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Silviculture for Multiple Objectives in the Douglas-Fir Region

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Errata

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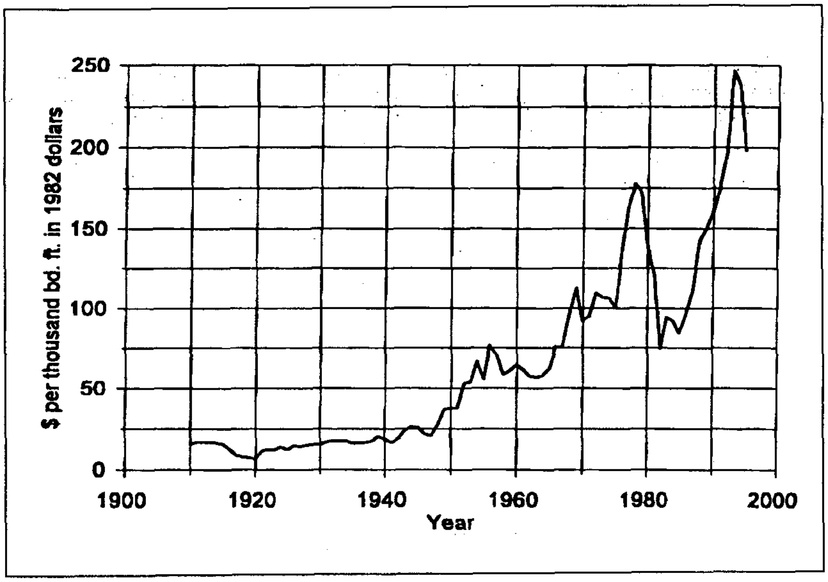

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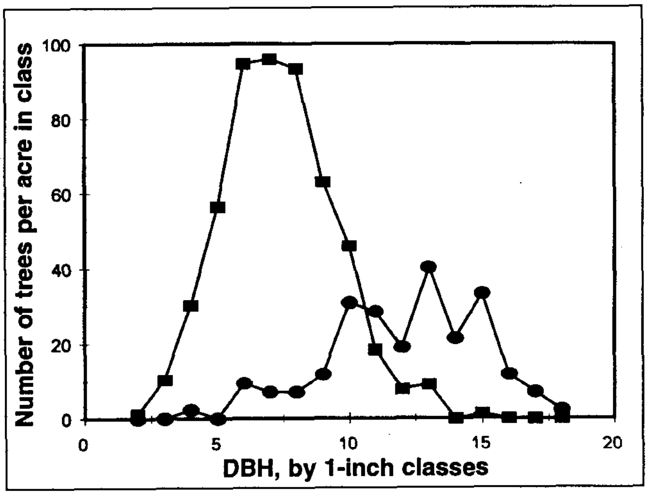

We apologize for any inconvenience this may have caused you.

Abstract

Curtis, Robert 0.; DeBell, Dean S.; Harrington, Constance A.; Lavender, Denis P.; St. Clair, J. Bradley; Tappeiner, John C.; Walstad, John D. 1998. Silviculture for multiple objectives in the Douglas-fir region. Gen. Tech. Rep. PNW-GTR-435. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 123 p.

Silvicultural knowledge and practice have been evolving in the Pacific Northwest for nearly a century. Most research and management activities to date have focused on two major topics: (1) methods to regenerate older, naturally established forests after fire or timber harvest; and (2) growth and management of young stands. Today forest managers can reliably regenerate the major conifer and hardwood species under most conditions by using combinations of natural and artificial regeneration. They also can control stand density and species composition and growth of individual trees, thereby influencing stand structure. Available growth models can reasonably predict the outcome of growing conifer stands under a range of densities, species composition, and management scenarios, providing tree numbers by size class as well as crown characteristics and wood yields.

Most silvicultural efforts have been financed through and directed toward production of wood. Although some other values have been produced or improved in conjunction with such activities, public interest and emphasis on nontimber values have increased. It has become apparent that some values are not benefitted by silvicultural practices aimed solely at wood production. In most situations, however, desired nontimber values can be enhanced by silvicultural measures implemented for their direct benefit or by some modifications of practices applied primarily to produce wood. We discuss the historical development of silviculture in the Pacific Northwest and review the silvicultural practices currently available to forest managers. We then point out how these practices can be modified and used to maintain and produce wildlife habitat, diverse stand structures (including those usually associated with old forests) and pleasing scenery, while also producing wood products. Most of the silvicultural knowledge needed to design and implement regimes for integrated production of these multiple values already exists.

Keywords: Ecosystem management, multiple use, silvicultural systems, wildlife habitat, thinning, landscape management, forest ecology, Douglas-fir.

Contents

Introduction

When biologists took their investigations of the relation of plants to the environment from the laboratory to the field, they found the silviculturist already there with the accumulated facts of a century of field work.

James W. Tourney of Yale University, 1928

The above quotation, from the preface to the first edition of Foundations *of Silviculture Upon an* Ecological Basis (Tourney 1928), emphasizes the fact that silvicultural practice and the research in silviculture and the ecological relations that underpin it antedate the settlement of much of North America. The early foresters in the Pacific Northwest (and elsewhere in the United States) began with forest management concepts imported from Europe. These concepts were in part unsuited to the economic and social conditions existing in the United States at that time (ca. 1900), and to species and climatic conditions that differed somewhat from those of Europe. But this introduction of forestry concepts began a continuing process of adaptation and evolution. In reading the early reports and research publications on forestry in the Pacific Northwest, one is struck by the keen observations and foresight and the tremendous accomplishments of a small group of pioneer workers.

Changing social and economic conditions have led to many changes in forest management practices and policies since the early 1900s. In recent years, the interested general public and specialists trained in disciplines other than traditional forestry have played increasing roles. New ideas have been introduced and outlook has broadened. But differences in background and experience often give rise to communication difficulties, misconceptions, and misunderstandings that are not always recognized. New concepts can be conceived, evaluated, and implemented most effectively when all participants have a shared knowledge about how current practices were developed and why they were adopted. Such understanding also will help to retain past gains, prevent old problems from reappearing, and avoid new problems as new ideas and practices are incorporated in forest management regimes.

Several years ago, the authors prepared a number of short papers for the symposium *Creating a Forestry for the 21st Century,* held in Portland, Oregon, August 24-26, 1993. These were subsequently published as chapters 8 to 10 in a book of the same title (Kohm and Franklin 1997). The symposium framework necessarily imposed constraints on length and scope of discussion, and we subsequently felt that an expanded discussion of the entire subject of silviculture for multiple objectives in the Douglas-fir region was needed. This publication is the result.

Historically, silviculture developed in response to society's need to grow wood to replace declining supplies from unmanaged natural forests, a need that arises sooner or later in all parts of the world. Much of the existing silvicultural literature and silvicultural terminology is therefore phrased in terms of wood production. But the utility of silviculture extends far beyond this. Silviculture consists of a body of knowledge and techniques that can be applied to shape development of forests to meet whatever objectives are selected-whether the emphasis be on watershed protection, scenic values, ecological restoration, development of wildlife habitat, or wood production. Most of our Northwestern forest lands have wood production as a major objective, and some lands have been dedicated to specific nontimber uses. It is now apparent that needs for wood and for other values can never be adequately met by setting aside major portions of the forest land base for single uses of any kind. Rather, there is a great need for management regimes that can produce multiple values. Such multipurpose management does not mean that all values must receive equal emphasis on all lands. We believe that a variety of regimes must be developed and applied in harmony with land capabilities and management objectives. These regimes may range from intensive wood production on a semiagricultural basis with some incidental production of other values, through management for joint production of wood and nontimber values, to management primarily for wildlife, aesthetic, and recreational uses with some associated production of wood (Curtis and Carey 1996).

In this report, we review the history of silviculture in the Douglas-fir region and the available silvicultural options and techniques. We provide some literature references for those interested in further information. We do not seek to duplicate the excellent discussion of regional silviculture given by Tesch (1995). Rather, our aim is to point out the wide range of possibilities for controlling stand establishment and development to meet a variety of possible objectives, with a focus primarily on the multiple objectives commonly involved in management of forest ecosystems on both public and private lands. And, we will point out some related policy questions and offer some opinions.

Foundations

The science and practice of silviculture provide the means for managing vegetation in forests and thereby influencing forest health, soil and stand productivity, habitats of diverse plant and animal populations, and the welfare of forest-dependent communities and of society in general. In this initial section, we provide general background and trace the development of silviculture in the Douglas-fir region of the Pacific Northwest as it has evolved in the 20th century with changes in knowledge, economics, and philosophies of forest land management. The next section discusses forest and stand development, changing social expectations and management goals, and opportunities to meet them through silvicultural practices. Subsequent sections discuss (1) regeneration systems, (2) silvicultural practices as means of shaping development of young stands to meet desired objectives, (3) harvesting options and rotations, (4) providing diverse structures and habitats, (5) maintenance of site productivity, (6) damaging agents and forest health, and (7) some conclusions and implications. Discussion is primarily in terms of coast Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco var. menziesil) in the Pacific Northwest west of the Cascade summit, although the associated western hemlock (Tsuga heterophylla (Raf.) Sarg.), red alder *(Alms rubra* Bong.), western redcedar *(Thuja phcata* Donn ex. D. Don.), and true firs *(Abies* spp.) also are considered. Many of the concepts involved have much wider applicability.

Some Definitions

Some silvicultural terms used in this report may not be familiar to or completely understood by all readers. Although most terms will be explained when first used, there is also a glossary at the back for easy reference. A few terms that are fundamental to the discussion are defined below.

Silviculture consists of the techniques used to manipulate vegetation and direct stand and tree development to create or maintain desired conditions. Silviculture substitutes small-scale controlled disturbances for large-scale haphazard natural events, such as wildfires and windstorms. It applies ecological knowledge to attainment of human ends. Silvicultural practices influence rates of tree growth and stand development, stand composition, stand structure, and biodiversity.

An **ecosystem** is a complex of plants and animals and the associated physical factors of their environment that functions as a unit. It has the attributes of structure, function (exchange of matter and energy), complexity, interaction and interdependency among its components, and dynamic change in structure and function over time. Spatial dimensions are not an inherent attribute. **Ecosystem** is therefore best regarded as a concept rather than a specific physical entity (Kimmins 1987, p. 26). Silviculture is (or should be) based on ecological knowledge, and the **ecosystem concept** is important in that it emphasizes the need to evaluate the many environmental and biotic factors influencing the choice and outcome of silvicultural treatments and their sequence over time, and the long-term consequences and sustainability of management regimes. **Ecosystem** is often loosely used as a synonym for such terms as stand, forest, and landscape. In this report, however, we elect to use the older, long-established, and more specific terminology.

Ecosystem management is a currently popular term that, again, represents a useful concept but lacks specificity. It is useful in that it emphasizes the need to take a holistic view-on a scale larger than the individual stand-of management possibilities and consequences of management actions on productivity and sustainability of the many values that humans obtain from forests. But it is loosely defined and is often given somewhat different interpretations by different people. And, it seems to be acquiring ideological and political connotations (e.g., Chase 1995). We have consciously avoided the term in this report, in favor of the more specific terms of stand, forest, and landscape management.

The words **tree, stand,** and **forest** are often used to describe various portions of the forest environment. A **stand** is a group of **trees** and associated vegetation sufficiently similar in composition, structure, and condition to be distinguished from other groups of trees within a forest, and large enough to be considered an entity for management purposes. A **forest** is composed of stands.

A **regeneration system** consists of the procedures by which a new stand or group of trees is intentionally established, after removal of the former stand or part thereof by harvest, fire, or other disturbance. It includes the harvest method used and subsequent operations to establish a new age class or classes.

Thinning is the removal of a portion of the trees from a stand to promote development of the remaining trees (and sometimes understory vegetation) and often to secure intermediate income prior to final harvest. A thinning is **precommercial** if the cut trees are too small for economic use. A thinning is **commercial** if trees are removed and sold.

A **silvicultural system** is a planned program of silvicultural treatments covering the entire life of a stand (in even-aged management), extending from regeneration through any intermediate operations to final removal and regeneration. In uneven-aged management, the silvicultural system encompasses methods of tending and removal and replacement of individual trees or small groups of trees within the stand in perpetuity. Although unforeseen events such as fire or blowdown often require modification of a previously planned system, this does not negate the need for a long-term plan of silvicultural activities.

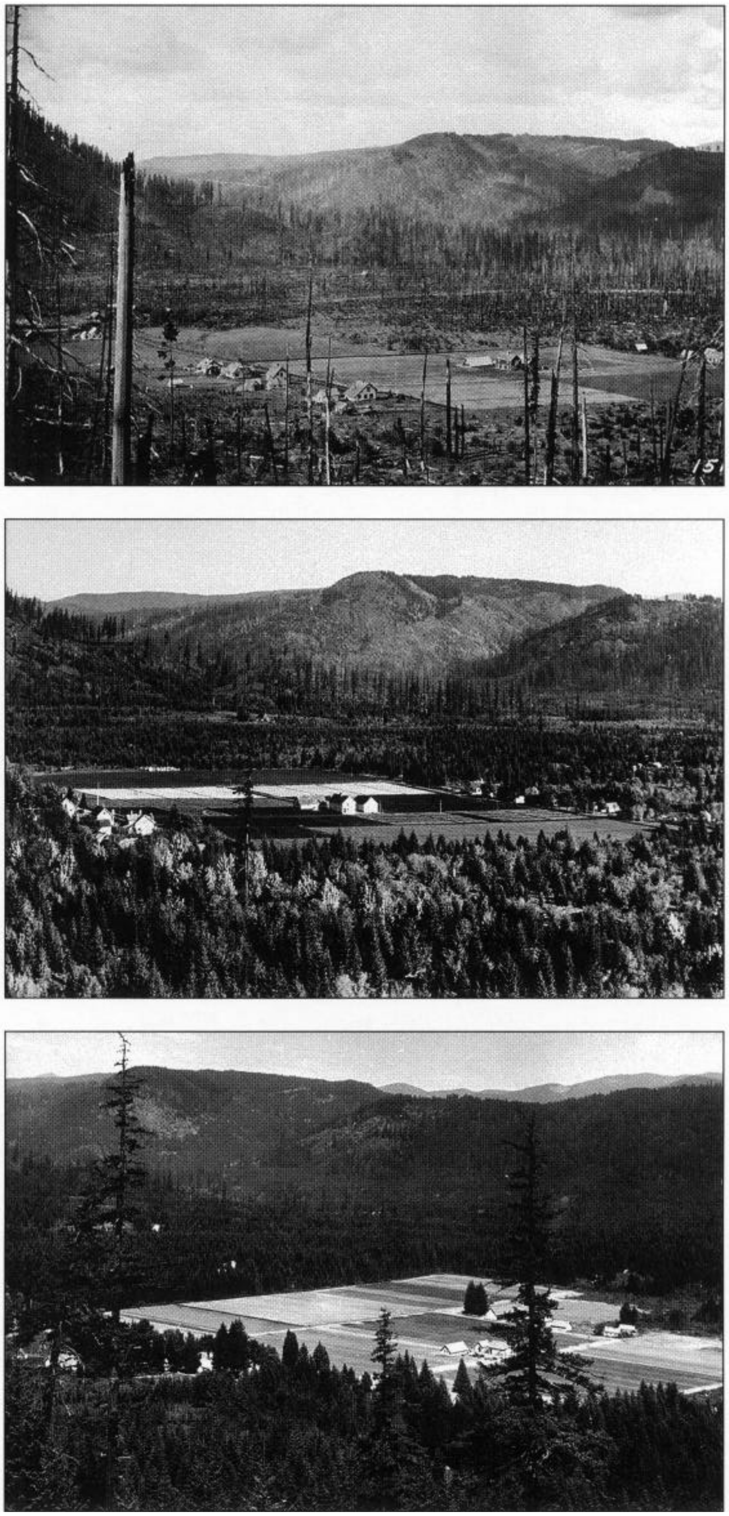

Figure 1-Return of the forest in the Wind River Valley. The Wind River nursery and surrounding area in (A) 1914, after extensive early logging and wildfire; (B) 1935; and (C) 1954.

Silvicultural systems are conventionally discussed under a few broad class designations, but there is, in fact, an almost infinite variety of possible systems. Most of the possible systems have been tried, somewhere, sometime. Silviculture and silvicultural systems are far from new. Their origins in western society extend back to the late Middle Ages; some simple systems were in use in parts of western Europe by the 17th century, and by the mid-19th century silviculture had become an organized and scientifically based discipline with more or less its present terminology (Fernow 1911). European silvicultural concepts and methods were introduced to North America around 1900 and have subsequently gone through a continuing process of modification and adaptation to North American species and changing North American social and economic conditions.

Harvest cuts consciously designed to secure regeneration and provide continued production of timber and other forest values are referred to by the name of the associated silvicultural systems. The wide variety of these are conveniently grouped for discussion purposes into the conventional categories of (1) clearcutting, (2) seed-tree, (3) shelterwood, (4) selection, and (5) accessory systems (Matthews 1989). Excellent discussions are also given by Daniel and others (1979), Nyland (1996), Smith (1986), and Smith and others (1997). In any of these systems, regeneration may be by natural seeding, planting, or a combination of the two. Direct seeding has been used occasionally.

Historical Development of Silviculture in the Douglas-Fir Region

Forest management practices in the Pacific Northwest evolved from beginnings in the mid-19th century. Until the early 19OOs, the forests were viewed as a static resource to be mined, and the usual objective was to harvest high-value timber at minimum direct cost, with little consideration given to reforestation, protection of soil or water, or provision for wildlife habitat. Because of the physical and economic limitations of railroad logging, cutting frequently began at the bottom of a watershed and continued to the uplands until an entire basin was logged. Unmerchantable trees were left standing, and logged areas often were accidentally or intentionally burned. Wildfires were frequent and largely uncontrolled. Some, such as the Yacolt fire of 1902 in southwest Washington, burned huge areas and caused major losses of property and sometimes of human life.

This pattern of large cut areas frequently followed by fire may have more closely mimicked natural disturbance by large fires than the staggered setting, dispersed clearcutting approach that followed. Natural regeneration of trees and shrubs often occurred following early logging or intense fire because mineral soil was exposed and seed was often available from residual trees or from adjoining stands. The results ranged from well-stocked, vigorous young conifer stands (fig. 1), to stands of red alder or sprouting hardwoods, to covers of shrubs or nonwoody plants of various densities with only occasional conifer or hardwood trees.

Change began with the establishment of the National Forests at the end of the 19th century. Establishment of the Wind River nursery in southern Washington (1909) and planting programs for rehabilitation of extensive burns followed. Forest research in the region began ca. 1910. Organized fire suppression was introduced after the disastrous turn-of-the-century fires and became increasingly effective through the 1920s and 1930s. Research leading to early yield tables showed the enormous growth capacity of Northwestern forests (McArdle and Meyer 1930). Methods for consistently regenerating forests after fire or timber harvest became a high priority for early research. Experimentation with harvest cutting and regeneration techniques began early and continues to the present.

