From the Program Manager

Occasionally we will devote an issue of the COPE Report to a unique topic such as the Special Issue that came out last July which summarized the COPE Symposium: The Ecology and Management of Oregon Coast Range Forests. Even more unusual is to devote a COPE Report issue to a topic that does not describe a COPE-sponsored activity. However, on rare occasions something comes along that merits special attention. The report on Cumulative Effects of Forest Practices in Oregon, prepared by Oregon State University at the request of the Oregon Department of Forestry, is such a case.

Cumulative effects present important issues that evoke different emotions depending upon your perspective. Three things remain clear, however. First, cumulative effects are complex and difficult to objectively evaluate, and it is difficult to confidently predict probable future impacts. Secondly, cumulative effects need to be studied more intensively so that managers have better information regarding potential impacts as they make policy and operational decisions. Finally, we need to appreciate the fact that different spatial and temporal scales influence how cumulative effects are viewed.

The intent of this COPE Report issue is to make you aware of the Cumulative Effects report and to give you a brief glimpse of its content. We hope that it stimulates your interest.

Steve Hobbs

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This issue of the COPE Report was prepared by Gretchen Brachet, Skye Etessami, John Hayes, and Judy Starnes. The COPE Report is produced quarterly as a contribution of Adaptive COPE. Because of space limitations, articles appear as extended abstracts. Results and conclusions may be based on preliminary data or analysis. Readers interested in learning more about a study should contact the principal investigator or wait for formal publication of more complete results. Comments and suggestions concerning the content of the COPE Report are welcomed and encouraged. To receive this free newsletter, or for information about Adaptive COPE, contact Adaptive COPE, 2030 S. Marine Science Dr., Newport, OR 97366, (503) 867-0220. For specifics on the overall COPE Program, contact Steve Hobbs, COPE Program Manager, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331, (503) 750-7426.

The COPE Program is a cooperative effort between Oregon State University’s College of Forestry, the USDA Forest Service, Pacific Northwest Research Station, the USDA Bureau of Land Management, other federal and state agencies, forest industry, county governments, and the Oregon Small Woodland Association. The intent of the program is to provide resource managers and the public with information relative to the issues and opportunities associated with the management of fish, timber, water, wildlife, and other resources of the Oregon Coast Range. The COPE Program emphasizes an integrated approach—an integration of research and education and an integration of scientific disciplines—to find effective ways to manage these diverse resources collectively.

The COPE Program has two related components: Fundamental COPE and Adaptive COPE. Comprised of OSU and PNW scientists based primarily in Corvallis, Fundamental COPE addresses problems related to riparian zone management and reforestation in the Coast Range through basic research. Adaptive COPE is comprised of an interdisciplinary team responsible for applying and adapting new and existing research information to solve specific management problems. Stationed on the coast in Newport at the Hatfield Marine Science Center, the Adaptive COPE team is also responsible for providing continuing education opportunities to facilitate technology transfer.

Preface from the editor:

The issue of cumulative effects of forest management practices is often surrounded in controversy. Because of complex interactions among resources, the interplay of past practices, natural forces, and current conditions, and the difficulty in projecting future conditions, multiple interpretations are possible.

In 1991, the Oregon State Senate requested that Oregon State University provide the Oregon Department of Forestry with information concerning the cumulative effects of forest practices on air, water, soils, fish, and wildlife resources. The initial phase of this evaluation includes identification of cumulative effects resulting from forest practices, a literature review and synthesis of current knowledge, development of conceptual frameworks, and identification of research needs and potential cumulative effects studies.

In response to the senate’s request, several scientists from Oregon State University worked together to compile a report entitled Cumulative Effects of Forest Practices in Oregon. The massive document is divided into 11 chapters, including chapters on definitions and the history of cumulative effects, the forest land base in Oregon, past and present forest practices, ecosystem integration, and identification of research needs and approaches. In addition, separate chapters are provided on the cumulative effects of forest practices on air, soils, water, aquatic biota, and wildlife.

In this special issue of the COPE Report, the authors of the Cumulative Effects report present a synopsis of their work, and some of their perspectives on the cumulative effects of forest practices on a diverse, but interconnected, array of resources. Because of space limitations, a thorough discussion of cumulative effects is not possible in a single issue of the COPE Report. As a result, important sections of the document are covered here in a cursory fashion, or not at all. For example, the document contains a chapter on forest practices that contrasts past and current practices and presents the framework for understanding how we got to where we are today. This section provides a valuable backdrop for evaluating cumulative effects. In addition, the report has a chapter entitled “Ecosystem Integration” that provides the conceptual framework for conducting actual cumulative effects assessments on a piece of ground. Specific examples are provided with hypothetical assessments of actual watersheds.
This issue of the COPF Report has two objectives: to alert you to the fact that a substantial resource and reference, the Cumulative Effects report, is available for your use; and to provide a cursory summary of the chapters on air, soil, water, aquatic biota, and wildlife. If the information provided in this issue whets your appetite for more information, I encourage you to obtain a copy of the report for more detail. The Cumulative Effects report will be available from the Oregon Department of Forestry for the cost of reproduction after the Oregon State legislature completes its 1995 session.

