

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

dynamics will differ among climatic and geological zones and management plans and practices will, in many cases, differ as a result.

Forest ecosystem patterns

The ecosystems of the Coast Range vary over spatial scales ranging from ecoregions (e.g. the coastal Sitka Spruce [*Picea sitchensis*] Zone) (Franklin and Dyrness 1988) to microsites. This variability is important for several reasons. The diversity of environments and biological communities enables different species with different needs to coexist. Variation poses challenges for forest management plans and monitoring activities which must be tailored to different environments (coastal, interior, riparian, upslope) and different spatial scales (stands, landscapes, watersheds, ecoregions) if they are to achieve their objectives. Knowledge of how ecosystems vary with spatial scale or extent is important because scale affects management potential: a greater diversity of ecosystem values can be produced in an area the size of the entire Coast Range than in an area the size of an individual stand or a small watershed.

Broad-scale vegetation patterns follow climatic patterns in the Coast Range (Ohmann and Spies 1998). Forest vegetation, which is strongly dominated by conifer species, varies most strongly along a gradient of summer moisture stress, annual precipitation, and seasonal temperature, ranging from the southwest interior to the north coast. Woody plant species on the dry end of this gradient (southwest interior) include Oregon white oak (*Quercus garryana*), Pacific madrone (*Arbutus menziesii*), and poison oak (*Rhus diversiloba*) (Figure 3-3). Those on the moist end (north coast) include Sitka spruce, western hemlock (*Tsuga heterophylla*), false azalea (*Menziesia ferruginea*) and salmonberry (*Rubus spectabilis*). Additional regional variation in vegetation is influenced by soil and geological factors such as coastal dunes, which support communities of grasses, shrubs, and shore pine, and wet soils around the Willamette Valley floor which support communities dominated by Oregon ash (*Fraxinus latifolia*) (Ohmann and Spies 1998).

Ecologists recognize three major vegetation zones in the Coast Range, which are named after the dominant tree species of the late-successional stage of development in that environment (Franklin and

Figure 3-3. Occurrence and distribution of (a) all plots, (b) Oregon white oak, (c) madrone, (d) Sitka spruce and (e) western hemlock in forest plots in the Oregon Coast Range.



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.

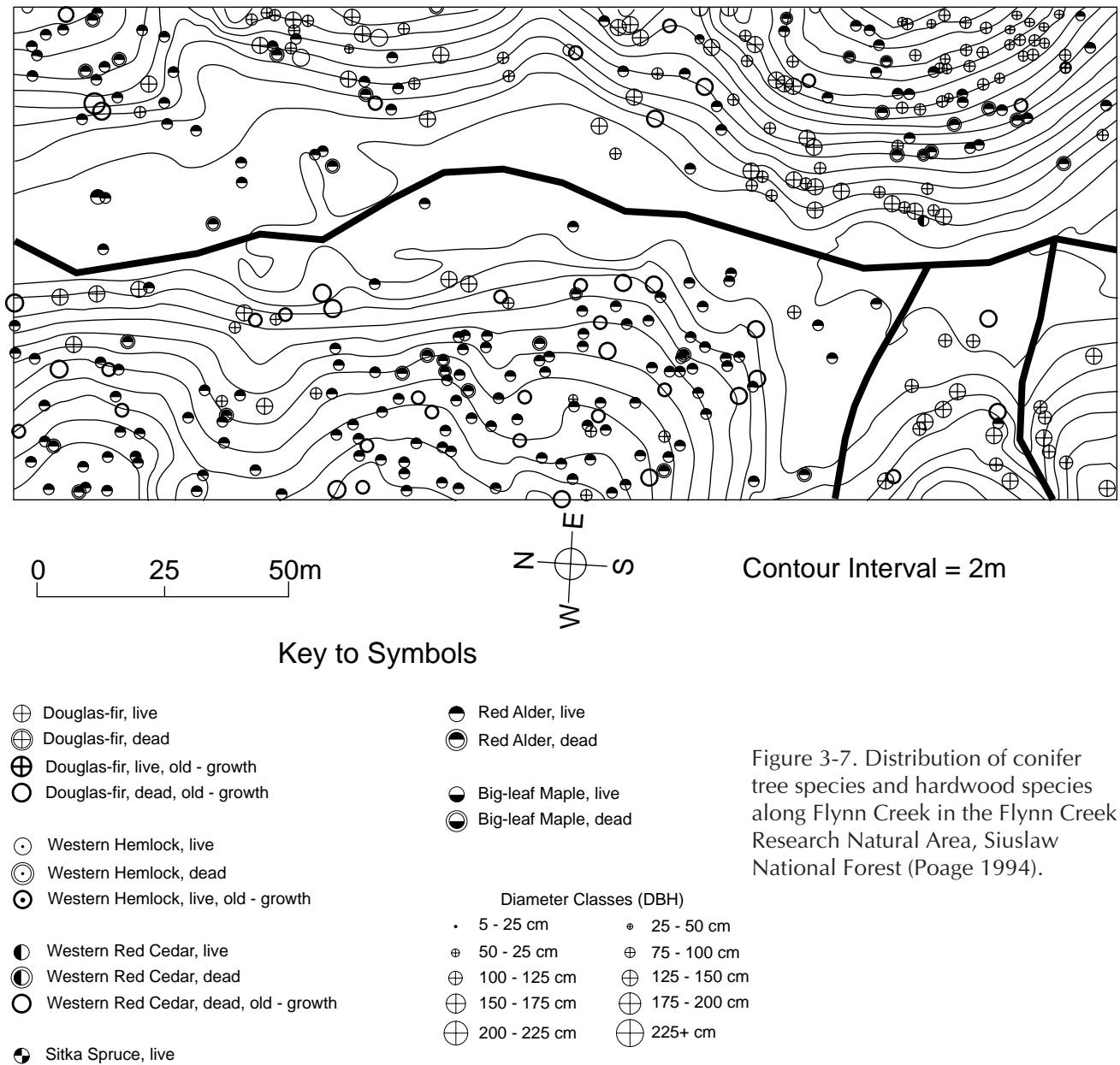


Figure 3-7. Distribution of conifer tree species and hardwood species along Flynn Creek in the Flynn Creek Research Natural Area, Siuslaw National Forest (Poage 1994).

Forests of the Coast Range may be thought of as a kaleidoscope of vegetation at different spatial scales. The patterns are constantly changing over time scales which span from decades to many centuries. Our ability to sustain desired levels of species diversity and ecosystem values is greatly dependent on the degree to which policymakers and managers take into account this dynamic mosaic in their plans and silvicultural practices. For example, at the regional level, it is clear that management practices appropriate for the interior and drier parts of the Coast Range will not be appropriate for the moist west slope and fog belt. Douglas-fir, which is the foundation of timber management throughout

most of the Coast Range, will become a less important timber species in moist areas of the western slopes as Swiss needle cast (*Phaeocryptopus gaumannii*) drastically reduces growth rates in these areas (G. Filip, personal communication). Hemlock, on the other hand, is resistant to the disease and has relatively good growth rates on these sites. At landscape and watershed scales, dry sites may have a lower potential to develop large amounts of down wood than moist, lower slope positions but they may have a higher potential for developing shrubs which provide food and cover for wildlife species. The potential for conifer stands to develop near streams is somewhat lower than it is in mid- and

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

the large-scale features of the Earth's climate that arise from a particular configuration of the large-scale controls of the climate system. In paleoclimatic research, the large-scale controls of interest are the variations in the seasonal cycle of insolation (produced by variations in the Earth's orbit around the Sun), the area covered by land and sea ice, atmospheric composition, and surface albedo (energy of reflected light) that occurred during the last 20,000 years (COHMAP Members 1988). The GCM simulations of full-glacial and Holocene climate conditions incorporate different configurations of these controls to show their influence on the position of the jet stream and the strength of atmospheric circulation features in northwestern North America for particular time periods (Thompson et al. 1993; Bartlein et al. in press).

The Oregon Coast Range has only a few records that describe past vegetation and climate based on pollen analysis (Heusser 1983; Worona and Whitlock 1995). An intensively studied site is Little Lake in Lane County, a landslide-dammed lake at 210 meters elevation and 45 kilometers inland from the

Pacific Ocean. A 17-meter-long core from Little Lake spans the last 42,000 years, based on a series of radiocarbon dates and the known age of the Mazama ash, which is present in the core. Pollen studies from this core identify the nature of vegetation changes in the central Coast Range before, during, and after the last glacial maximum (Worona and Whitlock 1995; Grigg and Whitlock 1998). A detailed charcoal analysis of the sediments provides a record of fire history for the last 9,000 years (Long et al. 1998).

