OLD GROWTH FORESTS: A BALANCED PERSPECTIVE

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OLD GROWTH FORESTS IN THE PACIFIC NORTHWEST: AN ECOLOGICAL VIEW*

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When settlers arrived in the Pacific Northwest 150 years ago, they found a vast region densely clad with virgin forests of large evergreen trees, the majority of them 200 to more than 1,000 years old. Initially these forests were considered inexhaustible and an impediment to settlement. They were slashed and burned to make way for farms and towns. The forests quickly came to be viewed as a major natural resource, however, and timber cutting became the economic mainstay of the region. In the last century the center of the industry has shifted from Puget Sound to southwestern Oregon as accessible virgin forests have been cutover.

Virgin old-growth forests are still common in the mountains of the Pacific Northwest but their extent is shrinking rapidly. Most of the remaining old-growth forests are on Federal lands, particularly lands managed by the U.S. Department of Agriculture Forest Service and U.S. Department of Interior Bureau of Land Management. Substantial acreages of old-growth forest have been preserved in National Parks, Wilderness, Research Natural Areas, and other reserves. Nonetheless, disposition of the remaining old-growth stands on public lands is highly controversial. There are strongly held opinions on such questions as whether additional old-growth forest should be reserved, for what purposes and where, and whether liquidation of this resource should be accelerated. How are other resource values, such as specific birds or mammals, affected by cutting the old growth?

This paper is an introduction to the ecological characteristics of old-growth forests in the Pacific Northwest. Old growth is contrasted with other forest stages (e.g., young forests) whenever possible, although information for such comparisons is often surprisingly limited. Comprehensive ecological knowledge is limited for all successional stages, including old growth. Douglas-fir (*Pseudotsuga menziesii*) forests are the major focus, although the principles outlined are broadly applicable to forests in the region, as will be pointed out. Much of the information has been generated by Forest Service and university scientists working at the H. J. Andrews Experimental Forest located on the Willamette National Forest but other sites have been extensively utilized including locations in the Cascade Range from Mount Rainier to northern California, in the Coast Ranges of Oregon, and in the Olympic Mountains. My purpose is to provide factual information for use in forming opinions and making decisions on this important resource issue.

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* Prepared paper (copy prepared in the U.S. Forest Service Forestry Services Lab, Corvallis, Oregon).

Old Growth is One Stage In Forest Succession

Forests are dynamic. They change constantly in form and content--on time scales from milliseconds to millenia. The dominant long-term pattern of change is "succession"; it generally begins when a fire, windstorm, or other disturbance destroys the existing forest. A new forest is initiated which progresses through a sequence of forest stages. For Douglas-fir forests a convenient set of stages is:

Stage	Typical duration under natural conditions
Herb and shrub	30 years
Young forest	30 to 100 years
Mature forest	100 to 200 years
Old-growth forest	200 to 800 years
Climax forest	over 800 years

Transitions from one stage to another occur gradually. Stages also vary widely in duration so the time scale indicated above is arbitrary. A much more elaborate breakdown of stages is, of course, possible; e.g., old-growth forests change quite a bit over 600 years.

Old-growth forests are the developmental stage between mature and climax forests. If left undisturbed, old-growth forests will evolve into climax forests; but a major disturbance can destroy the old-growth forest and return the site to the herb and shrub stage. The destroyed old-growth forest is strongly linked in this case to the regenerating forest, because huge amounts of dead wood are carried over from one stage to the other. Natural disturbances, such as fire and windthrow, kill trees but rarely consume much of the wood. In natural successional sequences, the old-growth stand also influences the young forest in other ways such as by providing the seed source.

Each forest stage has distinctive and positive attributes and functions. The herb and shrub-dominated periods that follow a major disturbance, such as fire or clearcutting, are typically richest in species of higher plants and animals. Many species survive the disturbance and many other species invade rapidly in response to the open environment and, in the case of animals, abundance of food. The young forest is the period of rapid tree growth in which annual additions of wood are greatest. Old-growth forests yield water of superior quality because few nutrients find their way through the soil into groundwater and levels of erosion are low.

It is important to differentiate old-growth and climax forests because they are not equivalent concepts as commonly used. Classic old-growth forests in the Pacific Northwest are usually characterized by species such as Douglas-fir, noble fir (*Abies procera*) (at high elevations), and Sitka spruce (*Picea sitchensis*) (on the coast). These species generally cannot establish themselves in a typical shaded forest but by virtue of growth habit and long life persist as awesome specimens for many centuries. They are sometimes referred to as "pioneers." Shade-tolerant tree species, such as western hemlock (*Tsuga heterophylla*) and Pacific silver fir (Abies amabilis), do establish themselves under the forest canopies and eventually grow to occupy canopy space vacated as Douglas-fir or other shade intolerant species die. A typical forest site in the Douglas-fir region, if left undisturbed long enough, would eventually be occupied by an uneven-aged and -structured stand of a shade tolerant species, the most common example being western hemlock. This is referred to as a climax stand because the hemlock can theoretically perpetuate itself unless catastrophically eliminated. Hemlock and Pacific silver fir do not attain the stature of the pioneer species. Hence, the climax forest is reduced in stature and often not as rich in tree species, relative to typical old-growth forests, as a consequence of the loss of the pioneer tree species.[1]

Climax forests can be thought of as a special kind of old growth in which pioneer species are absent. The pioneers may have been gradually eliminated over centuries or, perhaps, they were never present: many western hemlock forests along the Pacific Coast reproduce directly following a disturbance. Most commonly, Douglas-fir is present in the young forests in this region, however, and characteristic of the old-growth stands around which the management controversy swirls.

The fact that Douglas-fir is not climax is not a major cause for concern in attempts to preserve old-growth forest, however, certainly not for many centuries! The persistence of Douglas-fir is illustrated at Mount Rainier National Park. Based on investigations made there, over one-third of the plots taken in stands 1000 years in age or more still contained live Douglas-fir. Many of these veterans were in remarkably vigorous condition and persisted until killed by a catastrophic agent such as lightning. Since old-growth forests in Oregon are typically 250 to 500 years old, elimination of the old-growth Douglas-firs is not imminent.

