5 The Physical Environment as a Basis for Managing Ecosystems

Frederick J. Swanson, Julia A. Jones, and Gordon E. Grant

The physical environment sets the stage on which ecological phenomena operate. Our understanding of the physical environment, especially disturbances in forest and stream systems, has evolved through time. How we have used what we have learned has changed in tandem with changes in management focus. Early in the 20th century, when resource extraction was preeminent, hydrology and geomorphology were used to support activities such as repair of landslide-damaged roads. In the mid–20th century, environmental concerns grew, expressed in part by a series of laws—the Clean Water Act, the National Environmental Policy Act, the National Forest Management Act, and the Endangered Species Act—which directed public land managers to analyze and disclose the effects of proposed actions and to protect species and ecosystem productivity. Information on the physical environment was used to minimize undesired environmental effects through actions such as surveying proposed road locations to avoid potential landslide sites.

Late in the 20th century, growing concerns about the effects of management actions dispersed over large watersheds (considered under the rubric of cumulative watershed effects) has led to more holistic views of watershed function. Understanding of the physical environment dominates watershed analyses designed to identify and mitigate cumulative watershed effects (Washington Forest Practice Board 1992, FEMAT 1993).

A parallel development during the late 1980s and 1990s has been concern with potential loss of species, especially those associated with old-growth forests. This has led to conservation strategies focused on recovery of forest habitat for wildlife species. Knowledge about the physical environment has played a significant role in conservation strategies for fish species, but less so for terrestrial species.

What will the 21st century bring? We expect understanding of the physical environment to gain a more prominent position in land-use planning, forming the starting point for ecosystem management on public lands. Emphasis will shift from commodity production and single species to sustaining the dynamic ecosystems that support life. Development of the concept of managing within a range of natural variability is a harbinger of this shift. This concept recognizes that ecosystems are naturally very dynamic and subject to periodic disturbances. As such, they have exhibited a range of conditions (e.g., successional states) in the past that resulted in important controls on geographic patterns of disturbances and biotic resources.

The management implication of this perspective is that ecosystem patterns and processes should be managed with adequate similarity to those of the past so that diversity and productivity of assemblages of native species can be maintained in conformance with federal laws governing public forest land where some cutting and active fire management are permitted. Such an approach contrasts with past landscape management, which was largely a de facto consequence of numerous stand-level decisions. In contrast, an approach considering ecosystem dynamics is based on an understanding of landscape history and natural disturbance regimes. It is intended to fit the managed biotic landscape with the natural biological and physical character of landscapes, including disturbance regimes. The rationale is that native species have adapted to the natural disturbance regime over thousands of years. The survival potential of native species would be expected to be reduced if their environment is pushed outside the range of conditions that existed over this time period. Karr and Freemark (1985:167), for example, argue that "disturbance regimes . . . must be protected to preserve associated genetic (Frankel and Soulé 1981), population (Franklin 1980), and assemblage (Karr 1982a, 1982b; Kushlan 1979) dynamics."

Biotic landscapes include the patterns of vegetation patches of various ages and compositions and the fauna that find habitat in such vegetation patterns. Natural biotic patterns reflect, in part, the physical landscape of landforms, climate, and soil patterns. Managed biotic landscapes may be forced into poor fits with physical landscapes, creating biological and social problems. Fire suppression in ecosystems with naturally high fire frequency, for example, has led to fuel buildups that increased fire severity when it occurred. Forest cutting has reduced the extent of old-growth forest conditions, thus reducing habitat for a host of species. On the other hand, efforts to create areas of old-growth forest where it would not naturally occur because of frequent fire, wind, or other disturbances, have either failed or created unnatural habitat patterns. Midslope roads, a notably unnatural feature in landscapes, can contribute to increased peak flows in downstream areas (Wemple 1994, Jones and Grant 1996) and be major sources of debris slides (Sidle et al. 1985).

