march through the forest. Many tanagers are mostly fruit eating and don't digest the seeds they swallow, making them important seed dispersers. Most supplement their diet with insects.



One of the most important seed dispersers in the canopies of the tropical rain forests is the toucan. Toucans are well known for their large colorful bills. These bills are surprisingly light as the insides are full of a spongy web of tissues. The long bills help toucans reach berries and other fruits on branches that are too thin to support their weight. It's unknown why their bills are so colorful. Some theories include use in courtship rituals, intimidation of predators or camouflage with the bright flowers and fruits of the tropical rain forests. The diets of toucans consist mainly of fruits, but may also include insects, small lizards, snakes, bird eggs and nestlings.

Mammals

The canopy of Neotropical forests is also home to many primates such as howler monkeys. Howler monkeys produce large calls to delineate their territory and to avoid confrontation with other troops of howler monkeys. These leaf eaters have special adaptations to eating leaves. Unlike the colobus monkeys of Africa, which have stomachs similar to cows to aid in digesting leaves, howler monkeys have cellulose-digesting bacteria in their hindgut. To aid in the efficiency of their digestion, howler monkeys tend to select younger leaves, which are easier to digest. They will also eat fruits and flowers when available.

Another adaptation of some animals to the canopy layer is the prehensile tail, which acts like a fifth limb for canopy animals. Prehensile tails are tails that are able to grasp tree limbs. They are found in the porcupine, tree possums, kinkajou and tamanduas of Central and South America. New World monkeys are the only primates with prehensile tails. These monkeys, including howler monkeys and spider monkeys, are able to use these prehensile tails to hang from branches to gain access to leaves and fruit.

Emergent Layer

Plants of the Emergent Layer

The emergent layer is comprised of the crowns of trees that grow up through and emerge above the canopy layer. These trees can be more than 200 feet (60 m) tall and 120 feet (37 m) around. In some trees, branching begins 130 to 165 feet (40 to 50 m) up the trunk. Like the branches of the trees in the understory and canopy, many epiphytes and lianas grow on the branches of these emergent trees.

Falling emergent trees can clear large areas by taking down a multitude of plants as they fall. This occurrence provides light for the forest floor, light gaps for pioneer plants and dead plant material, which will decompose and release nutrients for plants to use.

Due to their extreme height, both canopy and emergent trees have large buttress roots for support. Emergent trees need additional support due to the fact that they stand so high above the canopy trees with no buffer from strong winds and storms. Buttress roots are woody flanges that extend far up the trunk and outward from the base. These buttress roots not only stabilize the soil and increase the trees' water and nutrient-gathering capacity, which helps the trees combat climatic stress, but also stabilize the trees against high wind and stormy conditions. If the buttresses were removed, the tree would be easily knocked over due to the fact that most tropical soils are too shallow for a deep taproot to grow and secure the tree.

One extremely important emergent layer tree is the kapok tree. These trees occur naturally in tropical rain forests or moist areas of drier forests in West Africa and in Central and South America. In the Americas, the kapok grows from southern Mexico to the southern boundary of the Amazon basin. Kapok trees are also grown on plantations in southeast Asia.

Kapok trees can grow thirteen feet (4 m) a year, reaching heights of 200 feet (60 m) (Janzen, 1983). They have wide buttresses at their base and large, flat crowns on top. The flowers of the kapok tree have a pungent odor, which attract their bat-pollinators. One to two flowers on each tree open each night, helping to ensure cross-pollination. In addition to bats, hummingbirds, bees, wasps and beetles have been seen visiting the flowers.

Each tree may produce 500 to 4,000 fruits each fruiting season. The fruits are thick, woody seedpods containing approximately 200 small, brown seeds (Janzen, 1983). The pod-like fruits open on the tree, releasing the seeds to the wind. Each seed is covered in white tufts of silky hair called kapok fiber. These hairs act as parachutes, helping the wind-dispersed seeds spread away from their parent plant. These hairs also act as a water repellent. In fact, unopened pods that drop into fresh or seawater can float great distances without danger of water penetration, suggesting that kapok trees may have spread from the Neotropics to West Africa via the open ocean (Janzen, 1983).

These kapok fibers were, and in some places still are, commonly used as insulation and stuffing material for furniture and upholstered automobile seats. Because they're lightweight and waterproof, lifejackets were exclusively filled with kapok fibers until the middle of the 20th century.

Oil is made from the seeds of kapoks and is then made into soap. Native tribes also put bits of kapok fiber on the base of their poison darts to make the darts fly better. Other tribes wrapped the fibers around the trunks of fruit trees to discourage leaf-cutting ants from clipping the leaves of the trees. The trunks of kapok trees were also made into carvings, canoes and coffins (Tico Ethnobotanical Dictionary, 1997).

In addition to the use of the products, the kapok tree is culturally important to different groups of native people in tropical forests. To the Maya and other Hispanic cultures in Central and South America, the kapok is a holy tree that connects the terrestrial world to the heavens above. Some cultures believe that the dead climbed the kapok to reach heaven.

Animals of the Emergent Layer

Many epiphytes and vines are found in the crowns of emergent trees. These plants provide permanent homes to many invertebrates and other small mammals, many of which never travel to the forest floor, much less to the layers below.

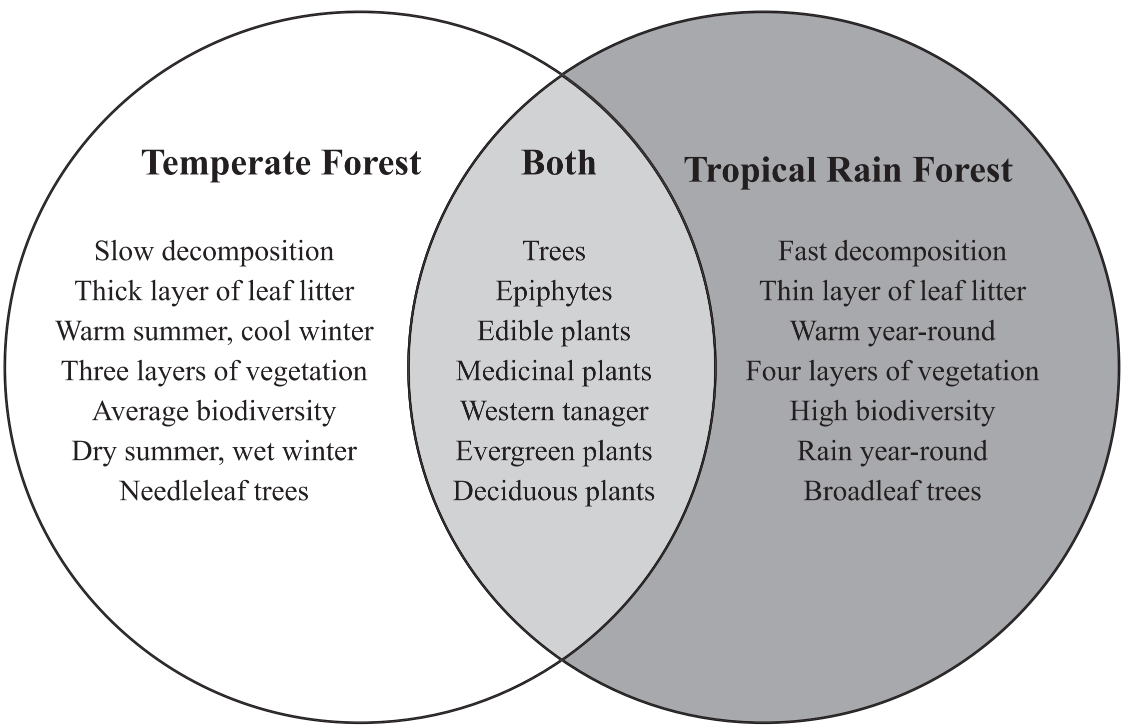
As with all layers of the forest, many animals use the emergent layer on a temporary basis. Due to immense heights of emergent trees, many animals will use these trees as lookouts while searching for prey or predators. Emergent trees can also provide vantage points for animals looking for flowering or fruiting plants. Crimson topaz hummingbirds and blue morpho butterflies will visit the flowers in the tall tree crowns looking for nectar. Macaws and toucans will forage for fruit in the emergent layer. Howler monkeys may venture into these tall trees to make their territorial calls at dusk. And harpy eagles will perch in the emergent trees looking for prey such as sloths, monkeys and other large birds.