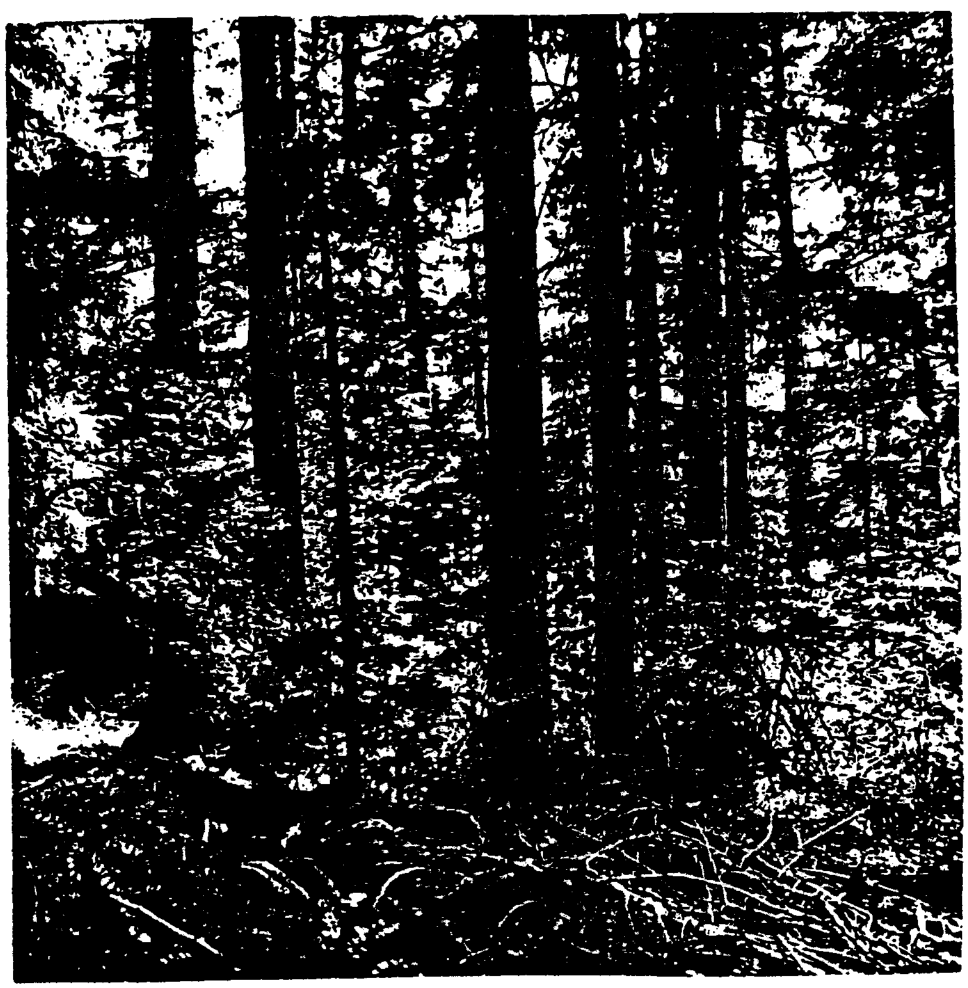
Old-Growth Is As A Complete Ecosystem

An old-growth forest, or any forest, is a very complex system of interlinked organisms and structures with various environmental controls. There is a tendency to focus on individual old-growth components, such as the Douglas-fir trees or northern spotted owls (Strix occidentalis). But it is impossible to really isolate such components; they have too many critical linkages to other parts of the ecosystem; our recent experiences lead us to suspect that most of these linkages are still unrecognized.

1/There are many exceptions to these generalizations. On many forest sites so-called pioneer species, such as Douglas-fir, can reproduce themselves within a forest setting. Warm, dry sites along the margins of the Willamette Valley are an example. Coast redwood (Sequoia sempervirens) is the ultimate example of a large, long-lived species that reproduces following disturbance but also can reproduce sufficiently in forest shade to perpetuate itself indefinitely. Redwood forest is an example, therefore, of a climax forest which is not reduced in stature.

Some general attributes of old-growth forests are immediately apparent to an observer with even a moderate background in natural history (figure 1). Trees typically vary in species and size; some specimens are truly impressive. Trees also vary in color and texture. A multi-layered canopy produces a heavily filtered light, and the feeling of shade is accentuated on clear days by shafts of sunlight and sunflecks on the forest floor. The understory of shrubs, herbs, and small trees is usually moderate, varied in species, and almost always patchy in distribution and abundance. Numerous logs, often large and in various stages of decay, litter the forest floor, creating some travel routes for wildlife and blocking others. Snags are common but often unobtrusive to the casual visitor. The forest is quiet. Few birds or mammals can be heard, except perhaps the melody of a winter wren (*Troglodytes troglodytes*) or the scolding of a chickaree (*Tamiasciurus douglasi*). Small to moderate size streams flowing through old-growth forests are shielded from the sun by canopies of adjacent trees. The small and even intermediate-sized streams may have heavy loads of organic debris. Clear, cool water runs through gravel beds behind old log dams and spills into plunge pools. Leaves, needles, twigs, and other organic debris float on the water surface and accumulate in backwaters.

FIGURE 1



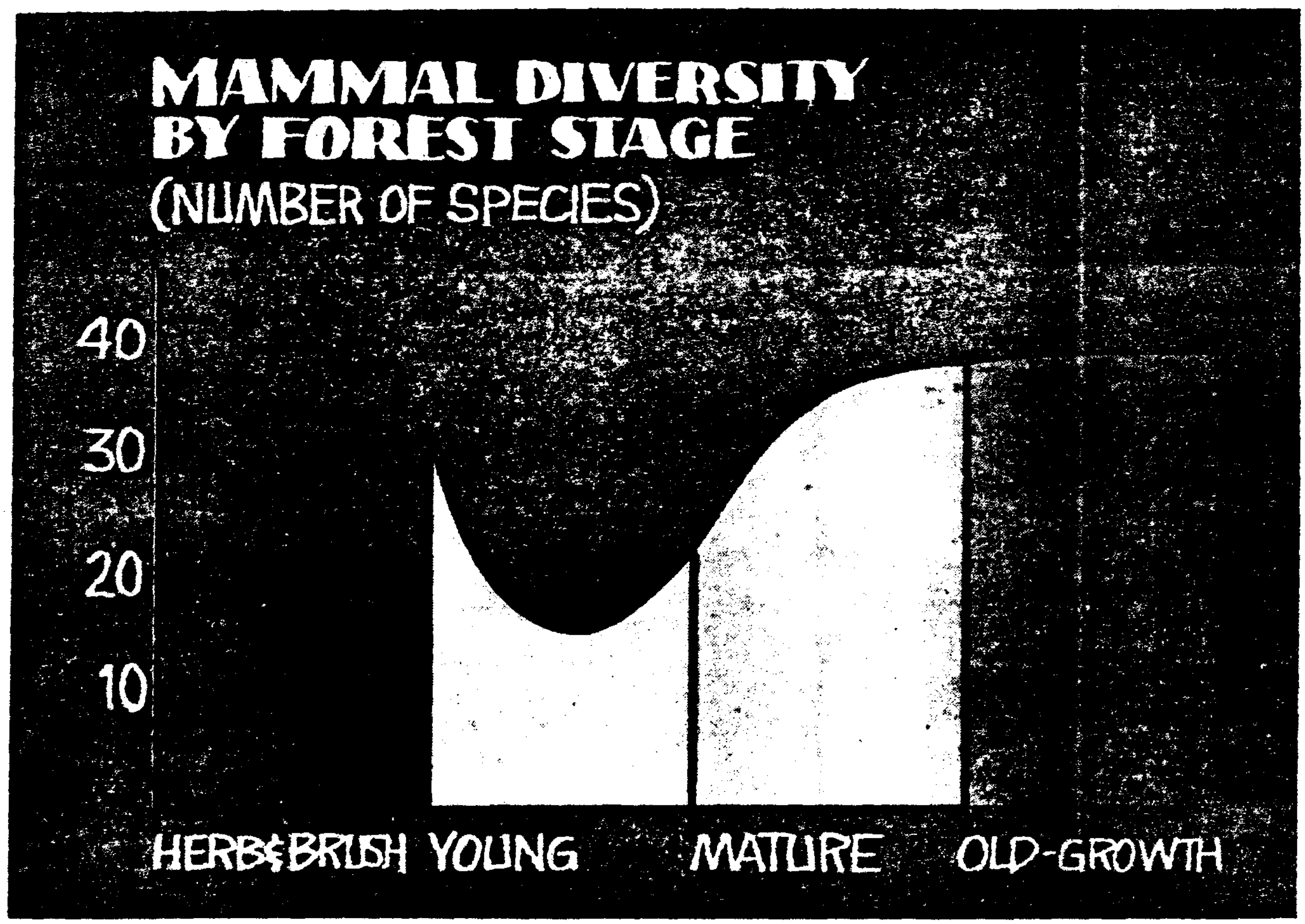
These impressions represent distinctive, important aspects of old-growth forest ecosystems. These aspects are discussed under the headings of organisms (or composition), function, and structural elements which prove to be the major unifying characteristics, as will be seen, and provide for many of the compositional and functional features peculiar to old-growth forests.

