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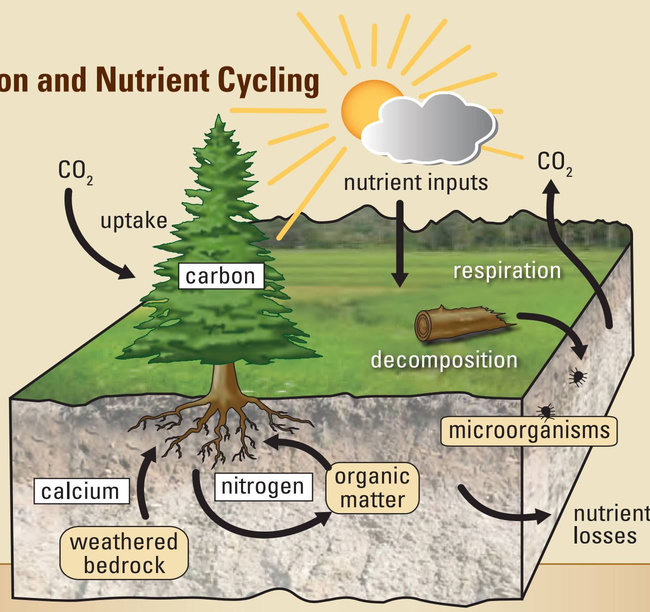
Unearthing Secrets of the Forest

Forests are a defining feature for large areas of the Pacific northwestern United States from northern California to Alaska. Coniferous temperate rainforests in the western Cascade and coastal mountain ranges are appreciated for their aesthetic value and abundant natural resources. Few people recognize the riches beneath the forest floor; yet, soil is a key ecosystem component that makes each type of forest unique. Soils harbor immense biological diversity and control the release of water and nutrients that support life above ground.

Understanding how carbon and nutrients cycle in forests, known as forest biogeochemistry, is crucial for evaluating forest productivity, composition, diversity, and change. At the U.S. Geological Survey (USGS) Forest and Rangeland Ecosystem Science Center, research in the Terrestrial Ecosystems Laboratory focuses on nutrient cycling in five themes: climate change, nutrition and sustainability, fire effects, restoration, and forest-stream linkages. This research is essential to understand the entire forest ecosystem and to use the best science available to make informed policy and management decisions.

Forested regions where USGS biogeochemistry research is conducted.

Carbon and Nutrient Cycling



Carbon, nitrogen, calcium, and other key nutrients are transferred from plant to soil to air and back to plant again through processes such as uptake, respiration, and decomposition. This nutrient cycling is a 'biogeochemical' process because nutrients follow pathways that are mediated by biological, geological, and chemical players. These players include plants, soil microorganisms, weathered rock, and gases in the air and soil. This diagram represents only some of the possible pathways involved in nutrient cycling.

Black Box Beneath the Big Trees

Old-growth forests of the Pacific Northwest store more carbon per unit area than ***any other biome, anywhere on Earth***. Much of this carbon is tied up in the huge trees. The regional temperate climate creates ideal soil conditions and properties that hold secrets to why these trees grow so big. Soil acts as a 'black box' in forest ecosystems because the vital processes are hidden underground. Soil fertility, or the ability of soil to provide plants with sufficient nutrients and water, is not visually obvious, but it can be measured using scientific methods and analytical equipment. USGS scientists are examining the black box to provide important information for balancing human needs and sustaining forests. The following examples highlight completed and ongoing research.

U.S. Department of the Interior
U.S. Geological Survey

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Fact Sheet 2009–3078
September 2009

Climate Change

Weathering the Storm

Precipitation and its effects on soil moisture shape forests across the Pacific Northwest, from the dense rainforests of the coast to the semi-arid woodlands of inland areas. Climate change likely will bring warming temperatures across the region, intensifying summer drought and moisture stress, which can limit tree growth. Climate predictions also call for wetter winters overall, with increased rain and declining snowpack. The USGS currently is studying how forests cope with the direct effects of changing rainfall and the indirect effects resulting from higher temperatures. Overall, the work seeks to understand how climate change will alter the amount of carbon stored in forests, and how this connects local and regional forests to rising levels of atmospheric carbon dioxide globally.

