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Creating a Forestry for the 21st Century

The Science of Ecosystem Management

Edited by Kathryn A. Kohm and Jerry F. Franklin

Foreword by Jack Ward Thomas

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Foreword

Two separate but connected factors have combined in recent decades to dramatically alter the practice of forestry in the United States. The first has been a rising environmental consciousness among a significant and politically effective segment of the population. The second was a spate of environmental legislation enacted in the 1960s and 1970s. Among laws that changed the practice of forestry are the National Environmental Policy Act of 1969, which requires the federal government to perform a detailed assessment of costs and benefits of all federally financed activities; the Endangered Species Act of 1973, which established a government policy that species should be preserved; and the National Forest Management Act of 1976, which sets high standards for management of national forests.

Of particular note is the statement of purpose included in the Endangered Species Act. Twenty years after passage of the act, that statement has emerged full-blown, with far-reaching consequences for federal land management. That statement is: "The purposes of this act are to provide a means whereby the ecosystems upon which endangered species and threatened species may be conserved" and not merely the welfare of the single species identified as 'endangered' or 'threatened.' In addition, there were regulations promulgated by the federal government pursuant to the National Forest Management Act that called for the retention of viable populations of vertebrate species well-distributed on national forests with particular emphasis on habitat.

In combination, these laws and regulations have had a profound effect on forest management on federal lands. These changes came about over a period of 25 years as governmental agencies (most notably the Forest Service and Bureau of Land Management) struggled to maintain or increase historic timber sale levels, satisfy the needs of traditional constituencies (such as grazers, hunters, fishers, and recreationists), and simultaneously remain in compliance with environmental laws. Under the U.S. legal system, citizens may challenge the government's compliance with law. Over the past 25 years, there have been numerous such challenges to federal land management activities—many of which have been successful. These federal court decisions have forced federal land management agencies to change some of their traditional approaches to forest management.

The most noted of these legal challenges is the case of the northern spotted owl (Thomas et al. 1990). This subspecies of the genus *Strix* was declared by the U.S. Fish and Wildlife Service to be "threatened" in early 1990. It is considered closely associated with the habitat conditions most commonly found in the late-successional/old-growth forests of the Pacific Northwest. These forests have been diminished significantly in amount and quality through timber harvesting (most commonly clearcutting) and losses to fire, blowdown, and other natural events since the late 1800s (Thomas et al. 1990). The late-successional/old-growth forests of the Pacific Northwest are extremely valuable as a source of large volumes of high quality timber and as a significant source of employment (FEMAT 1993). The reservation of significant amounts of old-growth from timber harvesting to maintain a range-wide viable population of a subspecies of owl (Thomas et al. 1990, FEMAT 1993) has been fraught with social, economic, and ecological consequences that have translated into prolonged legal and political battles which able sale quantity of approximately 1.2 billion board feet, with an additional 100–150 million board feet potentially available from thinning stands younger than 80 years for silvicultural purposes. This probable annual timber sale level compares to 4.6 billion board feet cut annually from 1980–1989, and 2.4 billion board feet cut annually from 1990–1992. However, a significant portion of the decline can be attributed to the accumulated experience of managers with conditions that precluded maintaining the sale quantities projected in the initial modeling efforts for forest plans.

Scientists doing the ecosystem assessments for President Clinton noted that despite the political and economic advantages of stable timber yields over time, experience has shown that this is unlikely over the long term. The world of forest management in the Pacific Northwest is, clearly and simply, inherently unstable—ecologically, economically, legally, and politically. Forest management plans are frequently changed and often unpredictable. They are subject to the vicissitudes of droughts, fires, insect and disease outbreaks, and volcanic eruptions, as well as funding shortfalls, frequent changes in laws and their interpretation, legal actions, court orders, public acceptance, and changes in policy. The only certainty seems to be the certainty of changing conditions—biological, social, economic, and legal.

The case of the spotted owl and old-growth/late-successional forests in the Pacific Northwest is but one example of the dramatic changes in forest management that are occurring in the United States. State after state has, or is in the process of, tightening up regulations defining appropriate forestry practices for private and state lands. Much of this revision seems to be a response to public demands for forestry practices that are more aesthetically acceptable and more sensitive (realistically or perceptually) to actual multiple-use values—primarily those associated with fish and wildlife habitat—than past practices almost solely directed toward profit and job maximization from timber production, harvesting, processing, and utilization.

Of particular interest to ecologists is the emphatic shift in public interest toward concern for all species of wildlife along with an increasingly holistic sense of ecosystems. This broadened perspective replaces the historic, rather single-minded emphasis on habitat for game species such as white-tailed deer, mule deer, and black-tailed deer. There is every reason to believe that this trend will continue. As a result, biologists will have to broaden their interests, increase their expertise, and work with foresters to produce habitat conditions for a myriad of life forms and ecosystems.

There are, however, countervailing pressures at play. The changes in forestry currently underway come about at significant costs. Those costs are measured in higher prices for wood, jobs lost or foregone, loss of revenue to federal and county treasuries, and disproportionately negative impacts on rural communities dependent on the timber industry and timber harvest levels that existed from 1980–1992 on federal lands (FEMAT 1993).

Yet the trend toward ecosystem management and forestry that is more benign in environmental and aesthetic effects seems likely to continue for the foreseeable future. These changes reflect evolving public demand and current law as interpreted by the courts. There seems to be a distinct and growing distrust of natural resource managers—particularly government and corporate managers—by at least a vocal portion of the public. That distrust must be allayed if land managers are to retain any semblance of their historic management prerogatives. One lesson to be learned is that, in a democracy, forests are managed at the sufferance of the citizenry or at least by the majority of the minority of that citizenry that cares about the issue. The greatest challenge that foresters and other natural resource management professionals face in the practice of their professions may not be the technical aspects of forest management, but public acceptance of those practices.

These are among the many issues raised and discussed in *Creating a Forestry for the 21st Century.* In this volume, well-qualified experts have combined to produce a comprehensive view of ecosystem management.

Ecosystem management is a concept whose time has come. But ecosystem management is only a concept for dealing with larger spatial scales, longer time frames, and many more variables (ecological, economic, and social) than have commonly been considered in past management approaches. To be useful, a continue today. The details surrounding this continuing controversy have been described by Thomas et al. (1993).

As the political and legal drama over old-growth forests and the northern spotted owl evolved, it became more and more obvious that the issue, as clearly foreseen and prescribed in the Endangered Species Act, was not one of saving or maintaining viable populations of an individual subspecies. Rather, it was centered on public and scientific concerns with the maintenance of ecosystem functions. These evolving concerns of scientists (and in turn the public) also began to surface under other names and allied concepts such as "sustainable forestry," "biodiversity retention," "new perspectives in forestry," and "new forestry." But most recently and predominantly, these concepts have come to be known as "ecosystem management" (Thomas 1993).

Ecosystem Management

By mid-1993, both the Forest Service and the Bureau of Land Management announced that they were embarking on a course of ecosystem management. That pronouncement was made without a detailed assessment of what such a management approach might entail or how it might be accomplished. However, the chief of the Forest Service did say that the agency would move away from clearcutting (except in certain circumstances) as the primary silvicultural prescription for stand regeneration.

By 1993, repeated successful lawsuits by organized environmental groups essentially brought timber sales on federal lands in the Pacific Northwest to a halt. Federal court judges ordered federal land management agencies to cease selling timber on lands designated by the U.S. Fish and Wildlife Service as critical habitat for the northern spotted owl. This impasse prompted vocal public concern, and received attention from all three major candidates during the presidential election of 1992. In the course of that campaign, candidate Governor Bill Clinton of Arkansas promised that, if elected, he would convene a conference to devise a means of ending the court-ordered injunction—that is, he would break the "gridlock."

Shortly after his inauguration, President Clinton convened a forest conference in Portland, Oregon, on April 2, 1993. At the close of that conference, the president promised a solution to the impasse over forest management in the Pacific Northwest within 60 days. He instructed the secretaries of Agriculture, Interior, Commerce, and Labor to carry out that promise. Three teams were organized to formulate management options for the president's consideration. The instructions given to one of those teams, the Forest Ecosystem Management Assessment Team (FEMAT), stated that an "ecosystem management approach" was to be included in their report, and that late-successional/old-growth ecosystems and species associated with those ecosystems that were listed by the U.S. Fish and Wildlife Service as "threatened" (northern spotted owls and marbled murrelets) were to receive specific consideration.

Approximately 90 days after the conference, the president selected an option from among 10 presented to him (FEMAT 1993). The consequences of that selection have been ecologically, economically, and socially profound. Of the land in federal ownership within the assessment area (the range of the northern spotted owl), 7.05 million acres (2.85 hectares) of reserves were established where late-successional/old-growth forest conditions are to be preserved and enhanced over time. An additional 2.23 million acres (.90 million hectares) were designated as riparian reserves to meet water quality standards and protect and enhance habitat for native fishes—particularly anadromous fishes considered to be "at risk" of being listed as "threatened" or "endangered."

These late-successional/old-growth and riparian reserves were established in addition to 6.98 million acres (2.83 hectares) already designated as wilderness or national parks or otherwise withdrawn from timber management activities for reasons such as soil stability, scenic corridors, or recreation needs. Approximately 7.34 million acres (2.97 hectares) out of 24.26 million acres (9.22 million hectares) in the analysis area remained available for timber harvest (about 30 percent of the total area). However, it should be noted that significant portions of the total area support no trees, offer little potential for growing trees, or have fragile soils, steep slopes, or other circumstances that preclude timber harvesting.

The acreage available for harvesting yields a probconcept must be rendered operational. That requires placing the concept in context and in operational terms.

This book is an attempt to take that critical next step—to move the concept of forest ecosystem management into an operational context. Other such efforts are underway. But this, in my opinion, is the best of such efforts to date.

This book can be likened to a river that is fed by many streams. It flows more strongly with the addition and mixing into the current of each stream. This volume has identified many of the contributing factors that must be considered and integrated to make up the first efforts of forest ecosystem management. It is an exciting prospect.

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7 Alternative Silvicultural Approaches to Timber Harvesting: Variable Retention Harvest Systems

Jerry F. Franklin, Dean Rae Berg, Dale A. Thornburgh, and John C. Tappeiner

Silviculture is the art and science of manipulating forest stands to achieve human objectives, including the production of various goods and services. As a discipline, silviculture has very strong traditions, most of which are rooted in European forest practices. Basic concepts underlying the establishment, tending, and harvest of forest stands were established by the beginning of this century.

Nowhere are traditions more firmly established than in the approaches to regeneration harvesting of forest stands. There are four recognized regeneration harvest methods (Smith 1986): clearcut, seed-tree, and shelterwood methods for use as a part of an even-age management system, and selection for use in uneven-aged systems. While rather precisely defined, there are recognized variations on these several methods, variations that have been defined and described in textbooks.

All regeneration harvest methods were created with a singular objective: regeneration and subsequent growth of a commercially important tree species (Smith 1986). Management objectives for forest harvesting have become increasingly complex during the last several decades however—a trend that will certainly continue into the 21st century. We are no longer seeking simply to create a free-growing replacement forest while safely and efficiently harvesting the mature stand. Today, multiple objectives typically include maintenance of specific levels of ecosystem processes, including habitat for elements of biological diversity. Tree regeneration and its subsequent growth are often still concerns, although these objectives—especially for rapid growth of the regeneration—often are subordinated to other goals. Harvest cutting may include such diverse goals as maintaining tree root strength; providing for specified levels of snags of various species, sizes, and conditions; and fulfilling specific aesthetic criteria. Although there is substantial flexibility in application of existing harvest methods (Smith 1986), foresters sometimes are forced to either take liberties with the technical definitions of the four harvest methods or to adopt awkward and confusing terminology, such as "clearcut with reserves." Most important, even with substantial modifications, the four recognized methods provide a very limited set of choices.

