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The Ecological Basis of Forest Ecosystem Management in the Oregon Coast Range

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Introduction

Human relationships with the forests in the Oregon Coast Range and indeed everywhere are characterized by at least three paradoxes. First, many of the essential qualities of these forests (e.g. large trees and large accumulations of dead wood) arise from long periods of slow development, (by standards of human institutions and human life spans) but many of these same qualities cannot be sustained without periods of rapid, destructive change. Secondly, we humans and our institutions prefer order and predictability, yet forest ecosystems are marked by variability and unpredictability. Finally, the ecological consequences of our actions may not appear for many years, and some effects may appear far from the site of the initial action. Forest managers face a two-fold challenge: (1) to find a balance among the forces of growth and destruction, predictability and unpredictability, that produces desired values (goods and services); and (2) to know how actions at one point in time or space affect values at another point. These challenges, although great, pale in comparison to the challenge faced by society to determine just what mix of values are desirable in the first place. The determination of what is socially desirable, however, must be set within the context of what is biologically and economically possible. The information in this chapter is intended to help to set the ecological constraints on the output of social and economic values of the Coast Range forests.

We discuss twelve major ecological themes (regional environment, ecosystem types and patterns, vegetation in geologic history, deciduous forests, riparian zones, productivity, disturbance, tree death and decomposition, forest development, human influences, road effects, and aquatic-terrestrial linkages) that we believe form the foundation of ecologically based forest management in the Coast Range. These are divided into three general categories: (1) ecosystem patterns and history, (2) disturbance and vegetation development, and (3) landscape interactions. We conclude with a discussion of how an understanding of natural processes can contribute to reaching ecosystem goals. We draw primarily on information developed in the Coast Range but include information from other parts of Oregon and other regions where appropriate.

Ecosystem Patterns and History

Regional environment

The diverse environments of the Oregon Coast Range provide the context for ecological processes and constrain the range of management options for the region's forests and streams. The Coast Range is one of 10 physiographic provinces—large areas of relatively similar geology and climate—in Oregon (Franklin and Dyrness 1988). Except along the coast and the major rivers, the terrain of the province is quite rugged, with sharp ridges and steep slopes. The Coast Range mountains are the major topographic and climatic divide in the province (Figure 3-1a-c in color section following page 52). Elevations of main ridge summits range from about 450 to 750 meters, and reach a high of 1,249 meters on Marys Peak. The Coast Range province encompasses all or part of 20 major watersheds (Figure 3-1c).

Most of the geologic strata underlying today's coastal landscapes (Figure 3-1b) were laid down during the Tertiary period, from 75 to 2.5 million years ago. Geologic formations are primarily marine sandstones and shales, with basaltic volcanic rock, and related intrusive igneous rocks. Before the sea floor was uplifted to form the Coast Range, vast marine sedimentary beds were deposited 60 to 40 million years ago. Volcanic rocks also were formed over extensive areas northeast of present-day Tillamook during this period, and pillow basalts were deposited near present-day Alsea. From 40 to 26 million years ago, sedimentary beds were laid down near Vernonia and along the Nehalem River, extensive basalt flows occurred near what is now the Columbia River, and scattered igneous intrusions capped many of the prominent peaks. During the Pleistocene, which began 2.5 million years ago, rising sea levels deposited sands along the coast and drowned the mouths of coastal rivers.

Soils of the coastal province vary widely because of complex interactions among rock type, climate, vegetation, and physiography over time. Most soils are well drained and have poorly developed horizons, dark surface horizons high in organic matter, and high capacity to hold exchangeable cations. Such soils develop in areas of high winter precipitation and moderate winter temperatures, conditions typical of most of the province. In the southeastern portion of the province, where summers are warmer, soils generally are more strongly weathered, with more fully differentiated horizons. Characteristics of soils that have developed on the extensive sandstone deposits of the coastal province vary widely. Soils on steep, smooth mountain slopes tend to be shallow, with a stony-loam texture, whereas soils on uneven, benchy, and unstable slopes are deeper and derived from colluvium. Sandstone soils on broad ridgetops tend to be deep, with thick surface horizons high in organic matter. Soils developed from siltstone or shale are finer-textured than those developed from sandstone, with a silt loam surface horizon and a silty clay or clay-textured subsurface horizon. Soils developed from basalt tend to be shallow and stony. Soils on old, stabilized dunes along the coast range from excessively well drained to poorly drained and comprise loamy sand or fine sand. Soils derived from alluvium along the major streams are variable, ranging from well drained to poorly drained silt loams and silty clay loams.

The moderate, moist, maritime climate of the coastal province supports some of the most productive forest ecosystems in the world. In general, the maritime climate is characterized by mild temperatures; a long frost-free season; prolonged cloudy periods; narrow seasonal and diurnal fluctuations in temperature; mild, wet winters and cool, relatively dry summers; and heavy precipitation. Most precipitation falls as rain from October to March, resulting from cyclonic storms that approach from the Pacific Ocean on the dominant westerlies. Storm tracks shift northward during summer, and high-pressure systems bring fair, dry weather to much of the province, although coastal fog is common during this period. Large-scale patterns of variation of the coastal climate are associated with proximity to the Pacific Ocean, orographic effects, and latitudinal gradients. To varying degrees, the coastal mountains, oriented north-south, block maritime air masses and the moderating effect of the Pacific Ocean from the eastern slopes of the Coast Range and the interior valleys. From west to east rainfall decreases (Figure 3-2a in color section following page 52), winters become colder and summers warmer, and annual variability in temperature increases (Figure 3-2c in color section following page 52). In addition, precipitation decreases (Figure 3-2a) and temperature increases from north to south. During the summer, a critical period for plant establishment and growth in the coast, climatic conditions range from hot and dry in the southeast to cool and moist in the northwest (Figure 3-2b in color section following page 52).

In conclusion, the coastal province encompasses a broad array of environments that provide habitat for terrestrial and aquatic plants and animals, and a template for ecosystem processes. The sources of this ecological diversity are many, but the most important at a regional scale include landform, geology, soils, and climate. These broad-scale patterns of environment must be taken into account when managing these forests. Forest growth and

Dyrness 1988). These are the Sitka Spruce Zone on the coast, the Western Hemlock Zone in the central and eastern regions, and the Oak Woodlands of the Willamette Valley foothills on the eastern margin. A fourth zone, the Silver Fir (*Abies amabilis*) Zone, occurs sporadically on isolated mountain tops in the Coast Range. Each of these zones has a characteristic set of potential natural plant communities, that is, communities that would be found in later stages of forest succession and are indicative of the climatic and soil potential of a site.

Finer-scale variation in vegetation composition and structure has been imposed on these forest zones by disturbances such as wildfires and forest cutting, which have created a mix of younger and older forests over large areas. For example, much of the Tillamook State Forest is dominated by young forests that originated following the Tillamook burns of the 1930s, '40s, and '50s (Chen 1998). Today many of the broad-scale patterns of forest age and structure in the Coast Range correspond to large ownership blocks (Figure 3-4 in color section following page 52). For example, most of the mid- and older-aged forests are on federal lands of the Bureau of Land Management (BLM), and Siuslaw National Forest, and on the Elliott State Forest.

At scales such as small watersheds or landscapes, vegetation patterns are influenced by topographic position and proximity to streams (Figure 3-5 in color section following page 52). Plant community composition typically follows topographic trends (Figure 3-6 in color section following page 52). In lower topographic positions western hemlock/ salmonberry plant associations are common types, whereas on drier, upper slopes, western hemlock/ salal (*Galtheria shallon*) communities are common (Hemstrom and Logan 1986). Forest structure may also be influenced by topography. Within watersheds in the interior and valley-margin areas of the Coast Range, southwest-facing sites on upper slopes and ridges have fewer trees of shade-tolerant species, higher levels of shrub cover, and less coarse woody debris than north-facing sites on lower slope positions (Spies and Franklin 1991). Shade-intolerant hardwoods are frequently dominant over conifers in lower slope positions and along streams, where moisture stress is relatively low and landslide and flooding disturbance create sites favorable for their establishment (Pabst and Spies 1999). The spatial pattern of hardwoods and conifers along streams and topographic gradients can be quite complex, however (Figure 3-7). For example, well-developed conifer stands can be found near streams on higher benches and steep streamside slopes, and hardwoods can occur near ridgetops. Additional sources of variation in vegetation at this scale include frequency and severity of disturbance. Impara (1997) found more old Douglas-fir (*Pseudotsuga menziesii*) trees in lower slope positions than in higher ones, which suggests that fires in the Coast Range have been somewhat less frequent or less intense on lower slopes than on midslopes and ridgetops. Vegetation composition is also influenced by the size of a stream and distance from a stream (Pabst and Spies 1999; Nierenberg and Hibbs 2000).

The imprint of human activities on Coast Range is evident at the watershed scale. The level, streamside areas of many of the larger watersheds of the Coast Range are dominated by agricultural lands, many used for grazing and livestock production (Figure 3-8 in color section following page 52). The slopes along the watercourse are frequently a mosaic of young forests of different ages, reflecting widespread logging over the last 50 years on all ownerships.

Within stands, variation in forest composition and structure is influenced by several factors including fine-scale disturbance and environmental patterns. Forests of all ages that have developed with little or no human influence are frequently a mosaic of canopy gaps, patches of shrubs and tree regeneration, pockets of standing dead trees, and patches of dead and down trees. Where trees have been blown down recently, gaps may be scattered throughout the stand with a characteristic pattern of pit and mound topography.

Riparian areas are especially diverse and frequently consist of a mosaic of conifers, hardwoods, shrubs, down logs, and deposits of sediment left by floods and debris flows (Figure 3-9 in color section following page 52). Many patches along streams, especially those recently flooded, lack any trees at all (Pabst and Spies 1999; Nierenberg and Hibbs 2000). The size of canopy openings may influence the tree and shrub species that develop (Taylor 1990). Patterns of regeneration of hemlock and other shade-tolerant tree species are patchy, perhaps reflecting the distribution of rotten wood seedbeds as well as the presence of nearby (< 20 meters) hemlock parent trees (Schrader 1998). Stream junctions may be repositories of large dead wood where debris flows that began as upslope landslides stop at tributary junctions.

upper-slope positions. Within stands, different habitat values are provided by canopy gaps, pockets of dead standing trees, and patches of multi-layered canopies. These structures increase the overall diversity of habitats and plant and animal species within forests.