Storms from the Pacific Ocean slam into the massive Olympic Mountains and drop a yearly average of 15 feet of precipitation on its wettest western forests. The resulting rain shadow on the eastern side of the mountains receives as little as 3 feet of precipitation each year. In this natural laboratory, USGS scientists are comparing sites across the rainfall gradient and transplanting soil cores between sites to mimic how changing climate may alter forest soils. By varying soil exposure to different levels of precipitation, scientists can predict which areas are likely to experience changes in nutrient availability that shape carbon storage capacity. Future climate warming that decreases soil moisture during the growing season is expected to decrease nutrient availability, plant growth, and carbon storage in many forests of the region, particularly in areas that already experience significant summer drought.

Nutrition and Sustainability

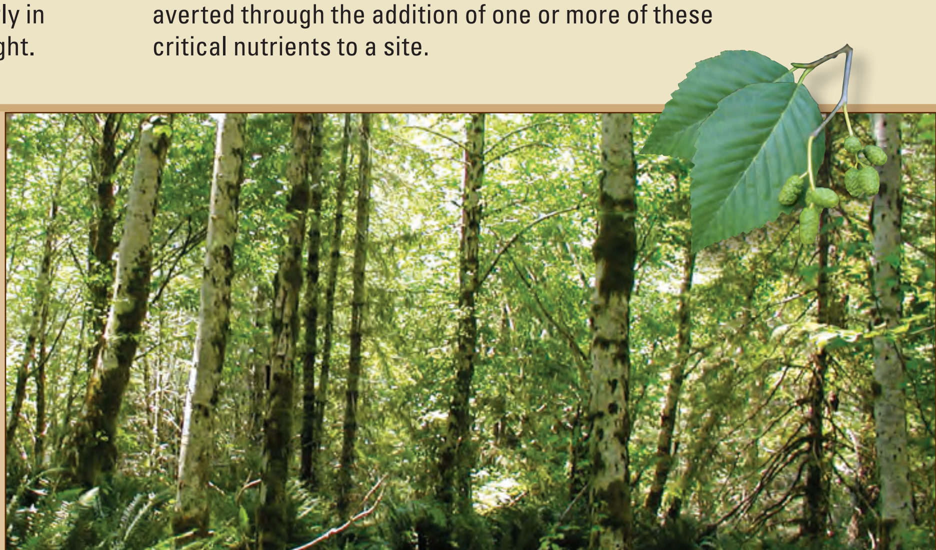
Administering the Multivitamin

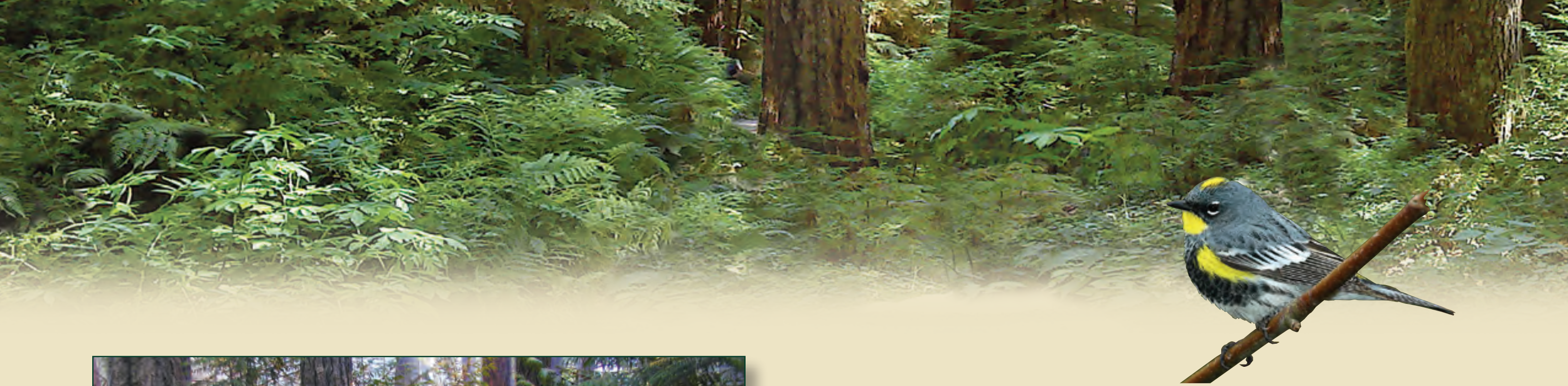
Forest ecosystems need a ‘multivitamin’ of nutrients to balance and sustain growth. Nutrient deficiencies can have detrimental effects on trees, making them susceptible to disease, root rot, and attack by insects. Historically, nitrogen has been considered the most limiting nutrient in Pacific Northwest forests, and as a result, nitrogen-based fertilizers are widely used to stimulate tree growth in young plantations. Interestingly, many forests in Oregon and Washington are not nitrogen-limited, mainly due to the presence of nitrogen-fixing red alder trees. USGS research has shown that naturally high levels of soil nitrogen result in low levels of soil calcium and associated calcium deficiency in Douglas-firs. These nutritional imbalances may predispose Douglas-firs to a fungal disease called Swiss needle cast, which can reduce a tree’s growth up to 50 percent.