Many Organisms Are Found In Old-Growth Forests

Old-growth forests are habitat for an array of plants and animals, some of them strongly associated with this environment. We sometimes use the term composition to refer to the collection of organisms or species found in a forest and diversity to indicate species richness. High diversity indicates that there are many species present.

Old-growth forests in the Pacific Northwest are generally intermediate in species diversity relative to other stages of forest development. The herb and shrub stage is typically the most diverse of the successional stages and young forests are the least diverse. This can be illustrated with mammals (figure 2) but also appears to apply to many other groups of plants and animals.

FIGURE 2



Higher (flowering) plant species determine much of the character of the old-growth forest. There is typically a mixture of three or more tree species including both pioneer (e.g., Douglas-fir) and climax (western hemlock) types. Sizes, colors, and textures of tree trunks are varied as a consequence. None of the higher plants found in old-growth appears to be confined to that successional stage although some plants (such as those that lack chlorophyll but are associated with fungi) may find optimum conditions there. There are also a number of lower plants (mosses and lichens) that are found primarily in old-growth forests. The diminuitive nature of these plants should not mislead us. For example, Lobaria oregana, a lichen that grows in old-growth tree canopies, plays an important ecological role by fixing nitrogen.

Old-growth forests are used as habitat by many species of birds and mammals. The diversity of vertebrate animals is intermediate in old-growth forests (figure 2). Seven birds and nine mammals apparently find optimum habitat in old-growth (Franklin et al 1980) including the northern spotted owl (table 1). Old-growth forest could be essential to the survival of at least some of these species, but this and related questions are unresolved.

Table 1--Vertebrate animals that find optimum habitat for foraging or nesting or both in old-growth Douglas-fir-western hemlock forest ecosystems[1/]

Group	Common name	Scientific name
Birds	Goshawk	Accipiter gentilis
	Northern spotted owl	Strix occidentalis
	Vaux's swift	Chaetura vauxi
	Pileated woodpecker	Dryocopus pileatus
	Hammond's flycatcher	Empidonax hammondii
	Pine grosbeak	Pinicola enucleator
	Townsend's warbler	Dendroica townsendi
Canopy	Silver-haired bat	Lasionycteris noctivagans
	Long-eared myotis	Myotis evotis
	Long-legged myotis	Myotis volans
	Hoary bat	Lasiurus cinereus
	Red tree vole	Arborimus longicaudus
	Northern flying squirrel	Glaucomys sabrinus
Ground mammals	California red-backed vole	Clethrionomys californicus
	Coast mole	Scapanus orarius
	Marten	Martes americana

1/On the Olympic Peninsula, fisher (Martes pennanti) exists only in old-growth forests and should be added to this list for at least the peninsula. Habitat changes caused by cutting rather than trapping, are probably responsible for eliminating this species from other sites. (Personal communication from Bruce Moorhead, Research Biologist, Olympic National Park, May 16, 1978.)

Old-growth forests are also gene pools for many widespread and important organisms. Genetically, the common plants and animals found in old growth are essentially present as they have evolved--without human intervention. Douglas-fir is an example. A natural gene pool is represented in the old-growth and other natural stands. The Douglas-firs that are being planted represent a different gene pool, one that has gone through at least a passive selection process different from that encountered in nature (e.g., seedlings grown under nursery conditions). Increasingly, planted Douglas-firs are the result of active genetic selection as part of tree improvement programs. Old-growth forests are, therefore, a potentially useful reservoir of genetic raw material.

Old-Growth Forests Have Functional Characteristics

Function is the work the forest ecosystem does and how rapidly it does it. Functions discussed in this section include productivity (capture, storage, and utilization of the sun's energy), nutrient conservation and cycling, and hydrologic cycling.

Biomass Accumulations and Productivity

The forests of the Pacific Northwest are noted for their productivity--the rate at which they photosynthetically capture the sun's energy and convert it to wood and other organic matter. This organic matter is often referred to as biomass. In northwestern forests massive amounts of biomass (predominantly wood) accumulate as a result of large long-lived tree species such as Douglas-fir and western redcedar (*Thuja plicata*).[2]

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[2] The reader should carefully distinguish between biomass production, which is often considered on an annual basis, and biomass accumulations or yields, which are the collective result of production over many years or even centuries. Obviously, sites of moderate or even low productivity can accumulate large amounts of biomass given sufficient time and low losses because of death or decay. Similarly, highly productive sites may have relatively low accumulations if the trees making up the forest never achieve large sizes before dying. An example of the first situation are old-growth mountain hemlock (*Tsuga mertensiana*) forests along the crest of the Cascade Range. Red alder (*Alnus rubra*) stands in the Coast Ranges are often examples of the second situation.

It is the very large accumulations of biomass in Northwest old-growth forests that makes them such a valuable resource.[3] Typical values for old-growth Douglas-fir--western hemlock forests in the Cascade Range are 225 to 400 tons/acre with maximal values of 535 to 625 tons/acre. Record stands of Douglas-fir and of noble fir run even higher but all of these are overshadowed by coast redwood forests with biomass accumulations of up to 1,547 tons/acre. Comparable accumulations of biomass occur in few other locations in the world (Franklin and Waring 1980). The average value of biomass in Northwest forests is two to three times greater than average world values of 109 and 142 tons/acre reported for temperate deciduous (hardwood) and tropical rain forests, respectively.

Merchantable wood accumulations in old-growth forests track biomass very closely and net volumes (after deducting defect and breakage from falling) typically run 75,000 to 100,000 board feet per acre (fbm/acre) in good quality old-growth Douglas-fir stands. Yields in excess of 150,000 fbm/acre are not unusual in localized areas, and record groves attain volumes of 350,000 fbm/acre.

Contrary to popular belief, annual productivity is very high in old-growth forests . The massive leaf areas in these forests are optimally displayed to capture the sun's rays and represent a huge photosynthetic factory. Much of this production, often referred to as gross or total production, must be used to maintain the huge standing crop, that is, to "pay" the cost of respiration. It takes energy to maintain living matter, and the larger the accumulation of matter the more energy required for respiration. Hence, relatively small amounts of the gross production are used to produce additional biomass. Nevertheless, substantial amounts of wood production do occur in old-growth forests and typically offset losses to mortality and decay.

