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Trends in Ecosystem Management at the Stand Level

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Introduction

One often hears that we are in or on the verge of a ''New Forestry'' in which the philosophy, perspectives and practices of forestry become more ecologically and socially sensitive (Gillis 1990). Actually, forest management has always been in a state of change—the term ''new forestry'' was first proposed in the early 1900s to describe practices of German plantation forestry that were become popular in England and parts of North America (Simpson 1990 *in* Savill and Evans 1986). Over the last century, human use of forest has often developed along two divergent lines: plantation forests primarily for timber production, and wilderness and reserve forests for recreation and other social and ecological values. However, as forest values have increased and diversified on a fixed or declining forest land base, it has become clear that dividing up the forest into plantations and preservations may not be the best way to provide for the diversity of human needs associated with forests (Franklin 1989). Consequently, a third more-recent perspective has developed, termed ''ecosystem management,'' in which forests are viewed as more than timber crops, and forest preserves are viewed as only one part of the solution to the problem of maintaining biological diversity and aesthetic values in managed forest landscapes which provide many values.

In this paper, we will provide a concept of ecosystem management as it applies to forest stands, identify some major trends and give some examples of new approaches either being planned or currently implemented. Our scope will be coniferous forests of northwestern North America, including British Columbia, Washington, Oregon and California.

Ecosystem Management Concepts

The ecosystem concept (Tansley 1935) has existed for over 50 years, and the idea that forests should be managed as ecosystems has been around for at least 20 years

(Van Dyne 1969). Many managers, scientists and the public recognize that forests should be managed as ecosystems, with outputs and conditions measured by descriptors such as soil, plant and animal productivity, diversity, and a broad range of products and values, including timber, fish and wildlife, as well as water quality, and recreation. However, practice often differs from theory and legislation (Salwasser and Tappiener 1981), and there are a variety of perspectives on what constitutes ecosystem management and how it should be implemented (Graul and Miller 1984, Franklin et al. 1986, Johnson and Agee 1988, Perry 1989). A full discussion of ecosystem management is beyond the scope of this payer. However, we highlight some of the major concepts below.

Complexity

Ecosystems are characterized by a diversity of biological and physical components tied together by a complex set of relationships. When forests are managed primarily for tree crops, relatively few components are considered explicity—often just wood fiber production and soil productivity. In broader ecosystem management many components such as non-game vertebrate and invertebrate species, shrubs and non-woody vegetation, hydrology, aquatic and soil animals and processes, and recreation are to be considered. The relationships among components can be quite complex and characterized by organismic responses, and flows of material and energy that include time lags, cumulative effects and non-linear relationships. The basic challenge of ecosystem management is to consider the broad diversity of components and apply manipulations to organisms and structures in ways that minimize undesirable ecosystem effects.

Ecosystem management can be viewed as manipulation of complex ecological structures including ecosystem structure, habitat structure and stand structure. Ecosystem structure is the kind and variety functional ecosystem components and linkages among them (i.e., foliage, detritivores, herbivores, and energy and nutrient pathways). Habitat structure, in a broad sense, is the kind, size and spatial distribution of live and dead organic matter and physical site conditions that are important for the growth and reproduction of organisms. Stand structure is primarily the kind, size and spatial distribution of live and dead forest vegetation. Obviously, there are overlaps and close relationships among these types of structure. In practice, forest ecosystem managers typically manipulate stand structure to meet management objectives including habitat and ecosystem structure and function.

Spatial Variation

The ecosystem is a ''one size fits all'' concept—an ecosystem can be the inside of a fallen tree or encompass a mountain range or an entire planet, depending on the components of interest. Stands, the traditional focus of forest management, can be viewed as patches of a larger ecosystem and at the same time as an ecosystem comprised of heterogeneous mosaics of finer-scale ecosystems such as fallen logs, canopy gaps and unique soil/topographic features. Where wide-ranging species and broad-scale processes are of interest, management activities at the stand level may be subordinated to conditions of the surrounding landscape.

