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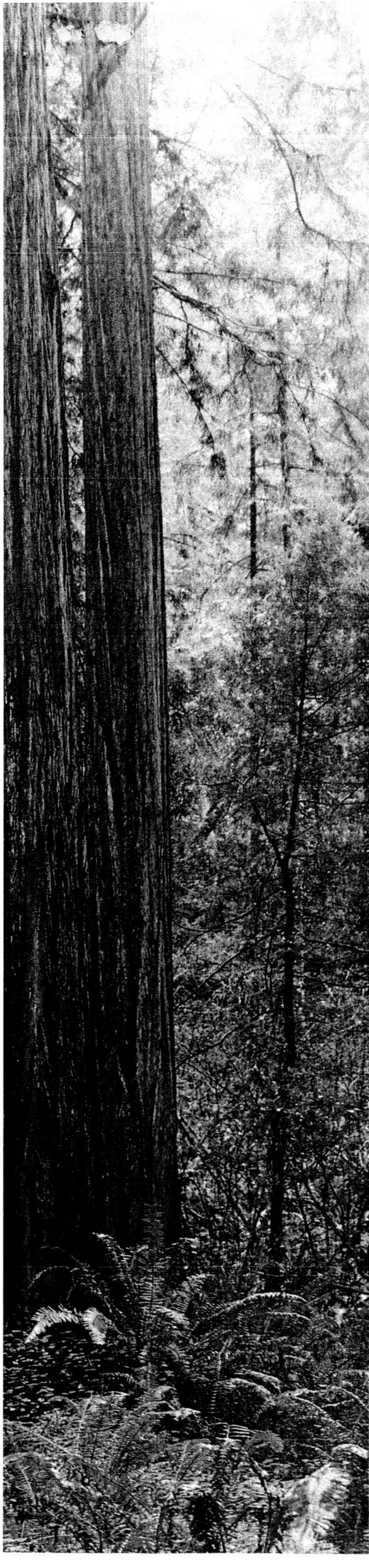
To my best friend,
Jerry

Dick



The massive trunks of coast redwoods and other Pacific giants hold vast amounts of water. In the warm summer, when trees transpire more and thus need more water, these conifers supplement soil moisture with water from their stem reserves.
Loren E. Lane, West Stock

Land of the Giant Conifers

In the Pacific Northwest, majestic conifers thrive in a climate that makes life difficult for most hardwoods

by Richard H. Waring

In the winter of 1805–06, when Meriwether Lewis and William Clark first traversed Oregon to the Pacific Ocean, they wrote in their journals about forests of giant conifers—trees more than 36 feet in girth with spires that towered more than 250 feet. At that time, these giants dominated the Pacific Northwest, a region that extends from California north to Alaska and runs east from the ocean to the crest of the Cascade Mountains in the south and the Coast Mountains in the north. Some of the trees alive at the time of Lewis and Clark's expedition are still standing, and today the forests of the Pacific Northwest are known throughout the world. More than twenty species of conifers, representing ten genera, populate the region, and many are the largest and longest lived of their kind.

The forests that make up this mantle of greenery are not only impressive, as all who visit them will attest; they are unique among temperate forest regions of the Northern Hemisphere. Most forests of the north temperate zone are composed of hardwood trees or a mixture of hardwoods and conifers, and scientists have long speculated about why giant conifers dominate in the Pacific Northwest. Only recently, however, have ecologists addressed the question in detail.

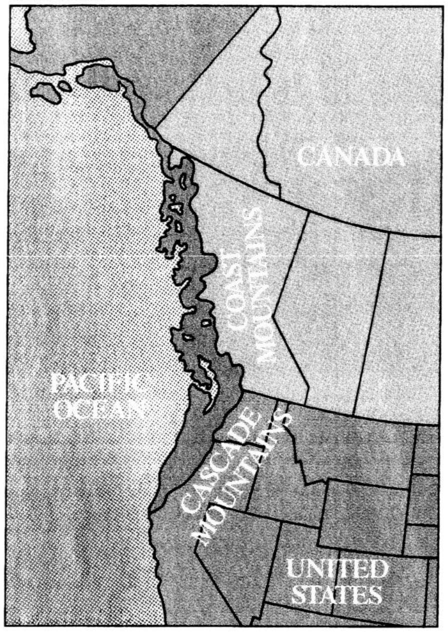
For millions of years, the region extending from northern California through Alaska to Siberia and Japan was largely forested with hardwoods. During most of that time—especially the early and middle Miocene, 15 to 30 million years ago—the Pacific Northwest conifers, which are of Asian lineage, were small in stature and restricted to harsh, high elevations, as are many conifers today in the Northern Hemisphere's subalpine zone. But by the early Pleistocene, more than a million and a half years ago and before any major glaciation had taken place, the makeup of the Northwest forests had changed dramatically. The conifers flourished and grew into giants, while many hardwoods, including genera still common in other temperate forest regions of this hemisphere, vanished. Today, hardwoods thrive only on disturbed sites where conifers either are not present or have not yet overtopped the shorter-lived hardwood species. What circumstances or adaptations might have favored the development of so many long-lived, massive trees? We are not sure, but as the findings of many studies are integrated, a picture is emerging.