In this chapter, we consider some implications of the physical environment and ecosystem dynamics in land management. We begin with a brief description of pattern-process relations in landscapes as a basis for managing ecosystems. We follow with a discussion of the history of landscape management in the Pacific Northwest and its relation to our understanding of the physical environment. To conclude, we consider implementation of these concepts in the 21st century.

These perspectives and the examples considered are derived from the Pacific Northwest, an area of strong interactions between biota, physical environment, and instructive pre- and post-settlement land-use histories. Rich vegetation and fire histories can be described, for example, from dendrochronological data (records extending back to 500–800 years before the present), paleoecological data (records extending back to 40,000 years before the present), and satellite remote-sensing data (records extending back to 1972 to the present).

Landscape Patterns and Processes

To see the value of using the physical environment as a basis for ecosystem management, it is necessary to have a conceptual framework. Such a framework considers forest landscapes and riverscapes in terms of a hierarchy of spatial and temporal scales. Questions regarding evolution of landscape patterns in natural and managed systems must be posed and answered at the correct temporal and spatial scale (Delcourt et al. 1983, O'Neill et al. 1986, Gregory et al. 1991). Many terms are useful for identifying scale, depending on subject matter—site, landscape, province, and region are common geographic scales. The specific definition of these terms depends on objectives: A region, for example, may be defined by the ranges of critical species of interest. Many tough environmental problems today are a result of management decisions made at fine spatial scales, which had undesired, aggregated consequences at coarser scales.

Interactions between biotic and physical patterns and processes (Figure 15.1) operate at each scale. Landscape patterns are dynamic as a result of interactions between vegetation succession and disturbance processes. Biotic patterns can take the form of patchworks of vegetation in various stages of development. Vegetation patchworks partly reflect pattern-creating (disturbance) processes and geophysical patterns, such as landform controls on disturbance or variations in soil properties that influence vegetation. Vegetation patterns in natural landscapes include both the indelible imprint of patches created by resource limitations (*sensu* Forman and Godron 1986), such as lack of soil on rock outcrops, and ephemeral patches initiated by biotic disturbances. Landform influences vary between disturbance processes that follow local gravitational flow paths (e.g., landslides, floods) and those that do not

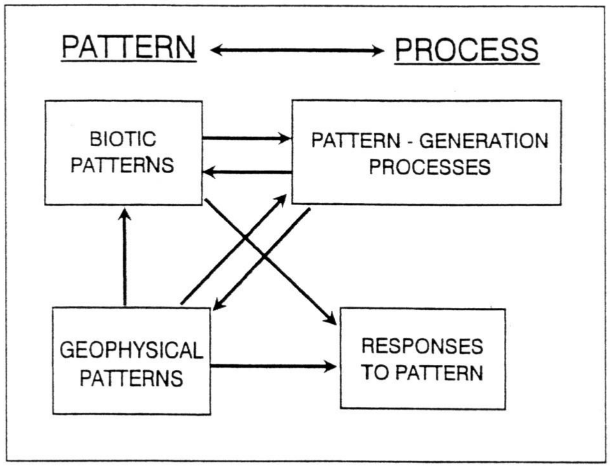


Figure 15.1 Dominant pattern-process relations. Geophysical patterns (e.g., soils, topography) underlie biotic patterns (e.g., vegetation type, productivity) and may influence landscape-related processes. Disturbance processes generate patterns; other processes may simply respond to patterns without modifying existing patterns.

(e.g., wildfire, windthrow). Human activities (e.g., cutting units) may overprint natural patterns, creating intentional or unintentional patterns (e.g., those arising from escaped slash fires). Some processes, such as generation of low streamflows, respond to biotic and landform patterns without creating new landscape patterns.

Landscapes are composed of patchwork and network structures, each with characteristic dynamics and functions. In forest landscape studies, patchwork structures are typically a collection of patches of varied vegetation type and seral stage. Natural network structures include streams, riparian areas, and ridgelines. Some disturbance processes, such as floods and debris flows, propagate through networks, while others, such as wildfire and windthrow, move through patchworks.