The first permanent research plots (still extant) to study growth and yield of young stands were established in 1910 (fig. 2). Seed crops and seed dispersal were studied. Experiments with plantation spacing and thinning followed. Two pioneering studies begun in 1912 by the United States Forest Service, Wind River Experiment Station (later to become the Pacific Northwest Research Station), compared seed sources and species for plantations. One of the earliest forest genetics studies in the United States (and in the world) compared results of using Douglas-fir seed from different locations and from different parent trees within stands (Munger and Morris 1936). A second study compared 152 forest tree species planted at the Wind River Aboretum over a quarter century (Munger and Kolbe 1932, Silen and Olson 1992); this showed that Pacific Northwest species were inherently superior to any of the exotics tried. Both studies demonstrated the importance of long-term research and the facts that (1) a long time span may be required to evaluate suitability of a species or seed source to the local environment, (2) occasional or rare extreme weather events or seasons may be particularly important in determining adaptation, and (3) maladaptation may be expressed quickly or may occur as a slow decline over many years.

The combination of effective fire control, high productive potential of Northwestern forests, and development of successful regeneration methods made forest management on a permanent basis possible. Very early, Allen (1911) stated the policy and information needs for planned forest management and permanence of the timber industries and forest-dependent communities. The basic silvicultural knowledge needed to regenerate stands after harvest was available by the late 1920s (Munger 1927), although many refinements remained to be worked out. Industrial and private owners and public agencies made substantial forestry investments (Greeley 1948, Hagenstein

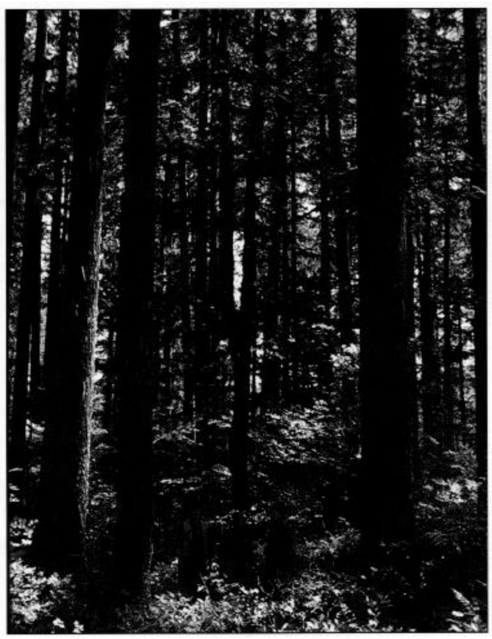

Figure 2-Willamette no. 1 in 1997: this and two adjacent study plots, established in 1910, were probably the first long-term research plots in the Northwest and provide an 87-year record of the development of a naturally established untreated Douglas-fir stand.

1986), and these accelerated rapidly in the changed economic climate that followed the end of the Great Depression and World War II. The marked and generally consistent trend of rising timber prices that began shortly after World War II (fig. 3; Haynes and Sohngen 1994) provided a powerful incentive to industrial and other owners to undertake long-term programs of active forest management, including both forest protection and large investments in stand regeneration and management. Along with increased emphasis on planting, tree improvement efforts began in the 1950s with selection of “plus trees” in native stands and establishment of the first seed orchards (Duffield 1955, Isaac 1955a). Tree improvement programs greatly expanded in the 1960s and 1970s (Campbell 1964, Silen 1966, Silen and Wheat 1979, Stonecypher and others 1996), as did the application of cultural treatments such as early respacing and fertilization. The Pacific Northwest became the first region in North America, and perhaps the world, where the people and organizations that came to harvest the original forests stayed and invested in succeeding ones-and made those investments while much of the original old-growth forest remained.

Early efforts to adapt silvicultural systems to the Pacific Northwest included the seed tree method and “selective” cutting, as well as clearcutting.

Though widely applied, the seed tree system did not consistently provide uniform and timely regeneration. Many seed trees were soon lost to wind and other causes (Isaac 1940a, 1943) and seed supply was often insufficient, although for some areas and circumstances it was adequate (Garman 1951).

The advent of the tractor and motor truck about 1930 as alternatives to the donkey engine and railroad logging introduced a new flexibility that made alternative harvest methods possible. On gentle terrain, tractors could skid logs around obstacles and residual trees, and expanding road systems allowed truck access to timberlands. A form of partial cutting popularly called selective logging developed on private lands as a

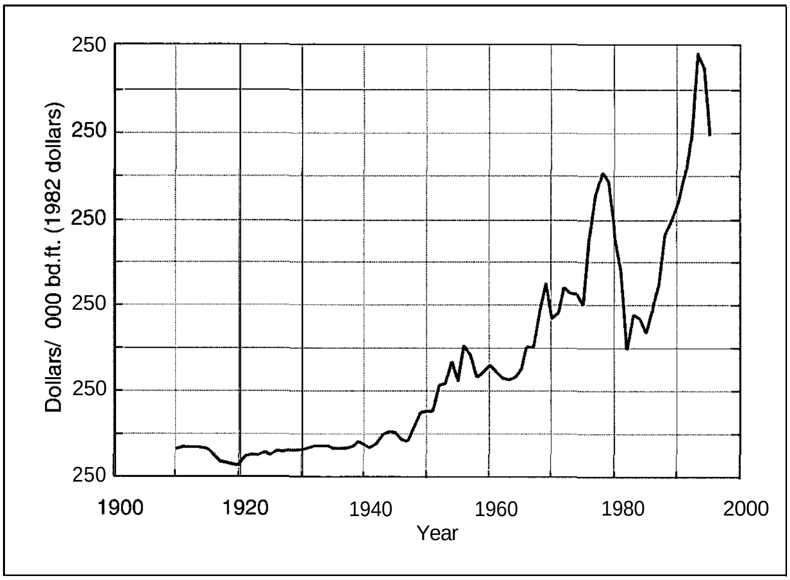

Figure 3-Price trend for National Forest timber sales, 1910 to present, in constant 1982 dollars. The steady rise since World War II provided a powerful incentive for owners to adopt management measures to enhance future wood production.

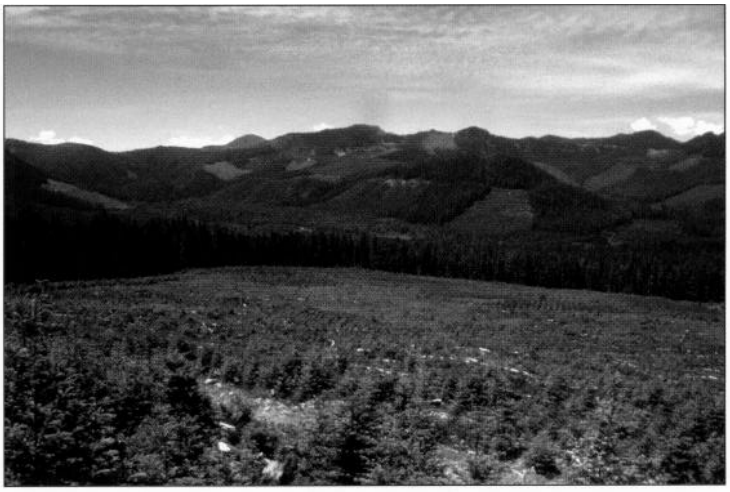

Figure 4-The "staggered setting" pattern of dispersed clearcuts was the most common harvesting practice on National Forests in the period 1950-90.

Figure 5-Clearcut unit with natural seeding from adjacent uncut timber, 1954.

Figure 6-It has been common practice of many owners to use large clearcut harvest units, which are then planted with genetically selected stock.

response to the economic pressures of the depression. Only the more valuable trees were cut and removed. Selective logging might better have been called high-grading or "logger's choice."

Kirkland and Brandstrom (1936) proposed an elaborate scheme for "selective timber management" in Douglas-fir and hemlock stands in the National Forests. This proposal was likewise stimulated by the economic problems of the depression era and was implemented on the public lands on a fairly extensive scale from the mid-1930s to the late 1940s. The proposed system called for detailed economic and stand analyses and frequent entries. It was thought that a number of light partial cuts, each removing mostly large overmature trees, could pay for roading and show favorable financial returns under the existing economic conditions. They envisioned eventual regeneration in group or small patch cuts on the order of 1 to 10 acres, to be introduced gradually over several cutting cycles after the initial entry.

Debate over selective cutting in Douglas-fir was quite lively (Munger 1950, Smith 1970), and its use apparently ended in the late 1940s. Munger (1950) reported that all new Bureau of Land Management and Forest Service sales called for clearcutting, except for some uneven-aged stands of mixed species in southwestern Oregon and certain other thrifty mature stands. Isaac's evaluation of partial cutting (Isaac 1956) and his studies of natural regeneration (Isaac 1943) discredited "selective cutting." Five to ten years of observation by Isaac on permanent plots within selectively cut areas of old-growth forest showed extensive residual tree damage and mortality, substantial windthrow, bark beetle attack, change in species composition from shade intolerant to shade tolerant species, and a lack of Douglas-fir regeneration. Isaac recommended abandoning general use of the system. He did suggest that some form of partial cutting or uneven-aged management might be appropriate for drier sites in southwest Oregon, gravel soils of the Puget Sound region, and severe southerly exposures elsewhere in the region where moisture and shade were critical factors.

In retrospect, Kirkland and Brandstrom's ideas were never thoroughly evaluated, because the unsatisfactory early results caused their abandonment before the stands reached the point of planned group or patch regeneration (Curtis 1998). The primary reasons for failure (Smith 1970) were that (1) the system was applied in old, previously unmanaged, and highly defective stands that were unstable when opened up; and (2) only the largest and best trees could be removed at a profit under the economic conditions of the period. Contributing factors were (1) limitations of existing logging technology, (2) inadequate attention to creating suitable openings for regeneration and to site preparation, (3) total reliance on natural regeneration, and (4) attempted implementation of a single policy despite differences in local site and stand conditions.

The poor results from "selective cutting" in these old stands, the observation that many of the old liquidation cuts had regenerated well when seed was available from nearby uncut timber and fire protection was provided, and accumulating information on reproductive requirements of Douglas-fir led to general adoption of the clearcutting system throughout the region. The clearcutting system evolved over the next half century from one of dispersed small (i.e., 40 acres or less; fig. 4) harvest units with natural seeding (fig. 5) from surrounding uncut timber ("staggered settings"), to large harvest units that commonly receive some form of site preparation and are planted with genetically selected stock (fig. 6). Clearcutting had biological, operational, and economic advantages. It favored Douglas-fir over its more tolerant and less valuable associates and enabled Douglas-fir to grow rapidly after establishment. It simplified slash disposal and brush control measures. It was well adapted to cable logging in steep terrain where other methods were inefficient or inapplicable. Because harvest was concentrated on limited areas, it required less road construction than partial cutting systems. But, it was also highly visible and it became controversial with many segments of the public.

Although clearcutting became the dominant system throughout the Douglas-fir region, there was some limited use of uniform shelterwood on severe sites (Williamson 1973) and some work on shelterwood in western hemlock (Williamson and Ruth 1976). Long-continued experimental trials of other forms of partial cutting and attempts at uneven-aged management do not exist in the region, although there are a few trials in early stages. This lack is unfortunate, for such trials could have provided information useful in designing and evaluating a range of silvicultural systems to meet current needs. Reviews of the underlying science and experience related to application of the various silvicultural systems in the Pacific Northwest are available in Burns (1983, 1989), Fiske and DeBell (1989) Franklin and others (1983), Harris and Johnson (1983), Tesch (1995), and Williamson and Twombly (1983).

The early foresters in the Pacific Northwest recognized that thinning was a beneficial practice that would someday become important. But with huge amounts of large timber available and a rudimentary transportation system, thinning did not become economically feasible until after World War II. In the 1950s many foresters saw commercial thinning as the wave of the future (Worthington and Staebler 1961a), and thinning experiments and some operational thinnings were begun. Subsequent decades saw a shift to shortened rotations-to as little as 40 to 50 years in some ownerships. A concomitant shift took place in attitudes toward thinning. As rotations became shorter, many owners invested heavily in precommercial thinning but most private and industrial owners lost interest in commercial thinning in favor of early harvest of the entire stand.

Until the mid-1970s, there was general agreement that timber production was the primary objective in management of most forest land. Basic assumptions, accepted by nearly all at the time, were that wood production in old-growth stands was essentially static (no net growth), and that insects and disease were diminishing the amount of usable wood in such stands. It therefore seemed desirable to replace old-growth forests with young, rapidly growing stands. The biological, political, and economic environments combined to favor investments in management of young-growth forests by both public and private owners. Much of the forest land in the Douglas-fir region, particularly that in non-Federal ownership, was converted from slow-growing natural mature and old-growth stands to rapidly growing younger managed stands. Although standing timber volume in Pacific Coast forests declined (about 19 percent) from 1952 to 1986 as old-growth forests were harvested, annual net growth in the region increased and came to exceed harvest (MacLean and others 1992, Waddell and others 1989); this is true for the United States as a whole, although differences exist among regions and ownership classes (MacCleery 1992, Powell and others 1993).

Many changes have occurred in the Douglas-fir region since the mid-197Os, and management issues on both public and private land have become much more complex. Human populations have increased and spread into rural, forested areas. Laws and regulations-some of which conflict with each other and with older legislation-have been enacted in response to concerns about environmental quality. Forest products markets have changed; they have expanded in size and location, and tree species that previously had limited value are in demand. And, nontimber values as well as wood production have become prominent management considerations.

Forest Conditions, Stand Development, and Management Goals

Forest Conditions

Although the early settlers of the region encountered many large tracts of old-growth forests with trees of impressive size, the common conception of the presettlement Northwestern forest as an unbroken sea of giant old-growth trees existing in perpetuity is false. The proportion of forest that was what we now term “old growth” cannot be determined with any precision, but several estimates suggest it was no more than 40 to 50 percent (Ripple 1994) and perhaps less, and that it fluctuated markedly over time. Old-growth forests currently occupy about 18 percent of the productive forest land in California, Oregon, and Washington (Bolsinger and Waddell 1993), of which more than 80 percent is on Federal land, primarily National Forests. Many sites in the region are, however, incapable of producing “cathedral-like” old-growth stands. Considerable lowland areas now in conifer forest were open prairie and oak woodland prior to settlement (Franklin and Dyrness 1973); at higher elevations extensive grass balds, shrub fields, and huckleberry fields were common. All were maintained by natural fires and by native burning. Presettlement forests were dynamic and were periodically disrupted or destroyed by fire (both lightning and human caused) and windstorms, which created a patchwork of ages and developmental stages over areas both large and small (Agee 1991, 1993; Henderson and others 1989; Kay 1995; Walstad and others 1990).

Most of our present Northwestern forests owe their origin to catastrophic events, principally fire, logging, or a combination of the two. Although all trees may not have been killed or removed and regeneration often took place over an extended period (Spies and Franklin 1991, Tappeiner and others 1997), most stands were more or less even-aged in youth. As they grow older, they gradually develop a more irregular age composition and canopy structure as tolerant understory species capture openings arising from death of individual overstory trees or groups of trees or small-scale disturbance. Because of their fire (or logging plus fire) origin, the forests over much of the region were and are dominated by the relatively intolerant and fire-adapted Douglas-fir, even without conscious human effort to maintain the species.

Plantations dominate the forest landscape on industrial lands, and scattered plantations of smaller extent are a major feature of public lands. Most were planted as pure Douglas-fir, but there are some plantations of other species, including mixed species plantings. Many plantations have acquired a considerable admixture of other conifers, hardwoods, and shrubs through natural seeding, sprouting, or advance reproduction carried over from the previous stand. These plantations do, however, differ considerably from naturally established old forests, as will be discussed in subsequent sections.

Stand Development

Stands and their boundaries are influenced by both natural processes and management activities. Stands are dynamic, changing with time and progressing through successive developmental stages as trees are established, grow, and die. Resource values provided by or occurring within stands change similarly. Changes occur rapidly

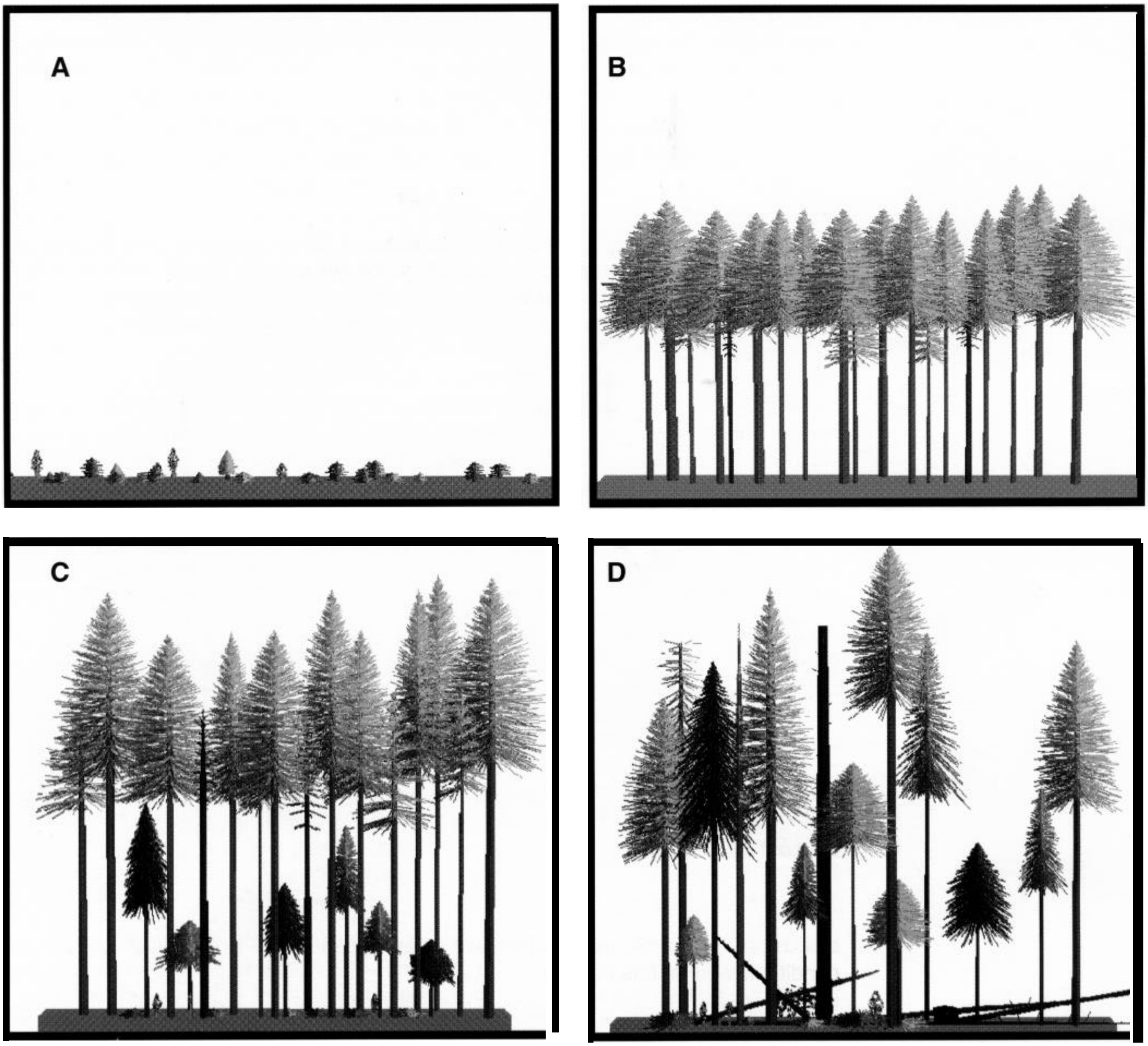

Figure 7-Development stages of natural stands can be characterized as (A) stand initiation, (B) stem exclusion, (C) understory reinitiation, and (D) old growth. Similar stages occur in managed stands but their duration is markedly modified.

and are readily apparent in young stands, but may be nearly imperceptible to casual observation in older stands. Conditions in unmanaged stands may sometimes correspond to the needs and desires of human society or some part thereof; in such cases, natural disturbance events, seed crops, and stand development processes have coincided to provide desired features at the time and place they are wanted. In other cases, natural events and processes have produced forest stands much less suited to human needs and desires.