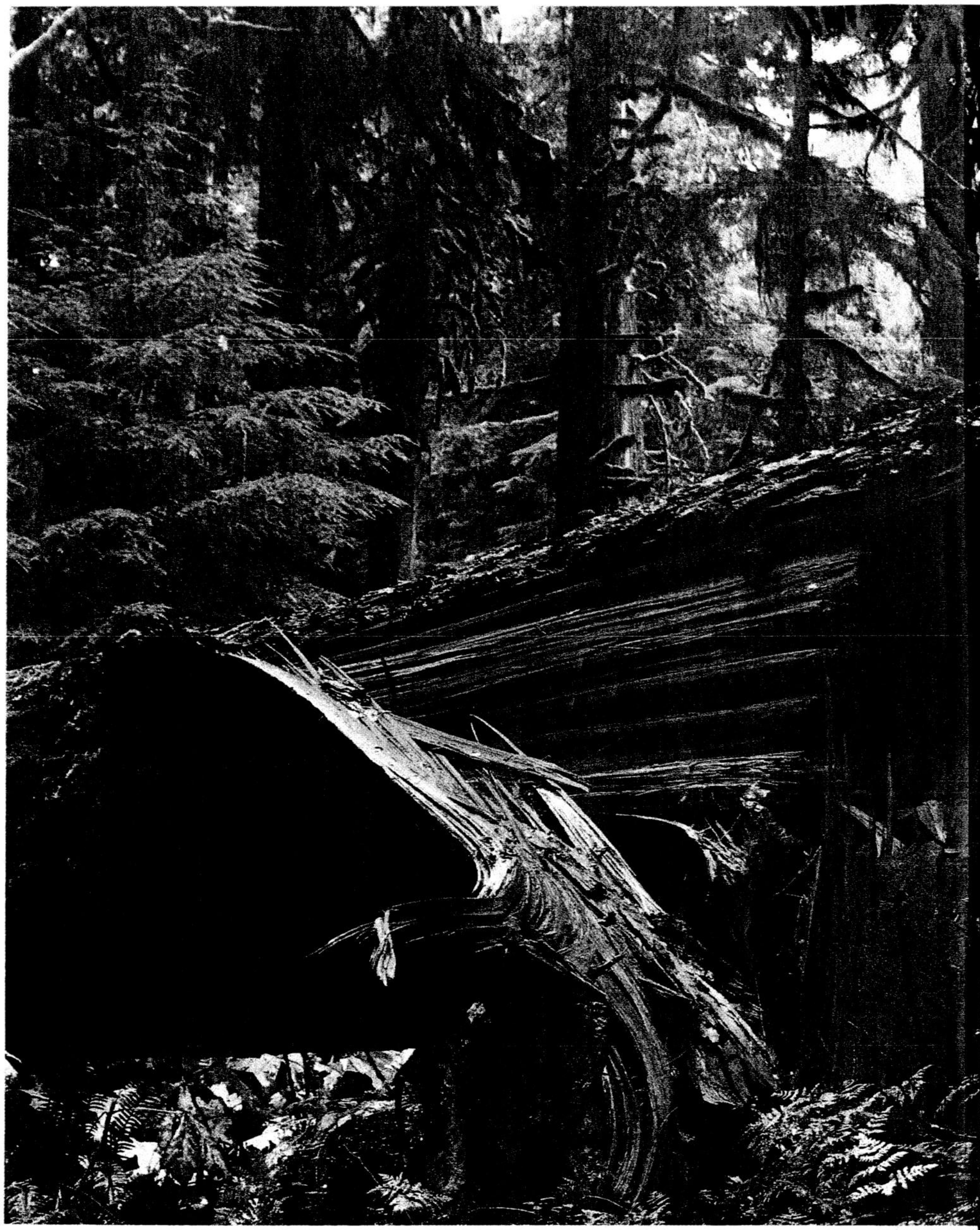
The critical event seems to have been a change in climate from one suitable for hardwoods to one favorable to conifers. As the Cascade Mountains and the Coast Ranges rose up over the last ten million years, they influenced the development of a climatic regime that has existed in the area ever since. The mountains trapped moisture-laden clouds coming from the Pacific Ocean. At the same time, rainfall patterns shifted; summers became drier, while heavy, cool air draining down the mountain slopes resulted in lower night temperatures during the growing season. Interactions between mountain ranges and maritime and continental air masses produce some local variation in climate, but in general summers are warm and dry and winters are mild and wet. The region is often shrouded in clouds and fog. Dur-

Art Wolfe, West Stock

The Pacific Northwest region (green area of map, below) provides the giant conifers with a relatively gentle but not entirely benign environment. Fires periodically destroy the forests; strong winds carry out a more selective pruning, often toppling older trees already weakened by heartrot or injured by fire, right.

Karen Karlsson





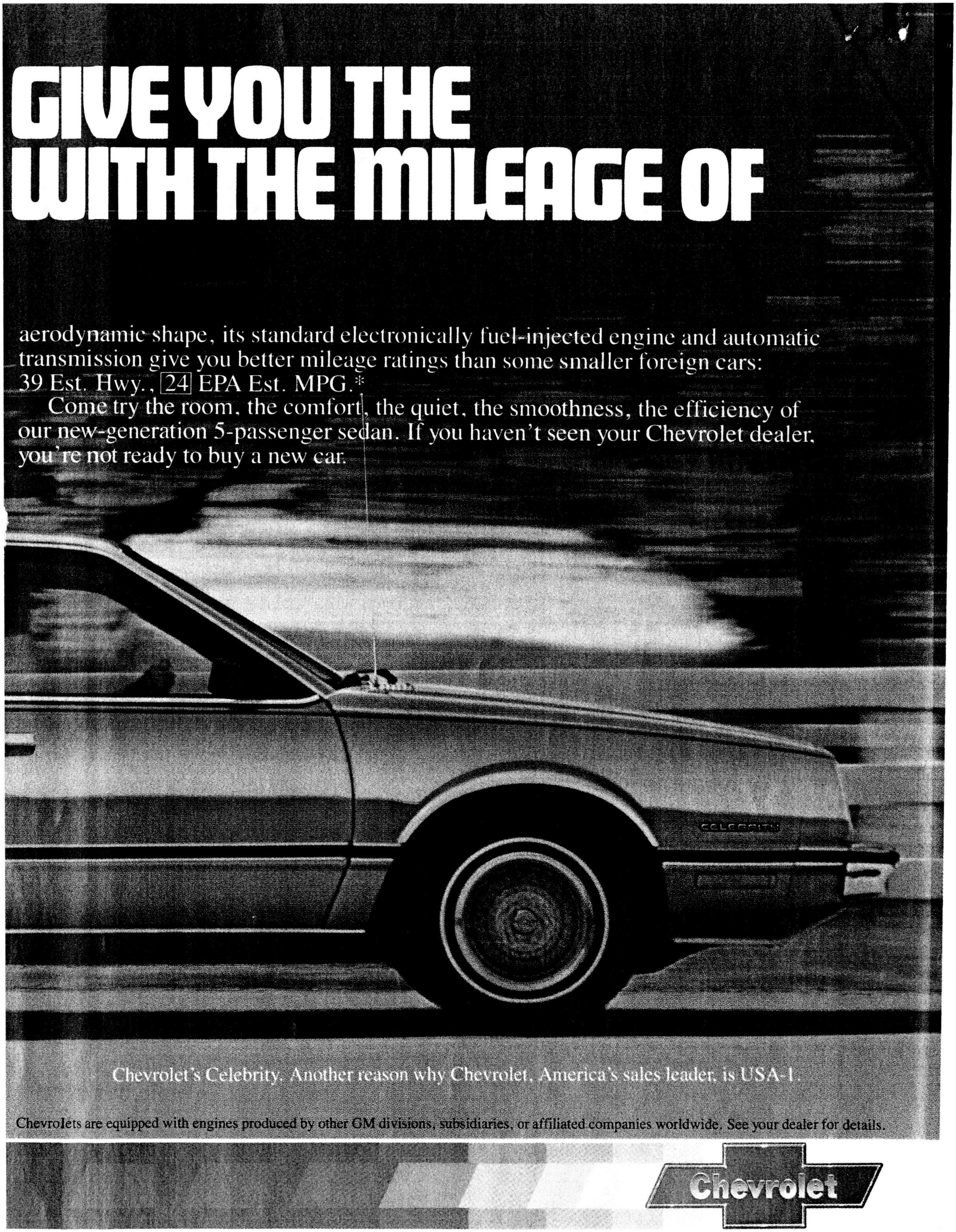
ing their half-year sojourn, Lewis and Clark frequently noted the perpetually damp climate, which they found somewhat less marvelous than the giant trees.