Western Tanager *Woodland Park Zoo*

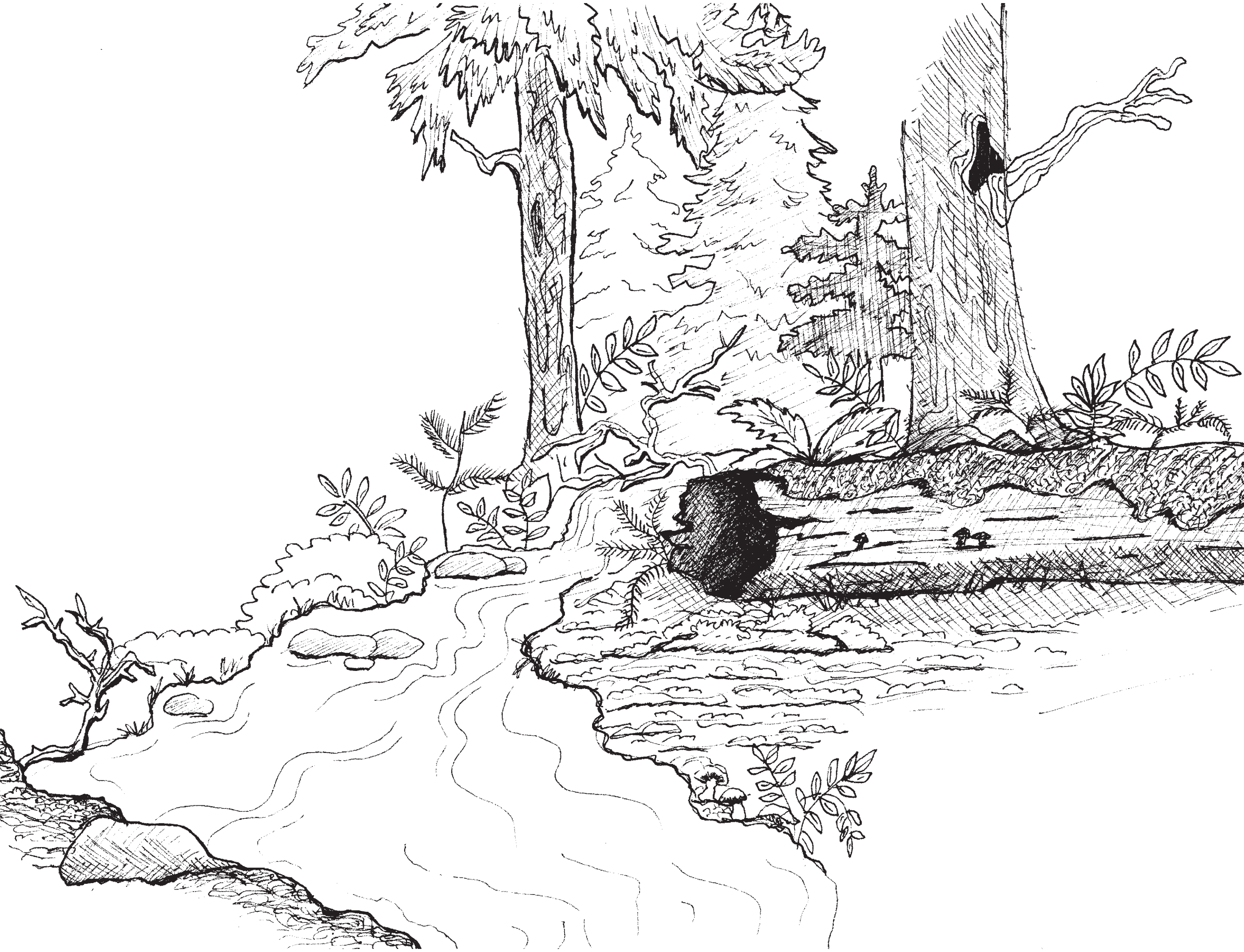
A Comparison of Forests

There are a number of similarities and differences in the ecological makeup of temperate forests and tropical rain forests. In addition to a similar physical structure, both forests have epiphytes, plants with medicinal benefits, and a number of similar animal species. The differences are myriad: climate, biodiversity, biomass, canopy density, plant species, and animal species.

Migrating birds, such as western tanagers and rufous hummingbirds, are examples of an ecological interconnection between temperate and tropical forests. The western tanager, the bird that serves as the Forest Explorers program's mascot, migrates every year from one forest to the other and back. Western tanagers spend the spring and summer in temperate forests breeding and raising their young, taking advantage of the abundant food supply (insects, fruits and seeds) available in temperate forests during these seasons. In fall, western tanagers migrate south to tropical forests of Central America, thus avoiding the cold and lack of food during the fall and winter season in temperate regions. The distance of each trip is more than 3,000 miles (4,800 km). This ecological connection demonstrates the importance of both temperate and tropical forest ecosystems to western tanagers and other migratory species.

