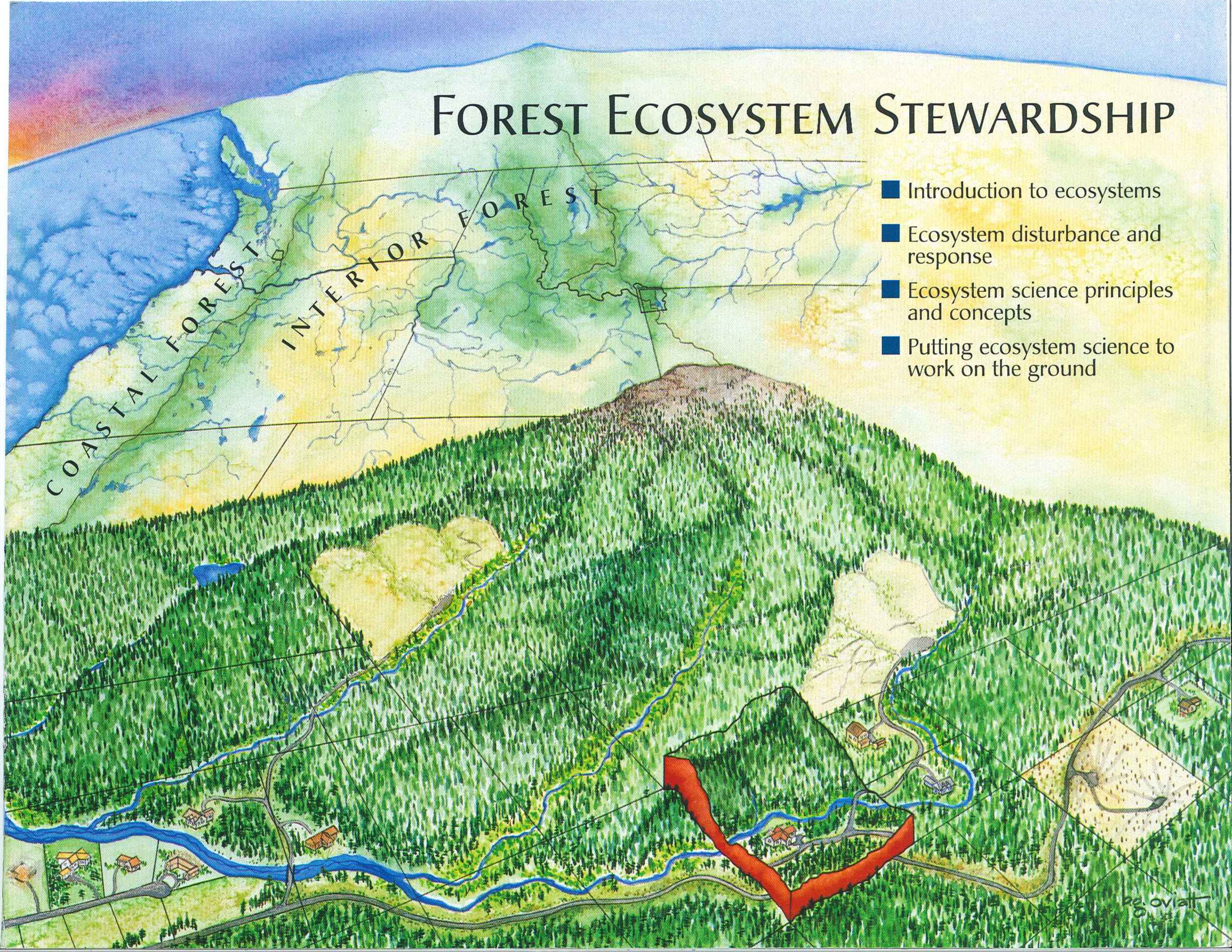
Forest Ecosystem Stewardship

- Introduction to ecosystems
- Ecosystem disturbance and response
- Ecosystem science principles and concepts
- Putting ecosystem science to work on the ground



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This publication is part of the Forest Ecosystem Education Project
Cooperating states include:
Montana State University Extension Forestry
University of Idaho Extension Forestry
Oregon State University Extension Forestry
Washington State University Extension Forestry

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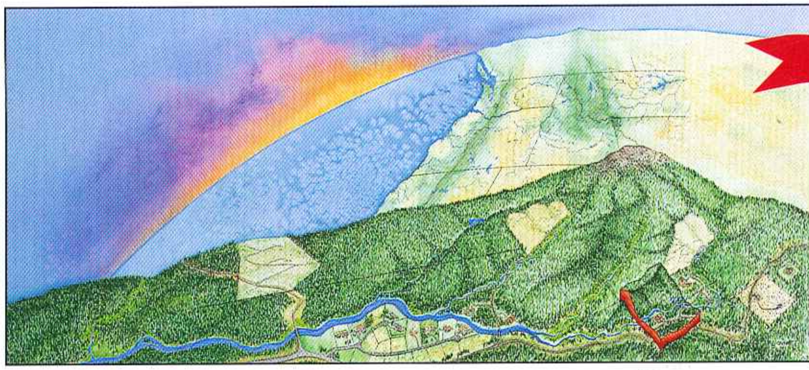
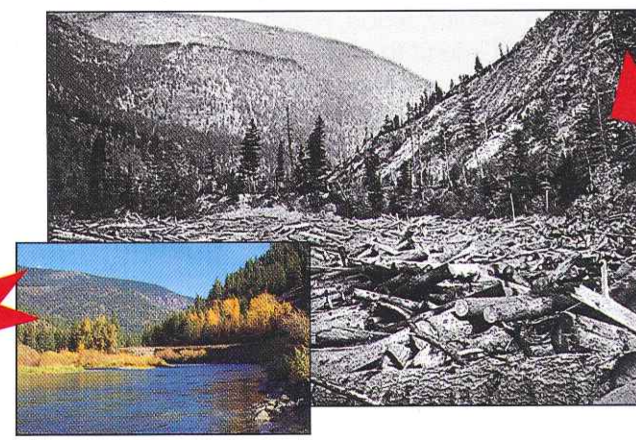
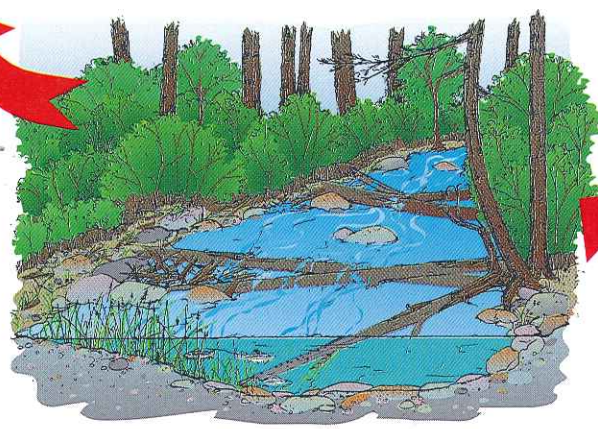
Table of Contents





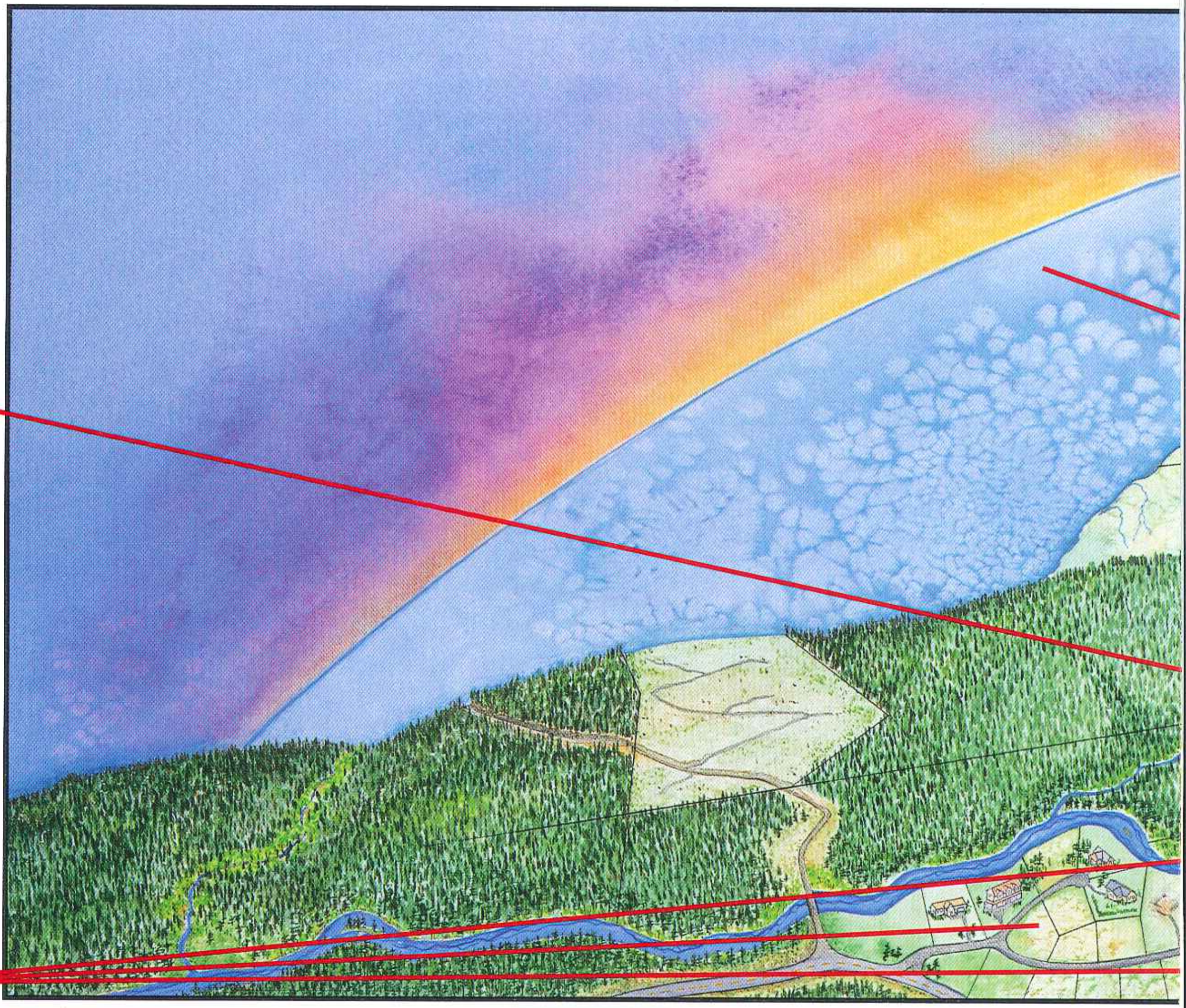


Section 1
Introduction to Ecosystems

Your forest property is part of a greater forest ecosystem, yet on your property there are individual ecosystems. Rotting logs laying on the forest floor, stands of trees, and the stream crossing your property, can be thought of as ecosystems. An ecosystem is a community of organisms (plants, animals, microorganisms and humans) interacting with each other and their non-living environment, within a defined area. Ecosystems can be examined and studied at many different scales: an individual tree, forest stands, watersheds and the landscape. Ecosystem science is the study of ecosystems and how they function.

It can be a challenge just to think about all the organisms in your forest, some not even discovered or named. Then consider the non-living parts of your forest (rocks, minerals, etc.) and the impact the environment (weather, wildfire, etc.) has on them. Now add the processes that allow these organisms to live (how they feed themselves and dispose of their wastes), and you quickly realize that you own and manage a very complex system. Finally, consider what you want from your forest (wildlife, wood, return on investment, home, water, etc.). We all intend to meet our personal objectives without sacrificing our forest ecosystem, but will we? Will subsequent owners be able to meet their objectives?

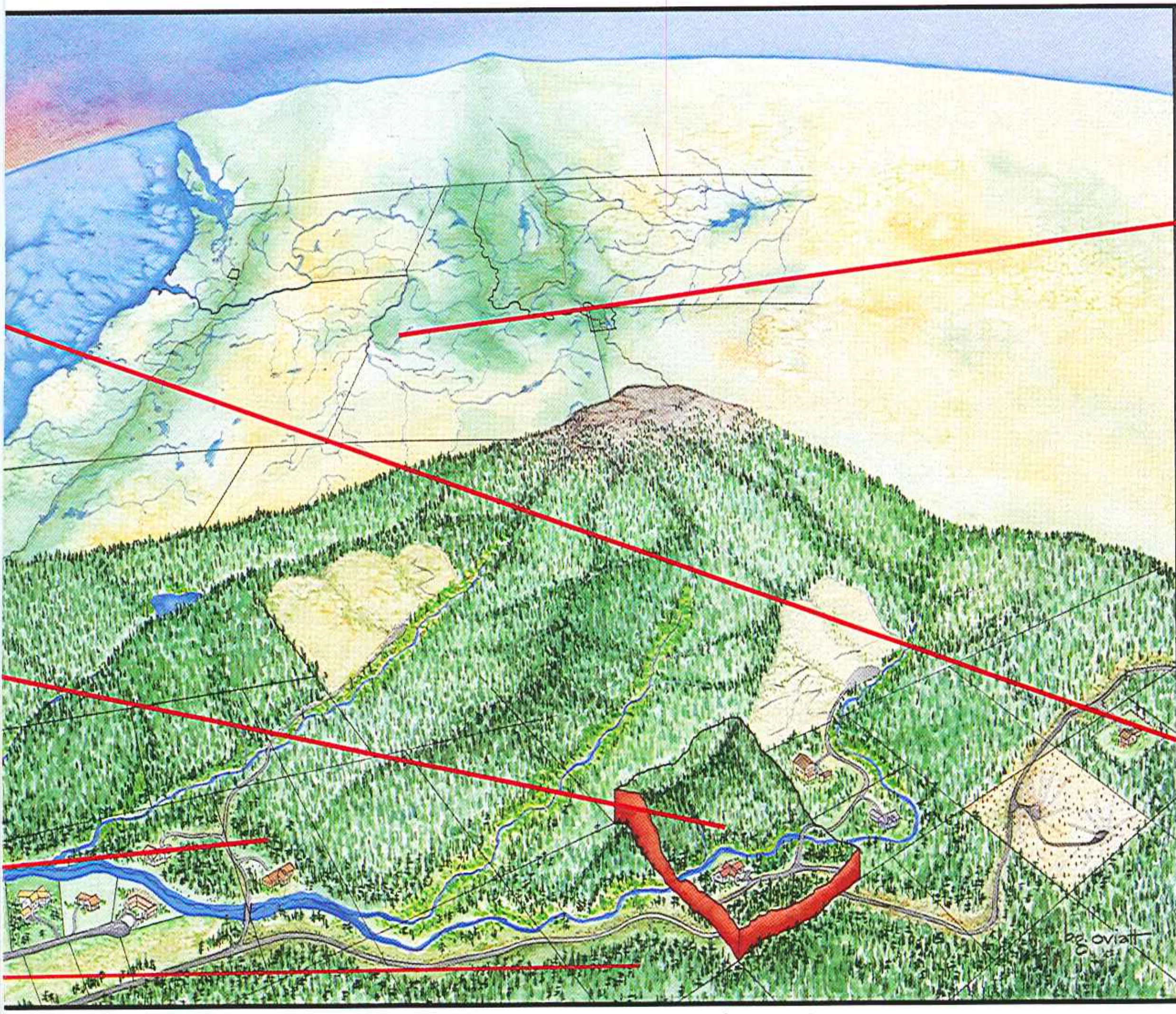
Individual forest ownerships are linked together within watersheds. Watersheds, with their defined area, are the next larger-scale ecosystem. Also referred to as drainage basins, they are an area of land that collects and discharges water into a single stream. They vary in size from a few acres to millions of acres (Columbia River Basin). Precipitation falls on, flows through, and empties out of a watershed. The principal goal of watershed management is to ensure the quality and quantity of water as it moves through a watershed. The individual properties within a watershed have influence on and responsibility for achieving that goal.



Four ecosystem science principles will be referred to throughout this publication:

- **Sustainability**
  Sustainable forests involve more than just annual wood growth. In addition to all the organisms in the forest (plants, animals, etc.), sustainability includes soil, water, air and human communities.

- **Biodiversity**
  The great variety of organisms that exist within individual forests and across the landscape is referred to by scientists as biodiversity.



Watersheds are nested within regions, and regions give us an even larger scale view of ecosystems. The Northwest region of the United States can be thought of as an ecosystem. It too is a distinct, defined area, yet it's also part of the North American continent. Within this region are two major forests, the coastal forest and the interior forest. The coastal forest lies west of the Cascade Mountain crest. The interior forest extends east of the Cascade crest to and including the Rocky Mountains. The Columbia River Basin connects seven states and parts of Canada. The Columbia River is a bridge between the Rocky Mountain and Pacific Ocean ecosystems. Scientific understanding about how ecosystems operate at the regional landscape level is limited. We have greater understanding of forest stands, stream reaches and watersheds. One of the goals of ecosystem science is to expand our knowledge of these larger, complex ecosystems.

The view that takes us from regions to continents and finally to the entire earth is almost too much to comprehend. Yet our planet Earth is an ecosystem too. It is a defined area, dependent upon solar radiation to sustain forests and influenced by humans and other life forms that inhabit its surface. While scientists study problems like ozone depletion at this whole-earth scale, answers to many other complex questions remain in the future.

■ **Disturbance and Response**

Forests are always being disturbed and responding to disturbance. Prior to the 1970s, it was thought that as a forest matured, it reached a climax or permanent condition. Today we see the forest as dynamic and always changing.

■ **Linkages**

The parts of a forest are linked in many ways as are adjacent forests across a landscape. For example, when the trees of a forest are impacted, so are the soil, water, animals and other forest components.

What's next?

The study of old forests, described in the next section, has helped to clarify these principles. You will be introduced to some of the recent scientific discoveries about how old forests work.

Section 2

What Have Scientists Learned by Studying Old Forests?

Forest ecosystem scientists study forest and stream ecosystems to unravel how they are structured (how their parts are arranged), their functions (how they work), and how they change over time. They attempt to understand processes such as the flow of genetic material in and through forests; how forests use and recycle energy, nutrients and water; forest food chains; and how disturbance brings change to the forest. Scientists suggest strategies that can better accommodate wildlife habitat, biodiversity and long-term site productivity. Learning about and applying the principles of ecosystem science may improve forest management and help maintain the forests' natural rate of production.

Forest scientists in the Northwest have mostly studied older forests in the western slopes of the Cascade Mountains. Concepts from these forests are useful in understanding other kinds of forests in the region but may not be directly transferable. For example, ponderosa pine open savannahs do not support the mix of tree species nor levels of coarse woody debris found in coastal forests. Likewise, forest plantations are different than old forests.

Old Cascade Mountain forests are structurally complex. They include a mix of trees of all sizes, standing dead and down wood, and habitats for many species.

Some mistakenly trace the origin of forest ecosystem science to the 1990 listing of the Northern Spotted Owl as an endangered species. While that event did draw increased attention to forest ecosystems, the concept of the forest as a system—consisting of organisms that interact among themselves and with their environment—was described long before the owl controversy. Its recent scientific basis is more accurately traced to the study of older Cascade Mountain conifer forests. It began in the early 1970s with scientists who were curious about old forests and their ability to survive as long as 500 years, with some trees living 800 to 1000 years. They wondered how forest landscapes could exist for such long periods without running out of nutrients. They speculated that if the processes that sustain old forests were better understood, it might help in managing other forests.

Forest ecosystem study began long before the Northern Spotted Owl was listed as an endangered species. Today, careful study of the owl indicates that it is able to reproduce in forests other than old forests if needed habitat is present.

What has 25 years of ecosystem science uncovered?

■ The structure of a forest refers to the size and arrangement of trees and other plants. Scientists describe old forests as ***structurally complex.*** Some of the most structurally complex old forests include the Douglas-fir coastal forest, the interior mixed conifer forest and interior mixed hardwood/conifer forests. Less complex in structure are interior forests of lodgepole and ponderosa pine. What makes these old forests complex? In contrast to many younger forests, they are a rich mix of plant species of all sizes and shapes. Their canopy is a patchwork of gaps, where trees have fallen over and created openings. In these openings, understory plants sprout up, adding to plant and animal diversity. In other locations their dense overstory can shade out all understory plants. It is this structural complexity of live trees, down logs, snags and gaps that provides many habitats and niches across the landscape.

■ As forests get older, their nutrient cycling process changes. In areas studied in the Cascade Mountains, lichens become important components of this old forest recycling efficiency. These plants exist in all ages of forests (lodgepole pine forests are rich in ground lichens), capturing nutrients and producing food. For example, the Lobaria lichen is an important nitrogen fixer

This lettuce-shaped, nitrogen-fixing lichen (Lobaria oregana) contains blue-green algae that convert atmospheric nitrogen to a form useable by both terrestrial and aquatic plants. It is more common in conifer stands at least 200 years old.

(see caption above) and becomes more abundant in older Douglas-fir forests. In one well-studied old forest in Washington, 1 to 1.5 tons of lichens per acre were measured (half were nitrogen fixing lichens). The interaction of lichens with other plants and animals contributes to the centuries-long survival of old forests.

■ Like private forest landowners who want to leave a forest legacy to their heirs, old forests pass legacies on to succeeding forests. When disturbance occurs (fire, windstorms, landslides, etc.) old forests leave legacies in the form of remnant live trees, snags and large down logs. Remnant live trees and other plants carry the genetic fabric of the old forest. Snags and down logs provide habitat for fungi, small animals, insects and other organisms, enabling them to survive while the next forest develops.

Snags and large down logs (coarse woody debris) perform valuable forest functions. With the onset of decay, large logs provide moist, temperature-stable environments for nitrogen-fixing bacteria, carried in by wood-boring insects. Over decades, these bacteria accumulate nitrogen. As logs collapse and melt into the soil, becoming "soil wood," the pool of nitrogen becomes available for tree growth. This is one of many nutrient cycling processes occurring in forests.

■ Both old and young forests are "open" systems, meaning that wildlife, water and genetic material pass through them. Ecosystem scientists point out that fragmenting old forests into smaller and smaller pieces interferes with these pathways of exchange.

■ At one time, scientists believed that old forests were in a state of equilibrium—that as a forest grew to its mature climax, it became naturally stable. Today, old forests are considered very dynamic. Just like young forests, they are ruled by disturbance and recover from large-scale occurrences of fire, wind, insects and disease. When disturbed, old forests pass surviving life forms on to the succeeding forest through remnant trees, snags and down logs. Even during volcanic eruptions *(pages 12-13)*, some life forms persist underground, under snowpack, and in lakes, streams and springs. Large catastrophic fires leave patches of different burn severity, variable numbers of live trees, snags and down wood *(pages 8-9)*. This legacy links old with new as recovery occurs.

■ Forest history indicates that massive forest fires burned the western Cascade Mountain slopes in the 1300s. Most of the Coast Range forest burned in the mid 1800s. Even more frequent wildfires, along with insect and disease outbreaks are part of interior forest history. As a result of disturbance history, Northwest forests form a mosaic of forest types and ages across this vast landscape. Old forests are part of that landscape. When forests are subjected to disturbance, the forest landscape remains resilient, and can recover from both natural and human-caused disturbances.

In summary

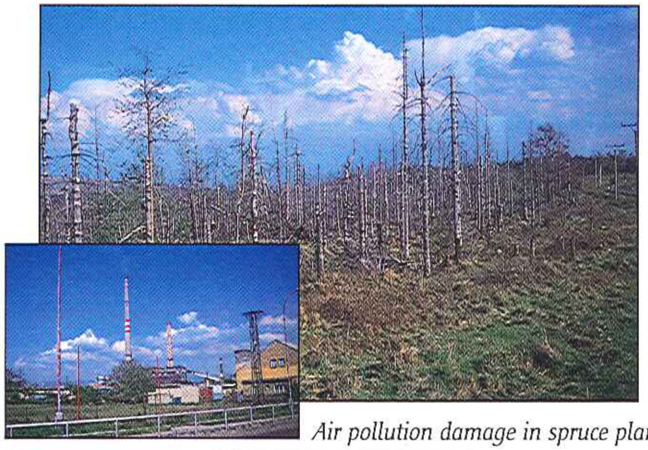
Scientists have only begun to understand and put together the pieces of Northwest forest ecosystems. Many questions regarding sustainable forest management are yet to be answered. For example, what is the best way to supply a steady rate of forest production while protecting the environment?

- Some say wait until we have more answers.
- Some say that postponing action because we don't have all the answers may only compound our problems.
- Others say look at what can be learned from other forest ecosystems around the world and in other parts of the Northwest.

So let's look.

What's next?

The next section visits four different forest landscapes to learn more about disturbance (natural and man-caused) and forest response.



Air pollution damage in spruce plantations attributed to coal power generating facilities.

Section 3

Disturbance and Response on a Landscape Level

Ecosystem scientists are looking at the underlying reasons why forests become susceptible to large scale disturbances. This section describes four forest ecosystems. Each gives greater meaning to the words disturbance, resistance and resilience. What led to these disturbances? How has each forest ecosystem responded? What is the role of humans in their management? We begin with a look at Germany, the cradle of modern forest management theory, with one of the longest records of management in the western world.