JPH

INTRODUCTION

Although several definitions of cumulative effects exist, most recent definitions indicate that cumulative effects occur through a combination of multiple management practices, often in combination with natural disturbance regimes. This definition emphasizes that certain types of cumulative effects may not express themselves except during periods when natural disturbances are also occurring. For example, increased frequency of landsliding as a result of harvesting on steep, unstable terrain will typically occur during periods of large precipitation events—the same type of events during which some level of natural landsliding may be expected. Thus, the separation of human-caused impacts from natural environmental conditions often present important research and management challenges.

Assessing cumulative effects is a complex task, and requires that forested landscapes be simultaneously viewed at multiple scales of both time and space. To assess the combined effects of forestry practices and natural processes, attention must be given to details at small temporal and spatial scales and sophisticated integration of information is needed at all scales. In order to assess potential cumulative effects several pieces of information are needed (Figure 1): definitions and mapping of landscape units; accurate assessments of ranges of natural variation and baseline conditions for critical characteristics of each resource in each area of interest; assessments of the probable impacts of past, present, and reasonably foreseeable future human activities on each resource and how these impacts relate to current resource conditions; development of a geographic information system for placing each forest operation in appropriate spatial context with adjacent or otherwise logically-connected landscape units; development and use of conceptual and computer models for connecting resource conditions and dynamics that occur in interacting landscape units; and establishment of levels of acceptable change for each resource characteristic in order to evaluate whether specific cumulative effects are unacceptable.

Difficulties in assessing cumulative effects are compounded by the fact that the pattern of forest land use generally differs with site characteristics and ownership.

![Diagram of On-the-ground Evaluations]

**Figure 1. The flow of information for cumulative effects evaluation and policy implementation.**

Because ownership patterns at a landscape scale are often fragmented and their boundaries seldom conform to the topographic ridges, individual watersheds usually experience a range of forest practices. The pattern of management practices across a watershed or landscape, combined with the natural disturbance regimes, can influence the magnitude, frequency, and duration of various cumulative effects associated with air, soil, water, aquatic biota, or wildlife resources.

THE EFFECTS OF FOREST PRACTICES ON AIR RESOURCES

Forest practices in Oregon have the potential to substantially affect air resources in and around forested areas. In some cases, the effects can extend many miles from forested areas because of transport of airborne material by prevailing winds. The most significant effects result from emissions of smoke and other air pollutants from forest burning. In addition, changes in forest cover can have profound effects on local climate parameters, including temperature and water balance. Finally, large-scale atmospheric changes
may result from modifications to the carbon dioxide fixation/removal cycle due to forest harvest and reforestation characteristics.

Air Pollution Effects

Forest fires, both natural and prescribed, produce large amounts of air pollutant material that can significantly affect areas far downwind. The major pollutant type is particulate material (small solid particles of dust or smoke), which can reduce visibility and affect human health. In addition, gaseous compounds, especially nitrogen oxides and organic compounds, can be emitted from forest fires in large amounts. Chemical and photochemical reactions (the latter involving sunlight) produce ozone, nitrogen dioxide, and other air pollutants for which ambient air quality standards have been specified in the Clean Air Act. If urban areas lie downwind of a fire, increases in concentrations of these pollutants could interfere with attainment of ambient air standards. However, this is not a common problem in Oregon, since most air quality standards are in attainment.

Temperature and Water Balance Changes

Changes in forest cover following harvest can cause major effects on ground-level temperatures. The most significant changes occur immediately after a forest has been extensively logged. Solar radiation reaching the ground, which previously had been limited by the forest canopy, rises dramatically after harvest. Minimum temperatures, however, often show little or no change (if anything, nighttime temperatures tend to be colder).

Evapotranspiration (ET) is the combined moisture loss from plant and soil surfaces (evaporation) and from vegetation (transpiration). Whereas evaporative losses from forest soils tend to increase following removal of a tree stand, relatively larger reductions in transpiration occur. Thus, overall ET losses typically are decreased following clearcutting with a resultant increase in total runoff. During forest regrowth on a harvested site, ET amounts will increase as transpiration by the reestablishing forest increases over time. The ET effects of partial cuts, and potential changes in annual runoff patterns, is usually relatively small.

Forest harvesting can also have important effects on patterns of snow accumulation. In general, snowpack accumulations tend to be deeper, and often denser, in forest openings and clearcuts than under the canopies of adjacent forest stands. The albedo of snow cover in harvested areas also tends to reduce surface temperatures in comparison with the darker, more light-absorbent characteristics of a forest. While snowmelt dynamics are complex, it is not uncommon for snow to accumulate more and remain longer where clearcutting has occurred than in adjacent forested areas.

In areas where snow represents a large fraction of winter precipitation and where cold, low humidity conditions are common (e.g., eastern Oregon), the return of water to the atmosphere through sublimation (direct conversion of water from the frozen to gaseous state) can be significant. The interception of snow by the forest canopy, and resultant increased surface area of snow, can accelerate the vaporization rate in eastern Oregon's forested regions.