Development stages of natural stands can be usefully characterized (Oliver and Larson 1996) as (1) **stand initiation, (2) stem exclusion, (3) understory reinitiation,** and (4) **old growth** (fig. 7). The stand initiation stage follows a major disturbance (e.g., fire, windstorm, logging) when new individuals and many species become established. The stem exclusion stage occurs after canopy closure, as the stand begins to differentiate into size classes and shading and competition for nutrients and water by larger trees lead to death of smaller trees and much or all of the understory vegetation. The understory reinitiation stage follows as crowns recede and scattered overstory trees begin to die, and herbs, shrubs, and tree regeneration (usually of tolerant species such as western hemlock, western redcedar, and true firs) appear on the forest floor. The old-growth stage occurs when overstory trees die sporadically and understory trees begin growing into the overstory, creating multiple canopy layers and a gradual shift toward a stand dominated by tolerant species. Subdivisions of these stages also may be recognized. Thus, Carey and others (1996a) add four additional stages between understory reinitiation and old-growth in their description of stages of forest ecosystem development.

The developmental stages described for natural stands also may occur in managed stands (including planted stands). The transition from stand initiation to stem exclusion, however, is generally accelerated, and the progression is often truncated by harvest near the end of the stem exclusion stage. Silvicultural practices strongly influence the rate of progression from stage to stage, the proportions of the forest in different stages, and the specific stand characteristics and values provided.

Observations on the ecology and development of forest stands, and in particular those of the Coast Range of Oregon, lead to the hypothesis that many young stands in these forests may not develop naturally into stands with traits considered typical of old-growth. This suspicion arises from the fact that forest conditions and other environmental factors differ from those prevailing during the formative years of existing old-growth stands, and these are likely to produce different patterns of stand development. These conditions and factors include:

1. Dense initial stocking. Stands established after logging are often more heavily and uniformly stocked with Douglas-fir than were preceding stands. The rapid diameter growth seen in increment cores and stump cross-sections of old-growth trees and differences in tree ages within some old-growth stands provide evidence of long regeneration periods and low stand densities during the first century of life of these old-growth stands (Tappeiner and others 1997).

2. Large populations of browsing ungulates. Current deer and elk populations are far larger than those in the late 19th and early 20th centuries, and possibly larger than those of the presettlement period (Kay 1995). Further, the large wildfires that resulted in

establishment of existing older stands undoubtedly caused a temporary reduction in browsing pressure, because an initially reduced animal population was spread over a very large area of regeneration. Today, selective browsing by deer and elk often retard or eliminate preferred forage species (such as western redcedar and bigleaf maple [Acer *macrophyllum* Pursh]) in the absence of special protective measures. An extreme example of this effect is the massive impact in the Queen Charlotte Islands of an introduced deer population with no predators.

3. Changing climate and weather patterns. Quite aside from the current concern over human-caused global warming, it is well established that there have been substantial variations in climate over periods of decades to several centuries (Layser 1980). Many of our present older stands were established under considerably different and more severe conditions than those prevailing in recent years (Henderson and Brubaker 1986).

4. Existing dense shrub understories. Stands in some areas and sites, particularly in southern and coastal Oregon, have well-developed understories of shrubs (salal [Gaultheria shallon] and vine maple *[A.* circinatum Pursh], as examples) and little conifer regeneration in the understory. In some situations-particularly in southern Oregon-this condition can be attributed to fire exclusion over the past 75 or more years. A similar situation exists on northern Vancouver Island. Work on natural regeneration suggests that these shrub layers often will continue to prevent establishment of conifers. Similarly, alder stands that were established in many areas after logging often have well-developed understories of salmonberry (Rubus spectabilis), swordfern *(Polysfichum munitum),* and elderberry *(Sambucus racemosa)* (Carlton 1988). As the short-lived alder dies, it is likely that many of these stands will be dominated by a dense cover of salmonberry and swordfern that may persist and prevent establishment of conifers for many years (Henderson 1978, Tappeiner and others 1991).

5. In some areas, exotic competing species have become established that have a considerable effect on regeneration, at least locally (e.g., scats broom *[Cytisus* scoparius], gorse *[Eulex europaeus],* Himalayan blackberry [Rubus discolor], certain introduced grasses).

Consequently, we believe that on many sites some management or treatment to obtain understory conifer establishment, to reduce shrub density, and to reduce overstory density in heavily stocked conifer stands will be needed if we wish to promote development of characteristics commonly associated with mature and old-growth forests. Desired characteristics are more likely to be attained by deliberate action than by neglect or passive management.

Changing Goals in Forest Management

Recent years have seen the steadily rising influence of an increasingly urbanized public, concerned about environmental issues and with greater interest in recreational and aesthetic features than in utilitarian forest values. Many people have raised questions about possible effects of current forest management regimes on wildlife, fisheries, and watershed values; on long-term productivity; and on biodiversity in general. There is great interest in and need for silvicultural practices and management regimes that will reduce conflicts among user groups while providing concurrent production of the many values associated with forest lands, on a biologically and economically sustainable basis.

These concerns are not confined to the Pacific Northwest or to the United States. Foresters and interested publics elsewhere also are giving increased attention to multiple values and are departing from past timber management regimes on significant amounts of forest land. Silvicultural systems other than clearcutting that have been applied on some ownerships in Great Britain are described in a recent Forestry Commission Bulletin (Hart 1995). The Swedish National Board of Forestry produced a well-illustrated book of practical advice to owners on how to manage forests to produce high-quality timber while maintaining their beauty and their value as habitat for plants and animals (National Board of Forestry 1990). Similar interests and major changes in management practices have occurred in Germany (Plochman 1992).

Many approaches have been or are being developed to meet these needs in the United States; they range from short-rotation fiber plantations involving intensive culture of genetically selected hardwood clones, to late-successional reserves, to habitat conservation areas and wilderness areas with little or no active management. Although many of these approaches may play significant roles in future forest management, we will focus in this report on silvicultural practices that may be appropriate for forests managed for multiple objectives, including both wood production and those values commonly associated with natural mature and old-growth forests. Many of these practices or modifications in practices have been suggested in recent years under several banners: “restoration forestry” (Maser 1988); “ecological forestry” (Minckler 1989); “new forestry” (Franklin 1989); “new perspectives” (Brooks and Grant 1992a, 1992b); “high quality forestry” (Kuehne 1993); “ecosystem management” (Galindo-Leal and Bunnell 1995, Loftus and Aune 1995, Overbay 1992, Stewart 1995); “landscape forestry” (Boyce 1995); and “biodiversity pathways” (Carey and others 1996a; Carey and Curtis 1996).

The ideas represented by these terms differ in many respects; goals of some practices or systems may not be clearly defined; and some measures advocated in connection with these ideas seem based on undemonstrated hypotheses rather than on concrete knowledge and experience. But they all advocate some change in conventional practices on portions of the forest land base to provide one or more of the features generally associated with older natural forests; they all recognize the desirability of intentionally managing forests for more than wood production; and thus all involve some degree of multipurpose management.

To sustain diverse, multiple values in specific forest landscapes, we need to systematically foster a balanced distribution in time and space of many stand conditions and stages of stand development (DeBell and Curtis 1993). Forests are dynamic entities, and no condition can be maintained indefinitely. If we wish to have stands with mature and old-growth (late-seral) characteristics in the future, we must provide for development of some stands with these characteristics as future replacements for existing stands. Some ideas on how a desirable balance might be attained are discussed by Carey and others (1996a), McComb and others (1993), and Oliver (1992). Unfortunately, the past history and ownership patterns of the region have created an unbalanced distribution of age classes, both in the region as a whole and within subregions and watersheds. Private ownerships consist predominantly of young age classes, (<65 years) with little mature and negligible old-growth forest; whereas Federal ownership consists predominantly of much older stands (including considerable amounts of old-growth forest) and young stands (<40 years), with more limited areas (differing considerably among individual National Forests) in intermediate age classes (Adams and others 1992, Sessions and others 1990). Many real and perceived forest management problems are direct consequences of this imbalance, which has grown more striking in recent years with the combination of drastic harvest reductions on Federal lands and accelerated cutting of immature stands on private lands. The latter is in part a consequence of reduction in public timber supplies, current business management practices, and landowner fears of possible future regulations and constraints on management and harvests.

Complete knowledge and absolute certainty are unattainable, and the limitations of existing knowledge often are emphasized by those seeking research funding and by those questioning or advocating some specific action or policy. But in fact, the research and experience of nearly a century in the Northwest (and longer in some other countries) have produced a huge body of information on tree biology, stand development, and forest ecology (Burns and Honkala 1990, Kimmins 1987, Perry 1994, Tourney and Korstian 1947) and on the application of this knowledge through silviculture. Given agreement on objectives for which forests are to be managed (which are primarily determined by social and economic forces) and the conditions needed to achieve them, much of the silvicultural information needed for designing feasible pathways and management techniques is currently available.

Regeneration Methods

In this section, we briefly review the research and experience that underpin current methods for establishing stands of forest trees. We consider natural regeneration (including advance reproduction), direct seeding, and planting. Additional modifications in harvest cutting used at the time that regeneration is desired are discussed in a later chapter.

Natural Regeneration

Although some of the earliest work on reproduction of western conifers was with planted seedlings (Munger 1911), most early work focused on natural regeneration, in both undisturbed forests and clearcuts. Because conifer regeneration was often found far from any existing seed source, it was hypothesized that Douglas-fir seed was stored in the forest floor (Hofmann 1917, 1924). However, Isaac (1935) showed experimentally that nearly all Douglas-fir seed germinate by the spring following seedfall. He also found that conifer seed could be dispersed over great distances (Isaac 1930). Although most seed falls within 100 to 200 feet of its source, thousands of seeds per acre were found at distances of 500 to 1,000 feet from seed trees. Thus Douglas-fir regeneration can occur at considerable distances from the seed source, without seed storage in the forest floor. This is also true of western hemlock.

Cone and seed crops are highly irregular, with an average of one heavy and one medium crop in seven years (Hermann and Lavender 1990). Extensive damage by cone and seed insects in some years contributes to this variability.

The two seed trees per acre specified in many early National Forest harvests were often quite inadequate to secure satisfactory natural regeneration (Isaac 1943), although results were satisfactory in some instances (Garman 1951). Williamson (1973) showed that good natural regeneration could be obtained in the Oregon Cascades in shelterwoods that retained 20 to 50 percent of the original basal area. Satisfactory natural regeneration of Douglas-fir was obtained with 10 to 12 large trees per acre in a recent study at Oregon State University's (OSU) McDonald Research Forest (Ketchum 1994), with the combination of a good seed year and some soil disturbance from logging. Some site preparation and supplemental planting usually would be needed, however, to ensure satisfactory regeneration.

Natural seedlings are small and susceptible to mortality from a number of factors during their first several years. Lavender (1958) as well as Garman (1955) and Hermann and Chilcote (1965) found that natural Douglas-fir seedling establishment is enhanced by partial shade that reduces soil temperature and soil moisture evaporation. Disturbance of the forest floor that provides a mineral soil seedbed-and consequently less herbaceous competition, reduced effects of root and stem pathogens, and pests-is also a key to successful natural regeneration (Haig 1936; Haig and others 1941; Isaac 1938, 1940b, 1943, 1955b). Gashwiler (1967, 1970) and Hooven (1958) studied the effects of rodents and other predators on seed supply. Seed predation rates of both conifers and hardwoods are often high both on the tree and on the forest floor (Schubert and Adams 1971, West 1992).

Studies on hardwood regeneration show that protection from high temperatures and frost are also important for small-seeded hardwoods like red alder (Haeusler and Tappeiner 1993, Haeusler and others 1995) and Pacific madrone *(Arbutus menziesii* Pursh) (Tappeiner and others 1986). Species with large seed such as bigleaf maple, tanoak *(Lithocarpus densiflorus* (Hook. & Arn.) Rehd.), and vine maple have less particular requirements for mineral soil seedbeds and shade, although they certainly are susceptible to predation by rodents and birds (Fried and others 1988, O'Dea and others 1995, Tappeiner and Zasada 1993, Tappeiner and others 1986).

Similar studies were carried out elsewhere in the West (e.g., Haig [1936] and Haig and others [1941] in western white pine *[Pinus monticola* Dougl. ex D. Don]; Dunning [1923] and Pearson [1923] in ponderosa pine *[P. ponderosa* Dougl. ex Laws.]; and McDonald [1976a] in Sierra Nevada mixed conifers).

Regeneration of shrubs and conifers in the understory of conifer stands is a relatively new area of investigation. Establishment of salal (Huffman and others 1994) and other shrubs, as well as western hemlock and western redcedar seedlings (Christie and Mack 1984, Harmon and Franklin 1989), is favored by decomposing stumps, snags, and logs on the forest floor although their establishment is not restricted to these substrates. Shrub and hardwood seedling establishment is greater in thinned stands than in unthinned stands (O'Dea and others 1995, Tappeiner and Zasada 1993), as is the vegetative spread by rhizomes and the density of aerial stems produced by developing clones. Clonal shrubs such as salal and salmonberry can apparently persist in the understory for many years, because they can replace dead aerial stems with new sprouts from the bud bank on the rhizomes (Huffman and others 1994, Tappeiner and others 1991).

These and similar studies provide information on biology, ecology, and regeneration of forest plants, define species regeneration niches (Grubb 1977, Haeussler and others 1990), and provide a basis for understanding responses to silvicultural processes.

Site preparation-Conditions on the specific area to be regenerated strongly influence establishment and early development of regeneration. These include surface soil conditions; slash accumulations; overhead shade, if any; aspect, slope, and geographical location as they affect moisture relations and surface temperatures; and existing and prospective vegetative competition and propensity to harbor animals, such as rabbits and mountain beaver *(Aplodontia rufa),* that damage regeneration. Failure to secure prompt and adequate regeneration may result in capture of the site by undesired vegetation, leading to prolonged delays in regeneration, animal damage to seedlings, and inadequate stocking when regeneration of tree species ultimately does occur (figs. 8, 9, and 10).

Figure 8-A 6-year-old Douglas-fir plantation developing without significant brush problems.

Figure 9--Conifer regeneration overwhelmed by unwanted red alder. Treatment is needed if conifers are to be a major stand component.

Figure IO-Dense salmonberry thicket developed after failed conifer regeneration. Treatment will be necessary if tree species are to be restored within a reasonable time.

Site preparation is a collective term for various measures that can be taken to alleviate conditions unfavorable to prompt and adequate regeneration, given an adequate seed supply. These conditions differ widely among physical locations, and the manager must select types and intensities of site preparation appropriate to the local conditions and the requirements of the desired species.

Douglas-fir, and many other tree species, regenerate best on exposed mineral soil. Therefore, some removal or at least some disturbance of the surface organic matter is indicated. This may be partially accomplished through the mechanical action of machinery used in harvesting operations, but additional measures may be needed.

Removal or temporary suppression of competing vegetation is commonly also necessary, and additional competing vegetation control may be needed after initial establishment of tree species. This is particularly true for sites where soil moisture and sunlight may be limiting. On sites characterized by highly aggressive shrub, grass and forb competition, as in much of coastal Oregon and southwest Oregon, thorough treatment to accomplish this is essential to successful regeneration.

Several site preparation methods, including fire, machine scarification, herbicides, hand slashing, and combinations of these methods, are employed in Northwest forests. Each method is effective when it solves the problem and does not conflict with other objectives, and ineffective where it fails to solve the set of problems that are preventing satisfactory regeneration or where it generates major conflicts with societal values. The choice of method depends on evaluation of local conditions and problems and the relative costs and effectiveness of alternatives.

In general terms the attributes of each method may be summarized as follows:

1. **Fire** exposes mineral soil and may control many species of competing vegetation for several years. Soil temperature, chemistry, and physical structure may be adversely affected, however, and certain competing vegetation, such as members of the *Ericaceae,* may be favored. In the past, fire has been widely used for the dual purposes of

site preparation and reduction of fire hazards posed by large slash accumulations (fig. 11). In recent years, air pollution concerns have increasingly restricted its use, while closer utilization and changes in harvesting practices have reduced slash accumulations and the need to burn slash for hazard reduction.

2. Mechanical site preparation with tractor-mounted equipment can prepare mineral soil seedbeds and remove some of the existing vegetation (fig. 12). However, this method also can stimulate establishment of a range of competing vegetation. Excessive removal of the nutrient-rich litter and upper soil horizons can be damaging, as can compaction by heavy machinery on some soils and in some seasons.

3. Herbicides combine the potential to selectively eliminate unwanted competing vegetation with minimal effects on soil productivity and low cost (figs. 13 and 14). They are not appropriate where the main obstacles to seedling establishment are slash or other materials that physically impede seedling establishment. Herbicides are viewed by segments of the public as health hazards, and therefore often cannot be used on sensitive areas (streams or wetlands) or near population centers. Great care must be taken in their use to adhere to regulatory constraints and label precautions.

4. Hand-slashing provides extreme selectivity and is the method least likely to arouse objections from the general public. It is, however, generally slow and expensive, must in many cases be repeated after 2 or 3 years, and is a hazardous activity for workers.

A

B

Figure 11-Broadcast burning of slash (A) was usual in the past, but with reduced slash accumulations resulting from closer utilization and other changes in harvest practices, partial disposal (B) or even no disposal often suffices.

Figure 12-Mechanical site preparation can be used to crush and pile slash, reduce existing vegetative competition, and expose mineral soil in preparation for either natural regeneration or planting.

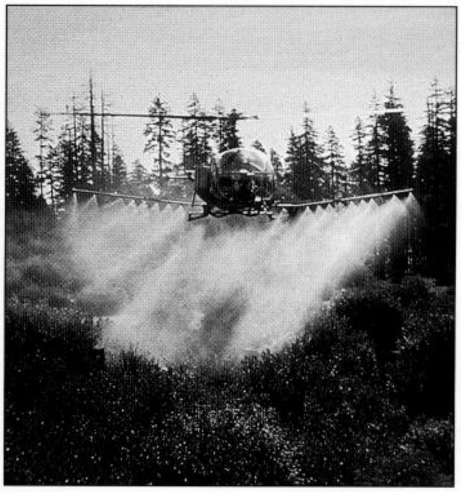

Figure 13-Broadcast spraying of herbicides provides inexpensive control of undesired vegetation that competes with tree regeneration on extensive areas.