Lessons from German Forests

The history of human-caused disturbance in German forests helps answer the following questions.

- How does societal development influence forest management?
- When natural forests are replanted with monocultures (single species forests), are these plantations sustainable?
- When forest ecosystem productivity is in decline, can the trend be reversed?

How does societal development influence forest management?

The German forest was cleared for crops as early as 5,000 B.C. Much of the natural forest remained intact though, until after the Roman occupation ended in 500 A.D. Between 500 and 1200 A.D. the German population quadrupled, forcing extensive clearing of the natural forest. Royalty owned the remaining natural forests, keeping them intact until the Industrial Revolution. By the early 1800s wood demand for charcoal, housing and industrial uses resulted in the deforestation of most of the remaining natural forest.

Faced with a depleted timber supply, the Germans developed the "regulated forest," a management concept still used today throughout the world. Regulated forests were based on producing an economical and constant supply of wood. From the 1850s to 1950, German foresters converted almost 40 percent of the forest landscape into spruce and Scotch pine plantations using two theories: soil rent and forest rent. Both theories considered trees as business assets. "Soil rent" favored short rotation and fast growing tree plantations to give the highest return on investment.

The regulated forest is a planted forest, managed on sustainable rotations with different aged stands scattered across the landscape.

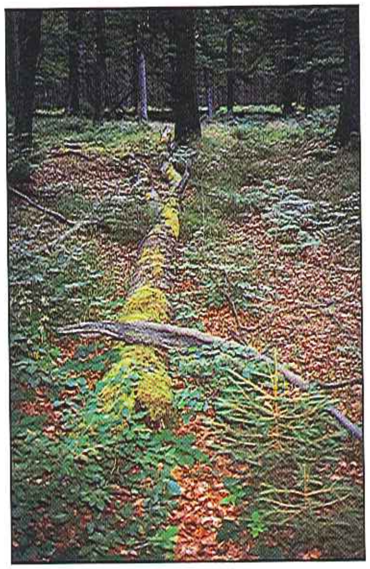
"Forest rent" attempted to correct soil rent's environmental and social shortcomings by basing economic returns on more than just the annual growth of wood. Forest rent encouraged longer rotations, mixing hardwoods into conifer plantations, and the use of selection harvest systems *(page 37)*.

Around 1950 the Germans adopted the "social market theory" which stated that forest products should be subject to free markets, but if necessary, there should be regulations to protect non-timber values. Public forests in Germany changed to reflect this theory, and today older forests are maintained by selection harvesting and rely on natural regeneration. However, to date, the return on investment from these forests has been less than one percent per year. With the costs of German unification and constraints on government expenditures, many question whether this kind of forest management is economically sustainable.

After hundreds of years, German experience shows that converting natural

The "forest rent" management theory encouraged longer rotations, group selection harvesting and natural regeneration.

forests to planted forest plantations can successfully produce wood. However, other forest amenities (coarse woody debris, aesthetics and wildlife) have not fared well. In non-plantation forests,

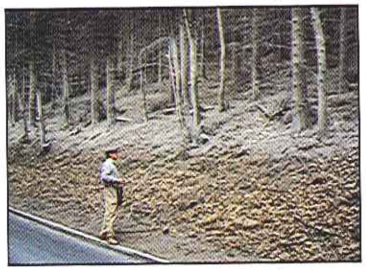


Coarse woody debris is rare in German forests. The photographer walked several kilometers before finding this single log.

recreation, wildlife, water and other amenities exist in greater abundance.

When natural forests are replanted with monocultures (single species forests), are these plantations sustainable?

Forest monocultures of spruce and pine have been planted and replanted for over 150 years and are the mainstay of German forestry.



Applications of lime and other fertilizers were used in an attempt to reverse the trend of lowered productivity in spruce and pine monocultures.

It wasn't until the 1950s and 60s that scientists first documented a downward trend in timber productivity in central European plantations. Researchers failed to explain the cause of the decline. In some cases it was tied to higher soil acidity and associated nutrient imbalances.

Declining wood growth in German plantations remains a mystery today, even though the symptoms have subsided. More important, the monocultures did not collapse and die as some experts expected. They have today recovered to their previous growth rates. To this date, German monocultures continue to produce wood in sustainable rotations.

When forest ecosystem productivity is in decline, can the trend be reversed?

German forests experienced declining forest health at a broader scale at the end of the 1970s. The condition spread from spruce and Scotch pine plantations to hardwood tree species in the mixed forests. Older trees and stands were particularly hard hit. Probable theories included weather extremes, acid rain, sulphur dioxide deposition and general forest stress caused by their combined effect.

Because pollution was tied to forest decline, the government forced the reduction of sulphur emissions from power plants *(photo, page 6)*. However, when the government attempted to also reduce nitrogen emissions from auto exhaust, the public refused to support the legislation. Although auto pollution levels continue to threaten forest health, Germans as yet appear unwilling to pay the cost of this forest restoration.

Spruce and pine forests grown under the soil rent theory. In the Northwest, Douglas-fir plantations reflect this theory of repeated 40 to 60 year rotations of tree growing, clearcutting and replanting (see page 36).

In summary

German history provides a long-term comparison of native and plantation forests, but scientific evidence cannot declare either strategy a clear winner from an economic and biological perspective. The German landscape of even-aged monocultures and mixed native forests appears to be providing a high level of forest products along with other amenities. There is however, no convincing evidence that ecosystem health is in long term decline. Less clear is how wildlife and other forest organisms have fared under German plantations. Where mixed forests have been reestablished, they are recovering into healthy, "natural looking" forests. This resiliency is good news for forest landowners desiring to restore natural forest areas.

1988 Greater Yellowstone Fire

The summer of '88 brought unprecedented wildfire conditions to Yellowstone National Park. By July, 21 fires had already blackened 17,000 acres. The unique climactic condition of drought, high winds, lightning ignitions and a forest ready to burn left 1.4 million acres consumed.

Yellowstone proved that technology and modern fire fighting techniques are no match for forests with decades of accumulated undergrowth and severe weather conditions. Only September snows, cold temperatures and diminished winds could completely extinguish this catastrophic forest disturbance.

While unprecedented since the park's establishment in 1872, there is evidence that a fire of similar proportion occurred in the early 18th century. Fire has played a significant role in this forest ecosystem since the retreat of the glaciers approximately 12,000 years ago. Before humans, lightning was the source of fire. In the past, Native Americans probably used fire in this ecosystem as they did in other western forests. Native Americans burned regularly for a variety of reasons, including attracting game to new areas, creating meadows, driving game when hunting, and clearing areas to protect villages or preparing fields for farming. In the early 1900s, the public viewed wildfire as a threat to life and property and pushed the government into the fire fighting business. Fire destroyed trees that could otherwise be used for developing the nation. Public policy sentiment was that wildfires should be eliminated if possible.

Wildfire often leaves behind structure in the form of snags and down logs.

Ironically, that policy has led to the current danger of high intensity wildfires. In spite of putting fires out we still experience catastrophic fire. The challenge we face is to figure out how to use other techniques like prescribed fire *(pages 46-47)* to mimic the stand replacement fires like Yellowstone.

Usually, wildfire does not kill all trees but leaves some behind. On a landscape level, fire often tends to skip around, leaving areas such as wetlands, riparian areas and north-facing slopes unburned. These are the "living legacy" of plants, animals, spores and seeds that inoculate the new forest. The mosaic created by the Yellowstone fire reset the clock for plant and animal development and guaranteed diversity across the future landscape. Plants responded by sprouting from underground parts or seed. Lodgepole pine seed densities of 50,000 to 100,000 per acre were documented in Yellowstone burn areas. Only in a few areas (under fallen logs that burned for several hours) did heat kill below-ground plant material. Nutrients, washed into the soil from the ash, grew vigorous new plants. After three years, vegetation cover on the burned and unburned areas was the same. Habitat diversity and forage productivity were dramatically improved by the Yellowstone fires. Affected areas now support greater numbers of animals and a wider variety of species. Impacts to fish and aquatic life were determined to be minimal and short-lived. Once the water cleared and sediment from the fire diminished, scientists predicted that production of algae, aquatic insects and fish would be enhanced over that found before the fire.

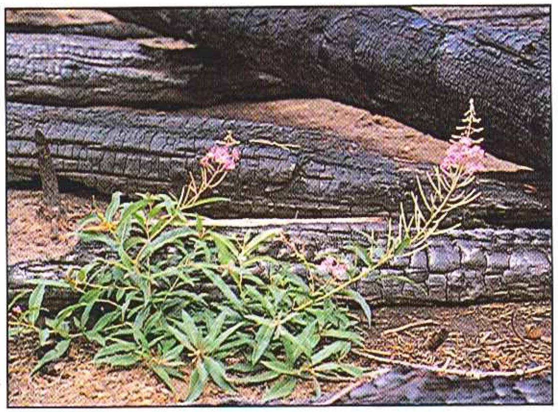
Yellowstone demonstrated that fire is an integral process that shapes and controls forest ecosystems. It is

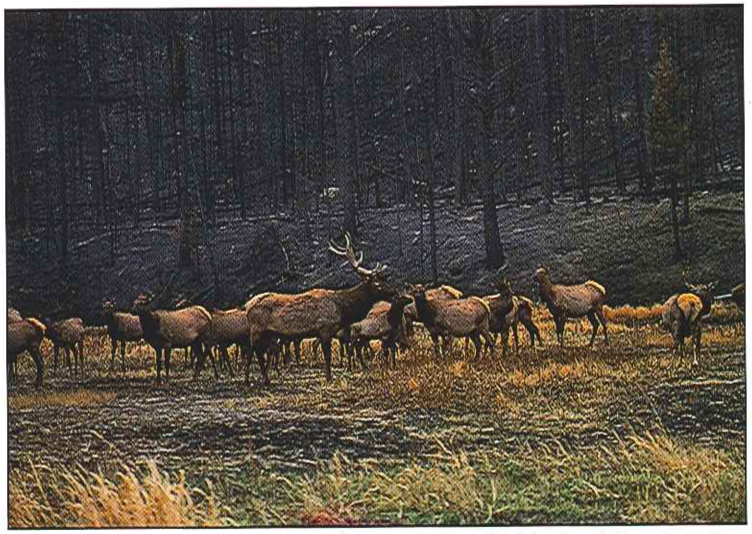
Lodgepole pine, the premier fire-adapted tree, stores seed in protective cones which open with heat, dropping seed into a perfectly prepared ash seedbed. Without fire, lodgepole is usually replaced by subalpine fir and spruce.

Wildfires often leave a mosaic of burned and unburned forest.

impossible to perpetuate the structural features of forest ecosystems without perpetuating the fire processes that maintain them. Where the landscape is a mosaic of different conditions, a fire can seldom get too big before it encounters an area not ready to burn.

Many post-fire Yellowstone visitors regretted the loss of scenic values and the loss of photo memories. But even though the aftermath of wildfire is often visual devastation, there are benefits to the ecosystem. Forest ecosystems require disturbance. Yellowstone and other recent fires in the Northwest point to the important role that fire plays in the forest. Ecosystem science calls for the reintroduction of fire as a component of forest management. In contrast to the 1920s, when wildfires annually burned 30 to 50 million acres of our nation's forests, today, 3 to 5 million acres burn each year. Prescribed fire management may be one way to reintroduce controlled fire and keep fire dominated ecosystems like Yellowstone healthy. Fire performs important functions like nutrient cycling and disease control. Simply removing trees and fuels may not mimic its role.





Surveys indicated that 335 elk and 36 mule deer died in the Yellowstone fire, but improved forage now supports additional animals.

Some think the practice of clearcutting replicates natural fire disturbance. However, ecosystem science has shown that clearcutting does not mimic fire disturbance. In fact, it often leaves behind an inadequate biological legacy. While natural disturbance ***kills*** trees (usually not all), clearcutting ***removes*** trees. Modifications to clearcut harvesting are being tested *(see pages 38-39).* Like volcanoes, windstorms, or insect and disease outbreaks, fire leaves behind large amounts of structure, much of it in the form of standing snags and logs on the ground. Dead structures left behind after a fire are important in passing along fungi and other organisms from the preburn forest.

In summary

The key to managing fire dominated ecosystems like Yellowstone, is to learn how to manage the changes that come with wildfires–not by excluding fire. Ecosystem integrity is maintained when adequate amounts of legacy are retained across the landscape–whether the disturbance is natural (wildfire) or man-caused (harvesting).

Central Oregon Cascade Mountains Ecosystem

A structural utopia or too much of a good thing?

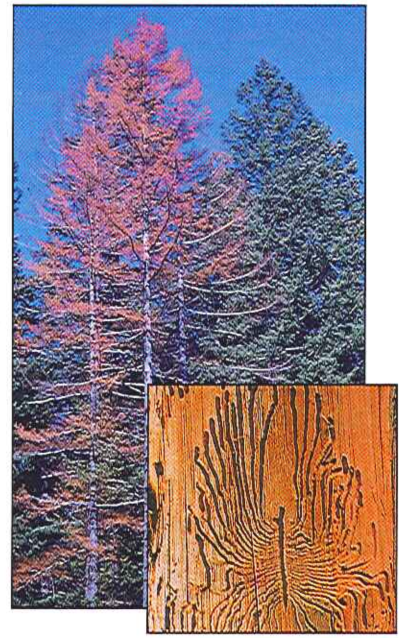
In the early 1980s central Oregon forests were a rich mix of biological diversity. As tree species changed with elevation, the forests exhibited a high degree of structural complexity. At low and mid-elevation, the forest consisted of old-growth ponderosa pine and Douglas-fir in the upper canopy with layers of grand fir, Douglas-fir and incense cedar beneath. Rounding out the multi-layered forest structure was a brush and shrub layer with grasses and forbes. At higher elevations were thick stands of fir, hemlock, spruce, lodgepole pine and scattered Douglas-fir.

But all this forest structure turned out to be too much of a good thing. The problem was too many trees and the wrong species. It was an ecosystem on the brink of major disturbance. As long as annual precipitation was adequate, this tree-choked structure could be maintained, but droughts in the 1980s changed all that. The forest fell victim to epidemic levels of insects and disease. Starting in 1985, the western spruce budworm fed for seven years on the foliage of white fir, grand fir, spruce, hemlock and Douglas-fir trees. Many trees died completely; others sustained top damage. Those that survived the foliage feeding were weakened, exhibiting reduced height and diameter growth.

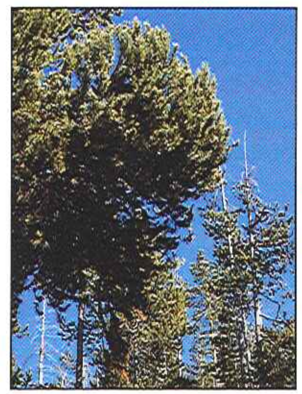
Eventually the budworm population ran its course and collapsed, leaving ideal conditions for secondary pests like the Douglas-fir bark beetle and fir engraver beetle. These pests specialize in finding and killing individual trees previously weakened by drought, defoliation, diseases and parasites (like dwarf mistletoe).

The result was a green forest turned gray. Dead and dying trees opened the understory to sunlight, changing the mix of forest plants. Bird populations shifted to woodpeckers and cavity nesters. Dead trees accumulated on the forest floor creating the potential for catastrophic fire.

Before this insect and disease epidemic, the forest had changed dramatically over the prior 100 years. How do scientists know? By looking at historical information and fire scars, they were able to determine the kind of forest that existed decades earlier.



After the budworm attack, bark beetles and dwarf mistletoe added to the dying forest. Douglas-fir bark beetle attacks (top left) start with yellowing, then reddening of the entire tree, all within one growing season. Once red, the tree is dead and the beetles move on. Trees die from the insect feeding on the phloem layer, under the bark, cutting off food to the roots. As the insects mature they chew distinctive "galleries" that identify them (inset). Thick, dense foliage growth, called "witches brooms," develop on mistletoe infected branches (bottom left). Mistletoe plants growing on tree branches (bottom right) reduce tree height and diameter growth.



Early land surveyors recorded their observations about this forest in the late 1800s. From their descriptions, a far different forest existed.

Prior to 1900, the low and mid-elevation forest was primarily ponderosa pine and Douglas-fir. Incense cedar and western larch were also present, but only as minor components. No understory tree species were noted, indicating that the understory was not dominated with trees. Instead, notes described manzanita and snowbrush being predominant in the

After seven years of drought, budworm, bark beetles and mistletoe infestations, the forest has been "thinned" nature's way. New openings in the canopy create space for plants in the understory. Dead wood begins to pile up, creating conditions suitable for high intensity fires.

shrub/grass component of that early forest. This historical insight gives credibility to the assumption that ground fires were common. Both of these plants (manzanita and snowbrush) increase in abundance after fire disturbance. Without fire, the forest understory became overstocked with Douglas-fir, white fir and grand fir. Less than a third of the original overstory was left. The reasons—decades of fire exclusion and selective harvesting of the old-growth ponderosa pine and Douglas-fir overstory.

Those responsible for managing this forest over previous decades were too successful at following the policy of fire suppression. In contrast to the low and mid-elevation forest, the high-elevation forest with its colder, more moist environment will probably react differently to the insect epidemic. It has no history of occasional low intensity groundfire. Instead, this forest follows a cycle of tree growth, insect or disease epidemic, fuel build-up from dead trees and high intensity fire. Then the process starts again. If fire does not occur in the near future, the few surviving trees will recover and eventually be surrounded by young, shade tolerant tree species like hemlock, spruce and fir. The larger openings will be filled with shade-intolerant lodgepole pine.

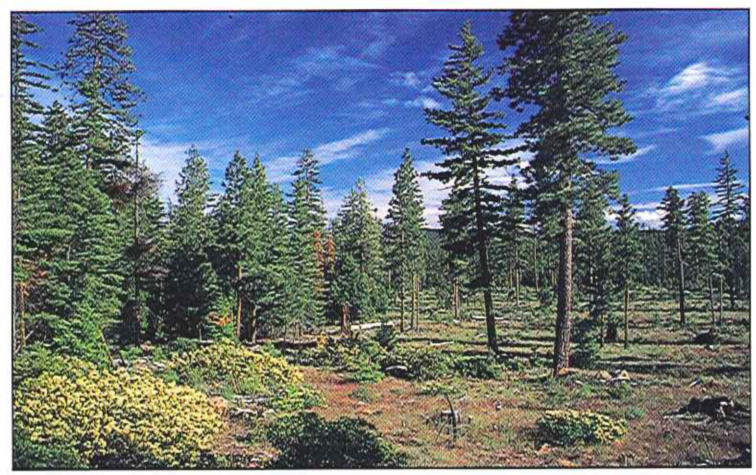
Could the current forest health problem have been avoided? Can it be corrected? Insects and disease, living and dead trees, and fire are all part of the natural forest ecosystem. Spruce budworm infestations help balance the trees use of nutrients against the need to recycle nutrients back to the soil. Insects become serious forest pests when their host trees become too abundant. Without the historically frequent, low-intensity ground fires, this forest will continue to change from ponderosa pine to fir.

This forest requires management actions like prescribed fire and thinning to help restore the natural processes of these ecosystems if future epidemics are to be avoided *(see pages 46-47)*.

In summary

Removing natural forest processes such as wildfire has profound impacts on forest ecosystems. In this case it led to more structural complexity and more tree species than could be supported by this forest environment. The result was an insect and disease epidemic and the serious threat of high-intensity wildfire.

A prescribed fire in 1980 mimicked nature. Large ponderosa were left and an understory of bitterbrush and Idaho fescue flourished.



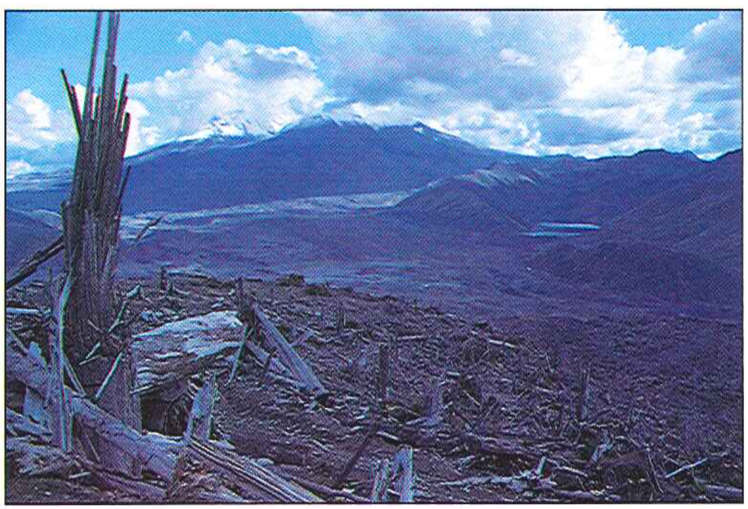
Thinning this forest removed the dense understory of fir species, leaving mature ponderosa pine. Seedlings have been planted to replace the old fir understory.

Mount St. Helens

Highest on the list of modern day disturbances is the Mount St. Helens eruption. After 123 years of inactivity, the volcano awoke with a vengeance in May 1980,

resulting in one of the most pronounced forest ecosystem changes ever witnessed. In a moment, 150,000 acres of forest landscape were reduced to a tangle of fallen trees. Even old-growth forests more than 400 years old, with multi-storied stand structures, were splintered like matchsticks. Hurricane-force winds stripped trees of their limbs. Forests conditioned by centuries of wind storms were no match for the explosive force. Anything standing above snowline, in a fan-shaped 14-mile-long area, was scorched by superheated ash and gas. Plants and animals were killed instantly. Fish and wildlife losses were staggering. Fifty-seven people in the path of the eruption perished.

The Mount St. Helens forest ecosystem was scorched, blasted and covered with mud 50 to 600 feet deep in



These old growth trees, 12 miles from the volcano were killed by heat. Two years of salvage harvesting removed thousands of these ash-coated trees.

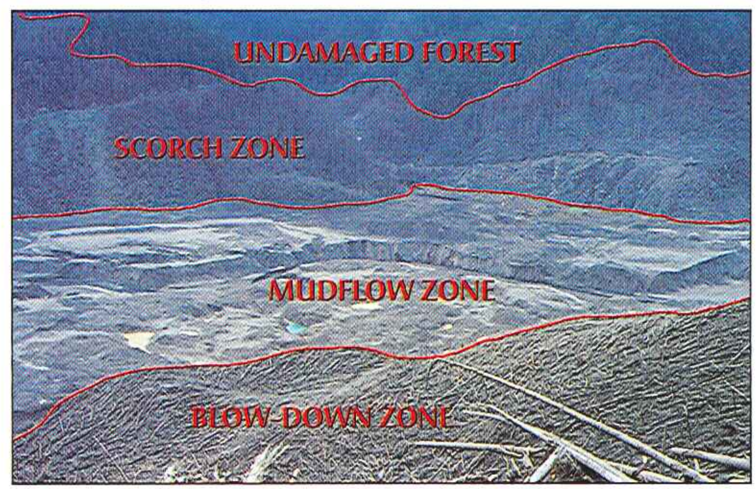
its valley. Its once pristine streams and river valleys flowed with mud. Highly productive soils were covered with sterile abrasive ash up to three feet deep. Was this forest ecosystem destroyed? Did this catastrophic disturbance result in a decline of biological diversity? Was the variety of organisms reduced and their habitat degraded?

Even a disturbance of such massive proportion could not destroy the Mount St. Helens forest ecosystem. Recovery has been dramatic across the entire landscape, more rapid in some locations, slower in others. The unexpected resilience of this ecosystem came as a surprise to some scientists, who estimated it would be 20 years before life returned to the blast zone. The *blow-down, scorch and mudflow zones* appeared to be a bleak landscape. However, a closer look revealed sprouting pioneer plants (thistle and fireweed) and signs of small

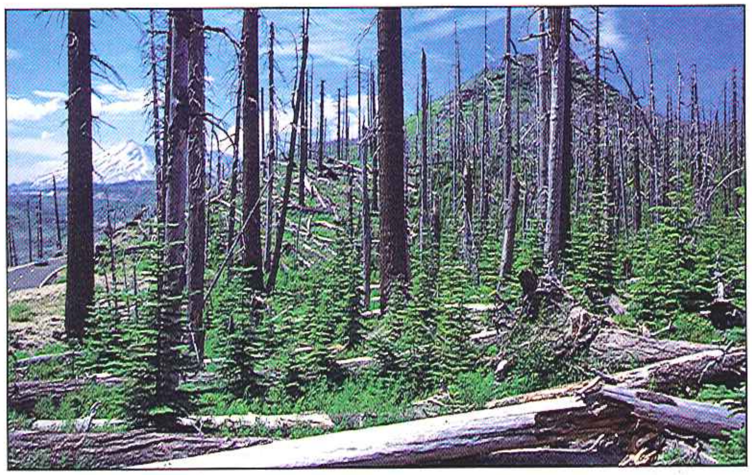
Plants like this big leaf maple, buried in 8-12 inches of ash, sprouted quickly.

animals. In the *blow-down zone,* riparian areas recovered quickly. Their basal-sprouting riparian plants were only top-killed and the ash deposit was minimal. Plants also sprouted along hillside seeps.