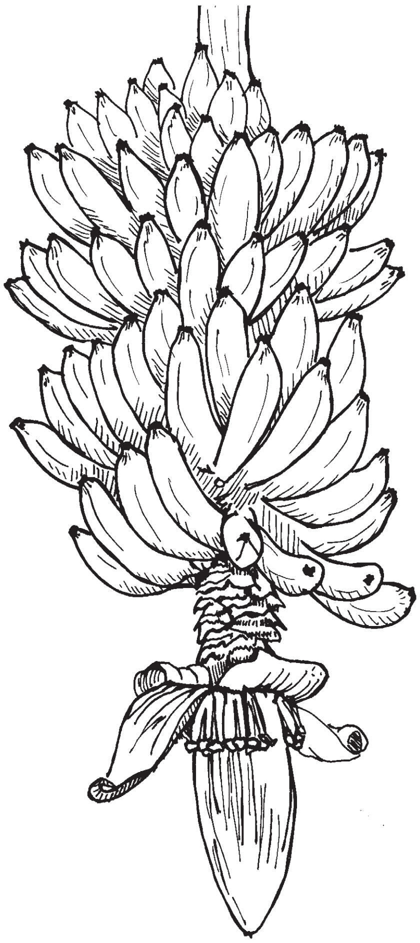


Human Uses of the Forest



People have relied on forests for thousands of years for hunting and gathering food, for fuel wood, medicines, and for building materials. Today, demands on forests have increased dramatically. One-half of the medicines available today owe their existence to plants and new medicinal plants are still being discovered (Newman, 1990). Drugs used to treat childhood leukemia, Hodgkin's disease and ovarian cancer come from forest plants, as do medicines for heart ailments, hypertension, arthritis, and many other conditions. The majority of these come from tropical rain forests although some medicines, such as taxine (Pacific yew) come from temperate forests. Still, only approximately one percent of all plant species has been studied for possible medicinal uses.

Almost 80 percent of plant foods we eat today originated in tropical forests: avocado, banana, black pepper, cashews, chocolate/cocoa, cinnamon, coffee, cola, corn, lemon, orange, peanut, potato, rice, sugar cane, tomato and vanilla to name just a few. Scientists continue to use wild ancestors of modern crop species for genetic material to produce new strains that are disease and insect resistant.



Most paper is made of cellulose, the major component of the cell walls of plants. The majority of cellulose used to make paper comes from wood pulp derived from trees. Cellulose is also processed into many other materials. When cellulose is combined with certain chemicals it can be turned into a thick liquid that, when squeezed through small slits or holes, produces fibers. These fibers are then used to make carpeting and fabrics such as rayon. Cellulose is also used to make cellophane, photographic film, Ping-Pong balls and many other products.

Many trees also produce special saps that can be used to make products. Maple sugar is a sap with which most of us are familiar. Other saps such as latex, gums and resins are used to make rubber gloves, paint thinner, perfumes, pill coatings, hoses and wood finishes. Wood bark of different species produces items such as cinnamon, cork and tannins for curing leather. Native Americans from the Pacific Northwest coast have used the western red cedar for thousands of years to make everything from ropes and baskets to canoes and longhouses.

Forests are also the home of many humans. Many indigenous people still live in traditional or near traditional ways as hunter-gatherers or subsistence farmers in rain forests throughout the tropics. The Yanamamo of Brazil, the Mbuti pygmies of Central Africa and the Lua of Thailand are just a few of the indigenous cultures that rely on forests to meet all of their **basic needs** for survival. Furthermore, many people rely on intact forests for extracting renewable resources such as Brazil nuts and latex. In the Amazonian region of Brazil, 500,000 people earn a living each year by collecting latex from wild rubber trees.

Beyond the physical gains humans draw from forests are spiritual ones. Belief systems of many cultures are based on the forest plants and animals that surrounded their ancestors and that will hopefully remain for generations to come. In Washington's temperate forests, native Northwest coastal people considered western red cedar a special gift to their people and a possessor of Great Spirit. Due to its physical and spiritual importance in their lives, a prayer to the spirit of the tree was, and in some cases still is, recited before any part of it is taken. To the Coastal people, cedar is the "tree of life."

Old growth forests of the Pacific Northwest are often referred to as "cathedral forests" because of the sense of awe they inspire in people. The benefits we derive from the beauty of plants and animals, and the recreational value of fishing, hiking, bird watching and camping are immeasurable.

Habitat

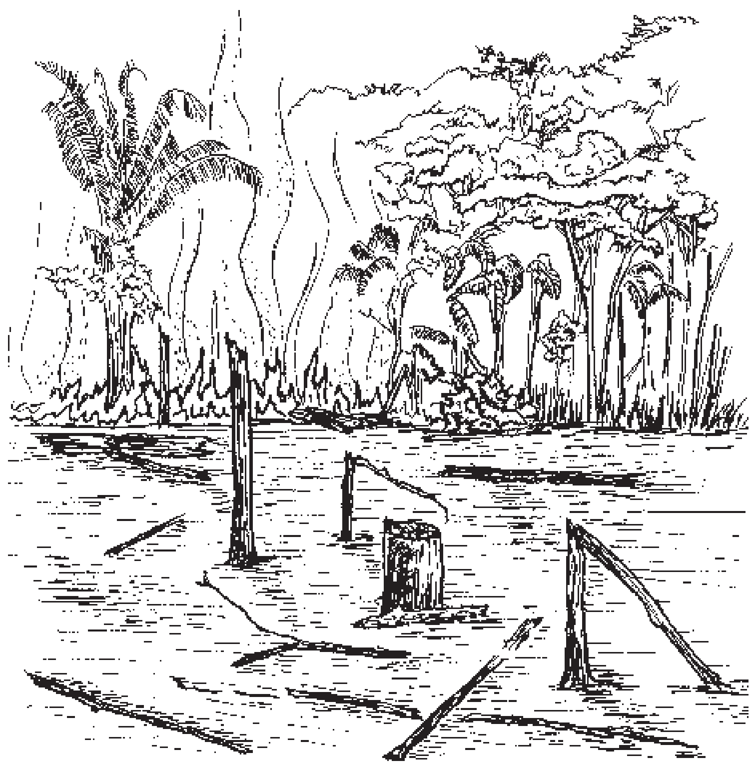
Habitat is the complete environment where an animal, or a plant, meets its basic needs for survival. To say a habitat is an organism's home is too simplified. The concept of habitat is much larger than that. A habitat contains not only shelter, but everything an animal or plant requires to live as well. For example, when walking through a local park, you notice a bird in a nest. The bird's habitat is not its nest or even the tree where you see it. Instead, the bird's habitat is any area in the park, including the tree and the nest, that the bird uses to perch, hide from predators, find food and water, and collect nesting materials. The bird's habitat might contain a variety of living and non-living things such as rocks, sunlight, grass, oxygen, dirt, worms, a stream, decaying logs, moss, garbage cans, insects, other birds, park benches, trees, shrubs and flowers. Understanding that a habitat meets a plant's or animal's survival requirements is the key to understanding the habitat concept.

An organism's requirements can be broken down into five basic needs:

- Food: All organisms require a source of energy. Plants can create their own food through photosynthesis. Animals rely on eating plants and/or other animals to fulfill their energy needs.
- Water: Animals consume food or liquids that contain water. Plants absorb the water they need from their environment.
- Air: Animals require oxygen, which plants make during photosynthesis. Plants need carbon dioxide, which both plants and animals make during respiration.
- Shelter: Animals and plants need protection from weather, extreme climatic conditions and predators. Animals need a place to birth their young.
- Space: All living organisms need room. Animals require space to move around in and plants require space in which to grow.