Management of Change

Change and uncertainty are inherent in ecosystem management. Ecosystems are dynamic and change as a consequence of relatively predictable processes, such as succession and stand development, and less predictable processes, such as wildfire, wind, insect outbreaks and climate change. Since many organisms and processes are adapted to natural disturbances, many ecosystem objectives are achieved through imitation of natural disturbance regimes (Hunter 1990). Ecosystems, at stand and landscape levels, are not equilibrium systems, consequently, long-term sustainability of some or perhaps all of their components will not be possible (Botkin 1990). This means that our desire for a constant flow of products or a constant proportion of ecological conditions must be tempered to allow fluctuations in the ecosystem.

Sources of uncertainty in management include: (1) imperfect knowledge of ecosystem processes and management effects; (2) climate change; (3) management practices that are not implemented as desired; and (4) changing social systems and values. All of these sources of uncertainty require that ecosystem management also be adaptive management (Walters 1986), allowing for corrections through monitoring and feedback to management.

Why Practice Ecosystem Management?

At least three motivations exist to practice ecosystem management: (1) more future options may be kept open, and management forest ecosystems may be more resilient to unexpected changes than when management has a narrower focus; (2) managing for whole systems, subsystems or guilds will be more efficient and realistic than if every individual species or process receives separate attention; and (3) where information is particularly lacking about a particular ecosystem component, natural ecosystems provide a valuable interim model until more specific management practices can be developed.

Stand Management Alternatives to Achieving Ecosystem Objectives: The Case of Old-growth Management

No single stand management practice is adequate to maintain the diversity of patch types and successional pathways that occurred in natural forest landscapes. We illustrate four management alternatives that could be used to create individual old-growth features in younger stands or imitate entire old-growth stand structures (Figure 1). Old-growth is used as an example because it is currently a critical issue in many parts of British Columbia and the United States and influences many current and planned management activities. Our use of old-growth as an example does not mean that management for features or stands is the only ecosystem management objective. However, management for old-growth characteristics does meet a variety of objectives including wildlife habitat, recreation, large-size timber, water quality, stream habitat, and aesthetics.

Old-growth management has often meant identifying old-growth stands to prioritize their cutting or to put them into reserve status. However, where little old-growth exists, as a consequence of natural or human disturbances, it may be desirable to passively or actively manage for old-growth features and stand structures (Nyberg et al. 1987). In managing for stand structure we assume that the relationships to habitat structure and ecosystem structure are at least generally known. Mature and old-growth stands which developed after fire and windthrow can be used as models for the desired structure of managed older stands (Spies and Franklin in press). Several practices could produce old-growth structures and whole stands that imitate old-growth.

Passive or Minimal Management Activity

Plantations or naturally regenerated stands will develop into old-growth given a long enough period of time (Figure 1, alternative I), assuming no intervening disturbances. However, stand structure may not be exactly the same as current old-growth stands (Spies and Franklin 1988a) because of differences in disturbance and stand history. In some cases it may be desirable to manage stands on very long rotations or, perhaps, on "natural" rotations, in which the stand is allowed to grow with minimal intervention and natural disturbances are allowed as long as the current and projected stand conditions are desirable. If disturbances or succession alter the structure of the stand, manipulations could redirect it back toward the desired conditions. Management activities during the life of the stand may include thinning, protection from disturbance, planting or use of prescribed fire to imitate "natural" conditions.