More than 90 percent of the total annual precipitation falls during the so-called dormant season, from late fall to early spring. In other temperate forests, by contrast, precipitation falls relatively evenly throughout the year. The Pacific Northwest winter is also atypical of temperate zones in that daytime air temperatures are usually above 32°F and soils do not freeze. Even in the subalpine zone, where more than ten feet of snow may accumulate and remain until July, soils remain unfrozen. In the valleys and throughout most of the Coast Ranges, winters are even milder; snow seldom falls, and when it does, it is washed away by the next Pacific rainstorm.

The mild winter weather and unfrozen soils have profound benefits for evergreen conifers. In a complex process called photosynthesis, all green plants combine carbon dioxide and water to produce carbohydrates, the chemical energy necessary to life. The conditions under which different kinds of plants are able to photosynthesize vary, however. Evergreen conifers can extract cold water even when soil temperatures are slightly below freezing, and many of them can continue photosynthesizing at air temperatures some degrees below freezing. So significant are these benefits that coniferous forests in the Northwest are estimated to accumulate from 30 to more than 50 percent of their total carbon products during the period from October through April. Deciduous hardwoods, on the other hand, shed their leaves in the fall and thus are totally dependent on stored reserves during the dormant season.

In most temperate forests, summer brings the warmth and rain on which deciduous hardwoods rely for growth. For trees growing in the Pacific Northwest, however, the summer growing season is the harshest time of the year. The rains nearly cease, and most of the region experiences extended summer drought. Water reserves in the soil may be largely exhausted and decomposition of litter may end, reducing the release of nutrients just when deciduous hardwood needs are greatest. Furthermore, atmospheric humidity is so low that leaf pores, called stomata, are nearly closed during most afternoons. This inhibits transpiration, the process by which water is taken in by the roots, pulled up through the tree, and ultimately released—primarily through leaf stomata—as water vapor. Because efficient uptake of water and minerals occurs only when leaves are actively transpiring, deciduous hardwoods are at a disadvantage in a climate where water is available mainly when they lack leaves.