In forest stands managed primarily for timber production, the goals are frequently to reduce spatial and species variability by filling as much of the available growing space with rapidly growing commercial timber crops. Although these efforts at homogenization are occasionally thwarted by regeneration failures, diseases, insects, and natural regeneration of noncommercial species, intensive forest management does result in less diverse stands and landscapes than might otherwise occur. The long-term consequences of these changes in diversity to ecosystem outputs are not well understood (Perry 1998); consequently, forest management in the Coast Range should be viewed as a large experiment, and as such should not proceed without controls, monitoring, and a willingness to change as new information becomes available.

Coast Range vegetation in geologic history

In the last 20,000 years, the Earth has undergone a shift from glacial conditions to the present interglacial period, the Holocene. In the course of this transition, the vast ice sheets disappeared, sea levels rose, and atmospheric carbon dioxide increased. This climatic change also triggered widespread biological reorganizations as species adjusted their ranges and abundance to form new biomes. In the Coast Range, subalpine forests and tundra, which were widespread during the last glacial period, were replaced by closed forests composed of plant species adapted to temperate conditions. This transition was most pronounced between 14,000 and 11,000 years ago, but major changes in vegetation also occurred before and since that time. Associated with, and perhaps triggering, these vegetational changes were alterations in the disturbance regime, that spatial and temporal pattern of events such as fire, windstorm, and floods that destroy vegetation and create new sites and resources for establishment and growth of new organisms. What can we learn from these past events that is relevant to understanding the modern Coast Range? What does the biotic response to previous environmental changes suggest about the sensitivity of present forests to future global change? Paleoecology, the study of past ecological interactions, provides an opportunity to answer these questions. With a long time perspective, one can consider the role of prehistoric events in shaping present-day vegetation composition and pattern. One can also evaluate whether pre-Euro-American conditions are an appropriate reference point for management, as some people have suggested (Aplet and Keeton 1999).

Our understanding of the long-term environmental history of Coast Range forests comes primarily from an analysis of the fossils preserved in the sediments of natural lakes and wetlands (Whitlock 1992). Pollen and plant macrofossils analyzed at closely spaced intervals in sediment cores are the primary tools used to infer the local vegetation history. When several sites show similar patterns of vegetational change, that is considered evidence of regional climate change.

Information on past fire occurrence comes from two sources. The first source is the forest of the present day; specifically, the study of fire-scarred tree rings and forest stand-age classes (Agee 1993; Impara 1997). These data provide fire histories with high spatial and temporal resolution, but they are only as old as the oldest living trees.

The second source of information is the analysis of particulate charcoal from cores taken in wetland sediments in which layers of abundant charcoal particles (so-called charcoal peaks) are considered evidence of a fire in the watershed (see Clark 1990; Long et al. 1998). The time between charcoal peaks in the core provides an estimate of the number of years between fires, or the mean fire interval. Charcoal records lack the spatial and temporal precision of dendrochronologic data, but they can disclose the changes in fire regime that accompany major reorganizations of vegetation over several thousand years. The interpretation of paleoecologic data is based on studies of the relationship of present-day pollen rain (deposition of pollen) and charcoal accumulation with modern vegetation, climate, and fire regimes. The better these relationships are known, the more confident we may be of the paleoecological reconstruction.

Another source of information is offered by general atmospheric circulation models or GCMs. These complex computer models, which are used routinely in present-day climate forecasting, depict mean fire interval of < 175 years (Figure 3-10). The forest composition and fire regime probably resembled present-day conditions at low elevations in the western Cascade Range and at the eastern margin of the Coast Range. The Little Lake data are consistent with other records from the Pacific Northwest which suggest that the climate of the early Holocene was warmer and drier than today's climate. The dry conditions probably resulted from higher-than-present summer insolation, which in turn increased summer temperature, decreased effective precipitation, and strengthened the eastern Pacific subtropical high pressure system.

In the middle Holocene, changes in the pollen layer pattern suggest that the Coast Range became progressively cooler and more humid. This shift was part of a regionwide trend ascribed to decreasing summer insolation and the weakening of the subtropical high-pressure system in the last 7,000 years. Western redcedar (*Thuja plicata*) and western hemlock became more abundant at Little Lake, and the forest apparently had fewer openings than before, as indicated by the decline of bracken fern and oak. The charcoal record suggests that fires continued to be frequent (mean interval of < 175 years) until 3,500 years ago, despite the shift in regional climate toward cooler, wetter conditions. The fire regime may have been maintained by episodes of drought or possibly by the activities of Native Americans. Between 3,500 and 2,400 years ago, fires became less frequent, with the intervals increasing to 275-300 years. The great abundance of charcoal in the sediments at this time suggests that fires were stand-replacing events that consumed large amounts of woody biomass. Because of the wetter climate, landslides probably also increased in frequency, and they undoubtedly carried charcoal along with other sediment to streams and lakes (Long et al. 1998). About 2,400 years ago, the vegetation at Little Lake corresponded to that of the present day, being composed of Douglas-fir, red alder, western hemlock, western redcedar, and true fir (*Abies* spp.). In the last two millennia, the fire return interval has decreased to 160-190 years, suggesting that fires have become more frequent.

The paleoecologic record has three important implications for forest management. First, the composition and dynamics of Coast Range forests have not been static, but have changed along with climate over thousands of years. The Little Lake record shows changes in forest composition in the past that were most likely responses to shifts in summer drought and winter precipitation, which in turn were driven by changes in the seasonal amplitude of insolation and position of winter storm tracks (Worona and Whitlock 1995). How rapidly can forest communities in this region adjust to climate change? One episode of rapid vegetational change at Little Lake 14,850 years ago suggests that major changes in composition can occur in a matter of decades (Grigg and Whitlock 1998). During this period, spruce forest was replaced by one dominated by Douglas-fir in less than a century. Douglas-fir forest persisted for about 400 years, and then the area reverted back to spruce forest. The increase in Douglas-fir at Little Lake was accompanied by a prominent charcoal peak, suggesting that a fire, or perhaps two or three, closely spaced, helped trigger the vegetation change by killing spruce and creating soil conditions suitable for establishment of Douglas-fir. Warmer conditions allowed Douglas-fir to remain competitive for several decades before spruce returned. Other records of comparable resolution are required in order to determine whether this event is of regional significance. Nonetheless, the Little Lake data suggest that vegetation changes can occur rapidly, especially when the disturbance regime is altered. Levels of carbon dioxide and other so-called greenhouse gases are predicted to result in a global temperature rise of 2°-5°C in the next century (Intergovernmental Panel on Climate Change 1996). Paleoecological data suggest strongly that rising temperatures will lead to changes in the rates of growth of forest trees, seed production, and seedling mortality. Indirectly, they will influence the disturbance regimes of fire, insect infestation, and disease (Franklin et al. 1992). The fossil record suggests that climate change will trigger changes in disturbance regimes, creating disequilibrium in Coast Range forests as species adjust to new conditions.

The second implication of paleoecologic records for forest management is that they reveal the relatively ephemeral nature of modern plant communities. Present-day forests represent an association that has existed for less than three millennia, and in the Coast Range only a few generations of the forest dominants have been present. Plants apparently have responded to Holocene environmental changes as species rather than as whole communities, and in the process plant et al. 1992). All these species either were left during logging or sprouted back from cut stumps to dominate many areas. Thus, their relative abundance, but not necessarily their absolute abundance, has increased in this area.

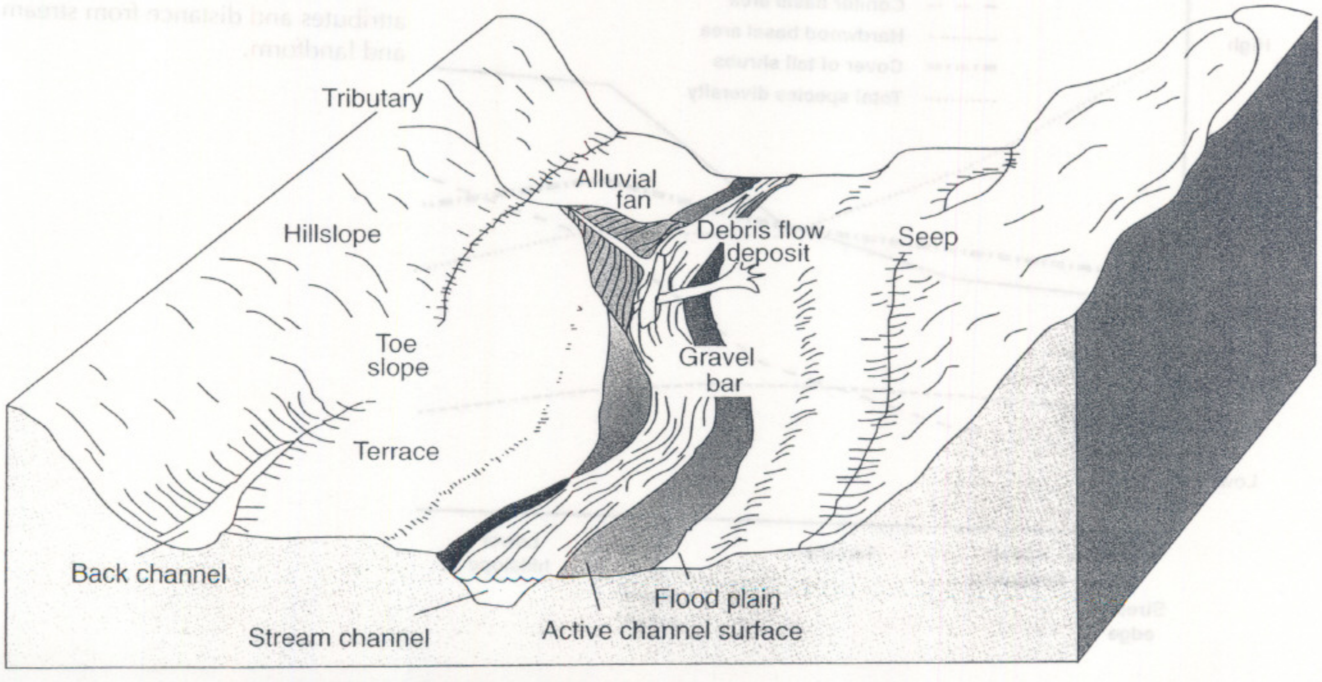
Coast Range hardwoods play a variety of ecological roles. Perhaps best known is alder's ability to fix nitrogen (Binkley et al. 1994). Alder uses bacteria housed in nodules on its roots to convert atmospheric nitrogen into ammonia at rates as high as 200 kilograms per hectare per year (approximately 200 pounds per acre per year; Figure 3-13 in color section following page 52). This nitrogen is used by the alder and later recycled through root decay and litter fall into the soil where it is accessible to other organisms. Most of the soils of the central and northern Coast Range have high levels of nitrogen (Bormann et al. 1994), suggesting that alder has grown on these sites at times in the past.