Figure 14-Hand application of herbicides provides selective control of scattered clumps of undesired vegetation.

Evaluation of natural regeneration systems-Designed experiments on natural regeneration have been integrated with evaluation of reforestation projects. These evaluations have identified problem sites, determined success of applied regeneration practices, and identified alternatives.

Lavender and others (1956) examined natural regeneration on staggered settings, and Franklin (1963) assessed natural regeneration on strip cuts, small patch cuts (l/4 to 4 acres), and staggered cuttings. These and other studies have shown that partial shade, aspect, reduction of competing plant cover, intensity of burn used to prepare a seed bed, and proximity to seed source all contribute to seedling establishment.

Considerable work has been done on regeneration by using the shelterwood method (Gordon 1970, 1979; Laacke and Fiddler 1986; Laacke and Tomascheski 1986; McDonald 1976b, 1983; Seidel 1983; Tesch and Mann 1991; Williamson 1973; Williamson and Ruth 1976). This work has shown that seedling density is generally satisfactory if sufficient seed producing and windfirm trees are left in the overwood and if there is adequate site preparation to prepare a seed bed and reduce competition.

Minore (1978) and Stein (1981, 1986) examined regeneration results following harvesting on sites considered difficult to regenerate in southwestern Oregon. Minore (1978) found that shelter prevented frost damage to seedlings and saplings on the Dead Indian Plateau in southwestern Oregon. Holbo and Childs (1987), Minore (1978) Stein (1981), and Williamson and Minore (1978) point out the value of advance regeneration, and of natural regeneration among planted seedlings, on sites with extreme variation in temperatures and on rocky soils that are difficult to plant.

Advance regeneration-Use of advance regeneration, established naturally before logging in some stands and after thinning in many others, can be a very effective way to regenerate forest stands. It should be a common practice on sites difficult to regenerate and in unevenaged systems (Minore 1978, Stein 1981) and may be especially desirable for preferred browse species, such as western redcedar. In dense stands, advance reproduction will be comprised almost entirely of shade tolerant species such as western hemlock, western redcedar, and some true firs; but in open stands and stands subjected to heavy thinning regimes (particularly on dry and warm sites), less tolerant species such as Douglas-fir may become established (fig. 15). Gordon (1973), Helms and Sandiford (1985) Oliver (1986), and Tesch and Korpela (1993) developed methods for assessing potential vigor of advance regeneration following logging. Logging damage to advance regeneration increases with seedling size. Tesch and others (1993) found that damaged seedlings often recovered within 3 to 6 years. Growth of advance regeneration was similar to that of planted seedlings (Korpela and Tesch 1992).

Genetic considerations in natural regeneration-Opportunities for genetic improvement are available through choice of seed trees for natural regeneration, and through selection among trees within a stand during intermediate treatments (Zobel and Talbert 1984). Genetic degradation can occur from dysgenic selection when the best trees are taken, leaving poor-quality, slow-growing trees to produce the next generation. Traits under strong genetic control, such as stem form and disease resistance, are the most responsive to genetic manipulation. Rate of stem growth is only moderately heritable

A

B

Figure 15-When advance regeneration of desirable species is present, naturally established before harvest or after thinning, this can often effectively supplement postharvest regeneration: (A) advance regeneration of Douglas-fir established in a windfall gap, southwest Oregon; (B) advance regeneration of western hemlock established under a thinned Douglas-fir stand, Vancouver Island, British Columbia.

and thus less responsive to selection. Nevertheless, comparisons between select and nonselect Douglas-fir in genetic tests in Oregon and Washington indicate that phenotypic selection in natural stands gives an average 5-percent improvement in juvenile height growth (Stonecypher and others 1996). Although selection may be less effective with typical silvicultural manipulations, these results indicate that over several generations selection for stem size and other traits will likely lead to large genetic gains. Conversely, removal of the better trees will produce losses from dysgenic selection.

Natural regeneration can be important for genetic conservation. Genetic conservation efforts usually involve both ex situ germ plasm collections and in situ habitat preservation. The objective of *in* situ management is to protect and perpetuate both samples of genes and genotypes representative of a species and the evolutionary processes and relationships between a species and its biotic and abiotic environment. Lands that specifically include this management objective have been termed gene resource management units (GRMUs) (Krugman 1984, Ledig 1988, Millar and Libby 1991). These may include both lands excluded from timber harvest and lands in which wood production is a major objective. In either case, natural regeneration can both perpetuate existing gene pools and allow evolutionary processes to proceed.

Summary-The following generalizations emerge from studies of seedling establishment and natural regeneration methods:

- Seed production is variable, with 6- to 8-year intervals between adequate seed crops frequent for some species, especially Douglas-fir. Cone and seed insects can cause partial failure of seed crops and accentuate this variability.
- Most seed falls within 100 to 200 feet of the source, although windborne conifer seeds can spread up to 1,000 feet.
- Seed predation rates of Douglas-fir, ponderosa pine, and large-seeded hardwoods, such as bigleaf maple and tanoak, are high both on the tree and on the forest floor.
- Mortality rates during the first 2 to 3 years after germination are high. Causes are high soil temperatures, pathogens and insects in the forest floor, competition for light and soil water, litter-fall, and frost.
- Seedling survival of Douglas-fir, red alder, ponderosa pine, and true firs is usually highest on bare mineral soil; Sitka spruce *(Picea sitchensis* (Bong.) Carr.), western hemlock, and large-seeded hardwoods survive well on both mineral soil and organic seed beds.
- Partial canopy cover often aids initial seedling survival-even for intolerant species-because it reduces soil temperature, air temperature, and evaporative capacity of air near the ground in summer. It also reduces the chance of frost damage in winter and early spring.
- Shade conditions that foster early seedling survival in the understory of forest stands generally do not favor subsequent growth. Seedlings of most species tend to be shade tolerant when very young but become less so after the initial establishment stage.

- Intense competition from established grasses, forbs, shrubs, and trees may cause high seedling mortality.
- Advance regeneration, when present, can provide successful regeneration after logging and may be especially useful on hard-to-regenerate sites. It often will be of different species than the former overstory. Augmentation by seeding or planting may be needed to attain desired species composition and stocking.
- The small openings created by group selection and single-tree selection methods generally favor shade-tolerant species such as true firs, western hemlock, western redcedar, tanoak, and bigleaf maple over the less tolerant Douglas-fir in most of the region. Small openings do, however, favor Douglas-fir and Pacific madrone, chinkapin *(Castonopsis chrysophylla* (Dougl.) A. DC.), and other sclerophyllous species over the less tolerant pines on dry, warm sites in southern Oregon and northern California.
- Shelterwood methods and small openings or small clearcuts (< 10 acres) appear to be most suitable for the regeneration of true firs at higher elevations (Gordon 1970, 1973, 1979; Gratkowski 1958), although they will work for other species, including Douglas-fir (Williamson 1973, Worthington 1953).
- Choice of leave trees during silvicultural manipulations may provide opportunities to achieve genetic gain, or conversely, may lead to dysgenic selection and genetic degradation. Response to selection may be minimal in one or two generations but could be significant after several generations.
- Natural regeneration can be a valuable tool on forest lands for which genetic conservation is an important objective.
- Natural reproduction may maintain a forest cover, but does not ensure desired species composition, stocking and distribution, or timely stand reestablishment (Lavender and others 1990).

Good overviews of the subject are the series of articles in Hobbs and others (1992) and Lavender and others (1990).

Direct Seeding and Planting

Conifers-Studies on planting western conifers began in the early 1900s (Munger 1911, Show 1930). The need for reforestation of the great Yacolt (1902) and other burns in southwestern Washington led to establishment of the Wind River nursery and initial planting programs. Also, the decision to use clearcutting on Federal lands (Munger 1950) and the Tillamook burns (a series of fires in 1933, 1939, 1945, and 1951 that burned over 360,000 acres in northwestern Oregon and created the area once known as the Tillamook Burn and now known as the Tillamook Forest) further stimulated both direct seeding and planting in the Pacific Northwest. The major blowdown and subsequent salvage operation resulting from the Columbus Day storm of 1962 was an additional catalyst for large-scale planting.

Prior to the Yacolt, Cispus, and Tillamook fires, most cutover lands were reforested by natural regeneration. Although seed trees were frequently retained, insufficient numbers of well-distributed seed-producing trees following intense fire and seed predation by small mammals (Hooven 1958, 1970; Schubert and Adams 1971) strongly limited the usefulness of the method. Direct seeding was used in early reforestation of the Tillamook Burn. Annual projects of 10,000 to 15,000 acres were seeded with Douglas-fir seed treated with rodenticides. Seed treatments were only partially successful in preventing seed predation. Also, direct seeding was limited by inadequate seed supplies and the fact that large, contiguous areas were needed for efficient application of aerial seeding. Although direct seeding accounted for reforestation of about 50 percent of the Burn, emphasis on planting increased as reforestation progressed.

State forest practices acts also affected reforestation practices. Thus, the Oregon State Forest Practices Act (1941), which required either leaving seed trees or planting, was changed in 1971 and subsequent years to require that reforestation efforts on clearcuts begin within 12 months, planting must be completed within two planting seasons, and at least 200 trees per acre must be "free-to-grow" within five growing seasons of planting. Current Forest Practices Board regulations for western Washington require at least 190 established and well-distributed seedlings per acre within 3 years after clearcut harvest.

Tree spacing in early plantations was often close (6 feet or so) but was later increased substantially on most lands (to 10 or 15 feet or more) in the hope that planting costs could be reduced and the need for precommercial thinning avoided. Early plantation spacing trials also showed poor development at close spacings. At the opposite extreme, most owners concluded that problems with very wide spacing, such as large branches, lack of opportunity to select trees during juvenile respacing, and unstacked areas resulting from early mortality, more than offset the decreased costs of planting stock and labor. And, there is some recent evidence indicating that early tree development is slower at very wide spacings than at intermediate spacings (Scott and others 1998). The most commonly used spacings at present are 10 to 12 feet, differing somewhat with species and ownership.

Most spacings have been nominally square, but with hand planting on areas that typically have numerous large stumps, down logs, and slash accumulations, there is usually considerable irregularity in spacing and geometrical arrangement, although less than exists in most natural stands.

Tree mortality was often high in the early plantations, and research sought to increase seedling survival and growth. This research had two major facets: (1) studies of seedling size and morphology (Hermann 1967, Iverson 1984, Jenkinson 1980, Newton and others 1993); and (2) studies of seedling physiology with particular emphasis upon the effects on seedling vigor of nursery practices such as lifting date, storage, and fertilization (Hermann 1967; Hermann and others 1972; Lavender 1964, 1984, 1985, 1988, 1990a, 1990b; Lavender and Hermann 1970; Lavender and Waring 1972; Lavender and others 1968; Ritchie 1984; van den Driessche 1984; Winjum 1963).

This research produced methods for growing high-quality seedlings of the major commercial conifer species (Duryea and Dougherty 1991, Margolis and Brand 1990). This work also provided a physiological basis for understanding seedling growth potential and stress from planting or planting site conditions. Foresters have developed guidelines to select stock types best suited to various microsites on harvested areas and improved methods for handling and planting of seedlings (Rose and others 1990). As a consequence, average survival of seedlings has increased to 85 percent or better.

Competition from other vegetation also affects regeneration success. Consequently, extensive research (Stein 1995, Stewart 1978, Stewart and others 1984, Walstad and Kuch 1987) has addressed effects of such competition and methods for controlling it when needed. Control of grasses, forbs, and shrubs often is used to ensure favorable light conditions and adequate soil moisture for seedling survival and growth. The degree and nature of competition is strongly related to site and plant association. Competition for moisture is most severe on dry sites in southwestern Oregon. On good sites in the high rainfall areas along the Pacific coast, shading by tall shrubs and hardwoods is generally of more concern.

The small openings created in the group shelterwood or group selection methods (Smith 1986) are similar to those created by small-scale disturbances by wind, insects, or root disease. Experience in regenerating small openings (0.5 acre) on OSU's McDonald Research Forest indicates that the reforestation methods used in larger clearcuts can be applied. After 4 years, growth and survival of planted seedlings in the openings were not different from that in clearcuts (Ketchum 1994). This similarity in seedling development will probably not continue unless openings are widened. As with clearcuts, animal browsing and shrub competition affect seedling survival and growth in these small openings. There is a great deal of variability among openings: some with high light intensity developed covers of grass or low shrubs; others with low light levels became dominated by tall shrubs. Grand fir *(Abies* amabilis Dougl. ex Forbes) appears better suited to regeneration in small openings than Douglas-fir, because the former is browsed much less and is more shade tolerant. Natural Douglas-fir regeneration was not plentiful in these small openings, although it was abundant in adjoining stands where 10 to 12 trees per acre have been left.

Although 0.5-acre openings were used in the study described above (McComb and others 1994), larger openings or a variety of opening sizes might be more appropriate. Size of opening, aspect, and height of surrounding trees will all affect seedling development. Thinning the stand between the openings or widening openings may be needed to increase light and growing space for the young conifers in openings, especially when on north aspects or surrounded by tall trees. Twenty-seven years of observation of openings of similar size in the Challenge Experimental Forest in northern California showed substantially reduced establishment and growth of natural regeneration, compared to larger openings (Aune 1996, McDonald 1976a). Isaac (1943) recommended openings of 1 acre or larger. Openings of 2 to 5 acres should both facilitate stand treatments and assure satisfactory development of regeneration (Curtis and Carey 1996).

Hardwoods-The ecological and economic roles of hardwoods, particularly red alder and black cottonwood *(Populus trichocarpa* Torr. & Gray) and Populus hybrids, have received increasing recognition during the past 20 years (Comeau and others 1996, Heilman and others 1991, Hibbs and others 1994). Both genera are rapid-growing, shade-intolerant pioneer trees that require bare or new soil to regenerate naturally. Thus, natural stands commonly occur along streams and other areas where soil has been exposed and moisture conditions are favorable.

Several industrial firms have recently begun to plant and intensively manage both alder and cottonwood. The primary objective of pure red alder plantings is raw material for solid wood products or fine papers. Mixed species plantings of hardwoods and conifers are less common and occur primarily on public lands; they are established mostly to enhance site productivity (through nitrogen fixation by alder), riparian habitat, and forest biodiversity. Plantations in the Wind River Experimental Forest (Miller and Murray 1978, 1979) and the OSU McDonald Forest demonstrate the gains possible with mixtures of alder and Douglas-fir. Also, red alder is immune to the common root rots that affect conifers and is thus a suitable species for planting in areas severely infected with *Phellinus weiri* (Thies and Sturrock 1995). Although competing vegetation may need to be controlled, trees can be planted successfully without the extensive exposure of bare soil needed for natural seeding.

Hybrid cottonwood plantations for fiber production have been established on marginal agricultural land along the lower Columbia River, in northwest Washington and British Columbia, and on irrigated sagebrush-steppe land in the Columbia basin of eastern Washington and Oregon. Rectangular spacings are sometimes used to facilitate cultivation between rows. These plantations are grown as agricultural crops and are harvested 6 to 8 years after planting (fig. 16). Such very intensive short-rotation regimes imply a likely future need for agricultural type soil amendments if they are to be sustainable.

With superior hybrid clones, optimal spacing, suitable soils, effective weed control, and in some cases irrigation and fertilization, poplars planted in the Pacific Northwest may average 60 feet in height and 6 to 7 inches in diameter at 6 years. Stemwood production rates may reach three times average production of Douglas-fir under conventional management regimes (Curtis and others 1981, DeBell and others 1996). One acre devoted to such management can produce as much wood as 3 acres under conventional forest management or even more devoted to extensive multipurpose management. Thus, in a mix of approaches, clonal poplar culture can reduce pressures on other lands and create additional opportunities to emphasize other uses on these other lands.

Figure 16--Hybrid cottonwood plantation, 4 years after planting. On suitable soils, such plantations can be grown as agricultural crops giving high fiber yields on very short rotations.

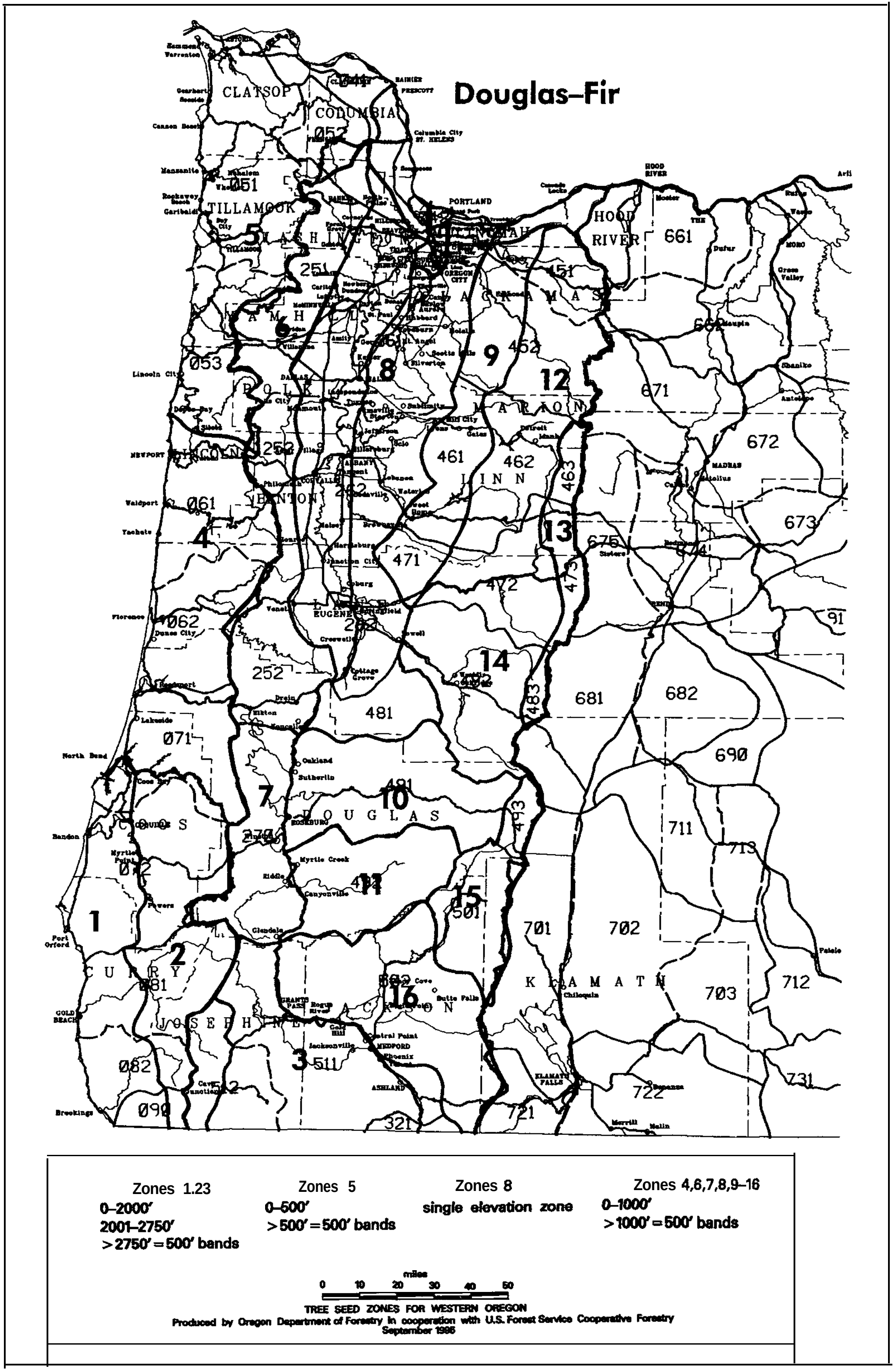

Figure 17-Seed collection zones have been established to ensure that planting stock is adapted to local climatic conditions.