The closing of the stomata causes additional difficulties: it prevents the atmospheric carbon dioxide needed for photosynthesis from entering the leaves. In the coastal valleys and at the seaside, where summer fog occurs, the moisture deficit is reduced, but so is the absorption of solar radiation. Decreased sunlight and closed stomata impede photosynthesis in both hardwoods and conifers. Again, however, the hardwoods suffer more than the ever-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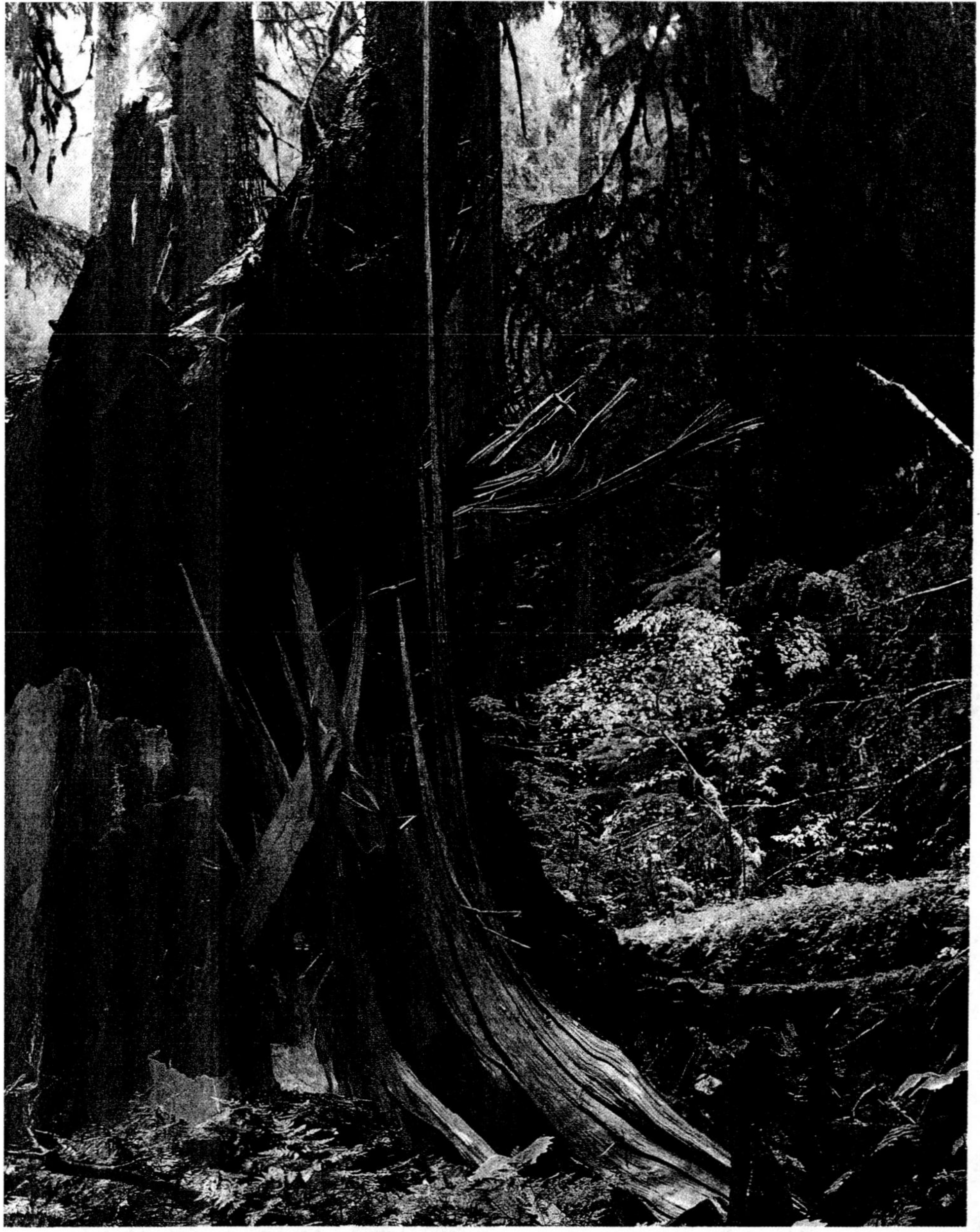
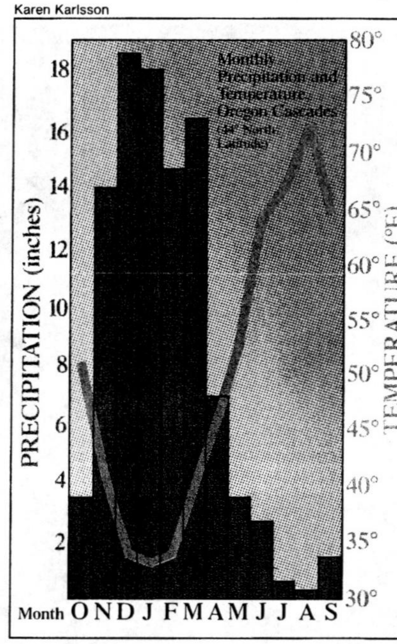


Dominated by Douglas fir and hemlock, the west-central Cascades of Oregon receive about 100 inches of precipitation annually. But this moisture falls unevenly throughout the year. The warm summer months are dry, putting deciduous hardwoods, totally dependent on the summer for growth, at a disadvantage.

Karen Karlsson



green conifers, which are not so dependent on the summer growing season.

Besides the ability to photosynthesize all year, the Northwest giants have large reservoirs in which to store water, minerals, and carbohydrates. Trees carry water and minerals upward from roots to foliage through sapwood, a wide band of dead, but porous, conducting cells in the outer part of the wood. Sapwood also contains horizontal bands of living cells, called ray parenchyma, adjacent to each vertically aligned conducting cell. Ray parenchyma store carbohydrates that are transported downward from leaves through the inner bark. These living cells represent only about 5 percent of the total sapwood volume in conifers (compared with 10 to 15 percent in hardwoods), but because the Pacific trees are so enormous, ray parenchyma form a storage reservoir equal to or exceeding that of the foliage, the other part of trees in which the carbohydrate products of photosynthesis accumulate.

This large volume of sapwood aids the conifers in several ways. Because the foliage is often 100 feet above the ground, the reserves held in the sapwood are the first drawn upon to heal wounds from fire, boring insects, or disease. In addition, sapwood reserves in the woody root system yield the carbohydrates necessary to grow most of the small feeder roots put out every spring.