It has been suggested that a mix of deciduous tree leaves and conifer needles decompose faster than conifer needles alone. Such a mix would then have higher rates of nutrient cycling (Fried et al. 1988) and thus increase soil fertility (Figure 3-14 in color section following page 52). Hardwoods have also been identified with lichen diversity "hot spots" in predominantly coniferous forests (Neitlich and McCune 1997).

Hardwood trees make distinctive and important contributions to wildlife habitat. A study found that Oregon white oak provides 10 times the cavity habitat provided by Douglas-fir trees of the same diameter (Gumtow-Farrior 1991; Figure 3-15 in color section following page 52). The large fruits of oaks, madrone, chinkapin, and tanoak are a major food source for many animals and birds. The fact that the breeding territory of spotted owls in the mixed hardwood-conifer forest of southwest Oregon is smaller than in the coniferous forests to the north may be linked to high productivity in the south of the owls' prime food source, the seed-eating rodents such as the wood rat. Some wildlife species show strong and very specific connections to hardwood communities, like the white-breasted nuthatch (*Sitta carolinensis*) in oak woodlands and the white-footed vole (*Arborimus albipes*) in riparian alder (McComb 1994).

The role of hardwoods, especially red alder, in riparian areas is often underappreciated with today's emphasis on growing large conifers for in-stream structure. The abundance of alder normally increases from minor patches on most intermittent streams, to a narrow strip along first-order streams, to large patches along second-order and larger streams. Even where patches of conifers are found,

Figure 3-16. Landforms and geomorphic features of riparian areas.



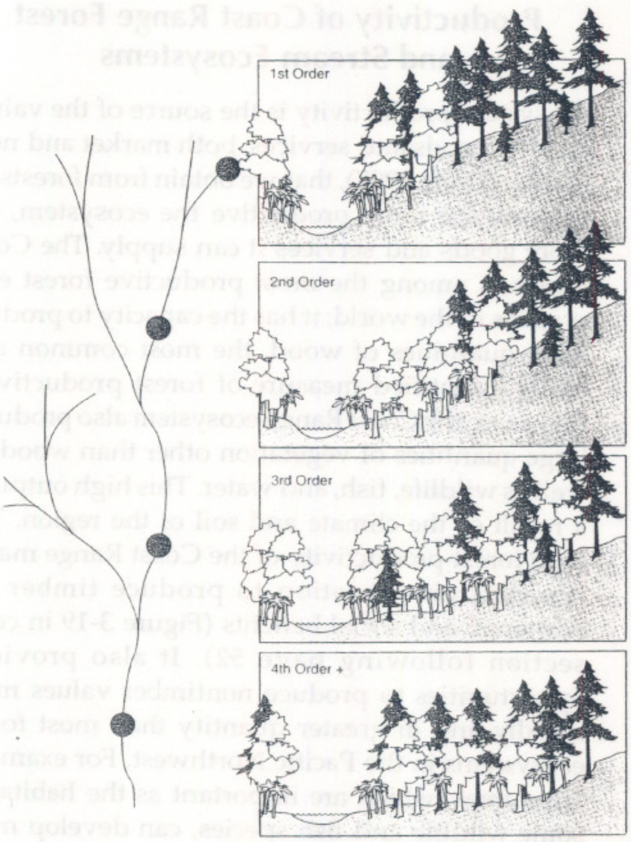


Figure 3-18. Stream valley cross-sections from first to fourth-order streams.

Range; for example, conifers are more likely to be found on hillslopes than on valley floors. The occurrence of snags reflects the distribution of live trees. Snag densities in unmanaged riparian forests range from 8 to 18 per hectare near the stream compared to about 48 per hectare upslope (Andrus and Froehlich 1988; McGarigal and McComb 1992; Pabst and Spies 1999).

A stand's location in the stream network also influences its structure and composition (Figure 3-18). Along steep-gradient headwater streams, riparian forests tend to be dominated by conifers, except where unstable slopes or competition with shrubs preclude trees from developing (Pabst and Spies 1998, 1999). The likely reason for this pattern is that small streams have less influence on the streamside environment than higher-order streams, allowing an upland environment to prevail.

Riparian forests along higher-order streams of the Coast Range generally have a mix of species, including an abundance of hardwoods. Valley floors of these larger streams are characterized by broader floodplains, greater hydrologic and topographic complexity, larger canopy gaps, and less constraint on the stream course compared to low-order streams (Naiman et al. 1992; Pabst and Spies 1999; Figure 3-18). Species composition in these locations may be affected by soil pH, soil moisture and depth to water table, soil texture and size of coarse fragments, successional status, landform, and the severity and frequency of flooding. Red alder, the dominant tree in Coast Range riparian areas, is well adapted to this environment. It germinates readily on newly deposited or exposed mineral substrates; can fix nitrogen in nitrogen-limited locations such as gravel bars; has a rapid juvenile growth rate that allows it to outcompete shrubs in some situations; can tolerate poorly drained soils and brief inundation, even during the growing season; and can sprout or produce adventitious roots (roots growing out of the stem) when the bole is buried with sediment (Harrington 1990). Bigleaf maple, western redcedar, and Sitka spruce tolerate moist soils and inundation to various degrees (Minore and Smith 1971; Walters et al. 1980), but their distribution along streams may be limited by competition, herbivory, lack of seed source, or the scarcity of favorable microsites for germination (Fried and Tappeiner 1988; Minore 1990; Emmingham and Maas 1994). Douglas-fir, which is intolerant of wet soils (Minore 1979), can grow along larger streams and rivers that are constrained by hillslopes or bedrock substrates, or where terraces are well drained and high above the water table.

Understory plant communities of Coast Range riparian forests are dominated by shrubs such as salmonberry, stinking black currant (*Ribes bracteosum*), red elderberry (*Sambucus racemosa*), and vine maple (*Acer circinatum*). These species have reproductive and physiological advantages allowing them to thrive in valley bottoms and on lower slopes (Tappeiner et al. 1991; O'Dea et al. 1995; Pabst and Spies 1998). In general, understory species composition is associated with landform and distance from the stream. For example, species diversity and the occurrence of non-native species are greater near streams and on valley floors than on adjacent lower hillslopes (Hibbs and Giordano 1996; Pabst and Spies 1998). There are two likely reasons for this: erosion and deposition provide germination sites in a relatively high, light environment for opportunistic species, and microsites such as seeps, back channels, and boulders provide

The above-ground net primary productivity of the moist coniferous forests of the Coast Range is higher than that of most forests in the world, including many tropical forests (Gohlz 1982; Kimmins 1987; Prince and Goward 1995). In the temperate zone, only the coastal redwood and evergreen broadleaf forests of northern California and southeastern Oregon may have higher above-ground productivity (Waring and Franklin 1979). Hemlock-spruce forests on the coast can produce 15 metric tons of aboveground biomass per hectare per year, whereas Douglas-fir-western hemlock stands in the Oregon Cascades produce less than 10 metric tons per hectare per year (Gohlz 1982). Trees are not the only source of productivity. In some stands in the Pacific Northwest, production by shrubs, herbs, and mosses is as much as 17 percent of the total net aboveground productivity (Long 1982). The cover of shrubs in the Coast Range, which is an indicator of biomass of shrubs and may be an indicator of shrub productivity, is higher than in any other province in Oregon (Ohmann 1996).

The most common indicator of potential productivity used in forest management is the forester's measure: site index or site quality (the total height of a tree at either 50 or 100 years). On this basis, the Coast Range is also quite productive. Much of the Coast Range is site quality II or higher for Douglas-fir (more than 170 feet in height at 100 years), although lower site quality is more common in the eastern portion of the province (Figure 3-20 in color section following page 52). The Pacific Northwest coastal region (west of the Cascade Mountains of Oregon and Washington), which includes the Oregon Coast Range, contains 7 percent of the forest land in the United States but 21 percent of the highest productivity lands, capable of producing 120+ cubic feet per acre per year of MAI (mean annual increment) at 50 to 70 years of age (Powell et al. 1993). Coast Range counties with the most productive timber lands (from highest to lowest) are Clatsop, Lincoln, Tillamook, Columbia, Coos, and Curry. The average forest land in all of these counties can potentially produce more than 100 cubic feet per acre per year of MAI.

The high rates of tree growth in the Coast Range also mean that large trees, which are important components of forest and stream habitat, can grow more rapidly than in almost any other region of the Pacific Northwest. In the Cascades, it may take over 200 years to produce trees over 170 feet tall, which is the height of the upper canopy at which many characteristics of old forest habitat begin to develop. Trees in the Coast Range can grow this tall in as little as 70 to 100 years (McArdle et al. 1961). Similarly, relatively large-diameter trees (24 inches) can grow in as little as 50 years on many sites in the Coast Range; such trees may require over 100 years to develop on many sites in the Cascade Range.