Recent research on forest ecosystems has clarified the importance of structural complexity to forest ecosystem functioning and the maintenance of biological diversity (Franklin 1993, Bormann and Likens 1979, Swank and Crossley 1988, Franklin et al. 1987, Maser et al. 1988, Harmon et al. 1986, Spies, Chapter 2). Important structural features include snags, woody debris on the forest floor, multiple canopy layers, varied sizes and conditions of live trees, and presence of canopy gaps. Research has also made clear the dramatic impacts that clearcutting and other management activities can have on biological diversity and ecosystem function; for example, in Sweden clearcutting is the major factor threatening endangered forest organisms (Berg et al. 1995).

Investigation of the effects of natural disturbances on forest ecosystems and their subsequent recovery also have dramatically altered our understanding of these events (see Perry and Amaranthus, Chapter 3). Results from these studies emphasize the importance of biological legacies—surviving organisms and organically derived structures, such as snags, logs, and soil organic layers—to the rapid reestablishment of ecosystems that have high levels of structural, functional, and compositional diversity. Similar patterns of extensive legacies emerge from disturbances as diverse as wildfires (Christensen et al. 1989, Schullery 1989, Knight and Wallace 1989), hurricanes (Foster and Boose 1992, Walker et al. 1991) and other storm events (Peterson and Pickett 1995), and volcanic eruptions (Franklin et al. 1995, Franklin et al. 1985). These natural patterns contrast sharply with low levels of biological legacies associated with even-aged regeneration harvest practices, particularly clearcutting, even when treatments do not involve intensive site preparation (see, e.g., Keenan and Kimmins 1993).

As a result of this new knowledge, the creation and maintenance of structurally complex managed stands is being developed as the primary approach to managing forests for multiple, complex objectives, including production of wood products. Indeed, such approaches have emerged independently in many countries and on several continents (see, e.g., Arnott et al. 1995; Lunney 1991; Larsen 1995; Squire 1990; National Board of Forestry Sweden 1990; Swanson and Franklin 1992; Scientific Panel for Sustainable Forest Practices in Clayoquot Sound 1995; Ciancio and Nocentini 1994a, 1994b; Ciancio, Iovino, and Nocentini 1994; Watanabe and Sasaki 1993).

Proposed approaches to creation of structurally complex managed stands include the use of long rotations, retention of structural features at the time of harvest, and silvicultural treatment of established stands to create specific structural conditions. None of these are mutually exclusive, although each has specific circumstances where it is particularly appropriate. For example, silvicultural treatments to achieve specific structural features often are proposed to "restore" structurally simplified stands created using traditional even-aged systems (see Carey et al. submitted, Debell et al., Chapter 8, and Tappeiner et al., Chapter 9). Both restoration and retention approaches have analogies in traditional practices, although there are significant differences, as will be seen. Retention is of course focused most heavily on harvest practices in mature and old stands, while restoration addresses the challenging issue of what can be done in young stands.

Silvicultural methods based on significant structural retention at the time of harvest are the subject of this chapter. Such approaches may involve retention of individual trees, snags, logs, or small patches of forest on the harvest unit, usually for at least the next rotation. Such cuttings are conducted in stands that are at least at economic, if not biological, maturity. Because long rotations are often proposed as an alternative to retention harvest methods, we begin by contrasting the relative advantages of the two approaches. Next we illustrate the flexibility of using a retention harvest philosophy and identify the important variables in retention silvicultural prescriptions: which structures, how much of each, and in what spatial patterns. Current evidence for the effectiveness of structural retention in achieving objectives such as maintenance of wildlife habitat is reviewed, and important research needs are identified. We conclude by proposing that traditional regeneration harvest methods and terminology be supplemented by a more flexible and ecumenical approach based upon a continuum of retention levels.

Although this chapter is focused on structure, we acknowledge the important contribution that tree species diversity (stand composition) can also have on maintenance of ecological functions, including habitat for specific organisms. Compositional diversity can be extremely important, as illustrated by the simple example of including some representation of hardwoods in conifer-dominated stands. Furthermore, many specific structural conditions are associated with only one or a few species. Hence, compositional diversity is commonly implicit in structural goals.

Long Rotations and Structural Retention at Harvest

Long rotations, structural restoration, and structural retention at harvest are approaches that can be combined effectively. However, long rotations and structural retention generally address different environmental issues and have different economic implications. Furthermore, long rotations are often proposed as an alternative to reservation of late-successional forest areas as well as to structural retention at harvest. Hence, it is important to contrast these approaches.

Long rotations involve management of forests on rotation ages that are longer, often much longer, than those currently in use for the forest property in question (Weigand, Haynes, and Wikowski 1994). Rotations are typically based upon either economic or biological criteria. In the Douglas-fir region, economic rotations of 40 to 60 years are common on private lands where good growing conditions exist; such rotations are driven primarily by traditional investment economics. Biological rotations, based on culmination of mean annual increment (MAI), are required on national forest lands with typical rotation ages of 80 to 120 years, depending upon site conditions. There is the potential for considerable flexibility, however, as culmination often extends over several years or even decades and typically is delayed by intensive forest management (see Curtis 1994, 1995, Chapter 10). Although the appropriateness of culmination of mean annual increment as an index of stand biological maturity is debatable from an ecological point of view, it is the traditional measure in forestry.

Proposals for long rotations take many forms, depending upon management objectives (Weigand, Haynes, and Wikowski 1994). Possible objectives can include (from Curtis 1995) reduced land area in regeneration and early development stages, hence reduced visual impacts; low annual regeneration costs and less need for herbicides and slash burning; higher quality wood and larger trees; improved habitat for some wildlife species; hydrological and long-term soil productivity benefits; increased carbon storage; opportunity to adjust present unbalanced age distributions toward a regulated forest; and maintenance of options to allow adaptation to future changes and to correct errors stemming from incomplete knowledge.

One generic proposal involves the use of long rotations to develop structurally complex managed forests that include large-diameter trees (Weigand, Haynes, and Wikowski 1994). Such proposals usually include a series of silvicultural treatments during development of the stand to ensure creation of specific structural elements. Rotations may be extended by 50 to 300 percent—for example, sites traditionally managed on an 80-year rotation would be extended to 120 to 240 years.

Ecological Advantages of Long Rotations

The primary ecological application of long rotations is in places where area-based ecological effects are of primary concern, such as with the cumulative impacts of timber harvest on watershed conditions. For example, clearcutting can increase peak flows associated with rain-on-snow storm events (Harr 1986, Harr et al. 1989); recovery to hydrologic conditions comparable to those in the preharvest forest may take many decades. Hence, the percentage of a watershed in a particular condition may have to be limited to reduce the potential for adverse effects.

Long rotations can effectively address the issue of cumulative effects, since they reduce the area of a watershed that is harvested in any given year. If rotations are increased from 50 to 100 years, then the percentage of a watershed harvested is reduced from 2 to 1 percent. In terms of cumulative effects, if 20 years is used as the recovery period, then the area potentially contributing to peak flows is changed from 40 percent of the watershed (with a 50-year rotation) to 20 percent of the watershed (with the 100-year rotation).

Long rotations also may make it possible to reduce the density of permanent transportation systems, an important consideration in reducing impacts of harvesting (see, e.g., Keenan and Kimmins 1993). While this is possible under other management scenarios, greater use of temporary roads and harvest systems that utilize fewer roads are likely where there are much longer time intervals between final harvests. Of course, if the management scenario calls for repeated silvicultural entries throughout the rotation, this advantage is much less likely to be realized.

Lengthening rotations from those based on discounted present net worth to those based on culmination of mean annual increment also will increase wood production. For example, Curtis (1994) has noted that harvest ages of 40 to 50 years in Douglas-fir reduces volume production relative to potential. Furthermore, intensive management, such as systematic thinning, generally delays culmination, which makes it possible to utilize even longer rotations without penalties in mean annual levels of wood production.

Limitations of Long Rotations

Long rotations have important ecological limitations if carried out without structural retention at harvest. First, some structural elements and related species and processes are completely lost from the harvested site until such structures can be re-created. This means that a much smaller percentage of the landscape will have key structural components than would be the case if such structures were retained at the time of harvest.

Large-diameter, moderately decayed snags provide an example. Using clearcutting, all such structures are removed at harvest. Re-creation of snags of this diameter and decay state would take at least 100 years. Under a 120-year rotation, the harvested site will have such structures in place for 20 years; in a fully managed landscape only one-sixth of the land area will have such structures. In contrast, retention harvest could maintain either a population of (1) large moderately decayed snags or (2) large-diameter green trees for postharvest conversion to snags. Thus, most or all of the managed landscape would have such structural features.

Large differences in the percentage of the managed landscape with such structural features (between 17 and 100 percent in this example) can be of great importance for associated species and processes. In part, this relates to the absolute number of such structures present; for example, research has shown that both diversity and density of cavity- or snag-dependent vertebrates is related directly to density of snags or trees with cavities (e.g., Lindemayer and Franklin submitted). Contributing factors include the territorial nature of some species and their need to move among several snags or trees.

Long rotations also have important limitations as alternatives to reserves for maintenance of values associated with intact old-growth forests. It is very doubtful that a forest ecosystem can be re-created by silvicultural treatments that is compositionally, functionally, and structurally complete, even over long rotations. Some elements of late-successional forests require very long periods of time for reestablishment (e.g., Henderson 1994). More important, we do not even know many of the organisms and processes that occur in natural late-successional forests, nor is even rudimentary information available on the temporal and spatial patterns associated with such organisms and processes, especially in soils and canopies.

The Variable Retention Harvest System

The variable retention harvest system is based upon the concept of retaining structural elements of the harvested stand for at least the next rotation in order to achieve specific management objectives. Variable retention is extremely flexible in application since it utilizes a continuum of structural retention options (Figure 7.1a) in creating silvicultural prescriptions to meet specific management objectives.

Development and maintenance of structurally complex managed forests is the overall rationale for retaining structural elements of the harvested stand. Unlike traditional regeneration harvest systems, the objective of regeneration and growth of a new crop of trees may not be a primary or even a secondary objective. Variable retention harvesting is also flexible with regard to age class and may lead to even-aged, multi-aged, or uneven-aged stands.

Variable retention harvest prescriptions are appropriate where management objectives include maintenance or rapid restoration of environmental values associated with structurally complex forests. At least three major purposes should be recognized: (1) "lifeboating" species and processes immediately after logging and before forest cover is reestablished, (2) "enriching" reestablished forest stands with structural features that would otherwise be absent, and (3) "enhancing connectivity" in the managed landscape.

Lifeboating: Refugia and Inocula

A primary objective of structural retention is to provide refugia for elements of biological diversity that might otherwise be lost from the harvested area—lifeboating. Lifeboating is achieved in at least three ways: (1) by providing structural elements that fulfill habitat requirements for various organisms, (2) by

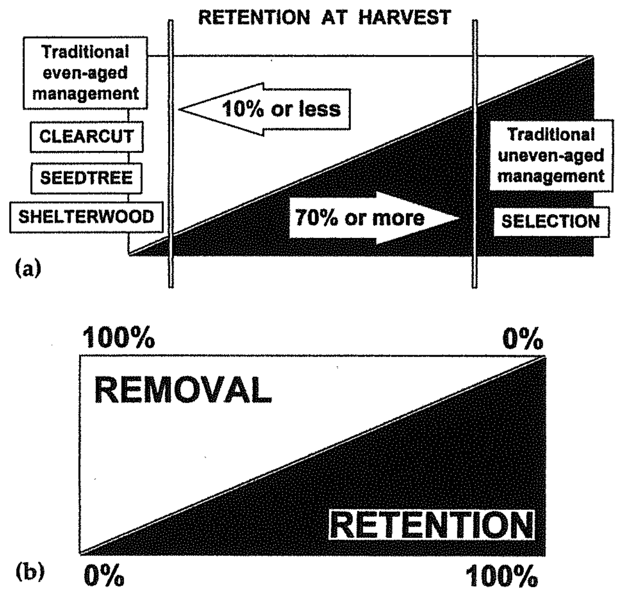

Figure 7.1 (a) The variable retention harvest system utilizes the full spectrum of structural retention or, conversely, removal that is available to silviculturists to achieve the complex and varied objectives typical of modern forestry. (b) Traditional regeneration harvest systems utilize a limited portion of this spectrum.

ameliorating microclimatic conditions in relation to those that would be encountered under clearcutting, and (3) by providing energetic substances to maintain nonautotrophic organisms.