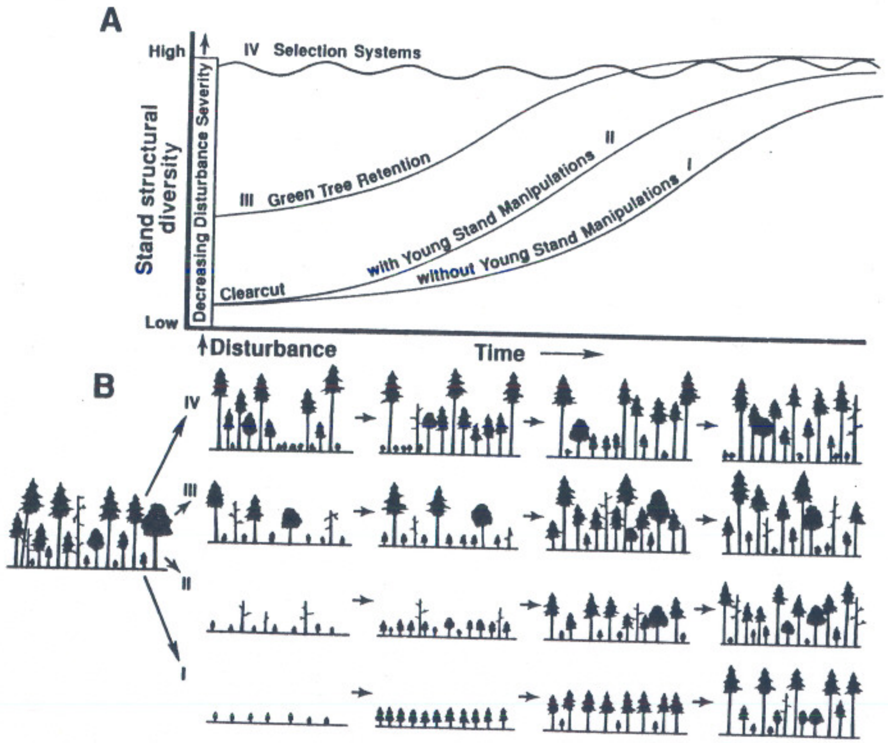

Figure 1. Alternative methods (A) (I–IV) to produce structurally diverse stands (B) that contain individual old-growth features or imitate the structure of natural old-growth stands.

Diversifying Young and Mature Stands

Several sivicultural activities can accelerate the development of old-growth characteristics in young stands (Figure 1, alternative II). Planting density, precommercial thinning and vegetation control early in stand development will have a major effect on species composition and structure throughout the life of the stand. Density control will ensure that desired species are not excluded because of competition. It appears that some natural developmental stages can be accelerated or skipped (Ashby 1987) through stand manipulation, and thereby shorten the period of time needed to develop later developmental stages such as old-growth. Precommercial thinning will prevent or delay the stem exclusion stage of succession (Oliver 1981) and prolong early seral species well into the life of a stand. Hardwoods can be grown in groups so that overtopping by conifers will not reduce their vigor or potential mast production. Grouping of hardwoods and thinning conifers to variable spacing will enhance horizontal structure—the patchiness of both trees and shrubs—and vertical structure by their effect on crown diameters and live crown ratios.

Commercial thinning can be used to further direct structural development. It maintains large, live crowns in the overstory and favors establishment and growth of new conifers, shrubs and hardwoods (Fried et al. 1989). Depending on the site, species, age and the presence of root diseases, thinning might increase the likelihood of windthrow. One important effect of judicious commercial thinning will be maintenance of vigorous stands, thus extending rotation length. Western conifers generally grow well at advanced ages, and given proper spacing, can remain productive well-beyond 100 years of age (Newton and Cole 1987). Current growth models also suggest that culmination of mean annual increment of western conifers can be extended by commercial thinning (Curtis et al. 1981, Hester et al. 1990). Thus, commercial thinning as the potential for maintaining a high degree of species diversity, growing large trees and encouraging merchantable wood production at advanced ages—thereby providing some elements of late successional forest ecosystems.

Where windthrow is not a major problem and the terrain is suitable to logging systems, green tree retention (Figure 1, alternative III) can provide timber products and allow old-growth characteristics to redevelop in a shorter period of time than with either of the first two alternatives. Harvest and site preparation practices can be modified to insure that large conifer and hardwood trees, snags, and logs on the forest floor are maintained in order to provide a carry-over of structural components for many decades or even centuries into the future stand(s). The stand will then consist of two or three age/size classes. Several different regimes are possible, ranging from simple long rotations to mixed age, layered stands. Pure or mixed forest stands can be produced by combinations of natural regeneration, planting and saving advanced regeneration.