Inadvertent Weather Modification

Small hygroscopic particles, called cloud condensation nuclei (CCN), act as centers for the condensation of water vapor. The condensation continues until a cloud/droplet is formed. This process depends on the size and composition of the CCN and the supersaturation percentage of an airmass. Smoke from forest burns is a significant source of CCN; enhanced convective activity and high CCN fluxes have been shown to cause increased cloud cover and precipitation near fires. There is strong evidence that the burning of forest products and debris causes inadvertent weather modification by altering local precipitation frequency and cloud droplet size.

Carbon Release and Fixation

Forests serve as a sink of carbon (C) by fixing atmospheric carbon dioxide (CO₂) to produce biomass; molecular oxygen (O₂) is released as a byproduct. While reintroduction of trees to a previously forested area will increase the carbon storage in biota, the tree harvest itself releases large amounts of carbon to the atmosphere, much of which is contained in the humus and soil layers at the ground. In addition, the major compounds emitted during prescribed burns are CO₂ and water vapor, thus further adding to the atmospheric CO₂ concentrations. Carefully managed forests could represent a significant sink of CO₂. Such management of existing forests will ultimately be the best method of slowing the buildup at atmospheric CO₂.

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THE EFFECTS OF FOREST PRACTICES ON SOIL

Forest soils are the foundation of the practice of forestry. For most of this century, forestry in the Pacific Northwest has been practiced with the general assumption that inherent soil productive capacity is a constant, and that sustained yield of forest products can be achieved through harvest scheduling and prompt reforestation. In some situations fertilizers have been used when economics have indicated likely returns on investment in fertilizer applications. In recent years it has been suggested that soil productive capacity may ultimately prove neither unlimited nor constant over the long-term, i.e., that it may be possible that some forestry practices adversely affect soil productive capacity — the
basis for future yields of wood and other forest values. Except in extreme cases, however, there is little evidence that sound forestry practices per se lead to demonstrable declines in soil productive capacity in the short-term. Rather the question is whether long-term declines might result from multiple, apparently insignificant effects caused by repetition of forestry practices through time and duplication through space.

Forestry practices are seldom carried out in isolation; they are commonly conducted in sequences of related operations, such as road construction/harvest/site preparation/ reforestation or thinning/fertilization. Although some effects may be unique to certain practices, several practices tend to lead to complementary or similar effects. For example, harvest and site preparation can influence erosion rates in similar ways, whereas harvest and roading can influence slope stability in dissimilar but complementary ways. Considered in isolation, effects of a single practice may not appear cumulatively significant, even when projected over several rotations. However, when viewed in conjunction with effects of associated practices, the combined effects may show greater cumulative significance.

We distinguish between two classes of effects: "immediate" and "intermediate." Immediate effects represent the initial or primary disturbances resulting from forestry practices. Examples include removal or destruction of vegetation and forest floors, soil disturbance, soil exposure, and soil compaction. Many "best-management" practices are designed to avoid or curb immediate effects. For example, designated skid trails are established to reduce overall soil compaction at a site. Intermediate effects represent effects that occur as results of immediate effects, independently of further direct disturbance. They may occur through combinations of immediate effects and natural factors, such as erosion due to soil surface exposure followed by an intense rainfall event (Figure 1). Intermediate effects are often not under direct human control.

Concern about effects of forestry practices on soils centers around individual immediate effects and several associated intermediate effects which have potential to affect soil conditions and productivity. These effects include: soil compaction, surface erosion, soil mass-movement, nutrient redistribution or loss, and effects on soil biota.

Most relevant literature about the effects of forestry on soils has focused on a single operation or a sequence of related operations on an individual site. Shifting the focus to cumulative effects involves consideration of multiple operations and sequences of operations repeated in time and duplicated in space. The possible combinations of various operations and sites through time and space is virtually limitless. For this reason, much of our synthesis is necessarily conjectural, based on what is known about direct effects combined with projections of trends in forestry practices and our limited ability to envision potential cumulative effects.

Silvicultural and harvesting practices, including road construction and maintenance, set the context for potential cumulative effects on soils. Characteristics of silvicultural practices requiring consideration include the silvicultural system (harvest intensity and utilization standards), rotation or cycle length, other silviculture-related effects on soils such as exposure, disturbance, or compaction, and related nutrient losses (decomposition, leaching, or erosion). Rotation length is especially significant from the point of view of cumulative effects since it determines the time periods allowed for recovery between harvests. In addition, rotation length determines the age and developmental stage at which trees are harvested; nutrient demand and the proportion of the overall nutrient pool in the standing crop vary with age. It has been suggested that rotation age may be of greater significance than harvest intensity for recovery of nutrient-supplying capacities of many sites.

Soil compaction, widely researched and discussed in the Pacific Northwest, has high potential to accumulate through time and space, and recovery is apparently slow. This effect is likely to be accentuated as more intensive forestry practices require more entries at shorter intervals. Monitoring of compaction and its effects on growth is essential.