These concerns led USGS researchers to consider sources and cycles of calcium in these forests. In some cases, most of the calcium used for tree growth comes from rainfall and atmospheric dust rather than the breakdown of minerals in rocks. Over time, trees accumulate this calcium in their wood and needles to support growth. At harvest, this calcium source is removed permanently from the ecosystem. Building on this information, scientists and forest managers have joined forces to investigate how different fertilizers can be used to improve and sustain tree growth on nutrient poor soils. Tree growth may be stimulated and disease averted through the addition of one or more of these critical nutrients to a site.

Nitrogen-Fixing Plants

Most plants take up nitrogen from the soil, but some form unique relationships with bacteria that can convert nitrogen gas from the atmosphere into forms of nitrogen the plants can use. Common nitrogen-fixing plants native to the Pacific Northwest include red alder trees, *Ceanothus* shrubs like deerbrush and snowbrush, and herbs such as Kincaid’s lupine. Nitrogen-fixing plants can ultimately enrich ecosystem fertility and benefit other plant and animal species.





Fire Effects

Inheriting a Burning Legacy

Wildfire can produce drastic changes to soil carbon and nutrients that alter the structure of the regenerating forests for years. USGS scientists and university partners are currently studying the immediate and long-term effects of fire on soil nutrients. In the Klamath–Siskiyou region in northwest California and southwest Oregon, shrubs such as deerbrush immediately colonize a burned area. Deerbrush can fix atmospheric nitrogen gas into mineral forms available to plants, restore soil organic matter, and renew soil fertility after wildfire. Current research focuses on how deerbrush aids the growth of longer-lived conifers by restoring soil fertility in areas that experienced catastrophic wildfire 10–20 years ago. By studying these processes at sites along a climate gradient, the scientists also hope to understand how the recovery of forests and soil fertility after wildfire may be shaped by future climate change.