Uneven-aged Stands

Where the site conditions, current stand structure, and species mix allow, selection systems (Figure 1, alternative IV) can be used to maintain old-growth characteristics. While selection systems have the advantage of maintaining high canopy cover and structural diversity, they may have other disadvantages. For example, fuels and fire management, disease control, and minimizing soil compaction effects may be difficult in these types of stands.

The different management scenarios are all likely to achieve old-growth stand structure given enough time. Some old-growth features can be produced in a relatively short period of time but a complete old-growth stand structure will require considerable time. The alternatives presented in Figure 1 can be applied in different combinations, creating even more options. Alternatives I, II and III (Figure 1) will also provide for some ecosystem objectives related to early successional ecosystems. Implementing these systems, especially green tree retention, will require stand specific analysis of: worker safety; fuels and fire management: logging systems layout; pathogen and insect effects; animal populations; costs; as well as stand development and yield.

Regional Issues and New Approaches

As mentioned above, a difference often exists between theory and practice on the ground. In this section, we briefly survey some current regional issues and trends. We discuss them in the context of five subregions, moving from north to south first within coastal areas and then north to south within interior areas. In all of these subregions many aspects of forest stand management have been partially ecosystem based since the mid-1970s. These are mostly post-harvesting activities, centered on regeneration and site preparation and based on ecosystem or plant association classification such as the biogeoclimatic ecosystem classification of British Columbia (Pojar et al. 1987) and the plant association of U.S. Forest Service land (Franklin 1979). These classifications might serve as a basis for management of ecosystem structure and dynamics.

Coastal Forests of British Columbia

Current harvesting in coastal B.C. forests is almost exclusively clearcutting of old-growth stands. Individual cutting units vary in size from 12–500 acres (5–200 ha) and have been more or less continuous in many areas, with only a short time interval between adjacent cuts. In accordance with Workers Compensation Board regulations, all snags are felled during the harvesting process. A practical way to sidestep these regulations and provide a continuing supply of snags and largely woody debris, would be to leave patches or strips of forest behind in the units.

Management of the remaining old-growth is probably *the* forest management issue in coastal British Columbia. Although old-growth is but a part of the larger issue of biological diversity, the spotlight of public and management concern has been mostly on old-growth (Fraser 1990). The discussion and debate have been based largely on facts and opinions from the northwestern United States, and focused on southwestern British Columbia (Pojar et al. 1990). In that regard, maintenance of coarse woody debris seems to be an issue with many people, but would appear to be a real problem mainly in the drier, low-elevation forests of southwestern B.C., which are ecologically similar to the forest of western Oregon and Washington. Wetter and higher elevation coastal stands often have a superabundance of coarse woody debris as well as thick (> 4–8 inches: 10–20 cm), wet, surface organic layers. Considerable dead wood remains after harvesting old-growth stands—72 tons per acre (161 tonnes/ha) on a typical site in the Coastal Western Hemlock (*Tsuga heterophylla*) zone (Meidinger and Pojar in press). Following broadcast burning 28 tons per acre (63 tonnes/ha) remained, of which 26 tons (59 tonnes) was in size classes greater than 2.8 inches (7 cm) (Douglas 1989). Forest floor depths averaged 4.7 inches (12 cm) prior to the burn and 3.5 inches (9 cm) thereafter.

Public pressure has stimulated some initial, exploratory efforts in partial cutting and alternative silvicultural systems. As part of the provincial Old-Growth Strategy, a Management Practices Subcommittee is (1) defining ecological attributes of old-growth that will be imitated in the managed forest, (2) exploring means by which old-growth attributes and values can be maintained or created in the managed forest, and (3) determining the extent that old-growth attributes are required in the managed forest.