Structural retention strategies may focus on many different types of organic structures—living, dead, or both—and individual or various combinations of structures. Individual structural features include living trees of various species, sizes, and conditions and their derivatives, such as standing dead trees or snags and logs on the forest floor. Such structures are critical habitat elements for many species (see, e.g., Berg et al. 1995, Carey and Johnson 1995, Lindemayer and Franklin submitted) and ecosystem functions. These species can be eliminated from the harvested stand when all of the structures on which they depend are removed; conversely, many of these species and processes can tolerate conditions on a harvested area provided that the structures are still present.

Necessary structural requirements actually may be for a collective stand structural condition such as undisturbed litter layers on the soil surface, multiple layers of vegetation, or the microclimatic conditions associated with multiple structures (see, e.g., Carey and Johnson 1995). Such conditions are most likely to be retained in small forest patches as part of the harvested unit—that is, by aggregating all or part of the retained structures. Aggregated retention of this type also has the potential to provide microclimatic conditions more like those of an intact forest stand.

Microclimatic conditions on the harvested unit are also critical for survival of some elements of diversity (see e.g., Berg et al. 1995). Structural retention will almost always result in harvested areas that have less stressful microclimatic regimes than those that are found on clearcuts. A well-known example is the use of shelterwoods. The shelterwood method uses temporary dispersed retention of dominant trees at moderate density to alleviate climatic stresses such as frost and high temperatures, thereby improving the prospects for successful tree regeneration. Aggregated retention can produce habitat patches on the harvest unit which have microclimates that are even more forest-like than shelterwoods (Jiquan Chen, personal communication, 1995). However, the microclimate within these patches will still be very different from those in the interior of large, intact forest patches, often known as forest interior environments.

Interactions between structures and microclimatic conditions are also important to the lifeboating function. Some species will not persist in a clearcut microclimate even if the necessary structures are present. Their persistence depends on at least some level of climatic protection, along with the required structures.

Provision of critical substrate to maintain populations of heterotrophs is a third aspect of lifeboating. For example, live trees are needed to function as host plants and energy sources. This is particularly important in the case of soil organisms, such as mycorrhizal fungal symbionts. The soil community is very dynamic with high turnover rates in populations and structures such as mycorrhizae. The persistence of many elements of the soil community depends upon a continuing source of readily available, high-quality energy, which is provided by vascular plants, especially trees (Perry 1994). Loss of this energy source following clearcutting may result not only in loss of species, but also of entire critical functional elements of the soil community (Perry 1994).

It is important to note in this regard that there are two distinct patterns of mycorrhizal association: endo- and ectomycorrhizae. These two patterns are associated with different groups of vascular plants and of fungi. Many angiosperms and the gymnosperm families Cupressaceae, Taxaceae, and Taxodiaceae form endomycorrhizae, while Pinaceae and the angiosperm family Ericaceae form ectomycorrhizae; hence, mixtures of tree and shrub species are important in maintaining a full complement of fungal associates.

Many elements of biological diversity that can be maintained by structural retention are essential to the sustained productivity and health of a harvested area. A common perspective is that lifeboating of biological diversity is primarily intended to sustain species of esoteric or peripheral interest in managed stands, such as officially listed rare or endangered species. In fact, much of the diversity that is sustained by structural retention, such as fungal species capable of forming mycorrhizae, play important functional roles.

Use of structural retention to sustain biological diversity assumes that refugia will provide the inocula for reestablishing species in the harvested area once the new forest stand and other suitable habitat conditions are reestablished.

Structural Enrichment of Established Forest Stands

Many forest species are displaced or eliminated even with significant structural retention. Except under light partial cutting, closed forest stand conditions typically are lost for significant periods of time. Factors responsible for displacement or loss include logging disturbances, absence or reduced levels of key structures, loss of forest integrity, and creation of more extreme microclimatological conditions. With tree establishment and growth, closed forest cover is reestablished, correcting several of these conditions. However, important structural features, such as large and decadent trees, snags, and logs, may be absent either permanently or for the extended periods of time required for their re-creation. Retention of some of these structures at the time of harvest can result in stands with much higher levels of structural diversity and therefore habitat carrying capacity.

Structural retention is a technique for enriching the structural complexity of managed forest stands for an entire rotation. As such, suitable conditions for species can be reestablished much earlier in the rotation than would otherwise be possible. In some cases, where rotation ages or management practices do not provide for re-creation of specific structures, they are lost entirely from the managed forest if there is no retention. Furthermore, structural retention can be used to restore structures that cannot be maintained during the harvest period. For example, large and highly decayed snags often are completely eliminated for safety reasons; retention of appropriate sizes and species of live trees at harvest can provide the material for managers or nature to quickly reestablish such structures following harvest.

Numerous examples illustrate how structural retention can enrich subsequent stands and thereby provide suitable habitat for species that are generally rare or absent in young stands of simple and homogeneous structure. These examples are of both natural and human origin. There are many forest stands 80 to 200 years of age in the Douglas-fir region of the Pacific Northwest that provide suitable nesting and foraging habitat for northern spotted owls (Figure 7.2) (e.g., North 1993). Such stands also sustain populations of other species associated with late-successional forest habitats (e.g., Carey 1995), even though old-growth forests are generally considered to exceed 200 years of age. These younger stands typically incorporate a component of large old trees and snags that survived the natural disturbance or partial harvest of the preceding stand; hence, they are multiaged rather than truly even-aged young stands.

Such examples provide a model whereby retention of some old-growth Douglas-fir trees can create managed stands that provide suitable nesting and foraging habitat for spotted owls within 50 or 60 years of harvest. Without retention, it may take 120 years or more to create the necessary structural elements, even with intensive silvicultural efforts. As noted earlier, desired habitat conditions exist for most of a rotation under retention approaches; whereas they are present for only a limited period under a long-rotation strategy.

Figure 7.2 Natural mixed-age stands resulting from legacies of large, living trees, snags, and logs provide models for structural retention. Large surviving trees and snags are components of this dominantly 80-year-old Douglas-fir stand developed following wildfire. Consequently, the stand provides habitat for species that would otherwise be absent, such as the northern spotted owl.

Retention is particularly critical where rotation ages or other conditions exist that prevent the predictable re-creation of some particular structure such as very large, old, and decadent live trees and large, highly decayed snags.

Enhancing Connectivity in the Managed Landscape

A third value of structural retention is enhancing the movement of organisms within a managed landscape. Conditions in the matrix or dominant patch type are the most important factor controlling connectivity in that landscape, including dispersion and migration of most organisms (Franklin 1993). Traditional conservation biology approaches fail to recognize this fact by fixing on intact corridors of specific habitat conditions as the primary technique to facilitate organismal movement; this limited perspective probably originated from an early focus on vertebrate organisms. In fact, most organisms probably do not respond to a corridor-based strategy. Rather, they are influenced most strongly by the conditions of the matrix. The importance of the matrix is obvious in many forest landscapes where it is composed almost entirely of managed stands.

Structural retention in managed stands can be designed to facilitate dispersion of organisms. In terms of traditional island biogeographical theory, the objective is to make the "sea" (i.e., the matrix) a less hostile environment for dispersion. The "sea" can effectively be made shallower and be provided with stepping stones by furnishing, for example, well-spaced logs, trees, and shrub patches for protective cover or transient habitat on cutover lands.

Retained forest aggregates—small forest patches—provide larger, more structurally diverse, and microclimatologically moderate habitat islands for dispersing organisms than do dispersed individual structures such as trees, snags, or logs, but they also tend to be more widely spaced. In designing strategies for improved matrix connectivity, a variety of issues needs to be considered, including the necessary size and spacing of various retained structural elements. For example, in coastal British Columbia one scientific team concluded that retained aggregates should be spaced no more than four tree heights apart (Scientific Panel for Sustainable Forest Practices in Clayoquot Sound 1995).

Structural retention also can work to the disadvantage of some organisms, such as when it creates favorable conditions for predation of a specific organism. Concerns have been raised, for example, that retention of trees and snags in cutover areas may create a "killing ground" for prey species dispersing through the cutover, such as predation by great horned owls on northern spotted owls.

Design Elements in a Variable Retention Harvest System

There are three major issues in development of harvest prescriptions based upon the variable retention concept: (1) what structures to retain on the harvested site, (2) how much of each of these structures to retain, and (3) the spatial pattern for the retention—that is, dispersed or aggregated or in some combination. Decisions regarding each of these questions is, of course, dependent upon management objectives and specific stand conditions.

Given the multiple and complex management objectives typical in modern forestry, standardized prescriptions are not likely to be sufficient. The variable retention concept allows silviculturists to be aware of and to utilize a broad array of harvest prescriptions (Figure 7.1b).

What to Retain?

A wide variety of individual and stand-level structural features can be conserved during harvest depending upon management objectives. Exemplary structural elements include (Figure 7.3) (1) live trees, especially large-diameter trees and trees with distinctive features such as rot pockets, cavities, and large limbs or clusters of limbs, (2) snags in varying states of decay, including snags of larger diameter, (3) logs and other woody debris in varying states of decay, (4) undisturbed layers of forest floor, and (5) forest understory species, including moss, herb, shrub, and small tree components. Following is a brief review of considerations with regards to these elements.

Large-diameter, decadent trees are particularly important features to consider for retention because they provide critical habitat for many organisms and will otherwise be absent from many managed stands. For example, in the mountain ash forests of southeastern Australia, large trees with hollows are essential habitat for over 400 species of vertebrates (Lindemayer and Franklin submitted). Trees with extensive, large-diameter branch systems are important to species such as marbled murrelets and northern spotted owls in northwestern North America (FEMAT 1993). Live trees also provide habitat for many other organisms, including invertebrates, epiphytes (e.g., mosses, lichens, and liverworts), and microbial organisms.

Large live trees are important hosts and energy sources for a wide variety of soil organisms, including fungal species that form mycorrhizae (Perry 1994). As the major photosynthesizing organisms in a forest, trees produce and transfer immense amounts of high-quality carbohydrates from leaves to root systems. A large proportion of these carbohydrates is utilized in the maintenance of mycorrhizae and fine

Figure 7.3 Structural features of old-growth stands having high value for retention include large old trees, snags, and down logs. The silvicultural prescription on this unit is for low (10–15 percent) levels of dispersed structural retention of large trees, snags, and logs (by volume) to meet minimal long-term goals for coarse woody debris (Blue River Ranger District, Willamette National Forest).

root systems. Eventually, they fuel most of the dynamic and complex belowground energy web.

Large live trees are also the sources of large-diameter snags and logs. The importance of snags to a large variety of animal species is well known for temperate forest environments throughout the world (Harmon et al. 1986, Maser et al. 1988).

Logs and other coarse woody debris on the forest floor and in associated aquatic ecosystems fulfills a wide variety of ecological functions (Harmon et al. 1986, Maser et al. 1988). These include habitat for a large variety of vertebrate, invertebrate, plant, fungal, and microbial species; sites for biological fixation of nitrogen; and long-term sources of organic matter and nitrogen. Coarse woody debris, including logs, plays similar roles in providing habitat in freshwater and marine ecosystems and by influencing geomorphic processes such as erosion and sediment retention. These influences are particularly well known for stream and river ecosystems where large logs are often critical structural elements for retentive and diverse stream reaches.