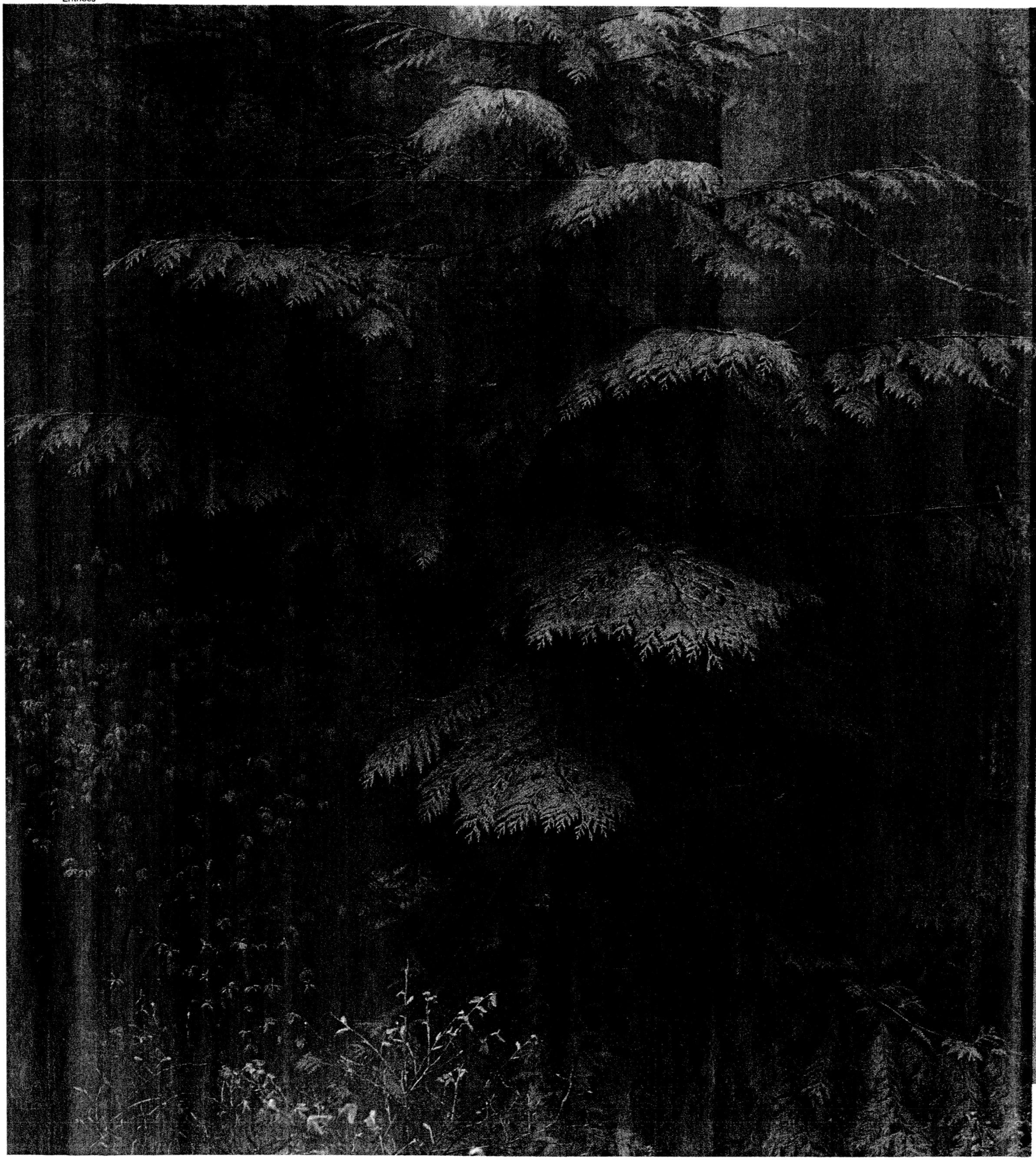
Perhaps most important, the massive conducting tissue serves as an auxiliary water reservoir during the summer. On most warm, dry summer days, when evaporation is high, the roots cannot transport water fast enough to the leaves. Instead, water is withdrawn from twigs and stem reserves to meet the deficit. The reserves are usually recharged from the soil at night when transpiration ceases. In many conifers, the reservoir provides a third of each day's water requirement; in the giants of the Northwest, the reserves are sufficient to meet at least a ten-day requirement at maximum transpiration rates. Hardwoods in the region are unable to hold even one day's needs in reserve.

Hardwoods also generally have fewer nutrient reserves and higher nutrient requirements than do conifers. Mature conifers replace only about 15 percent of their foliage every year, and individual leaves may live for thirty years; deciduous hardwoods replace all their leaves every year. Moreover, conifers can withdraw as much as two-thirds of certain required nutrients from older foliage, while hardwoods can meet less than one-third of their springtime nutrient requirement this way. They must rely on the uptake of nutrients from soil and litter on the forest floor.

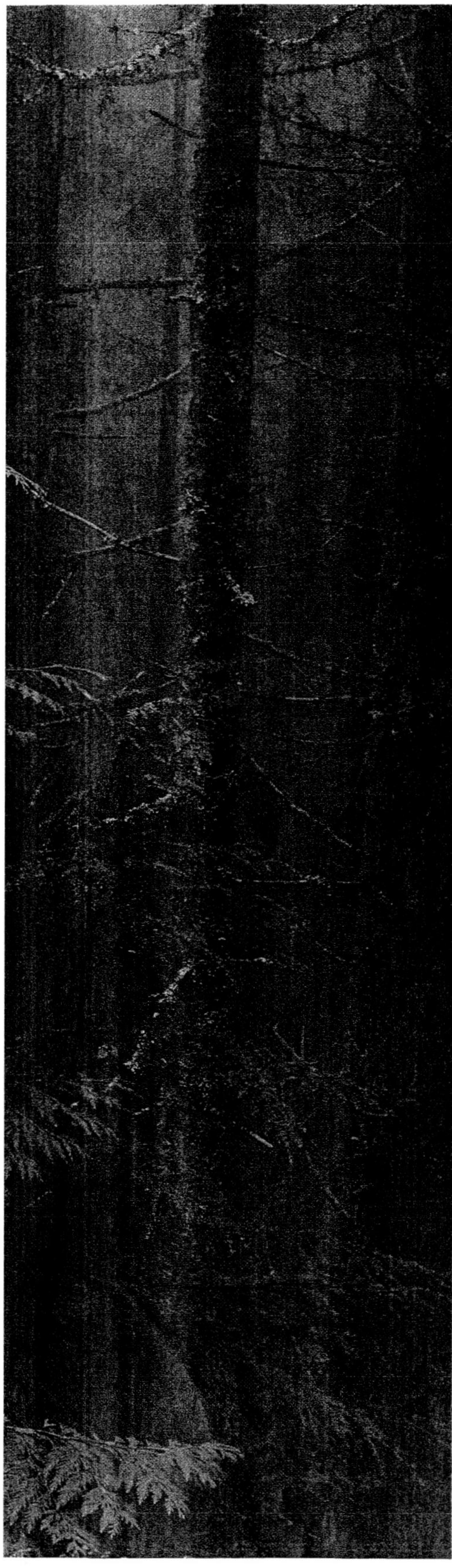
The giant conifers do not owe their position in the Pacific Northwest to superior physiological adaptations alone; their very shape helps foster their dominance. A pyramidal crown efficiently absorbs solar radiation at low sun angles and under cloudy skies, conditions common throughout the dormant season. In parts of the Northwest where deep and heavy snows accumulate, some conifer species, such as mountain hemlock and subalpine fir, have a particularly narrow shape. The branches of these trees are reduced in length and deflected downward. This increases the trees' ability to shed snow from their leaves, making it

Evergreen needles enable conifers such as this western red cedar to take advantage of the Pacific Northwest's mild, wet winters and to photosynthesize year-round. In the drier summer, fog condenses on the many needle-shaped leaves, adding to the tree's water supply.