Since 1980, several innovative approaches to wildlife management have been developed through integrated wildlife/forestry research projects, including ecosystem management for deer (*Odocoileus hemionus columbianus*) and elk (*Cervus elaphus*) habitat (Nyberg et al. 1989) and grizzly bear (*Ursus horribilis*) habitat (Hamilton et al. 1986). Although research and management initiatives have focused on high-profile mammal species, ecosystem concepts have been used as a basis for habitat management. For example, in management for deer habitat (Nyberg et al. 1986, Bunnell and Kremsater 1990), young stands are diversified by manipulating stand density and gap size to promote arboreal lichen production and growth of understory vegetation, reduce snow cover, and provide thermal cover.

Coastal Washington, Oregon and Northern California

The major issues and new management activities on federal forests are related to providing semi-natural and late successional stage ecosystems and maintaining the structure and function of streamside ecosystems. Until recently, clearcutting areas of 10–60 acres (4–24 ha) followed by planting, has been the predominant timber management practice on federal lands. On private lands clearcuts are often larger than on Federal lands and rotations are typically 40–60 years.

In the last 10 years, new management objectives on federal lands have included coarse woody debris and diverse stands. Hence, green tree and woody debris retention have become "standard practices" on federal forests and are being tried on some industrial forest lands. Typically, one to five large live green trees are left per acre (2–12/ha) and removal of coarse woody debris following cutting has been reduced. Large snaps are left where safety requirements allow. The green trees add structure to the next stand in the form of live trees, snaps or large fallen trees. Rotations of 70–120 years are planned for these stands, with the intent of leaving some of the plantation trees at the end of the rotation to provide future structural diversity. Some companies are commercially thinning young-growth stands but this practice has not yet been widely implemented. Westside forest typically have well-developed understories of shrubs and hardwoods which generally preclude the establishment of natural, advanced, conifer regeneration on many sites. Also, terrain is generally steep, so management systems have to be relatively simple. Because of these factors, it will be much more difficult to work with complex structures on steep slopes than it will be on the gentler terrain of the drier eastside forests. Helicopter logging may play a greater role in the future especially where wood values are high enough to make the operation cost effective.

Westside forest have millions of acres of well-stocked plantations 5–30+ years of age. Many of them have received early precommercial thinning and are stocked with vigorous trees. They are amendable to developing a variety of stand structures.

Several commercial thinnings beginning at early ages will enable these stands to provide large, full-crowned trees and develop a shrub and hardwood understory while yielding wood products over a long rotation (Staebler 1960). On one site, stands thinned to 50 Douglas-firs (*Pseudotsuga menziesii*) per acre (124/ha) at 40 years of age and planted with western hemlock have produced a well-developed second layer by 70 years. Openings occur naturally in root disease centers and pockets of windthrow which provide snags, woody debris and sites for development of shrubs, and tolerant hardwoods. This type of "small scale" disturbance can be simulated by harvesting trees from small groups (0.5+ acre) and possibly strips. These openings can be regenerated with Douglas-fir, western hemlock and possibly red alder (*Alnus rubra*), bigleaf maple (*Acer macrophyllum*), and tanoak (*Lithocarpus densiflorus*), vine maple (*Acer circinatum*), salmonberry (*Rubus spectabilis*), thimbleberry (*Rubus parviflorus*), salal (*Gaultheria shallon*) and other shrubs, thus adding to structural diversity; shrub and hardwood control will be needed to ensure conifer regeneration.

Where logging occurs near streams, buffer strips are often left to provide woody debris for stream habitat and shading to control stream temperatures. The long-term stability of buffer strips is an area of concern. Eventually, in many streamside stands conifers may have to be planted where natural regeneration is not occurring, which is often the case because of competition from shrubs and hardwoods. In those situations, planting tall seedlings (1–1.5 meters) along with vegetation and rodent control may be required to maintain stand structure and inputs of large wood to the stream.

Central and Northern Interior of British Columbia

Large live trees and snags are an important part of the habitat structure in interior as well as coastal forests. Some 87 animal species use snags for habitat or as a food source in British Columbia. Deciduous trees, such as trembling aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*) and black cottonwood (*Populus trichocarpa*), are used by cavity-nesting birds in interior B.C. forests, more often than conifers (Keisker 1987). This is not the case in coastal old-growth Douglas-fir forests, where conifer snags are the major or only habitat source for cavity nesting species.