Similarly, understory plants are often critical resources that may require long periods of time to reestablish once eliminated by logging (Halpern and Spies 1995). Herbs, shrubs, and small trees may provide important resources and habitat for animal species. For example, in Australian mountain ash forests, small trees found in the lower canopy belonging to the genus *Acacia* are important as a foraging substrate as well as in facilitating movement of arboreal marsupials (Lindemayer and Franklin submitted). In the same forests, tree ferns (*Dicksonia antartica* and *Cyathea australis*) act not only as nursery sites for other plants, but also as substrate for fungi that are a food resource for some marsupials. The importance of the diverse herbaceous and shrubby understories in coastal Alaskan Sitka spruce–western hemlock forests to deer is well known as is the very long periods of time required to reestablish such understories following clearcutting (see, e.g., papers in Meehan et al. 1984).

In addition to individual structural features, foresters may want to consider some aspects of stand structure, such as provision of multiple canopy layers and maintenance of areas of intact forest floor. Multiple canopy layers provide a diversity of habitat conditions for bird and invertebrate species. Undisturbed areas of forest floor can provide important refugia for many species of ground-dwelling invertebrates and fungal species; maintaining areas with deeper layers of organic matter can also be important, as indicated by North (1993), who found strong relationships between occurrence of truffles and forest floor depth. As will be seen, retention of small forest patches or aggregates is one strategy to provide for some stand-scale structural elements.

How Much to Retain?

Answering the question of how much to retain is conceptually very simple—it depends upon the management objectives for the harvest unit, which of course includes landscape-level considerations. As a beginning point, the silviculturist can decide whether to maintain essentially closed forest conditions, which will require high levels of retention, or to sacrifice closed forest conditions for some period of time, which will allow for low levels of retention.

Detailed decisions about actual levels of retention are complex, however, and data are limited. There is increasing evidence that retention is effective in maintaining biological diversity. However, there is very little quantitative information available on how specific ecological objectives respond to various levels of structural retention. For example, there are no quantitative studies on the effect of various amounts and spatial patterns of logs on movement of small mammals through cutover areas. Similarly, there have been no studies of the numbers of trees that are needed to effectively maintain the hydrologic behavior of an intact forest stand during rain-on-snow storm events. Finally, although live tree retention is known to be effective in maintaining certain bird (e.g., Hansen et al. 1995b), invertebrate (Schowalter in press, Berg et al. 1995), and lichen species (Hunter 1995, Berg et al. 1995, Sillett 1995), there is little quantitative data for most groups of organisms on how species diversity and population levels respond to levels of retention.

Resource managers have begun to develop guidelines for retention of some structural features, such as snags, logs, and live trees. But these guidelines are based upon limited scientific data. Hence, managers have had to rely on inferences based upon knowledge of species and processes of interest and upon practical field experience. Many agencies have developed guidelines for retention of wildlife trees (e.g., Washington State Department of Natural Resources 1992). Earlier wildlife habitat guides provided general information on types, levels, and distribution of snags and logs that is valuable in addressing questions of how much to leave (e.g., Thomas 1979, Brown 1985). Some of the most detailed information that has been developed is for woody debris in aquatic ecosystems, where the objective is often to maintain natural levels of such structures (Maser et al. 1988). This contrasts with objectives in harvested terrestrial areas, where it is understood that levels of specific structures will be substantially below that of natural stands. Individual forest units, such as national forests, have used a variety of information sources, including expert panels, to develop standards for structural retention.

What Spatial Pattern for Retention?

Dispersed and aggregated retention are two contrasting spatial models of structural retention. Each approach has advantages (Table 7.1); moreover, combinations of the two can be designed to gain the ecological benefits of both approaches.

Under dispersed retention, structures selected for retention are evenly distributed over a harvest unit (Figure 7.3). The tree overstory in a classical shelterwood harvest unit provides a model of this spatial pattern. Familiarity with this shelterwood model made dispersed retention the first approach adopted by foresters when challenged to develop alternative silvicultural prescriptions that call for significant retention.

A common application of dispersed retention focuses on dominant and strong codominant trees, since these are likely to be the most wind-firm and stress-tolerant individuals. Such trees can function as refugia for many organisms as well as provide for well-distributed sources of soil energy. They also provide a component of well-distributed large-diameter trees for the new stand once it becomes reestablished. Ultimately, these green trees will also become a well-distributed source of snags, logs, and woody debris incorporated into the forest floor and soil.

Aggregated retention focuses on small patches of forest within a harvested unit (see "Plum Creek Timber Company's Approach"). Patches may be of varied size and shape, but as currently applied in northwestern North America, aggregates are typically 0.05 to 1.0 ha in size. Patch size and placement, initial conditions, and treatment at the time of harvest can vary widely based upon management objectives. Objectives often include provision of patches that are representative of initial stand conditions in terms of composition and diameter distribution and that provide intact forest understories and soil organic layers (e.g., Scientific Panel for Sustainable Forest Practices in Clayoquot Sound 1995). Under such prescriptions,

Plum Creek Timber Company's Approach to Environmental Forestry

Plum Creek Timber Company L.P., a Seattle-based company, is the second largest owner of private timberland in the Pacific Northwest. The company owns 1.2 million acres of forest land in Washington, Idaho, and Montana. In the early 1990s, Plum Creek decided to change both the perception and the reality of their operations by experimenting with variable retention harvesting methods.

In an effort to redress a negative public image, Plum Creek began to transform their corporate identity by first adopting a set of environmental principles. Among other things, these principles include the enhancement of ecological and structural diversity where feasible, meeting or exceeding state and federal standards for protecting water quality and fisheries, enhancing soil and site productivity, and protecting wildlife habitat. Working from this base, company foresters began to develop alternatives to standard clearcutting. Their goal has been to improve upon the aesthetics and ecological functionality of harvest units—particularly with regard to the provision of habitat for the northern spotted owl and other old-growth-dependent species. Two harvest units inhabited by spotted owls are particularly noteworthy:

Frost Meadows is a 183-acre harvest unit located on the east side of the Cascades in Washington State. In 1990, when an active spotted owl nest was discovered just prior to harvesting, Plum Creek modified the harvest prescription to incorporate variable retention harvest strategies rather than the planned, traditional clearcut.

First a minimum 400-foot-wide, no-cut corridor was established along the creek as a travel and dispersal route for owls. Second, on the unit closest to the nest site, approximately 80 percent of the residual stand was left intact to maintain old-growth characteristics, such as large-diameter trees and decayed, dead, and downed timber. Yet, nearly 50 percent of the merchantable timber volume was removed from the stand. The remainder of the sale was changed to marked leave-tree units, reflecting the dispersed retention strategy. About 18 to 20 old-growth overstory trees per acre and the associated understory trees in their immediate vicinity were retained. The objective was to accelerate the development of future spotted owl habitat by providing for multilayered tree canopies and interspersed overmature trees.

Since the harvest, the adult spotted owls at Frost Meadows have been banded, and radio transmitters have been attached to monitor their movements throughout the year. This work has revealed that the female owl discovered just prior to harvest in 1990 remained in the area. In 1991, the male with whom she previously had nested was replaced by a sub-adult. The new pair did not mate in 1991. In 1992, however, this pair successfully raised two young owls, which have been banded and fitted with radio transmitters.

Cougar Ramp is a harvest unit in southwest Washington State on which Plum Creek has pioneered the development of aggregated retention of Douglas-fir forests. The Cougar Ramp unit was designed to meet three management objectives: (1) retain patches of representative green trees, snags, and downed logs with as little disturbance as possible for wildlife habitat; (2) address aesthetic concerns for travelers along a nearby highway; and (3) allow for future blowdown salvage and site preparation for reforestation, should the need arise.

Using uphill cable logging, approximately 15 percent of the 73-acre unit was set aside in contoured patches. The patches were designed, mapped, and marked within each tower setting. Timber was directionally felled away from the patches. Cutting of nonhazardous snags and understory vegetation was avoided in the harvest areas.

The contoured-patch design at Cougar Ramp provided a diverse mix of trees and shrubs representative of the pre-harvest stand. Douglas-fir was the primary tree species retained in the unit, although red alder, maple, and western hemlock were also represented.

Following harvest, researchers at the University of Washington evaluated residual vegetation and microclimate conditions in the unit. Wildlife habitat conditions have been studied by comparing bird, small mammal, and amphibian use of cut areas, uncut patches, and adjacent forest. Preliminary results of the wildlife research indicate that bird species diversity and abundance are highest in the contoured retention patches. The 55 bird species using the Cougar Ramp unit represent groups normally associated with forest canopies as well as species commonly found in clearcuts and openings. Research and monitoring will continue at Cougar Ramp, especially as the harvested areas regenerate to provide additional forest structure.

For more information on these and other environmental forestry projects underway on Plum Creek Timber Company lands, contact Lorin Hicks, Wildlife Biologist, 999 Third Avenue, Suite 1900, Seattle, WA 98104.

Table 7.1 Contrasts between dispersed and aggregated structural retention

	Pattern of Retention	
Objective on Harvest Unit	Dispersed	Aggregated
Microclimate modification	Less, but generalized over harvest area	More, but on localized portions of harvest area
Influence on geohydrological processes	Same as above	Same as above
Maintenance of root strength	Same as above	Same as above
Retain diversity of tree sizes, species, and conditions	Low probability	High probability
Retain large-diameter trees	More emphasis	Less emphasis
Retain multiple vegetation (including tree) canopy layers	Low probability	High probability
Retain snags	Difficult, especially for soft snags	Readily accomplished, even for soft snags
Retain areas of undisturbed forest floor and intact understory community	Limited possibilities	Yes, can be as extensive as aggregates
Retain structurally intact forest habitat patches	Not possible	Possible
Distributed source of coarse woody debris (snags and logs)	Yes	No
Distributed source of arboreal energy to maintain belowground processes and organisms	Yes	No
Carrying capacity for territorial snag- and/or log-dwelling species	More	Less
Windthrow hazard for residual trees	Average wind firmness greater (strong dominants), but trees are isolated	Average wind firmness less, but trees have mutual support
Management flexibility in treating young stands	Less	More
Harvest (e.g., logging) costs	Greater increase over clearcutting	Less increase over clearcutting
Safety issues	More	Less
Impacts on growth of regenerated stand	More, generalized over harvest area	Less, impacts are localized

Note: Contrasts various ecological and operational objectives. Comparable overall levels of retention are assumed.

selected aggregates are not entered during harvest or subsequent silvicultural treatments, such as slash treatment and site preparation.

Retention of patches of intact forest or aggregates as an integral part of a harvest unit is a relatively new concept for foresters and biologists. It is not analogous to any traditional harvest cutting practice, nor has it received much attention from wildlife managers or conservation biologists. Hence, aggregated retention is often misunderstood as an effort to create small forest reserves. In fact, aggregates are intended to be functional elements of a harvested unit—lifeboating and ultimately enriching a managed stand. As such, they are not intended to provide habitat for interior forest species that require large areas because of the edge influences that are experienced with small residual forest patches (see, e.g., Chen et al. 1992, 1993a, 1993b), home range requirements, or other factors.

Although dispersed and aggregated retention both broadly address maintenance of structurally complex forest stands, each has its own set of ecological advantages and disadvantages (Table 7.1) and therefore specific applications in retention harvesting.

Dispersed retention is obviously most appropriate where ecological objectives require that structures be well distributed (Table 7.1). Objectives for which relatively uniform distribution is desirable include provision of coarse woody debris (from logs and snags) to the forest floor and soil and provision of well-distributed sources of arboreal energy (from vigorous living trees) to maintain belowground organisms and processes. Dispersed retention can also provide habitat for wildlife that are strongly territorial or incompatible or that require high levels of some structure; vertebrates dependent upon cavity-bearing trees in Australian mountain ash forests provide an example of this circumstance (Lindemayer and Franklin submitted).