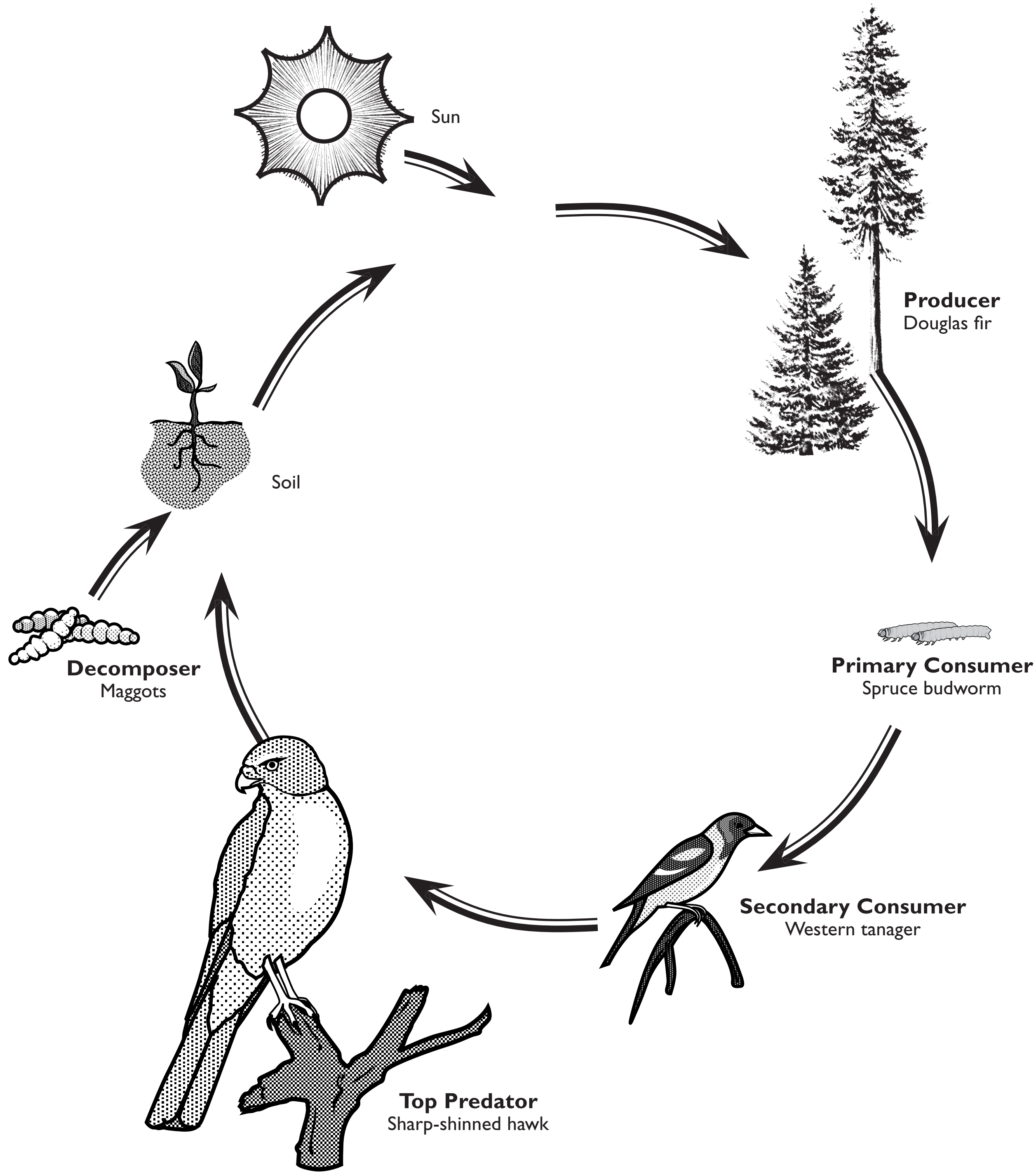
These needs must also be provided for in an arrangement suitable for the animal's use. For example, if water was present in the habitat but was up on top of a steep cliff and the animal was not adapted to climbing, this would not be a suitable arrangement for that animal. If a habitat is a good one, an animal or plant will not only survive, but it will thrive and breed or reproduce successfully. Requirements that are not essential for life but are needed to allow an individual to thrive and reproduce are called secondary needs. Secondary needs might include proper humidity levels, a specific temperature range, a minimum amount of sunlight per day, or a specific resource material to build a nest or lodge. The specific requirements and the way these requirements are met vary by species. Things that are not required for survival, or to thrive or reproduce, are often referred to as wants. Generally, wants are more applicable to humans than to other animals or to plants.

Humans have the same survival needs as other animals do. Although many animals may alter their habitat by building shelter and storing food, people are unique in the extent to which they can alter their habitats to meet their needs. Humans use technology such as centralized heating and cooling, cultivation, grocery stores, dams, plumbing, buildings and oxygen tanks to allow them to occupy places that would otherwise be unsuitable to meet their needs. Forests exist within a dynamic equilibrium, which means that change and variability are the norm. Natural disturbances—such as forest fires, insect damage, disease, drought, and storm damage from floods or high winds—are frequent occurrences in all forests. With each disturbance begins the process of succession. Forest floor and understory plants have the opportunity to grow up into the ensuing light gap and can help to sustain biodiversity within a forest by maintaining the structural diversity of the forest. However, natural disturbances, such as fires, can be exacerbated by the effects of human activities and forest management practices. (See "Conservation" in this packet for more information about human effects on forests.)



Interdependence and Niches

Every member of an ecological community relies on other members of the community, either directly or indirectly, for its own survival. Organisms also rely on the non-living components of their environment such as light, air, water and soil. If one component of the community disappears, or is affected in some way, other members that rely on it will also be affected. This intricate network of **interdependence** between all living and non-living things is often referred to as the web of life. One common and simple way of demonstrating the interdependence of living things is a **food chain**. A food chain shows the flow of energy from one organism to the next starting with energy from the sun. A simple food chain for a western Washington forest might look like this:



The sun provides the basis for all energy on earth. During a chemical process, known as photosynthesis, plants use the sun's energy to convert carbon dioxide and water into carbohydrates (including sugars) and oxygen. These forms of energy are then available for use by other organisms.

Because plants create their own energy they are called **producers**. Parts of plants, including leaves, bark, stems, sap, roots, fruit and nectar, are then eaten by plant-eaters, or herbivores. Herbivores are the first animals to make use of the plant's energy and are called **primary consumers**. Carnivores, or **secondary consumers**, then get their energy by eating the primary consumers. In this way, energy flows through the ecosystem, as plants and animals are eaten by animals that are later eaten by other animals. This continues until the top predator is reached.

However, the top predator is not the end of the line. The food chain operates as a cycle. A plant or animal may avoid being eaten; eventually however, it will die. At this point, many different organisms break the dead and decaying plant or animal down into components usable by the producers and the cycle begins again. **Scavengers**, such as most raptors and **carnivorous** mammals, help the decomposition process by consuming and digesting carrion. Much of the decomposition, however, is done by small decomposers, such as insects, fungi and bacteria, which are crucial in the conversion of organic material into nutrients.