Entheos



Under especially favorable growing conditions, conifers can reach truly spectacular ages and proportions. Among the trees that have been measured are a Douglas fir more than 400 feet high, a western red cedar nearly 21 feet in diameter, and a 3,500-year-old Alaska yellow cedar. Forests made up of these giant conifers accumulate more biomass than temperate and tropical forests in other parts of the world; redwood forests, for example, can contain more than 3,300 tons of biomass per hectare.



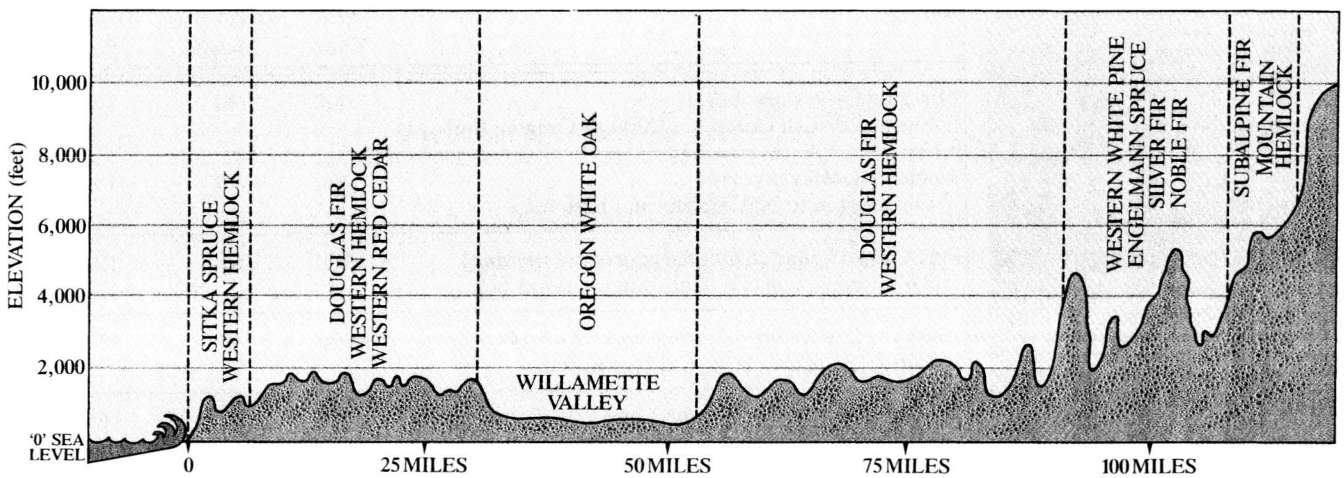
Ages and Dimensions of Typical Mature Trees in Pacific Northwest Forests

Species	Age Years	Diameter Inches	Height Feet
Silver fir (*Abies amabilis*) Central British Columbia through Oregon, high mts.	400	40	160
Noble fir (*Abies procera*) Washington to NW California, high mts.	400	50	190
Port Orford cedar (*Chamaecyparis lawsoniana*) SW Oregon and NW California, coastal belt	500	55	195
Alaska yellow cedar (*Chamaecyparis nootkatensis*) British Columbia to N California, mts.	1,000	50	115
Western larch (*Larix occidentalis*) SE British Columbia to central Oregon, mts.	700	55	165
Incense cedar (*Libocedrus decurrens*) W Oregon to S California and N Baja California, widely distributed	500	35	120
Engelmann spruce (*Picea engelmannii*) Central British Columbia to California and New Mexico, high mts.	400	40	160
Sitka spruce (*Picea sitchensis*) S Alaska to NW California, coastal belt	500	80	240
Sugar pine (*Pinus lambertiana*) SW Oregon through central California, mts.	400	45	165
Western white pine (*Pinus monticola*) S British Columbia to California, mts.	400	45	195
Ponderosa pine (*Pinus ponderosa*) SE British Columbia throughout the West, widely distributed	600	40	130
Douglas fir (*Pseudotsuga menziesii*) Central British Columbia throughout the West and into Mexico, widely distributed	750	70	245
Coast redwood (*Sequoia sempervirens*) SW Oregon and California, coastal belt	1,000	100	290
Western red cedar (*Thuja plicata*) SE Alaska to NW California, mts.	1,000	90	195
Western hemlock (*Tsuga heterophylla*) S Alaska to NW California, coastal belt and mts.	400	40	190
Mountain hemlock (*Tsuga mertensiana*) S Alaska to central California, high mts.	400	35	115

Within the Pacific Northwest, climate and topography vary considerably. As conditions change, so do the species that dominate the forests, as shown on the transect below (vertical relief is exaggerated twenty times relative to the horizontal scale). Conifers grow to great heights along the coast and on the mountains up to elevations of about 5,500 feet. Forests may be mixed or pure; the stand at right consists of relatively young Douglas fir, 100 to 125 years old. Hardwoods occur primarily as pioneer species or in more severe environments. Much of the Willamette Valley, for example, which is leeward of the Coast Mountains and therefore drier than the rest of the region, is dominated by white oak. Conifers at high elevations, such as subalpine fir and mountain hemlock, seldom reach the heights of trees at lower altitudes.

Karen Karlsson

Transect from Oregon Coast to Crest of the Cascade Mountains
(44° North Latitude)



possible for them to take advantage of the winter sun and photosynthesize.

The needlelike shape of conifer leaves has also been carefully tailored by evolution. The needles' narrowness causes them to dry quickly, a distinct advantage during the rainy season. Were the foliage to remain wet, transpiration and the associated mineral uptake would be minimal during the winter. In the dry summer, fog is caught by the dense canopy of needles, quickly condenses, and drains off the narrow leaves, measurably supplementing rainfall during the drought period. Moreover, although both conifers and hardwoods control water loss by closing stomata, the narrowness of conifer foliage dissipates heat more efficiently and prevents leaves from reaching lethal temperatures when transpiration is inhibited. When stomata are closed in hardwoods, the temperature of the leaves rises, metabolic activity increases, and carbohydrate reserves are depleted.