Long-term or chronic soil erosion may result from periodic or chronic soil exposure. The episode or "pulse" of erosion following a periodic disturbance (i.e., harvest or site preparation) is generally of short duration. This suggests that active erosion should not accumulate between rotations. On a given site, the next consideration involves whether the soil

![Figure 1. Potential cascading effects of roads on soil, water, and fish resources. Immediate effects on soils may result in intermediate effects on water, soils, and fish.](image-url)
loss resulting from an erosion episode could be recovered by soil formation during the succeeding rotation. This recovery is unlikely given very slow rates of soil development. Viewed from a wider spatial scale, periodic disturbances distributed through time may lead to increases in the overall area-wide erosion rate. Areas of chronically exposed soil (such as road cut-banks and surfaces) may experience continuous or chronic erosion. As the area of soil in a chronically exposed state is expanded, spatial accumulation of erosion may result.

Forestry practices may lead to increases in potential rates of mass movement; however, evidence is not yet sufficient to assess effects of practices on long-term average rates of mass movement. Forestry practices may also tend to increase the magnitude of events when they do occur. On a human (as opposed to a geologic) time-scale, the landscape area affected by mass movement will probably be limited to a small proportion of the area affected by forestry practices. At the site level, mass movement effects may be catastrophic, but at the landscape scale, mass movement may not be a major adverse influence on forest productivity. However, mass movement may be more significant to water sources and aquatic biota. Mass movement is a leading source of sedimentation in Pacific Northwest forests. Sediment from slope failures, especially large failures, resides in and is transported through channel systems over long periods.

Cumulative nutrient mobilization provides a good example of the intricacies of potential cumulative effects on soils. Most forestry practices result in creation of some amount of organic debris and influence conditions for its decomposition. Nutrient transfer between vegetation, the forest floor, and mineral soil can be influenced by timber harvest, site preparation, reforestation and revegetation, fertilization, and pesticide application. The effects are realized largely through influences on the composition and activity of soil biota. The result of such multiple effects may be an overall shifting of nutrient pools from organic/debris layers to mineral soil horizons. Assuming that such a transfer occurs, it is difficult to assess its implications. Overall increased levels of nutrient mobilization may lead to increased leaching rates in some soils. Other soils may be capable of retaining large quantities of nutrients without significantly elevated leaching, depending on ion-exchange properties of soil components.

Nutrient losses other than harvest removal depend on interactions between forestry practices and site characteristics. An example is soil erosion, which can be significant when soil is exposed on steep slopes, but is generally negligible when soil is exposed on level ground. For a given soil texture, slope gradient, and level of soil exposure, erosion might be higher in areas or seasons in which the local precipitation regime tends toward short storms of high intensity than those in which low intensity storms of longer duration are prevalent.

In many cases, factors such as erosion and leaching may prove to be of greater significance for water sources than for soil productivity. In relation to soil productivity, the magnitude of leaching losses is assessed relative to the sizes of nutrient pools in vegetation, forest floor, and mineral soil, or relative to nutrient removals or losses such as harvest, volatilization, or erosion. On this basis, leaching losses often appear insignificant as an influence on overall fertility. However, changes in streamwater nutrient concentration attributable to forestry practices are assessed relative to baseline concentrations in the water. From this perspective, increases in nutrient concentrations can be large in relative terms, and of potential significance, although they appear negligible in absolute terms.

There is currently little direct evidence to indicate that harvest removals in themselves lead to soil depletion over several succeeding rotations for most silvicultural regimes on most sites. Short-term productivity declines should be due to severe associated effects such as compaction, erosion, or loss of organic layers. If long-term declines in productive capacity become evident, they might be expected to occur gradually or incrementally following periods of continuous cropping or management. Some researchers predict eventual declines for highly intensive silvicultural regimes. The potential for cumulative decline in soil/site productivity is greatest when high silvicultural intensity is combined with low inherent productivity and harsh conditions; decline is least likely when low silvicultural intensity is combined with high inherent productivity and favorable conditions.

It may prove easier to demonstrate that some cumulative effects on soils have occurred than to demonstrate that productive capacity or productivity has been adversely affected. This would apply especially under the assumption that losses in productivity were realized as a cumulative effect through multiple, apparently insignificant, increments over long periods. Potential adverse impacts of soils effects on other resources, such as water quality, may be more readily amenable to quantitative evaluations of cumulative effects than adverse effects on soil productivity.

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**THE EFFECTS OF FOREST PRACTICES ON WATER**

During the last two decades, increased awareness of nonpoint source pollution has led to greater concern regarding potential cumulative effects of forest practices and other land use activities (e.g., rangeland practices, agricultural practices, urbanization) on water resources. Much of this concern is perhaps due to the recognition that changes in the quality and quantity of water draining upland watersheds can potentially affect a wide array of on-site and downstream values. These values include those associated with fisheries and aquatic habitat, domestic water supply and quality, estuary quality, reservoir storage, and others. Thus, the interpretation of cumulative hydrologic effects involves not only the interaction of basin characteristics and forest practices, but societal values as well.
The temporal and spatial scales at which forest practices occur become critical factors in affecting the magnitude and duration of potential cumulative hydrologic effects. From a temporal perspective, such factors as harvest rotation age, magnitude of hydrologic response, hydrologic recovery, and disturbance regime frequency often need to be considered. From a spatial perspective, watershed size and the areal extent (i.e., percent of watershed) over which forest practices occur and their location within the landscape become important for addressing potential impacts. Temporal and spatial considerations often include the following:

1. Initial response and subsequent recovery of system (magnitude and duration of individual effects)
2. Frequency of forest practice or proportion of watershed affected
3. Frequency and magnitude of natural disturbances that interact with management effects
4. Factors which influence the storage and routing of materials and energy.