A food chain is a very simplified way of showing the energy relationships between organisms. In a natural community many food chains are linked together into a food web. A food web or cycle can be disrupted naturally by many factors such as fire, drought, wind, flooding and disease. These disruptions are generally short term, causing relatively minor and temporary fluctuations in the cycle. Other changes, such as climatic change, may occur gradually, giving plants and animals time to adapt to their new surroundings. It is only when changes occur rapidly or on a large scale, such as massive habitat destruction or the eradication of a species, that the cycle may be severely affected or even break down. When one species is disrupted all the other species that have ecological connections to that species also are affected. Some of these effects will be direct, such as a predator losing its primary prey species. Other effects may be less direct and less obvious. The loss of an insect species may not seem significant but an insect may be responsible for pollinating certain flower species. These flowers would then not produce fruit, thus depriving certain herbivores of a food source and decreasing the herbivores numbers. This decrease in prey availability might then cause a food shortage to a predatory species.

This delicate balance is preserved, in part, by every living and non-living component of an ecological community playing unique roles within that community. Collectively those roles played by a species are referred to as that species' ecological niche. An animal's niche is defined by such things as what it eats, how and where it finds its food, where it lives, its habits and periods of activity. An organism's niche also includes what it is eaten by or how it is used by other organisms.

The concept of niche may seem complex but it is actually quite simple. A niche consists of the functional roles a species plays within its community and how it performs those roles. As an example, let us look at the western tanager. The western tanager is a small, colorful bird that migrates between forests of the Pacific Northwest and tropical rain forests from western Mexico south through Costa Rica. The niche of the western tanager might be described as that of a forest-dwelling bird that eats insects and berries and is **diurnal**, which means active during the day. Western tanagers disperse berry seeds and control insect populations. Western tanagers provide food for raptors (birds of prey) such as sharp-shinned hawks.

The concept of niche is important because it explains how different species can live in the same habitat without constantly competing against each other for resources. Because each species has a different niche, each species is using a slightly different part of the habitat in a slightly different way or at a different time of day. Some overlap may occur between the niches of species with similar adaptations and these species will compete with each other for space and other resources. Many species avoid competition by specializing, just as human professionals do. Let's look at birds of prey as an example. Hawks, owls and falcons all hunt small animals but these birds can all live in the same area because they have different niches. Hawks generally nest in trees and hunt small mammals, reptiles and occasionally birds during the day. Owls also nest in trees or tree cavities and hunt small prey, but owls are active at night and therefore eat small, nocturnal animals. Falcons tend to nest on cliff edges, not in trees, and they specialize in hunting birds during the day. The niches of these animals do overlap but not so much that they cannot live in the same area.

Just as many animals' niches depend on healthy forests, so do many human niches. Here are just a few human roles that depend on healthy forests:

loggers and foresters
grocery store employees
biologists
hotel and lodge employees
tourism employees
lumber mill employees
fishermen
paper and pulp manufacturers
outdoor recreation outfitters and touring companies
perfume and soap producers
wildlife photographers
cabinet makers
hikers and campers
outdoor equipment manufacturers
park rangers
bird watchers
construction workers

Conservation

*Most of this background information is provided solely for the teacher's information. For the most part, the Education Department at Woodland Park Zoo avoids discussing threats to animals and habitats with children younger than 4th grade. We want your students to fall in love with forests, not become overwhelmed with all the threats forests face. However, most likely your students will have heard about the threats facing forests and forest inhabitants, so we wanted to provide this information for you to be able to answer their questions. We ask that if the following topics come up in a discussion, that you wrap up with positive **conservation** messages, either about what others are doing to help conserve forest, or what your students can do to help conserve forests.*

We use forests every day. Even if we are not hiking, camping, fishing or bird watching, there are many forest products that are part of our daily lives, such as a wooden chair we sit on, or a chocolate bar we eat. Trees and other forest plants help clean our air, keep our watersheds healthy, store atmospheric carbon, moderate global climatic conditions and beautify our environment. People put many demands for products and services on forests and these demands continue to increase as the world's human population grows. Over the course of human history, people have used forests and their products in an increasingly unsustainable manner to such a degree that over the past 8,000 years scientists estimate that anywhere from 20 to 50 percent of land that was once forested no longer hosts forests (Matthews, et. al., 2000).

Threats to Forests

Temperate and tropical rain forests face different threats at different times; some threats that have already been resolved in temperate forests are still serious problems in tropical forests. However it's safe to say that all forests face the following threats in varying degrees: habitat loss, road building, introduced species, pollution, fire suppression, population (human) and overharvesting.

Habitat Loss

As the human population increases, so too does our demand for land for agriculture, homes and businesses. As the land is developed, wildlife is pushed back. Millions of acres of forests and other habitats are destroyed each year to supply the human demand for land.

In the tropics many landholders clear huge tracts of rain forest for cattle pastures or plantation crops. Agricultural land is also cleared by large numbers of small subsistence farmers. These farmers clear small tracts of forest and farm the area for several years. Once the trees are removed they can no longer break the force of the rain or hold the soil with their roots. The thin layer of nutrient-deficient soil soon washes away, or is leached of nutrients by the frequent rainfall. Deterioration of the soil forces farmers to move on and clear the trees from new tracts of land. This method of agriculture has been used sustainably for centuries on a small scale. The balance of sustainability has been thrown off, however, as large numbers of people move into the forests to farm. These large numbers of people clear the land much more rapidly, and open areas of land for settlement. This increases demands for firewood and forest resources even more.

Development has a negative effect not only because of the direct loss of habitat, but also on bird populations that utilize nearby forests. According to a study on the effects of residential development on forest-dwelling songbirds, the more houses that surround a forest, the less suitable that forest is for Neotropical migrants. These songbirds consistently decreased in diversity and abundance as the level of adjacent development increased, regardless of forest size. The study recommends that minimum distances for housing developments around forests need to be determined to lessen adverse effects on forests and forest inhabitants (Sallabanks et al. 2001).

In Washington state, development is still a major threat to temperate forests. According to a number of different sources, private companies, groups, or individuals own approximately 9.4 million acres of Washington's 22 million acres of forested land (Erickson, 2004). Forests come under greatest threat when ownerships change. From 1982 to 1997, 10.3 million acres of non-federal forest land converted to non-forest uses; this is an average of approximately 680,000 acres per year (Alig et al. 2003). Researchers estimate that close to 44.2 million acres of private forest land in the United States could experience large increases in development pressures between now and 2030 (Stein et al. 2005).

Road Building

A road through Mt. Rainier National Park, Washington Photo by Shane Farnor

Road building through both temperate and tropical forests also has myriad impacts on forest ecosystems. Roads open up previously inaccessible forests to other threats such as clearing for agriculture, settlement, logging (legal and illegal), forest fires and hunting (legal and illegal). Furthermore, roads themselves impact ecosystems and species through increased mortality from construction and collision with vehicles, changes in animal behavior (such as declines in reproductive success), changes in the physical environment (such as soil compaction and the flow of surface water), the introduction of chemicals (such as heavy metals and salt), and the dispersal of **invasive species** of plants and animals (Trombulak and Frissell, 2000). Some animals try to cross roads and are prone to being hit by vehicles. Other animals, particularly invertebrates, amphibians and small mammals, will not cross wide gaps, such as roads, and can therefore be stranded in fragments of forests bordered by roads. In the United States, a number of organizations have supported the protection of current roadless areas in national forests in order to prevent the recognized impacts of roads on forest ecosystems and wildlife. Understanding of the effects that forest road systems have on forest inhabitants, particularly on aquatic biota such as salmon, have improved immensely. In response to this improved understanding, Washington's Forests & Fish Law have specific guidelines and timelines for all medium and large forest land owners to develop Road Maintenance and Abandonment Plans (RMAPs). (See "Forest Management" for more information on the Forests & Fish Law)

Introduced Species

Wildlife habitats have been severely altered by introduced, or non-native, species. Species of plants, animals and even disease pathogens have, and continue to be, introduced from one region to another by humans, both accidentally and intentionally. Some plant species first became established as garden ornamentals before they "escaped" into the wild and spread. Pest species, such as Asian longhorned wood-boring beetle, may be transported from Asia to North America in raw logs. Other species travel along with shipments of fruits and flowers or even in the wheel wells of planes!