Dispersed retention is also appropriate where the objective is to broadly mitigate some condition over the entire harvest unit, such as modification of microclimate or hydrological processes, or maintenance of root strength to stabilize soils (Table 7.1). Although aggregated retention provides for conditions that are more forestlike, these effects are confined to the immediate vicinity of the aggregate.

Aggregated retention provides opportunities to maintain a broader variety of stand structural elements than dispersed retention (Table 7.1). For example, it is easier to maintain a variety of tree species, sizes, and conditions in aggregates. Some species and sizes of trees have low survival rates in open areas due to poor wind resiliency or low tolerance of moisture, temperature, or insolation stress. Retaining a diversity of trees is important because many organisms, such as invertebrates, are associated with only a limited set of host species (see, e.g., Schowalter 1996). It is also easier to retain a diversity of snag sizes and conditions in aggregates; this is particularly true for soft, highly decayed snags, which are likely to collapse when disturbed by logging activity.

Aggregate retention also affords opportunities to maintain multiple canopy layers, understory plant species and communities, and intact forest floor layers. Retaining these features provides refugia for many species, such as invertebrates and fungi, and processes that would decline or disappear in their absence.

There are many questions about appropriate sizes, shapes, and distributions for aggregates. Applications of the approach should be flexible and fitted to specific management objectives and stand conditions. In many applications, it will be desirable to incorporate representative areas of the preharvest forest stand.

Selective placement of aggregate areas of lower productivity or stand density may reduce their ability to provide desired structures or conditions following harvest. Integrating aggregates with protection of aquatic ecosystems may be appropriate in some areas. However, ecological goals for retention of the aggregates, along with economic and operational issues, are primary considerations.

Isodiametric shapes are often desirable for aggregates, but there are also good reasons for using linear shapes. Compact designs will be more effective than linear designs in modifying microclimatic conditions for a given aggregate size. Linear designs can provide efficient visual screening, corridors for movement, and protection for linear features, such as streams. Special shapes may be designed to achieve specific objectives; teardrop-shaped aggregates are being explored, for example, to reduce risk of windthrow.

Selecting an appropriate size for aggregates involves a variety of considerations, including tradeoffs between the number, potential distribution, and size of aggregates. In most applications, a well-distributed system of aggregates is preferred. Research on edge effects suggests that many microclimatic benefits can be achieved with relatively small aggregates (e.g., less than 1 ha in size). Achieving true interior forest conditions is impossible, of course, in the context of heavily harvested areas due to the extent of edge influences in most forest types (Chen et al. 1992, 1993a, 1993b).

Finally as will be noted below, aggregated retention generally provides fewer operational constraints and has less impact on growth of regeneration than dispersed retention.

Other Considerations in Designing Prescriptions

Although the preceding sections have emphasized stand-level considerations, it is extremely important to recognize that landscape- or larger spatial-scale concerns will be very influential in development of variable retention harvest prescriptions. What is prescribed for an individual stand will very much depend upon its immediate and long-term relationship to conditions and activities in surrounding areas. While such viewpoints are implicit in the notion of objectives such as "enhancing connectivity," this is sufficiently important to warrant specific mention.

Ecological objectives will rarely be resolved by activities on small individual tracts of land. Furthermore, current and planned conditions on surrounding areas may well mitigate much of the potential impact of a harvest unit, reducing the level of structural retention required to achieve some landscape-level objectives. As an example, riparian protection zones may provide for much of the retention required in some landscapes. This occurred under some options developed by FEMAT (1993); stream systems and associated riparian reserves occupied such a high percentage of some coastal regions that retention requirements could be relaxed on some of the matrix available for harvest.

Examples of Variable Retention Silvicultural Prescriptions

While there are essentially infinite possibilities, some generalized variable retention harvest prescriptions already are emerging. These reflect some broad similarities in management objectives as well as the early stages in learning about retention harvesting. Three examples are reviewed below.

Low Retention, Mix of Aggregated and Dispersed

Common objectives for many public and some private timberlands include provision of moderate to high levels of timber production, regeneration of shade-intolerant tree species, and maintenance of minimal structural levels to fulfill basic lifeboat and stand-enrichment functions. Silvicultural prescriptions to achieve this mix of objectives typically involve relatively low retention levels (10 to 20 percent) using both aggregated and dispersed approaches.

The standards and guidelines for structural retention during regeneration harvesting on "matrix" lands in the Northwest Forest Plan (USDA and USDI 1994b) are a generic silvicultural prescription of this type. In brief, the guidelines call for permanent retention of at least 15 percent of green trees on each cutting unit: "Seventy percent of the total area to be retained should be in aggregates of moderate to larger size (0.2 to 1 ha or more) with the remainder as dispersed structures (individual trees, and possibly including smaller clumps less than 0.2 ha)." This direction assumed that a mixture of dispersed and aggregated retention was most likely to achieve the full array of ecological objectives incorporated into the plan. Flexibility was provided to allow silviculturists to fit the mix of dispersed and aggregated retention and size of aggregates to specific site conditions and objectives (USDA and USDI 1994b).

Adoption of these guidelines reflected the strong sentiment of biologists working as a part of FEMAT (1993) that aggregated retention is likely to be more successful in conserving elements of biological diversity than comparable levels of dispersed retention. Indeed, a subsequent team preparing the final environmental impact statement (USDA and USDI 1994a) favored total reliance on larger (1 ha or greater) aggregates. The final wording in the Record of Decision was only adopted after energetic debate; absence of information about the effectiveness of various sizes of aggregates contributed to the difficulty in arriving at a decision.

Similar retention harvest guidelines were provided for cutting units "without significant values for resources other than timber, or without sensitive areas" in the Clayoquot Sound region of British Columbia (Scientific Panel for Sustainable Forest Practices in Clayoquot Sound 1995). These recommendations provided for retention of at least 15 percent of the forest, primarily as aggregates of 0.1 to 1 ha that are well dispersed throughout each cutting unit. Regardless of retention level, the scientific panel recommended that all portions of a cutting unit be within two tree heights of an existing aggregate or stand edge. The panel also advised that aggregates should be representative of forest conditions in a cutting unit—that is, not disproportionately located on sites of lower timber volumes or productivity.

The Scientific Panel for Sustainable Forest Practices in Clayoquot Sound (1995) did recommend high levels of retention on cutting units with significant values for resources other than timber. They rec-

Menominee Sustained-Yield Management

The Menominee Indian Reservation in northeastern Wisconsin stretches over 235,000 acres of land, 220,000 of which are forested. To the casual observer, the Menominee forest looks pristine. Large-diameter trees in a natural setting belie the fact that it is one of the most intensively managed tracts in the Great Lakes states. Over 2 billion board feet of lumber have been removed from the forest in the last 140 years—yet the volume of sawtimber currently is greater than when the reservation was established in 1854.

The 140-year history of forest resource use and management on the Menominee forest is a practical example of sustainable forestry—forestry that is ecologically viable, economically feasible, and socially desirable. The Menominee concept of sustained-yield management refers not only to forest products and social benefits, but also to wildlife, site productivity, and other ecosystem functions.

The Menominees' approach to forestry is based on a simple, farsighted management objective: to maximize the quantity and quality of sawtimber grown under sustained-yield management principles while maintaining a diversity of native species. To the Menominees, quality and quantity are concepts that favor growing those tree species most suitable to a particular site for as long as they remain healthy and vigorous. This concept is based upon the direction chosen by earlier Menominee leaders, who recognized the need to harvest trees for economic survival, but only at a speed or intensity under which the forest could replace itself. They promoted a timber harvesting system that removed timber according to vigor rather than merchantable size alone. The Menominee tradition of harvesting according to tree vigor (the ability to grow and regenerate itself) retains more larger and older trees compared to adjacent timber lands. As such, the Menominee forest is a mixture of older, larger trees with ample younger regeneration. This has provided the tribe with a diversity of forest plants and animals not seen on surrounding forests managed under short-term economic formulas.

A cornerstone of Menominee forestry is its monitoring program. Monitoring is accomplished through two inventory systems called the continuous forest inventory (CFI) and the operations inventory (OI). Using a systematic grid of permanent plots, the CFI monitors forest health (including the area, volume, and condition of the timber) to determine how much of the forest can be harvested annually or over a longer period. Observers thus can track changes in the forest due to management practices or natural occurrences. The OI system monitors all forest land to determine where the timber types described in the CFI occur. Data common to both the CFI and OI systems (such as cover type) are collected with the same specifications, allowing information from both inventories to be merged. This detailed stand information provides the basis for planning when and where to cut.

The annual allowable cut on the Menominee forest is determined based on the CFI. The forest management plan specifies the minimum stocking level necessary for each cover type before any green standing timber can be harvested. In this way, harvest prescriptions are based on the excess stocking of fully stocked stands—not on the net growth of all stands. Silviculture, rather than market forces, determines how much timber is harvested. Understocked acreage is allowed to grow and develop for future harvest.

The forest is divided into 109 compartments. Compartment management activities are based on a 15-year cutting cycle for timber types subject to all-age management—approximately 65 percent of the forest. The remaining forest types, which are managed under an even-age system, are harvested as closely as possible to the compartment schedule.

The compartment cutting schedule was initially determined by looking at the harvest history of specific areas and combining these areas into units of roughly equivalent volume or acreage. Planners have also tried to balance areas of dominant species composition throughout the 15-year cycle. The current schedule reflects the best combination of acres and volume that would produce a reasonably even flow of sawtimber and pulpwood to the mills. It may be revised as new information becomes available through the CFI.

The Menominee sustained-yield management program predates the ecosystem management concepts currently being debated among natural resource professionals. The Menominee tribe has inhabited the forests of this region for thousands of years. They have understood that the whole resource was needed to protect any individual part. This is a heritage that has been passed from generation to generation.

This case study was adapted from the Menominee Tribal Enterprises Forest Management Plan 1995-2005, as well as from the following articles which provide further information on the Menominee forestry program:

Bristol, T. 1992. Edge of the woods: Forestry for the seventh generation. *Turtle Quarterly* Fall.

Pecore, M. 1992. Menominee sustained yield management: A successful land ethic in practice. *Journal of Forestry* 90(7):12–16.

ommended retention of "at least 70 percent of the forest in a relatively uniform distribution . . . [including] some large-diameter, old, and dying trees; snags; and downed wood throughout the forest."

Retention of Dispersed Large-Diameter Cohorts

Prescriptions directed toward management of multiple cohorts are also emerging as an approach to maintaining structurally diverse stands, especially when maintaining a component of large-diameter trees is a major objective. Such approaches are appropriate in the fire-prone forests of western North America. In many of these forests, maintaining a large-diameter old-growth cohort in perpetuity is an important objective for wildlife and fire resiliency objectives, while managing the small- and medium-diameter component for wood production and reduction of catastrophic fire potential.

An example of such a silvicultural prescription of this type for the mixed-conifer forests common in the Sierra Nevada and interior mountains of eastern Oregon might be one that has as one of its objectives maintaining a population of 6 to 10 large-diameter trees and the snags and logs created through the periodic death of these trees. Definition of the diameter objective would probably vary with site productivity; a range might be from 75 to 100 cm d.b.h. (diameter at breast height). The stand would be managed to insure that replacements are available for losses from the large-diameter tree population. No salvage of the dead trees would occur in order to insure that there is also a continuing population of large snags and logs.

The interim California spotted owl harvest guidelines provide a starting point for this kind of system (Verner et al. 1992) (Figure 7.4). In forest stands of a type "selected" by California spotted owls (primarily mixed-conifer forest dominated by large trees), the guidelines call for retention of 40 percent of the basal area of large old trees, including all trees 30 or greater in d.b.h. In other strata that might be used for nesting, prescribed retention levels are 30 percent and at least 50 sq. ft. per acre of large old trees, including all trees 30 or greater in d.b.h. Retention of large snags (to a maximum of eight per acre) and the largest down logs (to at least 10 to 15 tons per acre) is also a part of the interim recommendations. These guidelines are currently being used on national forest lands within the range of the California spotted owl. Additional desirable developments for a long-term strategy might include refinement of the large-diameter tree population goals (i.e., numbers and species) and providing for replacements as mortality occurs.