The Holocene Epoch, the last 11,000 years, has the greatest bearing on our understanding of modern ecosystem dynamics, because plant taxa (species or genera) that grow today in the region have been dominant throughout this period. Between 11,000 and 6,400 years ago, the Little Lake record revealed Douglas-fir, alder, oak, and bracken fern (*Pteridium* sp.) in higher proportions than occur in modern (2,400 years ago to present) pollen samples from the site. The charcoal record, which begins at 9,000 years ago, indicates that fires in the early Holocene were relatively frequent, with a

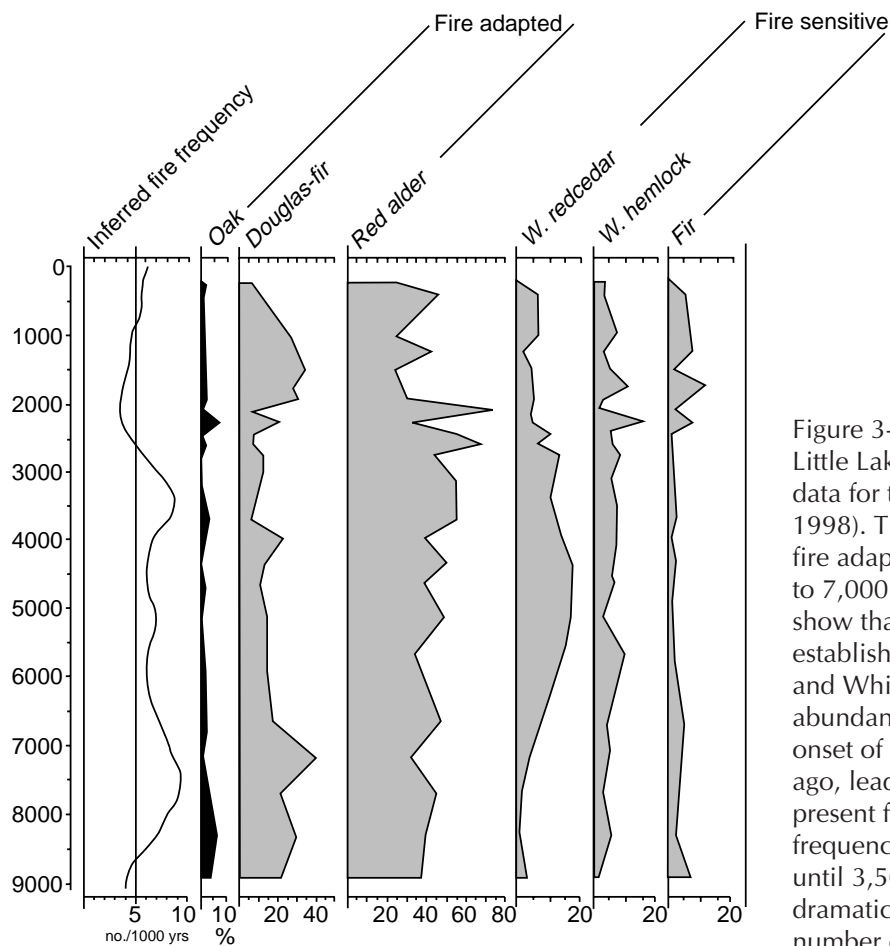


Figure 3-10. Fire and vegetation history at Little Lake based on charcoal and pollen data for the last 9,000 years (Long et al. 1998). The data show warm dry conditions, fire adapted species and frequent fires prior to 7,000 years ago. Longer pollen records show that these warm conditions were established about 11,000 years ago (Worona and Whitlock, 1995). Increases in the pollen abundance of fire-sensitive taxa imply the onset of cool wet conditions at 7,000 years ago, leading to the development of the present forest 2,400 years ago. Fires frequency, however, continued to be high until 3,500 years ago, when it dropped dramatically. In the last 2,000 years the number of fires has increased.

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

associations and competitive interactions have been dismantled and reformed. Our assessment of the present ecological condition of our forests should not focus on their geological age, which is a few thousand years and relatively short in terms of species generation times. Rather, we should consider their compositional diversity and structural complexity, which arose from a long history of adjustment of the species to changes in climate.

Finally, the records from Little Lake and other sites indicate that fire occurrence is closely tied to climate. The frequency of fires has fluctuated according to climatic shifts throughout the Holocene. In restoring natural fire regimes to forested ecosystems, we should recognize that studies based on tree ages and fire scars (Poage 1994; Impara 1997) sample only a small part of the prehistoric record and provide information on no more than the last stand-replacing event. The Little Lake record suggests that fires have become more frequent in the last 2,000 years, occurring about every 160-190 years. This fire regime would have produced a forest of mixed age classes at the time of Euro-American settlement. Prior to 2,000 years ago, a mean fire interval of 275-300 years in the Little Lake area suggests more extensive old-growth forests.

It would be impossible to recreate the coastal forests that existed at some point in the past, even if we could describe previous forest conditions perfectly (which we cannot) or knew the role of Native American activity precisely (which we do not). Restoration of forests based on some distant past mix of species and structures is untenable because the current set of climate conditions is unique on both centennial and millennial time scales. We cannot reconstruct the forests of the Little Ice Age, Medieval Warm Period, or the early Holocene, because the climate and disturbance regimes now are different than then. The paleoecologic record argues instead that natural ecosystems are best managed as dynamic systems, which in the Coast Range includes the possibility of changes in species' ranges and abundance and the occurrence of large stand-replacing fires because of global climate change.

The role of deciduous vegetation

One's first impressions of the Coast Range forests may be of conifers—Sitka spruce, western hemlock, and especially Douglas-fir. The landscape is

dominated by conifers, and most research and management has focused on them. Yet the Coast Range also contains 14 species of broadleaf hardwood trees, each with a distinct ecology and ecological role (Niemiec et al. 1995). They are red alder (*Alnus rubra*), big-leaf maple (*Acer macrophyllum*), black cottonwood (*Populus trichocarpa*), bitter cherry (*Prunus emarginata*), Pacific madrone, Oregon white oak (*Quercus garryana*), Pacific dogwood (*Cornus nuttallii*), white alder (*Alnus rhombifolia*), black oak (*Quercus kelloggii*), tanoak (*Lithocarpus densiflorus*), golden chinkapin (*Chrysolepis chrysophylla*), Oregon ash (*Fraxinus latifolia*), California-laurel (*Umbellularia californica*), and cascara (*Rhamnus purshiana*).

Two of these species, red alder and big-leaf maple, have quite large ranges, occurring over almost all of western Oregon. The others have much more limited ranges, although in specific locations each can be numerous. For example, Pacific madrone can be relatively common on dry sites in the southeastern portion of the Coast Range. Commercial markets exist for most of these species although only red alder occurs in enough volume to support a commercial industry.

Historically, the ranges of these species have been relatively stable for several thousand years although the abundances appear to have fluctuated, sometimes dramatically. Pollen records show that the present species composition has been in place for about 6,000 years (see below and Worona and Whitlock 1995) but abundance of each species appears to have varied by as much as 50 percent over periods of a few centuries. No one is sure of the cause of these variations but variation in fire regimes is a likely explanation.

The area covered by red alder probably increased greatly in the twentieth century as early forestry practices opened up favorable regeneration sites on slopes (Figure 3-11 in color section following page 52). Before this logging, some alder was seen on slopes, but most of it was probably restricted to riparian areas, where more frequent disturbance provided sites for regeneration (Figure 3-12 in color section following page 52). Before Euro-American settlement, Coast Range riparian areas appear to have contained a lot of alder with the amount increasing with stream size.

In southwest Oregon, forestry practices in the first two-thirds of the twentieth century increased the dominance of tanoak, madrone, and oaks (Hobbs

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.