Once introduced, species may not survive due to differences between their natural habitat and the new habitat. Some species, however, thrive and proliferate in their new environments. These invasive species, whether plants or animals, can severely reduce the numbers of native species in the area. Without the natural predators or disease controls found in their native regions, introduced species can proliferate at fantastic rates. Introduced species may prey on native species, alter the natural habitats of the native species, or they may out-compete native species for basic needs. Either way, the spread of an introduced species leads to the loss of biodiversity.

Introduced species of plants and animals have had great impacts on many native species of Washington state. Some non-native plant species aggressively invade forests and shade or choke out native plant species. Many temperate forest understories of western Washington have been invaded by the weedy geranium, herb robert (*Geranium robertianum*). Originating from Europe, Asia and North Africa, herb robert was introduced to Washington, most likely as a garden ornamental, in the early 1900s. This plant spreads readily in the shady forest floor of forests, often outcompeting native forest floor and understory plants, eventually covering up to 50 to 100 percent of the ground (Simon, 2003). There are many community groups in western Washington that are actively engaged in the removal of invasive plant species in order to protect the diversity of our temperate forests.

Herb robert *Photo by Katie Remine*
(Geranium robertianum)

Pollution

Environmental pollution, the chemical poisoning of air, land and water, poses a major threat to the survival of many plant and animal species, including humans. Carbon monoxide, a reaction product of the combustion of fuels in automobiles, approaches a hazardous level in many of our large cities. Lead, also emitted through car exhaust, ladens the air two or three feet from the ground, where it can be inhaled by small children and by wildlife.

Pollution negatively affects both temperate and tropical forests. Air pollution, water pollution and an excess in ozone all interfere with trees' physiological and biochemical processes, hampering photosynthesis and growth. Acid rain is particularly detrimental. Acid rain is precipitation that contains sulfuric, nitric and other acids, which originate from sources such as gasoline and diesel used in cars, fossil-fuel-fired electric power plants, industrial boilers, and residential furnaces. Acid rain damages leaves, harms organisms, and changes soil chemical composition.

Coal burning factories release chemicals high into the atmosphere which cause rain falling to the earth many miles away to have a high acid content. This can cause harm to trees as well as polluting water sources relied upon by a variety of species. As various gases (CO_2, CFCs, methane, etc.) form an increasingly large blanket around the earth, sunlight reaches the earth's surface, but heat is prevented from escaping, thus causing global warming. Global warming can result in increased global air temperatures and extreme weather patterns.

Fire Suppression

Fighting forest fires is important when the fires are accidentally started by humans. However, naturally caused fires are an important component of healthy ecosystem change. In fact, indigenous tribes across North America (and elsewhere) have used fire as a tool to manage their habitat for thousands of years. Fire suppression has been so effective that it has lead, in many cases, to an unbalanced ecosystem. This leads to loss of fire-dependent species and more intense fires than would occur if the natural fire interval was maintained. "Prescribed" (or deliberately set and controlled) fires can help remedy this problem.

Population

If you examine each threat to forests, you will notice that each is intrinsically tied to human activity. Needless to say, the impacts of human activity on biodiversity increase as the human population of the world increases. If the birth rate is greater than the death rate of a population, the population increases. With the onset of agriculture and the domestication of animals approximately 10,000 years ago, the human population began to grow steadily (Tesar, 1992). Since the Industrial Revolution, which occurred between 1760 and 1830, the human population has been growing at an extremely fast pace. Improvements in medical care have increased human survival and life span, also contributing to the increase in human population. If we are not conscious of the relationship between human population growth, consumption patterns and the problems facing forest species, we will not be capable of being part of the solutions.

Overharvesting

Some tropical forests are logged to supply international demand for specialty hardwoods. Forests in most developing countries are not yet managed as a crop as they are in most developed countries. Although forestry techniques, such as replanting, are now being used on a small scale in some developing countries, the widespread use of these forestry techniques may be a ways off. Many more acres will be lost before significant gains are made in the sustainable management of tropical forests. However, growing awareness in a number of Central and South American countries is leading to new legislation protecting forests.

Despite new temperate forest management plans, human demand for timber, paper and cellulose-based products continue to grow, while at the same time, more people are looking toward forests for recreational use. We have, in addition, become more concerned with maintaining the health and beauty of the environment. In order to meet both the economic and recreational demands placed on them, forests must now be managed so they will continue to provide for the needs of future generations and the many plant and animal species that rely on forest ecosystems.

What is Being Done to Help Conserve Forests?

The conservation of biodiversity, in forests and in other ecosystems, is a complex endeavor that encompasses social, political and economic factors as well as ecological considerations. With proper protection, scientific research, education, community involvement and forest management policies, forests can continue to provide people with necessary products, provide healthy habitat for a diversity of species, support traditional cultures, and carry out important ecosystem services. The following paragraphs illustrate just a few ways that people around the world are striving to conserve forest ecosystems, wildlife and resources.

Forest Research

Scientific research is an important part of forest conservation. Thousands of research projects are being conducted in forests around the world. One research area that has grown by leaps and bounds since the mid-1970s is forest canopy research. Over the years, new methods of exploring the forest canopy, such as towers, walkways, construction cranes and rope climbing, have been developed, facilitating our understanding of canopy ecosystems.

In 1995, a temperate forest canopy crane was established in Washington state, giving researchers new insights into this hard-to-reach forest level. As of 2003, there were a total of 11 canopy cranes around the world in both temperate and tropical forests (Basset et al., 2003). Washington's crane is located in stands of old growth at the Wind River Experimental Forest, between Mt. St. Helens and the Columbia River. The crane, which is 285 feet (86 m) tall and is similar to those used for city construction, is owned by the University of Washington and jointly managed by the university and the U. S. Forest Service. The crane is used by myriad researchers exploring such topics as the use of different forest levels by bats, life cycles of insects that breed in the canopy, the important role of invertebrate animals living on conifer needles in the food chain, the role of lichens in fixing nitrogen and improving air quality, canopy photosynthetic rates under varying environmental conditions, and weekly counts of songbirds inhabiting this layer of the forest. These studies, as well as similar studies in tropical forest canopies, have turned up large amounts of new information, adding to our knowledge of the complexity of forest canopies and aiding in designing new forest management and conservation practices.