Genetic considerations in planting-Basic and applied research in forest tree genetics has contributed to planting programs for several decades. Proper seed source selection and deployment is important to ensure high productivity and long-term stability of planted forests. Two general sources of seed are (1) seed collected from parents in commercial forests or forest reserves, and (2) seed from tree improvement programs, usually produced in seed orchards. Both assume that seed originating from parents near the planting site is best adapted to that site. Seed zones and seed transfer rules are used to ensure adapted seed sources from commercial forests or reserves. Restrictions in mating of parents from different locations ("breeding zones") are used to ensure adapted progeny from tree improvement programs.

The degree of local adaptation depends on the genetic structure of the species; that is, whether genetic variation is predominately among individuals or among populations of different geographic origin. Thus, western white pine has considerable genetic variation within stands but little variation among populations (Campbell and Sugano 1989, Rehfeldt 1979). Western white pine seed therefore may be safely moved over large geographic and elevational distances, and breeding populations in tree improvement programs may encompass parents from a large area. Douglas-fir typifies species with considerable genetic differences among populations and strong geographic patterning (Campbell 1979, 1986; Campbell and Sugano 1993; Hermann and Lavender 1968; Rehfeldt 1989; Silen, 1982; Sorensen 1983). Thus, a considerable number of seed zones and breeding zones are recognized for Douglas-fir.

Seed zones and seed transfer rules were first developed in the Pacific Northwest in the 1960s as a consequence of early observations of poor growth and survival of plantations established with seed from distant, apparently poorly adapted sources. Seed zone maps (first published in 1966, revised in 1973) were based on local knowledge of topography, climate, and tree growth. These maps have since been extensively used to certify origin of forest tree seed. Later, knowledge of geographic genetic variation for individual species led to the development of mathematical models to more effectively determine safe limits for seed movement (Campbell 1979,1986; Campbell and Sugano 1987, 1989, 1993). In general, the greater the environmental difference between the planting location and the seed origin, the greater the risk of maladaptation. Recently, new seed transfer guidelines and maps have been developed for individual species in western Oregon based on current knowledge of geographic genetic variation (Randall 1996; fig. 17). The new guidelines are less restrictive, particularly for north-south movements.

Seed orchards in the Pacific Northwest are beginning to produce a considerable amount of seed, and genetically improved planting stock is being used increasingly for reforestation. Tree improvement programs in the region constitute a considerable investment in enhancing productivity on commercial forest lands. Progeny from more than 42,000 parent trees are being tested in over 1,300 test plantations covering over 10,000 acres with an investment estimated at approximately a quarter-billion dollars (Adams and others 1990). Data from these tests are used to rogue (see "Glossary") seed orchards and select parents for the next generation of improvement. More than 10 species are included in tree improvement programs, but most effort is focused on

Douglas-fir. The primary trait of interest is increased stem volume growth. Wood quality, tree form, disease resistance, and adaptation to environmental extremes are given varying emphases in different programs and species.

Adaptation is maintained in improved populations by working with many small, localized breeding populations, particularly for programs in western Oregon and Washington (Adams and others 1992, Silen and Wheat 1979). The small breeding zones may be overly conservative, and opportunities exist in future generations to extend the geographic range of parents in a breeding program (Lester 1986, Stonecypher and others 1996). Genetic sources should be tested over a large geographic area to define the limits of adaptation, and these tests also should include screening for important adaptive traits such as drought tolerance and cold hardiness (Aitken and Adams 1996, Zhang and others 1994). Compared to agricultural crops, trees are long-lived and subject to greater risk from weather extremes. Early results should be interpreted cautiously, in view of failures of some seed sources in long-term studies and plantations after many years of previously good growth (Silen and Olson 1992). Risk of maladaptation is minimized by including many parent trees in a program, both within the initial base population (usually more than 200 selections originating from throughout the breeding zone) and within the population that is deployed (seed orchards usually include more than 50 unrelated clones or families). Deployment of mixtures of seed of parents from different environments may provide another opportunity to create stands with a broad base of genetic diversity, particularly given the uncertainty of future climates.

Figure 18-Western white pine (A) is a fine species that has been nearly eliminated from Northwestern forests by blister rust, a disease accidentally introduced in the early 1900s. (B) Selection for blister rust resistance has provided resistant planting stock that promises restoration of this species in Northwestern forests. Pruning provides additional protection against infection (spores are most abundant near the ground) as well as improved wood quality.

Results from genetic tests indicate heritable differences that support tree improvement investments, although empirical evidence of realized genetic gains in stand (as opposed to individual tree) productivity is lacking. The gains to be achieved from tree improvement appear substantial, particularly because even small gains add up quickly when spread over a large land base. Estimates of genetic gains, however, depend on many factors. Some factors differ among programs and landowners (e.g., selection intensities in seed orchards), some are difficult to measure annually (e.g., unequal contributions of parents and pollen contamination in seed orchards), and some involve untested assumptions (e.g., the effects of selection at young ages and before appreciable competition). Much forest genetics research is aimed at addressing these factors, and stand-level plots are being established in the region with the goal of providing estimates of realized genetic gains to be incorporated into growth and yield models (St. Clair 1993).

Multipurpose silviculture and ecosystem restoration stand to benefit greatly from regional tree improvement programs. The rapid juvenile growth of improved planting stock may help alleviate stand establishment problems associated with reduced site preparation, increased competition from grass and shrubs, and animal browsing. Rapid growth also may promote stand development, allowing us to achieve desired tree sizes and stand structures more quickly. Restoration efforts may benefit from an assured supply of seed from seed orchards, particularly from species and populations with infrequent seed years. The development of disease-resistant planting stock allows continued planting of species such as western white pine and sugar pine *(Pinus lambertiana* Dougl.) that might otherwise be extirpated from large areas (fig. 18).

Genetic diversity is a key component of biodiversity, and continued care in the management of genetic diversity is essential to long-term ecosystem health. Components of genetic resource management include adherence to guidelines for the movement of seed, avoidance of disgenic selection practices, proper design of advanced generation breeding programs to maintain adapted and diverse populations, proper deployment of genetically improved planting stock, and an active genetic conservation program. Resource managers and restoration specialists are beginning to plant and transfer seed of many species for which we have no guidelines for seed movement. Development of seed transfer guidelines is badly needed for these noncommercial tree, herbaceous, and grass species. Until guidelines are established, seed from local populations should be used as much as possible. Genecological studies are critical to the development of seed transfer guidelines, as well as to the design of genetic conservation and breeding programs.

Site preparation-Considerations and methods similar to those previously discussed under natural regeneration also apply to establishment of stands through planting. There are some differences, however. Normally, planting immediately follows (or should follow) harvest, and planted seedlings commonly make more rapid early height growth than do natural seedlings. Consequently, the period during which control of competing vegetation must be continued is often considerably shorter with planting than with natural regeneration. Exposure of mineral soil often may be unnecessary or can be limited to the actual planting spot. But, an additional objective of removing or reducing heavy slash and shrubs or undesired tree species is to remove physical obstacles to planting crews.

Summary-Successful planting requires careful attention to the details of seed source and nursery and planting practices, as well as a thorough evaluation of environmental conditions (Hobbs and others 1992) and control of competing vegetation, where needed. Microclimate, competition from herbs, shrubs, and hardwoods, and animal browsing (discussed in a later section) often affect seedling survival and growth. The effects on early growth also carry over into later stand development.

Cafferata (1986), Cleary and others (1978), Hobbs and others (1992), and Lavender and others (1990) provide excellent overviews of the application of current reforestation practices. Guidelines for conifers (DeYoe 1986, Schubert and Adams 1971, Strothman and Roy 1984) and hardwoods (Ahrens and others 1992) are available. In summary, measures must be taken at all stages to ensure careful attention to the following:

- Proper selection of seed source and proper seed handling
- Nursery procedures that optimize seedling vigor, and storage and handling procedures in nursery and field that minimize seedling dehydration, respiration, and damage
- Careful planting, including onsite inspection of planting procedures
- Site-specific prescriptions for site preparation and weed control
- Monitoring for 3 or more years to ensure seedling survival and growth
- Early thinning to control stocking and species composition

The ability to consistently regenerate forests with present technology is demonstrated in the annual reforestation report of the Oregon State Board of Forestry for 1992. This shows that of 85,689 acres of private land requiring reforestation by the end of 1992, 82,034 acres or 96 percent were in compliance with the standards of the Oregon State Forest Practices-Act.

Shaping Development of Young Natural Stands and Plantations

The choice of regeneration system and decisions about patterns of cutting, including retention of live and dead trees, influence the nature of a regenerating forest after harvest and affect later growth. Subsequent silvicultural treatments are the tools for shaping development of established stands to meet specific or multiple objectives, which may change over time and over the life of the stand.

During the past half century, silvicultural practices (harvest systems, spacing control, vegetation management, and-to a lesser extent-fertilization and pruning) have been applied throughout the world, wherever soils and climate, social policies, and markets combine to favor long-term forestry enterprises. Research, development, and implementation of these practices were justified primarily by the quantity or quality of wood that could be grown or harvested, although other goals also were served. The basic knowledge and experience acquired, however, can be applied to meet additional objectives. Appropriate further silvicultural investments may be justified to meet expanded social desires and concerns for other forest values and products, provided that goals are specified in terms of desired forest conditions and mechanisms exist for equitable (or acceptable) distribution of associated costs and benefits.

In this section, we first provide some background on changing societal expectations and their influence on silvicultural opportunities. Then, we describe several silvicultural practices, how conventional application influences stand development, and how they might be applied or modified to meet other or additional objectives.

Social Expectations and Silvicultural Opportunities

It has long been recognized that forests provide the multiple benefits of timber production, watershed protection, wildlife habitat, recreational and aesthetic values. Increased attention to nontimber values is now demanded by various segments of society and required by public law. As these values and the stand conditions required to produce them become more clearly defined, their provision and enhancement over time will require silvicultural manipulation of stands, integrated at the landscape level.

Although managed forest landscapes may appear more natural and more diverse than landscapes associated with most human endeavors, extensive areas of young managed plantations do contrast markedly with natural mature and old-growth forests. Many of the features associated with older natural forests (Franklin and others 1981, Ruggiero and others 1991) are reduced or absent in young stands, whether managed or unmanaged (Carey and Johnson 1995); and many are minimized with conventional short-rotation plantation management. Such features may include large trees, snags, down woody debris, “ragged” edges, within-stand structural complexity, and diversity in age, size, shape, and distribution patterns of stands across the landscape (Hansen and others 1991, 1993). Many of these features contribute to habitat for wildlife (Brown 1985, Hunter 1990, Thomas 1979) or are otherwise thought by some groups or individuals to be related to or essential to other forest values and general forest health. Existing young natural stands (or plantations) will not necessarily develop into stands comparable to present old-growth in the absence of human intervention. The desire to retain such features or to produce similar features in managed forests has stimulated interest in various modifications of conventional silvicultural practice (Carey and Curtis 1996, DeBell 1989, DeBell and Curtis 1993, Franklin and others 1986, Kohm and Franklin 1997).

The general nature of silvicultural practices needed to foster structural features similar to those of natural mature and old-growth forests is fairly apparent, but the specifics of implementation are not. It may be obvious, for example, that a given feature (such as a shrub species in the understory) provides important habitat for one or more species. But little is known about the response of the forest ecosystem or of other species to various levels or distribution patterns of that feature. Even less is known about other biological or economic costs and benefits associated with such management. Appropriate practices undoubtedly will differ with forest types, landscapes, specific stand and site conditions, and public preferences. These uncertainties should not be used to justify reluctance or failure to modify conventional practices. But they should foster a skepticism of widespread implementation or legislative requirement of untested, highly specific modifications, particularly in the absence of effective monitoring efforts. And such uncertainties also should stimulate soundly designed experiments to test and compare a range of approaches or options.

Figure 19-(A) An exceptionally uniform plantation in the Mount St. Helens blast area. Aerial photography (B) shows that the unthinned stand is actually much less uniform than it appears from the road. Conventional thinning (C) increases uniformity, but heterogeneity can be enhanced by irregular thinning (D).

Figure 20-The Wind River plantation spacing trial is a striking example of the effects of differences in initial spacing on a relatively poor site, without subsequent thinning: (A) 4-foot spacing, and (B) 12-foot spacing, 71 years after planting.

The greatest near-term opportunity to develop such management knowledge and experience and to provide more diverse habitat lies in the millions of acres of existing plantations, which range in age from 1 year to 40 or 50 years. Plantations are sometimes disparaged as uniform monocultures of minimal or even negative value for purposes other than wood production. This view arises in part from the fact that many plantations in the Pacific Northwest are now in the early stem exclusion stage, in which relatively uniform and dense canopies have eliminated most understory vegetation. Moreover, plantations usually appear much more uniform when viewed from a highway or forest road than they are in fact (fig. 19). Even without further management, this uniformity is gradually modified by natural processes of stand development and by such agents as root diseases and snow breakage, in a manner similar to that occurring in natural stands (Silviculture Interpretations Working Group 1992). Many plantations established 40 or more years ago are now barely recognizable as plantations. With appropriate management, stand differentiation can be accelerated (Curtis and others 1997). Most of these plantations are now in a highly plastic stage of development, and there are major opportunities to mold them-individually and in a landscape context-toward a variety of objectives.

Objectives will differ by ownership, geographic location, condition of surrounding stands and landscapes, and public desires. Rapidly growing uniform stands focused primarily on wood production will be a major or sole management objective for some plantations. Accelerated development of habitat for threatened or endangered species may be the primary objective in some others. Many owners and managers will have multiple objectives, which can be met through use of a variety of silvicultural practices. A number of modifications of conventional silvicultural practices merit consideration and some are now being applied by several landowners and organizations.

Early Density Control

Initial density has a strong influence on subsequent stand development (Dilworth 1980, Omule 1988, Reukema 1979, Reukema and Smith 1987, Smith and Reukema 1986). The effects of initial plantation spacing in the absence of subsequent stand treatment are well illustrated in the Wind River spacing test (figs. 20 and 21). In dense naturally seeded stands and in plantations established at close spacings or having a substantial component of naturally seeded stems (fig. 22), early thinning (=precommercial thinning =respacing) is often needed to keep stand density within acceptable limits.

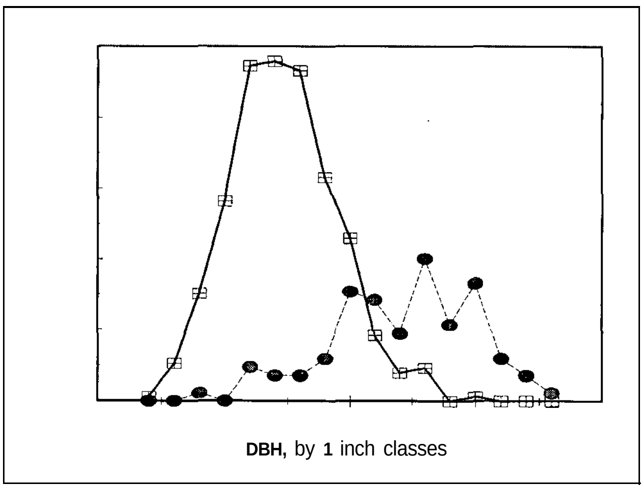

Figure 21-Differences in initial spacing have produced widely different diameter distributions in the Wind River spacing test. Numbers of trees per acre by diameter classes in the 6- and lo-foot spacings in 1991, 66 years after planting.

Figure 22-Excessive tree numbers without subsequent thinning produce stands with small diameters, slender boles, and small crowns, with little understory vegetation (A). Such stands become very susceptible to breakage from wind, ice, and snow (B).

Figure 23-Precommercial thinning of dense young stands accelerates tree growth, promotes understory development and browse production, and allows selection of the better individual trees. Young noble fir stand (A) before and (B) after precommercial thinning.

Precommercial thinning is commonly applied near the end of the stand initiation stage (10 to 15 years) to enhance survival, growth, and value of future crop trees (fig. 23). Thinnings usually are aimed at leaving the most valuable larger trees at relatively even spacing (Reukema 1975). This treatment increases stand uniformity; but the reduced stand density also accelerates tree growth (Hoyer and Swanzy 1986, Omule 1985) and may promote development of a shrub and herbaceous understory and browse production. It frequently also leads to early establishment of natural regeneration of tolerant tree species, such as western hemlock and western redcedar (Curtis and others 1997).

Past prescriptions sometimes overemphasized current market values or current tree size. Thus, western redcedar often was discriminated against in early respacing of stands on the Washington coast, where long-term growth potential of the species is high and the species has considerable value for wildlife and possibly in nutrient cycling. Hardwoods such as red alder (useful in nitrogen fixation) and bigleaf maple likewise have been singled out for removal.

A number of modifications to promote biodiversity are possible and have been applied to a limited extent on some public lands. These modifications involve selection criteria for residual trees, spacing distances, and intentional creation of small openings. Trees left after thinning can be selected to increase diversity in size and species, thus accelerating stand differentiation and increasing structural complexity. Many spacing prescriptions on public lands now specify that occasional hardwoods, western redcedar, Pacific yew (Taxus *brevifolia* Nutt.), and western white pine shall not be cut during thinning, although they are not actively favored. Wide spacing, either initial or in early thinning, will enhance development of understories and large live crowns and branches. Spacing can be varied in patches throughout the plantations, and some patches may be retained in an undisturbed condition. Small openings or gaps can be created to retain some components of the early stem initiation stage and later develop patches of young trees. Park and McCulloch (1993) give some guidelines for such operations.

Thinning in Older Stands

Thinning in older stands (=commercial thinning) has long been a generally accepted practice in European countries and rests on over a century of experience and research embodied in an enormous literature (Braathe 1957). Commercial thinning was not widely applied in the Pacific Northwest until very recently, because large volumes of old timber were available, markets for smaller and poorer quality material were limited, and equipment then available was not well suited to thinning operations. But the economic, technical, and social context has changed, and thinning is rapidly increasing in importance. It provides opportunities to both produce wood and enhance nontimber objectives. Thinning combined with extended rotations can maintain visually attractive forest cover for long periods while still producing wood products and current income.