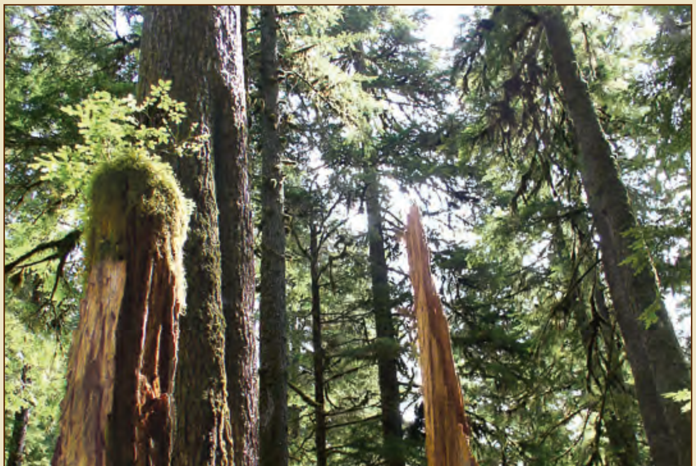
The long-term effects of fire on soil carbon and nutrients can last for centuries. A USGS study in the western Cascade Range in Oregon compared soil nutrients in forested areas that burned 550 years ago with other areas that burned 150 years ago. Scientists detected more carbon and nitrogen in the forest floor material in the older forests. Additionally, nitrogen was more available in the older forests than in the younger forests. Study findings suggest that more frequent fires may prevent accumulation of carbon and nitrogen and may ultimately decrease the role of forests in long-term carbon storage. In this way, policy decisions on managing wildfires can have multi-century effects that go well beyond the short-term effects usually considered by forest managers.

Old-Growth Restoration

Bridging the Generation Gap

Less than two decades ago, most Federal forest land was managed to produce high yields of timber and associated wood products. A new regional forest plan implemented in 1994 dramatically shifted the old management goal for millions of acres of young forests. Many dense, young forests were incorporated into a network of conservation reserves to accelerate the development of old-growth structure. One approach Federal forest managers are taking to restore old-growth conditions is to create various-sized gaps in dense, young forests. Managers harvest wood to create gaps that mimic naturally occurring disturbances, such as wind damage, landslides, and insect infestations. Gaps are a significant attribute of old-growth forests that reduce competition for sunlight and other resources, resulting in forests that vary more in age, species, and structure.

Gap creation in forests alters soil nutrient availability in ways that can influence plant growth and recovery within gaps. Using a combination of laboratory studies and field manipulations at sites in western Oregon, USGS scientists determined that the availability of soil nitrogen was greater within created gaps than in the adjacent forest. Higher nitrogen in gaps results from reduced tree uptake of nitrogen when trees are removed, and from the rapid recycling of nitrogen by shrubs and herbs that initially colonize the gaps. Gaps, acting as high-nitrogen 'oases,' create a mosaic of nutrient supplies that can contribute to the development of more diverse conditions as young dense forests gain old-growth characteristics.



Forest-Stream Linkages

Nourishing Food Webs

A riparian zone describes the forest-stream boundary area where land meets water. In the Pacific Northwest, coniferous and deciduous trees occur naturally along streamsides. When restoring riparian forests, managers emphasize retaining and growing large conifers, which are more effective than deciduous trees at providing shade and large wood for fish habitat. These functions, while critical in riparian forests, do not consider nutritional contributions from riparian plants that support stream- and land-based food webs. Deciduous red alder and coniferous Douglas-fir trees are common species that managers can manipulate in riparian zones. The chemistry of leaf litter differs greatly between Douglas-fir and red alder trees, so managing for different tree species can have consequences to consumers, such as fish and amphibians, farther up the food web.

As part of a multi-disciplinary study examining many aspects of food webs, USGS scientists assessed how the leaf litter produced by different tree species drives the base of food webs in riparian ecosystems. This work has shown that red alder-dominated riparian zones contribute more leaf litter and nitrogen than conifer-dominated riparian zones, especially in autumn. Once on the ground, red alder leaves decay and release nutrients more rapidly than Douglas-fir needles, more effectively feeding the organisms that depend on these resources. Additional work by USGS scientists has determined that riparian red alders enrich soil nitrogen levels and fuel the subsequent growth of conifers for decades. Each of these studies highlights the importance of red alders in riparian areas and helps to educate managers about balancing shade, wood, and nutrients when restoring aquatic ecosystems.

Forest Biogeochemistry Research Addresses

- Carbon uptake and storage
- Climate change
- Tree nutrition and productivity
- Soil fertility
- Young forest management
- Old-growth requirements
- Watersheds and water quality
- Restoration techniques
- Fertilization practices
- Fire effects and recovery
- Riparian food webs
- Native plant recovery
- Air pollution effects
- Resource protection

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Graphic Design by Bill Gibbs

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