Farther away from ground zero, in the *scorch zone,* all overstory trees were heat-killed and transformed into snags. Understory trees, embedded under snowpack during the eruption, survived



The degree of disturbance followed distinct lines across the landscape.



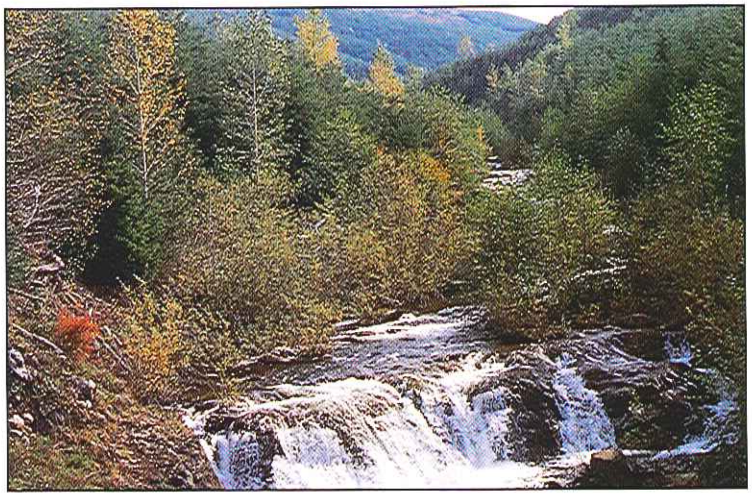
Coarse woody debris left by the volcano will feed the new forest for decades.

Herds of Roosevelt elk have returned to the blast zone to feed on the dense vegetation.

and grew normally within months of the blast. Today, these seedlings are a vigorous young forest beneath the old snags. This coarse woody debris will feed the new forest for decades *(see photo, upper left)*. Animals have returned to recolonize the area. Streams within the devastated watershed were soon occupied with fish and aquatic insects.

Douglas-fir seedlings were planted on the left in 1983. National Volcanic Monument land is on the right.

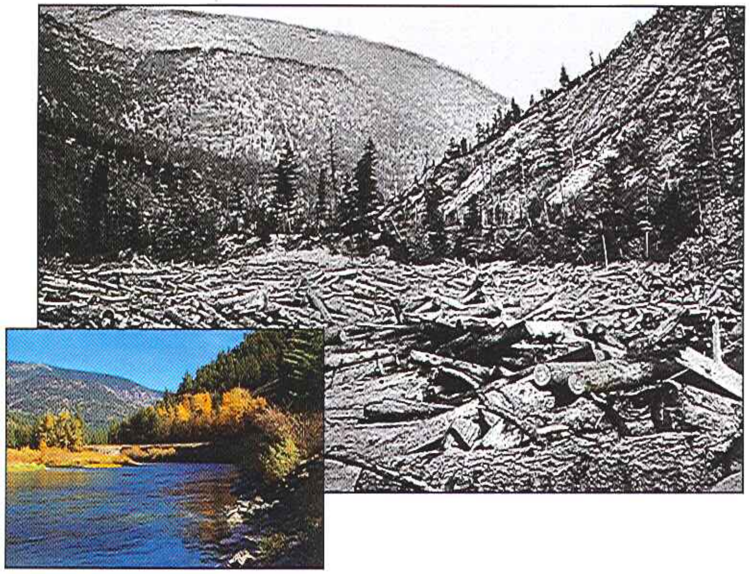
Mount St. Helens continues to offer a contrast between human influenced restoration and natural restoration. On National Volcanic Monument lands, restoration has been left to natural processes. In contrast, owners of the remaining lands affected by the eruption followed an aggressive forest management approach. Harvesting of blowdown timber occurred as soon as the area was declared safe, followed by tree planting on thousands of acres. Property line boundaries between the two management styles show the contrast *(see photo, left)*.



The scene at Schultz Creek, 13 miles from the volcano (above, left). Salvage logging removed the down logs. Above is the creek today. Hillsides were planted with Douglas-fir seedlings. Willow and other riparian vegetation have grown along the banks. Coho salmon, planted in Shultz Creek in 1983, have thrived in its waters.

In summary

The volcano left hundreds of tons of dead material per acre. Salvage harvesting on lands outside the National Monument removed much of that biological legacy. Some scientists are concerned what the loss of this legacy might mean for succeeding forests. However, the scientific community does acknowledge that trees, fish, wildlife and other components of the Mount St. Helens ecosystem have recovered more quickly than expected.



Section 4

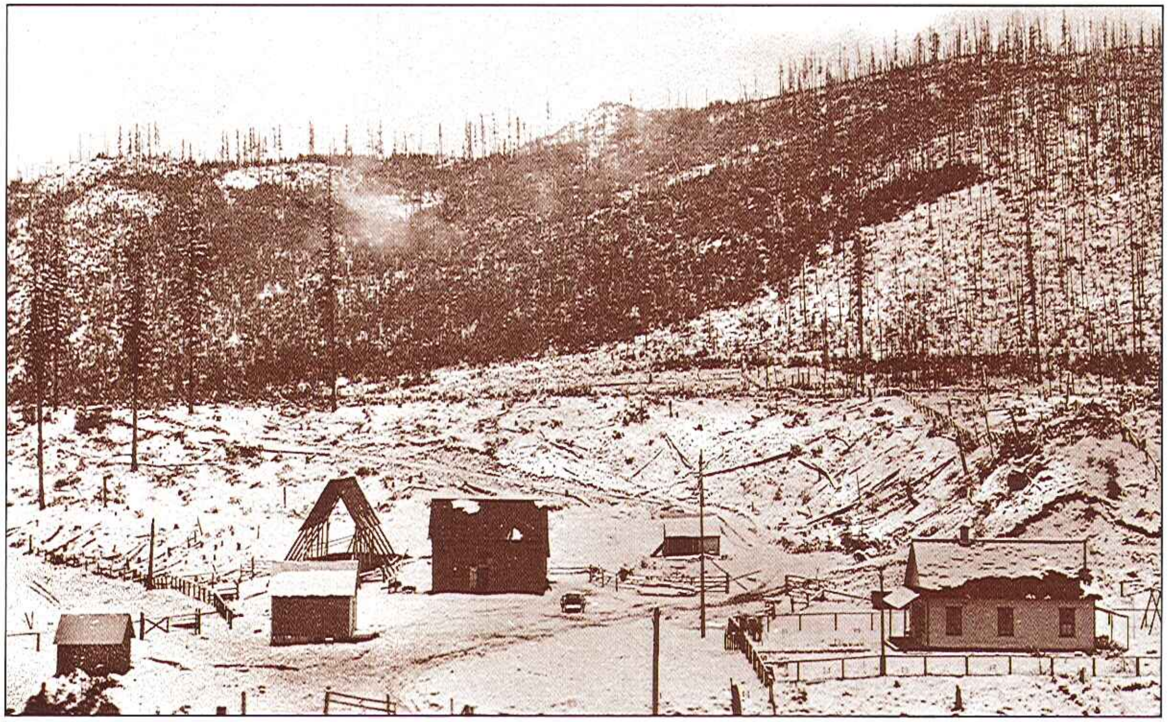
Looking to the Past to Understand the Present

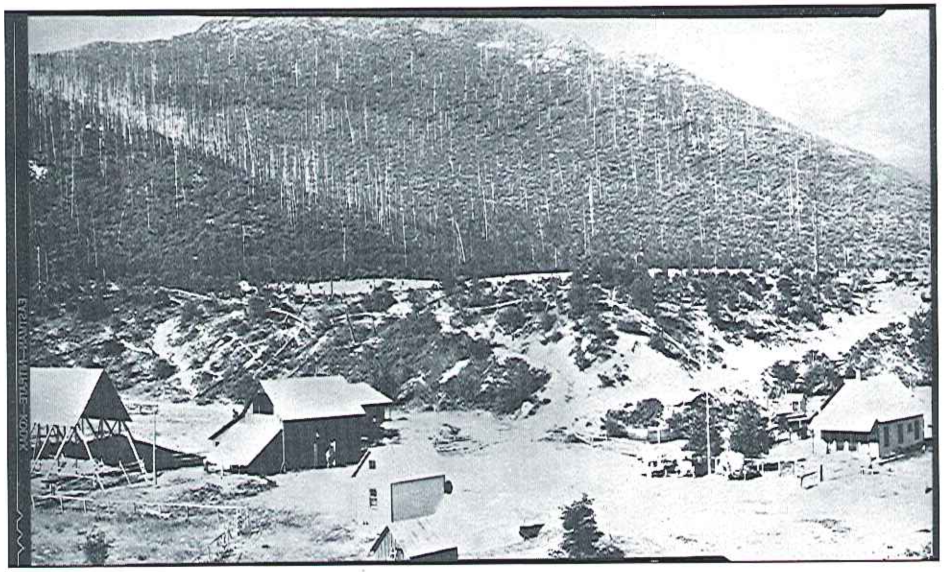
Some ecosystem scientists point to the era of pre-European settlement as a model for what present day forest landscapes should look like. The actual dates of that era, and whether or not that point in history should be the goal of today's forest land manager, is debatable. Even pre-European forests were influenced by Native American burning, natural fires and other catastrophic events. Change since European settlement has shaped forest ecosystems into what we see today.

Photo records, like those shown in the following eight examples, are one way to "see" how interior forest ecosystems have been changed by human and natural forces. Unfortunately, they don't tell all the details we want to know. We can't see beyond the edges of the photos and learn about the greater landscape. However, even these narrow views are extremely informative.

Wildfire–disturbance and response

For an on-the-ground view of forest fire recovery, this historical photo sequence of forest land surrounding the former Trout Creek Ranger Station in western Montana is useful. Results of the 1910 "Big Burn," the Northwest's most extensive forest fire in recorded history, is pictured in this 1913 photo. This catastrophic fire consisted of many separate fires which ravaged three million acres and killed 85 people. Trout Creek Ranger Station was built after the fire, at a time when the newly-formed U.S. Forest Service was given the task of preventing such a conflagration from ever happening again. Notice the tremendous quantity of standing and down coarse woody debris left three years after the fire. From this winter scene it appears a few large trees around the compound survived the fire. ▶





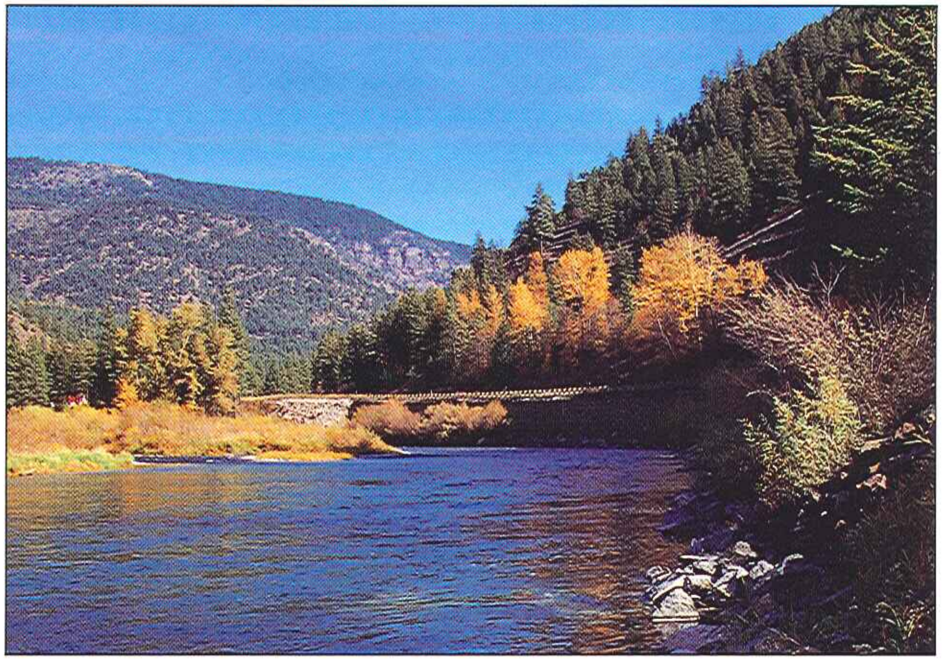
◄This 1921 photo, from a slightly different angle, shows recovery of woody shrubs and sapling-sized trees around the compound grounds. The same appears to have happened across the hillside in the background. Many bleached white snags continued to stand in memory of the wildfire 11 years earlier. Comparing the 1913 and 1921 photos, it is apparent that fire intensity differed across the hillside. Even though it is a north facing hillside, some portions of the original forest seem to have burned with greater intensity, and the new forest growth pattern reflects those differences.

Another 20 years shows continued change. Conifer trees have become the dominant cover on the background hillside, replacing shrubs. Old snags are still scattered across the new forest. Trees in the immediate vicinity of the compound have grown well, especially the two deciduous trees directly in front of the old headquarters building (it appears the flagpole had to be moved). New buildings indicate an expanding workforce. ►

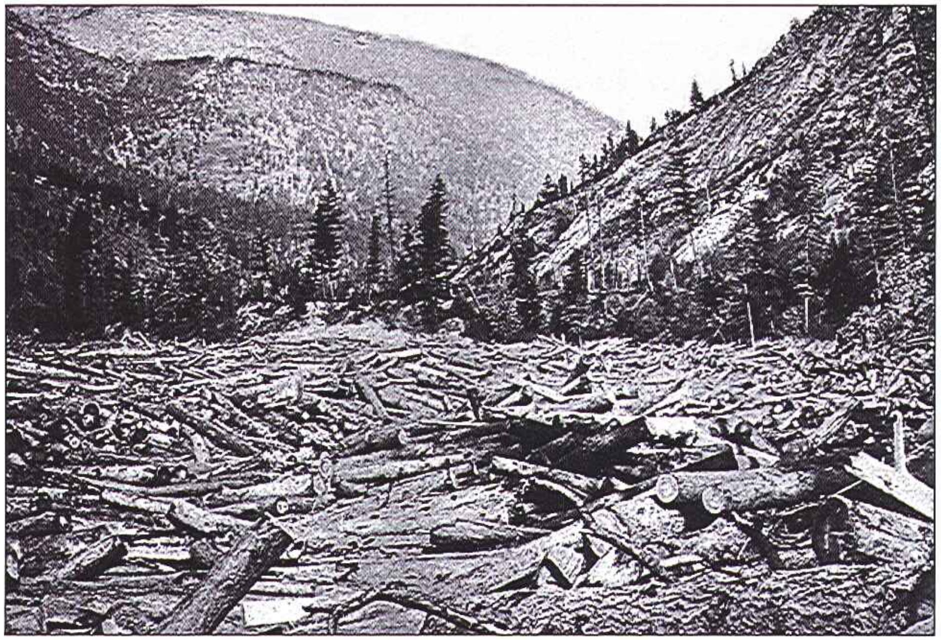
◄The next view is in 1995. The ranger station was closed and buildings removed. The only evidence of the station is a slowly shrinking clearing with one or two concrete building foundations. The forest matured and the standing snags all but disappeared within the new forest canopy. From a landscape view, wildfire evidence disappeared. But a walk across the reforested hillside encounters many remnant snags and down logs of the pre-1910 forest.

River and riparian disturbance

Western Montana's Blackfoot River was recently made world famous by the book and Hollywood movie by the same name: ***A River Runs Through It,*** by Norman Maclean. The Blackfoot's waters make their way to the Pacific Ocean by way of the Clark Fork and Columbia Rivers. The Blackfoot drainage has a hundred year history of logging, mining and livestock grazing. Early European settlers wanted homes, farms and towns along the river as in other parts of the west. Today, the scene is far different than a century ago. The drainage has regenerated another forest. The river's riparian areas share space with state and local highways which parallel much of its length. Its forested riparian area and uplands provide corridors for wildlife to reach the river's edge. And today, more than ever, it's a magnet for tourists interested in fly fishing, whitewater rafting and other forms of recreation.

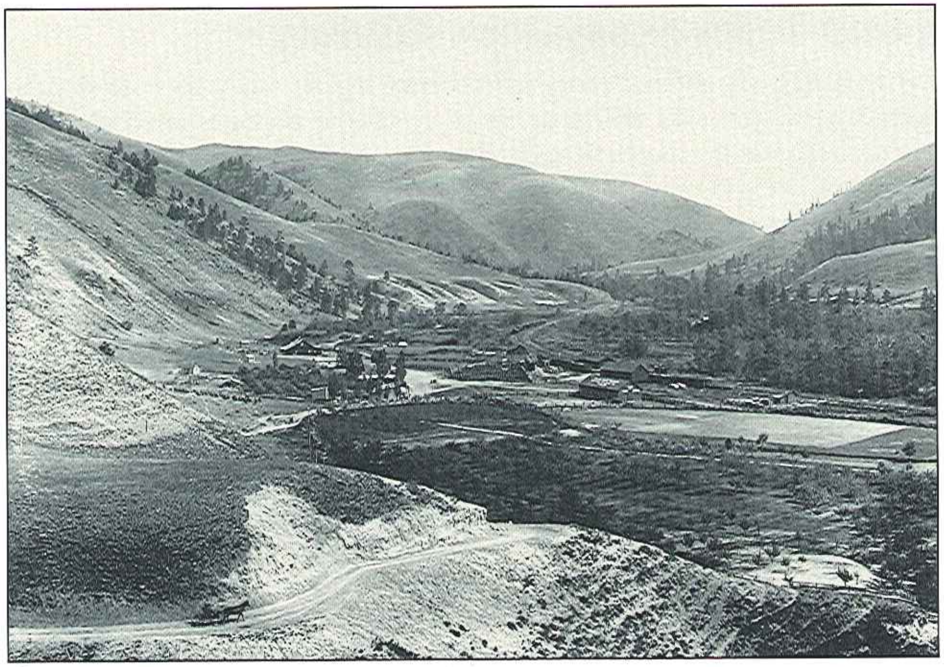


▲ *1995* ▼*1899 log drive, same river location*

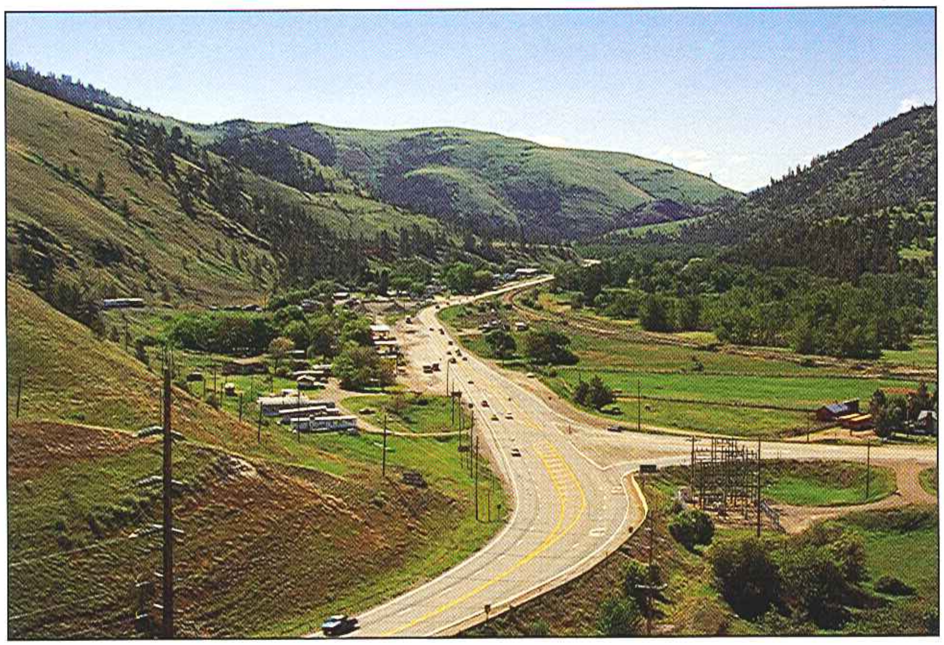


In 1899 the river was the "highway" used for transporting logs to the mill. The forests of the Blackfoot drainage provided large trees to build and develop our young nation. Early forestry was primarily the job of moving logs out of the woods and ingenious methods were used. Log drives like the one shown were duplicated in hundreds of rivers in the forested Northwest. By using the rivers for transportation, entire drainages were cleared of timber and logs moved to sawmills. Splashdams were constructed across narrow stretches of river, and the riverbeds were filled with logs. Once the river was filled to capacity, dynamite was used to blow the dam, sending water and logs crashing down the drainage to the sawmill. These huge quantities of wood supplied the Anaconda Mining Company with mine shaft timbers and fuel for refining ore.

The implications of this repeated disturbance on the watershed, the river and its adjacent riparian forest are staggering. Both the river bottom and banks were scoured. Pools were altered and natural instream log structures were swept away. Yet the Blackfoot River, two decades later, was eulogized by Norman Maclean as a premier fly-fishing river. Norman, his brother Paul and father John, along with other angling enthusiasts of their day, were allowed a limit of 25 trout per day. Obviously the aquatic ecosystem recovered from the human-induced disturbance of the earlier log drives.



▲ *1890* ▼ *1995–one hundred years of change*



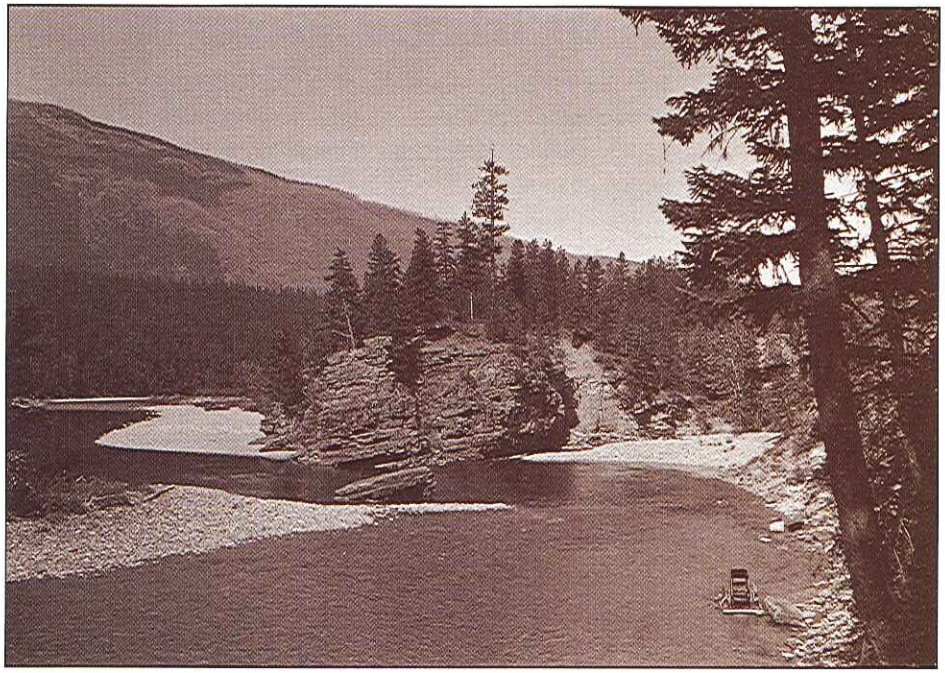
Human impact on interior valleys

It was logical for early settlers in the Northwest to occupy valley bottoms where there were productive soils and water for agricultural needs. This 1890s photo of the Jocko Valley in western Montana is typical of the horticultural and grazing activities common in similar locations. Early road construction (notice horse and buggy traveler in lower left corner), provided access into and through these fertile valleys. Clearly, human activities were a dominant part of the ecosystem in the 1890s. Providing for human needs was part of the land management strategy then and continues today.

One hundred years later the scene has changed. Most dominant are the infrastructure changes (highways and electricity). Housing development has increased too. Evidence of orchards and intensive agriculture has disappeared, replaced by highway construction and native vegetation. What's the effect of expanded infrastructure on the forest? Look closely at the forested landscape– both the valley bottom riparian forest and upland forest. The riparian forest appears little changed, while hillsides are far more densely forested, probably due to land use changes and wildfire control.

What's the effect of this change on wildlife? Is there greater wildlife diversity now than in 1890? While the additional forest cover may benefit some wildlife, it may be a barrier to others. For certain wildlife, grasslands and shrubfields act as corridors. More forest is not always equivalent to better wildlife habitat and biodiversity.

As in earlier times, modern-day development has concentrated in valley bottoms on former farm land and near riparian areas. However, future population increases could push residential housing up the hillsides. Since low elevation ecosystems are important for plant and animal diversity, and much more of this area is being occupied by towns, agriculture and industrial development, how will the ecosystems be impacted?



▲ *1926* ▼ *1995*

Long-term ecosystem stability

While some parts of forest ecosystems change rapidly, others seem to stay the same. At first glance it's difficult to notice any change on the South Fork of the Flathead River at the mouth of Spotted Bear Creek, from 1926 to 1995. The sluice box in the lower right corner of this 1926 photo is evidence of an active mining operation. The hillside in the background shows evidence of an earlier wildfire; the remaining timber has irregular boundaries as opposed to straight lines, and there are no roads. In 70 years, what would you expect to change most, riparian areas or uplands? Most people would say riparian areas, given the frequency of flood events throughout the Northwest. But judging from the modern photo, that isn't true here.