A considerable body of thinning research exists in the Pacific Northwest, dating from about 1950 (Curtis and Clendenen 1994; Curtis and Marshall 1986; Hilt and others 1977; King 1986; Marshall and others 1992; O'Hara 1990; Oliver and Murray 1983; Oliver and others 1986; Omule 1985; Reukema 1972; Reukema and Bruce 1977; Reukema and Pienaar 1973; Worthington and Staebler 1961a, 1961b). A number of more or less equivalent density control guides and density measures are available for planning and administering thinning activities (Curtis 1982, Drew and Flewelling 1979, Long and others 1988, Reineke 1933). Several publicly available simulation models and a number of proprietary models exist that provide useful guidance in developing stand management regimes; for example DFSIM (Curtis and others 1981, Fight and others 1984), ORGANON (Hann and others 1995), WinTIPSY (Mitchell and others 1995), STIM (Bonnor and others 1995), SPS (Arney 1988), and FPS (Arney 1995).

The traditional purposes of thinning are to harvest potential mortality, maintain or increase growth rates of remaining trees of desired species, and promote stem quality and tree vigor while producing intermediate income. Thinned stands produce larger trees at any given age than do unthinned stands; thinned stands are more open and sometimes more diverse. One recent study in the Pacific Northwest (Marshall and others 1992) showed that over a 20-year period repeated thinning in a young stand on a good site produced increases of 33 to 56 percent in diameter growth of the largest 40 stems per acre, compared to the unthinned condition (fig. 24). Thinning also provides income and timber flow during the intermediate stages of stand development.

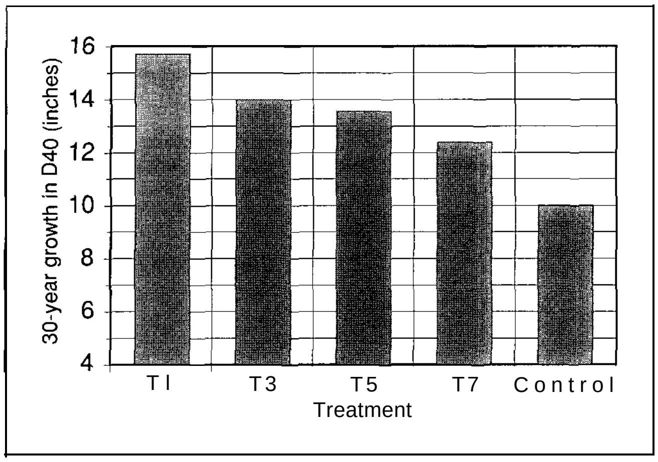

Figure 24-Thirty-year increment (ages 20 to 50) in average diameter of the largest 40 trees per acre, for four treatments involving early and repeated thinning and a control. Thinning treatments range from one with low growing stock retention (Tl) to one with high growing stock retention (T7). Data are from Hoskins LOGS study (Marshall and others 1992).

Most past thinning studies were oriented to timber production, but thinning also strongly influences other stand attributes. Thinning, depending on how it is done, may or may not promote vertical stratification (figs. 25 and 26). It usually accelerates understory development and succession and movement of the stand into the understory reinitiation stage. If begun early, changes can be striking over comparatively short periods (fig. 27). Operationally, there can be considerable loss of understory from damage during thinning. If understory reduction is considered undesirable, such effects can be minimized by training, use of designated skid trails and corridors, proper equipment, and heavy initial thinning that allows relatively long intervals between subsequent thinnings.

Most thinning research has been done in young and intermediate-aged stands (<60 years). Opportunities to influence tree and stand development through thinning are greatest if thinning is begun early. A first thinning that is delayed until after stands have developed high relative densities and shortened crowns involves an increased risk of windthrow and snowbreakage as well as delayed growth response and therefore must be lighter (usually) than an early initial thinning. Crown expansion potential slows with age, and therefore thinnings should generally become lighter and entries less frequent as stands age; however, even late thinning in vigorous, relatively old stands (>lOO years) can be effective in capturing some mortality, maintaining stand vigor, and reducing losses from insects and disease (Williamson 1982, Williamson and Price 1971). The maximum age at which thinning is justified in relatively vigorous stands is more a matter of owner objectives than biological limitations. Financial returns and development of specific habitat characteristics may be important considerations.

A less obvious but important effect of repeated thinning is that trees and stands maintain rapid growth to older ages than without thinning. Culmination age (age that maximizes wood production) has yet to be determined for repeatedly thinned Douglas-fir in the Pacific Northwest, but it is greater than for dense unthinned stands (Curtis 1994,

Figure 25-Thinning on good sites can produce large trees and considerable vertical structure within relatively short periods: (A) Delezenne thinning study (Curtis 1995, O'Hara 1990) at age 73, first thinned at age 36, natural origin; and (B) developing hemlock understory in a thinned stand, Soleduck Ranger District, Olympic National Forest, Washington.

Figure 26-Late thinning in a poor site stand of natural origin, first thinned at age 60, and now 117. Mount Walker thinning study: (A) heavy thinning, and (B) unthinned control.

Figure 27-On good sites, early thinning can greatly accelerate diameter growth and markedly alter stand structures. These photographs from the Iron Creek LOGS study at age 45 (Curtis and Clendenen 1994) show (A) untreated control plot containing planted trees plus much natural regeneration, (B) plot with repeated light thinning, and (C) plot with repeated heavy thinning, showing understory western hemlock, western redcedar, and shrubs and vertical structure developing in response to thinning.

1995; Curtis and Marshall 1993; Worthington and Staebler 196la). Where terrain and harvesting methods permit thinning, large trees can be grown on longer rotations, with no loss and perhaps even an increase in annual wood production per unit area. Stem quality and value per unit of volume may be increased. Repeated thinnings on extended rotations can maintain forest cover for long periods while providing current income and employment (Curtis and Carey 1996, Lippke and others 1996), maintaining tree and stand vigor, promoting stand health and stability, and developing stand structures favorable to certain wildlife species associated with late successional stages (Carey and others 1996a). It also may provide additional opportunities and flexibility to capture benefits from stands composed of mixed species with differing tolerance and growth patterns.

Thinning encourages seedling establishment of shade-tolerant conifers (Del Rio and Berg 1979), hardwoods (Fried and others 1988) and shrubs (Huffman and others 1994, O'Dea and others 1995, Tappeiner and Zasada 1993), but it also results in vegetative expansion of shrubs by rhizomes (Tappeiner and others 1991) and layering. By reducing overstory density and providing a seedbed, thinning results in invasion by new plants not previously in the stand (Carey and others 1996b) and the spread of those already established. This generally produces a dense, diverse understory of shrubs, herbs, and tree seedlings and saplings that may provide enhanced wildlife habitat.

Regeneration of understory conifers after thinning often will enhance the development of stands with structures similar to mature and old-growth stands. On some sites, however, thinning may produce dense shrub layers that inhibit later establishment of desired conifers. Dense understories of salal, Oregon grape (Berberis nervosa Pursh), salmonberry, vine maple and other shrubs may develop and prevent establishment of a second layer of conifers. Conifer seed will germinate under such shrub layers but few seedlings survive. These shrub layers often are quite persistent. They produce new aerial stems annually that replace older stems as they die, thereby maintaining a dense cover for decades (Huffman and others 1994). On some sites (particularly at low elevations and in the Oregon Coast Range), some disturbance of these brush layers and possibly underplanting of conifers may be necessary to establish multilayer conifer stands.

Nutrient Management

Nutrient management is an important consideration, particularly in the Douglas-fir region where soils are young and considerable nitrogen is immobilized in organic matter. Inadequate supplies of available nitrogen limit natural productivity and rates of stand development on many sites. Relatively small and infrequent applications of nitrogen fertilizers have been used to increase wood production in conventionally managed forests, and often produce striking responses in tree growth and stand development (fig. 28) (Chappell and others 1992b, Gessel and others 1979). The largest and most long-lasting responses occur when nutrient deficiencies are severe (Miller and Pienaar 1973, Miller and Tarrant 1983, Miller and others 1986) and when fertilizer application is combined with thinning (Brix 1993, Chappell and others 1992a).

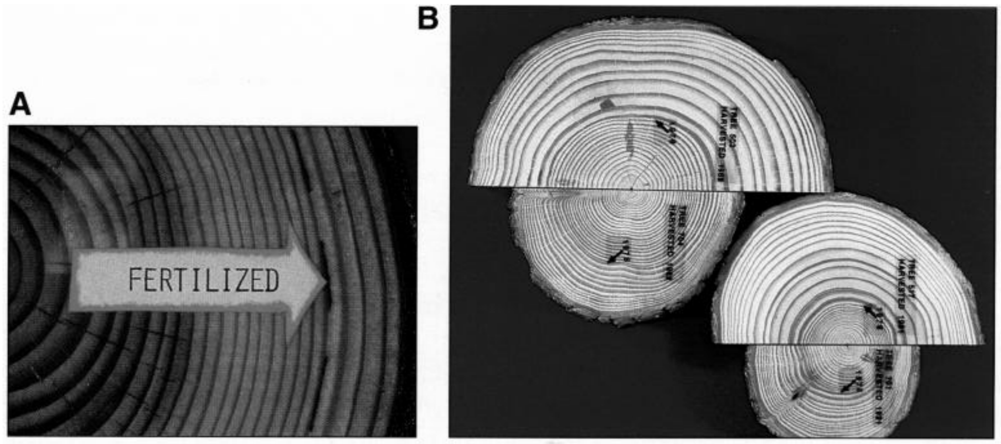

Figure 28--Relatively small and infrequent applications of nitrogen fertilizer often produce striking response in tree vigor and stand development, particularly on poor sites. Typical response in diameter growth (A), shown by wide growth rings commencing in the year following fertilization; and an extreme example of response (B) shown by paired stem sections, cut from trees on adjacent fertilized and unfertilized plots on a very poor site.

In newly established and very young plantations, broadcast applications of fertilizer produce earlier canopy closure and greater stand uniformity (DeBell and others 1986); in older stands where trees have begun to differentiate into crown classes, fertilizer application accelerates the stand development processes of crown differentiation and competition-related mortality (Miller and Pienaar 1973, Miller and Tarrant 1983). Other site resources, such as amount and nutritional quality of wildlife forage (Sullivan and Rochelle 1992), may be increased.

One modification of the conventional practice of broadcast application of fertilizer that could be considered is small-scale individual tree or group application. This could be used to promote development of a layered canopy and differences in understory vegetation, in contrast to broadcast applications that simply increase the overall rate of stand development. It also could be used to enhance growth and nutritional value of forage in openings created for that purpose. Individual tree application was deemed feasible and profitable nearly 20 years ago by scientists of the Washington Department of Natural Resources (Anderson and Hyatt 1979). Coupled with selective thinning and pruning, individual tree applications also could increase production of high-quality wood.

Introduction or favoring of nitrogen-fixing plants also merits consideration. These can provide benefits similar to those of fertilization on some nitrogen-deficient sites (Miller and Murray 1978, Tarrant and others 1983, Trappe and others 1968) and may have additional benefits in economic and ecological diversity. Natural red alder regeneration often is abundant in conifer plantations. Mixed stands could be established by retaining selected alder stems during precommercial thinning. Individual, scattered red alder trees have been favored in early thinnings of young conifer plantations on nitrogen-deficient soils of the Siuslaw National Forest (Turpin 1981). Early height growth is much more rapid in alder than in conifers, so wide spacing of the alder would be necessary to maintain the conifers. Unlike shade tolerant species, alder will not survive beneath a conifer overstory. After 25 to 30 years on good sites, conifers that have not been suppressed will dominate the alder (Newton and others 1968). Stemwise (tree-by-tree) mixtures thus are difficult to maintain. Planting or retention of naturally established red alder in groups or small blocks within conifer regeneration should reduce the crown competition problems encountered in stemwise mixtures, while still providing nutrient benefits. A pure alder crop grown prior to establishment of a new Douglas-fir stand would have nutritional benefits for the latter and may be particularly appropriate on land heavily infected with Phellinus *weirii* (a serious root disease of conifers) because of alder's immunity (Harrington and others 1994). Other nonleguminous nitrogen-fixing species, such as Sitka alder *(Alnus sinuata* (Regel) Rydb.) (Binkley and others 1984, Harrington and Deal 1982) ceanothus *(Ceanothus* ssp.) (Binkley and Husted 1983), and leguminous species (Miller and Zalunardo 1979) may offer fewer competition problems and add some soil nitrogen and organic matter.

Mixed stands of red alder and conifers are more productive than pure conifer stands on soils with low nitrogen levels (Miller and Murray 1979), provided the conifers are not overtopped by the alder. An interplanting of red alder with Douglas-fir at Wind River Experimental Forest in southern Washington is a classic example of potential opportunities; nearly one-half century after planting, heights of dominant Douglas-fir grown with interplanted red alder were taller than those in an adjoining pure Douglas-fir stand by the equivalent of one full site class (Miller and Murray 1978). Volume of Douglas-fir in the mixed plantation equaled that in the pure stand, but it occurred on fewer and larger stems and hence had greater value. Total volume of Douglas-fir and alder in the mixed stand was double that of the surrounding pure Douglas-fir stand. Soil under the mixed stand contained about 1,000 pounds of nitrogen per acre more than soil under the adjoining pure Douglas-fir stand (Tarrant 1961, Tarrant and Miller 1963).

Such mixed species stands might also benefit some wildlife species (McComb 1994). Mixed plantations of red alder and Douglas-fir also have been established by William Emmingham and Denis Lavender at OSU's McDonald Forest. The purpose was to use alder's nitrogen-fixing ability to increase growth of Douglas-fir while producing greater diversity in both the tree and herbaceous layers than might occur in a pure Douglas-fir stand. Because of alder's rapid juvenile height growth rate, alder in this instance was planted when the Douglas-fir was over 15 feet tall. Early data demonstrate that competition with Douglas-fir improves the form of alder and that the Douglas-fir are 30 percent larger than saplings in pure stands, although spacing also may be a factor in the observed size differences.

Planting different species in small groups rather than as stemwise mixtures should avoid many of the problems in maintaining stemwise mixtures, although some of the possible benefits may be delayed or foregone. Harrington and Deal (1982) examined comparative height growth patterns of Sitka alder and Douglas-fir and provide recommendations for planting mixtures of this less competitive species with Douglas-fir to avoid overtopping the Douglas-fir while providing a source of nitrogen.

Pruning

Pruning (removal of branches from the lower bole) has been advocated primarily to increase the amount of clear wood produced in young stands (Hanley and others 1995). Pruning has been little used until very recently because of uncertainties about economic returns and future markets, but there is now increased interest and operational application by some owners. It has also been recommended as part of a program to control blister rust in western white and sugar pines (Russell 1988). Most pruning for improved wood quality has been in stands in the stem exclusion stage. Current practice is to begin pruning much earlier than was common in the past. Pruning may be done on all trees, but-to reduce costs-often is confined to a subset of trees corresponding to the number expected to be retained after future thinning.

Pruning gives stands an open appearance, which may make them more attractive aesthetically. If begun before stand closure, removal of lower branches could increase the amount of light reaching the forest floor and favor development of the woody and herbaceous understory (which also may somewhat reduce overstory growth). Because some wildlife species use branches as hunting perches or use some trees with long continuous crowns, there may be benefits, in addition to cost savings, to retaining some unpruned trees within pruned stands. In regimes with repeated thinning on relatively long rotations, removal of some pruned trees during thinning might increase financial returns and perhaps offset some costs of other silvicultural activities.

Summary, Shaping Development

There are many opportunities for directing development of young naturally established or planted stands toward desired future conditions. Well-established techniques are presented in standard texts such as Smith and others (1997). Although many were originally developed to promote wood production, these techniques are equally applicable to production of multiple forest benefits. These techniques include:

- Initial planting spacing or early thinning, or both, can be used to control spacing and species composition.
- Thinning can be applied in older stands to:
  - -control species composition and stand structure
  - -shorten the duration of the stem exclusion stage and enhance understory development
  - -produce larger, more valuable, and visually more attractive trees at any given age
  - -produce current income while maintaining visually acceptable forest cover for long periods
  - -promote forage production
  - -promote tree and stand health
  - -forestall or harvest mortality
- Nutrient management can improve stand vigor and growth rates through application of fertilizer on nutrient deficient sites, or through use of nitrogen-fixing species (such as red alder) as alternatives to artificial fertilizers.
- Pruning can improve quality and value of wood produced, help control blister rust in white and sugar pines, and give stands a more open appearance.

Harvesting Considerations

Timber harvest and the subsequent site preparation and regeneration are probably the most influential of all operations that can be carried out in multipurpose forests. The methods used and the manner in which they are applied have dramatic and long-lasting effects on forest characteristics. Harvesting is the operation that generates the most conflict between objectives, between people, and between institutions. It also generates most of the revenue that directly or indirectly supports management of forests for multiple objectives.

In this section, we discuss primarily harvests that may occur at the end of a rotation (even-aged management) or harvest cycle (uneven-aged management) as part of a planned management regime. Similar considerations apply to harvests that take place as a response to unplanned, perhaps large-scale, natural disturbances such as windstorms, fire, severe insect outbreaks, and volcanic eruptions; or as a component of efforts to restore forests that have been drastically altered or degraded by past natural or human-caused events. We also discuss the question of harvest ages, and conclude with brief discussion of some considerations related to harvest of special forest products.

Regeneration Harvests

A silvicultural system or management regime consists of a regeneration method, intermediate stand treatments (if any), and a harvest method. The choice of harvest method is influenced by both desired future conditions and comparative costs. A method that is perfectly feasible and highly desirable on gentle terrain may be quite impractical on steep topography. Details of application are influenced by present and desired future species composition and by differences in site and expected vegetative competition.

In the appendix, we illustrate a number of possible regimes that appear feasible for lands having both wood production and nontimber values as objectives, and that are included in trials now being established on Washington Department of Natural Resources (DNR) lands (Curtis and others 1996). These regimes are expected to produce widely different stand conditions with differing visual effects and habitat values, while retaining wood production as a major objective. Many variations are possible.

Planned regeneration harvests are conventionally classified into several broad categories or associated silvicultural systems (Matthews 1989, Nyland 1996, Smith 1986, Smith and others 1997). These represent segments of a continuum of possible practices classified by site exposure and sequence of operations, rather than rigid and clearly demarcated alternatives.

The **clearcutting** method removes all trees from relatively large areas at one time, followed by regeneration by either planting or natural seeding from adjacent uncut trees or stands (see figs. 4, 5, and 6). It is highly cost-efficient for wood production with species and sites where large open areas are readily regenerated. It minimizes road costs and direct harvesting costs (especially on steep terrain) and markedly simplifies planning and future administration and management. It is commonly thought, though not fully demonstrated, to give greater wood production per unit area than alternative systems. It was the dominant system throughout the Douglas-fir region for many years and remains important on non-Federal lands. In recent years, it has come under public attack and its use has been greatly diminished on Federal lands. A clearcut is a highly visible treatment that is aesthetically displeasing to many people. There also are perceived or actual unfavorable effects on some wildlife and other environmental values. These problems are exacerbated by short-rotation management on many ownerships and by unbalanced stand age distributions. Some of the problems in part reflect changes in societal attitudes and effects of past forest planning, harvest scheduling, and other management practices, rather than inherent characteristics of the clearcutting method. But such distinctions are commonly lost in public debate.