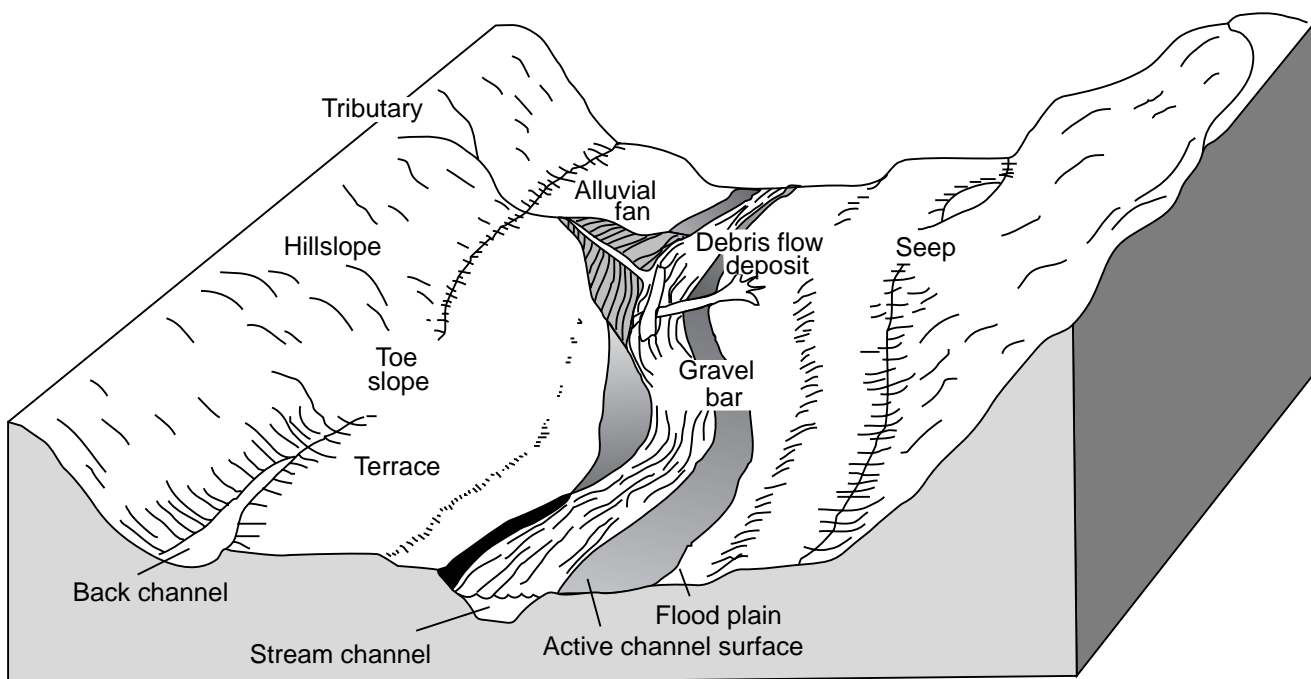
Coast Range hardwoods play a variety of ecological roles. Perhaps best known is alder's ability to fix nitrogen (Binkley et al. 1994). Alder uses bacteria housed in nodules on its roots to convert atmospheric nitrogen into ammonia at rates as high as 200 kilograms per hectare per year (approximately 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 (Guntow-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.



there is often a strip of alder trees immediately adjacent to the stream (D. Hibbs, personal observation). This alder is the primary source of bank-stabilizing roots; Douglas-fir is not sufficiently flood tolerant to play this role.

The nitrogen fixed by alder enters the stream in litter and groundwater, playing a role in regulating stream productivity (Gregory et al. 1991). Because deciduous hardwood leaf litter is readily decomposed, it is a major energy source for invertebrates. Alder produces more litter than Douglas-fir and therefore is a better source of food to the aquatic food chain (Zavitkovski and Newton 1971). Being deciduous, alder allows light to reach the stream in the spring and fall for in-stream photosynthesis and its leaves maintain shade in summer, when stream-temperature concerns are greatest. Hardwoods often provide the branches and small logs that transform a large conifer log into an effective sediment trap or complex hiding cover for wildlife.

Riparian forests

Riparian forests are distinctive ecosystems that thread through the coniferous landscapes of the Coast Range. The vegetation of these forests is shaped by forces originating within and beyond stream corridors. Floods, debris flows, and channel migration create landforms and expose or deposit substrates along streams (Figure 3-16). Landslides

and other processes deliver sediment, wood, water, and nutrients to riparian areas from hillslopes. Other disturbances such as fire, wind, and pathogens influence both riparian and upland environments. The diversity of disturbances and unique environmental conditions that typify riparian areas are reflected in the patterns of vegetation. Riparian forests differ from upland forests in species composition, structural attributes, and consequently, in the way they function. In this section, we highlight what is known about the structure and composition of riparian forest vegetation in the Coast Range, and discuss the reasons why these patterns exist.

Riparian forests in the Coast Range are characterized by a mixture of hardwoods, conifers, and shrub-dominated openings. Tree densities are usually lower near the stream than further upslope, and conifers increase in dominance with distance and height from the stream (Figure 3-17) (McGarigal and McComb 1992; Minore and Weatherly 1994; Pabst and Spies, 1999). Conifer basal areas in mature, unmanaged riparian forests average 8-12 square meters per hectare within 5 meters of the stream, and 25-40 square meters per hectare within 30 to 50 meters of the stream. Hardwood basal areas range from 8 to 18 square meters per hectare over the same distances, but do not show clear trends with distance from the stream. These patterns of distribution are strongly related to landform over much of the Coast

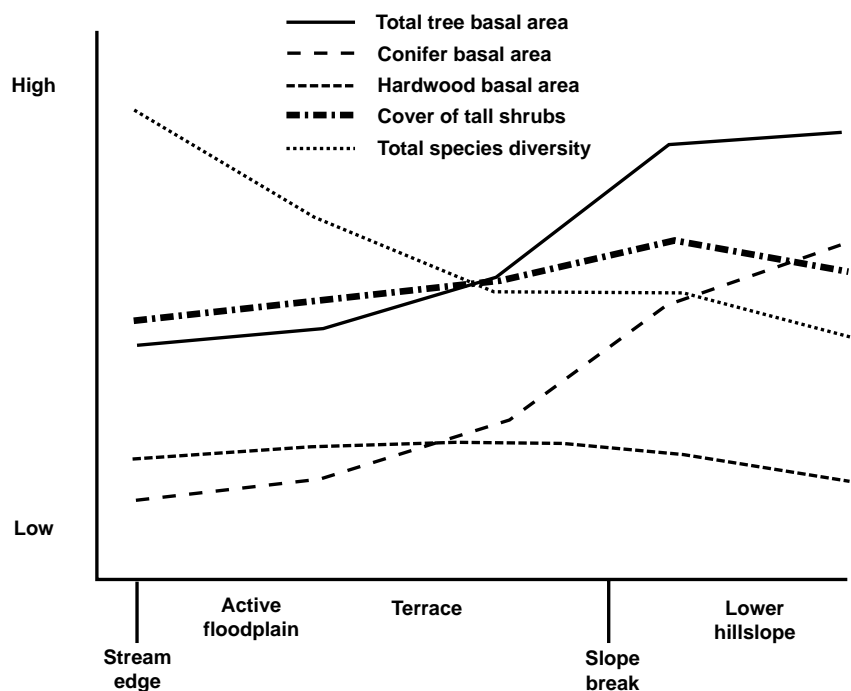


Figure 3-17. Generalized relationships between riparian forest attributes and distance from stream and landform.

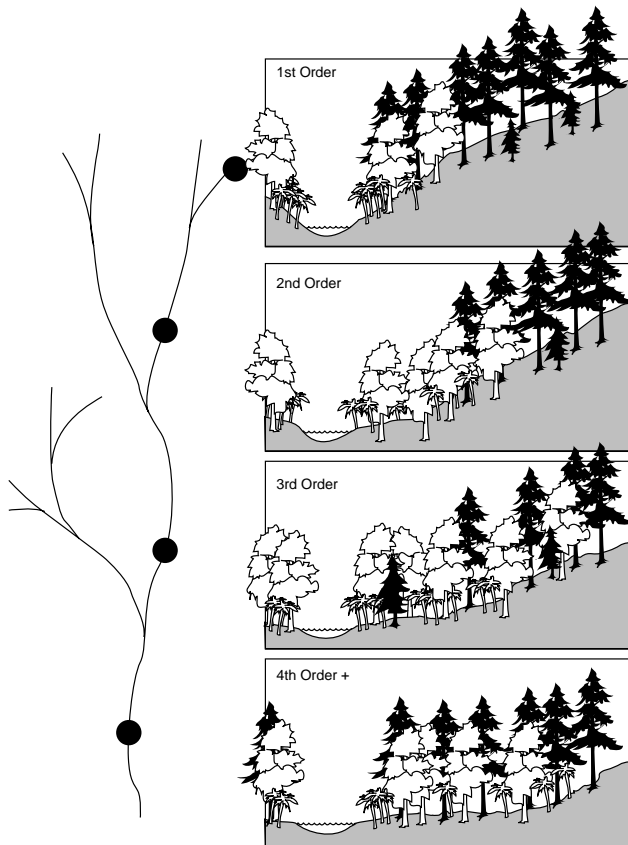


Figure 3-18. Stream valley cross-sections from first to fourth-order streams.

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

unique environments that are uncommon on hillslopes.

Species composition is also influenced at broader scales by factors such as climate. For instance, riparian forests in or near the coastal fog belt (within a few kilometers of the ocean) have more Sitka spruce than elsewhere in the Coast Range, whereas those at the eastern and southern fringes have more grand fir (*Abies grandis*). In addition, there appear to be less red alder and salmonberry in riparian forests at the southern extreme of the Coast Range than in the north.

Coast Range riparian areas are difficult sites for tree establishment because of competition from shrubs (especially salmonberry), herbivory, and seed source limitations for some species. Where conifer regeneration does occur, it is usually at sites with large conifers (Minore and Weatherly 1994), particularly shade-tolerant conifers (Pabst and Spies 1999). Shade-tolerant species dominate conifer regeneration, whereas Douglas-fir (a shade-intolerant species) is uncommon (Minore and Weatherly 1994; Hibbs and Giordano 1996; Pabst and Spies 1999). Conifer regeneration is generally absent under dense cover of shrubs or hardwood trees. It is most prevalent on large, rotting, conifer logs, which provide an elevated, and possibly less-competitive, environment than the forest floor. Hardwood regeneration is dominated by red alder, which is found most frequently on newly exposed mineral substrates of floodplains and gravel bars.