With respect to this section of the South Fork, the river and its adjacent banks have changed the least. Look closely at the tallest tree on top of the rock formation in the center of both photos–the one with the dead top. Its dead spire still reaches to the sky after 70 years of exposure. While all the trees around it have continued to grow, it has stayed the same. Having served as a perch and nesting site for countless numbers of birds and other wildlife, it's a stark reminder of the service provided by streamside snag-topped tree structures. Dead-top trees have incredible staying power once formed, but may take hundreds of years to grow.

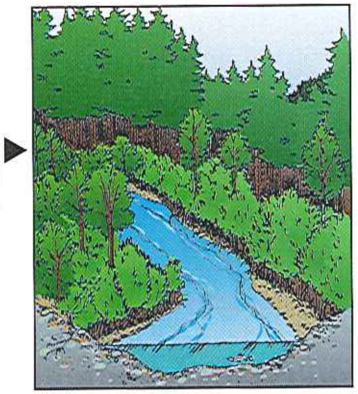
In 1995, the previously burned hillside has regenerated. A forest of mixed conifers provides a linkage between low and high elevation landscapes. The open ridgetop meadows continue to persist and will probably never grow trees. Notice that the fire did not burn the low elevation forest along the stream. Also notice the s-curve pattern of the river, its banks and gravel bars. There's been little if any change there either. Obviously, the 50 or 100 year flood events *(see next photo example)* had little influence on channel formation and shape. The difference is that the river channel is contained by the adjacent rock formation. And the mining activity? From this view, it's impossible to know it was even there.

From this example, it's easy to see that some parts of an ecosystem have more long-term stability and resistance to disturbance than might be expected.

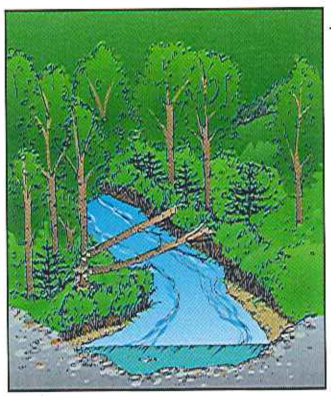
Riparian response after a flood

In contrast to the unchanged South Fork of the Flathead River *(previous example)*, Bear Creek, a tributary of the Middle Fork of the Flathead River, is another story. River flooding is a watershed disturbance that can often have profound effects on riparian forest zones. In 1964, rain and snowmelt forced Bear Creek to leave its banks, ignoring the confinement of U.S. Highway 2 (built in the floodplain parallel to the left side of the creek). The creek swept across its original floodplain, wiping out riparian forest vegetation, leaving a freshly scoured streambed many times its original width. Shortly after the river subsided, earthmoving equipment *(visible in photo at right)* attempted to return the creek to its confined channel and rebuild the highway.

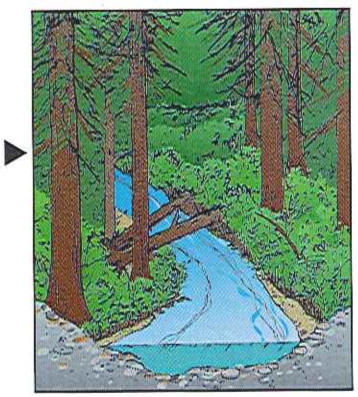
◀ **After major flood**
(bare soil and debris)



Ten years after flood ▶
(young willows and deciduous trees)



◀ **50 years after flood**
(mature deciduous trees and conifer understory)



100 years after flood ▶
(mature conifer forest, assuming no major flood for 100 years)

▲ *1964 Bear Creek flood*　▼ *1995 view of the same area*

Today, after 30 years of regeneration and growth, the riparian forest shows signs of recovery. Riparian forests in northwest Montana often recover from floodplain scouring events in a predictable manner *(see drawings above)*. Restoration begins with cottonwood sprouting on the newly deposited silt and sand. In fact, cottonwood requires floodwater scouring before it will successfully regenerate. Cottonwood often dominates the riparian forest for the first 60-80 years and then shade tolerant conifer species take over. This process of plant succession continues until the next major flood event. Then the process begins anew.

▲ *1995* ▼ *1906*

Urbanized lakes and waterways

The town of Polson is located on the south end of Flathead Lake in western Montana. Named after David Polson, a rancher who settled in the area in 1870, Polson had its first post office in 1898. When incorporated in 1910, the town had a population of 1,000. By 1960 there were 2,300 within the city limits. Today's community (population 4,000) illustrates the kind of ecosystem impact that has occurred around many water bodies (lakes, streams, wetlands, etc.) throughout the Northwest. Flathead Lake is the largest fresh water lake west of the Mississippi with 120,300 surface acres and 185 miles of shoreline. It was formed by glaciers during the last ice age some 10,000 years ago. The Flathead River flows into the lake at its north end and out the south end. The town of Polson lies at the river's outlet and adjacent to terminal moraines left by the glaciers. We see how the landscape appears today, but what did the tree lined streets of Polson look like 100 years ago? What kind of vegetation occupied the landscape? What species of wildlife frequented the area? What did the shoreline look like?

A very different landscape existed 100 years ago. Lakeside marshes have been replaced by golf courses and boat docks, native vegetation replaced with ornamental trees and shrubs. Roads and development block the movement of wildlife to and from the lakeshore. From wildlands to urban lands, the ecosystem has been reshaped by human disturbance. Wetlands occupied an area adjacent to the shoreline where the lake used to fill during spring and early summer runoff and then recede during summer. The Flathead Irrigation Project, started in 1909, began to change all that. Construction and reconstruction of reservoirs and ditches altered groundwater throughout the area. In 1910 the Federal government funded the deepening of Polson Harbor to provide dock facilities for steamboats, accommodating increased commerce. In 1938, Kerr Dam (a hydroelectric dam) was built on the Flathead River six miles downstream from the lake and town and brought additional water control. The dam raised the lake's maximum level about ten feet. Operation of the dam for generating electricity and for flood control causes the lake level to fluctuate through the year.

Polson is one of many towns and cities across the Northwest built near water and riparian areas. What have the impacts been on groundwater, aquatic species, terrestrial species and other natural processes? And what are the cumulative effects on the surrounding landscape? These questions are not easily answered.

Response after repeated wildfire

This 1940 aerial photo *(right)* of the South Fork of the Flathead River illustrates the impact of repeated wildfire. The view includes the eventual location of Hungry Horse Reservoir *(see color photo)* completed in 1952. The airfield in the center of the photo was built in the 1930s to assist with fire fighting activities. Four different South Fork wildfires swept across this forest between 1903 and 1929. The area on the left side of the river was burned twice: in 1919 and again in 1929. The right side of the river burned three times: in 1903, 1910 and again in 1929. Did the forest respond differently in these areas? Did the number of repeated fires have any impact on how quickly the area regenerated?

Today, the landscape surrounding the South Fork of the Flathead River has changed. The area most recovered from those early wildfires is the left side of the river. In fact, growth was so good that there is evidence of logging in the 40-50 year old valley bottom forest. However, the areas on the right side of the river which burned in 1903, 1910, and 1929, have been slower to recover. Notice that some openings are still not reforested. There may be several reasons. Obviously those areas of rock outcrops and talus (slopes covered by coarse rock) may never grow forests. Another reason is aspect, the direction a slope faces. Aspect affects forests after fire; south facing slopes can and often do remain non-forested for many years. Excessive soil heating during successive wildfires can also be a factor. If, for example, an early fire leaves many standing dead trees and subsequent fires come at intervals when that material has fallen to the forest floor, fire intensity can be so severe that soil can be left sterile, unable to grow trees for many years.

More recently, ecosystem scientists have learned about mycorrhizal fungi. These beneficial soil fungi attach to tree roots helping trees absorb water and nutrients. These fungi gravitate to and survive in and around large down logs as they decompose and become incorporated into the soil. Scientists have observed that forests subjected to repeated wildfires, where most or all of the logs and other coarse woody debris are consumed, are slower to reforest. They explain that this delay may be the result of fungi depleted soil. Green trees and down logs remaining after a wildfire are places where mycorrhizal fungi can survive and be available to the next forest.

▲ *1940 aerial photo* ▼ *1995 view of same area*

Human manipulation of forest vegetation

This mid-1950s photo shows an active hay harvesting operation on a ranch near Prineville, Oregon. Below is the same meadow in 1995. What changes do you notice in vegetation between the two photos? How do you suppose vegetation has changed since European settlement, and how does it compare with presettlement conditions?

This ranch, like many others in the interior forest, is in an area occupied by ponderosa pine, juniper, sagebrush and grass. Prior to settlement, the upslope forests were dominated by mature pine with an understory of grasses and forbes. Meadows maintained by frequent wildfires and burning by Native Americans were common. Naturally regenerated trees tended to exist in small clumps, avoiding the wildfires' path until they were large enough to withstand the frequent fires.

While sagebrush was the common plant in the meadow areas, frequent burning kept most of the juniper trees in the upslope forest areas. Analysis of juniper invasion into the meadows reveals that juniper has steadily moved downslope since the late 1800s. While the upslope juniper forest has trees up to several hundred years old, junipers in the meadows are much younger, indicating their recent invasion. And there are other noteworthy impacts. Juniper stands that invade meadow environments redistribute soil nutrients, use the site's water and crowd out other plants.

Why has this shift to juniper domination occurred? Primarily due to the exclusion of fire. Without fire, sage comes in first. Juniper is then able to become established in the protected microsites afforded by mature sagebrush. Look again at the lower photo, and note the young junipers invading the 1950s hayfield. Without fire or other continuous disturbance, like haying, the site eventually shifts to juniper domination like the slope in the background.

Unless juniper forests are the objective of the landowner, juniper should be controlled. Burning and cultivation prevented its domination in earlier times. Grazing alone is not as successful. If the objective is to restore the meadow environment, periodic disturbance by fire or other means will be needed. In upslope forests this same kind of disturbance, along with retention of larger trees, will be required to reestablish the ponderosa pine/grass (open savannah) plant community.

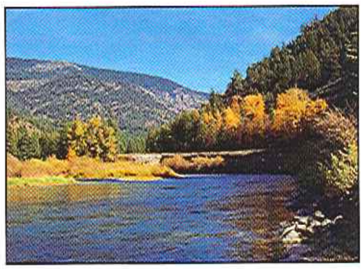
▲ *1950s hay harvest* ▼*same field in 1995*

In summary

Unless you're a third or fourth generation landowner with historical photos, you may not realize how your forest has changed, both naturally and through human disturbance and intervention. In addition to how ecosystems have changed, photos provide clues to future change. The historical photo comparisons in this section are intended to encourage you to search for the photo history of your forest property by contacting neighbors, historical societies, libraries and government agencies. Listed below are some ecosystem messages from this comparative photo series, and questions you can ask about your forest property.

from **Wildfire–disturbance and response**

- Fire is a major manipulator of Northwest forest ecosystems.
- Forest landscapes recover from catastrophic wildfires.
- Is there evidence your forest has been part of an earlier wildfire disturbance?

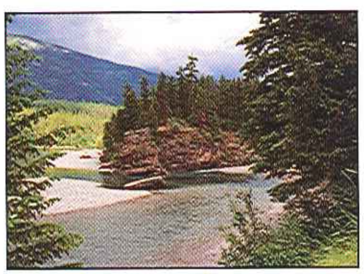


from **River and riparian disturbance**

- The famous log drives of the last century did not destroy the fishery resource.
- Is your stream recovering from past practices?

from **Human impact on interior valleys**

- Human development has changed the landscape, sometimes dramatically.
- Wildfire control has resulted in more forest cover.
- How has development influenced your forest property–what about the future?



from **Long-term ecosystem stability**

- Even river and riparian ecosystems, thought to be constantly changing, have structures such as trees and gravel bars, that remain in place for decades.
- Is your stream confined by its unique geology?

from **Riparian response after a flood**

- Humans are often unable to control natural flood disturbance.
- Plant succession (replacement of one plant community by another) in riparian areas is a predictable process.
- Have you observed it on your stream?

from **Urbanized lakes and waterways**

- There are profound impacts on the groundwater, aquatic and terrestrial species from development in riparian ecosystems.
- What impact is your community/property having on adjacent riparian ecosystems?

from **Response after repeated wildfires**

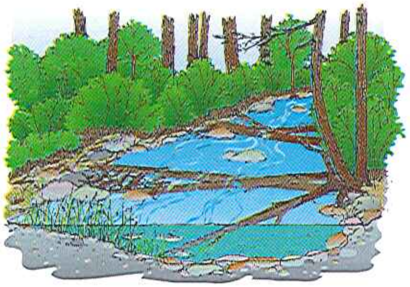
- The forest can be burned repeatedly and still recover.
- Upland sites are often slower to recover than bottomlands.
- Islands of unburned trees and down logs can speed forest recovery.

from **Human manipulation of forest vegetation**

- When fire is removed from forested ecosystems, the mix of plants often changes dramatically.
- Do your land management objectives match the vegetation changes that are occurring (i.e. grass vs. juniper)?

What's next?

Knowing what may happen to some forest ecosystems over time is the subject of the next section, "Ecosystem Science Principles and Concepts."



Section 5

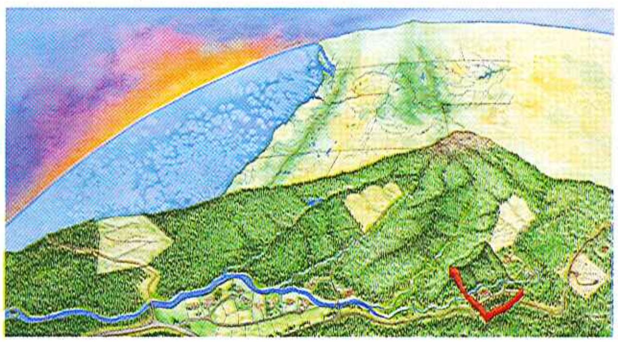
Ecosystem Science Principles and Concepts

The complexity of forests in the Northwest, and around the world, continues to humble scientists. However, viewing forests as ecosystems has enabled scientists to better understand the processes that sustain forests and the linkages between forest organisms. This section describes some ecosystem science concepts that relate to the four principles of sustainability, biodiversity, disturbance and response, and linkages.

Sustainability: What to sustain, that is the question. Ecosystem science points to the importance of sustaining a forest's long-term productive capacity with an adequate supply of rotting wood and large green trees. In turn, the forest's carbon storage process sustains other life processes.

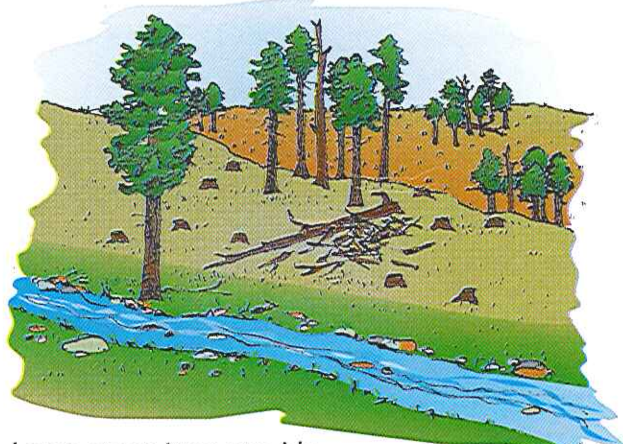
Sustainability–Maintaining capacity

Whether for wood, water, wildlife, forage or recreation, society has thought of forests as a resource capable of producing a continual supply of goods and services. There are limits to the forests' productive capacity to supply goods and services. If society overuses productive capacities, future societies may not be able to meet their needs. Ecosystem science cannot determine the desired level of the forests' goods and services, but it can identify the impacts of those removals on the forest ecosystem.



Efforts to ensure productive capacity can be made on individual properties, watersheds, and regional and national landscape scales. For example, if a local forest cannot maintain productive capacity, then attempts can be made to achieve that on a watershed or regional scale.

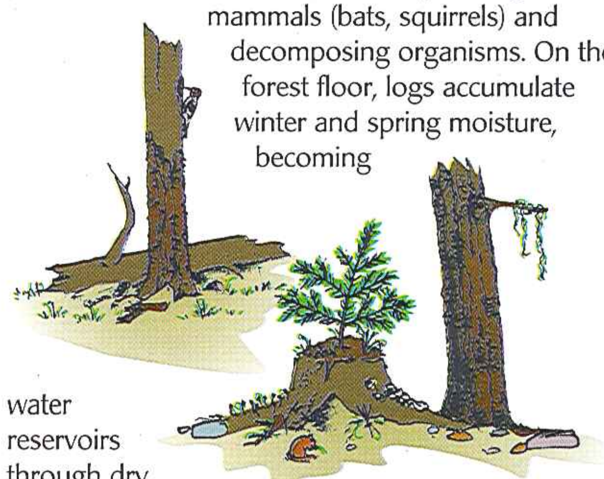
Sustainability–Maintaining green trees



Large, green trees provide immediate structural complexity in the new forest. Depending on their location, whether upland or riparian, they increase the rate at which disturbed habitats regain mature forest characteristics. They carry a gene pool into the next forest that has adapted to, and survived, thousands of years of natural disturbance. They also serve as connection points, linking together adjacent parts of the forest landscape. Ultimately they become a source for coarse woody debris and instream log structures that are places of refuge for many organisms. Maintaining these trees in disturbed landscapes is important to ecosystem health.

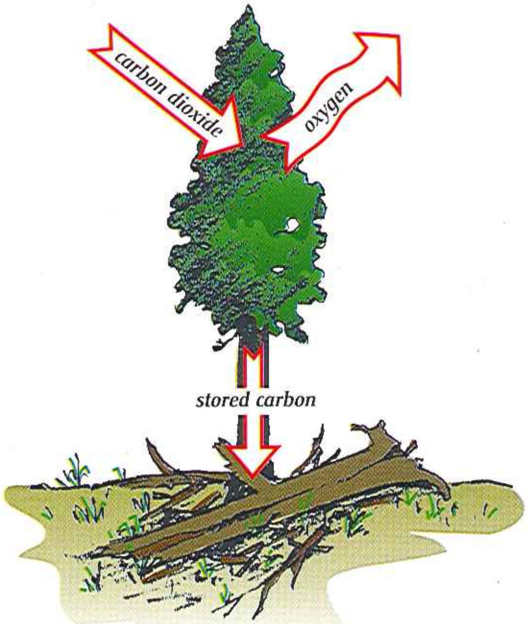
Sustainability–The value of rotting wood

Coarse woody debris (standing and down) is an important structural feature *(pages 32-35)*. Standing dead trees become habitat for cavity nesting birds, mammals (bats, squirrels) and decomposing organisms. On the forest floor, logs accumulate winter and spring moisture, becoming water reservoirs through dry summer months. Large down logs accumulate nitrogen which is crucial to tree growth, and attract insects, fungi, amphibians and other organisms–all important to forest health. These structures are part of a forest's ***biological legacy,*** a means of carrying over organisms from the preceding forest to the succeeding forest. Because they last for decades, rotting logs are an ideal means for holding and transferring all kinds of organisms, including pathogens, often considered forest pests.



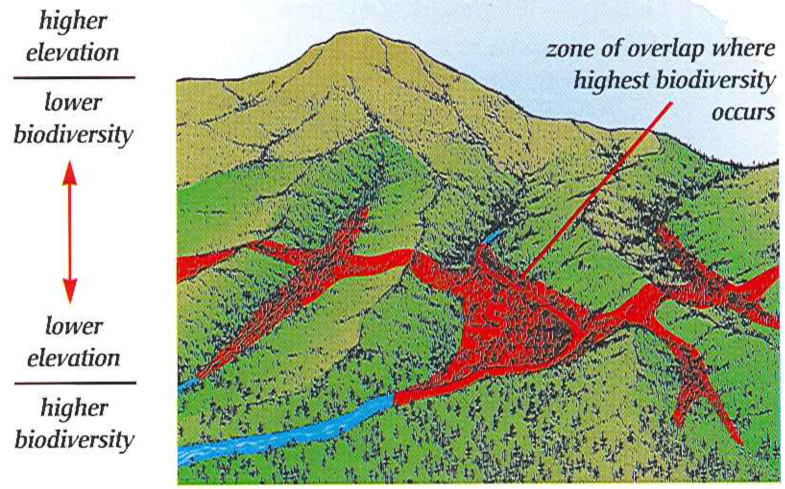
Sustainability—Carbon storage

Trees are storehouses for carbon. Through the photosynthetic process trees remove carbon dioxide from the atmosphere (a contributor to the greenhouse gas effect). When combined with water from the soil, carbon products such as wood, needles, cones and roots are created. In exchange, the atmosphere is cooled with the release of water and augmented with oxygen. The carbon storage process occurs in both old



and young forests. However studies indicate that old forests store much larger total amounts of atmospheric carbon than younger forests. On the other hand, young forests accumulate carbon at a faster rate. Even though wood is rotting in old forests and releasing carbon dioxide back into the air, a greater amount of carbon is captured than is lost.

Biodiversity: Survival of individual species and the impact extinction might have on ecosystems are part of biodiversity. How biodiversity changes across the landscape and the home territory needed for various species are important concepts.



Biodiversity—Zones of Biodiversity

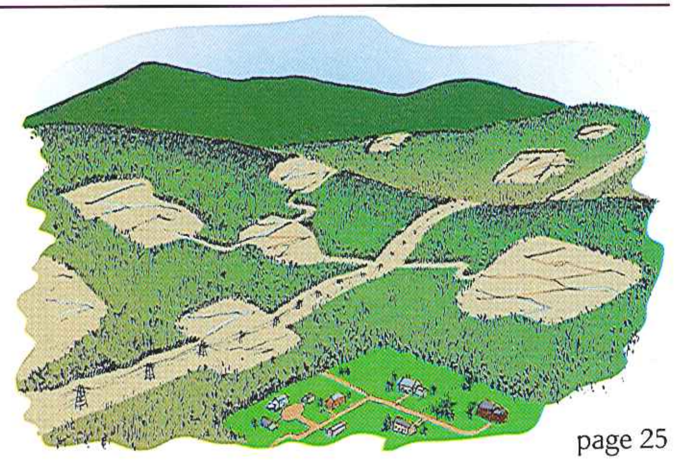
One kind of biodiversity is the genetic variation within a species of plant or animal. If the gene pool becomes too narrow, a species can become susceptible to insect and disease epidemics. This has occurred when a single clone of hybrid poplar has been planted on thousands of acres, and the entire plantation was lost to a disease.

Another kind of biodiversity is the variation in plants, animals and other organisms within a geographic area. For example, when an even-aged plantation *(pages 40-41)* of Douglas-fir occupies an entire landscape, its ability to maintain plant and animal species found in older structurally complex forests is questionable.

Note how elevation affects biodiversity *(diagram)* and how the zone of overlap between high and low elevation can offer the highest biodiversity. Forests located in this part of the landscape are important for maintaining biodiversity. In interior forests more diversity is not always better. When true fir and Douglas-fir invaded the central Oregon ponderosa pine forest *(pages 10-11)* the temporary result was more biodiversity, but eventually the forest became susceptible to epidemics and wildfire.

Biodiversity—Minimum territory for certain species

The break-up of forest landscapes into smaller and smaller fragments takes place in many forms. Urban fringe housing developments, road construction and the growing enthusiasm for outdoor recreation have all contributed to forest fragmentation. Since the 1950s, forest harvesting on many large ownerships has followed the "staggered setting" pattern (clearcut blocks spread across the forest) rather than concentrated harvesting in one area. The result is the possible reduction of populations of wildlife such as the spotted owl that require large blocks of forest cover.

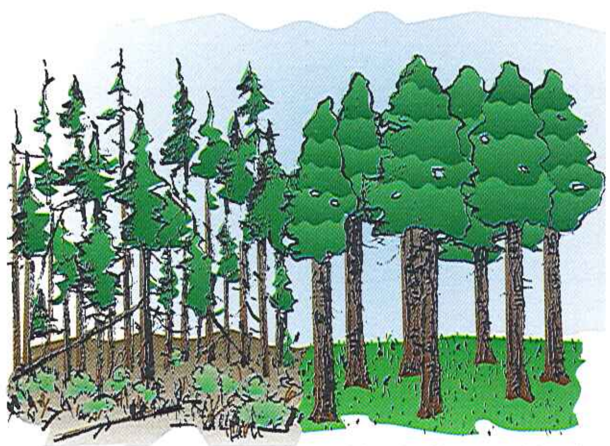


Disturbance and Response:

Natural and human-caused events alter the structure and composition of an ecosystem. It's important to understand these change processes and the direction forest ecosystems are headed.

Disturbance and Response–Forest change

Forests are constantly changing. Disturbance is a major factor influencing how forests change. Disturbance can be natural (wind, wildfire, insect and disease) and human caused (fire suppression, harvesting, building forest roads, etc.). Decades of interior forest fire control have resulted in forests choked with fuel, often leading to high-intensity forest fires *(pages 8-9)*. Within the past ten years wildfire infernos, with intensities well beyond natural fire disturbance, have occurred in some interior forests.