Intensive management to maximize production of wood and financial return on a site in the Coast Range (i.e., rotation lengths of 40 to 50 years) will not produce high levels of some other ecosystem goods and values including wildlife habitat associated with large trees (more than 30 inches in diameter) and large snags and down wood, carbon storage, and recreational opportunities (McComb et al. 1993; Curtis 1994). Timber productivity, as measured by MAI, may peak relatively early (50 to 70 years) but can increase or stay high for relatively long periods of time (Curtis 1994). Consequently, harvest ages of 40 to 50 years result in reduced total volume production and less than the trees' potential (Curtis 1994). Extending rotations could provide benefits not only in terms of total timber volume produced but to other forest values as well.

Why are Coast Range forests so productive? Climate is the main factor. Climate plays a major role because productivity is determined to a large degree by the constraints on growth set by climatic extremes, such as drought and freezing temperatures, that limit the ability of green plants to photosynthesize and fix carbon in plant tissues. Climatic constraints on the ability of forests to use light energy for photosynthesis are lower in the Coast Range than other regions in Oregon. For example, freezing temperature, soil drought, and vapor pressure deficit reduce the annual capture of photosynthetically active radiation (PAR) by only 8 percent compared to the potential maximum at Cascade Head on the Oregon Coast. Annual capture of PAR is reduced by 13 to 42 percent in the western Cascades and by more than 69 percent in the eastern Cascades and Juniper Zone of central Oregon, where colder winters and seasonal drought limit the time that plants can photosynthesize (Runyon et al. 1994).

In contrast to forests, where the social interest in productivity focuses on the primary producers (i.e. the trees and other vegetation), in streams the interest is on secondary productivity (i.e., consumers, especially fish, which are further up the food chain). Although the primary producers in the surround them. Consequently, what managers do in forests on the slopes will have long-lasting direct and indirect effects on various forms of productivity in the streams.

Ecological Forces of Disturbance and Development

Forest disturbances

Disturbances come in all types, shapes, and sizes in Coast Ranges forests and watersheds (Table 3-1). Ecologists define disturbances as discrete events that disrupt ecosystem function, species composition, or population structure, and change resources, sites for establishment, or the physical environment (Pickett and White 1985). Disruptions are integral to the productivity and biological diversity of the Coast Range ecosystems. For example, disturbances of one size or another control much of the timing and patterning of tree regeneration. Disturbances are often described in terms of regimes. A disturbance regime indicates the pattern of a given disturbance agent over long time periods and relatively large areas (Pickett and White 1985). A disturbance regime is described by measurements of the intensity, timing, and spatial distribution of a particular disturbance agent. Disturbances common in the Coast Range include: fire, wind, disease, insects, landslides, debris flows, flooding, and the activities of vertebrates such as beavers, bears, and humans. Although the natural disturbances of the Coast Range are diverse, they can be classified into four categories based on the general type and ecological effect (Table 3-1). These major categories are: (1) fire, (2) canopy gaps and patches resulting from forces such as wind, disease, insects, or beavers, (3) soil disturbances from landslides and floods, and (4) inundation from floods. Two or more of these can happen simultaneously; for example, wind may blow a tree over, creating a canopy gap and disrupting the soil. Humans create a fifth type of disturbance, either directly through cutting and removal of trees in small to large patches, or indirectly through activities such as fire suppression, road building, and introduction of exotic pests (e.g. gypsy moth) that affect natural disturbance regimes. In this section, we will highlight what is known about natural disturbance regimes in the Coast Range forests and briefly discuss how they influence ecosystem function and biological diversity.

Ecological responses of vegetation to these disturbances will depend on the individual species and the kind of disturbance. For example, surface and understory fires may kill the cambium of thin-barked species such as western hemlock and western redcedar, but not that of Douglas-fir, which has thick bark. On the other hand, Douglas-fir may be more susceptible than western redcedar or red alder to wet soils created by flooding

Until the advent of large-scale logging and effective fire suppression in the middle part of the twentieth century, wildfires were the dominant disturbance in Coast Range forests. The return interval for fires in the Coast Range over the last 2,000 years prior to Euro-American settlement probably ranged between 90 and over 400 years, depending on the ecoregion (Agee 1993; Long et al. 1998). The moist spruce zone in coastal and northerly areas experienced longer intervals between fires, while fire was a more frequent visitor to the valley margin areas in eastern and south-eastern parts of the Coast Range. Fire intensity ranged from severe, in which fire killed more than 70 percent of the canopy trees (Figure 3-22 in color section following page 52), to light, in which surface fires killed few canopy trees. Where fires were more frequent, they may have been less severe (Agee 1993). This general pattern was observed by Impara (1997), who found that fires were more frequent in the drier, eastern portions of the central Coast Range than in the central and coastal areas, but that more old-growth trees were present in the eastern areas. Fires were typically quite large in size. Impara (1997) estimated that mean fire sizes ranged from 66 square kilometers (16,309 acres) to over 190 square kilometers (46,930 acres) in one study area in the central Coast Range. Many fires were larger than these mean values. A large fire that occurred between 1845 and 1849 is estimated to have burned over 500,000 acres between the Siuslaw and Siletz rivers (Morris 1934). These large fires in the mid to late 1800s set the stage for extensive 100- to 150-year-old Douglas-fir and hemlock forests seen today in many areas of the Coast Range.

The estimates of fire sizes and return intervals suggest that before Euro-American settlement, the Coast Range was a slowly shifting mosaic of large and small patches of forest vegetation, ranging from shrubby areas to dense old forests dominated by conifers. Although fire has been the major force in shaping the forests in previous centuries, the Coast management goals seek to maintain the range of native forest conditions and species, the challenge for managers will be to incorporate natural disturbances of different frequencies and sizes into management plans. This could be done in several ways. For example, young stands could be thinned in small groups to simulate gap disturbances or older stands could be harvested with a green tree retention approach to simulate low- to moderate-severity wildfire.

Tree death and decomposition

Every year more than 1.5 million trees greater than 25 centimeters in diameter probably die in the Coast Range from natural causes, based on inventory estimates of 322 million live trees (J. Ohmann, personal communication) and assuming an average annual mortality rate of 0.5 percent. The accumulations of dead trees can be quite high in coastal forests of all ages. For example, the mass of dead-wood accumulations in old-growth forests of the Coast Range can exceed 25 percent of the live-tree biomass. The ratio of dead wood to live biomass in young forests that originate following wildfire or blowdown is generally much higher (100 to over 1,000 percent). When trees die, the boles and large branches continue to influence ecosystem processes and biological diversity in many ways. In this section, we will briefly review the overall dynamics of dead wood in stands, including the processes of wood decomposition, and their ecological functions.

The amount of coarse woody debris (CWD) in unmanaged stands varies according to disturbance history, stand development, and site conditions (Spies et al. 1988; Figure 3-25). Consequently, it is difficult to establish standards and guides that represent the "natural" state, because there are many natural states. Amounts of CWD are typically highest not in old-growth forests but in young forests that originated following severe disturbances that killed most of the live trees of the previous mature or old-growth stands. However, amounts of CWD can also be very low in young stands in the Coast Range if the predisturbance stands were young, with little carryover of wood into the new stand, or if the stand was logged. Carryover of dead wood from the previous stand is a legacy that can persist for many decades or centuries. It can play an important role in providing habitat for species that use dead wood if the current stand is young or

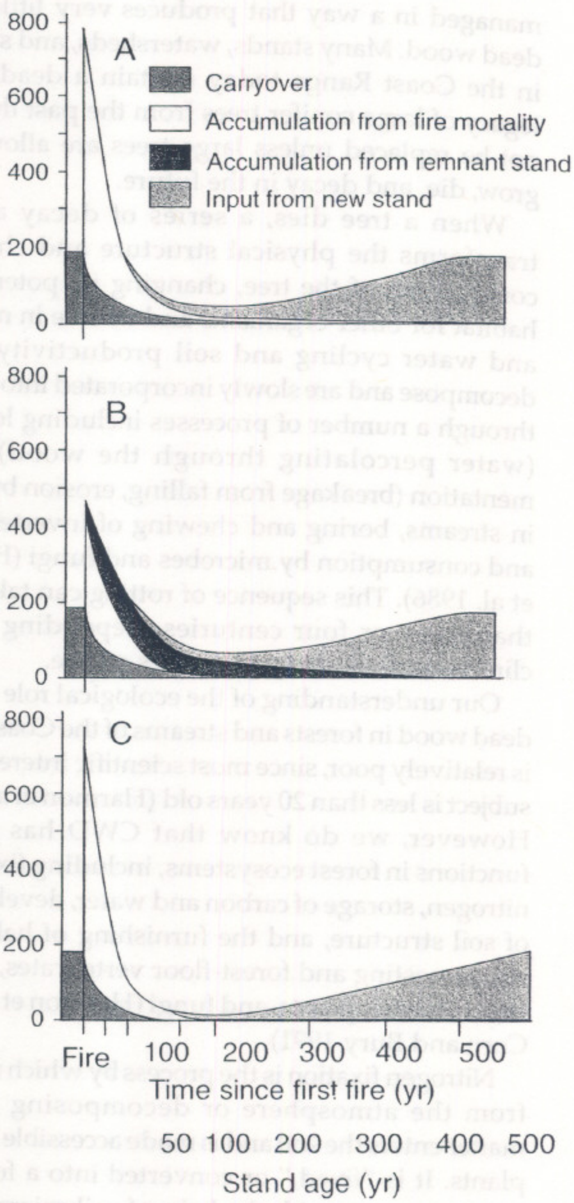


Figure 3-25. Dynamics of dead wood as a function of disturbance history (modified from Spies et al. 1988).