Effects on Hydrologic Response Categories

The separation of watershed functions into individual parameters is often misleading since watersheds do not function on an individual parameter basis, but involve complex interactions. However, to make the problem of cumulative effects more tractable, we have identified several major categories of hydrologic response and consider some of these categories separately below.

Physical Hydrology — Small watershed studies have shown that clearcut harvesting can increase water yields (for tens of years) and lowflows (for several years). Even so, without rigorous statistical control and precise flow measurements, the effect of forest harvesting on water yields and lowflows of larger basins is likely to be generally indistinguishable from natural flow variations. Although long-term trends of increasing water yield occur in streamflow records (e.g., the Grande Ronde in northeastern Oregon), the causes for such trends are not clear and their relationship to forest management practices indeterminate. Most small watershed studies indicated that magnitudes of peakflows increased following harvesting, although variable peakflow responses, including decreases and no changes, have also been reported. It would appear that any increases in peakflows derived from the harvesting of small watersheds are not a major contributor to peakflow magnitudes associated with larger basins; however, this topic has not been adequately studied.

Riparian Function — For many of the riparian functions that were investigated (including riparian microclimate, nutrient dynamics, bank stability, and floodplain function), little research has been conducted regarding the direct effects of various forest practices; therefore, cumulative effects remain speculative. The one riparian function that has been widely researched is large woody debris recruitment. The cumulative effects of historical forest practices in Oregon have resulted in the widespread reduction of large woody debris loadings in and along stream channels.

Water Quality — Numerous forest practices have the capability of increasing sediment delivery to stream channels. The magnitude and timing of sediment delivery depends on erosion processes (including mass wasting, debris torrents, or surface erosion) and the types of forest practices (such as road building, yarding, and site preparation) which cause erosion to occur. Though, high concentrations of suspended sediment resulting from forest practices may decrease in a downstream direction due to dilution effects, total loads invariably increase but at a decreasing rate with distance. Without adequate shading from riparian vegetation, stream temperature increases can accumulate in a downstream direction at a rate greater than would occur naturally. The cumulative effects of forest practices on dissolved oxygen, nutrients, and chemicals have not been adequately researched.

Channel Morphology — Forest practices have dramatically altered a large proportion of stream channels in Oregon through splash dams, stream cleaning, increased frequency of debris torrents, sedimentation, streamside harvesting, and the reduction of large wood in channels and riparian areas. Altered peakflows, and by themselves, are unlikely to significantly change channel morphology without concurrent changes in other factors such as sediment inputs, large woody debris loadings, or loss of root strength from streamside vegetation. The magnitude of any potential channel change is also influenced by local differences in channel morphology. However, many of the channel changes associated with periods of accelerated sedimentation or removal of riparian forests, particularly along unconstrained stream reaches, are likely to last decades or centuries.

General Conclusions

Scientific results indicate that while forest practices can significantly alter hydrologic systems in some instances, in others they may have little or no effect. Part of the variability in response can be attributed to the wide range of practices associated with roadbuilding (e.g., location, endhaul vs. sidecast construction, drainage systems, maintenance), harvesting (e.g., silvicultural system, logging system), site preparation (e.g., mechanical scarification, burning, use of chemicals), and riparian management practices. Furthermore, the magnitude of hydrologic response (or lack thereof) may be contingent upon an array of watershed variables including geology, climate, topography, landforms, stream density, vegetative patterns, and natural disturbance regimes. Even so, several conclusions emerge from a review of the scientific literature.

(1) The distinction between "direct" and "cumulative" effects is largely artificial. Almost all environmental ef-
fects can be considered cumulative since rarely does a forest practice occur in isolation.

(2) Most watershed research has been approached from a reductionist perspective, i.e., single parameter effects have been correlated with specific land use practices. These approaches have implicitly assumed that the identification of cause-and-effect relationships will provide a better way of managing forest resources. In contrast, understanding cumulative effects involves essentially the opposite of this process and involves reforming the individual pieces and multivariate relationships in a cohesive manner to understand the interaction between forest practices, landscapes, natural disturbance regimes and resultant effects. This integrative approach is vastly different from a simple scaling-up of results from small, single-parameter watershed studies. Thus, while simplification of the system may be appropriate in some cases to understand it, we must also strive to increase our understanding of complexity in order to ultimately manage it.

(3) Although direct and cumulative effects are typically presented on a parameter-by-parameter basis, in reality, a watershed does not function on a parameter-by-parameter cause-and-effect basis. A wide range of physical, chemical, and biological processes interact simultaneously to influence one another and the eventual responses to a specific set of forest practices. Such systems have relatively large temporal and spatial variability. Thus, without adequate controls or reference conditions against which to compare, it is often difficult to decipher the effects of management practices on flow regimes or water quality from those associated with natural disturbance regimes. Hydrologic responses to forest practices are seldom explained by one or two variables.