Accumulations of live organic matter generally stabilize in old-growth forests as a consequence of the balance between photosynthesis and respiration, growth and mortality (figure 3). Gains tend to offset losses. Two long-term growth studies of old-growth forests are illustrative (table 2). The substantial tree growth recorded in these stands was sufficient to replace trees lost to mortality, which was very high during the period of study because of bark beetle epidemics. There is, of course, some gradual shifting in the wood volume from more valuable Douglas-fir to western hemlock. The general principle of stability in old-growth stand volumes has been known in Northwest forests for decades, however; foresters have often referred to "storing wood on the stump" in talking about old-growth stands.

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[3] All values given are for live aboveground biomass. Live belowground biomass is typically 18 to 20 percent of the total live biomass.

FIGURE 3

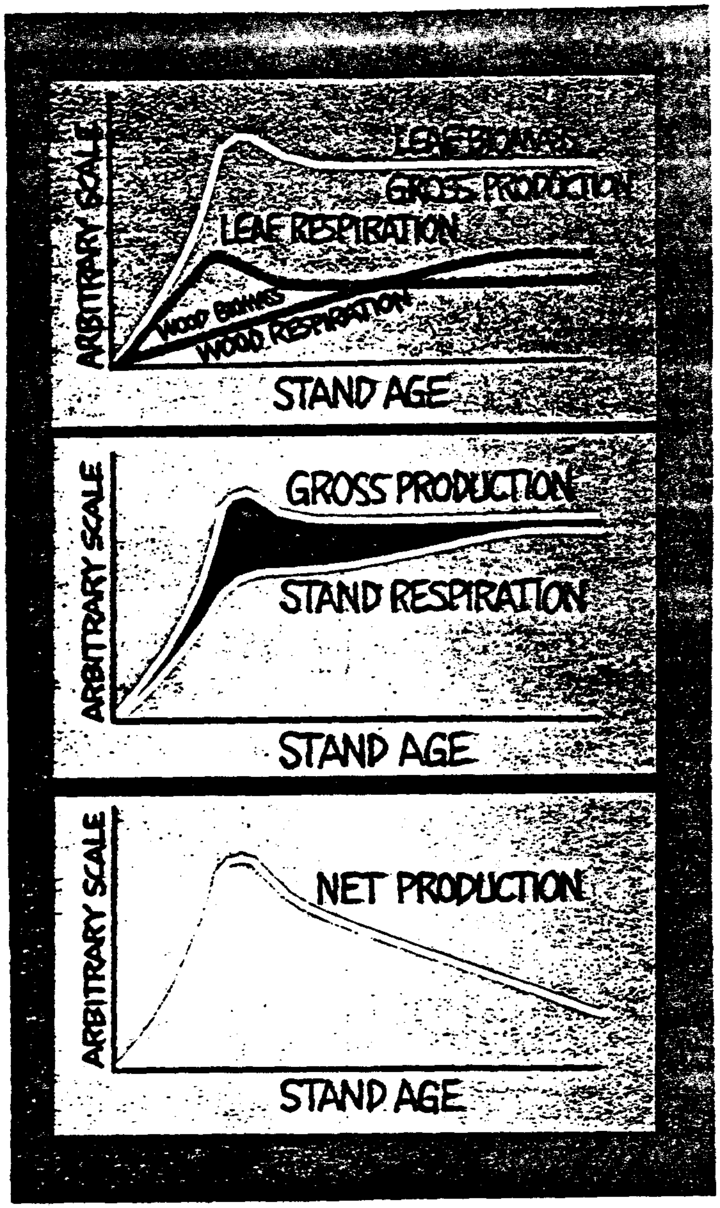


Table 2--Annual growth of two old-growth forest stands in the Cascade Range.

Stand name and age	Period studied	Gross growth	Mortality	Net growth
	--years--	-------board feet/acre/year------		
Tar Creek, 250 years	10	1,582	1,156	426
Wind River, 450 years	12	699	614	85

Nutrient Cycling and Erosion

Large amounts of energy and nutrients, such as nitrogen, phosphorous, and potassium, are represented in the accumulated organic matter (live and dead) of an old-growth forest. Related to this is the development of complex pathways by which this material is decomposed and released. These "detrital" pathways involve a diverse array of organisms including invertebrate animals, fungi, and bacteria. Materials are released slowly and little actually escapes from the surface soil since there are always organisms present to "capture" any freed nutrients and energy from easily decomposed organic molecules. These old-growth forests are identified as being very "conservative" of nutrients because nutrients are tightly retained within the ecosystem. The low level of nutrients and other dissolved or suspended materials in water flowing from old-growth ecosystems reflects this pattern of conservation.

Erosion is also at a low level in old-growth forests (Swanson 1981). In nature, high levels of erosion appear to be associated with infrequent catastrophic events, such as wildfire. But normally, the large and deep root mantles and thick litter layers of the old-growth forest and the numerous logs on the ground surface contribute to low levels of erosion.

As a result of low erosion and low levels of nutrients leaching into the ground water, water quality is typically very high in old-growth stands.

Differences in water yields between old-growth and other stages of forest succession is not completely understood. The herb and shrub stage generally has highest water yields but these tend to rapidly diminish as leaf areas return to predisturbance, forested levels after only a few years. Differences in water yields from young- and old-growth forests are also presently in question. Old-growth forests may have some advantages in precipitating moisture and aerosols from fog and cloves due to the deep crowns.

Stream Functioning

Streams in old-growth "run on leaves and litter", not sunlight. That is, the energy base for these stream systems is detritus (needles, twigs, leaves, cone scales, wood and soforth, which is broken down and utilized by a myriad of aquatic organisms, including bacteria and invertebrates. The invertebrates include a fascinating array of guilds known as shredders, grazers, gougers, scrapers and raspers, collectors, and predators. By contrast, the energy base for streams in open environments is typically algae and other green plants growing in the streams that capture the sun's energy via photosynthesis and become the food base for other aquatic organisms.

Streams in old-growth forests tend to be intermediate among successional stages in productivity, at least in terms of fish and other vertebrates (Murphy and Hall 1981). Provided water quality is not degraded, streams associated with the herb and shrub stage are typically highest in productivity and those associated with young forests are lowest in productivity.

Streams in old-growth are typically intermediate in species diversity between those associated with herb and shrub and with young forest. As with productivity this is largely a consequence of the quality and diversity of food bases available and with the diversity of available habitats. Old-growth stands provide a multilayered canopy of deciduous shrubs and trees and conifers as well as riparian herbs. This contrasts with the closed single-level canopy characteristic of a dense young conifer forest.

Finally, organic debris (particularly logs) is a primary factor shaping the physical structure of streams in most natural forests, including old-growth. Woody debris largely determines the distribution and types of habitats such as pools, dams, and sediment accumulations.