In summary, the CWD created by the death of trees plays many roles in Coast Range ecosystems. On moist, highly productive sites the role of CWD in forest growth appears relatively small. However, large dead wood appears to play a very important role in creating habitat for several species of plants and terrestrial and aquatic vertebrates, and for many more species of fungi and invertebrates. Our understanding of the ecological role of dead wood in the Coast Range comes from a few studies on a very limited number of sites and for a small number of species. We have only a qualitative grasp of the implications to forest management of a decline in stocks of dead wood or reduction in sizes of pieces in managed stands. In other words, we can state whether effects of management are positive or negative on stocks of dead wood and habitat potential, but we do not have quantitative ways to predict how ecological benefits will change as amounts of dead wood change. Consequently, managers face considerable uncertainty in making site-specific decisions regarding amounts and kinds of dead wood to leave or produce in these forests.

Forest development

Disturbance and succession go hand in hand. While they differ in many characteristics, all disturbances have the effect of killing or removing some or all of the existing vegetation and freeing up resources for the establishment and growth of new plants. Plant growth in the forest is limited by one or more resources, most commonly light, water, and nitrogen. From the viewpoint of a seedling trying to get started on the forest floor, both light and water are usually in very short supply. Disturbance, by removing some or all of the living plants, makes light and moisture more available and creates mineral or organic substrates for establishment.

After a disturbance, new plant growth is usually abundant in the Coast Range (Franklin and Dyrness 1988; Stein 1995). New plants may be residuals from the previous forest, or they may grow from seed that was already in the soil, or seed that is carried in by wind or animals after the disturbance. Dispersal distances for plants in the latter group are quite variable, from several kilometers for fireweed (*Epilobium angustifolium*) to just a few tens of meters for hemlock in closed forests (Schrader 1998). In the residual-origin group are most of the mature-forest herbs and shrubs as well as broadleaf trees; they sprout from underground rhizomes (e.g., salmonberry; Tappeiner et al. 1991), roots (blackberry [*Rubus* spp.]), and stumps (maple). Many of the early-successional herbs and shrubs such as ceanothus (*Ceanothus* spp.) (Gratkowski 1962) come from seed that has been in the soil since the last big disturb-ance, often many decades. Many early-successional herbs (e.g. fireweed) and both early- and late-successional trees (e.g., alder and hemlock, respectively) rely on the wind to disperse seed into new areas. Plants that produce berries, like cherry and salmonberry, rely on animals for dispersal.

The complement of species present or arriving after a disturbance is variable, depending on the nature of the disturbance (what residual propagules are left) and the presence of nearby seed sources. This initial complement determines the early course of succession.

Competition among plants for resources after a disturbance can quickly become intense. The window in time when resources are available in excess—the best time for new plants to get started—is very short. Many early-successional plant species grow quickly, filling empty space and using all available resources.

Salmonberry is one nearly ubiquitous shrub species in the Coast Range that has been well studied (Tappeiner et al. 1991; Zasada et al. 1994). It is a strong competitor with tree regeneration, and its growth habitat is similar to that of several other common clonal plants (e.g. salal, bracken fern, and snowberry [*Symphoricarpos albus*]). Although salmonberry produces seed that are dispersed by birds, it regenerates after disturbance most often by sprouts from an underground rhizome. In a vigorous stand of salmonberry, a square meter of ground can have 10 meters of rhizome with buds every few centimeters. Salmonberry, well adapted to surviving disturbance, is usually among the first plants to colonize disturbed areas. The salmonberry rhizome is protected from most fire, and it contains lots of stored energy for quick growth after a disturbance. And because the plant contains such an abundance of buds on the rhizome, a disturbance such as a landslide, which breaks up a salmonberry patch and moves it around, rapidly spreads plants to new areas.

After a disturbance in a forest initiates a new plant community, the process of succession begins. This long sorting process is determined largely by the different abilities of species to colonize after a

Table 3-2. Expected percentages of landscape in different age classes in relation to fire interval (Van Wagner 1978).

Interval between wildfires (yrs)	*Age class of forest (yrs)*					
	> 80	*> 100*	*> 150*	*> 200*	*> 250*	*> 400*
	Expected percent of landscape					
50	20	14	5	2	<1	<1
100	45	37	22	14	8	2
150	59	51	37	26	19	7
200	67	61	47	37	29	14
250	73	67	55	45	37	20
300	77	72	61	51	44	26
350	79	75	65	56	49	32
400	82	78	69	61	53	37

in between these extremes. Fires tended to be large and stand replacing (Impara 1997). Shade-tolerant seed sources were probably patchy so succession to hemlock and redcedar forests may have been slow and sometimes truncated by succession to shrubs following senescence of short-lived shade-intolerant red alders.

If the frequency of stand-replacing disturbances is known, it is possible to estimate the amount of different successional stages or age classes of forest that have occurred in the past, or that might occur in the future landscape. Van Wagner (1978) developed a mathematical formula to calculate age-class distributions in landscapes based on the frequency of wildfires. In its simplest form, this model assumes that fire frequency is equally likely at any stand age. This assumption means that when a fire occurs in a landscape, some old stands may escape and some young stands may get burned, which is a scenario that has occurred frequently in the Coast Range. Under this scenario, a landscape will contain a percentage of forest that is older than the typical fire rotation. For example, in a landscape with a fire frequency of 150 years, about 30 percent of the landscape will be older than 200 years (Table 3-2).

A change in fire regime (e.g., frequency or intensity) can alter the development of forests. The control of fire in the drier parts of western Oregon has already resulted in some major changes in the composition and dynamics of forests and will certainly result in further changes. In southwest Oregon, fire control has increased the density of the understory and, in some places such as the eastern Oregon ponderosa pine forests, this understory growth is competing with overstory trees and competition is beginning to kill some trees (J. Tappeiner and T. Sensineg, personal observation). In the central and northern Coast Range, historic fire has made hemlock less common than it would be otherwise. Over the next century or more, fire control on lands managed for old-growth forest may result in an increase in hemlock and a concomitant reduction in regeneration of Douglas-fir.

Predicting compositional changes in succession in the Coast Range is not as easy as we might think. Figure 3-27 shows a complex web of pathways for vegetation change in the central and northern Coast Range. There is no single, linear pathway of change. Rather, depending on the disturbance type and intensity (i.e., the amount and distribution of available resources) and the available seed sources, several pathways are possible. For example, if fire and hemlock seed source are both lacking, succession in both alder and Douglas-fir stands can lead to a shrub-dominated community.

Influence of human activities

In the last 100 years, extensive human activities have become a dominant disturbance in the Coast Range. Presettlement activities by Native Americans and early patterns of Euro-American settlement and land use have left their mark on today's forested landscapes. Native Americans frequently burned the Willamette Valley grasslands and oak woodlands and the adjacent dry Douglas-fir forest of the foothills of the Coast Range (Boyd 1986; Agee 1993). However, according to Agee (1993), "…the case for widespread aboriginal fires throughout the wetter part of the Douglas-fir region is not convincing." Fire was thought to be used primarily to improve hunting and encourage growth of edible plants (Agee 1993; Robbins 1997). Burning by Native Americans stopped upon the arrival of Euro-Americans, who set fires of their own to clear land and to remove logging slash to prevent subsequent fires. Organized fire protection and regulation of

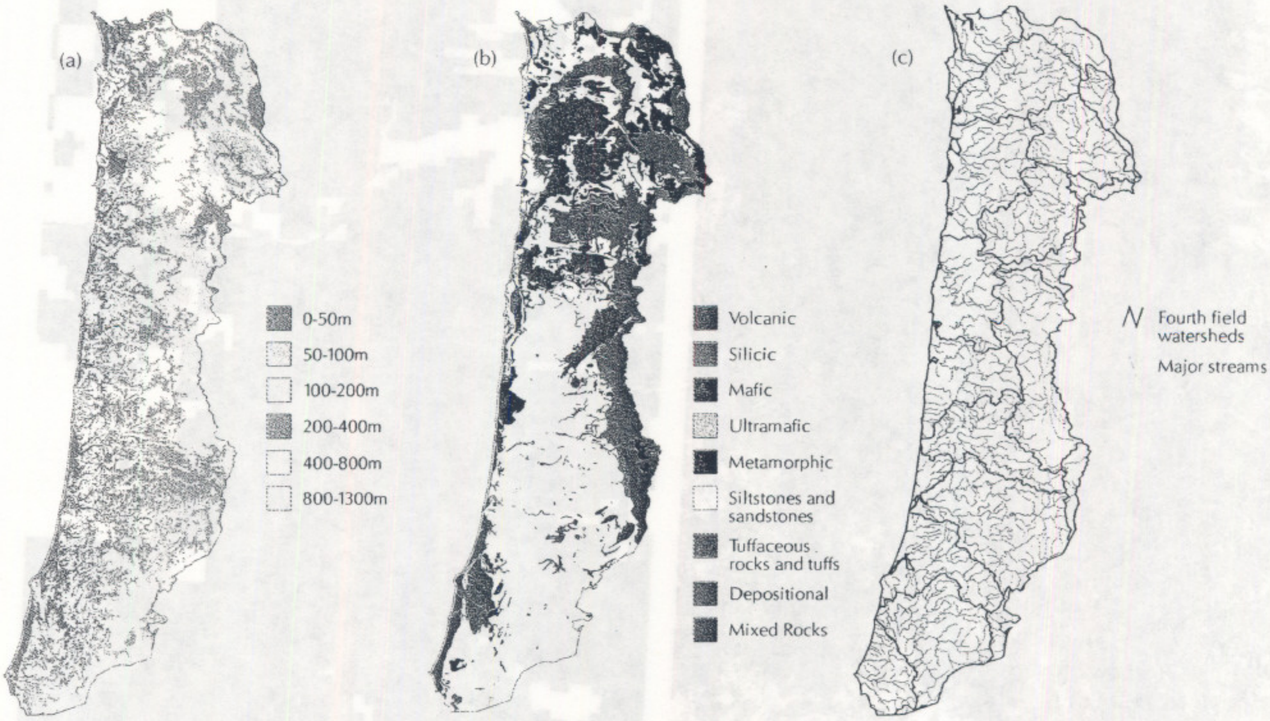


Figure 3-1 (a) Elevation (m) from digital elevation model of the Oregon Coast Range, 90-m resolution; (b) Geologic types, modified from Walker and MacLeod (1991). Red = igneous: volcanic and intrusive rocks; brown = igneous: silicic rocks (granite, diorite, rhyolite, dacite); violet = igneous: mafic rocks (basalt, basaltic andesite, andesite, gabbro); tan = igneous: ultramafic rocks (serpentine); black = metamorphic; yellow = sedimentary: siltstones, sandstones, mudstones, conglomerates; medium green = sedimentary: tuffaceous rocks and tuffs, pumicites, silicic flows—miocene and older; purple = depositional: dune sand, alluvial, glacial, glaciofluvial, loess, landslide and debris flow, playa, lacustrine, fluvial; dark green = mixed rocks (unspecified); and (c) Fourth-field hydrologic units (HUCs).