A structurally complex but unnatural and unstable interior forest condition.

An historically natural interior ponderosa pine forest. Structurally more simple, but stable.

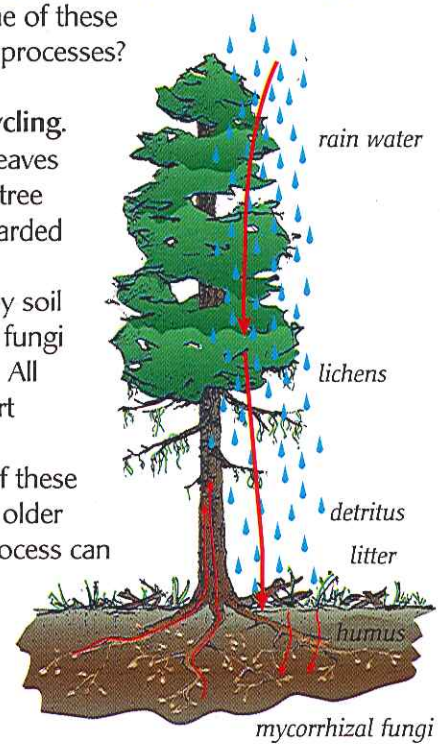
Tree density control and reintroduction of controlled fire are management techniques that can reduce the incidence of large wildfires.

Linkages:

Since the forest is a system it's important to know the linkages between forest components. Pathogens, water and soil each play a role in maintaining the system.

Linkages–Keep natural systems working

What are some of these natural forest processes?



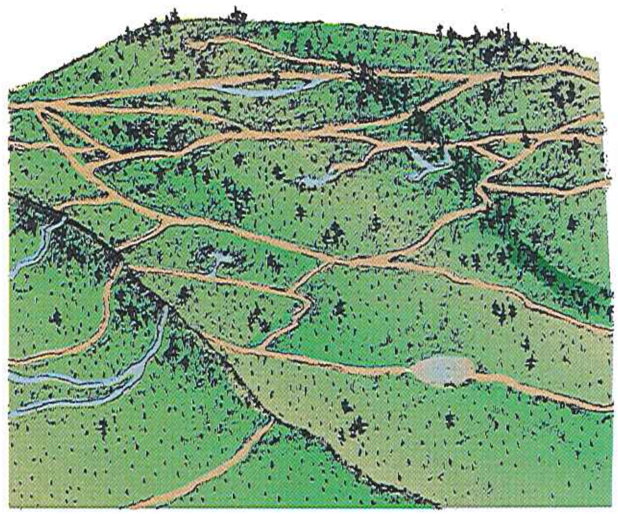
- **Nutrient cycling.** Mineral-rich leaves (detritus) and tree roots are discarded annually and reprocessed by soil microbes and fungi (mycorrhizae). All forests support important populations of these organisms. In older forests this process can add up to five tons of organic material per year.

- **Water acts as a medium for cycling nutrients.** The tall, deep, layered branch structure of old forests intercepts moisture from clouds. Precipitation washes off the surfaces of nitrogen fixing canopy lichens, delivering nutrients to the forest floor.

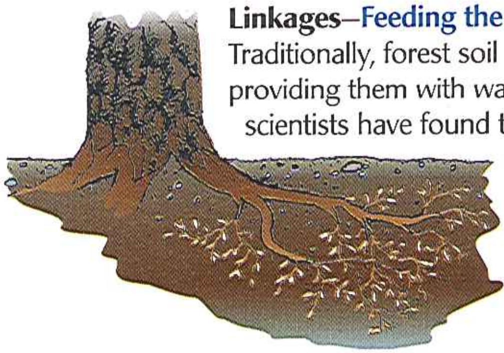
- **Mycorrhizal fungi and trees.** These beneficial fungi live on tree roots. They increase root surface area, allowing access to nutrients beyond the reach of roots. They also increase water availability and protect roots from soilborne diseases *(see page 21)*.

Linkages–
Water movement change in the forest

Forest roads are proven sources of stream sediment and in recent years major corrective actions are being made. Roads can alter both surface ***and*** groundwater drainage patterns. Some scientists point out that ditch lines are changing the movement of water in the forest, and creating countless miles of new "man-made streams" possibly at the expense of the natural drainage system. More forest road planning is needed to minimize road impact on water movement while at the same time providing for management and fire control. More cooperation and planning among



adjacent forest landowners within a watershed could help reduce road impact on the other forest resources. For example, roads on adjacent 80-100 acre ownerships often exceed five miles of road per section of land. The cumulative impact of such road density becomes excessive.



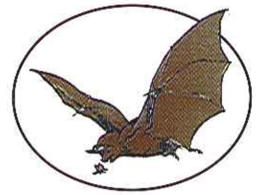
Linkages—Feeding the soil

Traditionally, forest soil has been thought of as supporting trees and providing them with water and wood-building nutrients. Ecosystem scientists have found that it is not a one-way relationship. In fact, trees and their root systems maintain soil production. Tree roots and their associated fungi release chemical nutrients to the soil. This is the way all forests feed the soil and when forests are not present, as in the case of grasslands, other vascular plants keep the soil productive.

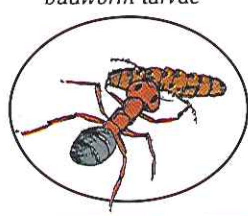
Linkages—Pathogens are not only enemies

Insects and disease are a necessary and inevitable component of the forest *(pages 44-45)*. While serious outbreaks do occur, there are important organisms such as bacteria, parasites and predators that help keep insects and disease at low levels between epidemics. Studies show that old forests in the Cascade Mountains support far greater populations of predatory invertebrates, primarily spiders, than younger forests. Knowing the requirements and maintaining habitat for these controlling organisms can maintain forest health and improve biodiversity. If the forest had no dead and dying trees, there would be no habitat for birds, mammals and many other organisms.

predatory birds that feed on Douglas-fir tussock moth larvae



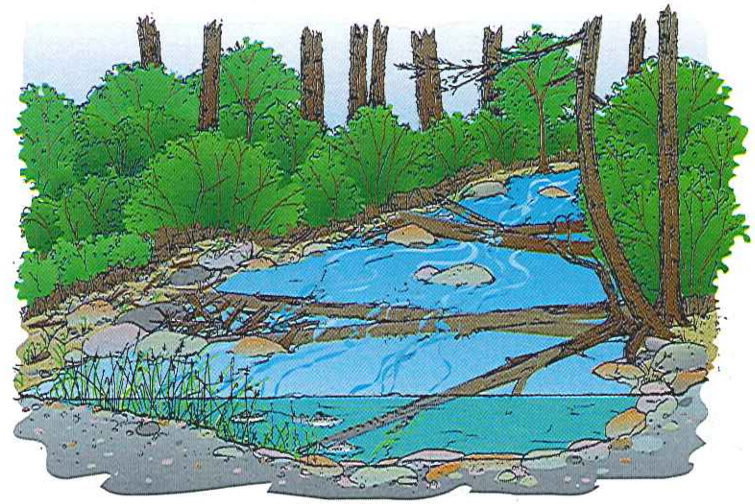
bats that feed on insects



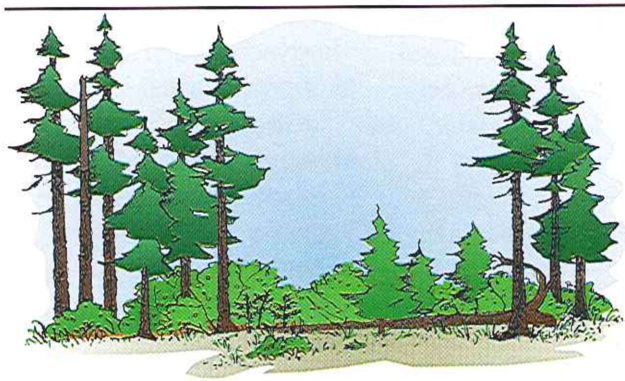
ants preying on western spruce budworm larvae

other parasitic insects lay their eggs on Douglas-fir tussock moth larvae

Linkages—Consider the entire stream system

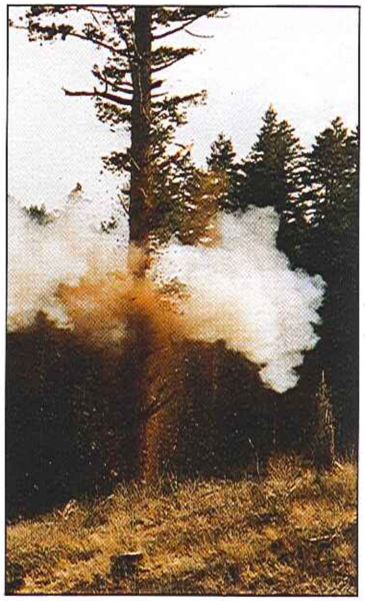


Both stream and riparian protection are critical for maintaining healthy forest ecosystems, because biodiversity is highest in riparian forests. Some stream scientists suggest that streamside protection zones should extend up and into non-fish bearing headwater streams. They are the batteries that charge the lower aquatic system with food for aquatic organisms. Nearly all of the food for stream organisms comes from riparian vegetation. Riparian forests are also the source of instream logs that create aquatic habitat (deep pools) and streamflow control structures (log jams and stair-step waterfalls). The aquatic world of forest streams and their surrounding riparian areas are dependent on forest uplands. Disturbance, whether caused by natural events or logging, road building or other development can directly impact our water resources.



Linkages—Structural complexity

Forests are structurally complex to varying degrees. Structural complexity refers to tree size and age differences, multiple plant layers (an overstory and mid-level canopy and an understory of plants), and gaps in the upper canopy that fill with diverse understory plants. Natural disturbances and human activities shape a forest's structural complexity. Structural complexity varies considerably with the type of forest. Ponderosa-grass open savannahs and lodgepole pine forests naturally have less structural diversity than coastal Douglas-fir and hemlock forests. Forest scientists have suggested the use of silvicultural systems that promote greater structural complexity in future forests *(see pages 38-41)*.



Section 6

Using Ecosystem Science in Forest Management Actions

Moving from principles and concepts to on-the-ground management actions is beginning to happen. If you want to apply some of the ecosystem science presented in this publication to your forest, here are some examples. This section describes some ideas that are being used or tested. They don't fit every forest, nor every landowner's objectives. However, they do apply ecosystem science to individual forest properties and suggest ways to link individual properties to the greater landscape.

Sustainability:
- Ensuring water quality and quantity in forests
- Growing big old trees
- Assessing and providing down coarse woody debris
- Creating standing coarse woody debris

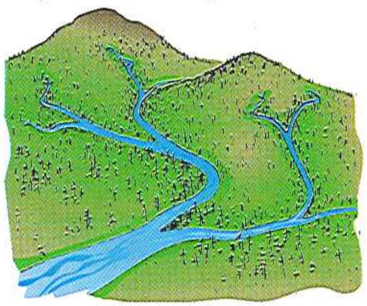
Disturbance and Response:
- Reducing insect and disease outbreaks
- Reducing catastrophic fire

Biodiversity:
- Applying ecosystem science to silviculture
- Promoting more structural and biological diversity in an even-aged plantation
- Creating habitat for threatened and endangered species

Linkages:
- Establishing forest linkages at two different scales

Sustainability—Ensuring water quality and quantity in forests

Water is one of the most important forest products.



First order streams are headwaters, located in the highest reaches of a watershed. When two first order streams join, they become a second order stream. When two second order streams join, they become a third order stream, and so on.

Forest vegetation, soils and riparian areas regulate the quantity of water delivered downstream. Instead of releasing water all at once, riparian forests regulate its flow.

Ecosystem science has drawn attention to small streams, identifying the linkages between first, second and third order streams *(left diagram)* and the riparian forest surrounding them.

The riparian forest controls stream temperature and the amount of sunlight reaching the stream. High water temperatures can often be traced to removal of streamside vegetation both on second and third order fish-bearing streams and small first order tributaries that supply cold water to the larger streams.

Leaves, needles, twigs, wood and insects falling into the stream provide energy and nutrients for the stream. Simultaneous with leaf drop in the fall is a buildup of stream aquatic insects, ready and waiting to decompose this heavy flush of "energy soup."

Forests provide coarse woody debris for streams. This material falls in from streamside areas, floats down from upstream tributaries and slides into the stream from upland slopes. The shape of the stream channel and formation of pools are influenced by this large wood. Log jams, once thought to be barriers to fish movement, are now known to be essential structures. They are responsible for creating pools and quiet water where decomposition takes place and fish feed and rest. Log structures also trap huge quantities of organic material, allowing it to decompose. Logs stabilize streambed gravels, provide fish cover and influence streambanks by directing stream flows.

Streamside trees and shrubs stabilize banks, reducing floodwaters' erosive potential.

While ecosystem science is still inadequate to describe how all of these land, water and subsurface linkages function within a watershed, there are many land management actions that help protect forest streams, wetlands and riparian areas. These actions can help:
- Improve habitat structure in streams,
- Improve the condition of riparian vegetation when grazing livestock, and
- Control and prevent road-related runoff and sediment production.

Actions to improve habitat structure in small streams

As fish habitat, not all parts of a stream are equal. Certain stream segments may be biological ***hotspots***– productive areas where the number of fish are highest.

Biological hotspots seem to be associated with accumulations of coarse woody debris.

Hotspots seem to be most prevalent where instream structures exist–where water, nutrients and organic matter are slowed, and deep pools are available. Hotspots seem to be maintained by coarse woody debris that gathers in first order streams. From time to time, this material is flushed downstream into hotspot locations by floods, thereby providing a continuous source of instream wood to second and third order streams. This allows hotspots to be replenished with woody debris which continues to benefit the watershed.

Emphasis on riparian protection along large fish-bearing streams has shifted to include smaller streams as scientists learn more about the role of small streams in watershed health. For example, scientists have focused more attention on the connection between small first and second order streams and the third and fourth order streams they feed. Some large trees must be grown and allowed to fall into these streams so they can be carried downstream to hotspots. Concern over fish and wildlife habitat seems to be pointing toward riparian protection further up in the drainage and further out into land adjacent to the stream. Since small streams make up most of the stream network miles, protecting these riparian areas will involve more of the land base.

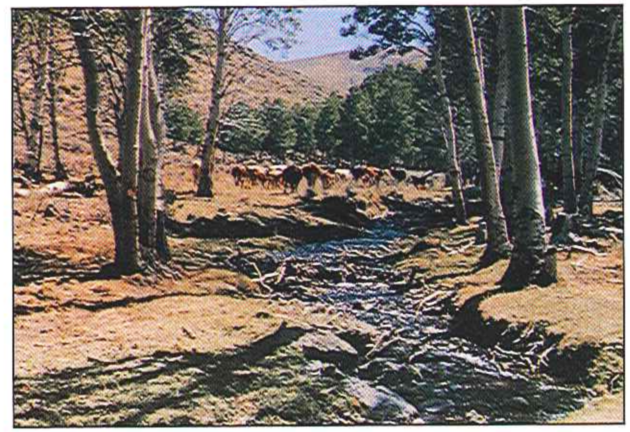
Actions to improve riparian vegetation when grazing livestock

The riparian forest is susceptible to bank trampling, soil compaction and loss of vegetation. Uncontrolled or season-long livestock grazing can result in wide, shallow stream channels, with flattened or steep eroding banks *(1973 photo at right)*. The following is a typical example.

In 1973, the trampled and heavily grazed riparian area of this stream provided little protection from sediment and other pollutants. The consequences were poor water quality and the loss of fish and wildlife habitat.

Fencing out livestock for four years resulted in dramatic riparian and stream improvement *(1977 photo)*. The wide, shallow stream channel was gradually replaced by a narrower, deeper, more stable channel with well-vegetated banks. Improved summer streamflow and enhanced fish and wildlife habitat were direct results of this riparian forest recovery.

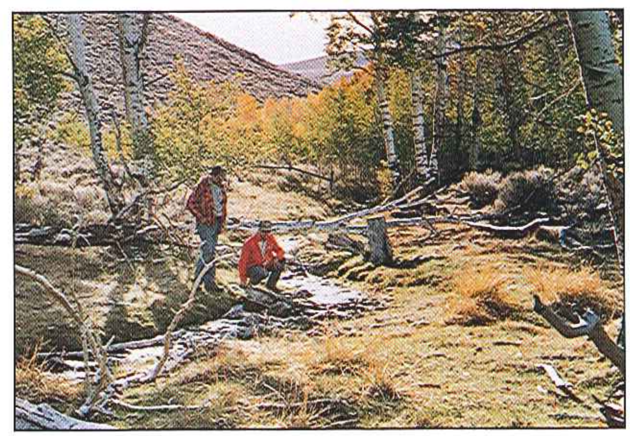
In 1992, livestock were allowed to re-enter the restored riparian area. Grazing was limited to 2-4 weeks in July. The result–bare soil on the banks–illustrates the need to carefully manage grazing in riparian areas and allow time for regrowth. The key to healthy riparian forests is grazing management.



▲ *1973–Uncontrolled, season-long grazing.*

◀ *1977–After four years of fencing out livestock.*

▼ *1992–Even short duration grazing can sometimes be too much.*



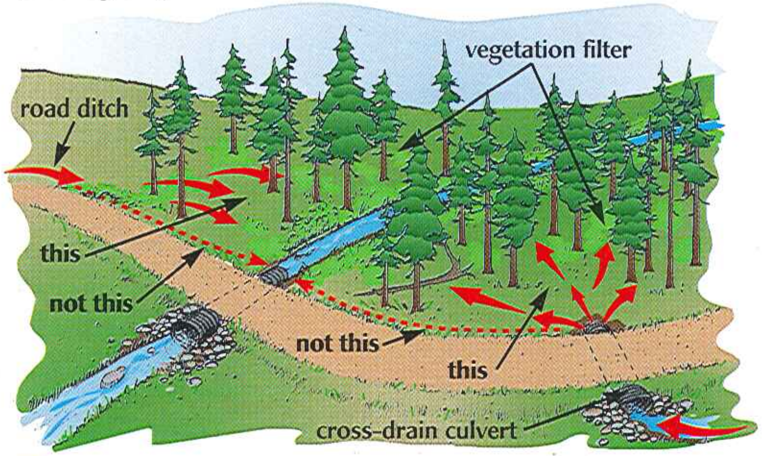
Actions to minimize roads and road-related runoff and sediment

■ Planning, design and location of forest roads is critical because of the sediment they produce and their impact on hydrology *(Linkages, page 26)*. Through cooperation and planning among adjacent landowners within a watershed, forest road impacts can be reduced.

■ Avoid plugged culverts and road washouts with regular maintenance.

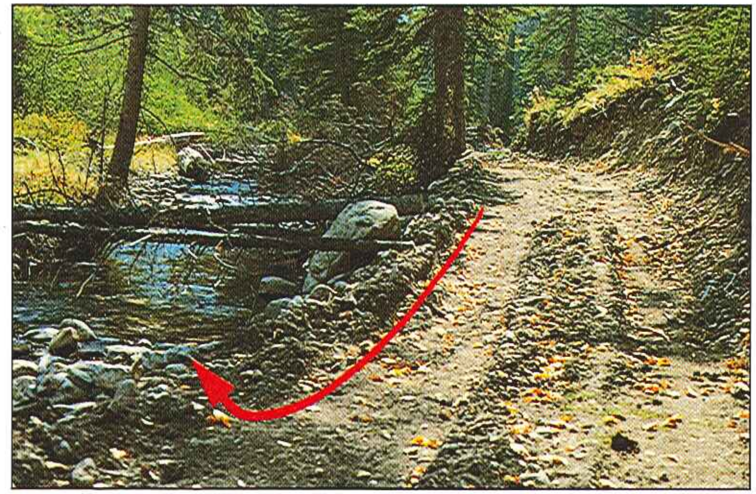
Hand, shovel and chainsaw work are usually all that are required. But delay until a storm occurs can result in a damaged road, road washout and stream sediment.

■ Never allow road ditches to drain directly into streams. Drain them into a "vegetation filter" far enough from the stream so ditch sediment will not reach the stream channel *(see diagram)*.



■ Never allow cross-drain culverts to drain into streams. Direct culvert drainage through a "vegetation filter" before reaching the stream. Install stream crossings at right angles to the channel *(see diagram)*.

■ Grass can be seeded on exposed cut and fill surfaces. Exact seed mixtures, proper timing and fertilizers are important for success. Use native species when possible. Seeding stabilizes soil, prevents erosion and demonstrates a landowner's concern for watershed health.



■ Temporary roads can be designed for short-term minimal use during timber harvesting. When stream crossings are needed, portable bridges can be used.

Low-standard roads involve only vegetation clearing and minimal construction.

A portable railroad flatcar provides access across streams less than ten-feet wide with minimal disturbance to streambanks or stream bed.

Besides being portable, this temporary bridge is strong enough for all harvesting activities.

Road restoration includes pulling up roadside berms, ripping compacted areas, restoring natural drainage and reseeding.

■ If road grading along a stream produces excess material, feather it out or haul it away. Never sidecast material into streams. Avoid leaving a berm that channels water down the road unless it is routed into a vegetation filter. The photo shows a berm that incorrectly channels road surface water directly to the stream without any filtering.

Sustainability–Growing big old trees

Big old trees contribute to forest diversity by providing structure. Large trees provide multiple tree canopy layers. As their platform-like limbs begin to form, the crowns of old trees become more open and irregular in shape. While still alive, old trees often have as much as 30–70 percent rotted wood, providing niches for many organisms. Old trees are more resistant to fire because their crown bases are often high above the understory and their bark is thicker. Beneath old trees there's often a unique understory that contributes to forest diversity. When they fall over, big old trees create gaps in the forest canopy where understory plants are stimulated. Certain mosses and lichens, known to produce nitrogen in significant quantities, grow on the limbs of old trees *(see photos–below and on page 5).*

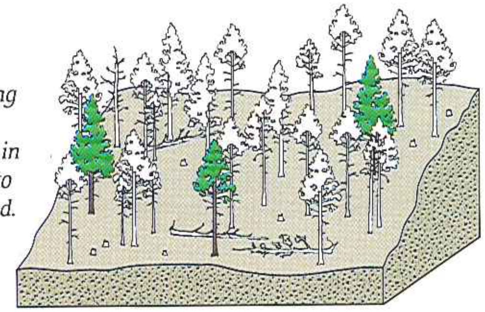
"Forage lichens," not to be confused with nitrogen-fixing lichens, are long and pendant, hanging from limbs and stems. They are important food for small mammals (flying squirrels, red-backed voles and woodrats), deer and mountain goats especially in winter.

If your objective is to provide more old forest structure in your young forest, how can you grow big old trees? The answer to big old trees is time.

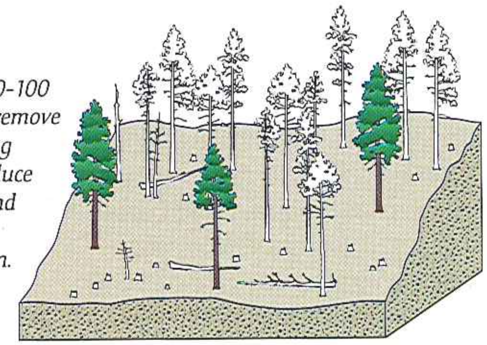
While there are some silvicultural techniques that can accelerate tree growth, there are limits to how fast we can push nature. On the other hand, it is possible to inoculate the stems of trees with fungi *(page 35)* and speed up the wood rotting process, but the maturation of tree crowns and the thickening of bark cannot be accelerated.

Some techniques can be used in young forest stands to foster the development of big old trees *(see diagrams at right).* First, find individuals or groups of trees that are dominant in the stand (those trees that are taller, have a deeper canopy and larger diameter). When choosing trees, pick long-lived species adapted to your site. In coastal forests select Douglas-fir, cedar, oak and madrone in contrast to grand fir, alder, cottonwood and big leaf maple. In interior forests choose ponderosa pine, larch and Douglas-fir rather than lodgepole, spruce or aspen. By harvesting the trees in the immediate vicinity, these specimens can be encouraged to develop into big old trees. Removing adjacent trees also reduces competition for soil moisture. Once identified as old tree candidates, these specimens need to be maintained into future forest rotations for as long as they survive. At the same time "new" old trees need to be recruited. The idea is to continually find and cultivate old tree specimens that remain intact as their peers are harvested and a new forest regenerates around them. Growing these large structures is not without cost or risk; you may sacrifice some income. In addition, old trees could attract certain wildlife which could reduce management options. You will, however, meet goals of sustainability by maintaining them.

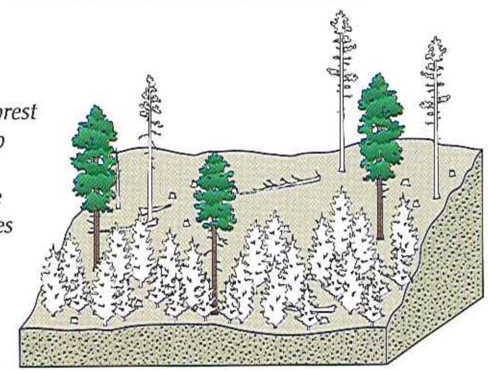
Start looking for old tree candidates in stands 40 to 80 years old.