Forest Management

In the United States, although most of the public forest land, and many privately owned forests, are currently managed for sustainable harvest, this has not always been the case. This unsustainable management had serious implications for wildlife. In Washington state, the Forest Practices Act was passed in 1974. This act was developed to ensure the protection of soil, air, water, fish, wildlife, and forest resources. Following clearcutting, intensive management is required; three years is the time allowed for replanting. Any company or individual working in state or privately owned forests in these two states must comply with the practices set out in this Act. Federally owned forests are exempt, but federal management agencies have agreed to meet or exceed the standards in the respective Forest Practices Acts.

Despite the Forest Practices Act, in the early 1990s in the Pacific Northwest, significant conflicts erupted over forest management when declining employment in the timber industry, a result of increased automation and decreased supply, coincided with the addition of the northern spotted owl to the endangered species list. The conflict rose between people who were impacted by declining employment and people who felt that logging of ancient forests had had drastic impacts on watersheds and plant and animal species, including the northern spotted owl. The conflict was so intense that logging of old growth forests was halted by court order until a new management plan could be put into effect.

In 1994, a new forest management plan for federal lands in western Washington, Oregon and northern California (the area concerned was defined by the range of the northern spotted owl) was adopted. This plan, the Northwest Forest Plan (NWFP), is based on an ecosystem management approach aimed at fulfilling economic, social and ecological objectives. In order to maintain diversity in northwest forests, the NWFP aims to establish a patchwork of reserves of old growth forests within a matrix of logged land. This land use pattern is based on the theory that viable populations of species within the old growth reserves can disperse across the matrix of logged land to other old growth forests, ensuring the survival of healthy populations of these species. Other species that are less likely to survive the effects of logging and are less able to disperse are sustained by a system of protected lands called riparian reserves and late successional reserves.

The Northwest Forest Plan has been a significant compromise between ecological interests and social and economic interests in forests. In addition, the plan has facilitated the close cooperation among numerous federal agencies and better communication between these agencies and state agencies, tribes and the general public. The Northwest Forest Plan "established a common vision for the management of federal lands within the range of the northern spotted owl. It delineated a set of objectives covering ecological protection as well as commodity production and committed all the agencies to work toward all those objectives. Even more importantly, it required them to work together, on an interagency basis, to implement the Plan" (James, 1998).

The marbled murrelet is just one example of a species threatened due to loss of old growth forest in the Pacific Northwest. The marbled murrelet is a sea bird but it builds its nest inland and depends on large, old trees present in old growth forests. Ecologists estimate that the trees marbled murrelets nest in must be at least 150 years old in order to have the necessary mosses and lichens present for nest building.

In 2002, Washington state passed the Forests & Fish Law, which aims to protect 60,000 miles of streams running through 9.3 million acres of state and private forestland through the creation of the Forest Practices Habitat Conservation Plan, a 50-year agreement between landowners or local governments and the federal government. In this Habitat Conservation Plan, landowners will be involved in improving forest roads and culverts, enlarging buffer zones along stream banks, and locating unstable slopes around the state. In addition, these landowners receive assurance that if they follow the state's forestry regulations, they will be complying with the federal Endangered Species and Clean Water Acts.

Protection and Reforestation

In some areas of the world, people have chosen to set aside forests where no logging or other extraction is allowed to occur and forests are designated to remain in their wild state. These lands may be publicly owned, privately owned or a patchwork of the two. In Costa Rica, 23.4% of the country's total land area is protected in the form of nature reserves, national parks, wilderness areas and natural monuments (World Resources Institute Earth Trends, 2003). Outside of these protected areas, however, deforestation is rampant. To combat this problem, the Costa Rican government created a program that protects intact forests on private lands and reforests disturbed lands. Part of the program is funded through the sale of carbon certificates to industrialized countries. These countries can then use these carbon credits to fulfill their own commitments to limit emissions of greenhouse gases. Costa Rica has already used the proceeds of the sale of carbon offsets to Norway to help finance the Private Forestry Project, a forest incentive program that pays thousands of participants to reforest or protect forest on their lands. Another component of the Private Forestry Project is a monitoring program conducted by Costa Rican forest engineers that seeks to determine the amount of net carbon storage in the protected forested areas each year.

Supporters of the Loomis Forest Fund have achieved permanent protection for 25,000 roadless acres in the Loomis State Forest located in Okanagan County, Washington. The forest encompasses a vast expanse of old growth temperate forest wilderness, habitat for some of the world's most majestic and, in many cases, endangered wildlife. Grizzly bear, wolverine and the healthiest remaining populations of lynx left in the lower 48 states inhabit this great wilderness. In the fight to save this area, a 1998 agreement with the state placed a moratorium on logging in key old growth forest habitats while obligating conservationists organized by Conservation Northwest to raise enough money to compensate the Common School Construction Trust Fund for permanent land protection. Woodland Park Zoo's Jungle Party Conservation Fund and the Puget Sound Chapter of the American Association of Zoo Keepers contributed funds to this effort. The Cascade Conservation Partnership, administered by Conservation Northwest, continues to work toward purchasing and protecting more than 75,000 acres in the North and Central Cascades.

Community Forestry

Local communities are increasingly involved in implementing sustainable forest practices when government capacity to properly manage forests falls short. In some cases, governments have passed forestry laws that turn over forest management to communities, recognizing that management at the grassroots level can be more successful. Community forestry efforts often benefit from the support and experience of organizations, such as the Forest, Trees and People Program of the Food and Agriculture Organization of the United Nations, in the management of their forests to achieve ecological, economic and social objectives.

Communities can benefit from the sustainable production of non-wood forest products. The harvest and sale of these products can provide economic incentive to local communities to protect their forests.

Forest Certification

Forest certification was begun to help protect forests from unsustainable harvesting practices and is intended as a way to let consumers know that a wood or paper product comes from forests managed in accordance with strict environmental and social standards. The certification efforts of the following organizations help to ensure that forest product consumers contribute to maintaining environmentally, socially and/or economically sustainable forests around the world:

- Forest Stewardship Council (FSC): originally designed for tropical forests in underdeveloped countries where there are few protections for workers and the environment
- Sustainable Forestry Initiative (SFI): developed for medium to large forest landowners in the United States, where there is a substantial infrastructure for worker protection (labor laws) and environmental protection (forest practice rules, Clean Water Act, etc.)
- American Tree Farm System (ATFS): adapted for small forest landowners that have fewer resources and different challenges than large industrial forest landowners
- Canadian Standards Association (CSA): focused on forests that are largely owned by the government and privately managed under long-term leases
- Programme for the Endorsement of Forest Certification schemes (PEFC): originally developed as the Pan European Forest Council to be an umbrella organization for European forest certification

Forest Stewardship Council (FSC)

The FSC is a private group consisting of environmentalists, community groups and professionals in the timber industry whose aim is to “encourage environmentally appropriate, socially beneficial and economically viable management of the world’s forests” (Forest Stewardship Council, 2001). FSC accomplishes these goals by implementing a rigorous set of standards that certified forests must meet. Consumers who purchase FCS certified wood products are assured that the forests from which the wood came meet the principles and criteria as set forth by the FSC. In order to be certified, companies must:

- Meet all applicable laws
- Have legally established rights to harvest
- Respect indigenous rights
- Maintain community well-being
- Conserve economic resources
- Protect biological diversity
- Have a written management plan
- Engage in regular monitoring
- Maintain high conservation value forests, and
- Manage plantations to alleviate pressures on natural forests.