(4) Cumulative effects assessments often focus on watershed hydrologic functions and responses associated with forest practices. In most instances, these approaches determine those areas most at risk and then attempt to manage them by reducing or minimizing potentially adverse hydrologic effects, while concurrently applying standard forest practices to other "non-risk" areas. Thus, only those areas of a watershed that appear to be at risk of causing a major impact are likely to receive special management consideration. Gradual or chronic changes in watershed functioning or condition for remaining areas in a watershed may be largely ignored.

(5) Cumulative effects models related to hydrologic or water quality issues are typically difficult to construct, and, in their current state of development, may be of relatively little utility to land managers. Furthermore, there is an increasing need for improving monitoring theory, practice, and commitment in order to decipher trends within a given basin.

(6) Some cumulative effects methodologies use timber harvest levels as a surrogate for impacts, e.g., limiting timber harvest to a certain percent of the basin per year to keep average annual sediment levels below a set level. This relatively simplistic approach seldom accounts for aspects such as regional or watershed variability, harvest location, yarding system, and roading, and assumes a direct causal mechanism between timber harvest and the magnitude of impact. In most cases, it is not the fact that trees were harvested, but how they were harvested, where on the landscape, the methods of roading and yarding, the degree of riparian protection, and other factors that ultimately determine the impact of a forest practices operation.

(7) Early cumulative effects methodologies usually identified threshold levels beyond which unacceptable changes to the system would occur. However, natural systems rarely recognize discrete thresholds and can respond incrementally and interactively to change. In general, the threshold for instigation of an event (such as landslides or channel morphology adjustments) changes with differing site conditions. Thus, a threshold should be defined as a tolerable level of impact to resources, or an acceptable probability of detrimental response.

(8) While information regarding historical forest conditions can provide important perspectives to land managers, simply trying to recreate certain conditions may not provide desired benefits. For example, simply increasing large woody debris levels in streams that are relatively deficient of such debris because of fisheries habitat concerns, without addressing accelerated sediment inputs or degraded riparian conditions may provide little improvement in habitat conditions.

(9) The potential for various forest practices to cause cumulative effects can materialize at a wide range of spatial and temporal scales. However, if the accumulation of individual impacts from various forest practices provides the mechanism for causing an undesirable cumulative effect, then the prevention of potentially adverse impacts to water resources at the project level is of fundamental importance in reversing this situation.

(10) Cumulative effects are "ownership blind" in that they can occur across a wide variety of ownerships and land uses. Because most forested watersheds occupy the headwater areas of the various regions within Oregon, the quality and condition of water exiting these areas has an important effect on its utility for downstream users. However, specific basins seldom experience only the effects of forest practices. Grazing, agriculture, urbanization, and other land uses represent important additional contributors to potential cumulative effects affecting the water resources of the state. A systems perspective indicates that real progress towards solving water resources problems in Oregon's streams and rivers will not occur by only evaluating and refining the management of forested landscapes.
Further Reading


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THE EFFECTS OF FOREST PRACTICES ON AQUATIC BIOTA

Physical changes created by forestry practices cascade through the aquatic food web, affecting not only species within assemblages but also connectivity between assemblages. Temporal patterns of abundance vary naturally because plants and animals differ in development, behavior, and physiology. When a system is disturbed, the synchrony of biological events can be altered, accumulating as changes in community composition and species abundance. Aquatic assemblages also are subject to cumulative spatial effects as events in the upslope, riparian, and upstream reach affect downstream communities. Cumulative effects can affect aquatic biota through changes in abundance and diversity, changes in dominant life history patterns associated with altered timing of physical processes, and changes in food webs resulting from altered energy resources.

The stream foodweb derives its energy from two basic sources: plants, primarily as algae, and woody and leafy litter from riparian vegetation. Forestry practices that alter availability of these primary resources potentially restructure the aquatic assemblage that depends on them. In headwater streams practices that increase light levels, such as clearcutting or overgrazing in the riparian zone, will exhibit their greatest effects through increased algal production. As riparian zones revegetate, the plant composition changes to deciduous trees and herbs, differing significantly from old-growth stands. The timing of litterfall in these altered stands will shift to an autumnal pulse and material will decompose more rapidly. Practices that select for particular forest species will affect plant succession, and may result in the loss of nitrogen-fixing species such as red alder and ceanothus.

When there are changes in primary energy sources, effects accrue to invertebrate and vertebrate consumers. Where riparian vegetation was removed in the Oregon Cascades, increases in algal abundance resulted in more stream invertebrates; in turn, increased invertebrate abundance provided food for higher numbers of young trout. The increased number of fry persist only as long as the tree canopy stays open. However there are critical tradeoffs. Increased exposure to solar radiation also warms the stream. Increased temperatures resulting from streamside and upslope forest removal have been shown to be one of the major effects on fisheries. Higher summer and winter temperatures lead to faster fish development. Whole stream populations of coho salmon in Carnation Creek, British Columbia began migrating to sea as one-year-olds because of premature development; these fish were smaller and probably more likely to die in the ocean than older smolts.