The **seed-tree** method leaves widely scattered individual trees or clumps of trees as a seed source. This has long been abandoned as a regeneration method over most of the region because it is usually less effective and less reliable than other methods in regenerating Douglas-fir, though not invariably so (e.g., Garman 1951).

The **shelterwood** method consists of removal of a sufficient portion of the old stand to provide the environmental conditions needed for establishment of Douglas-fir seedlings (either planted or natural), while the remaining overstory (= overwood) provides protection from excessive insolation, temperature, and frost (fig. 29). Once regeneration is established, the remainder of the old stand is removed to allow free growth of the new stand. The shelterwood method can be applied uniformly over large areas, or as a so-called irregular or group shelterwood in which openings are gradually enlarged as regeneration becomes established.

The above methods produce even-aged stands; i.e., stands in which the trees are of similar age. If applied over contiguous stands within a short period, a large forest area may consist of stands with little variation in ages; however, such large-scale uniformity is a result of harvest patterns and scheduling and is not inherent in even-aged methods.

In contrast, **selection** methods aim to develop unevenaged stands, which contain a wide range of tree ages within the individual stand. Differences in age structure and general appearance between adjacent stands will tend to disappear over time. In **single-tree selection,** different age classes are developed in a stemwise mixture through removal of individual trees. This method strongly favors shade-tolerant species because of the small size of openings. It is difficult and expensive to carry out, and damage to remaining trees can be extensive. Single-tree selection is therefore rarely used in the Douglas-fir region. In **group selection,** the aim is to develop a mosaic of small even-aged groups or patches of differing ages within a stand (fig. 30). As the area

Figure 29-Regeneration established under a shelterwood. The overwood is usually removed after a few years, to produce a new even-aged stand. Alternatively, the overwood can be retained for further growth, as a reserve shelterwood or two-aged stand.

Figure 30-Group selection in Douglas-fir, McDonald Forest, Oregon State University.

of the group or patch is increased, conditions within the patch approach those under clearcutting and become suitable for intolerant species and amenable to the same regeneration practices.

Accessory systems (Matthews 1989) include conscious establishment of layered and two-aged stands, potentially important in the Pacific Northwest. These include **two-aged systems** such as clearcutting with reserves (retention of scattered trees or groups of trees from the former stand) and reserve shelterwoods (Nyland 1996), in which a more or less uniformly distributed overwood is retained for much or all of the next rotation. Both two-aged and layered but essentially even-aged stands often arise naturally because of differences in species tolerance and growth rates, and often are thought favorable to wildlife and biodiversity values. Such conditions can be created by planting appropriate species mixtures or by cultural practices designed to favor development of such species mixtures in either natural or planted stands.

It has become common practice, mandated by state regulations and by management guidelines on Federal lands, to leave scattered green trees or groups of trees on harvest units for wildlife and other ecological purposes. Although this may initially produce stand conditions that appear similar to those created by the seed tree method, the retained trees are not left primarily for seed production and are not intended or expected to provide adequate regeneration (fig. 31). Harvest cuts including such features are sometimes referred to as “retention harvests” or “retention harvest systems” (Franklin and others 1997). This is inconsistent with long-established terminology used worldwide. Depending on number, arrangement, and planned retention of leave trees, such harvests are more accurately characterized as “clearcut with reserves,” “irregular shelterwood” (Smith 1986), or “reserve shelter-wood” (Nyland 1996). Questions of terminology aside, Franklin and others (1997) provide a good discussion of some of the variations on the basic ideas involved and of the hypothesized value of these measures in promoting wildlife habitat and rapid recolonization of harvested areas by a variety of plants and animals.

Figure 31-It is now common practice to leave scattered green trees or groups of trees and snags on harvest units for wildlife and other purposes. Although such “new forestry” harvest units have a superficial resemblance to the seed tree cuts of the past, the trees are not retained for regeneration purposes.

Timber harvesting after large-scale catastrophic events often does not easily lend itself to overall classification, because many of the critical harvesting considerations are landscape rather than stand-level ones. The scale of disturbance can be orders of magnitude greater than the mean stand size (many thousands of acres vs. less than 100 acres). Thus, recent management plans in Oregon (e.g., following the Silver and Longwood fires in the Siskiyou National Forest and the Warner Creek fire in the Willamette National Forest) have redefined stand boundaries in ways that attempt to mimic natural patterns on the landscape and have reduced the amount of salvage or cutting of green trees in some units in an attempt to recreate natural patterns and accelerate the development of a range of stand structures within the landscape.

Rotations

The progressive reduction in harvest ages (rotations) in recent decades has contributed to current problems. The net result of past harvest practices, reduced harvest ages, and historical harvest patterns is that many landscapes are dominated by recent clearcuts and by stands in the stand initiation and stem exclusion stages (fig. 6). Many people find this aesthetically distasteful and regard it as irresponsible destruction of "nature," creating horrendous public relations and political problems with huge indirect costs to the landowner and the public. The possible effects of frequent drastic disturbance on wildlife, hydrology, biodiversity, site productivity, timber quality, and long-term sustainability also have been questioned. Similarly, people have raised concerns about regimes in which most of the landscape is occupied by relatively uniform young stands.

A shift to extended rotations on some part of the land base (combined with increased commercial thinning and-where feasible-regeneration systems other than extensive clearcuts) can help to reduce the visual impacts of forestry operations. Longer rotations also would help maintain species diversity, wildlife, and other environmental values on lands where continued and sustainable timber production is a major objective.

Douglas-fir, because of the past history of the forests and the relatively intolerant nature of the species, is usually grown in even-aged stands and will probably continue to be so managed for the foreseeable future. This does not necessarily imply the large units of a single age class that are common today. Below, we define and discuss some terms and relations related to even-aged management. Although these are defined in terms of wood production, they remain important in management and policy decisions involving any form of integrated management for production of multiple benefits, including wood production.

Definitions-Rotation is the planned number of years between stand regeneration (or removal of the previous stand) and final harvest. **Yield** is the sum of standing volume + cumulative amount removed in thinnings since stand establishment, at a specified age. **Mean annual increment** (MAI) is volume produced (standing volume + volume removed in thinnings), divided by stand age (i.e., average annual production rate from establishment to the age in question). **Current annual increment** (CAI) is growth rate in volume per year at specified age (which is not directly measurable). **Periodic annual increment** (PAI) is an approximation to CAI, calculated as the difference in stand volume at two successive measurements, divided by the number of years between measurements.

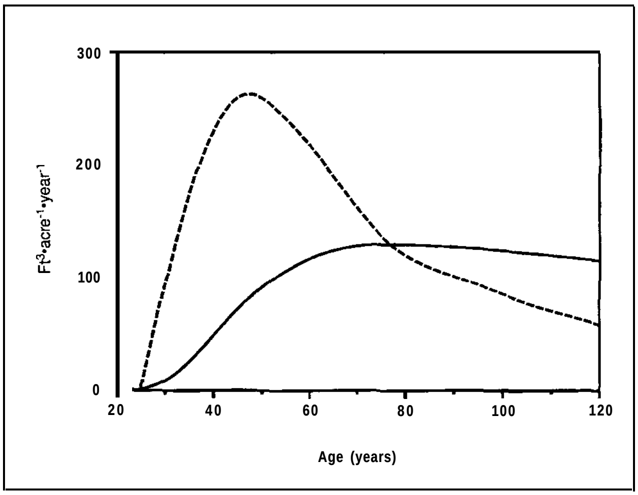

Figure 32-The curves for mean annual increment (solid line) and periodic annual increment (dashed line) intersect at culmination of mean annual increment, at the age which gives maximum average volume production. Values are as shown for site Ill in McArdle and others (1961) adjusted to volumes to a 6-inch top.

The MAI and PAI trends over time are important expressions of stand and species development patterns. The MAI and PAI curves for a given stand have characteristic patterns, (shown schematically in fig. 32) and intersect at the maximum point ("culmination") of the MAI curve.

Historically, there are three basic theoretical concepts of "optimum" rotation. In traditional presentations, these are based on timber volume or timber value only (Chang 1984, Newman 1988, Pearse 1967):

- The first maximizes **value** of timber produced per year and corresponds to age of culmination of mean annual value increment.
- The second maximizes timber **volume** produced per year and corresponds to age of culmination of mean annual volume increment.
- The third or financial rotation maximizes the **net value** of all costs and returns, **discounted** either to the present or to the year of stand establishment, at some specified interest rate. The value discounted to year zero is known as **soil expectation value** and represents the amount that an investor could pay for bare land to be used for timber production and still earn the specified interest rate, given full knowledge of future costs and returns.

In general, the first is longer than the second; the financial rotation is the shortest of the three-much shorter if the assumed interest rate is high. Foresters have argued about these for a century and a half. Forest economists usually advocate the third, or variations thereof, as the theoretically "correct" answer. In real life, many other considerations enter into the rotation decision. A major factor today is the existence of multiple management goals, not restricted to or necessarily emphasizing timber production or economic return, and often not readily expressible in monetary terms.

Extended rotations-Extended rotations can be a major component of any strategy to reduce conflicts and promote joint production of commodity and ecological values (Curtis and Carey 1996, Curtis and Marshall 1993, Kuehne 1993, Lippke and Fretwell 1997, Newton and Cole 1987, Voelker 1973).

As rotations have become shorter, a greater percentage of forest land is cut annually, and more of the stands and total forest area are in the visually least attractive and least diverse stand initiation and stem exclusion stages. Although short rotations may maximize the discounted present net value of timber, trees are smaller, wood quality and value at harvest are lower, and productivity of both wood and other forest values are reduced in comparison with biological potentials.

Long rotations are biologically feasible in the Pacific Northwest because Douglas-fir and its conifer associates are very long-lived and can maintain rapid growth to advanced ages. The widespread perception in the United States that high yields and intensive management imply short rotations is not necessarily true. On the contrary, long rotations have long been associated with very intensive management regimes in some European countries.

Possible advantages of extended rotations include:

- Reduced land area in regeneration and early development stages, hence:
  - reduced visual impacts
  - reduced frequency of major site disturbance
  - less need for herbicides, slash disposal, etc.
  - lower (less frequent) regeneration and respacing costs
- Larger trees and higher value wood
- Opportunity to adjust present age distributions for better balance and a greater range in ages across landscapes, and to develop multistoried stand structures
- Higher quality wildlife habitat for some species and enhancement of biodiversity
- Hydrological and possible long-term site productivity benefits
- Increased carbon storage associated with larger growing stock
- Preservation of options for future management changes

Maximum long-term volume production is attained when stands are grown to the age of culmination of MAI. The MAI curve is relatively flat in the vicinity of culmination age, systematic thinning will probably delay culmination, and there is a considerable range of possible rotation ages that will produce approximately the same MAI (fig. 33). Moderate extension of rotations over those common at present would not decrease long-term volume production (Curtis 1992, 1994, 1995; Curtis and Marshall 1993), might well increase value production, and would certainly increase aesthetic and some wildlife and biodiversity values.

Age of culmination of MAI is the minimum harvest age specified for National Forest lands under the National Forest Management Act of 1976. (In application, the age corresponding to 95 percent of estimated maximum MAI is usually taken as a minimum.) Subject to this constraint, actual harvest ages are determined by a combination of even-flow constraints on harvests; age class distribution constraints; existing stocking and growth rates; and economic, environmental, and political considerations. One

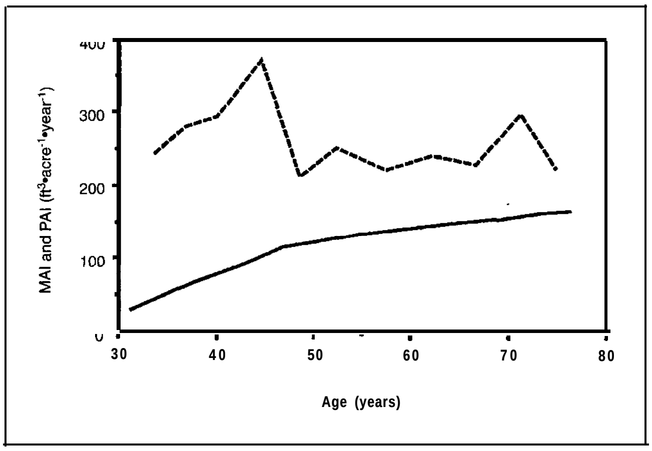

Figure 33-Systematically thinned stands often maintain rapid growth well beyond the culmination age indicated in old normal yield tables, as shown by mean values from four repeatedly thinned plots at Cowichan Lake, British Columbia. Culmination of mean annual increment (solid line) has not been reached at age 76 (Curtis 1995).

difficulty is that culmination age is not a fixed known quantity. It is influenced by management regime, and within regimes, there are substantial differences among available estimates.

The conventional economic argument based on maximizing the discounted monetary value of all future costs and returns gives great weight to near-term income and negligible weight to long-term societal values (Overton and Hunt 1974). The most common and simplistic analyses have major shortcomings. Employment, wildlife, water, fish, biodiversity and amenity values, which usually do not provide revenue to the landowner, often are ignored. Expression of many of these values in monetary terms is imprecise at best, and impossible for some. Yet, public policy considerations demand maintaining productivity of all values and avoiding actions with unacceptable effects on social values. Public desires for nontimber values have become dominant influences on management of Forest Service and some other public lands. And, public perceptions are strongly influenced by the visual impact of management regimes and are a major driving force behind costly and increasing regulatory constraints and pressures for land withdrawals for special uses.

Rotations are strongly influenced by financial and supply considerations and owner objectives as well as by biology, and rotations of maximum MAI in volume or in value are probably not appropriate for many private owners. Unpredictable damage by wind, fire, insects, disease, or current stand conditions will always make early harvest of some stands advisable (Harrington and Knapp 1994). Continuation of the recent trend toward very short rotations on many non-Federal lands, however, likely will lead to sharply reduced productivity compared to potential, restricted future management options, reduced nontimber benefits, and exacerbation of antiforestry attitudes among major segments of the public.

Wood Supply, Cash Flows, and Distribution of Stand Ages and Conditions

A “desirable” or “optimum” rotation represents a long-term goal, rather than a measure that can be immediately implemented everywhere. Change must be gradual because of constraints of existing age class distributions, economic demand and supply, and public and political pressures. Extending rotations could ultimately increase wood supplies as well as the associated nontimber forest values. Unfortunately, both extension of rotations and some recent changes in harvest practices also imply temporary reductions in harvest volumes and (probably) increased operating costs. An immediate practical problem is the need to maintain some acceptable level of wood supplies and cash flows (which are generated primarily from timber) during any transition period.

This need is critical for private and industrial ownerships, and should not be ignored by public agencies. Legislative bodies may be reluctant to fund large-scale land management programs over extended periods to promote intangible benefits, in the absence of concurrent revenues. Programs based on silvicultural regimes that truly integrate production of timber and nontimber values and produce substantial current revenues along with nonmonetary values seem much more likely to survive and prosper.

Increased thinning can help to maintain wood supply and cash flow during any transition period. Silvicultural regimes might be selected to maximize yields from thinnings even though they may result in some reduction in yields at final harvest. A number of examples (Curtis 1995) suggest that thinning regimes can be designed that combine high intermediate yields and relatively infrequent entries with development of stands acceptable for both timber and nontimber objectives.

Balanced age distributions (i.e., a "regulated forest") have traditionally been a long-term goal of forest management, motivated primarily by the desire for stable wood supplies and cash flows. Balanced stand condition distributions also have an important role in promoting nontimber values (Oliver 1992). Distributions of stand ages and of stand conditions are not the same thing, although obviously related; stand conditions are jointly determined by age, management regime, and site. Stands cannot be maintained in any given condition indefinitely. Given a mix of different silvicultural regimes and differences in objectives among owners, we do not necessarily need equal areas in all age classes. But if we wish to have a given stand condition represented in the future, we must provide for future replacement of the stands now in that condition. Stand condition or stand age distributions that are in some sense balanced on local or landscape scales provide a range of seral stages and stand conditions and a variety of wildlife habitats and are an essential part of long-term sustainability of both commodity and noncommodity values. Landscapes dominated by a single developmental stage (sometimes visually monotonous or unattractive or otherwise undesirable for some values) thereby would be avoided and some impacts related to human and natural disturbances would be lessened.

Existing stand age distributions are quite unbalanced, on both regional and local scales (Adams and others 1992, Sessions and others 1990). Figure 34 shows the regional distribution of age classes for (1) all ownerships combined; and for (2) National Forests and (3) industrial ownerships, which are the two ownership categories with the greatest differences in age distributions. Overall age distributions of nonindustrial private owners and other public agencies (primarily states) appear fairly well balanced to about age 80 but contain few older stands.

On a regional scale, age distributions within National Forest lands appear reasonably well balanced for production of multiple values and preservation of future management flexibility. In contrast, that for industry lands is quite narrow and severely limits options available to owners (Haynes and others 1995). Regional totals such as those for National Forests, however, mask major differences among Forests and among watersheds or other localized areas within Forests, which reflect differences in fire history

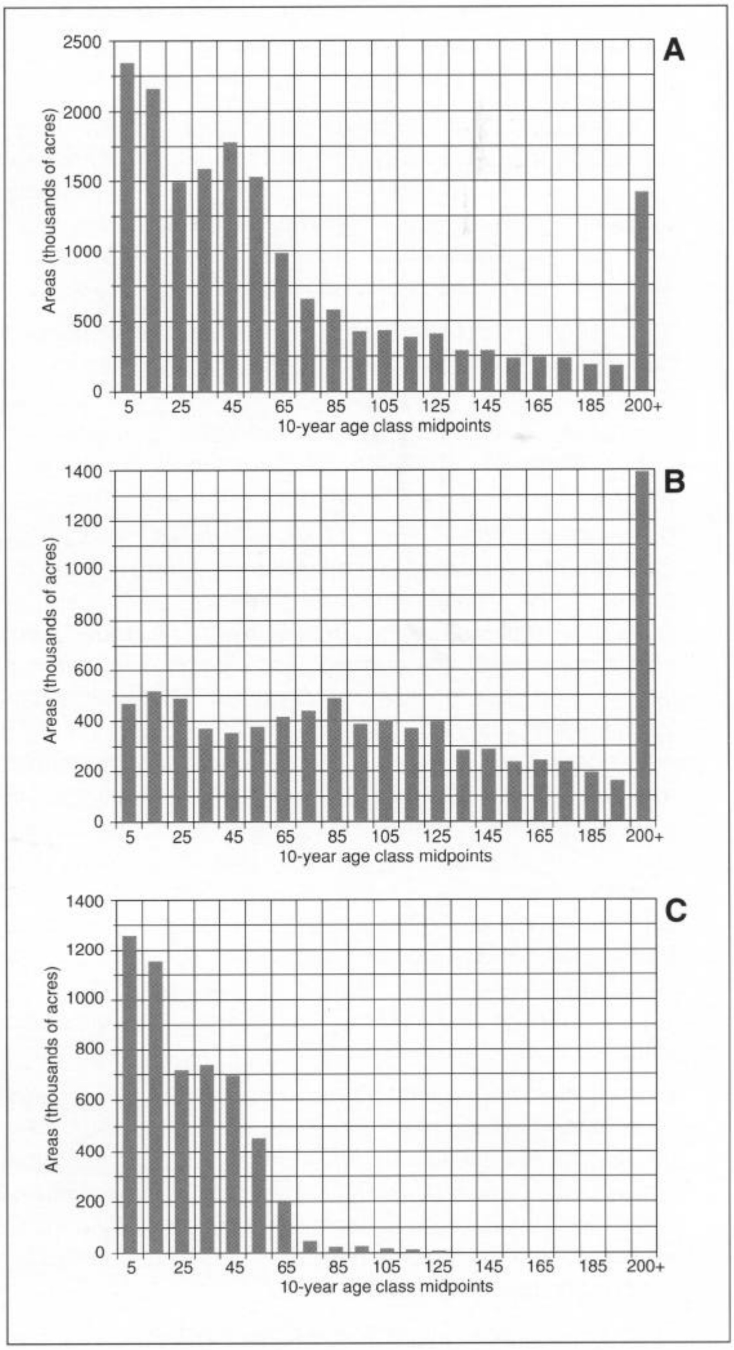

Figure 34—Overall distribution of ages class in western Washington and Oregon for (A) all ownerships, (B) National Forests, and (C) industrial ownerships.

and harvesting history. And, because of the delays involved in the inventory process, the figures shown (derived from Bolsinger and others 1997 and unpublished data[1]) do not include changes arising from accelerated harvesting on industrial lands (and other private, not shown) following the near-cessation of harvests from National Forest lands in 1992. The narrow range in ages on industrial lands and the continuing reduction in harvest ages imply that large blocks of land are and will continue to be devoid of stands older than about 45 to 50 years. Development of stand age or stand condition distributions that are more nearly balanced on watershed or other local scales will require that some stands be carried to advanced ages and some others be harvested at ages substantially less than might otherwise be desirable (which also aids in meeting the short-term timber supply problem). Spatial distributions and total areas involved are both important.