(Forest Stewardship Council, 2001)

What You Can Do to Help Conserve Forests

It’s true that many factors affecting forests are dependent on economic policies put in place by governments in areas of the world from which we may be far removed. However, there are powerful things that every person can do to contribute to the protection of forests around the world and in our own backyards. Here are a few ideas for what teachers and other adults can do.

Smart Purchasing

As consumers, there is a lot that we can do to protect forests in our region and around the world. If you are purchasing wood or paper products, either for home or school use, be sure to look for certified forest products, from building materials to charcoal. Look for the Forest Stewardship Council label that indicates that the wood comes from a certified forest. If you are unable to find certified wood, ask your local home and hardware stores to stock it.

One way you can help to protect tropical forest ecosystems, if you are a consumer of coffee, is to look for shade-grown, organic coffee when you’re purchasing coffee for yourself or for an event. Coffee plants are naturally adapted to grow in the shady understory of tropical forest canopies. In order to increase production, many large-scale coffee growers have converted to “sun” coffee plantations, in which new varieties of coffee plants are grown in full sun. Sun coffee plantations substantially increased the yields of coffee; however, this technique requires the application of fertilizers and pesticides (insecticides, herbicides and fungicides). Shade coffee, on the other hand, is grown under the canopy of tropical forest trees, reducing the need for fertilizers and pesticides and enhancing soil stability and health. The canopy trees provide necessary food and shelter for many birds, including hummingbirds, swallows, warblers and tanagers. You can find out more from the Northwest Shade Coffee Campaign on the Web at www.shadecoffee.org.

How You Can Help Students Conserve Forests

You and your school community can have a big impact by making more environmentally sustainable choices. Become an environmental leader in your school

- Bring students and teachers together to restore forest habitat on your school grounds or in the community
- Help your students to conduct a recycling or energy assessment of your school building. Using the results, find ways to increase your school’s amount of recycling and reduce your school’s paper and energy use.

- Teach by example through your actions, both for your students and for your colleagues. Teachers are in a unique position to model environmentally conscious behaviors.

The Conservation activities in this packet also list a number of projects that you and your students can work on together, such as creating a worm bin, providing habitat in your schoolyard and adopting an acre of tropical rain forest.

Help students fall in love with forests

- Explore forests with your students—take a walk in a local forested park or go for a hike in a nearby forest; encourage students to tell their friends about what they see, hear and feel when they explore a forest; help them draw pictures, take photographs or make a journal to show to your friends and family.
- When visiting the forest to take in the natural wonders, it is important to remind your students to tread lightly, respecting the plants, animals and other organisms that call the forest their home. Explain why they shouldn't collect or disturb plants, animals, and non-living things of the forest and why they should take out everything that they brought with them to the forest. In addition, remember that we share our habitat with predators and we must use caution when traveling in areas inhabited by them. Research the area you plan to travel in and take appropriate precautions.

Get your hands dirty

- You and your students can sign up to help out with a community restoration project in a forested park—help to pull invasive weeds or plant native plants. You can find out about projects in your area by contacting your local department of parks and recreation or your local public utilities department.
- Work together with your school or community members to establish schoolyard habitat at your school. Agencies, such as the Washington Department of Fish and Wildlife, and organizations, such as the National Wildlife Federation, can provide you with some great information about nurturing habitat in your backyard or schoolyard.

Contribute some cash

- Your class can think of some creative ways to raise money for a conservation organization. Explore opportunities to Adopt-An-Acre of rain forest, Zoo Parent Animal Adoption at Woodland Park Zoo, or support a local or international forest conservation project. You might try bake sales (you can sell shade-grown coffee too!), t-shirt sales, skating parties or other fun ways of raising funds for forest conservation.

Reduce, reuse, recycle

We often hear about the benefits of reducing our consumption of products, reusing when we can and recycling things such as paper, metals and plastics. Recycling can help to conserve raw materials (such as trees), conserve energy that goes into making new products, and reduce the volume of garbage disposed in landfills. Here are some specific things you can teach your students about saving healthy forests for the future.

Paper

By reusing and recycling paper and paper products (such as paperboard used to make cereal boxes and corrugated cardboard) you can help to ease the demand for pulp from trees to make new paper and paper products and also help to decrease the volume of garbage put into landfills.

People in the United States have been recycling increasing amounts of paper over the years, with the portion of paper and paperboard that is recovered for recycling increasing from 33.5 percent in 1990 to 51.5 percent in 2005 (American Forest and Paper Association, www.paperrecycles.org/recycling/index.html). We're doing a great job—let's keep it up and set our sights even higher! Here are a few ideas for reusing paper, reducing the amount of paper you use and getting into the recycling loop:

- Encourage your students to experiment with different ways of reusing and saving paper:
- take notes at school on the backsides of pieces of

paper that have already been printed on one side.

- take cloth bags to the grocery store (that way you don't need to get paper or plastic bags at the store.)
- "Close the loop"—when your school buys paper products, buy recycled products. Look for products made from at least 30 percent or more post-consumer waste. Point out to your students that the paper they're using is recycled.
- Look for "tree-free" paper alternatives, such as products made from banana, coffee, hemp or other alternative fibers.

Aluminum

Recycling aluminum and reducing our use of aluminum are other ways you and your students can help to protect forests around the world. Bauxite, the ore used to produce aluminum, is mined in open pits in many areas of the world, often in forested areas. Australia, Guinea, Brazil, Jamaica and former republics of the Soviet Union are major bauxite producing countries. Forests are cleared to make way for mining of bauxite. Fortunately, many mining companies spend time and money on habitat restoration efforts at former mining sites.

If your students make efforts to reduce their use of aluminum and/or recycle all the aluminum they use, not only will they cut down on the amount of ore needed to produce aluminum, they will reduce the amount of energy and water used to process aluminum. Aluminum processing requires large amounts of energy and water. In many cases, aluminum-processing plants obtain their energy by damming forest rivers, greatly impacting the forest ecosystem.

- Ways to reduce our use of aluminum:
- Bring drinks to school in a sturdy plastic, reusable bottle instead of buying soda in cans.
- Buy soda for home in large two-liter bottles instead of cans (and make sure to recycle the plastic bottles).
- Be sparing in your use of aluminum foil. If possible, use reusable airtight containers to store left over food.
- Recycle aluminum
- If you do use aluminum cans at home or at school, be sure to recycle them in the proper containers. Let your teachers know if there aren't enough recycling bins around your school grounds.
- Note: Aluminum foil cannot be recycled.

For more ideas, you can consult the article "Seven Things You Can Do to Save the Rainforest" at the Rainforest Action Network Web site http://ran.org/fileadmin/materials/education/factsheets/RAN_SevenThings.pdf .