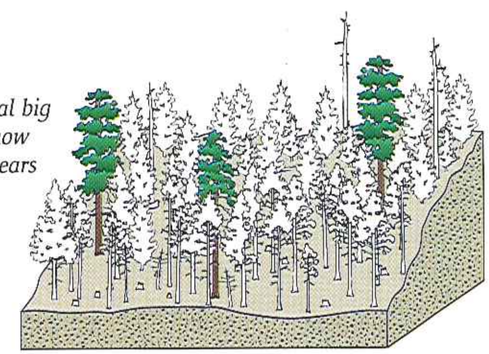
Between 50-100 years old, remove neighboring trees to reduce shading and nutrient competition.



The next forest will start to grow up around the big old trees (100-200 years old).



The original big old trees, now over 200 years old, stand above the younger stand.



Sustainability–Assessing and providing down coarse woody debris

Coarse woody debris (CWD) is an important structural component of both coastal and interior natural forests.

Rotting wood on the forest floor has many benefits. It physically protects soil from erosion. It also contributes to forest soil development. Even though soil wood amounts to only a small part of total soil volume, buried CWD in advanced stages of decay is a primary location for mycorrhizae. These soil fungi help tree roots absorb water and nutrients, and their fruiting bodies (truffles) provide food for many small rodents. CWD also contributes to the nutrient cycling process. Sulfur, phosphorous and nitrogen are released as CWD decays or is burned. CWD provides habitat for plants and animals as new plants become established in its shade. In cedar-hemlock forests, CWD acts as seedbed and nursery areas for new conifer seedlings. When decay advances, CWD becomes a water holding reservoir that plants can tap during drought. Large diameter logs, stumps and decaying tree roots provide nesting sites for ants, birds and mammals. Ecosystem science calls for the recruitment and maintenance of CWD. It includes decaying tree limbs, stems and roots, the preferred minimum size being three inches in diameter.

In some forest ecosystems, CWD lasts for hundreds of years; in others its life span is only 50-60 years. In western hemlock forests, with forest fire intervals of more than 200 years, CWD lasts a long time. In ponderosa pine forests with historical fire frequencies as short as ten years, CWD disappears more rapidly. Since CWD is an important part of forest ecosystems, some must be maintained in managed forests.

What different amounts of CWD look like.

Pictured at right are three different amounts of CWD for three Northwest forest types: Douglas-fir, grand fir and ponderosa pine. In addition are details about tree size classes in each pictured stand.

Photo Legend

- CWD tons/acre includes only CWD 3″ diameter or more. Stumps are not included in calculations because they often remain after wildfire or harvesting disturbance.
- The perspective marker is 1 foot square. The pole is painted with one foot interval stripes.

Is the CWD in these forests anything like yours?

Douglas-fir

CWD: *7 tons/acre*

About the living forest:
- *350 trees/acre under 8″ diameter*
- *263 trees/acre 8-20″ diameter*
- *25 trees/acre over 20″ diameter*

CWD: *27 tons/acre*

About the living forest:
- *950 trees/acre under 8″ diameter*
- *121 trees/acre 8-20″ diameter*
- *47 trees/acre over 20″ diameter*

CWD: *52 tons/acre*

About the living forest:
- *350 trees/acre under 8″ diameter*
- *336 trees/acre 8-20″ diameter*
- *3 trees/acre over 20″ diameter*

Grand fir

CWD: *6 tons/acre*

About the living forest:
- *1650 trees/acre under 8″ diameter*
- *347 trees/acre 8-20″ diameter*
- *4 trees/acre over 20″ diameter*

CWD: *15 tons/acre*

About the living forest:
- *1400 trees/acre under 8″ diameter*
- *263 trees/acre 8-20″ diameter*
- *3 trees/acre over 20″ diameter*

CWD: *37 tons/acre*

About the living forest:
- *150 trees/acre under 8″ diameter*
- *156 trees/acre 8-20″ diameter*
- *17 trees/acre over 20″ diameter*

Ponderosa pine

CWD:
6 tons/acre

About the living forest:
- *1785 trees/acre under 8″ diameter*
- *14 trees/acre 8-20″ diameter*
- *0 trees/acre over 20″ diameter*

CWD:
16 tons/acre

About the living forest:
- *0 trees/acre under 8″ diameter*
- *50 trees/acre 8-20″ diameter*
- *3 trees/acre over 20″ diameter*

CWD:
30 tons/acre

About the living forest:
- *600 trees/acre under 8″ diameter*
- *13 trees/acre 8-20″ diameter*
- *38 trees/acre over 20″ diameter*

How much CWD should be maintained?

Scientists don't know for sure. Historically, Rocky Mountain wildfires left large amounts of CWD–as much as 45 tons per acre (t/a) on ponderosa pine sites and 265 t/a on western hemlock sites in northern Idaho. Current research in Rocky Mountain forests indicates that on average almost 30 t/a of CWD has accumulated in cedar/hemlock forests. Ponderosa pine forests have accumulated an average of about 10 t/a. Northwest forests have great diversity and each forest type develops and retains different amounts of CWD. How much you decide to leave will be a tradeoff between the risk of fire and access for management, with the need for CWD.

What kind of CWD is best?

Douglas-fir and western larch wood is particularly good for CWD because it decays slowly. True fir (grand fir and subalpine fir) decays relatively quickly. Ponderosa pine is between Douglas-fir/larch and true fir in its decay rate. CWD from all species contributes organic matter on the forest floor. Longer, large diameter pieces (more than 8 feet long) have more decay resistant heartwood and last longer than small pieces. Larger pieces of CWD may also survive fires.

How to provide CWD

Recruiting new CWD and maintaining existing CWD is becoming an important part of forest management. With demand for wood products and our ability to use more wood fiber, less CWD is being left on the forest floor after harvesting. CWD should be spread out across the forest floor of harvested forests. Chipping slash destroys the advantages of CWD for nitrogen fixation and animal habitat. CWD that is charred on the outside by prescribed fire does not interfere with rotting. Within one year of burning, decay fungi colonize most charred CWD.

Concentrating CWD in large piles should be avoided. If piles are burned, most CWD is lost. If unburned, this concentrated debris benefits only a portion of the site.

Scarifying too heavily removes CWD, compacts soil, promotes erosion and disturbs nesting sites for ants, birds and mammals.

Using CWD to link forest stands is being done experimentally by "edge meshing." This technique involves felling large trees from an adjacent older forest into a younger stand. There are two purposes:

- It puts newer CWD into the younger stand, connecting one stand to the other.
- It injures some of the younger regenerating trees, providing future dead and decaying tree habitat.

Edge meshing.

Sustainability—Creating standing coarse woody debris

Diameter is the primary consideration when searching for suitable snags. The bigger the better. A pileated woodpecker can't fit in an 8 inch diameter tree, but both a mountain bluebird and a pileated woodpecker can occupy a 25 inch ponderosa pine snag. Height is another important consideration. Most animals prefer tall snags to reduce the threat of predators. Tall snags serve as wildlife "skyscrapers" and provide habitat for many creatures. Be aware of the tradeoff between the benefits of tall decaying snags and their threat of spreading wildfire and increasing logging danger. Ridgetops are a poor location for snags, because if hollow, they can act like a chimney, spewing large chunks of burning embers for great distances.

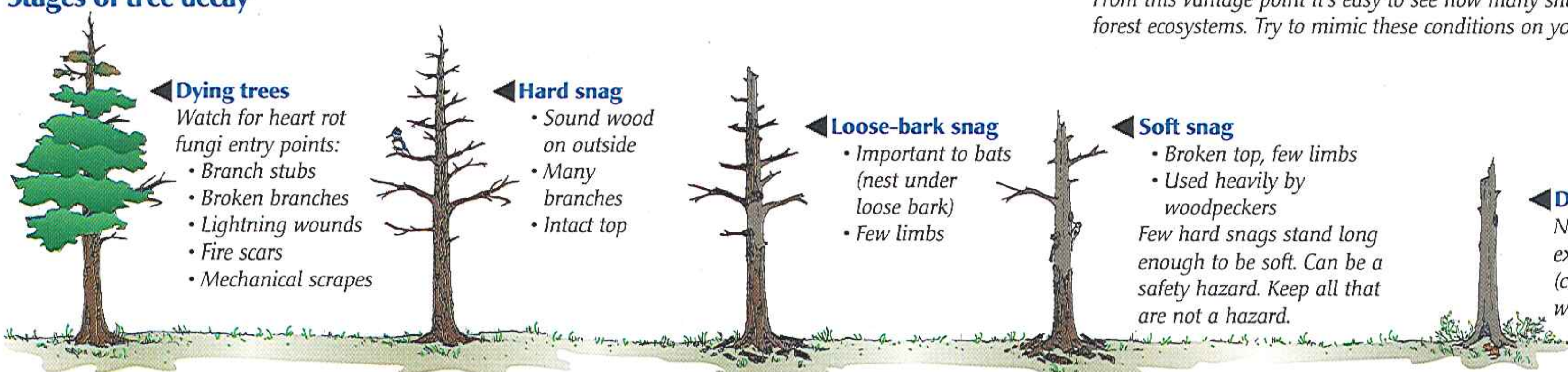
Woodpeckers, owls, nuthatches and swifts must have cavities for nesting. They require either snags or a suitable substitute such as nest boxes. Providing a continuous supply of snags requires planning. Snags in various stages of decay are also needed. Snags are recruited from green trees, so watch for candidates. Take note of large trees that are dying. Look for conks—indicators of heart rot. Branch stubs and broken branches are locations where heart rot fungi enter trees. Trees with fire, lightning and mechanical wounds are snag candidates. Consider leaving trees that already contain rot as a way to make them usable by cavity nesters in a shorter period of time. It's a good idea to permanently mark future snags. That way there's no confusion during a timber harvest. Be aware of the signs of snag use.

Pileated woodpeckers require snags at least 20 inches in diameter.

Mammals, like this pine marten, use cavities made by woodpeckers.

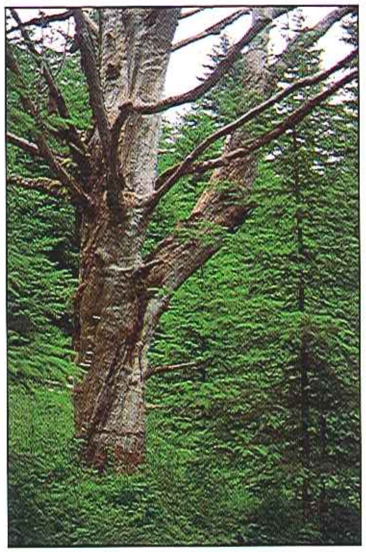
From this vantage point it's easy to see how many snags are common in old forest ecosystems. Try to mimic these conditions on your property.

Stages of tree decay



How to create snags

■ The simplest way to create a snag is by girdling a green tree (either deciduous or conifer). A hand ax or chainsaw is used to cut away a bark-free band around the main stem, usually at waist height. This severs the water circulatory system of the tree. Sometimes a small amount of chemical herbicide is squirted into the bark openings to ensure that the tree dies.



This limby big leaf maple was girdled and left standing when this young Douglas-fir forest was started.

When left standing, girdled trees are used by cavity nesting wildlife. Wildlife biologists like the large cavities that oaks, maples, cottonwoods and other hardwoods can provide. Unfortunately, this method is not ideal. Girdled trees can fall over prematurely due to rot that infects the tree at the location of the girdle. However, it does provide a necessary snag structure in the early decades of a new stand.

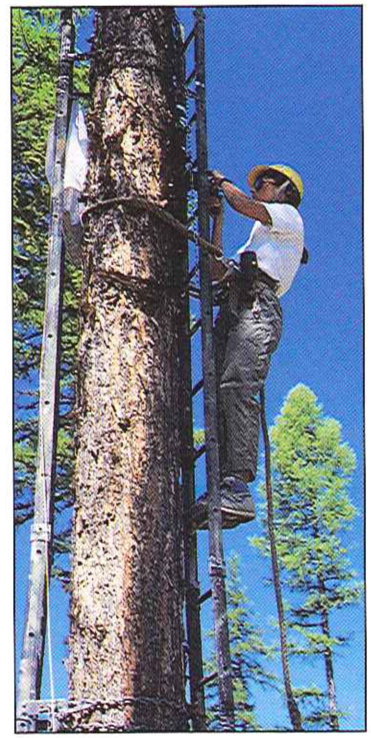
■ Dynamite charges can be set in the tops of large green conifers to create snags. The jagged top created by the blast collects water and promotes rapid fungal decay in the heartwood, making the snag more appealing to cavity nesting birds in less time. Cutting the top with a chainsaw can also be done, but at a greater risk to the operator.

Using explosives to create a snag. ▲ *Before* ▲ *After*

■ Single grip mechanical harvesters *(page 43)* can also be used to create snags. They can reach 15-25 feet up the stem of a tree and cut off the top. The stem becomes a snag and the top is cut into saleable logs. This safe and efficient technique is being used more and more in timber harvesting operations.

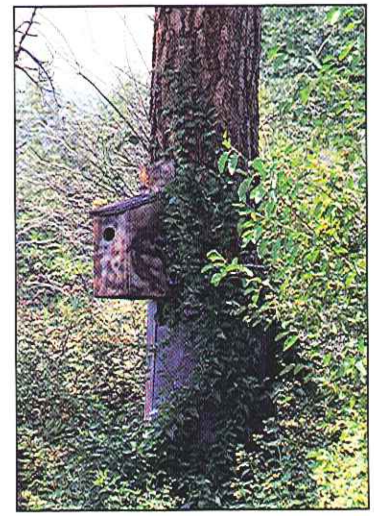
■ Fire can be used to create snags. Brush can be piled around green snag candidates and burned when conditions are safe. To be effective, the fire must burn long and hot enough to create lethal temperatures in the cambium tissue under the bark.

■ A new technique involves inoculating green trees with rotting fungi to cause decay. Scientists have isolated several decay-causing fungi and have inoculated live trees. Holes are drilled and five-inch long inoculated dowels inserted. Within five years, cavity nesters can use the artificially created decaying stems.



Inoculating a tree with decay-causing fungi.

What about nest boxes?



Nest boxes can be a substitute for snags, but are a time consuming and costly remedy. Use of nest boxes in European forest plantations, devoid of significant snag habitat, has been common. Evidence indicates that their use can enhance populations of cavity-nesting birds. They require annual cleaning, are expensive to install, and require a different design for each species you wish to attract. While some species find nest boxes acceptable, others do not. And while they provide nesting habitat, they don't provide a food source like snags do.

Biodiversity–Applying ecosystem science to silviculture

For decades, foresters have used the science of silviculture (the practice of growing, harvesting and regenerating forests) to guide them as they manipulate forest stands. Silviculture has primarily tried to grow trees faster, better and stronger. Recently, silviculture has been modified by ecosystem science discoveries. The focus is on what's left as a legacy for succeeding forests. The goal is to provide forest legacy while continuing to harvest timber. That means maintaining some stand structures, including standing green trees, large down logs and existing seedlings and saplings.

Before exploring new silviculture, let's review traditional silviculture. Traditional silviculture has relied on harvest regeneration systems, where mature stands are removed and replaced by regenerating a new stand.

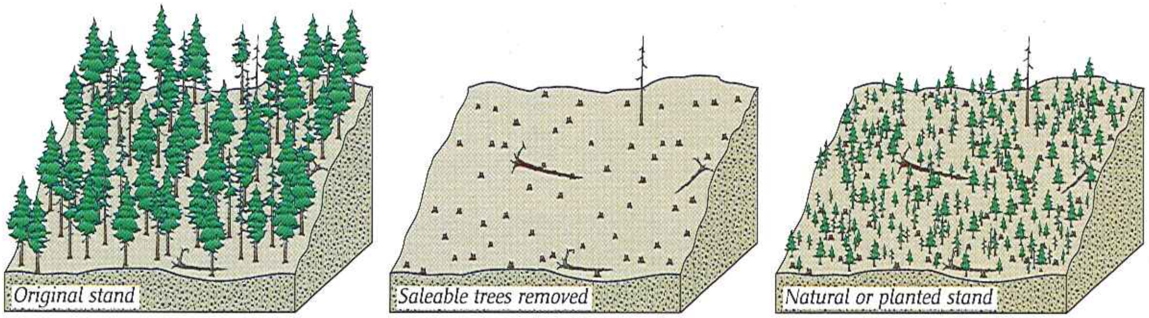
Traditional

The most common techniques have been:

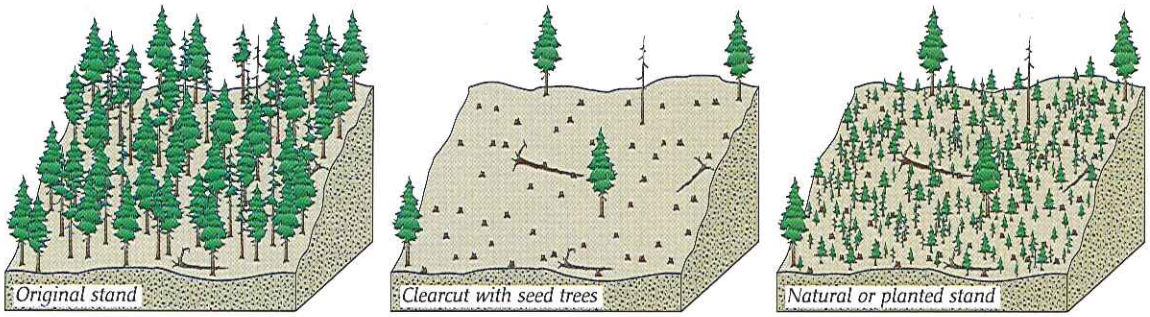
Even-aged silviculture

In even-aged stands, the majority of the trees are close to the same age. Commonly used techniques *(shown at left)* in **even-age** stands include:

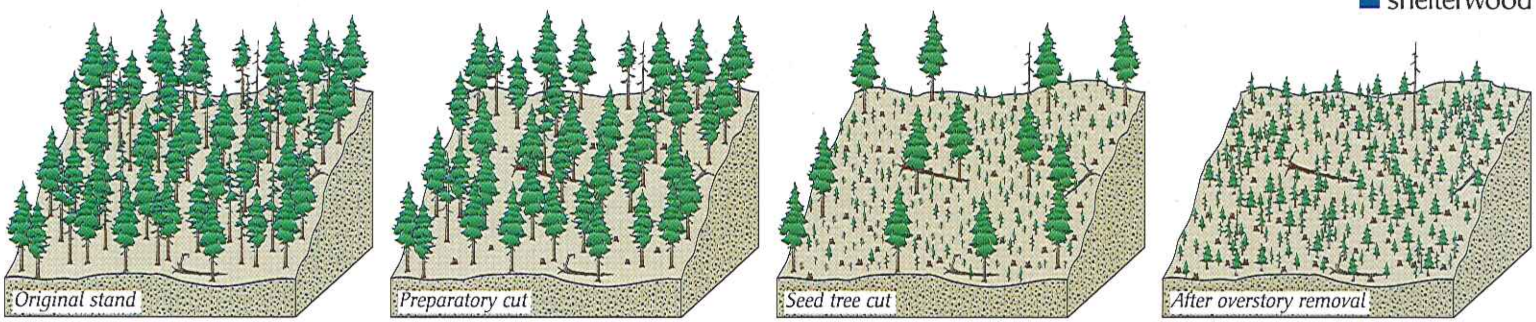
- clearcut
- seedtree
- shelterwood



Clearcut silviculture: As clearcuts regenerate through natural seeding or planting, they often don't have the structural diversity that is important to many plants and animals. Dense, one-story stands develop. After one or more intermediate thinnings, the stand is clearcut and the process begins again.



Seedtree silviculture: Leave 1 to 10 seed trees with the best genetic attributes per acre. When feasible, seed trees are harvested after regeneration is assured.



Shelterwood silviculture: First, a preparatory cut removes 25-30 percent of the trees, so those remaining become windfirm. Next, a seed cut removes all but the best seed trees, opening the canopy to allow seedlings to get established. Finally, overstory removal takes out the seed trees after regeneration is at least waist high.

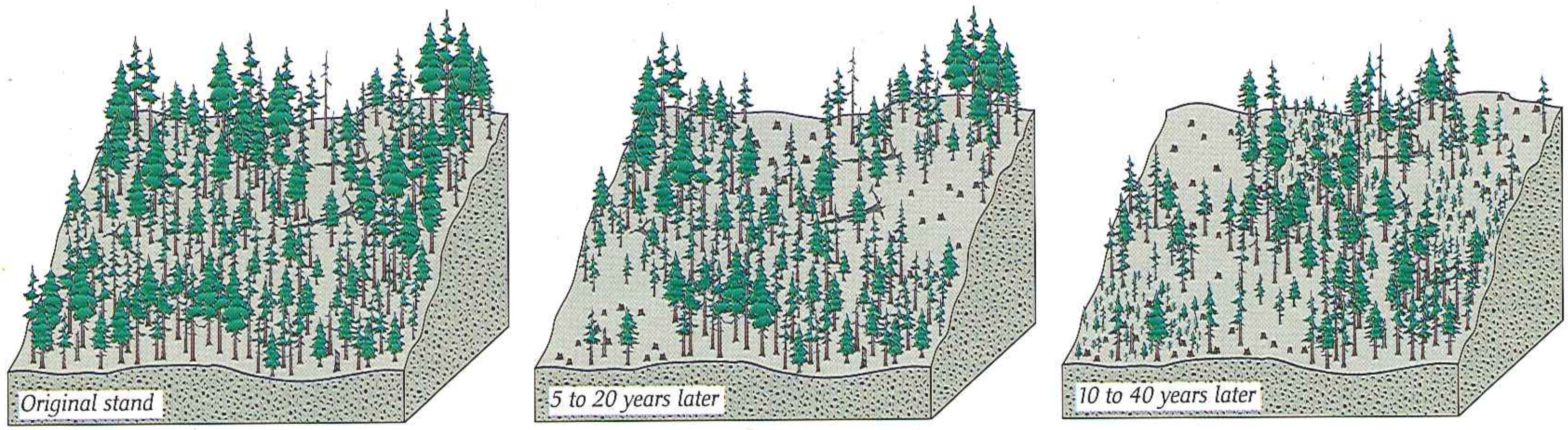
Uneven-aged silviculture

In uneven-aged stands, trees of several different age classes are present, from young to old. There are two silvicultural techniques *(pictured below)* used to harvest and regenerate forests under **uneven-aged** management:

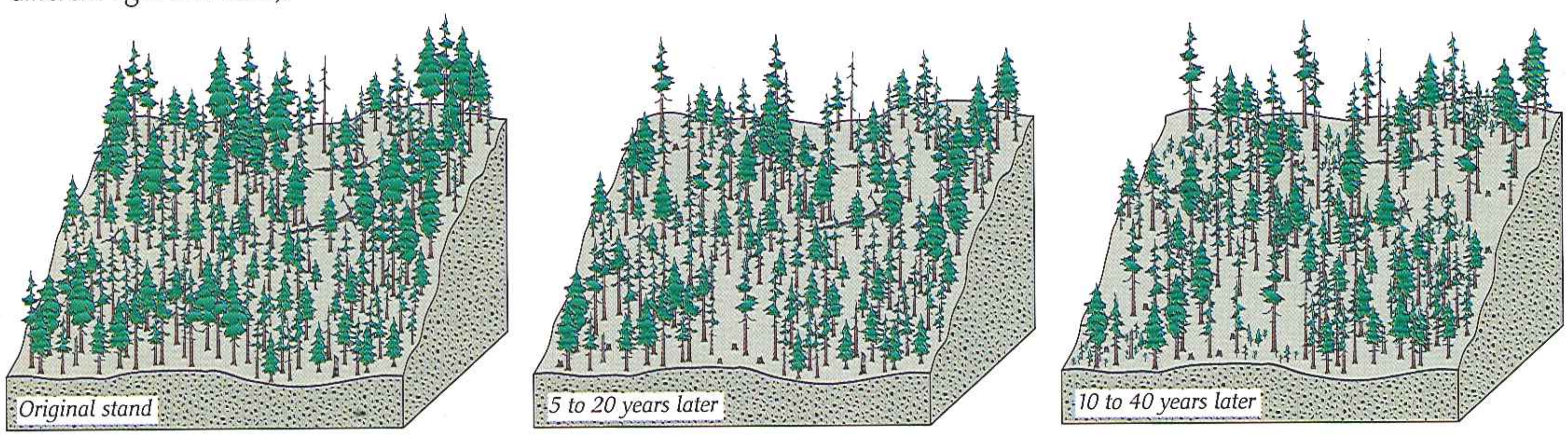
- group selection
- individual tree selection

Neither one of these techniques leads to a clearcut. The goal is to maintain a continuous forest canopy across the landscape.

It is critical to know the type of forest you have before deciding on a silvicultural system. Do **not** assume that one or the other of these traditional silviculture techniques can be used in *any* type of forest or *any* location. For example, in the coastal forest, Douglas-fir regenerates more easily in even-aged versus uneven-aged systems. In interior forests, Douglas-fir regenerates well in uneven-aged mixed conifer forests.