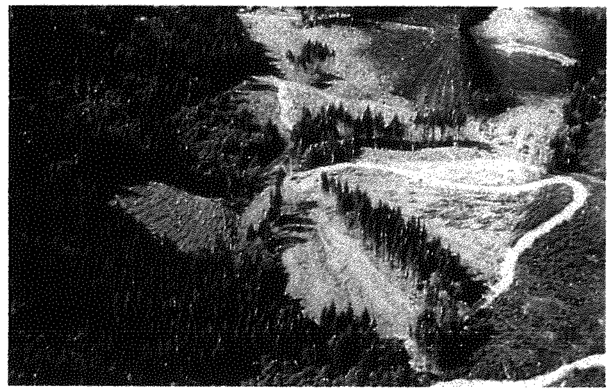

Figure 7.4 Silvicultural prescription designed to maintain a dispersed population of large-diameter trees on the harvest unit following the California spotted owl interim guidelines. All trees greater than 30 in. d.b.h. have been retained with complete removal of smaller merchantable stems (Plumas National Forest, California).

Silvicultural prescriptions designed to produce multiple cohorts as outlined above contrast sharply with traditional selection-cutting approaches. Traditional selection prescriptions focus on creation and maintenance of a particular tree diameter distribution. Larger, older trees are systematically removed as a part of this process.

Group Harvest with Low Retention

Group selection is often proposed as a technique to mitigate impacts of timber harvesting on biological diversity since it generally involves clearing of relatively small areas within a forest matrix. Smith (1986) describes a maximum size for selected groups as an opening two tree heights in diameter, about 0.7 and 2.9 acres for trees 100 and 200 feet tall, respectively. The harvest of these small areas cycles through the stand, eventually resulting in harvest of the entire area. As traditionally practiced, group selection does not provide for retention of structural features within the harvested patch. Consequently, any structural features that have development periods longer than the rotation will be lost from an area subjected to classical group selection. Groups that are completely cleared obviously have much simpler structures than most natural openings, which have a structural legacy of living or dead trees or both.

Hence, group selection combined with structural retention has been proposed as an alternative approach to maintaining structures that have very long development times or are required in large numbers. Such a modification has been proposed by the California Spotted Owl Technical Group (Verner et al. 1992) for Sierra Nevada pine and mixed-conifer types. Incorporating structural retention within selected groups is very straightforward in such timber types.

One of the few examples of group selection with structural retention known to the authors is in second-growth coast redwood stands located in the Arcata, California, city forest (Figure 7.5). This approach was developed by the third author in 1982 after an attempt to apply a uniform, single-tree selection system proved unsatisfactory. Prescriptions provided for retention of large live trees (especially dominant coast redwoods), snags, and down logs within selected groups up to 4 acres in size. Typical retention levels are 25 percent of the merchantable volume.

Another alternative for maintaining structural features under a group selection approach would be to permanently reserve an appropriate percentage of the subject stand from harvest.

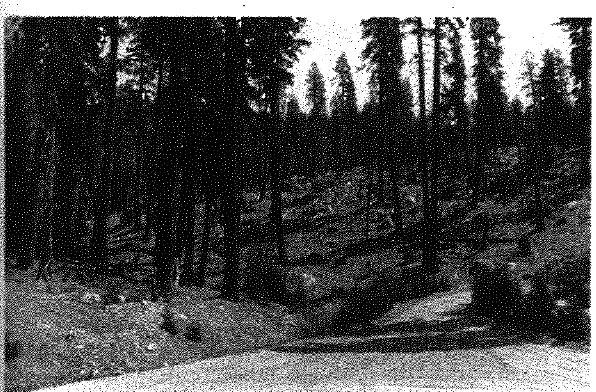

Figure 7.5 Silvicultural prescription for second-growth stand involving harvest of selected tree groups up to 4 acres in size with 25 percent retention (by volume) of coast redwood and other trees and large snags and logs (watershed for City of Arcata, California).

Management Issues in the Application of Variable Retention

Conceptually, structural retention is as old as forestry. But, at the same time, it is revolutionary because none of the traditional regeneration harvest systems truly has utilized the concept, as will be discussed below. Consequently, practical experience—let alone designed scientific studies—is very limited. Numerous questions are associated with forest protection, regeneration and growth, and the effectiveness of retention prescriptions in achieving management objectives. Some of these issues are discussed below along with current scientific information providing valuable insights for understanding and evaluating retention harvest approaches. The Cascade Center for Ecosystem Management has produced a very useful review of much of the existing scientific and anecdotal information in its *Residual Trees as Biological Legacies* (Hunter 1995).

Forest Protection

Protection of forests from a variety of factors—including wind, wildfire, insect pests, and diseases—has always been an important element of any forest management program. Indeed, justifications of even-age management often are based, at least partially, upon control or exclusion of some pest or pathogen, such as parasitic mistletoes. In particular, clearcutting—which eliminates all existing trees—is viewed as a technique to reduce or eliminate pathological legacies and start over with a fresh slate.

In any case, retention harvest prescriptions must address forest protection concerns if they are to be successful.

Wind

Wind is always an important consideration in timber harvest because of possible impacts of residual stand and landscape conditions on the potential for major windthrow events. Hence, wind is a key consideration in designing silvicultural prescriptions. All harvest cutting practices can increase the potential for windthrow. The only way to ensure that there will be no windthrow is to cut all of the trees. Yet even clearcutting affects windthrow potential in adjacent unharvested stands. Increases over endemic levels of windthrow will depend upon the amount (e.g., Franklin and Forman 1987) and topographic location of boundaries or edges between uncut and cut forest (e.g., Gratkowski 1956).

Retention harvest systems are of particular concern because isolated trees and tree groups are much more vulnerable to wind damage than trees in intact stands. In the Douglas-fir region, an early study found very high rates of mortality in residual seed trees (e.g., Isaac 1943). This led to the conclusion that such trees were ineffective as seed sources. On this basis, large tree retention on harvest units was dropped until the 1960s when Roy R. Silen, working at H. J. Andrews Experimental Forest in the western Oregon Cascades, resurrected seed tree and shelterwood cutting to address problems in natural regeneration of Douglas-fir forests (Franklin 1963). Silen hypothesized that if residual trees were sound dominant trees—rather than culls or defective trees as had previously been the case—survival would be much better. He was proven correct by his initial trials (Franklin 1963) and by a much more extensive series of Douglas-fir shelterwood cuttings stimulated by his research (Williamson 1973).

Trees will be lost to wind-related causes. However, retention harvest prescriptions can be designed to minimize windthrow. Selection of species and individuals that have a high likelihood of surviving windstorms is an important element in minimizing potential losses; such distinctions are generally understood in most forest types. For example, in old-growth western hemlock–western red cedar stands along the Pacific Coast of North America, red cedar have a much higher probability of surviving as residual trees in partially cut stands than western hemlock. As noted earlier, sound dominant trees are more likely to survive than trees that are subdominant or have advanced states of decay. Deep-rooted species, such as Douglas-fir and many pines, are more likely to survive than are shallow-rooted species such as hemlocks and spruces.

With regard to windthrow, aggregated patterns of retention are likely to be superior to dispersed patterns of retention. A group of trees provides at least some mutual support. It is also possible to site aggregates in more wind-firm locations within a harvest unit. Likewise, the shape of aggregates can minimize windthrow potential; for example, teardrop shapes tend to be more aerodynamic than linear designs. The advantage regarding windthrow may not be entirely with aggregated retention, however, if trees selected for dispersed retention are generally sound dominants of more wind-firm species. Furthermore, the windthrow susceptibility of retained trees can be reduced by removing a portion of the canopy by topping or branch pruning, thereby reducing the sail area.

Topographic and soil conditions are also important variables in the design of retention harvest prescriptions. Sites that are exposed to frequent, intense windstorms are not prime candidates for retention harvest if long-term survival of residual green trees is the objective. Note, however, that retention harvesting may be appropriate if development of snags and logs on the harvested area is the objective. Similarly, sites with restricted rooting depths as a result of shallow or poorly drained soils are not good candidates for retention harvest.

The preceding comments apply primarily to harvest prescriptions involving low levels of structural retention and high levels of exposure for residual trees. Silvicultural prescriptions with very high levels of partial retention—which basically retain the conditions of an intact forest—present different circumstances. For example, experience suggests that selective harvest of up to 30 percent of stand volume may be possible in alluvial Sitka spruce–western hemlock stands in coastal British Columbia without seriously increasing windthrow in the residual stand (Scientific Panel for Sustainable Forest Practices in Clayoquot Sound 1995). Of course, much depends upon the local situation (e.g., species), specific silvicultural prescription, and the damage sustained by a stand in such a selective harvest operation. Of course, potential wind damage should not be ignored at high levels of retention. Rather, prescriptions with a high level of retention offer different opportunities and problems than those with low levels of retention.

Levels of mortality in residual trees following retention harvest will vary widely depending upon such variables as retention level, age, condition, and species of residual trees; geographic region; topographic location; and soil conditions. Some early data are already available for retention units in northwestern North America (Adler 1994, Hunter 1995). Variability in mortality is high: Zero to 58 percent of residual trees were windthrown on 44 units 1 to 10 years of age, while average mortality was 15.9 percent (Adler 1994). Losses are generally viewed as being within acceptable levels (Hunter 1995). Rates of loss of retained trees appear to be highest in the first few years following harvest (Adler 1994, Hunter 1995).

High rates of mortality in retained trees may necessitate retention of larger numbers at harvest in order to maintain minimal levels. This is a potential problem in Australia, for example, where trees with cavities experience accelerated rates of collapse following harvesting (Lindemayer and Franklin submitted).

Of course, windthrown trees have not lost all of their functional value. As noted earlier, objectives for structural retention often include provision of logs on the forest floor and in streams. Generally, however, resource managers prefer not to have the majority of retained live trees converted to down logs within the first 5 to 10 years of harvest.

Fire

Fire is an important element in the management of most forest types for both its potential negative and positive roles. Protection of forests from destructive, uncontrolled wildfires is typically one of the first issues addressed in forest management. For this reason, treatment of slash and fuels generated during harvest and other management activities is typically a part of most silvicultural systems. Slash burning and other activities are often used to reduce or redistribute fuels.

Fire also can have important and positive effects on ecological processes within forests; as such, it is an important silvicultural tool. Prescribed fire appears to be especially important in forest types which evolved under frequent light to moderate fire regimes. Such types are widespread in western North America and Australia. Hence, the effects of silvicultural practices on opportunities for use of prescribed fires is an important consideration.

Retention harvesting—in comparison with clearcutting—does introduce some complexities to the treatment of slash and other forest fuels. However, forest managers have adapted traditional practices—such as broadcast burning or piling and burning—for slash treatment on shelterwood and on retention harvest areas. When treating retention harvest units, there are the duel concerns of keeping the location and intensity of the fire within desired bounds and insuring the survival of the retained vegetation and other structural elements. There is, of course, the potential to use prescribed fire to convert retained live trees to snags; such an approach might have some ecological advantages over creation of snags by topping.

In the Douglas-fir region, fire has been used to treat slash on the majority of retention harvest units cut to date. A variety of techniques has been used, including broadcast burning and burning of concentrations and piles. The presence of retained vertical structures does not appear to create insurmountable problems, although slash treatment costs are generally greater than after clearcutting. Even though most existing cuttings involve dispersed retention, slash treatments have generally been achieved without causing major damage to retained green trees. Much remains to be learned, however, regarding long-term effects of varying fire intensities on survival of residual trees. It is also clear that very intense slash fires can cause unacceptable rates of mortality in residual trees, as has been reported for Eucalyptus forests, for example (Lindemayer and Franklin submitted).