Silt and sediments associated with road and harvesting activities can result in lower survival of fish eggs in spawning gravels and reduced growth of trout or salmon young. These disturbances also affect other parts of the food web, with cumulative results of less food for fish. Sediments cover up rocky substrates for algae and bury litter inputs; stream invertebrates lose not only potential food resources but also small spaces between stream gravels and rocks that provide refuges from stream flow. Other organisms that might live deep within subsurface layers lose sources of high quality water and protection when streams become highly silted or embedded.

Many forestry effects accumulate over long periods of time, creating chronic disturbances, often off-site from the original operation. For example, chronic suspended sediments decrease growth rates of fish, increase competition for food, increase susceptibility of fish to disease, and reduce successful migration to the ocean. Effects of residues from herbicides and insecticides also may create chronic problems. Because toxicities increase with changes in pH and temperature for products such as malathion and Roundup, bottom-dwelling organisms subject to these conditions may be especially vulnerable. Little is known about minimum dosages that produce no biological effects for natural assemblages of aquatic organisms, and wide margins of safety are recommended in the use of chemicals.

Loss of large woody debris, resulting from either instream, riparian, or upslope removal of large wood, results in extremely deleterious chronic deficits. Large wood in streams creates diversity in habitat for fish and invertebrates, provides refuge from stream flow, and retains both leafy litter substrates for invertebrates and nutrients for algae. Potential consequences for fish are shifts in population structure, greater mortality during periods of high flow, and changes in species distribution. Moreover, recruiting large wood into the stream following site-removal of mature trees requires approximately 60 years.

The loss of stability in stream habitat and assemblages characterizes systems recovering from logging-related disturbances. Though short-lived invertebrates and young fish may colonize disturbed sites, biological stability and habitat complexity are slow to return. Twenty-five years after clearcut logging in the Alsea Watershed, cutthroat trout and coho salmon populations have not recovered. In British Columbia instability of large wood persists 10 years after logging.

Cumulative effects on downstream aquatic assemblages reflect watershed-scale disturbances. The legacy of diminished riparian forests caused by previous practices already limits the function and integrity of existing watersheds. Ecosystem processes and organization can be "reset" by cumulative effects across a landscape. More than 10 percent of channel networks in the Cascade and Coast ranges
have been scoured by debris flows related to logging activities. These debris flows affect most directly second- and third-order channels where salmon and trout spend the majority of their lives in streams. Changes in floodplain dynamics, associated with altered streambanks and wetlands, alter delivery of nutrients and food resources to the streams, as well as eliminating nursery grounds for fish and invertebrates. Cumulative effects of increased temperature and sediment loads add to downstream degradation. Consequent losses in biological diversity and abundance on a watershed-level basis can put entire stocks of fish and other fauna at risk. Uncertainties about the effectiveness of future practices, in combination with questionable status of many fish stocks, demand prudent and conservative actions that retain resource options for the future.

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THE EFFECTS OF FOREST PRACTICES ON WILDLIFE

Forest practices can affect habitat quality for the nearly 300 forest-associated vertebrate species (excluding fish) that occur in Oregon. Management practices can result directly in alteration of animal survival rates, or can indirectly cause changes in abundance and distribution of species by altering habitat throughout forested regions of the state. Although animals in Pacific Northwest forests have evolved with disturbances that alter habitat, silvicultural activities in Oregon over the past 40 years have represented a narrower range of scale, intensity, frequency, and pattern than natural disturbances of the past. For example, the natural disturbance regime in western Oregon was represented by a range of disturbances from infrequent, but intense fires and windstorms to frequent, small disturbances that leave canopy gaps. Both types of disturbances lead dead wood, an important habitat component for many wildlife species, on the affected sites. High contrast edges between late and early seral stages probably were rare.

In these systems, fine-scale heterogeneity dominated large areas for long periods of time, punctuated by less frequent coarse-scale events. Spatial and structural features of forests, derived from both fine- and coarse-scale disturbances, such as gaps, patches, woody debris, and a diversity of plant species, provide habitat for indigenous wildlife species. However, the use of the clearcut regeneration system that has predominated in the past several decades has imposed a more frequent and intense coarse-scale disturbance regime on forests. In addition, the frequency of harvest (rotation age) and the adjacency requirements established by the Oregon Forest Practices Act have resulted in a cumulative loss of late seral forests, isolation of remaining patches, and establishment of high contrast edges. Forest practices that cause disturbances that depart significantly from natural disturbances may result in more pronounced changes in the abundance, distribution, and persistence of species. Thus, while the alteration of habitat by forest practices changes habitat for animals on a local scale, it is the frequency and intensity at which practices are applied that causes these changes to accumulate, changing species abundance and composition on a regional scale.

The effects of forest practices on wildlife can accumulate on three levels. First, animals can be indirectly affected by impacts on forest substrates and processes (e.g., vegetation, soil, aquatic environments, and hydrologic systems). Therefore, the effects of forest practices on water, soil, and invertebrates also may accumulate to affect vertebrate wildlife. However, little is known about these cascading impacts because of the difficulty of tracing a chain of effects through the ecosystem. Secondly, direct and accumulated effects on individual animals can eventually cause population-level changes. Much of our discussion will focus on this level because the effects of forest management are most obvious when populations are affected. Thirdly, population-level changes in one species may influence populations of other species. For example, forest management activities that impact keystone species may have indirect consequences for vertebrate communities.