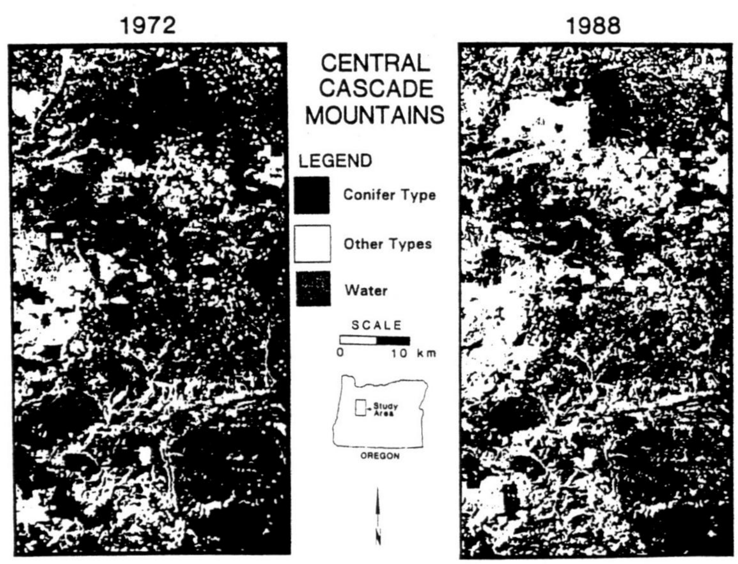
Most landscape ecology studies have examined patchwork structures; few have considered network components of landscapes; and still fewer have dealt with network–patchwork interactions. Understanding interactions between landscape structures of the same or different type is critical to forest and watershed management. Road segments, for example, may follow ridges and large streams (fourth-order and larger). But roads in steep terrain are likely to intersect groundwater flow paths and first- through third-order streams at right angles. This may accentuate the effects of roads in increasing the density of stream channels and thereby the potential of watersheds to generate peak flows (Wemple 1994, Jones and Grant 1996). An extensive network of road ditches and stream flow paths may help to transport increased runoff from clearcut patches (Harr 1981, 1986) to downstream areas where peak flows may be increased (Jones and Grant 1996). Such interactions between network and patchwork structures are significant but often overlooked because of disciplinary instincts; stream ecologists tend to see landscapes as networks, while forest and wildlife ecologists see them as patchworks.

History of Landscape Change in the Pacific Northwest

Postglacial landscape patterns in the Pacific Northwest have developed sequentially through three stages: (1) a wild landscape dominated by natural disturbances and actions of native people, spanning most of the Holocene until the early 1800s; (2) the landscape managed by European settlers through much of the 19th and 20th centuries; and (3) the present period of regional ecological assessments and associated management plans focused on species conservation on public lands. The physical environment dominated ecosystem change in the first stage; human forces attempted to override some influences of the physical environment in the second stage; and the physical environment will be an increasing consideration in management through the present and future.

The transition from the wild landscape of the first stage to the present, managed landscape created during the second stage has occurred over a century of piecemeal land-use decisions. A simple, visual expression of this is revealed in maps of closed-canopy forest and of disturbance patterns (mainly harvest cutting) from 1972 to 1988 in an area of mixed ownership and varied land-use designations in the central Cascade Mountains of Oregon (Figure 15.2) (Spies et al. 1994). Here we see patterns created by

(a)



(b)

Figure 15.2 (a) Maps of closed-canopy conifer (>40 years in age) forest type in 1972 and 1988 for a 259,000-ha study area in the Oregon Cascade Range (from Spies et al. 1994). (b) Land ownership and land-use designations (modified from Spies et al. 1994).

large, aggregated cutting units on private industrial lands cut on approximately 50-year rotations, smaller, dispersed cutting units on public lands where the cutting cycle was 80 to 100 years, and very low levels of disturbance in Wilderness, Research Natural Areas, and other reserves where logging does not occur and fire is suppressed. Note how the reserves and other areas of limited forest cutting emerge as distinctive landscape features over this 16-year period.