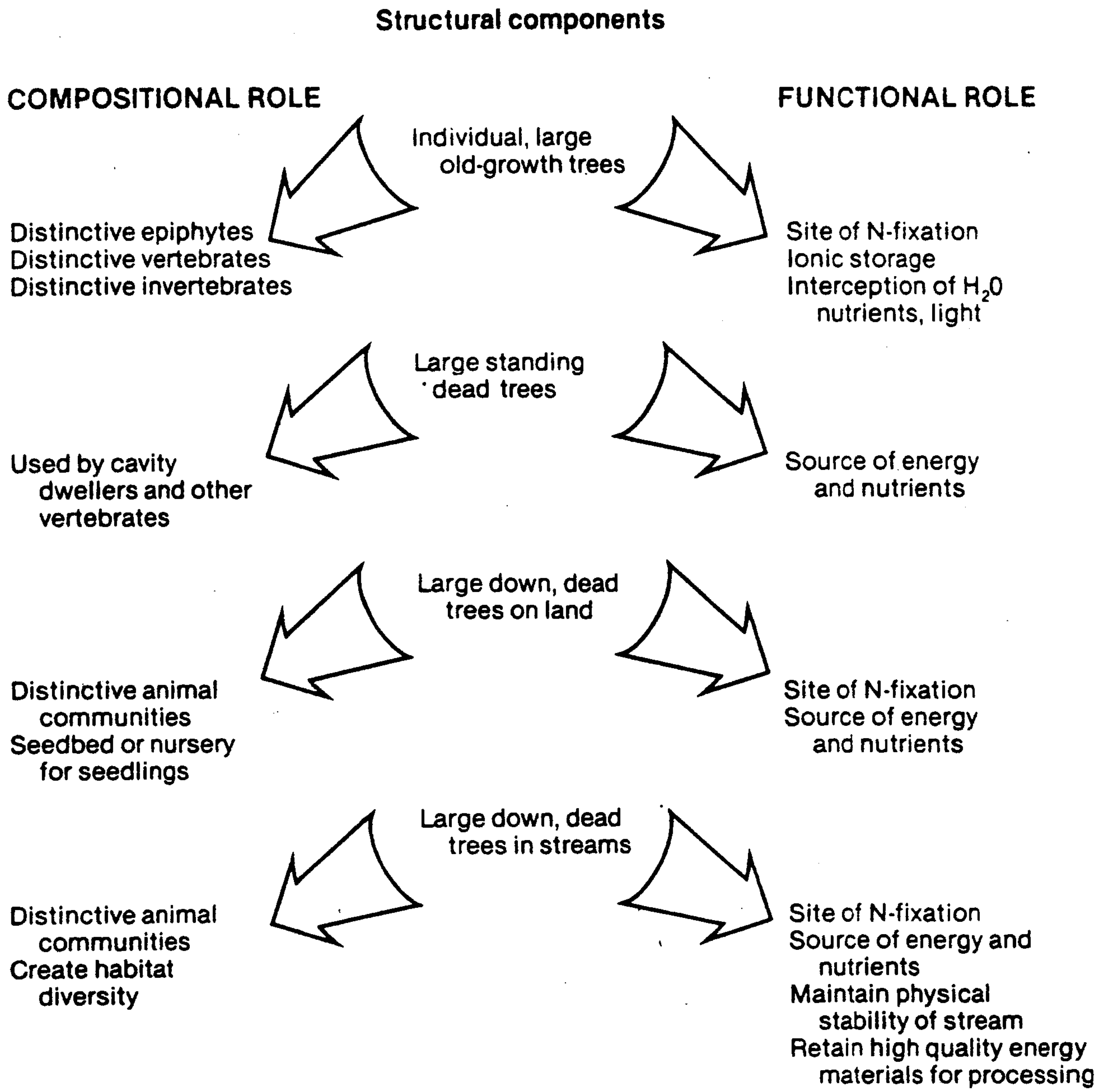
Old-Growth Forests Have Structural Features

Structural features refer to the various objects or structures in a forest, including rocks, logs, trees, bushes, snags, etc. Structural diversity in old-growth tends to be greater than in young-growth forests. There is a larger range in tree sizes, for example, and greater abundance and patchiness in understory shrubs.

Three structural components are of overwhelming importance in the old-growth forest: (1) individual, live, old-growth trees; (2) large standing dead trees or snags; and (3) large down trunks or logs. Logs are at least as important ecologically to the stream as to the terrestrial ecosystem so logs in streams are discussed separately. The live old-growth tree is, in large measure, unique to the old-growth forest. Snags and logs may be very abundant in natural young forests due to carryover from the old-growth stand. The presence of all three structural features distinguishes natural from managed forest ecosystems.

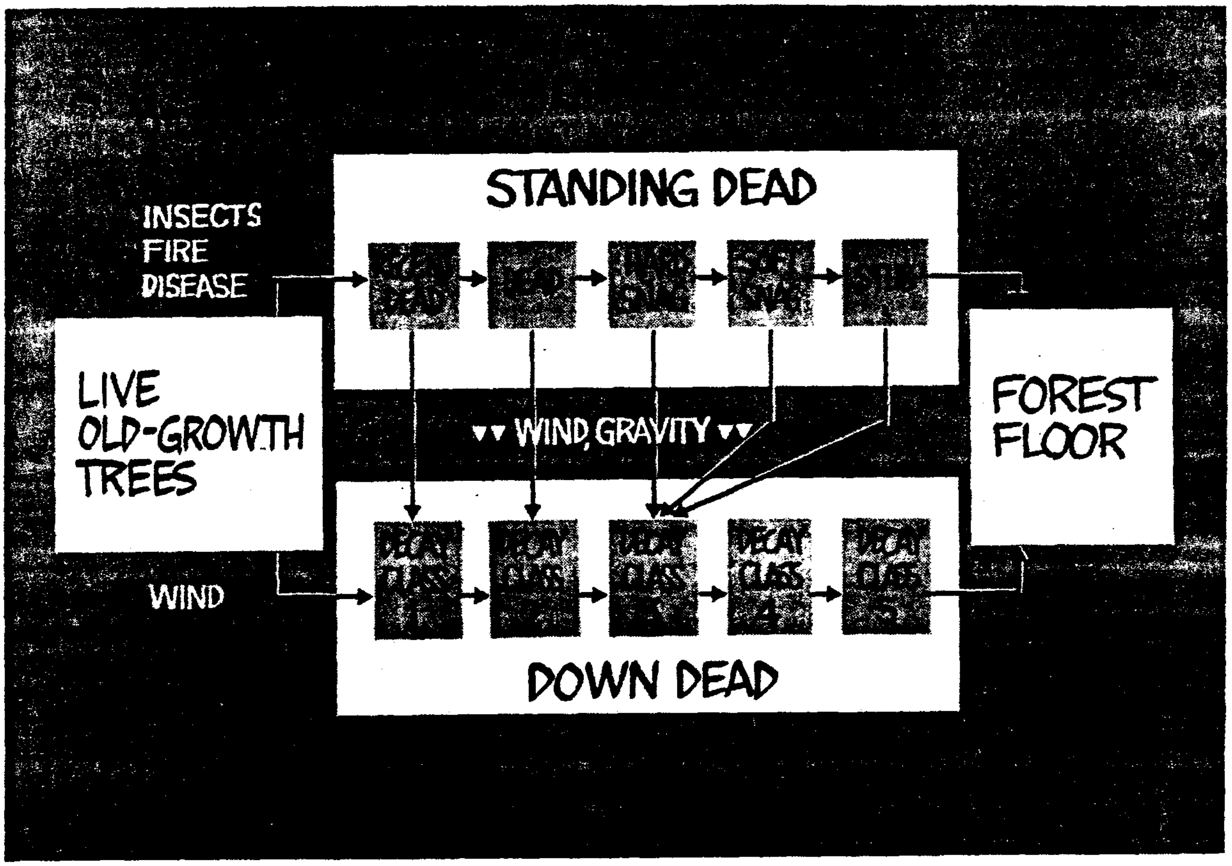
These three structural components are the key to most of the compositional and functional peculiarities of old-growth forest (figure 4). They provide the habitat needed by animal species which prefer or depend upon old-growth forest. They also control the rates at which energy, nutrients, and water flow through the ecosystem.