Each needle-shaped leaf is small, but conifers carry a huge number of them. As a result, their total surface area is large, which makes them efficient filters of atmospheric dust and gases. In the relatively unpolluted Northwest, this is a definite advantage. Minerals deposited on the leaves are leached to the roots or trapped on foliage and eventually made available for uptake as the leaves fall and decompose.

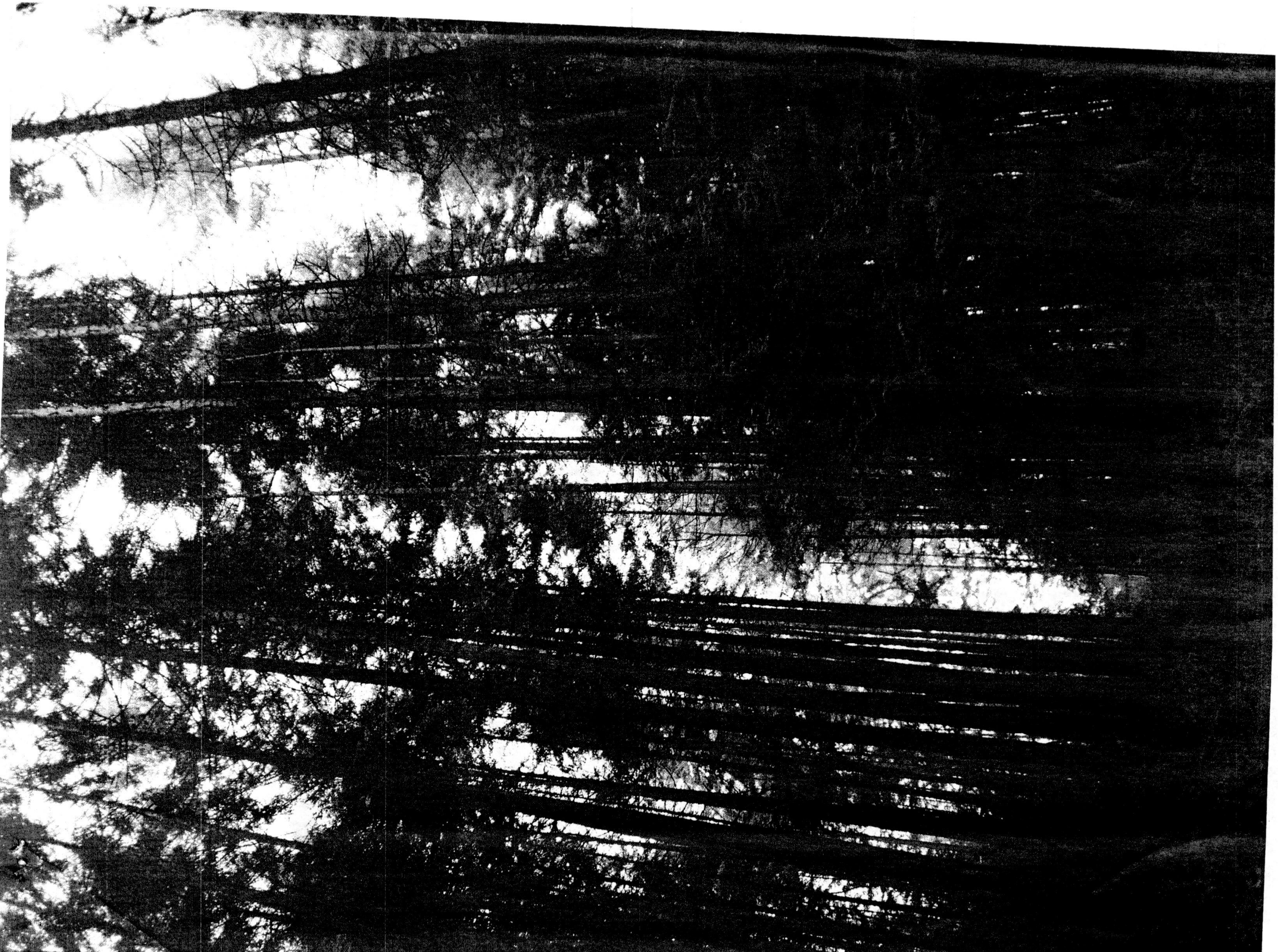
The many traits of conifers—shape, large storage reserves, efficient use of nutrients, year-round photosynthesis—are crucial to their dominant position in the Pacific Northwest, but they do not result in exceptionally high growth rates. Annual productivity in these coniferous forests is comparable to that of many hardwood forests in other temperate regions. The conifers, however, can continue to grow in height for centuries and in diameter until they die, often after more than a thousand years. This ability to thrive for hundreds of years after attaining spectacular heights distinguishes these conifers as giants and contributes to forest stands with biomass accumulations far exceeding those of other north temperate forests. Most hardwood forests rarely accumulate more than 550 tons of biomass per hectare, while coniferous forests in the Northwest often reach 1,000 tons per hectare and, in the case of redwood, more than 3,300 tons.

A variety of other factors, more or less directly related to climate, contribute to the giant conifers' success. Winds in the region, except those directly on the coast or on mountain ridges, are relatively gentle. Unlike all other north temperate forest regions, hurricanes and tornadoes are rare. Storms do blow down patches of trees but not whole forests, as happens at less than one- to two-century intervals in Japan, Europe, and much of the eastern United States.

Periodically, the giant coniferous forests have been destroyed by fire. More than a century before Lewis and Clark, a Spanish sea captain noted in his log that he had to sail more than twenty miles off the coast to keep flying embers from setting his rigging aflame. Generally, however, when fire burns through the understory of such a forest, its flames are unlikely to reach the lower branches of the lofty overstory trees or to penetrate their protective bark, which may be more than a foot thick; hardwoods have no such advantages. Fires in the region occur infrequently, perhaps one a century. At that rate, they provide increased nutrient cycling and clear away encroaching understory vegetation, thus reducing competition and preventing a buildup of fuel for potentially more serious fires.