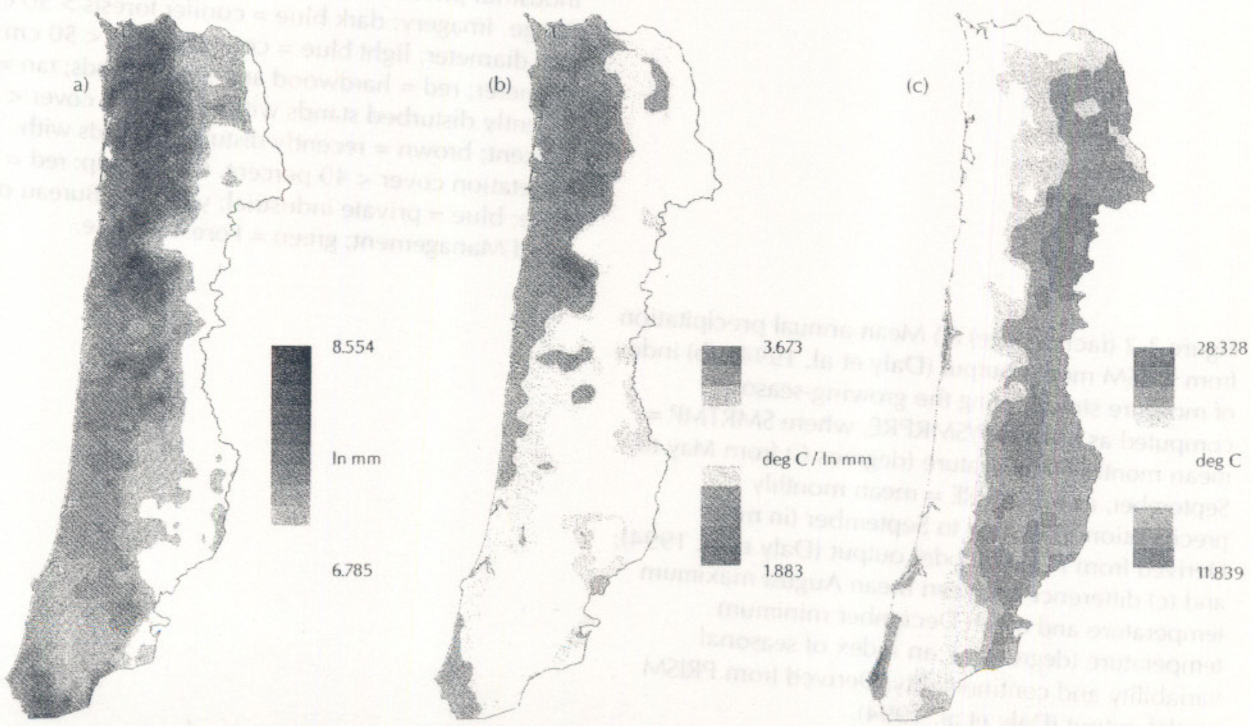


Figure 3-5. Patterns of vegetation (from Landsat TM satellite imagery) and stream drainages in the Cummins Creek Wilderness area, Siuslaw National Forest.

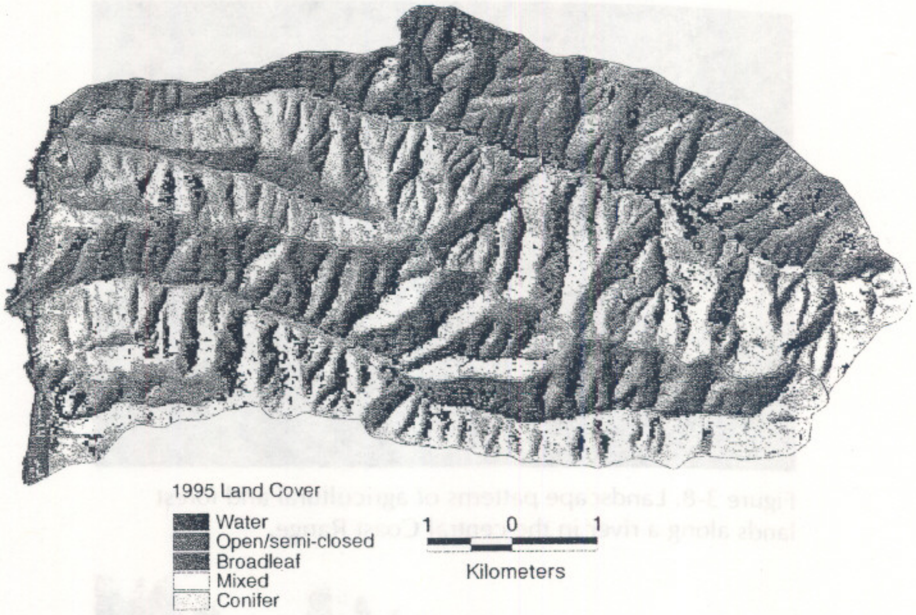


Figure 3-6. Distribution of plant communities in relation to topographic position and aspect in the western hemlock zone of the central Coast Range (adapted from Hemstrom and Logan 1986).

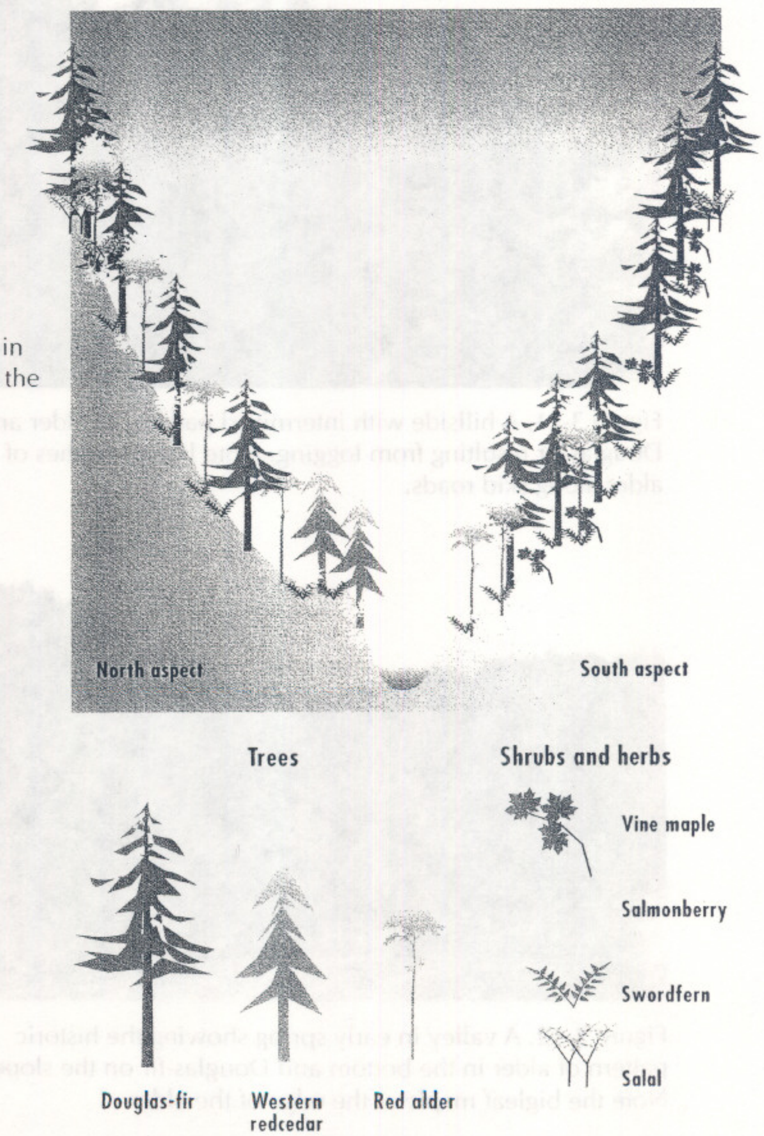


Figure 3-14. An older planted mix of red alder and Douglas-fir on this nitrogen-poor site resulting in Douglas-fir trees twice the normal size.

Figure 3-15. White oak in the foothills, a resource for wildlife and people.