FIGURE 4



An important point is that these structural elements are related (figure 5). The dead organic structures--large tree snags and logs--are derived from the live trees. The large old-growth trees thus play a progression of important roles from the time they are alive through transformation to unrecognizable segments of the forest floor.

FIGURE 5



Live Old-Growth Trees

The most conspicuous of the structural components is probably the live, old-growth Douglas-fir trees. Although their size varies with age and site conditions, diameters of 3 to 6 feet and heights of 175 to 275 feet are common. They are highly individualistic (compared to trees in younger forests), each having been shaped over the centuries by its genetic heritage, site conditions, competition with nearby trees, and the effects of wind, diseases, insects, and mass soil movements. Broken tops and massive branch systems are characteristic. Furthermore, the crowns are often surprisingly deep with live branches extending down three-fourths of the trunk. A single old-growth Douglas-fir tree may have as many as 60 million needles with a total surface area of 30,000 square feet. Needles are well arranged on the deep crowns to intercept the sunlight, including during periods when the sun angle is low (e.g., during the winter). These crowns are particularly affective in intercepting water when fog or clouds blow through the forest. Huge amounts of energy are captured by photosynthesis in these old-growth crowns; but most, as mentioned, goes to maintain the life functions of the tree. Wood increments are small, as is obvious to any who have attempted to count rings on old-growth stumps.

The old-growth trees are very rich biologically. The large, fan-shaped arrays of branches typical of many old-growth trees are particularly important because they become perched ecosystems with organic soil, insects, plants, and higher animals. Trunks, single branches, twigs, and needles also provide habitat for many organisms. As many as 1,500 species of insects and other invertebrates live in the canopy of a single old-growth stand. Some carry out their full life cycles in the canopies while others arrive as adults from earlier growth phases on the forest floor and in streams. Old-growth trees are rich in spiders that prey upon the insects. Vertebrates complete the picture with species such as the red tree vole that lives many generations in a single tree eating Douglas-fir needles and building nests from the remnants. The northern flying squirrel lives in old-growth trees but descends to the ground to feed. The northern spotted owl heavily utilizes both the vole and squirrel as prey.

Mosses, lichens, and other epiphytes (literally plants growing on other plants) add much to the biological richness of the old-growth trees, coating trunks, branches, and twigs. Some of these deserve special mention because of specialized functions they perform. Lobaria oregana, a large lettuce-like lichen found primarily in old-growth forests is an outstanding example. The Lobaria is capable of "fixing" nitrogen, that is, absorbing elemental nitrogen gas from the air and converting it into forms that can be effectively used by other plants fertilizing the ecosystem. Leaching of the lichen during its life and decomposition after its death makes this nitrogen available to other organisms. A single old-growth tree may support as much as 35 pounds of this lichen. On a stand basis, 2 to 4 pounds per acre of nitrogen can be fixed per year, a considerable sum when added up over decades and centuries.

Old specimens of other tree species play roles comparable to old-growth Douglas-fir, but they have not been as thoroughly studied as Douglas-fir. Sitka spruce attains comparable size in coastal regions; deep crowns and heavy epiphyte-laden branch systems are characteristic of older specimens. Noble fir and western white pine (Pinus monticola) are subalpine species with some of the characteristics of Douglas-fir as is sugar pine (Pinus lambertiana) on dry sites in southwestern Oregon. All of the so-called cedars--western redcedar, incense-cedar (Libocedrus decurrens), Alaska-cedar (Chamaecyparis nootkatensis), and Port-Orford-cedar (Chamaecyparis lawsoniana)--are capable of attaining sizes and fulfilling roles comparable to Douglas-fir in their respective forest types. Cedars also have the additional advantage of fostering improved soil conditions through their nutrient-rich litter.

Large Snags

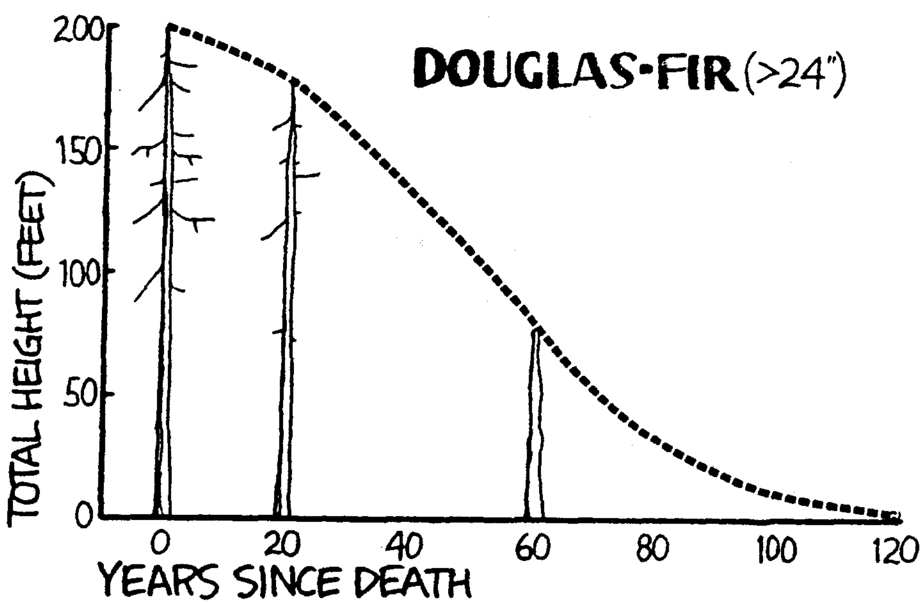
All natural forests have standing dead trees or snags as a major structural component. In young forests, they are typically carried over from the catastrophically destroyed forest that previously occupied the site. Snags are abundant in old-growth forests and form continuously as trees die from various causes (Franklin et al. 1981).

The primary role of snags is provision of habitat for wildlife. They are the primary location for cavities created and used by many species of birds and mammals. In the Blue Mountains of eastern Oregon, 39 bird and 24 mammal species use these sites for nesting and overwintering, as food sources, and for other functions (Thomas 1979).

The large hard snags required by primary excavators such as the pileated woodpecker (Drycopus pileatus) are especially important for wildlife. These snags are difficult to perpetuate in managed stands but are critical to certain species and yield smaller, soft snags through the decay process. In western Oregon, larger snags have greater diversity and more hole-nesting birds than smaller snags (Mannan, 1980). There are also indications that the number of snags is a limiting factor for cavity-utilizing vertebrates; larger numbers of snags have been correlated with greater numbers and higher diversity of such species.

Snags gradually disappear through various decay processes (Cline et al. 1980). Even the largest Douglas-fir snag is relatively short-lived (figure 6) and last a maximum of 100 to 120 years within a forest (Graham 1981). Snags left in an open area (e.g., burn or clearcut) disappear even faster. Other factors affecting the pattern and rate of disintegration of snags include tree size, species, and incidence of rot at the time the tree dies. A Douglas-fir snag under 16 inches in diameter completely disappears in 40 years or about 2-1/2 times as fast as one over 24 inches in diameter. Western hemlock disintegrates much faster than Douglas-fir while western redcedar is the most persistent.