The role of large woody debris in northern forest ecosystems is not well understood. There is little doubt that woody debris provides habitat for a variety of forest organisms. Quantities of woody debris and reserves of forest floor organic matter vary considerably within mature forests of spruce (*Picea* spp.), lodgepole pine (*Pinus contorta*) and subalpine fir (*Abies lasiocarpa*) of northern central B.C., depending on climate and local moisture conditions. For example, woody debris averaged 7 cubic yards per acre (13 m^3/ha) on dry sites, 135 cubic yards per acre (255 m^3/ha) on mesic sites and 174 cubic yards per acre (328 m^3/ha) on wet sites on western central B.C. (Lofroth 1991). In addition to the woody debris, forest floor depths average 1.1 inches (3 cm) or 16 tons per acre (36 tonnes/ha), 3.5 inches (9 cm) or 48 tons per acre (108 tons/ha), and 5.9 inches (15 cm) or 90 tons per acre (1980 tons/ha) on dry, average and wet sites, respectively. In contrast, old-growth Douglas-fir forests of western Washington and Oregon average 166 cubic yards (313 m^3/ha) of fallen tree boles (Spies et al. 1988b). In coastal Douglas-fir stands forest floor depths average about less than 1 inch (2 cm) in old-growth forests (Spies and Franklin in press) as a consequence of relatively rapid decomposition and variable-intensity fires.

The issue of retention of coarse woody debris and organic matter reserves, and their role in maintaining long-term site productivity, seems less urgent in subboreal and boreal ecosystems, at least in the present initial harvesting cycle. Not only do the moist cold soils benefit (in terms of tree productivity) from some removal or mixing of the surface organic matter, but also, on most sites, post-harvest residues are substantial, even after broadcast burning. To a certain extent, forest harvesting imitates the natural, stand- destroying disturbance regime of these forests, although logging and slash-burning usually leave little standing and also remove much coarse woody debris and some forest floor from the site, so the long-term effects of present practices are still a concern.

Prior to the early 1970s, most harvesting/regeneration methods in the central and northern interior were either single-tree or group selection, diameter-limit, or strip logging. With changes in sawmilling technology and the establishment of a pulp industry, large-scale clearcutting became the norm by the mid-1970s and currently less than 1 percent of the area harvested is by methods other than clearcutting (Ministry of Forests 1989a). There is renewed interests in earlier methods used prior to clearcutting. They resulting in structurally diverse stands, but often failure to achieve regeneration, resulting in extensive blowdown, and were thought to have increased insect and disease problems. Trails and experiments are just beginning on alternatives to clearcutting that achieve structural diversity and desired regeneration levels, and mitigate against windthrow and pest problems. At an operational level, it is becoming more common for deciduous trees to be left standing in cutting units. Horse logging is increasingly being recommended for environmentally sensitive areas and areas where some level of green tree retention is prescribed. It also is common practice to plant two or more crop trees species and to leave several tree species during early stand tending.

Southern Interior Forests of British Columbia

In the Interior Douglas-fir, Ponderosa Pine (*Pinus ponderosa*), Montane Spruce, and Interior Cedar—Hemlock zones (Meidinger and Pojar in preparation), 15–20 percent of all stands in 1988–1989 were regenerated seedtree, shelterwood or selection methods. Even so, the use of clearcutting increased in the five-year period from 1984–1989, in the face of increasing public opposition to the practice.

Management of old-growth forests is of increasing concern, especially because of their role in wildlife habitat and in water management—an especially important issue in the dry southern interior. Snags as wildlife habitat are also an issue in the interior, especially in the dry forests of the southern interior where snags are a diminishing resource in some forest types (Harcombe 1988).