Group Selection: Small groups of trees (up to 1/4 to 1/2 acre in size) are removed in repeated entries (as often as every five years). Trees reoccupy the openings either naturally or by artificial planting. The result is a stand with an uneven-aged structure (tree groupings with different ages and sizes).



Individual Tree Selection: A small number of trees are removed on a regular cycle. Since a significant proportion of these trees are often the oldest trees, they can amount to 15–20 percent of the standing volume. Small forest landowners find individual tree selection attractive because it meets their need for steady income. However, just like group selection, if these openings do not regenerate naturally, landowners are faced with the cost of site preparation, artificial planting and protecting young trees.

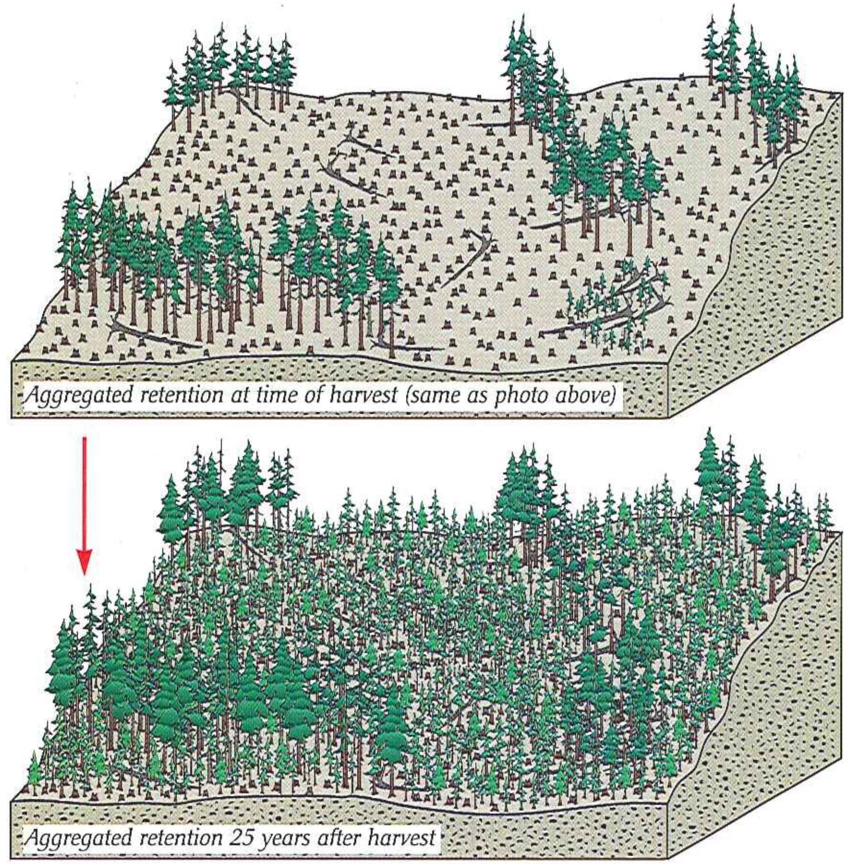
Silviculture using ecosystem science concepts

In contrast to traditional silviculture, ecosystem science calls for the retention of significant amounts of trees, snags and coarse woody debris from the preharvest stand. Especially important are those structures that require a long time to develop or are difficult to create, such as large diameter trees, large diameter snags and partially decayed down logs. That's why this new silvicultural technique is called retention harvesting. It's being tried in coastal Douglas-fir forests. Over time, we'll learn how well it works and whether it can be applied successfully to other forest types.

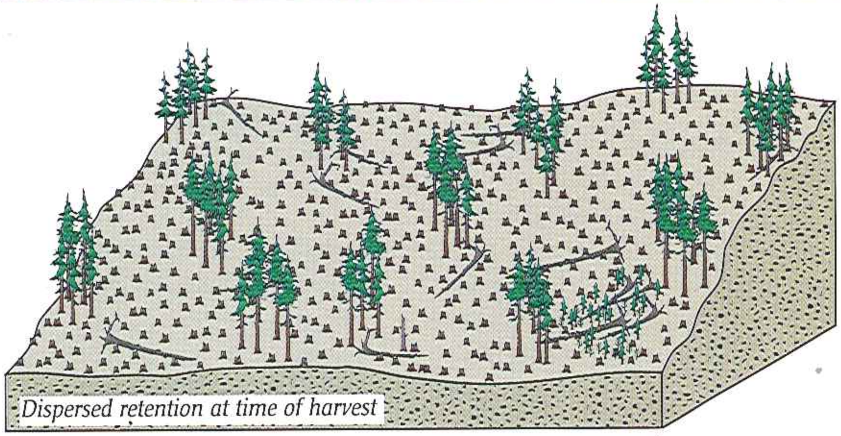
What is retention harvesting?

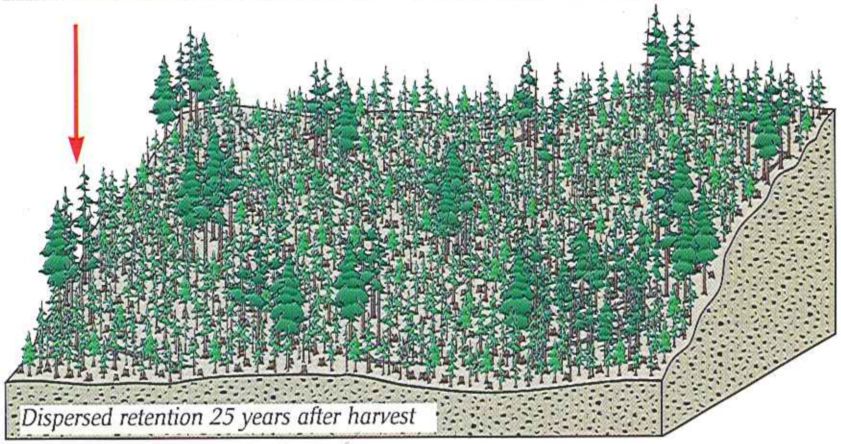
The idea is to retain 15 to 20 percent of the preharvest stand and incorporate some older and bigger trees into the new regenerating stand. The structures left from the preharvest stand may vary in number, size, condition and distribution. They may be ***aggregated*** *(pictured at right)* or ***dispersed*** *(pictured on opposite page)*. In some stands this technique may be partially accomplished by complying with forest laws that require riparian management zones, green tree retention and leaving snags and down logs.

- Retention harvesting allows for the carry-over of biological diversity from the previous stand. This carry-over habitat (i.e. snags for cavity nesters) also provides habitat for lichens, fungi, birds and small mammals while a new forest environment is reestablished.
- Retention harvesting provides the new stand with structures that sustain biological processes. Leaving large rotting trees provides for continued decomposition.
- Retention harvesting provides connections across the landscape (organisms can still migrate across new harvest areas). For example, down logs are movement routes for small mammals like the California redback vole, an animal that spreads important fungal spores in coastal forests. Standing green trees and snags provide movement routes for other wildlife.



This is a photo of the "real" forest portrayed in the four diagrams (right) four years after completion of the retention harvest. There are good reasons for doing it, but only time will tell how well it works. The aggregates contain the ecological parts of the original forest. Even soft snags were retained within the green tree islands. As the new forest grows, the aggregates serve as reservoirs of genetic material. Deer, elk, small mammals and neotropical birds are using them. Side-light will stimulate understory plant growth. There may be some tree mortality, but the retention trees will become more windfirm with time.





The graphic sequence (left) shows how the forest pictured above might look if harvested according to the idea of dispersed retention, in contrast to aggregated retention (opposite page).

Planning a retention harvest

While large green trees, large snags and large down logs are important structures, no one knows the ideal number that should be left per acre. How the structures are left, whether dispersed across the harvest area or aggregated, is also open to opinion. Some scientists advocate dispersed retention of coarse woody debris, saying it's needed throughout the new stand. They also point out that since many snag-using species are territorial, concentrating snags in one location could limit their populations. But there are economic and safety tradeoffs to these arguments. Dispersed retention increases logging costs and creates safety hazards, especially when snags are left standing. For these reasons, green trees are often retained and then converted to snags *(see page 35)*.

Advantages of aggregated over dispersed retention

- Logging costs and safety problems are minimized by keeping these structures (especially snags) in predesignated areas.
- Areas between aggregates are more easily managed as even-age stands which is important for some tree species.
- Keeping pieces of forest intact has value for sustaining the ecosystem. Even though they are small, aggregates can include a range of tree sizes, species and canopy layers.
- The forest floor and understory plants are more likely to remain intact in aggregated retention areas as long as they are not disturbed by harvesting equipment.
- The microclimate in aggregates is more moderate than dispersed retention.
- Even though aggregates do not provide "interior forest conditions" important for some wildlife species, most scientists agree they provide more plant and animal niches than dispersed retention.

Biodiversity–Promoting more structural and biological diversity in an even-aged plantation

1971 - Pasture reforested with genetically improved Douglas-fir seedlings.

1975 - Seedlings are four years old.

1982 - The former pasture, now 11 years old.

1994 - After 23 years, nothing is growing beneath the one-story stand. There is no structural complexity.

1995 - Mechanical thinning leaves the trees with deep crowns and the greatest value.

Across the Northwest, in both interior and coastal forests, there are thousands of acres of dense, young plantations created by clearcutting and planting even-aged monocultures patterned after German forestry *(pages 6-7)*. Other areas have been converted to plantations from fields or second growth forests. The result is a landscape with reduced structural diversity (compared to pre-European settlement conditions).

Some landowners are now asking how to develop more structural and species diversity in their even-aged forests.

This forest in the Oregon Coast Range *(time sequence above)* is one example of how these even-aged forests develop. Formerly an old pasture, this field was in agriculture from the mid 1800s until 1971. Prior to that time the area was burned frequently by Native Americans, and it supported forest or grass-oak habitat for several thousand years before European settlement.

After using herbicides to clear the site of competing vegetation, the landowner planted with genetically improved strains of Douglas-fir in 1971. The landowner's objective was to create an even-aged forest plantation that would produce good quality sawlogs over a 60 year rotation.

By 1975, the young trees were already 10-12 feet tall and beginning to crowd out the understory of ferns and grasses. By 1982, the 11 year old plantation had completely dominated the site, with trees growing 3-4 feet in height each year. By 1994 the trees were crowded, leaving little structural diversity. From a wildlife standpoint, the dense forest provided thermal and hiding cover for a few species of wildlife. At a landscape level, too much of this forest type greatly reduces habitat and biodiversity.

Landowners confronted with this situation commonly thin out the smaller trees to salvage the trees that would eventually die from overcrowding. The idea is to concentrate growth on the most valuable timber trees. While this may achieve a timber objective, landowners desiring to increase structural diversity and biodiversity may want to consider other alternatives. One idea is to create both ***horizontal*** and ***vertical*** spaces in these plantations to speed up the development of structural diversity.

Horizontal spaces can be created by thinning. However, creating evenly spaced trees across the stand (as is commonly done in conventional thinning) may not give the best results.

- Consider using group selection harvesting *(page 37)* to clump the residual trees and create larger horizontal spaces by removing small groups of trees. Although the details of this method are currently being researched, gaps of a half acre or more may be necessary to successfully introduce shade-intolerant species like ponderosa pine or red alder.

Markets are increasingly available for plantation thinnings.

Smaller openings may suffice for more shade tolerant species such as hemlock or grand fir. In coastal Douglas fir, about 50-100 trees per acre may be left after a heavy thinning, but actual numbers must be based on forest type, stand history, landowner objectives and site characteristics.

- Pre-plan the logging system carefully. Minimize the amount of area covered by skid roads. Plan roads so that clumps of trees can be progressively removed over time. On steeper ground be prepared to use sophisticated and expensive cable logging systems.

■ Trees left should be those with potential for high timber or ecological value. They should have rapid growth rates and full crowns. This will ensure their continued growth and windfirmness. Poor quality, limby or defective trees may be left as potential replacement snags in the future forest.

■ Immediately after thinning, plant the gaps with a mix of appropriate species. It may also be necessary to control competing vegetation to ensure the survival and growth of these young trees. In time, the result will be a two-aged stand with a multi-layered canopy.

Vertical spaces can be developed in young plantations by pruning lower limbs. This practice produces knot free, high value wood, normally only available from old-growth forests.

■ You may want to prune to remove a portion of the live tree crown, allowing light to filter down to the forest floor and stimulating growth of understory plants. For optimum results, prune young trees, removing no more than one third of the live crown, and no more than 50 percent of the total height. Older trees can be pruned, but their larger limbs are more expensive to remove and offer less economic incentive.

■ From an economic standpoint, only prune trees that you plan to grow long enough to develop a layer of clear wood. For coastal Douglas-fir, about 100 trees per acre are commonly pruned. This number approximates the maximum tree density that can be maintained in an even-age 60-80 year-old forest. Science has not developed guidelines for how many trees to prune when developing a multi-layered canopy, but this number will likely be less than for even-aged systems. Trees left as future snags or coarse woody debris normally will not be pruned unless they are competing with understory trees.

■ Pruning is generally done during the dormant season. Make cuts close to the tree stem, but avoid scarring of the stem. Cutting can be done using saws, lopping shears, or a variety of specially designed power equipment. Pruning is normally done to a height of 20 feet, but occasionally trees are pruned to 27 feet or more.

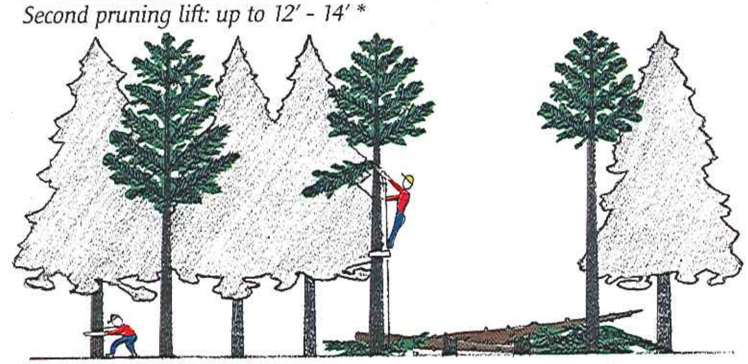
■ Through a combination of pruning and thinning, you can develop vertical and horizontal spaces. At the same time you can retain higher tree densities, while continuing to develop multi-layered stands. This technique allows stands to develop greater structural diversity at younger ages than with conventional even-age thinning regimes.

* *In any pruning lift, remove no more than one third of live crown, and no more than 50 percent of the total height.*

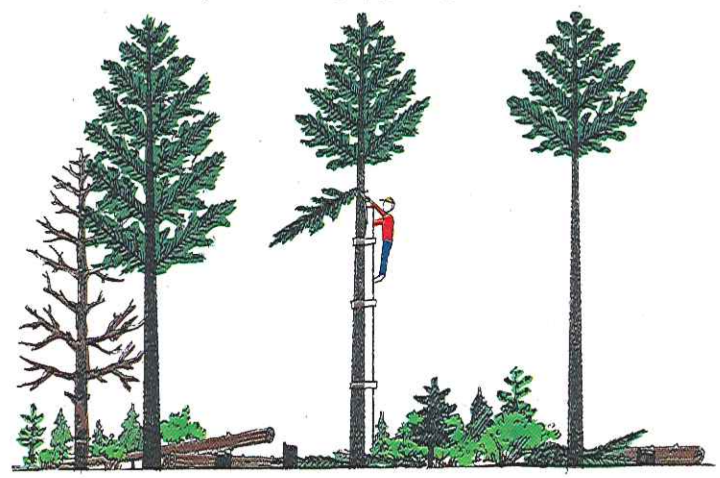
Pruning and thinning to develop structural diversity.

*First pruning: start with 6′ - 8′ tall trees **

*Second pruning lift: up to 12′ - 14′ **



*Third lift: up to 18′ - 20′ * Remove some unpruned trees to create gaps in the stand. Deliberately create a snag by girdling a tree (left side).*



*Possible fourth lift: to 27′+ * Remaining unpruned trees are harvested. Earlier gap is now occupied by new understory canopy.*

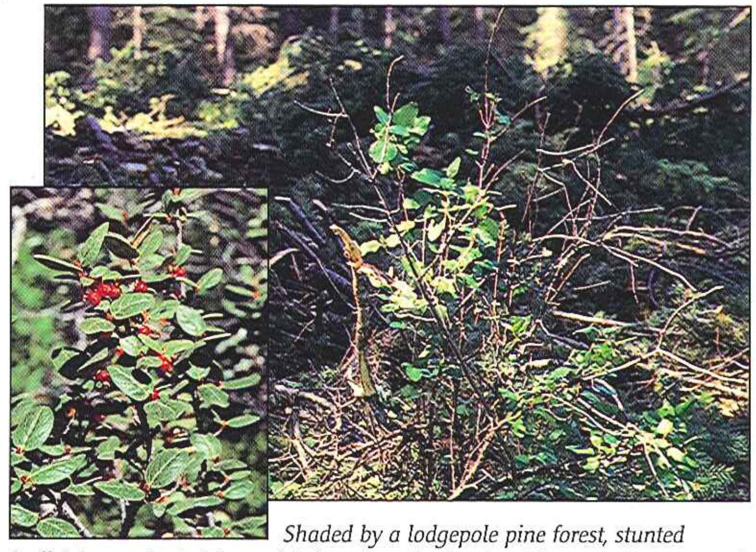
Biodiversity—Creating habitat for threatened and endangered species

Today's society seems to be taken with grizzly bears, spotted owls and salmon, but there are many other creatures and plants affected by habitat loss. Since 1976, an average of 34 species per year have been listed as threatened and endangered in the United States. Over the past eight years, listings have increased to more than 50 per year. In addition to those listed, thousands of other species are "candidates" for protection under the Endangered Species Act.

Rather than managing threatened and endangered plants and animals on a species by species basis, ecosystem science suggests we concentrate on protecting and restoring their habitat.

One example of this approach is buffaloberry shrubfield restoration. Buffaloberry shrubfields provide classic grizzly bear habitat along the eastern front of the Rocky Mountains. The berries are important grizzly food. Bears consume large quantities during the summer and early fall.

Before 1900, recurring wildfires kept the forest from shading out and replacing buffaloberry shrubfields. Today, decades of fire suppression has allowed lodgepole pine forests to replace buffaloberry shrubfields. As a result, grizzlies venture off public lands, onto adjacent private land, attracted by the lure of traditional and nontraditional food including livestock. In an attempt to correct the problem, controlled fire and timber harvesting are being used to restore buffaloberry shrubfields.



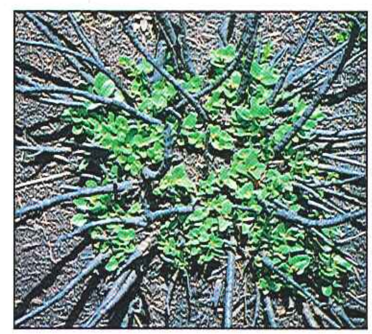
Shaded by a lodgepole pine forest, stunted buffaloberry plants (above right) produce few berries. After overstory removal, buffaloberries are again prolific (inset).

This classic grizzly bear habitat of buffaloberry is being restored by controlled burning and timber harvesting.

A prescribed fire is used to restore buffaloberry habitat. After the fire, the dead trees leave a perfect environment for buffaloberry to thrive.

Buffaloberry restoration using fire

Prescribed fire is one method used to restore buffaloberry shrubfields. In areas where the forest is inaccessible or trees are not saleable, controlled fires mimic the wildfires that were common along the Rocky Mountain Front.



Buffaloberry plants, beneath the fire-killed trees, are adapted to fire and quickly resprout after their tops are burned off. Within a few years the plants recover and produce heavy crops of berries. ▶

Buffaloberry restoration through timber harvesting

When accessible and saleable, lodgepole pine is harvested using a cut-to-length single grip harvester and a forwarder. This innovative equipment is changing the way logging is being done throughout the Northwest. It enables cost-effective harvesting of small tree logs. When the lodgepole forest is removed, the openings allow shade-stunted buffaloberry plants to thrive in the new environment.

▲ 1. The single grip harvester's arm can reach out to a tree 30–40 feet away, cut the tree down, strip the limbs, cut the stem into computer programmed lengths, and lay the logs on the ground, all in less than one minute.

▲ 2. Tree tops and limbs are laid in the machine's travel path, creating a "slash carpet" which cushions the soil.

▲ 3. Following behind the single grip harvester, using the same slash carpet, is the forwarder, which picks up the logs and carries them to waiting trucks.

◀ 4. Forwarders can economically travel long distances (2,500 feet) from existing roads. This can reduce the number of roads needed by two-thirds. Fewer roads are an advantage in grizzly country.

▲ 5. Landings for log storage and sorting are eliminated because the forwarder unloads directly onto log trucks. These specially designed log trucks have fifth wheel pins that allow each individual trailer to track like a log truck for travel along narrow mountain roads. This is important because small logs from small trees are more costly to handle than larger logs.

Disturbance and Response—Reducing insect and disease outbreaks

The Northwest's two most significant foliage feeding insect pests are the Douglas-fir tussock moth and the western spruce budworm. They feed on multi-story forests with shade tolerant species like Douglas-fir, grand fir, spruce and larch. Attacks over repeated years slow tree growth. The tops and sometimes entire trees are killed. Millions of acres can be affected when these insects reach epidemic levels as was true in the central Oregon Cascade Mountains *(pages 10-11)*. But both of these "pest" organisms are an integral part of the forest.

Insect infestations are nature's way of thinning overcrowded forests.

What causes tussock moth and budworm outbreaks is not totally understood. Tussock moth outbreaks have a predictable cycle of two to three years, but spruce budworm has no reliable pattern. Most important is learning what keeps both of these insects at low levels of activity between outbreaks in a forest ecosystem. The answer is the predation process. Knowing and providing for the hunters of tussock moths and budworms can help reduce both the frequency of outbreaks and lower the extent of damage.

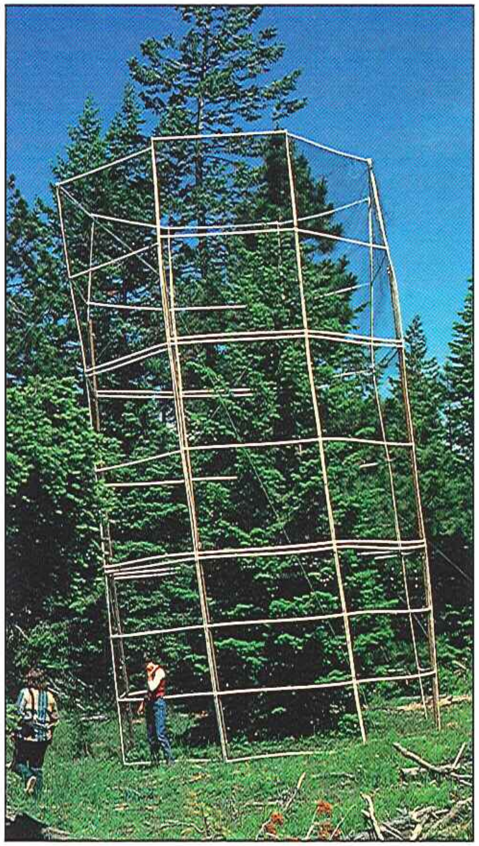
Like any forest pest, there are diseases, parasites and predators that are natural enemies of the tussock moth and budworm. Viruses, bacteria and fungi are known to attack these insects.

Western spruce budworm larva with parasite larva attached.

Certain wasps and flies lay eggs in or on tussock moths and budworms and as the larvae of these parasites grow, the tussock moths and budworms die.

Scientists have also discovered that birds have a dominant influence over these two insects. Experiments in Washington, Oregon, Idaho and Montana compared the effects of birds on these two foliage feeders. We now know that without birds there could be 10 times as many tussock moths on a single tree. Birds and ants combined can reduce spruce budworms on individual trees by 12-19 times.

In addition to birds, at least nine different ant species have been observed preying on budworm pupae. Ants also tear apart tussock moth egg masses and carry off the eggs.



Scientists enclosed trees up to 30 feet tall with netting to keep birds out. Other trees excluded both birds and ants by using sticky barriers at the base to keep ants from climbing. The number of insects on these trees were far greater than trees accessible to bird and ant predators.

Budworm larvae feed inside new buds and old needles in the spring. Then they move to new foliage as it begins growing. They leave silky nests of webbed, chewed needles. Repeated years of feeding can cause branch die-back, top kill and even tree mortality.

Western thatching ants prey on a budworm larva.

Both resident and neo-tropical migratory birds play important roles in controlling insect populations. All in all, a total of 30 bird species are high-potential predators of tussock moths (some are pictured on this page). Two dozen species of birds prey on western spruce budworm. Half of these birds are also confirmed tussock moth predators.