Fire is generally less of a problem with aggregated retention if managers are trying to limit losses of retained structures while treating fuels. The problem is simply one of keeping slash fires out of the aggregates, rather than trying to manage an intricate mosaic of slash and dispersed structures. Of course, in some forest types subject to frequent low intensity fires, managers may specifically wish to burn within aggregates as part of a management strategy.

Using prescribed fire to manage structurally diverse stands developed under retention harvest prescriptions does not appear to pose any unique problems. In fact, it is possible to create stands that are not only well suited to prescribed fire, but also are more resistant and resilient to intense wildfire. For example, large-diameter dominant trees—such as those maintained in the dispersed, large-diameter cohort prescription described earlier—are most likely to survive intense wildfire.

Insects and Diseases

Insects and diseases are important considerations in forest management; often they provide the rationale for specific silvicultural prescriptions. For example, clearcutting is sometimes justified based on the notion that all potential hosts need to be removed from an area to eliminate sources of infection. Conversely, the existence of insect or disease infestations or the potential for their development are often identified as factors that preclude retention harvest systems.

Conceptually, there is a basis for concerns over retention harvest prescriptions providing opportunities for persistence or intensification of pathological problems (see, e.g., Shaw et al. 1994). If structural retention can be used to provide refugia and inocula for desirable insects, fungi, and similar organisms, then it also can provide refugia and inocula for pathogens. Note that the converse is also true—drastic treatments to completely eliminate pathogens, hosts, or critical substrate have the real potential to eliminate many desirable organisms, such as detritivores and symbionts. Some criticisms by pathologists are based on the assumption that retention systems involve more-frequent stand entries than even-aged systems (e.g., Shaw et al. 1994), but this is not necessarily the case.

From a managerial perspective, the key is specificity—identification of the pathogens of specific concern and development of silvicultural prescriptions that balance those concerns against other objectives. Even-age management can accentuate pest problems, especially when it involves monocultures; similarly, long rotations can result in increased problems when they involve numerous intermediate stand entries (Shaw et al. 1994). Dwarf mistletoe, root rots, and bark beetles provide examples of differing challenges and potential silvicultural responses.

Dwarf mistletoe is a parasitic plant that is very common in forests of western North America. Often it is the rationale for rejecting retention harvest prescriptions. If a mistletoe-infected overstory is retained, it will infect susceptible tree species in the understory. Aggregated retention can reduce the conflict between structural retention and containment of problem areas, although it does not totally eliminate the problem. The potential for intensification of mistletoe infections within aggregates remains along with the potential for spread to adjacent areas. An alternative in such situations is dispersed retention in which only nonsusceptible tree species or mistletoe-free individuals of susceptible species are retained.

Root diseases are among the most difficult pathological problems faced in forest management (Shaw et al. 1994). With regards to root diseases, it is not clear where the advantages, if any, would lie between clearcut and retention harvest systems. Even-aged approaches allow for removal of all host species and, possibly, replacement with nonsusceptible or less susceptible species, but this is also possible with retention harvest systems. The retention approach would provide for greater structural complexity in the subsequent forest, but might also result in higher levels of inoculum than under clearcutting. Complete elimination of the root disease from a site is unlikely under either approach. Retention approaches are more likely to provide for a more complex soil ecosystem, which may help hold pathogens in check.

Forest insect pests are generally not likely to be a problem with retention harvest systems. Different species of bark beetle attack different age classes and species of trees as well as different sizes and conditions of material. Typically, retained trees are much older and have a different set of insect pests than the younger, managed component of a stand. Perhaps the greatest problem is the potential for excessive mortality in the retained tree component, especially if wind or fire create opportunities for increased populations of specific pests. Again, choosing various combinations of aggregated and dispersed retention and appropriate retained tree species on dispersed retention sites may minimize insect problems.

Emerging evidence suggests that retention harvest will maintain greater varieties and numbers of insect predators and parasites than occur under clearcutting regimes (Schowalter 1989, 1996). This could be an important factor in maintaining natural controls on insect pests.

Forest Harvest and Management

Operational issues associated with retention harvest strategies include safety; transportation and logging issues, including costs; impacts on management practices and costs; and impacts on forest product receipts.

Worker safety is a critical issue in all forest operations, particularly logging operations. Retention of structural features, especially decadent trees and snags, has the potential to create major hazards for workers who are felling, bucking, and yarding logs. Indeed, removal of all snags and any hazardous trees in and adjacent to work areas is standard practice for most forest regions. Until recently, all logging contracts on federal lands in the Pacific Northwest called for removal of all snags within 200 ft. of a cutting boundary or road. Safety issues are not only confined to harvest operations, but also extend to workers in subsequent operations, such as tree planting and thinning.

Developing safe approaches to structural retention is a major challenge that must be addressed. From a safety perspective, aggregated retention may be particularly appropriate since it is consistent with creation of no-work zones around areas where snags and hazardous trees have been retained.

Worker safety was a major concern of the Scientific Panel for Sustainable Forest Practices in Clayoquot Sound (1995). The panel, which included a highly qualified representative of the Worker's Compensation Board, concluded that "[s]afety concerns are inherent in any silvicultural system. The hazards of clearcutting are better understood than those of other systems. . . . Safety concerns are much easier to address using aggregated [than dispersed] retention . . . principles, which must be observed regardless of the silvicultural system used: procedures must be developed and implemented to minimize risk to workers; and workers must have the right to refuse to carry out procedures that place them at risk."

Retention harvest practices will generally result in higher logging costs than clearcutting, and they may or may not require selection of alternative logging technology. Experiences with shelterwood harvesting are probably very relevant to low to moderate levels of dispersed retention. In general, logging costs for dispersed retention are likely to be significantly greater than for clearcutting, but costs will be only slightly greater for aggregated retention than for clearcutting. Some data from actual retention harvest operations (e.g., Zielke 1993) support these hypotheses.

Loggers can provide some very useful insights into the relative merit of various retention harvest prescriptions and logging methods under specific conditions of access and topography (Berg 1995). These ideas address a variety of concerns, including worker productivity and safety. Incorporating worker input into the design of silvicultural prescriptions needs to be greatly expanded. Training programs, including basic education in ecological concepts, clearly is another important part of implementing new and complex silvicultural procedures, including retention harvest prescriptions (Scientific Panel for Sustainable Forest Practices in Clayoquot Sound 1995).

Retention harvest methods also can introduce complexities into the management of the subsequent stands. One of the early objections to dispersed retention was the potential for interference with aerial applications of pesticides, fertilizers, or herbicides. Aggregated retention can essentially eliminate this problem since it is possible to manage intervening areas essentially as even-aged stands. In such circumstances, aggregates should be laid out so as not to interfere with flight paths.

Concerns have also been raised about the compatibility between retention harvesting and the amount and genetic composition of tree regeneration. Retention harvesting is likely to result in high levels of natural tree regeneration since significant seed sources and protective cover are retained on the site. This does not preclude planting or seeding of desirable species or genetic strains not already present on the site. Indeed, there are many options for multiple-species management using retention approaches utilizing a mixture of regeneration practices and rotation periods on the same site. Genetic impacts of retention harvest techniques on tree populations will depend, of course, upon the nature of the silvicultural prescriptions and are not necessarily more likely to have negative consequences than traditional silvicultural systems (see Friedman, Chapter 13).

Excessive stocking of tree regeneration is likely to be the most common outcome using retention harvest prescriptions. Hence, precommercial thinning and other activities that reduce stand densities will generally be the most important intermediate stand-level silvicultural treatment.

Retention harvesting clearly will reduce wood yields relative to even-aged systems, especially clearcutting. These reductions take two forms: (1) wood volume in the structures (trees, snags, and logs) permanently retained on a site and (2) reduced growth of a regenerated stand due to effects of the residual overstory.

Calculation of volumes and values associated with retained structures is straightforward, assuming that no subsequent removal of these structures is planned. For example, Weigand and Burditt (1992) found that the potential value left behind ranged from $102 to $1,114 per acre depending upon the prescription that was used. The key variables are the amount and type of material retained and the per unit value of such material.

The impact of retained structures on growth of subsequent stands is much more difficult to calculate. Few empirical data exist on the effects that residual trees have on growth of a regenerated stand. Similarly, there are few growth models that allow realistic simulation of growth under such complex stand structures. Two general hypotheses are (1) that growth effects will be related to level of overstory retained and (2) that dispersed retention should have greater impacts than aggregated retention.

Some empirical data on effects of residual trees on growth of associated younger cohorts do exist for forests in northwestern North America (Zenner 1995, Rose 1994). In young to mature stands of Douglas-fir and western hemlock in the Cascade Range, Zenner (1995) found that total understory volume reduction was 22 and 45 percent with residual tree densities of 5 and 50 per acre, respectively; this converts to a growth reduction of 2.4 and 1.5 percent per residual tree. Douglas-fir volume and basal area declined more rapidly than that of western hemlock when residual tree density exceeded 15 trees per acre, although average size and growth rates of dominant Douglas-fir were not reduced by residual trees. Zenner (1995) hypothesized that growth impacts can be reduced by thinning in the understory. Rose (1994) compared 70- to 110-year-old stands with and without an overstory of large old trees. Young stand densities declined when remnant tree densities exceeded about 15 per hectare. Total stand basal area was relatively constant regardless of remnant densities.

Rotations, Entries, and Age Classes

There is often confusion about such issues as rotation lengths, numbers of regeneration harvest entries per rotation, and age class structures (even-, multiple-, or uneven-aged) under retention harvest strategies.

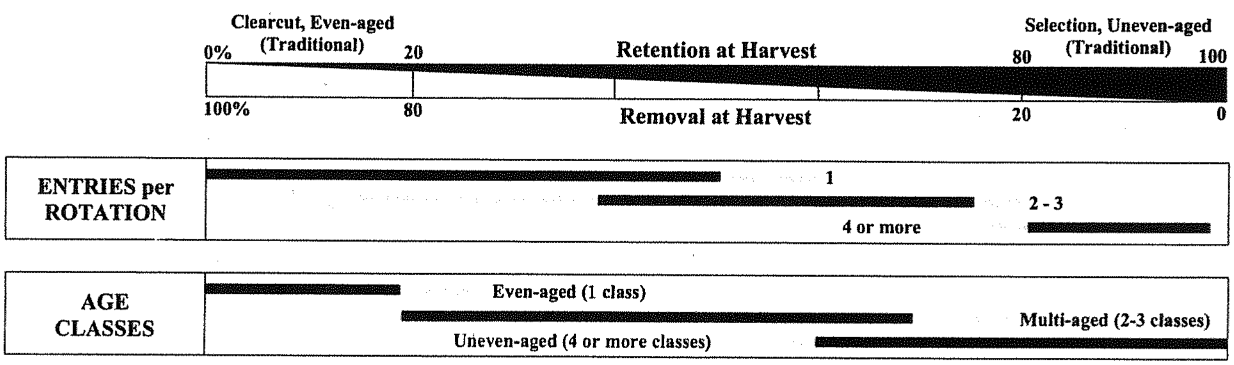

Figure 7.6 Hypothetical relationships between retention levels and entries per rotation and stand age classes.

Foresters often assume that retention harvest approaches necessarily involve more than one entry per rotation or involve an uneven-aged strategy. Some hypothetical relationships between rotation, entries per rotation, and age class structures are illustrated in Figure 7.6. There is substantial overlap among variables over the retention gradient depending upon the particular silvicultural prescription, which of course reflects specific management objectives for the stand.

Strategies involving low to moderate levels of retention (10–30 percent) typically involve only a single entry per rotation and creation of a two-aged stand. After initial harvest operations and regeneration of a new stand, entries probably can be confined to precommercial and commercial thinning operations in the young stand. Strategies involving high levels of retention may involve multiple regeneration harvest entries per rotation and creation of multi-aged (two to three age classes) or uneven-aged (four or more age classes) of trees.