In summary, compared to upslope areas, riparian forests of the Coast Range are characterized by lower densities and basal areas of live and dead trees, greater cover of shrubs, less tree regeneration, and higher diversity of plant species. Many of these stand attributes vary with landform, proximity to the stream, and location within both the stream network and the region. Hardwoods and shrubs seem better adapted than conifers to the disturbance regimes and soil moisture conditions of most riparian areas; thus, the competitive balance is tipped in their favor. For management purposes, it is important to recognize how the factors determining vegetation patterns are connected in the landscape, not only along stream networks, but between streams and adjacent hillslopes.

Productivity of Coast Range Forest and Stream Ecosystems

Ecosystem productivity is the source of the values and the goods and services, both market and non-market (Daily 1997), that we obtain from forests. In general, the more productive the ecosystem, the more goods and services it can supply. The Coast Range is among the most productive forest ecosystems in the world; it has the capacity to produce huge quantities of wood, the most common and easily quantified measure of forest productivity. However, the Coast Range ecosystem also produces large quantities of vegetation other than wood, as well as wildlife, fish, and water. This high output is a result of the climate and soil of the region. The high forest productivity of the Coast Range makes it a desirable location to produce timber for economic and social benefits (Figure 3-19 in color section following page 52). It also provides opportunities to produce nontimber values more rapidly and in greater quantity than most forest ecosystems in the Pacific Northwest. For example, large trees, which are important as the habitat of some wildlife and fish species, can develop more rapidly in the Coast Range than almost anywhere else in the region. In this section, we examine the basis of the high productivity of the Coast Range for both timber and nontimber resources.

Productivity of ecosystems can be defined in several ways. Net ecosystem productivity is the accumulation of matter in a given period of time by green plants (net primary productivity) plus the secondary accumulation of matter by other organisms including arthropods, insects, and vertebrates (net secondary productivity) that consume the primary production (Perry 1994; Barnes et al. 1998). In forests, net primary productivity, the most easily measured of the two, consists of the growth increment of plants, the fine and coarse litter (leaves, branches etc) they shed, the trees that die, and the plant parts consumed by other organisms. In stream ecosystems, algae, rather than trees, are the photosynthetic factories that capture sunlight and produce organic matter. Primary productivity in small streams is strongly controlled by conditions of the surrounding forest through its influence on light and nutrient inputs. As streams become larger, and are less shaded by vegetation, their primary productivity increases.

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

streams, the algae, play an important role in fish productivity, fish production is also influenced by many other factors as well, including habitat, temperature, oxygen, and mortality rates. Net primary productivity of streams in the Coast Range and other areas of western Washington and Oregon is relatively low in contrast to streams in other parts of the world (Gregory et al. 1987). The low net primary productivity of forested streams may be a consequence of the high productivity of the forests because stream productivity is strongly related to how much sunlight reaches the water. Net primary production is higher in open stream reaches; net primary productivity within recent clearcuts, deciduous forests, and closed coniferous forests averaged 210, 58, and 26 milligrams of carbon per square meter of stream surface per day, respectively (Gregory et al. 1991). In contrast, net primary productivity in a coastal coniferous forest has been measured at 1,800 milligrams of carbon per square meter per day (based on Fujimori et al. 1976). In steep, narrow coastal streams with dense conifer shade, the light reaching the stream may be less than 5 percent of full sunlight (Figure 3-21 in color section following page 52; Naiman and Sedell 1980). In larger, more open streams where red alder is dominant and in watersheds where forest cover has been removed by some disturbance, net primary productivity increases. This increased production of organic matter may move up through the food chain to produce more fish (Murphy and Hall 1981). However, productivity of fish is also related to in-stream habitat structure and temperature and thus may decline following disturbances even if net primary productivity of the stream increases (Gregory et al. 1987). Stream productivity is also

influenced by inputs of fine and coarse litter from streamside and upslope vegetation. Leaves from herbs and deciduous shrubs and trees are important sources of energy and nutrients (especially nitrogen) to streams and are more readily decomposed than conifer needles (Gregory et al. 1991). Large wood contributes to stream productivity by forming dams that retain litter and sediment in the stream ecosystem and creating complex channels that are important in forming prime salmonid spawning and rearing habitat.

Although the primary productivity of streams in the Coast Range is relatively low, the Coast Range watersheds are capable of producing large amounts of fish biomass. Around the year 1900, the number of adult salmonids returning annually to coastal Oregon streams was estimated at 1,385,000 coho (*Oncorhynchus kisutch*) and 305,000 chinook (*Oncorhynchus tshawytscha*) (Lichatowich 1989). This represents over 15 million pounds of fish, assuming an average weight of 10 pounds. In the past, when many of these fish made their way into coastal streams and ended up as carcasses on the shore, they provided a source of food and nutrients for predators and scavengers, thus contributing to the productivity of the ecosystem as a whole (Willson and Halupka, 1995).

In summary, the Coast Range is one of the most productive forest ecosystems in the world, making it an ideal place to grow trees for profit and to produce wildlife species that use large live and dead trees. In contrast to the forests, the streams have relatively low productivity, largely as a result of shading by dense coniferous canopies. The productivity that these streams do have is greatly dependent on the terrestrial ecosystems that

Table 3-1. Examples of different kinds of natural disturbance agents in the Coast Range, by ecological categories.

Fire	Canopy gaps from wind, diseases, insects or animal damage	Soil disturbances	Inundation by water and sediment
Surface fires	Wind snap, breakage	Wind throw	Flooding
Understory fire	Root-rot mortality	Landslides	Deposits left by floods and debris flows
Crown fire	Death and damage from Douglas-fir bark beetle, Swiss needle cast, and Sitka spruce weevil	Debris flow	Inundation of riparian areas from beaver dams
	Herbivory by large vertebrates (beaver, elk, bear)	Stream bank failure Erosion from floods	

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 Range 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 southeastern 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

Range would not ever have been totally covered by recently burned and young forests. In fact, it is estimated that the amount of old forest (more than 200 years old) probably ranged from 25 to 75 percent during the last 3,000 years (Wimberly et al. 2000).

Although wildfires have often killed trees over large areas, giving rise to landscapes of early successional forests, localized, more-frequent disturbances of canopy trees have played and continue to play important roles in advancing forest succession and creating habitat for animal species that use dead trees and multiple-layered forests. The death of individual trees and small groups of trees during stand development is a common and necessary process. During the first 100 years in the life of a moderately well-stocked stand of Douglas-fir, more than 90 percent of the trees will die from competition, disease, insects, and other causes. It may take another 400-900 years for the remaining Douglas-firs to die if there is no intervening stand-replacing disturbance. As the large trees in the canopy die, especially in middle-to-late stages of stand development, canopy openings are created that do not close from expansion of crowns of the surrounding trees. The resulting gaps are sites of increased light and moisture availability in the forest (Gray and Spies 1997) and they offer potential sites for invading shrubs and trees.

In western Oregon, canopy gaps in mature and old forests range between 0.0025 and 0.25 hectares in size (Spies et al. 1990; Taylor 1990; Figure 3-23 in color section following page 52). Near the coast, where high winds are more common, gap sizes are probably larger. In mature and old-growth forests, canopy gaps may cover 13 to 29 percent of the forest. Gaps can form at an annual average rate of 0.2 to over 1.0 percent. Thus, a point may experience a gap event every 100 to 500 years, or about the same average interval as wildfires of the past. The frequency of gap-forming events varies by topography, especially near the coast, where gaps caused by wind disturbance are more common on ridgetops and upper slopes than in lower slope positions (Ruth and Yoder 1953; Taylor 1990).

Tree species composition of coastal forests is influenced as much by gap dynamics as it is by larger-scale disturbances. For example, Taylor (1990) found that hemlock could regenerate in both small and large gaps, but that Sitka spruce could regenerate only in large gaps from 800 to 1,000 square meters in size. The occurrence of dis-

turbances that create large gaps is apparently frequent enough to maintain spruce in the canopy of these forests. Douglas-fir probably requires very large gaps (more than 1,000 square meters) to regenerate and grow into the canopy (Spies et al. 1990). Gap formation, however, does not always lead to tree regeneration. Schrader (1998) found no relationship between abundance of gaps and hemlock regeneration in a survey of Douglas-fir stands 40 to 200 years old in the Coast Range. Other factors such as presence of seed sources, density of the shrub layer, and presence of rotted woody debris were more important than abundance of gaps in explaining the pattern of hemlock regeneration (Figure 3-24 in color section following page 52). In addition, seedling regeneration in gaps does not necessarily mean the trees will reach the canopy. In many forests, small canopy gaps will close after a few years and young trees will reach the canopy only if subsequent gap-forming events occur near the site of the initial tree regeneration.