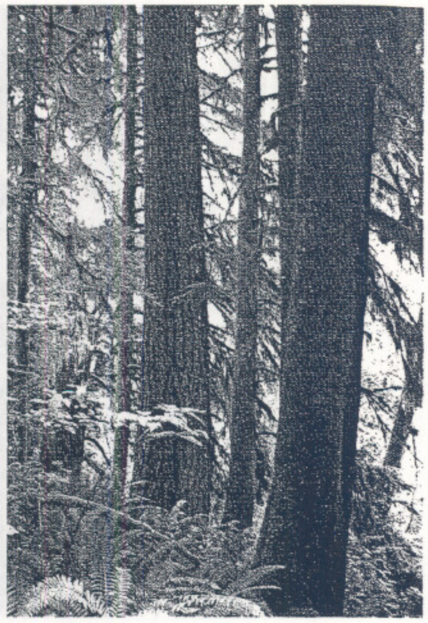
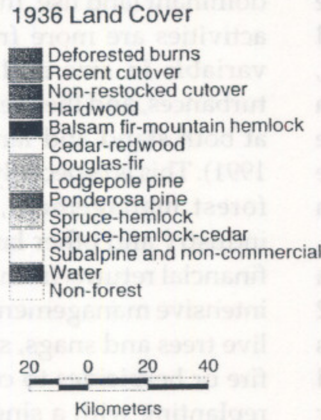


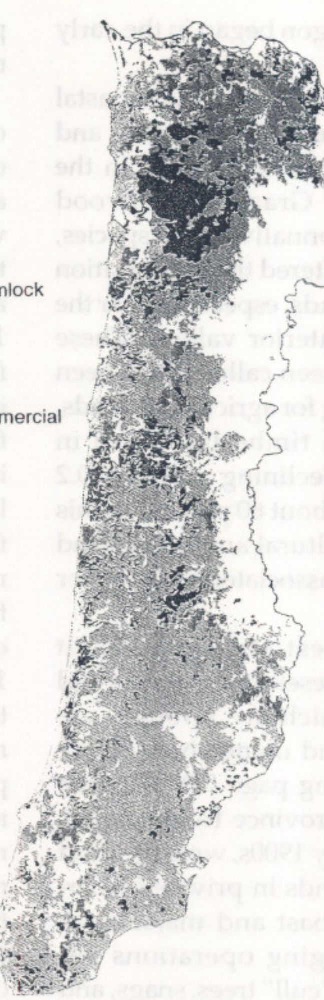
Figure 3-19. 120-year-old Douglas-fir/western hemlock stand on productive site in the Drift Creek watershed.

Figure 3-20. Douglas-fir site index map of western Oregon (Anonymous 1946).

Figure 3-21. Densely vegetated stream in the Oregon Coast Range.

Figure 3-29. Forest vegetation patterns in 1936 (U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station).





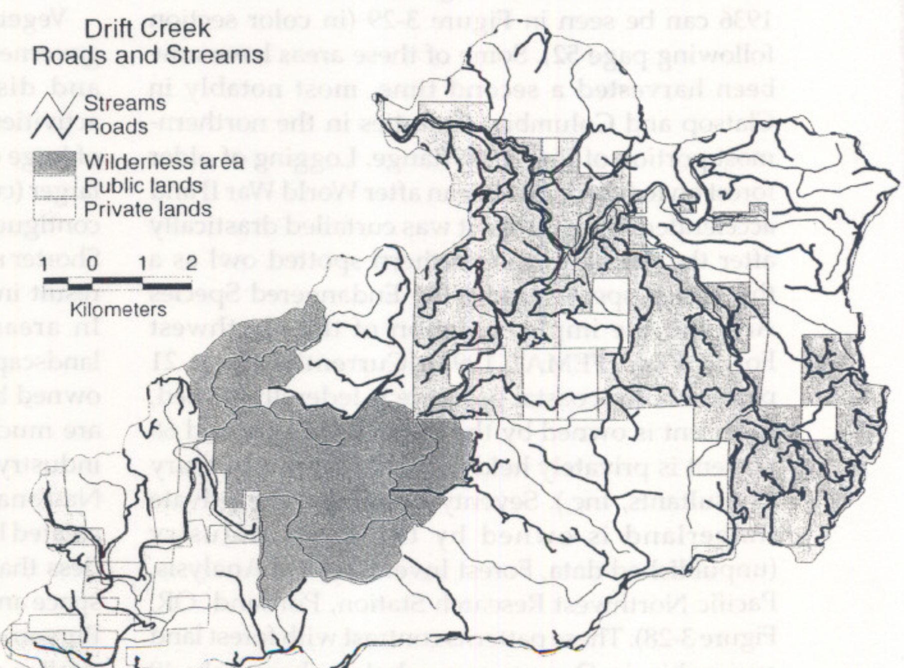


Figure 3-30. Three levels of road network development in the Drift Creek watershed, Oregon Coast Range: high level of development (road network to access complete forest harvest over entire area) (private lands), moderate (roads restricted to major ridges in area with less than 50 percent forest harvest) (public lands), and no road or forestry development (Wilderness Area).

licated by the section-by-section checkerboard of BLM land holdings, which results in a landscape of patchy older forests mixed with young forests on the adjacent private lands.

As of the mid-1980s, 12 percent of the nonfederal timberland in the coastal province was in an early-successional structural stage (approximately zero to 15 years old), 82 percent was mid-successional (approximately 15-80 years), and only 6 percent was late-successional (approximately more than 80 years; unpublished data, Forest Inventory and Analysis, Pacific Northwest Research Station, Portland, OR). Virtually all forest lands in private ownership have been harvested at least once in the past and current forests on these lands are less than 80 years old. Most of the scattered large, live trees, snags, and down logs that remain on nonfederal lands are the legacy of earlier logging of older forest. These stand structures are gradually decaying and are not being replaced (Ohmann et al. 1994). Most remaining late-successional forest in the coastal province is concentrated on federal lands, where it covers about 30 percent of the land area (T. Spies, unpublished data). Old-growth forests (more than 200 years old) cover only approximately 6 percent of the federal lands in the Coast Range (Siuslaw National Forest 1999). Under the Northwest Forest Plan, most of the early- and mid-successional forest on federal lands is being managed to accelerate the development of characteristics of late-successional forest.

Across the entire Coast Range, tree species are distributed along climatic gradients (Ohmann and Spies 1998). Within particular stands, however, timber management influences the relative abundance of species, although few species are totally eliminated from a site by logging (Ohmann and Bolsinger 1991; Ramey-Gassert and Runkle 1992; Halpern and Spies 1995). Intensive forest management aims to shift stand composition to the most valuable timber species: Douglas-fir across most of the province and western hemlock in the northwestern portions of the province. Harvested sites in the Coast Range that are not successfully regenerated to conifers are generally dominated by pioneer hardwood species, primarily red alder, or by shrubs such as blackberry, salmonberry, or salal. Planting of Douglas-fir over the last few decades on coastal sites historically dominated by western hemlock and Sitka spruce is believed to be contributing to spread of Swiss needle cast, a native forest pathogen. This foliage disease results in Douglas-fir needle loss, reducing tree growth and in some cases causing death. Incidence of laminated root rot (*Phellinus weirii*) is also believed to be increasing in coastal forests, in part due to forest management activities. This pathogen kills Douglas-fir in small patches, creating gaps in forest canopies. Spread of these tree diseases may force forest managers to convert many Douglas-fir plantations to hemlock or other conifers in the case of Swiss needle cast, or to broadleaf species such as red alder in areas where laminated root rot is a problem (A. Kanaskie, personal communication).

Watershed and Landscape-scale Processes

Influence of roads on ecosystem function at multiple scales

Forest roads have served many positive functions, including access for extraction of wood and other forest products, silvicultural activities, fire detection and suppression, and recreation. The unintended negative impacts of roads on forest ecosystems and watersheds include effects on water runoff (Harr et al. 1975; King and Tennyson 1984; Jones and Grant 1996; Wemple et al. 1996, Bowling and Lettenmeier 1997), surface erosion and attendant impacts on fish habitat (Reid and Dunne 1984; Duncan et al. 1987; Bilby et al. 1989; Foltz and Burroughs 1990), landslide initiation (Dyrness 1967; Swanson and Dyrness 1975; Megahan et al. 1978; Sessions et al. 1987), invasion of forest landscapes by exotic species (Forcella and Harvey 1983; Tyser and Worley 1992; Parendes 1997), spread of pathogens, wildlife dispersal, mortality due to collisions or hunting, and a range of other factors (Transportation Research Board 1997). Much is known about the layout, design, construction, and maintenance of roads in forest landscapes from engineering points of view. Various studies have focused on road location and improved engineering practices to reduce effects of roads on watersheds (Silen 1955; Burroughs et al. 1984, Swift 1984; Sessions et al. 1987, Piehl et al. 1988). In this discussion, we comment on effects of road networks on the ecosystems of steep forest landscapes with regard to movement of water, sediment; earth flows, exotic plants, and pathogens.

Extensive road networks are now widespread in Pacific Northwest landscapes. In developed parts of the Coast Range, for example, Freid (1994)

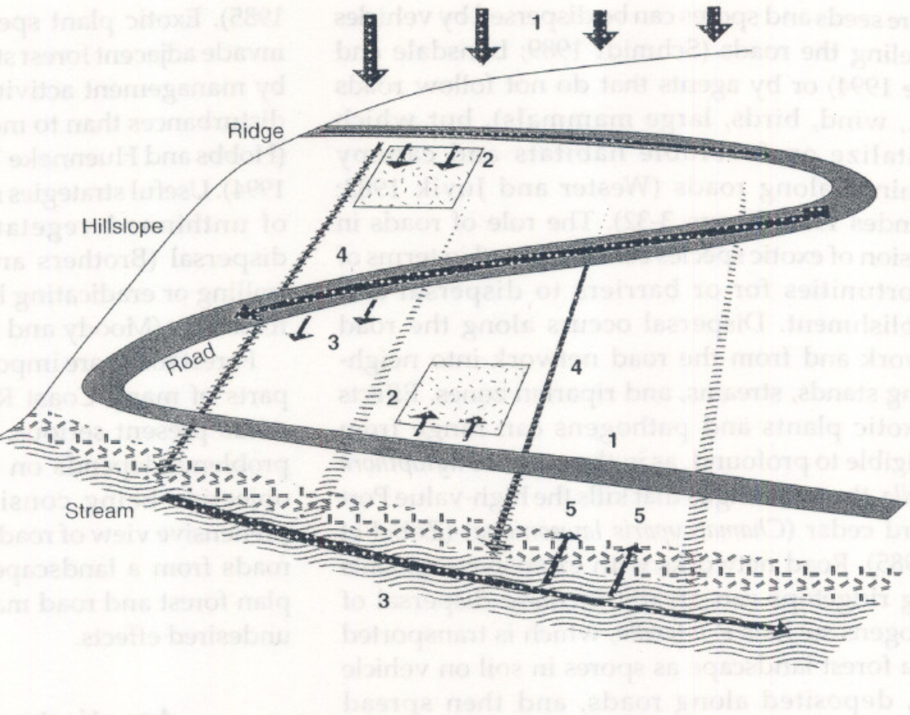


Figure 3-32. Schematic view illustrating movement of propagules via roads and associated air currents, animals and streams. Roads may function to (1) collect and transport propagules by air currents, animals or vehicles (cross pattern), (2) move propagules into clearcuts (confetti pattern) adjacent to roads, (3) move propagules into roadside forest (white), (4) move propagules into streams (wave pattern), and (5) deliver propagules to riparian forests (bird's foot pattern).

roads in increasing the number of flow paths through interception of subsurface water movement at roadcuts and conversion of it to surface flow along ditches that reach natural streams (Wemple et al. 1996; Bowling and Lettenmeier 1997). These changes in water routing through watersheds may alter the timing and magnitude of peak streamflows (King and Tennyson 1984; Jones and Grant 1996). Assessment of road-related erosion events during the February 1996 flood in the Cascade Range reveals that (1) the frequency and diversity of erosion events along road segments are greater the lower the road is situated on the hillslope, and (2) roads at near-ridge and especially midslope positions are net sources of sediment and channelized mass movements (debris flows); roads along valley floors tend to trap sediment and impede movement of debris flows before they can reach main channels and contribute to aquatic processes (B. Wemple, personal communication).