Direct and accumulated effects of forest practices on the habitat of individual animals become cumulative when populations or subpopulations of species are affected. Impact accumulation on wildlife populations can result from forest practices occurring over time, over space, and jointly over time and space. Impacts may accumulate over time if forest practices are repeated at intervals that do not allow recovery of late-seral habitat. Habitat quality may decline for some species, but others may benefit from the altered conditions. For example, a deficit of woody debris, perpetuated on many sites by repeated harvesting and site preparation practices, has been implicated as a factor in the declines of some populations of cavity-nesting birds. On the other hand, frequent harvests increase habitat for species associated with early-seral conditions.

Impacts on habitat also may accumulate spatially. Forest fragmentation, one example of an accumulation of impacts across landscapes, may be associated with changes in the abundance of species either negatively or positively associated with edges. Furthermore, fragmentation can influence habitat availability by changing the amount of area occupied by particular stand conditions or plant communities. Forest patches that do not contain sufficient area of suitable habitat may not be used by some forest-dependent species. The distribution of developmental stages across a landscape also can influence connectivity among areas. As each forest age-class becomes more isolated, dispersal among populations and sub-populations becomes problematic for some species; both gene flow and population size may decrease when dispersal is limited, increasing the risk of local extinction.

Finally, impacts may accumulate in both time and space. Because forest management has emphasized mid-successional stages (the most productive period for wood fiber), both the time and space occupied by early and late seral stages has been reduced. Early seral stages have
effectively been shortened by management practices which encourage full occupation of a site by conifers as early as possible. Late seral stages also have been truncated because rotation ages of managed forests are usually much shorter than is typical of unmanaged forests. The net result of these practices is a landscape-scale increase in area occupied by mid-seral stages relative to that occupied by early (grass/orb, shrub) and, especially, late seral stages. Short rotations do not allow for replacement of large structural features associated with old growth over time unless they are explicitly included within the management regime.

Maintaining Viable Wildlife Populations

At least seven environmental gradients seem to be both important in structuring wildlife habitat and significantly impacted by forest practices. These gradients are: edge density and contrast, seral stage, canopy cover, floristic composition, dead wood, special habitat features (e.g., caves, cliffs, talus), and riparian areas. Life history information is available for many species, and responses to habitat change along environmental gradients have been predicted for some species. However, most species have not been intensively studied, and, to date, relationships to landscape level habitat gradients have only been addressed for birds.

Until more data are available, forest planners are faced with making decisions regarding resource allocation without complete knowledge of the influence timber management has on wildlife resources. However, information that is available should be used by managers to help meet the habitat needs of vertebrates in Oregon while maintaining an active timber management program. Silvicultural systems currently used in the region could be altered to provide opportunities for meeting the needs of certain species while simultaneously extracting timber. One approach to developing silvicultural systems that would maintain populations of indigenous wildlife is based on knowledge of natural disturbance regimes in the region. This approach is based on the premise that indigenous wildlife species have evolved life history traits which enable or enhance survival under natural intensities and frequencies of disturbance. Therefore, forest management practices that strive to replicate stand structure and landscape patterns representative of the range of historic conditions should increase the probability that populations of indigenous, forest-associated species will be maintained. Such silvicultural approaches would give consideration to fine-scale patterning of snags, logs, residual large trees, and other special habitat features for each harvest unit. Landscape-level considerations would include adjacency, connectivity, and representation of each seral stage through time, in order to design forest patterns that more closely represent those with which indigenous wildlife evolved.

Recent concern with the cumulative effects of forest practices on non-timber resources reflects a broadening of the scope of forest management from single projects (e.g., harvest units) to landscapes, and the recognition that management activities have long-term ecological consequences. Whether impacts are synergistic or additive, direct or indirect, the net results of cumulative impacts for wildlife are changes in the population dynamics and distribution of individual species. The ultimate consequence may be regional decreases in abundances of certain species as forest specialist species are displaced by habitat generalists. In order to lessen the negative impacts of forest management on wildlife populations, careful consideration should be given to the silvicultural systems used, the frequency of stand replacement disturbance, and the planning of harvest units on the landscape, with different goals for each landscape. The integration of these considerations may allow an active timber program and persistence of indigenous vertebrates across the state.

Recommended Reading


Joan C. Hagar and William C. McComb, OSU Forest Science Department

OPPORTUNITIES

PLANTED FOREST: CONTRIBUTIONS TO SUSTAINABLE SOCIETIES

June 28–July 1, 1995 Portland, OR

This symposium will discuss attributes and values of forests in all their forms — from extensively planted forests in mountainous wildlands to intensively cultured “fiber plantations.” Leaders in a number of forest-related areas will illustrate the variety, nature, and significance of planted, managed forests in our societies. Speakers will discuss opportunities and challenges associated with managing planted forests in landscapes of the world — forests as diverse as the cultures in which they occur. This symposium will emphasize planted forest systems in appropriate context with other managed forests and with native forest systems.

Day 1 will address species and groups of species planted around the world. Day 2 will address forests planted for different primary objectives. Day 3 will address emerging technical information. Day 4 will be field trips to observe planted forests in Oregon and Washington. Individuals