Scientific Issues Raised by Variable Retention

There are numerous important scientific and technical issues regarding the variable retention harvest system. These include fundamental questions about which and how many structures need to be retained and what spatial patterns are desirable to achieve specific objectives. Current working hypotheses are largely based upon inferences from ecosystem science, conditions in multi-storied stands created by nature or past human activities, and short-term studies of recent harvest cuttings that used some form of retention. Problems with using traditional silvicultural systems, particularly clearcutting, to achieve many objectives are clear, along with the need for greater variety in harvest prescriptions. Nevertheless, the knowledge base for implementation of retention harvest is limited.

Evidence for Effectiveness of Structural Retention

Questions are frequently raised about the effectiveness of retention harvest prescriptions in achieving either the lifeboating or structural enrichment objectives outlined earlier. Is there greater species diversity in stands with structural retention than in those that were clearcut?

Studies of young and mature stands which incorporate an old-growth tree cohort provide evidence of greater biodiversity than stands of comparable age lacking such a cohort. In the Pacific Northwest, catastrophic wildfires in the 1800s and early 1900s produced numerous stands that contained residual old-growth Douglas-fir trees; portions of the 1902 Yacholt burn in southwestern Washington State provide a good example of these stands (Figure 7.2). A 1921 windstorm on the Olympic Peninsula produced stands with similar structural complexity. In both cases the resulting mixed-aged stands provide suitable habitat for northern spotted owls when the dominant age class is only 70 to 90 years.

Vertebrate research in such stands provides further evidence. Carey (1995) found that northern flying squirrel populations in young stands with old-growth legacies and well-developed overstories were equivalent to those in old-growth stands. Flying squirrel abundance could be predicted by the density of large snags and abundance of ericaceous shrubs; at least seven large snags per hectare were required to achieve high abundances. North (1993) examined ecological features of 41 non-old-growth stands utilized by northern spotted owls on the Olympic Peninsula and in the northern Cascade Range of Washington. These stands originated following partial destruction of old-growth forests 60 to 70 years ago by wind, fire, or selective cutting. Snag volume and tree height diversity were important predictors of owl use intensity in these stands.

Recent harvest units have been studied for the effects of retention on microclimate, birds, small mammals, lichens, and invertebrates. Unpublished microclimate studies indicate significant amelioration of environment under either dispersed or aggregated retention (Jiquan Chen, personal communication, 1995). Of course, the extensive body of data on microclimatic conditions under shelterwood cutting is relevant in assessing the effects of dispersed retention.

Results of avian studies on retention harvest units and in other stand types clearly indicate that retention enhances structural complexity and provides habitat for many native bird species, including species which are characteristic of late-successional forests but absent from clearcuts (Hansen and Hounihan 1995, Hansen et al. 1995a, 1995b, Vega 1993). Hansen and Hounihan (1995) found higher bird species richness and diversity in retention stands than in clearcuts in the High Cascades of central Oregon. In a more comprehensive analysis, Hansen et al. (1995b) compared bird abundance and habitat functions for forest birds across a wide range of natural and managed stand structures and ages and found that several species of birds benefit from retention of canopy trees, including four species that were characteristic of late-successional forests. Model simulations (Hansen et al. 1995a) also predicted favorable effects of structural retention on several species of birds.

Retrospective surveys of mixed-cohort stands have shown that structural retention can provide effective refugia for invertebrates and lichens. Schowalter (in press) found substantially greater arthropod diversity in partially harvested stands than in plantations regenerated following clearcutting. Similarly, Sillett (1995) finds that many lichen species, including the nitrogen-fixing cyanolichens, will survive on old-growth trees retained on cutover areas and will inoculate the young trees.

Research Needs

Implementation of new silvicultural prescriptions must proceed even in the face of limited existing knowledge in order to meet the complex, multiple objectives of modern forest management. A great deal of relevant scientific knowledge does exist on which to base alternative harvest prescriptions.

An adaptive management approach is required, however, which recognizes that all silvicultural prescriptions are effectively working hypotheses, as Smith (1986) emphasizes. Retention harvest systems should incorporate a strong monitoring component. Furthermore, harvest units that allow for informal comparisons of alternative prescriptions can be established and observed.

Formal research on retention harvest approaches is also critical, however. Particularly critical are experiments designed to provide quantitative information about the types and levels of structures and spatial patterns of retention to achieve various objectives. For example, what are the tradeoffs between levels of coarse woody debris on cutover areas and persistence and movement of small mammal populations? How does avian diversity respond to increasing numbers of retained snags and green trees?

The relative merits of dispersed and aggregated retention currently rank as one of the most important silvicultural research questions associated with retention harvest approaches. This is because of the important economic and operational tradeoffs between the two approaches as well as issues of ecological effectiveness. Currently there are no empirical data comparing the two approaches.

For aggregated retention, important questions center on the appropriate size of aggregates and tradeoffs between aggregate distribution and size under a specific level of retention. These two issues were intensely debated during development of the Northwest Forest Plan (FEMAT 1993, USDA and USDI 1994b) as noted earlier. Few empirical data exist on environmental and organismal responses to increases in the size of isolated forest aggregates (e.g., between .05 and 4 ha). Studies of microclimatic gradients at clearcut-forest boundaries (Chen et al. 1993a, 1993b) provide a basis for inferring that the environmental changes in aggregates are rapid with increased aggregate size initially, but quickly slow after an aggregate size of 0.5 to 1 ha is attained. Creation of interior forest conditions requires very large forest patches (e.g., 25 to 40 ha) and cannot be achieved in aggregates.

Tradeoffs between aggregate size and distribution at a given level of retention is similar to the SLOSS (single large or several small) debate over reserve strategies at the landscape and regional scale (Noss and Cooperrider 1994). Are more ecological objectives achieved by having more small aggregates well distributed over a harvest unit or by having a few large aggregates? The Scientific Panel for Sustainable Forest Practices in Clayoquot Sound (1995) emphasized distribution—no portion of the harvest area was to be greater than four tree heights from an aggregate or patch. At one stage in the development of the Northwest Forest Plan (USDA and USDI 1994a), the strategy using a few large aggregates was emphasized, although this was changed in the final document (USDA and USDI 1994b). In any case, aggregate size and distribution are very important topics for future scientific work.

Major silvicultural experiments to answer basic questions about retention levels and patterns are difficult and expensive undertakings. This is why so few experiments have been conducted, and those that are undertaken are often abandoned after a short time (see, e.g., the Silvicultural Systems Project in Australia [Squire 1990]). There has never been a large-scale, replicated scientific study of any regeneration harvest system in the Douglas-fir region, for example, including clearcutting. Such experiments are made even more challenging when relatively large areas need to be treated to allow evaluations of at least some vertebrate responses. Some harvest trials, such as at Plum Creek Timber Company's Cougar Ramp unit (Zielke 1993) and at several innovative retention harvest units created by the city of Seattle at the Cedar River Watershed have been very instructive. They have provided sites for initial studies of wildlife responses, tree mortality, regeneration and growth, and microclimate. However, most trials of retention harvest approaches to date do not qualify as statistically valid scientific experiments.

Replicated experiments are now being planned and implemented at several locations in the United States, Canada, and other countries. One of the more notable is a project known as DEMO (Demonstration of Ecosystem Management Options), subtitled "A Study of Green Tree Retention Patterns and Levels in Western Oregon and Washington" (USDA Forest Service 1996). DEMO involves six different treatments (Figure 7.7), each replicated at eight locations:

- 15 percent retention in dispersed pattern
- 15 percent retention in aggregated pattern
- 40 percent retention in dispersed pattern
- 40 percent retention in aggregated pattern
- 75 percent retention with harvest in small groups
- 100 percent retention for control

Response variables include small mammal, bird, and fungal populations; forest understory communities, including vascular plants and ground-layer cryptogams; understory response; regeneration and growth of tree regeneration; and growth and mortality of retained trees.

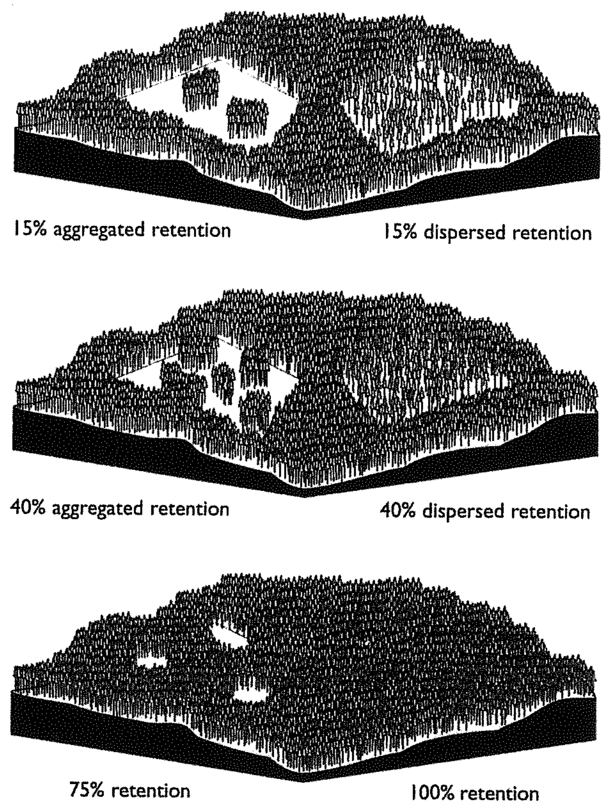

Figure 7.7 The primary focus of the DEMO (Demonstration of Ecosystem Management Options) experiment underway in Oregon and Washington is comparison of ecological and silvicultural responses to three different retention levels (15, 40, and 75 percent) and two retention patterns (dispersed and aggregated) replicated in eight locations. The six treatments are illustrated here.

Another example of an important large-scale harvest-cutting experiment is the Montane Alternative Silvicultural Systems (MASS) project being conducted on Vancouver Island, British Columbia (Arnott et al. 1995). This experiment is designed to address regeneration, wildlife habitat, and aesthetic concerns in managing forests at higher elevations, and it considers both biologic and economic issues. Prescriptions under study are small patch cuts, green tree retention, and shelterwood.

Conclusions

Forest managers are faced with the challenge of designing and implementing timber harvest prescriptions that address multiple ecological and economic objectives. These often call for the development and maintenance of complex forest stand structures that differ from either even- or uneven-aged managed forest concepts. Traditional regeneration harvest systems were designed with the singular objective of harvesting trees while providing for regeneration and growth of commercial tree species, and they do not readily accommodate the complex management objectives that will be typical of the 21st century on many forest lands.

We propose that silviculturists consider using the variable retention concept in developing timber harvest prescriptions. The objectives in retention are (1) to lifeboat species and processes on the harvested tract immediately following harvest, (2) to structurally enrich the subsequent forest stand, and (3) to improve connectivity in the managed forest landscape. In this approach, silviculturists prescribe the type and levels of structural elements that are to be retained on the harvested area and the spatial patterns for the retention.

Variable retention harvest prescriptions are emerging as a major strategy for integrating ecological and economic objectives throughout the temperate forest regions of the world. This approach is extremely flexible and provides benefits that cannot be achieved simply by using long rotations with traditional clearcutting.

Variable retention harvest is not simply a modification or adaptation of the traditional harvest systems—clearcut, seed tree, shelterwood, and selection. Variable retention harvest prescriptions typically focus on ecological objectives, such as maintaining biological diversity, as well as economic management objectives. Regeneration of commercial tree species or the rapid growth of this regeneration may not be primary objectives of such harvest prescriptions.

We feel that by stipulating the kind, amount, and distribution of retained structures, silviculturists can clearly communicate their objectives and proposed treatment. Confusion associated with efforts to adapt to old terminology, including such oxymorons as "clearcut with reserves," could thereby be avoided.

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