Partial cutting systems (shelterwood, group selection and single tree selection) are commonly used in the southern Interior and their use is expected to increase, especially in visually sensitive landscapes and where important wildlife habitat is involved (e.g., Armleder et al. 1986). Resource planning guidelines in the south-central interior (Ministry of Forests 1989b) now invoke special considerations for planning zones such as community watersheds, ungulate winter range, riparian ecosystems and lakeshores. The harvesting guidelines for these zones generally call for partial cutting and/or reduced cutting unit size, with additional recommendations for buffer zones and unit shape, pattern and timing.

Interior Forests of Washington, Oregon and Northern California

The mixed-conifer/true fir and pine forests offer a range of possibilities quite different from the Douglas-fir and hemlock forests of the west of the Cascades Mountains. These forests typically occur on drier sites with generally less vigorous components of shrubs and hardwoods. Fire suppression and individual tree logging have resulting in stands with different structure than would have developed under natural disturbance regimes. Often, the natural regeneration is primarily of shade tolerant true firs and Douglas-fir. Insect and pathogen populations are of major importance in managing these forests; they include mountain pine beetle (*Dendroctonus ponderosa*) in pure lodgepole pine, to spruce budworm (*Choristoneura fumiferana*), mistletoe (*Phoradendron* spp), annos root disease (*Fomes annosus*) and larch casebearer (*Coleophora laricella*) in the mixed forests. Here, forests with diverse structure and species composition do not appear to have mitigated against pathogens and insects, although these biological disturbances may be partially related to the structure of the stands. A combination of relatively dry sites, the lack of light ground fire, the resulting increase in stand density, and amount of tolerant species may have contributed to increases insect and pathogen populations.

Silvicultural practices in these stands, especially on federal lands, seem to have embraced many stand-level "New Forestry" concepts for several years. Uneven-aged management, use of advanced regeneration, thinning to reduce susceptibility to bark beetles and maintaining diverse structure are common practices. Probably the biggest challenges will be to determine how to use fire or replicate its natural effects, and how to work with the wide array of pathogens and insects. The recent, large wildfires and clearcuts of the 1970s and early 1980s have created many areas of relatively simple, early successional stands. Perhaps a prescribed fire regime or thinning could be used to set development on a course toward structurally diverse, yet vigorous older stands.

Conclusions

The practice of ecosystems management is continually developing in response to changes in social and economic values, scientific understanding, and management objectives and technology. Silvicultural options are available to create a greater diversity of managed stand ecosystems than is traditionally found in many managed forest landscapes. Providing a greater array of stand types based on structure, composition and disturbance regime can help to meet many different ecosystem objectives. The development of structurally and functionally diverse stands is one of the major new directions in stand management, particularly in moist coastal forests in British Columbia and in Northwestern United States, where short rotation clearcutting has been the dominant timber management activity. Several alternatives exist to create structurally diverse stands in these coastal types, including long rotations, diversified young plantations and green tree retention. Group selection may be an option on some sites.

In cold, moist northerly ecosystems, where decomposition is a limiting factor in autotrophic productivity, soil disturbances from logging and slash burning may actually improve productivity. However, maintaining a diverse stand structure through retention of green trees is still important to maintaining habitat structure.

On drier interior forest types, the traditional silvicultural systems, involving various types of partial cuts have often resulted in relatively diverse forest stands, although clearcutting has become common in some areas. The drier interior types may be ecologically more amendable to development of structurally diverse stands. Future ecosystem management in drier forest types will involve controlling density in stands through thinning and prescribed fire to imitate natural disturbance regimes and maintain more natural stand structure and vigor.

From British Columbia to California, the continuing challenge to ecosystem management is to create variety of ecologically and operationally viable stand structures by implementing silvicultural practices that imitate natural disturbance regimes. This does not mean that we know enough about these disturbance regimes or ecological structure-function relationships to dispense with reserve areas or passively managed "natural rotation" stands. These stands will continue to be important in maintaining biological diversity and ecosystem function in managed landscapes. However, we can apply many of the lessons we are learning from natural ecosystems to managed stands and increase the probability of sustaining ecological values through time.

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