Scientists caution that ants and birds do not ***control*** tussock moth or budworm outbreaks. They simply cannot increase in numbers fast enough to keep up with an outbreaking insect population. Instead, they ***regulate*** the low, non-outbreak levels. They act as control agents, lengthening the stable periods between outbreaks. But the success of their performance is only as good as their living space habitat. How can we conserve and enhance these hunters? By knowing their habitat requirements. Many of these birds nest in grasses and low shrubs, others in tree canopies and under the bark of trees or snags. Some feed on or near the ground, others in the canopy of trees, and still others specialize in capturing flying insects. Ants nest in rotting logs or stumps, both on and under the soil surface. Ant colonies are located near trees where they have access to aphids for their honeydew, and at the same time they prey on other insects.



All of these birds except the Evening grosbeak prey on both the western spruce budworm and the Douglas-fir tussock moth. Evening grosbeaks specialize in feeding on western spruce budworms. Pictured above (l. to r.) are Audubon warbler, Chipping sparrow and Red-breasted nuthatch. Pictured below (l. to r.) are Evening grosbeak, Dark-eyed junco, Western tanager and Pine siskin.




What are some management actions you can take to assist these natural predators as they regulate the levels of insect pests?

- Encourage a variety of appropriate tree species and age-classes across the landscape. For example, harvesting has historically removed ponderosa pine, leaving stands of shade tolerant Douglas-fir, grand fir and spruce. Instead, harvest the shade tolerant fir species. Without their unnatural abundance, the incidence of budworm and other forest pests will be reduced.
- Provide structural diversity appropriate to the forest type. Some forests, especially those with dense multi-story shade tolerant species such as grand fir and spruce are susceptible to spruce budworm. On the other hand, some single-story forests of lodgepole, ponderosa pine and western larch are less susceptible to budworm.
- Create greater amounts of snags and coarse woody debris. Large diameter logs, stumps and snags provide nesting habitat for ants and birds. Forests without this woody debris are more susceptible to insect outbreaks.
- When using heavy equipment, be aware of established ant colonies and work around them. Colonies can last 20 or more years and house populations of 30,000 or more ants.
- Protect riparian areas. Streamside and pond habitat is extremely valuable. It improves bird nesting success. Regulate livestock grazing in these fragile areas to minimize their impact.
- Use herbicides selectively around the shrubs, grasses and forbes that these bird and ant predators depend on.
- Be aware that insecticides affect beneficial insects and spiders along with target pests.

Mountain chickadee with western spruce budworm larva. This is one of the primary year-round birds that prey on budworm and Douglas-fir tussock moth.

Disturbance and Response–Reducing catastrophic fire

Northwest forests have been shaped by fire. Lightning-caused fires along with fires set by Native Americans and early settlers have swept across this region for hundreds of years. Scientists believe that these forests cannot be sustained without the ecological benefits of fire.

Interior forest fire history

Prior to 1900, fire occurred in low and mid-elevation interior ponderosa pine, larch and Douglas-fir forests as often as every 5 to 30 years. These forests developed a tolerance to repeated fire. The frequent fires cleared out the smaller shade tolerant Douglas-fir, grand fir, white fir and spruce at regular intervals, leaving rather open stands with occasional fir trees. These fires crept through the forest without damaging the large fire resistant ponderosa pine and Western larch. Forest health problems have been traced to the removal of fire from the interior forest ecosystem. The result is forests that have changed from pine to fir; from open park-like stands to dense thickets. In some cases, fir thickets have moved in under large ponderosa pine, larch and Douglas-fir, forming a continuous fuel ladder that reaches from the ground into the canopy. This often guarantees that any fire will turn into a lethal crown fire.

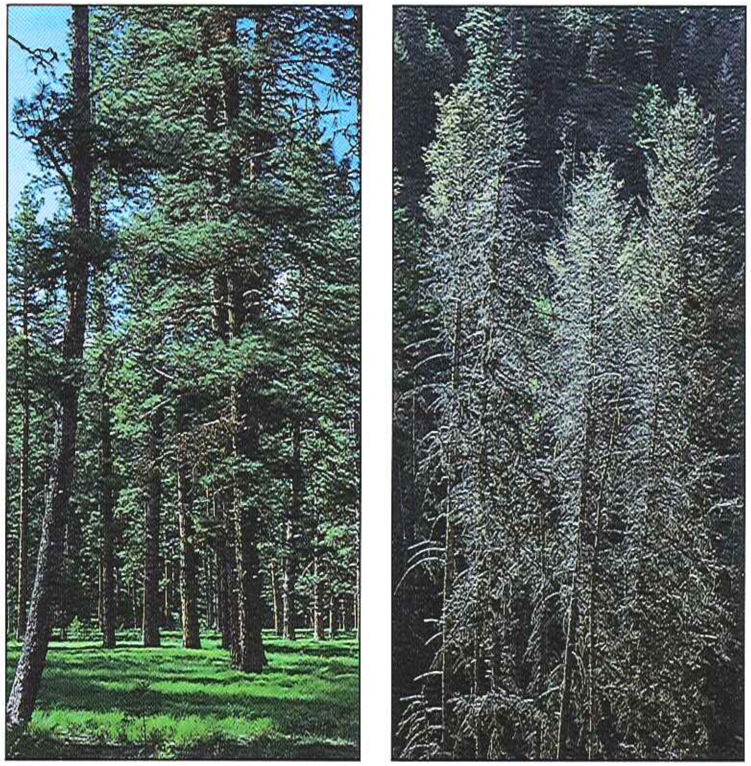
This changed interior forest has been ideal for the foliage feeding spruce budworm *(page 44)*, along with other tree pests like the Douglas-fir tussock moth, bark beetles, dwarf mistletoe and root diseases. These pests have enjoyed a steady diet of stressed fir trees. The result has been dead and dying trees, fuel buildup and high-intensity wildfires.

Coastal forest fire history

In contrast to interior forests with their historically frequent forest fires, coastal forests (Douglas-fir, cedar and hemlock) and high elevation interior forests (lodgepole pine) evolved with a far different fire frequency. Because of the moist environments of coastal forests, fires occurred naturally every 150-250 years. The years of accumulated dead and down fuel naturally carried these fires to catastrophic proportions. These forests are adapted to starting over from blackened soil and the seed from surviving ridgetop and riparian seedtrees or, on some sites, the fire-heated cones of lodgepole or knobcone pines. There is a dilemma for coastal forest landowners: trying to avoid catastrophic fire while at the same time providing coarse woody debris. High amounts, tinder dry in late summer, may be too large a risk. However, improved fire prevention and control measures that include roads, forest closures and quick response equipment, along with harvest slash burning, may reduce fire risk. Planting buffers of fire resistant hardwoods like red alder between conifer stands may also help.

Strategies for reducing fire in interior forests

We now understand more about the role of fire and the contrast between interior ponderosa forests versus high elevation interior and Douglas-fir dominated coastal forests. Ecosystem

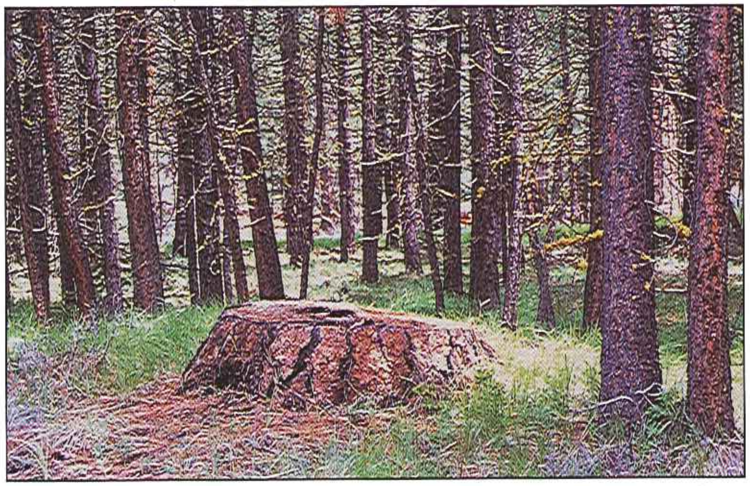


Fire suppression and extensive harvesting of large, overstory pine and larch have shifted interior forests from open stands (left) to an unnaturally dense understory of Douglas-fir, grand fir, or white fir and spruce which can become vulnerable to high-intensity fire.

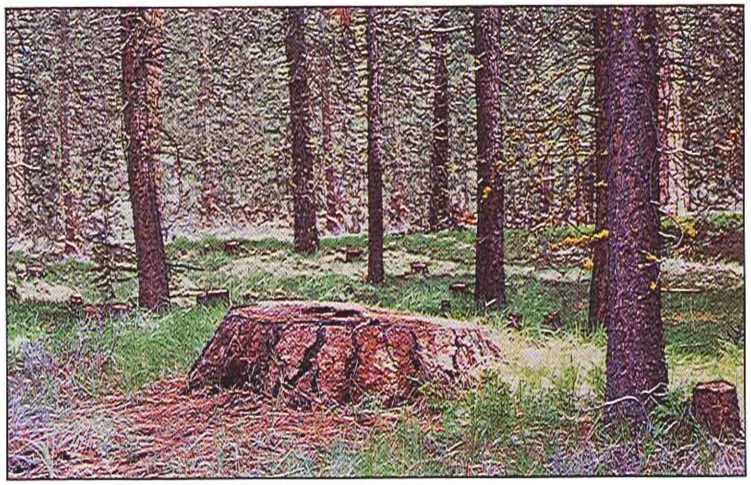
science has suggestions for limiting fire in interior forests. Ponderosa pine, western larch and Douglas-fir forests can be restored to their earlier, more fire hardy condition. However, the solution will not be easy and will involve the following two part process.

1. Reduce the density of fir species in these forests.

Harvesting the shade tolerant fir species will reduce the ladder fuels that result in crown fires. Without the unnatural abundance of Douglas-fir, grand fir, white fir and spruce, the incidence of catastrophic fire will be reduced. At the same time, harvesting must retain larch and ponderosa pine in the overstory as a seed source for future regeneration. If ponderosa and larch numbers are inadequate, they may have to be planted.



Before thinning. The ponderosa pine stump in the foreground is an indication of the once open park-like forest now choked with a dense thicket of trees.



After thinning. Stand density has been reduced and now must be maintained for the long-term health of the forest.

2. Maintain these forests over the long term at lower tree densities. Achieve a more open overstory of ponderosa pine and larch. Once the initial harvesting is complete, this second phase is intended to maintain the forests at far lower tree densities to achieve a more open overstory. Occasional clumps of trees and understory thickets can be scattered throughout the ponderosa and larch forest, but grasses should be the dominant understory plant. The increase in grasses and other forage plants should be maintained with prescribed underburning, done on a repeated cycle to mimic historic intervals. The purpose of prescribed fire is to reduce fire-hazard. Prescribed fires are done on designated areas under specific weather, soil moisture, and time of day limitations. This combination of harvesting and prescribed fire will achieve the fire resistant landscape of the ponderosa pine and western larch forest.

Using prescribed fire isn't easy because of the decades-long buildup of both fallen limbs and dead trees, and ladder fuels (sapling and pole size trees that carry ground fire up into the crowns of taller trees). Where large quantities of these fuels are present, salvage logging will be needed to remove these accumulations.

When large quantities of coarse woody debris cannot be removed mechanically, the use of two or three prescribed fires, over many years, can gradually reduce the accumulations.

Prescribed fire workers, with drip torches, lay strips of fire to keep flame lengths at heights of two feet or less. They avoid burning large logs because they provide wildlife habitat.

Although smoke is an unwanted by-product of this technique, careful burning can control smoke levels and minimize negative human health effects. Prescribed fire can clean up years of accumulated fuel without harming mature ponderosa pine and larch.

Actions that may reduce your losses to wildfire:

- Manage your forest density through tree thinning.
- Practice selective harvesting, if appropriate, but remember that adequate light from openings in the forest canopy will be necessary for the regeneration of preferred species.
- Reduce the density of shade tolerant species that create ladder fuels.
- Encourage alder or other hardwoods as natural fuel breaks where appropriate.
- Remember that open pasture or rangeland can stop or slow forest fires.
- Gradually move your forest to older trees that are more resistant to fire.
- Branch pruning can be used to reduce ladder fuels.
- Consider using prescribed fire for fuel management, but be aware of the risk of escaping fire.

Linkages—Establishing forest linkages at two different scales

On a small scale:

While small forest properties can support a number of plant and animal species, when linked together they can promote biodiversity on an even larger scale. Small properties often serve as connection points, linking parts of the landscape and allowing movement of organisms. Most people think of wetlands, streams and other forest habitats as linkages for the "flow" of plants and animals from one part of the landscape to another, but forest stands on smaller properties are also linkages.

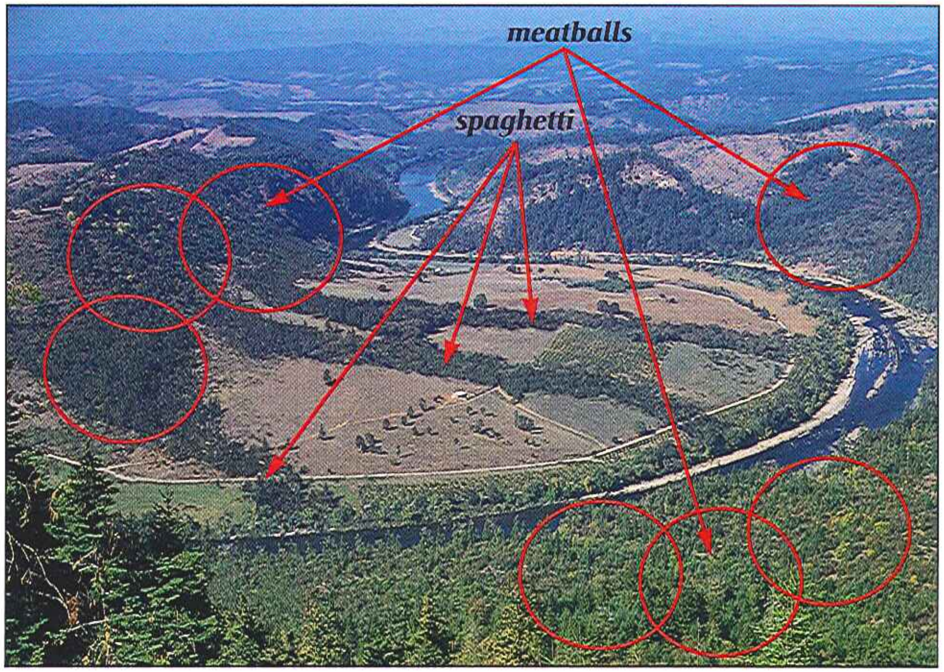
Think of forest linkages as spaghetti and meatballs. The large tracts of forest cover are the meatballs of the landscape, the linkages connecting the larger tracts of forest are the spaghetti. Management actions that break the linkages into even shorter segments, cut off and isolate the large tracts of forest. A concept of ecosystem science is to maintain linkages across the forest landscape for plants and animals.

On the forest stand level, individual landowners are able to maintain connectivity. Knowing that even-age silviculture tends to produce stands that are low in structural diversity, consider using uneven-aged silviculture. If even-age silviculture meets your land management goals, retention harvesting *(pages 38-39)* where snags, down logs, green trees, and small patches of unthinned trees are left, will help to ensure connection linkages.

If you own unique habitats in the watershed, such as older forests, seeps, springs, ponds and marshes, ask yourself the following questions:

- Does my property contain corridors that connect one habitat with another?
- Can these habitats be managed to maintain or increase their occurrence in the watershed?
- Can I manage my property in a way that reduces the breakup of important connection points.
- Is mine the only stand of older forest left in the watershed? If so, would I consider deferring harvest until other portions of the watershed mature?

The open agricultural land provides no linkages (spaghetti) between the forest land (meatballs) and the river.

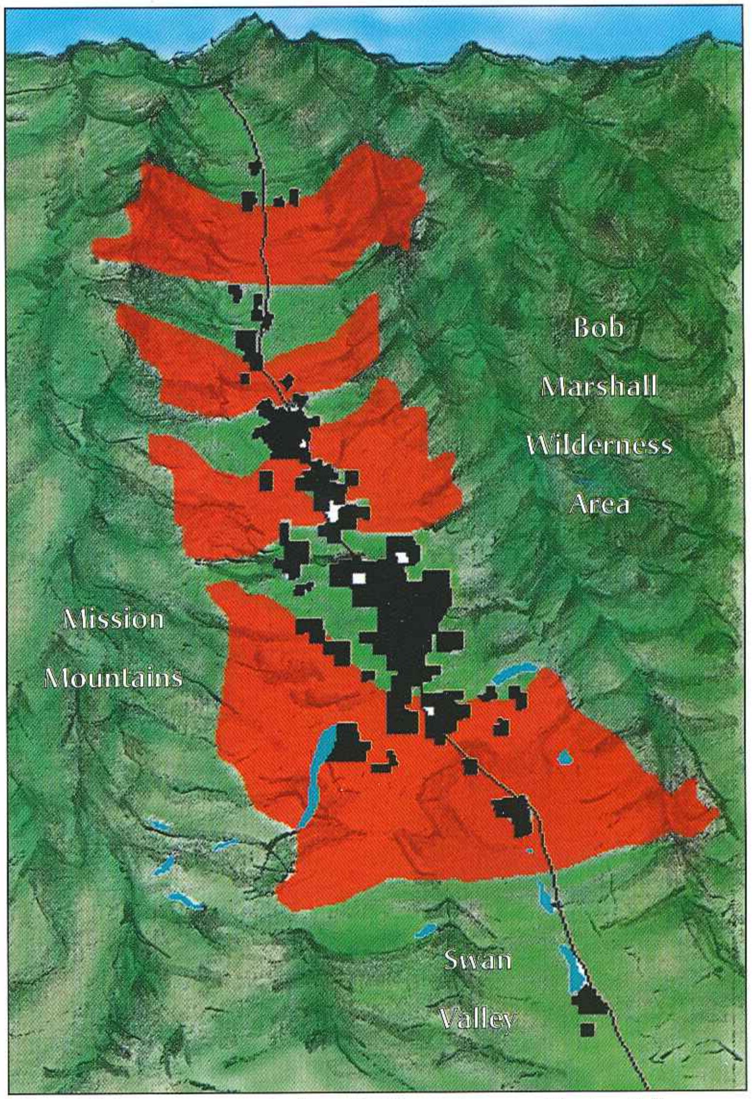


Widening the riparian area along the river and connecting existing strips of forest cover give wildlife access across this forest property to the river.

On a large scale:

Habitat fragmentation can be caused by subdivisions, industrial development, buildings, roads, railroads and timber harvesting. Fragmentation occurs when development expands across a valley, cutting off safe travel routes for wildlife. One effort to manage this problem is being attempted in western Montana's Swan Valley. A group consisting of private citizens, federal, state and county government, and timberland owners have recently developed a plan for maintaining wildlife linkage zones. The Swan Valley separates the Mission Mountains from the Bob Marshall Wilderness Area. Grizzly bears, elk and other wildlife move between these wilderness areas in search of food and security. Without adequate territory, food and access to breeding partners, the survival of these wildlife populations is questionable.

Of the 329,000 valley acres, 33,000 are held by private landowners, the rest by the forest industry and government agencies. The plan provides guidelines for how residents can voluntarily protect private lands–especially those within the four remaining linkage zones–from development that could jeopardize opportunities for wildlife *(see diagram below)*. The Swan Valley linkage zones are areas of low human use that provide visual cover for wildlife movement, food resources and proximity to other usable habitats.



The red linkage zones are the "spaghetti" strands across Montana's Swan Valley connecting the "meatballs" of the Mission Mountains with the Bob Marshall Wilderness Area. The black areas in the valley represent private property (not including forest industry).

Guidelines for the Swan Valley Linkage Zones

Voluntary subdivision and land development guidelines recommend:

- No more than one dwelling per 40 acres within linkage zones.
- Landowners should consider conservation easements that legally preserve a piece of land and its natural amenities forever.
- Landowners and residents should be aware of problems associated with wildlife attractants (garbage, livestock and pet foods, and raising vulnerable livestock such as pigs, chickens and bees).

Voluntary livestock grazing guidelines recommend:

- No cattle turnout before June 1.
- No new grazing allotments on public and corporate land.
- No increase in current livestock numbers.

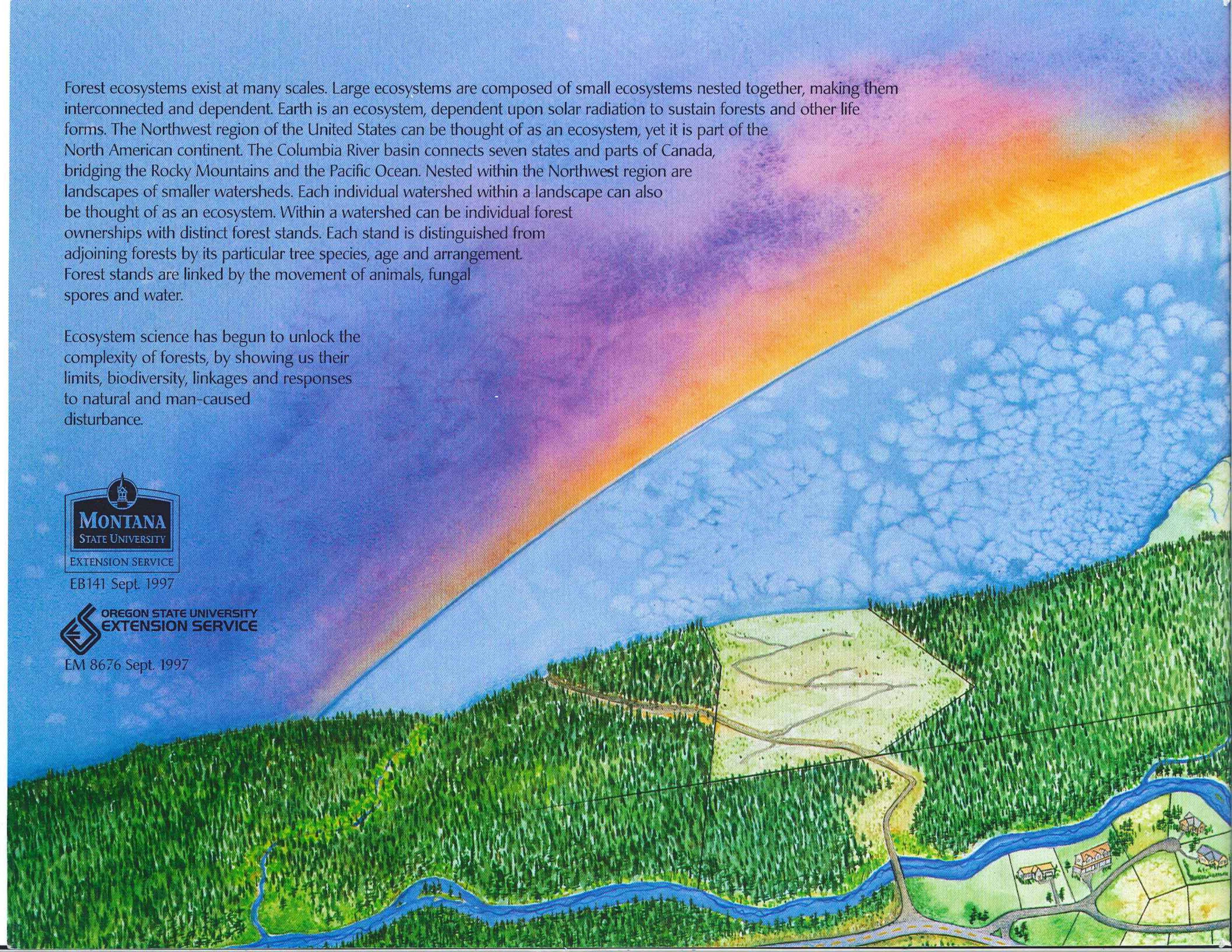
Voluntary forest management guidelines on private, non corporate lands recommend:

- Opening forest roads only when necessary–otherwise closed or limited use.
- Limiting or eliminating motorized activities such as logging from April 1–June 15.
- Maintaining hiding-cover for grizzly bears and other species with a visual screen of vegetation.
- Retaining hiding cover in wetlands.
- Harvesting trees in winter when bears are denning.

Success of the plan will be measured in future years by reviewing county plat maps and other information to learn the extent of change in the linkage zones. This will indicate how growth and development have affected their shape, size, habitat security and effectiveness. Wildlife populations will also be monitored.

Forest ecosystems exist at many scales. Large ecosystems are composed of small ecosystems nested together, making them interconnected and dependent. Earth is an ecosystem, dependent upon solar radiation to sustain forests and other life forms. The Northwest region of the United States can be thought of as an ecosystem, yet it is part of the North American continent. The Columbia River basin connects seven states and parts of Canada, bridging the Rocky Mountains and the Pacific Ocean. Nested within the Northwest region are landscapes of smaller watersheds. Each individual watershed within a landscape can also be thought of as an ecosystem. Within a watershed can be individual forest ownerships with distinct forest stands. Each stand is distinguished from adjoining forests by its particular tree species, age and arrangement. Forest stands are linked by the movement of animals, fungal spores and water.

Ecosystem science has begun to unlock the complexity of forests, by showing us their limits, biodiversity, linkages and responses to natural and man-caused disturbance.



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