Other disturbances that disrupt the forest floor and soil layers, such as windthrow, landslides, and floods, also are important to forest dynamics in the Coast Range, but rates, frequencies, and consequences of these types of disturbance are less well known. Landslides within intact, mature forests are typically less than 100 cubic meters in volume or 100 square meters in area (Swanson et al. 1981; Robison et al. 1999) and are confined to steep narrow low-order stream drainages. Landslides and other disturbances that expose mineral soil may be important to the maintenance of deciduous shrub and tree species, including salmonberry and alder, by providing establishment and colonization sites within the dense coniferous forests. Beavers (*Castor canadensis*) are also an important and often overlooked force in shaping the structure and dynamics of riparian and aquatic habitats. These rodents were quite common in the Coast Range in the past and are increasing in abundance again. Although beavers kill trees, they also can facilitate development of rearing habitat for coho salmon by creating large pools behind their dams (Leidholt-Bruner et al. 1992; Naiman et al. 1992). In addition, the breaching of beaver ponds exposes bare substrates for establishment of herbs, shrubs, and trees in riparian areas.

In sum, the structure and composition of the forests of the Coast Range are shaped by disturbances of many kinds and at many scales. Where

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

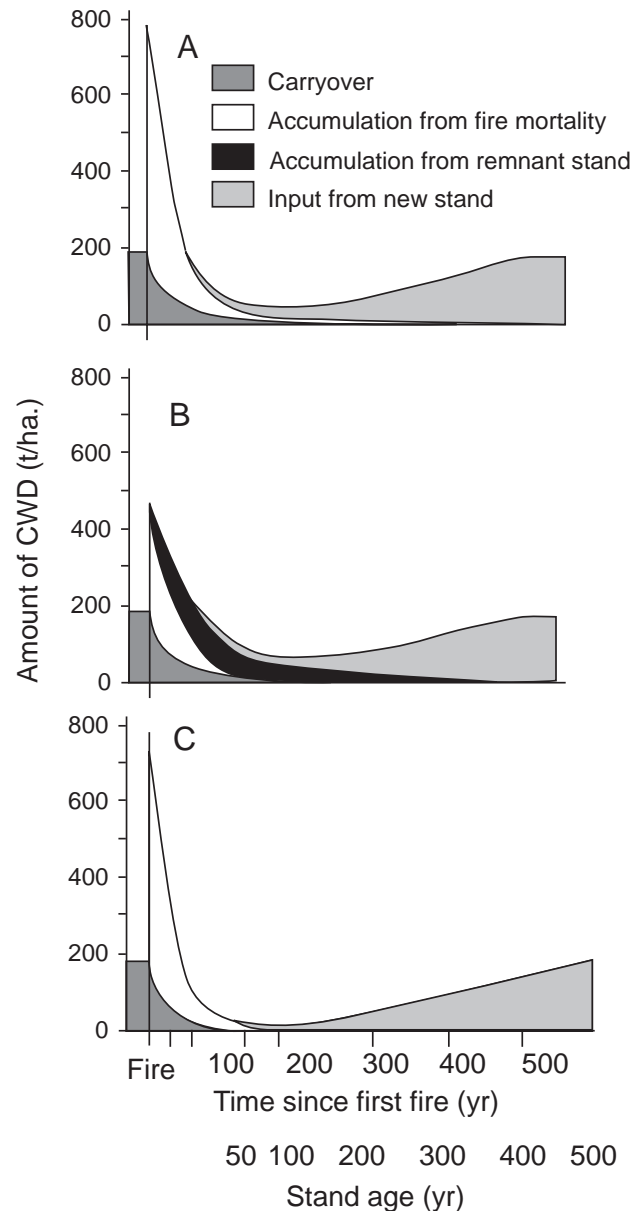


Figure 3-25. Dynamics of dead wood as a function of disturbance history (modified from Spies et al. 1988).

managed in a way that produces very little large dead wood. Many stands, watersheds, and streams in the Coast Range today contain a dead wood legacy of large conifer trees from the past that will not be replaced unless large trees are allowed to grow, die, and decay in the future.

When a tree dies, a series of decay actions transforms the physical structure and chemical composition of the tree, changing its potential as habitat for other organisms and its role in nutrient and water cycling and soil productivity. Trees decompose and are slowly incorporated into the soil through a number of processes including leaching (water percolating through the wood), fragmentation (breakage from falling, erosion by water in streams, boring and chewing of invertebrates), and consumption by microbes and fungi (Harmon et al. 1986). This sequence of rotting can take more than three or four centuries, depending on the climate and the size and species of tree.

Our understanding of the ecological role of large dead wood in forests and streams of the Coast Range is relatively poor, since most scientific interest in the subject is less than 20 years old (Harmon et al. 1986). However, we do know that CWD has several functions in forest ecosystems, including fixation of nitrogen, storage of carbon and water, development of soil structure, and the furnishing of habitat for cavity-nesting and forest-floor vertebrates, and for invertebrates, plants, and fungi (Harmon et al. 1986; Corn and Bury 1991).

Nitrogen fixation is the process by which nitrogen from the atmosphere or decomposing organic matter enters the soil and is made accessible to living plants. It is "fixed," or converted into a form that plants can use, with the help of soil microbes that sometimes interact symbiotically with the roots of certain plants. Nitrogen fixation occurring in CWD can add 1 kilogram per hectare per year of nitrogen to conifer ecosystems in the Pacific Northwest. Although this is a relatively small amount, it can be an important contribution in some nitrogen-limited conifer forests of western Oregon. In the Coast Range, where nitrogen levels in soils and inputs of nitrogen from precipitation are relatively high (but availability for plant growth is still limiting) the effect of input of nitrogen via fixation may be relatively small (Grier 1976; Harmon et al. 1986). Generally, CWD has a low nutrient content and a slow decomposition rate, suggesting that it plays a minor role in nutrient cycling during forest

development, except perhaps following catastrophic disturbances, when large amounts of CWD are produced (Harmon and Hua 1991). Unlike its role in habitat, the role of CWD in site productivity in the Coast Range is unclear. In one modeling effort for a site containing old-growth spruce and hemlock near the coast, merchantable yield was 5 percent higher after six 30-year rotations when CWD was left after clearcutting of the initial stand than when the CWD was removed (Harmon et al. 1986). The effect of wood removal on productivity might actually be greater than indicated by the model because the model assumed that CWD actually made nitrogen unavailable during early stages of decomposition, whereas recent research indicates that the nitrogen leaches out of CWD throughout decomposition (M. Harmon, personal communication).

The role of standing and down dead wood as habitat for cavity-nesting birds such as pileated woodpeckers (*Dryocopus pileatus*) is well known (Maser et al. 1988), but its role in habitat for mammals, amphibians, plants, fungi, and invertebrates is less well known (Figure 3-26 in color section following page 52). Large decayed tree boles on the ground can function as seedling establishment sites in dense shrub layers in riparian forests (Pabst and Spies 1999). In the Coast Range, clouded salamanders (*Aneides ferreus*) are most often found under the bark of large Douglas-fir logs, while ensatina salamanders (*Ensatina eschscholtzii*) are associated with well-decayed logs (Corn and Bury 1991). The abundance of some fungal species differs with decay state and species of down logs in western Oregon (Harmon et al. 1994). It has been reported that species of mosses and lichens are associated with large down logs in boreal coniferous forests in Sweden (Esseen et al. 1997), but it is not known whether these associations also occur in the Coast Range. Several invertebrate species in European forests prefer dead tree boles of a particular size and state of decay (Heliovaara and Vaisanen 1984), but these relationships also are poorly known in the Pacific Northwest. In general, it is thought that large pieces of down wood (50 to more than 100 centimeters in diameter) are more biologically valuable than small pieces because of their longevity and the diversity of their substrates (thick bark, sapwood, and heartwood). However, accumulations of small down wood may also provide important habitat features for some wildlife species such as small mammals (A. Carey, personal communication).