These and related observations of how roads function in landscapes have significant management implications. The position of a road segment relative to the flow paths of water, sediment, and mass movements can strongly influence site-specific engineering decisions. Roads near ridges in some surveyed landscapes have the lowest hydrologic and landslide impacts; hence, they may deserve lowest priority for erosion-control and watershed-restoration measures. On the other hand, locating roads near ridges in landscapes where sliding commonly begins in the oversteepened heads of stream channels, such as in the sandstone formations of the Coast Range, may cause increased sliding (Montgomery 1994). Managers should assess the potential for landslides to wash out bridges. If the potential is high, it may be prudent to design stream crossings to accommodate debris flows and minimize damage when they occur. Where the potential for debris flows is high, it may be prudent to design structures to accommodate debris flows and minimize damage when they occur. Intensive use of water bars may decrease slide damage to little-used roads by reducing the delivery of water to potential slide sites (Siuslaw National Forest 1997).

Roads appear to foster movement of some exotic plant and pathogen species into forest landscapes transition area between the riparian zone and the upland area and is a zone where vegetation still influences the stream under some conditions (Gregory et al. 1991).

The width of the riparian zone and the extent of the zone of influence are related to stream size and valley morphology (Naiman et al. 1992). Small, headwater streams (i.e. first and second order) have relatively small riparian zones (Figure 3-18). However, while the amount of riparian zone for such a stream may be small, the total amount of riparian area in a watershed can be extensive because of the abundance of such streams (Figure 3-33). First- and second-order channels may compose more than 90 percent of the total stream network. These small channels are strongly influenced by terrestrial vegetation. Mid-order channels (third- to fifth-order) have larger riparian areas (Figure 3-18), which are determined by long-term channel dynamics, annual discharge, and valley morphology. Unconstrained reaches, those characterized by a low gradient and a wide valley, generally have larger riparian zones than more confined, steeper reaches. Larger rivers and streams (greater than sixth order) have well-developed floodplains and terraces that contain diverse riparian vegetation. The extent of the riparian zone is directly related to the size and complexity of the floodplain (Naiman et al. 1992).

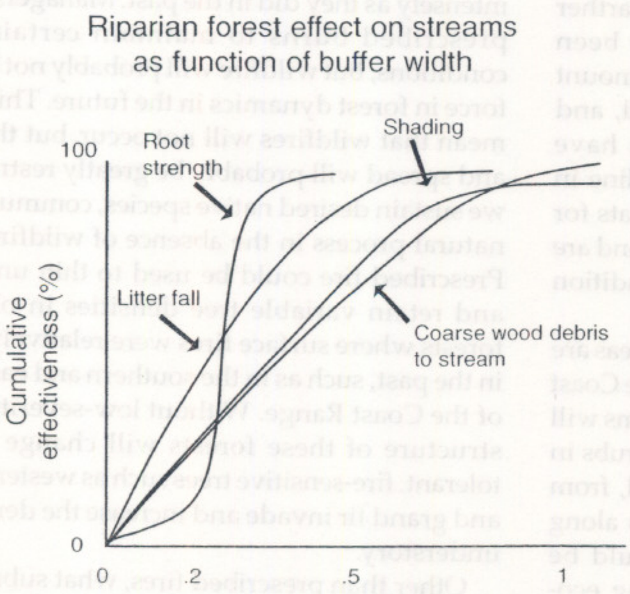


Figure 3-34. Generalized relation between distance from stream and ecological functions (FEMAT 1993).

Riparian vegetation has many functions in the aquatic ecosystem. It increases bank stability and resistance to erosion by two mechanisms: large and fine roots bind soil particles together, helping to maintain bank integrity during high flows (Swanson et al. 1982), and stems and branches which enter the stream increase roughness in the channel, reducing the erosion potential of flowing water (Spence et al. 1996). Litter from riparian vegetation provides major sources of energy for biota in streams. The quality, quantity, and timing of litter delivered to channels depend on vegetation type, stream orientation, valley topography, and stream morphology (Naiman et al. 1992). Deciduous and herbaceous materials decompose more quickly than coniferous inputs (Gregory et al. 1991). Riparian vegetation and downed wood in the riparian zone trap sediments and reduce the likelihood of landslides (Swanson et al. 1982). In addition, riparian vegetation controls the amount of solar radiation that reaches the channel, which in turn influences water temperatures and primary productivity (Beschta et al. 1987). These biotic and physical factors exert a strong influence on the structure and composition of biological communities in all sizes of streams.

The effect of riparian vegetation on the aquatic functions varies with distance from the channel (FEMAT 1993; Figure 3-34). Litterfall and bank stabilization are provided by vegetation closest to the stream. Shade and large-wood sources are influenced by a wider band of vegetation that extends further upslope.

Movement of materials from riparian areas to stream channels occurs both continuously and episodically. Litter input occurs throughout the course of the year, although input of deciduous materials occurs predominately in a 6-8 week period in the fall (Naiman et al. 1992). Large-wood input is both continuous and episodic. Single or small groups of trees fall periodically as a result of disease or wind and flooding. The relative importance of episodic and continuous inputs of wood and sediment into a given stream varies according to topography, geology, soil type and depth, and vegetation type. Large episodic inputs will be more pronounced in steeper, more unstable watersheds and less prominent in more stable areas.

Coast Range in the last 100 years. Silvicultural practices such as thinning, patch cutting and green-tree retention, and some clearcutting can substitute for some aspects of partial disturbances and large, severe fires, creating, for example, large patches of early-successional forest. However, we now know that traditional clearcutting disturbances have little similarity to wildfires. Although clearcutting removes the canopy and increases light at the forest floor, it differs from wildfires in many ways, most importantly in that clearcutting does do not leave the large live trees and dead wood that wildfires did. These legacies probably helped maintain habitat at stand and landscape levels for species such as pileated woodpeckers, ensatina salamanders, foliose lichens, fungi, and invertebrates. Consequently, new management practices such as green-tree retention (leaving one to 10 or more large trees per acre in cutting units), maintaining riparian buffer strips, and leaving live and dead conifers on a logging site make the effects of logging disturbances more similar to those of wildfires than traditional methods.

While it may be possible to imitate the dynamics and effects of wildfire at the stand level, it is far less clear how well we can do this at the landscape level. At this large a spatial scale we encounter the whole diversity of ecosystems and disturbance patterns. We know much less about the dynamics of forests at landscape scales and the effects of those dynamics on forest attributes such as upland and aquatic habitats. We do know that return intervals of natural disturbance have been much more variable (ranging from 5 to over 500 years) than are those determined solely by timber management objectives, which promote a single type of disturbance on a regular cycle of 40 to 60 years. The current mix of forest policies and practices in the Coast Range appears to provide for a certain range of disturbance intervals, with long rotations on federal and state lands and short rotations on private industrial lands. However, even with this greater temporal variation in disturbance regime, disturbances within large blocks of land will be relatively constant over time. One type of disturbance regime will be found on one area and a very different type on another area, according to ownership pattern. Can native species and processes be maintained if disturbance frequencies remain spatially relatively constant, between ownerships? Maybe. However, there is evidence that whole watersheds must occasionally cycle through a full range of successional stages if high-quality fish habitat is to be sustained (Reeves et al. 1995).

We now know that watershed disturbances such as landslides and debris flows help maintain aquatic habitats by delivering coarse sediments and large pieces of wood to streams. It is becoming increasingly clear that landslides originating in certain kinds of small, intermittent stream drainages have been a major source of large wood and coarse sediments in higher-order streams. Will streams provide the same quality of habitats they have in the past if landslide frequencies change (increase or decrease) and the wood delivered to streams declines in amount and size? Probably not. Will current forest practices on public and private land provide watershed processes and dynamics that meet aquatic conservation goals? Maybe. Are there alternatives to landslides for creating aquatic habitat? Yes, but they may not be practical over large areas or for long periods of time. Stream habitat can be engineered to some degree by placing large tree boles or boulders at selected points within stream networks. These structures probably can improve stream habitat quality in some localities for short periods of time. However, such structural enhancement of streams is difficult to do over large areas, and the added structures may function only until a flood transports them downstream or pushes them onto the floodplain. Developing management systems that incorporate landslides and debris flows containing large wood may be the best long-term solution.

Finally, it is clear that natural processes of vegetation development must be better understood if managers can hope to reach a goal of retaining native species and communities. Late-successional communities characterized by large trees, multiple canopy layers, and large amounts of dead wood require many centuries to develop. Some of these features, such as large trees and multiple layers, can be accelerated through silvicultural practices such as thinning of young plantations. This approach, which is practiced most commonly on federal and state lands, can probably be used in conjunction with long rotations (more than 120 years) to provide habitat for species that find optimum conditions in older forests. However, there may be a limit to the late- successional species or population numbers that can be maintained in stands created by accelerating habitat development. Some organisms

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