Some hardwoods, such as alder and snowbrush, play a special role after a catastrophic fire destroys a coniferous forest. Associated with the roots of these widely distributed plants are symbiotic bacteria (actinomycetes) that change atmospheric

Paul Kotz, West Stock

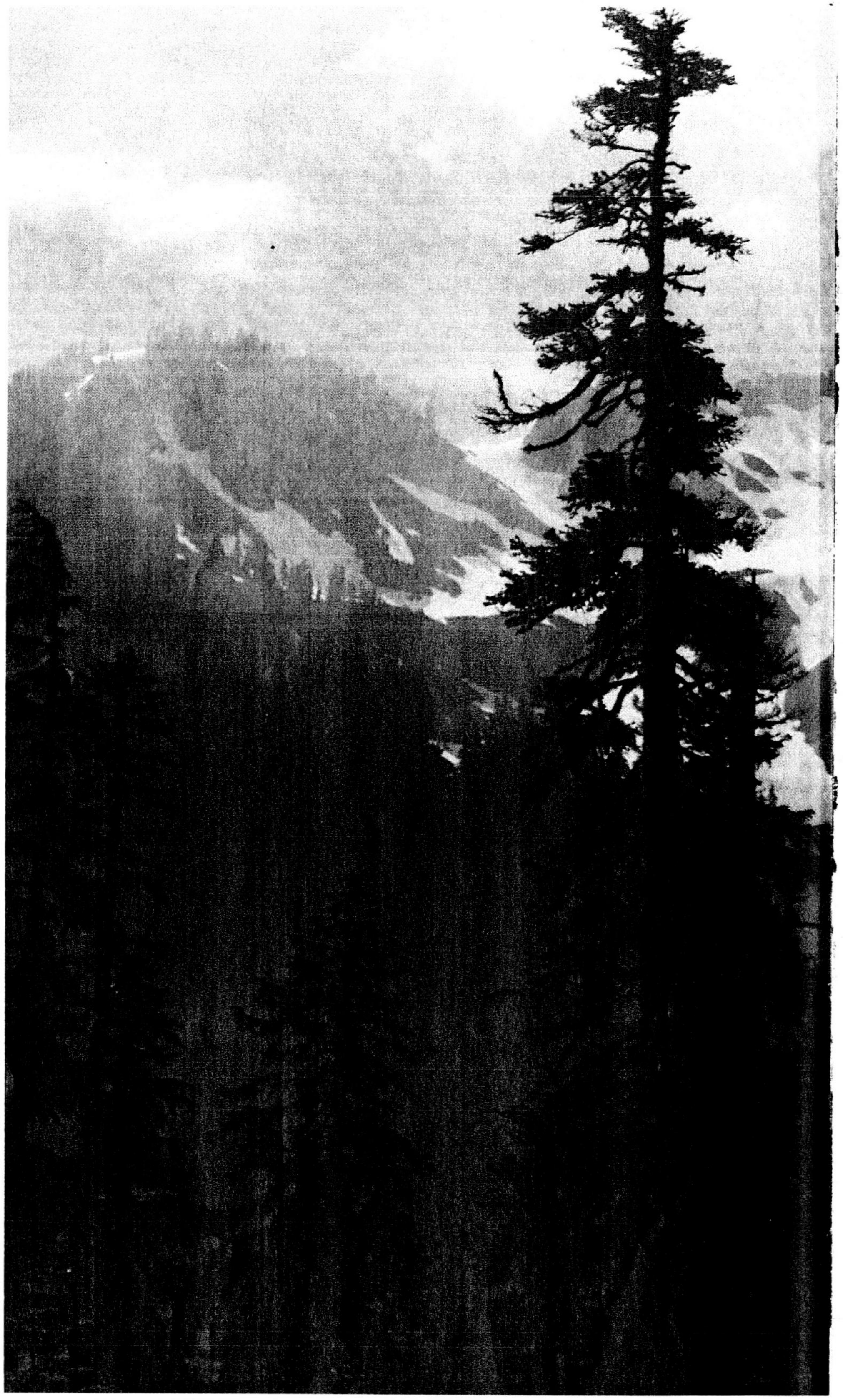


nitrogen into organic fertilizer at annual rates of 110 to 440 pounds per hectare. These plants germinate in the ashes left by the fire, and once the nitrogen they fix is incorporated into the soil, it stimulates and then maintains the growth of another generation of conifers.

Pathogens are active throughout the region but generally cause mortality only in younger coniferous forests, essentially weeding them and leaving growing space for the survivors. In the older forests, heartrots slowly decay nonliving wood in the trunks of trees previously injured by fire or infected with root rot. Even with heartrot, however, the trees may live for centuries until they are finally toppled by wind. The wood of some Northwest conifers, including western red cedar and redwood, is impregnated with protective tannins. These trees remain so resistant to fungal attack that their corpses are still around a century after falling to the ground. Even parasites such as dwarf mistletoe, a scourge of forests east of the Cascades, are notably ineffectual in, or absent from, most of the giants' realm. Where they are active, they kill only a few limbs or smaller trees.

Conifers are generally less palatable to insects than hardwoods, which have more nutritious foliage. Although certain insects occasionally defoliate or girdle some giant conifers, their activity is usually limited to forests suffering from damage caused earlier by wind, fire, or pathogens.

Perhaps the biggest threat to the giant conifers today is human activity. Although the coniferous forests still dominate the Pacific Northwest, their realm is much smaller now than in the time of Lewis and Clark. We might imagine that the giants are now protected in the more than one million acres of parks, research forests, and wilderness areas set aside for them in the United States. But our protective policies may be overzealous. History teaches us that nature restores these forests with episodic fires, waves of hardwoods, and even epidemics of pests. In human hands now lie the knowledge and responsibility to perpetuate—or doom—the largest forms of life this planet has ever known. □



Most conifers have a pyramidal or conical crown. These shapes facilitate the absorption of solar radiation on cloudy days and when the sun is low in the sky, common conditions during the Pacific Northwest winter.
Art Wolfe