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 disturbance, 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

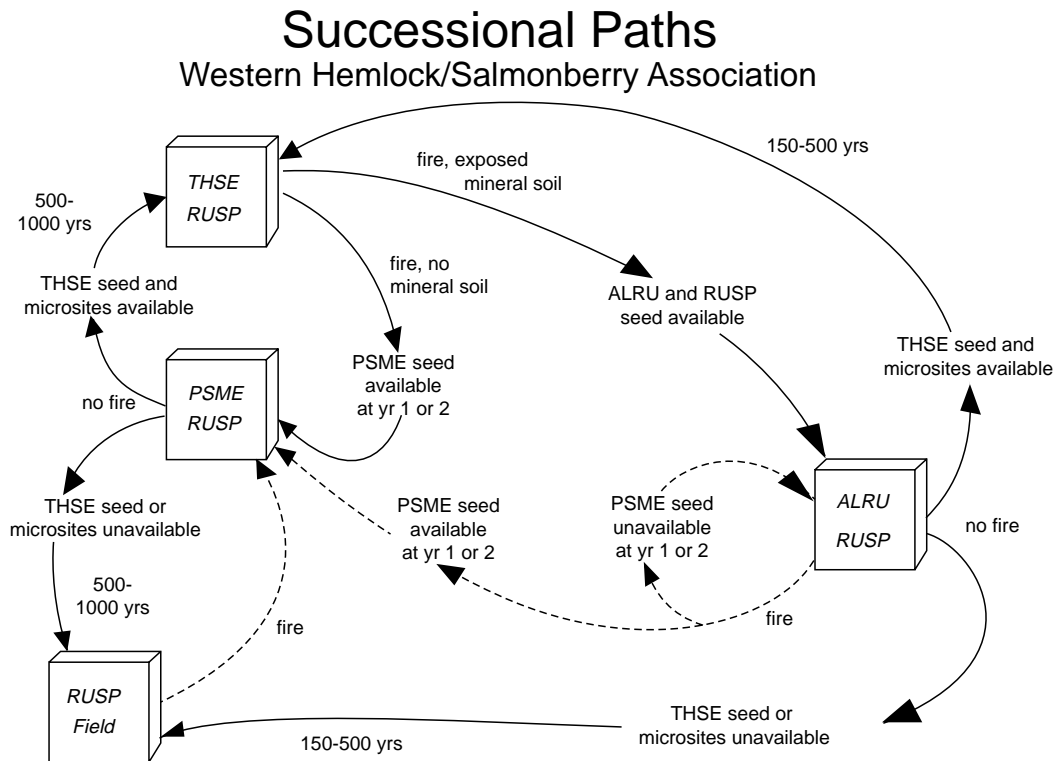


Figure 3-27. Depending on a variety of disturbance, site and seed source factors, the pathways of succession in the Oregon Coast Range can be quite varied. This figure represents the multiple pathways found in the western hemlock/salmonberry association on the Siuslaw National Forest (Hemstrom and Logan 1986).

disturbance and to compete with their neighbors. It is difficult to describe post-fire or post-logging succession because of the diversity of pathways that can occur (Figure 3-27). A common sequence following stand-replacement disturbance begins with dominance by invading and residual forest herbs and grasses such as fireweed, woodland groundsel (*Senecio sylvaticus*), candy flower (*Claytonia sibirica*), and bentgrass (*Agrostis capillaris*). After a few years, shrubs such as blackberry and salmonberry dominate the vegetation cover. Trees such as red alder, Douglas-fir, or western hemlock may become established in the first few years after disturbance, but do not form closed tree canopies for 10 to 25 years depending on the site (Henderson 1978; Hemstrom and Logan 1986).

Because many of today's Coast Range forests are young, the successional process now at work is a competitive sorting of species that colonize an area within a fairly short time after disturbance. After 50-75 years, the forest overstory begins to let through

more light and shade-tolerant species begin to invade the forest understory. Later, canopy gaps are created as overstory trees age and die. This entire developmental process can take several hundred years.

The tree composition of late-successional forests varies throughout the Coast Range as a function of fire severity and return interval. In the moist near-coast zone, where fires were least frequent and seed sources of shade-tolerant conifers were abundant, mid to late stages of forest succession are dominated by hemlock and moisture-sensitive Sitka spruce. Douglas-fir is relatively less common in these areas than other areas of the Coast Range. On the other hand, in southwestern Oregon and the Willamette Valley margin, where fires were relatively frequent and less intense, fire-tolerant species like Douglas-fir, incense cedar (*Calocedrus decurrens*), ponderosa pine (*Pinus ponderosa*), madrone, and oaks are common in late successional forests. The central and northern parts of the Coast Range fall somewhere

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

<i>Interval between wildfires (yrs)</i>	<i>Age class of forest (yrs)</i>					
	<i>> 80</i>	<i>> 100</i>	<i>> 150</i>	<i>> 200</i>	<i>> 250</i>	<i>> 400</i>
	<i>Expected percent of landscape</i>					
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

slash burning in western Oregon began in the early 1900s.

The current structure and composition of coastal forests is most strongly influenced by logging and forest management activities which began in the 1800s and continue today. Grazing, fuelwood harvesting, introduction of nonnative plant species, and urbanization also have altered the composition of coastal forests and woodlands, especially near the population centers of the interior valleys. These fringe forests, as they have been called, have been highly fragmented by clearing for agriculture, roads, and buildings. Nonfederal timberland area in western Oregon has been declining at about 0.2 percent per year since 1960; about 60 percent of this has been converted to agricultural and urban land uses, and 40 percent to roads associated with timber harvest (MacLean 1990).

Current patterns of forest structure result primarily from historic and present-day logging and management activities, which are strongly associated with patterns of land ownership (Figure 3-28 in color section following page 52). The first stands in the Coast Range province to be logged, from the mid-1800s to the early 1900s, were the most accessible and productive lands in private ownership, primarily along the coast and major river drainages. These early logging operations left behind many more large live "cull" trees, snags, and logs than are commonly left today. Locations of recent cutovers and young restocked forests as of 1936 can be seen in Figure 3-29 (in color section following page 52). Some of these areas have now been harvested a second time, most notably in Clatsop and Columbia Counties in the northernmost portion of the Coast Range. Logging of older forest on federal lands began after World War II and accelerated in the 1970s; it was curtailed drastically after the listing of the northern spotted owl as a threatened species under the Endangered Species Act, and the implementation of the Northwest Forest Plan (FEMAT 1993). Currently, about 21 percent of the coastal province is federally owned, 9 percent is owned by the State of Oregon, and 68 percent is privately held (GIS data from Atterbury Consultants, Inc.). Seventy percent of the private timberland is owned by the forest industry (unpublished data, Forest Inventory and Analysis, Pacific Northwest Research Station, Portland, OR; Figure 3-28). These patterns contrast with forest land ownership in Oregon as a whole, where only 40

percent of timberlands are privately owned, and much more is federally owned.

Although landowners hold a wide variety of objectives for their land, timber production is the dominant land use. In general, timber management activities are more frequent and intense and less variable in size and intensity than natural disturbances, and they tend to simplify forest structure at both stand and landscape scales (Hansen et al. 1991). This is especially true of lands under intensive forest management, as practiced by the forest industry and other landowners seeking maximum financial returns from their land. At the stand level, intensive management consists of clearcutting most live trees and snags, site preparation by prescribed fire or herbicides to control competing vegetation, replanting with a single species (usually Douglas-fir), periodic thinning to maintain vigorous and evenly spaced crop trees, and harvesting at 40- to 100-year intervals (Hansen et al. 1991). Nonindustrial private lands in general are less intensively managed for timber, and partial harvesting is practiced more often. Where even-aged forest management is practiced on federal lands, management prescriptions generally call for (1) retaining more live trees, snags, and down logs after harvest than is typical in more intensively managed forests, (2) harvesting stands at older ages, and (3) managing competing vegetation without using herbicides. Management intensity on state lands falls somewhere in between that on federal and private lands.

Vegetation patterns at the landscape scale are governed primarily by the frequency, size, shape, and distribution of stand-level management activities. On industrial lands, which often consist of large ownership blocks, clearcut units tend to be larger (current maximum size is 120 acres) and more contiguous than on public or other private lands. Shorter rotation lengths (typically less than 50 years) result in landscapes dominated by young forests. In areas of nonindustrial private ownership, landscape patterns reflect the distribution of parcels owned by individual landowners, which typically are much smaller than those owned by the forest industry or managed by the federal agencies. Many National Forest landscapes retain the patterns created by three to four decades of staggering small (less than 16 hectares or 40 acres) harvest units in space and harvesting them at a constant rate. Many Bureau of Land Management (BLM) lands have a similar mosaic of clearcuts; this pattern is comp-

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)

observed road densities of 2.7 to 3.5 kilometers per square kilometer in sampled areas of federal and private forest management. An example is the Drift Creek watershed, which exhibits a variety of road densities and distributions, ranging from a roadless Wilderness Area, to Forest Service lands with road development limited to major ridges, to private timber lands where extensive roads are built during the first harvest cycle and then maintained indefinitely (Figure 3-30 in color section following page 52). Although roads commonly occupy less than 4 percent of the area of a forest landscape, they have distinctive properties that may disproportionately affect terrestrial and stream ecosystems. These properties include the wide distribution of roads in the full range of hillslope positions across a landscape (e.g. riparian, midslope, ridge); the persistent exposure of mineral soil, resulting in the invasion of a variety of plant species; compacted surface and subsurface materials; ditches and other drainage structures (e.g. culverts and water bars) that alter natural water flow paths; road cuts and fills on the hillside; vehicle and animal traffic; and