FIGURE 6



Large Logs

Down dead trees or logs are a major structural feature of natural forests at all stages of successional development. As for snags this is because most catastrophes that kill forests do not consume or remove large amount of wood. This is well illustrated by the weak correlation between stand age and amounts of woody debris (snags and logs) found in one sample of stands that ranged from 100 to over 1,000 years of age; largely because of carryover from the predecessor old-growth stand, many young forests had as much dead wood as the sampled old forests.

Large masses of down logs are characteristic of old-growth forests. Typical concentrations are 40 to 85 tons per acre with up to 188 tons recorded for some intact stands. Logs generally cover 10 to 20 percent of the ground surface in old-growth stands. These logs represent major pools of energy and nutrients which are slowly made available as the logs decay. They also play many important ecological roles within the old-growth forest.

Down logs provide essential habitat for a variety of invertebrate and vertebrate animals. Wildlife utilize logs as food sources, as nesting sites, for protection and cover, and as lookouts. High moisture content of logs makes them especially important to amphibians. In the Blue Mountains, logs are utilized by 49 mammal, 115 bird, and 14 amphibian and reptile species (Thomas 1979). The persistence of large logs, especially through major catastrophes such as wildfire, has special importance in providing wildlife with structural or habitat continuity. Logs also contribute to animal reinvasion of severely disturbed sites such as clearcuts and burned areas by providing protected pathways. This may be important in ensuring reinoculation of these sites with spores of fungi that are beneficial to the growth of the new forests; small mammals are the primary means for dispersal of these spores.

Logs serve as sites for reproduction of tree species, especially western hemlock. This is an important function in natural stands since these seedlings and saplings provide replacements as openings appear in the overstory canopy. The phenomenon of "nurse logs" reaches its peak in the coastal Sitka Spruce Zone where reproduction of tree species is essentially confined to rotten logs (figure 7).

FIGURE 7

Other functions of down logs are as sources of energy and nutrients, sources of soil organic matter, erosion-reducing structures, and sites for nitrogen fixation (Franklin et al. 1981). The recently discovered bacterial fixation of nitrogen in logs provides yet another pathway by which the nutrient requirements of the forest are met. This also adds to the pool of nitrogen in forms that can be used by plants.

Like snags, logs go through recognizable stages of disintegration (refer to figure 4). One system recognizes five log decay classes defined by physical characteristics ranging from freshly fallen (class 1) to highly decayed and barely recognizable material (class 5). Important physical and chemical changes are associated with the progress of decay, including a rapid early increase in moisture content, gradual increases in the concentration of nitrogen, and gradual reductions in wood density (Triska and Cromack 1980).

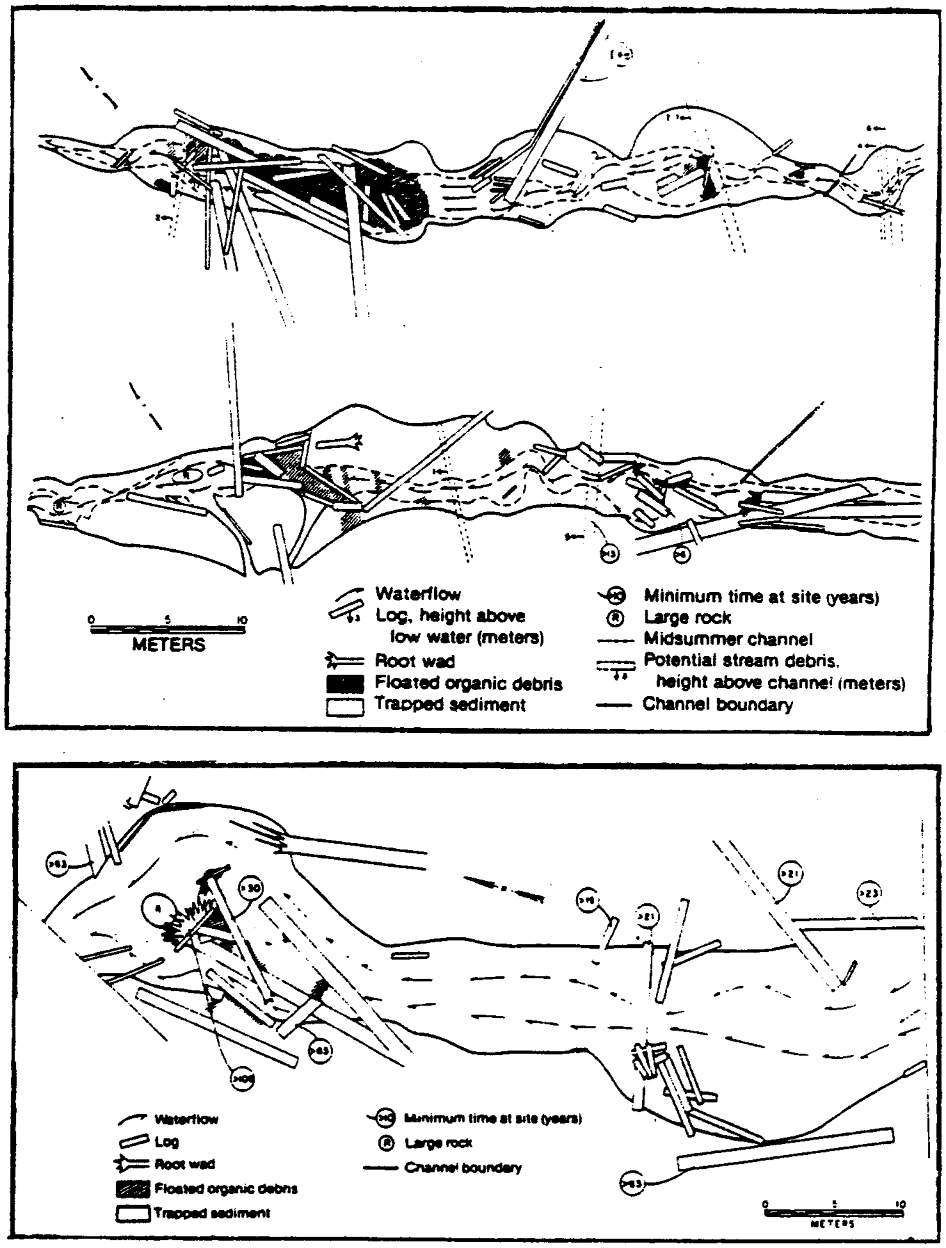
Logs persist much longer than snags of equivalent size. Large Douglas-fir logs can remain identifiable (although greatly reduced in volume and density) for over 240 years whereas snags reach comparable decay states in one-third the time. The activity of animals (invertebrates and vertebrates) and effects of gravity are believed to be factors in the more rapid demise of snags. Species differ substantially in log decay rates. Western hemlock and true fir (*Abies* spp.) logs decay many times more rapidly than Douglas-fir logs. Cedars and coast redwood are most resistant to decay.