Efforts to create a wider range in ages and stand conditions and more balanced age and spatial distributions are likely to be severely hampered by the current near-elimination of timber harvests from Federal lands. Indeed, current policies are having an effect directly counter to that intended. The scramble for timber supplies following the near-cessation of harvests from Federal lands has produced sharply accelerated and excessive cutting of immature stands on private lands. This cannot be continued for long and will result in decreased future production and degradation of environmental values that will last for decades. Conversely, stable supplies of Federal timber at some reasonable and predictable level would reduce pressures for immediate harvest on private lands and thereby could help in achieving improved management of the region's forests for both commodity and noncommodity values. There is precedent for some form of cooperative harvest planning-though in a different context-in the Sustained Yield Forest Management Act of 1944 (Dana 1956, p. 284).

Special Forest Products

Harvesting of special forest products (floral greens, Christmas trees and boughs, berries, mushrooms, bark for medicinal purposes, moss, shrubs, plants for landscaping) is becoming a substantial revenue source and involves a number of scientific and management questions (Molina and others 1997). Management practices can either promote or degrade productivity of these values. Information on the effects of repeated harvesting of these products and specific measures to promote their production is quite limited, but common sense indicates that harvesting of some of these must be controlled to be sustainable. It has been shown, for example, that repeated harvesting of swordfern fronds reduces frond length and plant survival considerably (Isaac 1945). Anecdotal information suggests that repeated harvesting of mushrooms and some harvesting practices may reduce future crops; studies are underway on this topic (Amaranthus and Pilz 1996). Stand density control has obvious effects on productivity of species such as salal and huckleberry *(Vaccinium* ssp.). Production of Christmas trees and boughs from young true fir stands often enables managers to turn needed spacing and pruning into revenue-producing operations (Murray and Crawford 1981).

Summary, Harvesting Considerations

Harvest operations that take place at the time of removal and regeneration in even-aged management (or in each cutting cycle in uneven-aged management) are the major source of both user conflicts and revenues that support management of most

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[1] Data for western Oregon provided by Tim Swedberg, Pacific Northwest Research Station, Portland, OR, April 25, 1997; and by John Teply, USDA Forest Service, Pacific Northwest Region, Portland, OR, May 7, 1997. On file with: Forestry Sciences Laboratory, 3625-93d Avenue SW, Olympia, WA 98512.

forest benefits. They have a profound effect on the nature and development of stands and forests. Appropriate methods must be used to attain desired objectives.

- Regeneration harvests are conventionally classified into a number of silvicultural systems or methods, discussed at length in standard texts. These are not rigid procedures, but segments of a continuum of possible actions. Selection and application of harvest methods depend primarily on characteristics of the specific stand and site, tempered with public relations and environmental considerations. No one system should be applied everywhere.

- Rotation length affects forest productivity for all values. Extension of rotations beyond ages now in common use would have important benefits for some values. Reduced frequency and extent of regeneration harvests would benefit aesthetic, fish, and watershed values. The older stands would include stand structures more favorable to some wildlife. Extended rotations would provide more flexibility to respond to future changes. They might also give greater long-term wood production and employment.

- Rotation choices involve important economic and policy considerations. Choices will be different for different owners and owner objectives. The need to maintain some stability in wood supply and cash flows is an important limitation on the rate and magnitude of changes in rotations and management regimes.

- Stand age and stand condition distributions are important in long-term sustainability. No stand condition can be maintained indefinitely. Provision must be made for continuous replacement of stands over whatever range of stand ages, stand conditions, and spatial distribution is considered desirable for owner and societal objectives.

- Special forest products (commodities such as floral greens, boughs, berries, Christmas trees, mushrooms) have become important and in some cases provide substantial revenues. Special forest products create additional opportunities but may require some management modifications.

Providing Diverse Structures and Habitats

Forest management goals are commonly expressed as desired forest conditions. The characteristics of individual stands as well as broad landscapes strongly influence attainment of management goals and the choice of appropriate silvicultural measures. Stands can be described in terms of structure, species composition, and site quality. Stand structure includes the dimensions and vertical and horizontal arrangement of trees, shrubs, herbs, grasses, nonvascular plants, and also snags, down logs, forest floor depth, etc. Species composition describes the variety or relative species richness of plants present within a given stand. Site quality integrates a combination of factors (soil physical characteristics, soil fertility, climatic conditions) that affect potential stand growth. Recent work suggests that increased diversity in structure and composition, within and between stands, will enhance some wildlife habitat, biodiversity and aesthetic goals (Carey and Curtis 1996; Carey and Johnson 1995; Carey and others 1996a, 1996b).

Biological diversity has several aspects. These include the number (richness) and relative abundance (evenness) of species present in a given stand; the variation in species and their abundance among stands and across landscapes; the variation in presence and structure of canopy layers, within and between stands and across landscapes; and the genetic variation among individuals within a species. Stand structure and composition change over time as stands develop. Different wildlife species tend to be associated with different stand conditions. Thus, landscapes that include substantial areas in early successional stages favor deer, elk, and berries; those with substantial areas in late successional stages favor spotted owls (Strix occidentalis). It follows that to provide and maintain habitat for a wide variety of species, a balanced distribution of stand structures and developmental stages needs to be developed across landscapes (Oliver 1992).

Because forests are dynamic entities, this implies active management to produce desired structures and regenerate stands as needed to maintain the desired age and stand condition distributions. The biggest current imbalance is the general lack of mature and old-growth stands on non-Federal lands. The recent establishment of large late-successional reserves will, if long continued, produce a similar shortage of early successional stages on Federal lands in the future. These imbalances will not be mutually compensating because of wide geographic separation.

Much recent discussion of biodiversity has focused on old-growth stands and on efforts to shape younger stands toward similar conditions, although this represents only one segment of the needed range in stand conditions. This emphasis on old growth probably arises from the perception that this is the condition in most limited supply and most difficult to replace if lost.

Forest characteristics important for some wildlife and aesthetic values do include some characteristics commonly associated with mature and old-growth stands: (1) large trees; (2) layered structure including some understory trees and shrubs; (3) mixed species composition; (4) presence of large snags and live trees with cavities or other attributes needed for nesting, roosting, and foraging; (5) presence of large woody debris on the forest floor; and (6) within-stand variation in overstory density and corresponding variation in density of the understory. Although these characteristics commonly develop at advanced ages in unmanaged stands, there is abundant evidence that their development can be markedly accelerated in much younger stands by appropriate silvicultural measures (e.g., table 1; Curtis and Carey 1996). Currently heavily stocked young stands may not develop these characteristics without silvicultural treatment (Tappeiner and others 1997). Many of these measures also can produce direct economic benefits through the concomitant production of wood.

Composition and structure of forest stands can be markedly altered by silvicultural practices applied at appropriate stages in stand development. Some examples of such practices have been mentioned previously. Below, we further discuss (at risk of some repetition) practices that can be used to increase the range and diversity of stand structures and to promote wildlife and other nontimber values. Practices must be evaluated for each site, in relation to management objectives, stand characteristics, cost, and safety considerations. If practices are properly applied, inherent site quality can be maintained indefinitely.

Table I-Measures for producing diverse structures and habitats

At harvest	At stand establishment	Young to mid-age stands
Use long rotations	Plant with mixed species, irregular spacing	Thin to produce large trees with deep crowns and to promote understory development
Use advance regeneration, group selection, group shelterwood, strip shelterwood small patch cuts (1-10 acres)	Thin to variable densities within same stand	Thin to variable densities within stand
Save advance regeneration	Encourage natural seedlings within plantations	Release advance tree and shrub regeneration
Retain snags and down logs	Save patches of hardwoods and shrubs to increase future stand variability	Retain existing snags and down logs when thinning
Retain green trees, groups or singly	Leave portions of stand undisturbed by site preparation or slash disposal	Make additional snags and down logs where needed
Work toward balanced age distribution on landscape level		Underplant where natural understory regeneration is lacking

Species Mixtures

Mixed species planting with suitable density control can produce multilayered stands because of differential species growth patterns and differential browsing by herbivores. For example, Douglas-fir and western redcedar planted together may form stands with multiple layers, because the redcedar generally grows slower than Douglas-fir, is more susceptible to browsing, and its shade tolerance allows survival in the understory. Subsequent thinning may be needed to maintain the slower growing species in the understory. Natural regeneration of hemlock and other tolerant species often is abundant in young Douglas-fir plantations, and retention of some stems of these species during precommercial thinning will favor development of mixed stands and layered structures. Differences in species susceptibility also may make such mixed species stands less susceptible to damage from root rots.

Douglas-fir plantations often quickly develop a considerable component of other conifers and hardwoods. Good stems of species such as western hemlock and western redcedar, and occasional hardwoods such as bigleaf maple, can be retained in precommercial and later thinnings to enhance species and structural diversity of the future stand.

Stand Management for Structural Diversity

Modifications of conventional thinning practice (table 1) might include favoring trees of diverse species and sizes to foster crown stratification and understory development for improved wildlife habitat (Hagar and others 1996). Small openings or gaps can be created, which ultimately will be occupied by younger trees. Root rots, bark beetles, and windthrow often do this independent of human intervention. As stands grow older, dead trees can be retained to provide snags needed for some wildlife species; if needed, additional snags can be created. Tolerant tree species such as western redcedar, grand fir, Pacific yew, western hemlock, and bigleaf maple can be introduced through underplanting, if seed sources of these species are lacking. Most species are more tolerant when young, and conditions suitable at establishment may have to be altered as plants age. Regeneration in riparian areas can be especially challenging; these sites often have substantial existing understory vegetation, and animal damage to young trees may be severe.

Modifications such as irregular thinning and underplanting are being evaluated in the forest ecosystem study recently installed at Fort Lewis, WA (Carey 1993, Carey and others 1996b), the Olympic habitat development study (Harrington and Carey 1994), and the COPE (Coastal Oregon Productivity Enhancement) program (Emmingham 1996). Thinning prescriptions in these studies are designed to increase within-stand variation in crown lengths, tree size, species composition, and understory distribution. Although large-diameter trees are a desired component of these stands, the thinnings are designed to promote increases in spatial heterogeneity and in the other structural attributes found in natural stands. This contrasts with conventional uniform thinning prescriptions, which produce more evenly spaced, large-diameter trees with more even understory distribution. As stands grow older, some trees will die and provide snags needed for some wildlife species. Other cavity trees will form as a result of damage from wind, snow and ice breakage, and thinning injuries. If needed, managers can provide additional cavity trees by killing, wounding, or topping some trees.

There are many well-stocked young stands (10 to 50+ years) in the Douglas-fir region that have been established after fire or timber harvest. About 30 to 60 percent of many watersheds on Federal land, and a majority of private lands, are stocked with these young stands. For the most part, they have been regenerated and managed at high densities to produce high yields of wood, and not to develop diverse structure. In contrast, old-growth stands often have only 10 to 30 trees per acre in the upper canopy (Spies and Franklin 1991). Thus, if we wish to develop future old-growth-like characteristics in some portion of these young stands, considerable reduction in stocking over time is needed to produce large trees with deep crowns and provide a more open environment for understory development. Seedlings of tolerant species can be established after thinning in young conifer stands, but subsequent reduction in canopy density will be needed to ensure their future development.

Thinning and regulation of overstory density can be used to produce large trees quickly, develop stand structure, and generally aid the development of mature forest and old-growth-like characteristics (Curtis and Marshall 1993, Newton and Cole 1987, Hayes et al. 1997). Advance regeneration can be released to produce multiple layers. There often are numerous hardwood seedlings and conifers (Fried and others 1988, Tappeiner and McDonald 1984) in the understory that will respond to a reduction in overstory density. In dense stands with no tree understory, the increased light and limited soil disturbance from thinning favor establishment of both conifer seedlings (Del Rio and Berg 1979) and hardwood seedlings (Fried and others 1988, Tappeiner and others 1986). In a western Oregon study that compared understory characteristics in thinned and unthinned Douglas-fir stands, one of the most striking differences between the stands was the stocking of natural conifer seedlings in the understory of the thinned stand (Bailey 1996). Additional thinning to mimic natural stand development could release conifers and hardwoods and leave the overstory at variable densities to encourage "patchy" understory development, but this also would cause considerable damage to the existing understory.

Shade-tolerant conifers can be planted in the understory after thinning to develop multilayered stands, with some of the characteristics that are found in naturally developed stands of much greater age and that are considered favorable to some wildlife species. Thus, Alan Berg of Oregon State University thinned a 40-year-old Douglas-fir stand to 50 trees per acre and planted western hemlock in the understory. About 40 years later, this is a well-developed two-storied stand (Curtis and Marshall 1993). At 80 years of age, the overstory of 50 trees per acre is probably too dense for continued understory growth, although the overstory trees are still growing rapidly. Average diameter of the Douglas-fir overstory is about 30 inches. In the nearby unthinned stand, average diameter is only 15 inches with practically no understory.

Pure red alder stands are common in riparian areas, especially in coastal forests. But, some conifer component is often desirable in these areas to provide large logs for stream channnel structure and to produce a more diverse forest for wildlife. Emmingham and others (1989) successfully planted western hemlock under thinned red alder stands. Both overstory density reduction and long-term salmonberry control were needed to establish hemlock. Elk (Cervus elaphus) and beaver *(Castor canadensis)* have caused major damage to planted seedlings on similar sites. Chance of seedling establishment is increased by using large planting stock and planting large areas at a time, to reduce animal damage (discussed in a later section). Where advance conifer regeneration is present under red alder, it can be released to grow large conifers. Newton and others (1996) discuss problems and applicable techniques.

Use of Advance Reproduction

Current methods of planting and tending young stands can be altered to produce stands of diverse structures and species composition after fire, clearcutting, or other disturbance. Retaining poles, saplings, and seedlings of acceptable vigor and form from the previous stand will accelerate the regeneration of the next stand and tend to encourage development of more "patchy" stands and a variety of tree sizes and species (Tesch and Korpela 1993). Such use of advance reproduction is most promising on the drier sites and in the mixed species stands common in southwestern Oregon. On the better sites and in the northern part of the region, advance regeneration is likely to be of tolerant species (hemlock, true firs) that are highly susceptible to rot entering through logging wounds, and early removal of damaged trees may be needed.

Shrub and Hardwood Management

Managing competition of shrubs, herbs and hardwoods at the time of regeneration will affect species composition, structure, and subsequent development of the future stand. The models developed by Harrington and others (1991 a, 1991 b) for tanoak and Pacific madrone and by Knowe and others (1995) for bigleaf maple estimate the amount of cover produced by sprouting hardwoods, the effects on conifer survival and growth rates, and effects on stocking of understory shrubs and herbs. Use of such models will help forest managers forecast the development and influence of hardwoods during early stages of stand establishment.

Shade-tolerant hardwoods such as bigleaf maple and tanoak will provide a layered stand as they are overtopped by conifers at about 40 to 50 years of age. Large overtopped hardwoods provide cavities as large branches die and decay. California black oak *(Quercus kelloggii* Newb.) and Pacific madrone are more likely to be shaded out by overtopping conifers. They can be maintained in well-stocked older conifer stands by growing them in groups and thinning adjacent conifers. Hardwoods provide important structural diversity and diverse food sources (seeds and nuts) for wildlife.

Thinning favors regeneration of shrub understories under established stands. These understories can be beneficial from a wildlife standpoint but also can be a major obstacle to future regeneration of tree species. Salal (Huffman and others 1994) and salmonberry (Tappeiner and others 1991) commonly increase with reduction of overstory density through rhizome extension and other means of vegetative expansion. Vine maple clones are spread by "layering" as a result of thinning. Slash from natural disturbance of the overstory or from commercial thinning may pin the vine maple crowns to the forest floor where the branches often root and form a dense understory of new sprouts (O'Dea and others 1995). Establishment of salal, vine maple, and salmonberry seedlings is also favored by thinning, but their expansion and development of a dense cover is mainly by vegetative clonal expansion. (Huffman and others 1994, Tappeiner and Zasada 1993, Tappeiner and others 1991). Thus, dense, continuous understories of these and other shrub species can develop after heavy thinning or partial removal of the overstory. Because of the potential for rapid vegetative expansion of shrubs, there may be a relatively "narrow" window for establishment of new conifer plants by natural seeding or by planting, and vegetation control measures also may be necessary. Composition and severity of shrub competition are strongly influenced by differences in site and canopy density (Klinka and others 1996) and by stand history.

Providing Cavities, Snags, and Coarse Woody Debris

In stands managed for wood production, decadent, dying, and dead trees have been viewed as problems to be avoided or at least minimized by harvesting before they deteriorate or contribute to spread of insect pests and disease. Thus, spacing guidelines are based on the number of trees that can be grown to some desired size before significant competition-induced mortality occurs. Trees killed by insects, diseases, and fire usually have been salvaged immediately where economics and accessibility permit. Until recently, existing snags were commonly felled for fire hazard reduction and worker safety. Debris from harvesting operations often was burned to reduce fire hazard, facilitate planting, and control shrub competition. Yet dying, dead, and down trees are important components of forest ecosystems, and a variety of organisms are associated with them. These organisms range from cavity-dwellers like squirrels and other small mammals and many birds, to amphibians and invertebrates, to diverse vascular **and** nonvascular plants and microorganisms. Provision therefore should be made for dead wood management in multipurpose forests, particularly those where conservation of biodiversity is a primary management objective. Low-value tops, defective logs, and

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