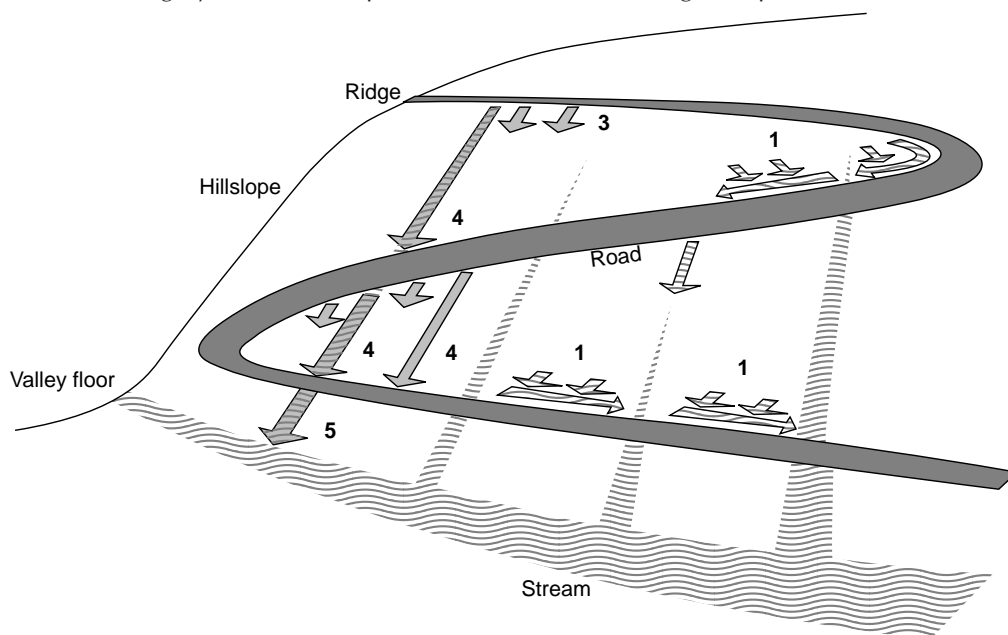
linear openings in the forest canopy. Individually and together, these properties of roads affect many ecological and watershed processes.

A landscape or watershed perspective offers an important basis for evaluating effects of roads on forest and stream ecosystems (Jones et al. 2000). Assessing road effects at only the site level may miss important larger-scale effects. A landscape perspective includes the effects of interactions (e.g. routing of water and timing of peak flows) along road systems as well as interactions between roads and the adjacent forest and stream networks. Such interactions may be mediated by movement of water, other materials, and organisms. Assessing road effects from a landscape perspective is particularly critical now, when many managers and policymakers are focusing on protection of watersheds and species diversity.

Road networks interact with stream networks to influence the routing of water, sediment, and soil mass movements as they follow gravity flow paths through forest watersheds (Figure 3-31). Several recent studies have examined the possible roles of

Figure 3-31. Schematic view of interactions between road (pale gray) and stream (wave pattern) networks in terms of routing of water sediment, and mass movements down gravitational flow paths. The road network consists of a valley floor road segment parallel to a large stream, hillslope road segments perpendicular to streams, and near-ridge roads without streams (mostly). Water (wave pattern arrows) and debris slide/flow (gray arrows) flow paths are

illustrated. Roads (1) intercept water in surface and subsurface flow paths, (2) alter water flow paths and extend the channel network, (3) initiate mass movements of sediment in unstable roadfills, (4) deposit sediment moved by mass movements on roads, and (5) on valley floors. Overall, roads function to divert water and sediment from paths followed in roadless landscapes, and they initiate multiple new, cascading flow paths.



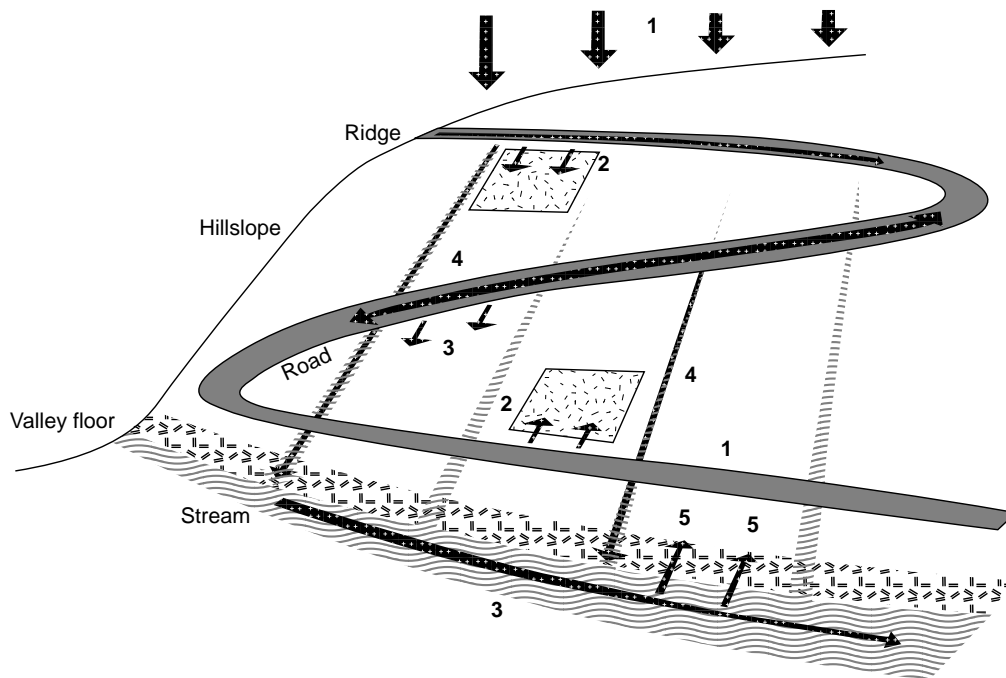


Figure 3-32. Schematic view illustrating movement of propagules via roads and associated air currents, animals and streams. Roads may function to (1) collect and transport propagules by air currents, animals or vehicles (cross pattern), (2) move

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

where seeds and spores can be dispersed by vehicles traveling the roads (Schmidt 1989; Lonsdale and Lane 1994) or by agents that do not follow roads (e.g., wind, birds, large mammals), but which capitalize on favorable habitats and canopy openings along roads (Wester and Juvik 1983; Parendes 1997; Figure 3-32). The role of roads in invasion of exotic species can be viewed in terms of opportunities for or barriers to dispersal and establishment. Dispersal occurs along the road network and from the road network into neighboring stands, streams, and riparian zones. Effects of exotic plants and pathogens can range from negligible to profound, as in the case of *Phytophthora laterella*, the root fungus that kills the high-value Port Orford cedar (*Chamaecyparis lawsoniana*) (Zobel et al. 1985). Road networks with extensive segments along ridgetops can greatly increase dispersal of pathogens such as *P. laterella*, which is transported into a forest landscape as spores in soil on vehicle tires, deposited along roads, and then spread downslope by groundwater and streams.

The role of roads in movement of exotic plant and pathogen species has several implications for managing forest landscapes. The initial introduction of pests and pathogens that could damage high-value resources should be minimized along road networks, even at the time of road construction. Measures to stop the spread of *P. laterella*, for example, include thorough cleaning of equipment used in construction and maintenance (Zobel et al.

1985). Exotic plant species may be more likely to invade adjacent forest stands that have been opened by management activities (e.g., thinning) or other disturbances than to move into unmanaged stands (Hobbs and Huenneke 1992; DeFerrari and Naiman 1994). Useful strategies may include leaving a buffer of unthinned vegetation along roads to limit dispersal (Brothers and Spingarn 1992) or controlling or eradicating hosts of the pathogen along roadsides (Moody and Mack 1988).

Forest roads are important and possibly indelible parts of many Coast Range landscapes. Whether roads present serious, manageable, or negligible problems depends on the area and management objective being considered. By taking a comprehensive view of road functions and approaching roads from a landscape viewpoint, we can better plan forest and road management to minimize the undesired effects.