Large Logs in Streams

Logs and other woody debris are conspicuous elements of small- to medium-sized streams flowing through old-growth forests (Swanson *et al.* 1976; Swanson and Lienkaemper 1978). They are typically very stable structural devices because of their large size relative to streamflow and because they are often anchored to adjacent land surfaces by their root wads. Their dominance of both physical and organic aspects of the stream ecosystem is reflected in the many critical roles played by logs in old-growth and other natural forest ecosystems. Woody debris largely controls the type and distribution of aquatic habitat, stability of streambeds and streambanks, routing of sediments and water through the stream system, and retention of the energy base of the aquatic ecosystem.

Aquatic habitats created by woody debris include sediment accumulations behind and plunge pools below debris dams as well as the woody debris itself. The amount of wood-related habitat does vary with local conditions and the size of the stream (figure 8). Commonly from 1/4 to 1/2 of the habitat is wood or wood-created in small streams within natural forests. Obviously, the wood-related habitat diversity contributes directly to species diversity and makes stream ecosystems richer in whole classes of organisms than would be the case in the absence of woody debris.

FIGURE 8



Large woody debris produces a stepped profile in streams resulting in dissipation of much of the stream's energy through waterfalls or cascades. This pattern of dissipation reduces the energy available for erosion of streambeds and banks, allows for greater sediment storage in channels, and produces greater habitat diversity than in straight, even-gradient channels.

Woody debris in streams is a major source of energy and nutrients for the stream ecosystem. Although woody materials are processed slowly, relative to leaf litter, huge quantitites are available and are utilized by various groups of microbiological and invertebrate organisms. In addition to the nutrients contained in the wood, woody debris is also a major site for nitrogen fixation within the stream ecosystem. In one study, 52 percent of the total input of nitrogen into a small stream was associated with wood.

One of the most important roles of woody debris in small forested streams is as a retention device which traps leaves and other litter until they can be utilized by stream organisms. The energy or food base for small streams in forests includes leaves, twigs, and other inputs of organic matter from the surrounding land. Much of this input occurs during a relatively short period in the fall. Also, much of the material has to undergo a period of "preparation" or colonization by microbes before it can be utilized by many of the invertebrates. These, in turn, provide the food base for vertebrates, such as fish. Biological activity in the stream is at its peak in the winter when streamflow is highest.

Structural devices such as debris dams are critical for holding the food base within the reach of stream until it has been prepared and can be processed by various organisms. Without such devices, leaves and other litter would be flushed down the stream and onto floodplains before aquatic organisms could use them. Although logs and other woody debris are not the only stream structures that serve a retention function, they are of overwhelming importance in smaller streams within natural forests in the Pacific Northwest. Without such structures, the composition (of insect and fish species and productivity of streams are very different and much simplified from the natural state.

Coarse woody debris also plays important roles in larger streams and rivers flowing through natural forests but these are somewhat different roles than in smaller streams. One key difference is the ability of large streams to move the debris and accumulate it on banks at high flow. Studies on the South Fork of the Hoh River in Olympic National Park, Washington have identified several roles for woody debris, including formation of protected off-channel habitats that have very high species diversity and biological productivity (Franklin et al. 1980).

On Ecological Characteristics of Old-Growth Forests: A Conclusion

Our knowledge about the structure, function, and composition of forest ecosystems is extremely rudimentary, and this applies to young- as well as old-growth forests. Forest science has often taken a narrow view in attempting to resolve current management problems. It is astonishing to find how little basic information exists on such fundamental topics as: root production and turnover; amounts, distribution, and dynamics of woody debris; and crown structure of trees of all sizes, ages, and species. Recent research reminds us of the magnitude of our ignorance: root systems may require 50 to 60 percent of the food produced by a tree (photosynthate) for maintenance; much of the photosynthate (even a majority on some sites) is produced during the non-growing-season period of fall, winter, and early spring in the Pacific Northwest; off-channel aquatic habitats function as biological hotspots in mountain river valleys; and so forth. The numbers and implications of recent findings on forest ecosystems should certainly humble us enough to consider seriously the maintenance of much ecological diversity and as many management options as possible.

It is clear from this paper that we do know some important things about the ecological characteristics of old-growth forests. These forests are distinctive and neither decadent, unproductive ecosystems nor biological deserts.

Old-growth stands do differ markedly from young-growth forests and, particularly, managed forests. Differences between natural young- and old-growth forests are reduced because of woody material carried over from the old to the new forest as snags and logs; such structures will not be present in managed young-growth stands except by management design.

Old-growth forests do have some unique or special values. Some terrestrial and aquatic organisms are provided with specialized habitat requirements. Gene pools of both common and unusual species are perpetuated. Biomass is maintained at a high plateau. Streamflow is well regulated. Water quality is generally very high as a consequence of low nutrient leaching and low rates of erosion.

These, then, are some of the attributes and values associated with the old-growth forest ecosystem.

Management Options For Old-Growth

There are several alternatives by which we can attempt to manage for old-growth ecosystems or attributes: (1) retain examples of existing old-growth forest; (2) recreate forests with old-growth characteristics by using long rotations; (3) manage for individual attributes (e.g., snags) on lands subject to intensive forest management; and (4) substitute artificial structures to serve functions previously provided by old growth.

Preservation of exemplary old-growth forest stands has been going on for many decades in the Pacific Northwest. Old-growth forests are protected, for example, within National Parks, wilderness areas, and Research Natural Areas. Strictly preserved sites of this type are limited in number and often poorly distributed geographically. Change in these old-growth forests is so slow that we need have little concern about the loss of characteristic elements, such as the Douglas-fir.

Recreation of old-growth-type forests on long rotations is theoretically possible. It would appear that we have sufficient knowledge of old-growth characteristics and silvicultural systems to accomplish such a goal. The final proof will, of course, be sometime in coming.

Some general management guidelines for preserving or recreating old-growth forests appear appropriate. Blocks of land of several hundred acres appear necessary to maintain the integrity of the forest although minimum size will vary depending upon management of surrounding lands. Small drainages may be ideal as management units because of the distinctive and protective nature of their natural boundaries (ridges) and the inclusion of the stream as well as the forest. Streamside and roadside corridors may be particularly valuable as old-growth reserves because they provide protected and continuous travel routes for migraton of plants and animals over the landscape. Salvage of large snags and down logs is not appropriate in sites for old-growth or long-rotation management since these structures are keys to the composition and functioning of old-growth ecosystems. In fact, the best management practice for reserved old-growth stands is no entry at all. This may create problems along roads. Use of streamside corridors for old-growth or long-rotation management has the added advantage of allowing the perpetuation of a natural stream structure including woody debris.

Some individual old-growth attributes can be incorporated into schemes for intensively managed forests. Examples include provision for snags and logs within managed stands on rotations of 40 to 100 years. Such structures can greatly augment the ecological diversity in these forests which will, after all, occupy the bulk of our commercial forest land here in the Pacific Northwest, regardless of what is done with the remaining old growth. Learning to manage dead wood as cleverly as the live tree will require creativity on the part of silviculturalists.

We might consider substituting artificial for the natural structures provided by old-growth and other natural forests. Construction of gabions in streams and using bird houses in place of snags are examples. This approach is expensive temporary, and incomplete. Perhaps more important, managing for individual attributes or substitute structures does not provide for an integrated natural forest ecosystem.

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