Aquatic-terrestrial linkages

Aquatic and terrestrial ecosystems of the Coast Range are linked through the many riparian zones that dissect the mountains and forests. The riparian zone extends upslope from the edge of the average high-water mark of the wetted channel (Gregory et al. 1991) and includes that portion of terrestrial areas where vegetation and microclimate are controlled by high water tables. The riparian “zone of influence” lies beyond the riparian zone. It is the

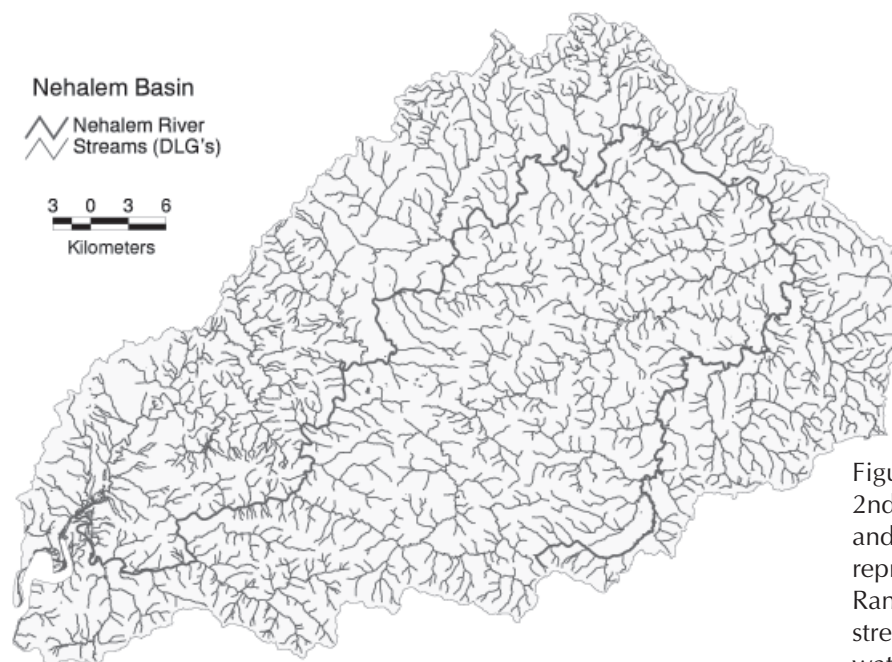


Figure 3-33. Stream (approximately 2nd to 3rd order and longer) density and riparian zone distribution for a representative watershed in the Coast Range. Area within 50 meters of the streams covers 14 percent of watershed.

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).

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.

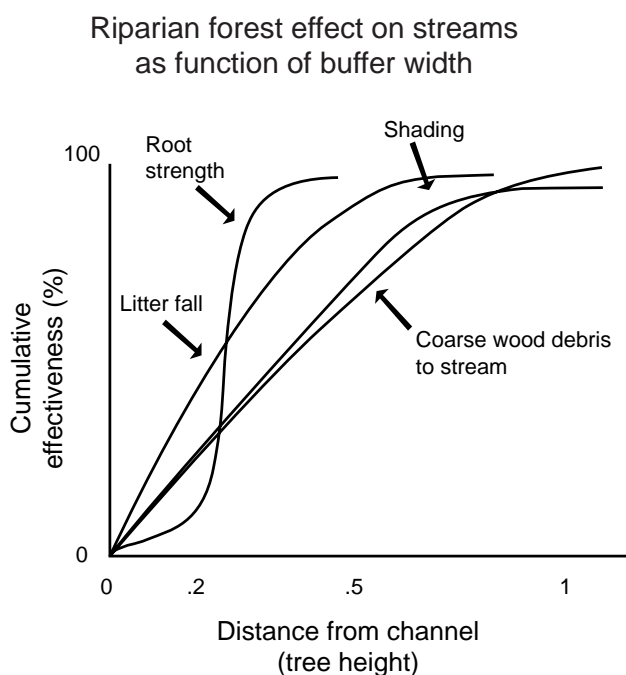


Figure 3-34. Generalized relation between distance from stream and ecological functions (FEMAT 1993).

Infrequent catastrophic disturbances may deliver large pulses of material to mid- and higher order channels. McGarry (1994) found that 48 percent of the large wood in Cummins Creek, a small wilderness-area stream on the Oregon Coast, was delivered to the channel via landslides. Historically, landslides and debris flows moved sediment and wood from riparian zones along lower-order channels and upslope areas and down stream to mid- and higher-order channels. In the past, these events were frequently associated with wildfires (Benda and Dunne 1997). The sediment and wood deposited in lower-gradient reaches had long-term impacts, from decades to centuries, on the physical and biological features of streams in the Coast Range (Reeves et al. 1995). The pattern of fire and landslides in the uplands gave rise to a changing mosaic of habitat conditions in streams. It has been proposed that streams followed a kind of "succession" or cycle of changes in sediment and wood that was closely tied to catastrophic disturbances and vegetation structure in the uplands (Reeves et al. 1995).

The pattern of human activities such as conversion of forest to agriculture and intensive forest management for timber production also affect the pattern and characteristics of inputs of wood and sediment. Riparian vegetation has been removed in all parts of watersheds, especially in the lower segments where forest was cleared for agriculture and other development. The riparian areas farther upstream in most watersheds have also been extensively altered. As a consequence, the amount of large wood in streams has been reduced, and landslide rates and stream temperatures have increased. These changes have led to a decline in the quality and quantity of freshwater habitats for anadromous salmonids (*Oncorhynchus* spp.) and are responsible, in part, for the current poor condition of many of these populations.

New management strategies for riparian areas are required if degraded aquatic ecosystems in the Coast Range are to be restored. Restoration programs will need to reestablish appropriate trees and shrubs in riparian zones in all parts of the watershed, from small headwater streams to valley bottoms along large rivers. Management strategies should be directed toward restoring and maintaining ecological processes that connect the riparian zone with the aquatic ecosystem (Reeves et al. 1995). These processes include the chronic and episodic delivery of sediments, wood, and organic litter. This

conclusion does not mean that riparian zones become «no touch» areas, however. Many riparian areas need active management to accelerate the development of desired conditions and attributes. Strategies are needed that achieve the necessary goals and requirements of riparian zones and also provide for the production of wood and other products for human consumption.

Natural processes as a foundation for management

The production of goods and services from Coast Range forest ecosystems, including the maintenance of native species and natural ecological processes, is best achieved when we understand how natural disturbances and ecological processes have operated in the near and distant past and how they work today. We need this information not to recreate the past but to better understand the forces that created the forests we see today with all the diversity of their native species. Armed with this knowledge, we can better understand how the kinds of forest changes we are imposing either directly (through logging) or indirectly (through climate change or fire suppression) might affect the forests of the future.

As discussed above, fire has been a major force in past forest dynamics in the Coast Range. Today, few people want wildfires to burn as frequently or intensely as they did in the past. Managers are using prescribed burns to maintain certain habitat conditions, but wildfire will probably not be a major force in forest dynamics in the future. This does not mean that wildfires will not occur, but their extent and spread will probably be greatly restricted. Can we sustain desired native species, communities, and natural process in the absence of wildfire? Maybe. Prescribed fire could be used to thin understories and retain variable tree densities in old-growth forests where surface fires were relatively common in the past, such as in the southern and eastern parts of the Coast Range. Without low-severity fires, the structure of these forests will change as shade-tolerant, fire-sensitive trees such as western hemlock and grand fir invade and increase the density of the understory.

Other than prescribed fires, what substitutes are there for wildfire? Harvesting might be the first thing that comes to mind and, certainly, active management through the felling of trees has replaced fire as the dominant disturbance across the

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 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

such as canopy lichens or slow-moving salamanders may simply need more time to colonize forest than these strategies provide.

Another important natural process of vegetation development in the Coast Range is the competitive interaction between deciduous and coniferous woody plants. The outcome of the competitive struggle between these two life forms can determine the structure and function of forest ecosystems for many decades or even centuries. It is clear that the competitive ability of hardwoods relative to conifers is greater in riparian areas than upslope. Consequently, managers should not expect conifers to dominate the vegetative community near streams, except in low-order (headwater) streams. Efforts to regenerate conifers along streams must be tempered with the knowledge that conifer trees have probably always been patchily distributed in these environments because deciduous shrubs and hardwoods are naturally more competitive. If the goal is to increase the inputs of large conifer boles to streams, growing more large trees along headwalls and first-order streams may be more effective than trying to achieve conifer domination along higher-order (downstream) drainages.

Through focused research efforts, our knowledge of native species and natural processes of Coast Range forests has progressed tremendously over the last 10 to 20 years. We now recognize the ecological values of old-growth forests, large down wood in streams, and watershed-scale disturbances such as landslides and debris flows, and are beginning to understand how forest management practices affect resources other than wood-fiber production. We have a general knowledge of the habitat needs of many species of plants and animals that we lacked just a few years ago. We are beginning to understand how landscape-scale process might affect biological diversity. However, we lack knowledge of many of the details of ecological processes and habitat relationships that are essential to modern forest planning and the ability to predict the consequences of specific actions. We also lack the ability to see the big picture of forest management at the scale of the Coast Range and understand how individual management activities might add up to affect the ecological and social conditions as whole. Research will continue to provide answers to current questions but managers and the public should be prepared for some of the scientific "truths" of today to evolve into different forms as new information comes forth.

How should managers respond to uncertainty and new information and ideas? Certainly practicing some form of adaptive management (McLain and Lee 1996) is prudent, just as it is prudent to maintain a diversity of management strategies. Managers need to know details for managing particular sites and stands; however, it is these details that are slow in coming from research on ecosystems and it is these details that are most likely change over time and geography. General scientific and management principles are probably more durable. We hope this chapter provides some of the principles to empower managers to fill in the details as they struggle to sustain forest values.

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