Management of landscape patterns on public lands in the Pacific Northwest has changed dramatically in the past few years. After 40 years of dispersed-patch clearcutting, brief consideration was given to more aggregation of cutting units, assuming that the rate of cutting was unlikely to change (Franklin and Forman 1987, Swanson and Franklin 1992). Yet, from the early 1990s, cutting rates have dramatically decreased, and concepts about how we manage landscape patterns have changed. For example, there is growing interest in allowing more wildfire in the wilderness areas, and state regulations are limiting the size of cutting units on private lands. The most profound change will probably be in areas formerly designated as general forest lands of the U.S. Forest Service and Bureau of Land Management. Management in those areas will be altered by the Northwest Forest Plan developed by the Forest Ecosystem Management Assessment Team (FEMAT 1993).

Regional Ecological Assessments

Recently for the first time, broad-scale patterns of forest vegetation in the Pacific Northwest were subject to conscious design. Regional ecological assessments, such as FEMAT (1993), the Columbia River Basin/East-Side Ecosystem Project, and the Sierra Nevada Ecosystem Project, are defining broad templates for ecosystem management on major pieces of public lands in the United States. Some of these assessments derive from legal and other imperatives to conserve threatened and endangered species and old-growth forest ecosystems.

These regional management plans use a variety of land designations to define future patterns of forest development. Existing reserve lands, such as congressionally designated wilderness areas, are combined with new designations to create an interacting network of reserves. Guidance for management of lands between reserves and for designation of riparian corridors is intended to provide dispersal habitat between reserves. In these and other ways, reserves established in the past as independent entities are intended to fit within a larger design to meet ecological objectives. Physical processes and landscape features have minor roles in the design.

The focus on species conservation and the cumulative effects of past ecosystem alterations severely limit opportunities to reintroduce features of natural disturbance regimes in some areas. This is particularly acute in areas characterized by infrequent, stand-replacement wildfire and where management is focused on conserving old-growth forest habitat. Reserve placement and design in the Northwest Forest Plan, for example, are structured to provide old-growth habitat for the northern spotted owl and to accommodate aquatic resources, but with little reference to landscape patterns created by historic, natural disturbance regimes. Under this regional plan, only a small fraction of the forest landscape of public land is subject to cutting—but the forest patterns created on those lands are highly fragmented and unlike natural patterns. Perhaps once certain levels of ecosystem recovery have been achieved, it will be possible to more nearly match management patterns with natural patterns.

In other regions, ecological assessments and plans may provide for a somewhat better fit of managed biotic patterns to patterns controlled by natural disturbance regimes and landforms. Where wildfire was frequent and has been suppressed for several natural fire recurrence intervals (with resulting problems of insect outbreaks and buildup of fuels), there is greater attention to matching management practices with natural disturbance regimes. This may be the case in the Columbia River Basin assessment and plan.

Future Landscape Management

We expect that management of forest and riverine ecosystems in the 21st century, at least on public lands, will depart substantially from earlier and current approaches. These traditional approaches have been based either on site-specific best management practices, which lack long-term, large-scale perspectives, or on the habitat-restoration emphasis of conservation strategies for threatened and endangered species. Emerging new approaches will define a range of desired ecosystem states based on natural states and disturbance regimes interpreted from analysis of past events and controls of climate, landforms, soils, etc., on process location and rates. Hence, management interventions are treated as modifications of the natural disturbance regime. They can be applied at the site or landscape level—the first is most suitable to sustaining productivity and the latter to sustaining elements of the larger ecosystem.

Characterization of landscape dynamics is essential to planning ecosystem management. This can be approached in several complementary ways. One method is to define the range of past ecosystem conditions, such as extent of old-growth forests, early successional habitat, or unstable stream banks (Figure 15.3)(Caraher et al. 1992). A second approach focuses on disturbance processes in terms of the range of frequency, severity, and geographic pattern (such as size distribution) of patches created by these processes before and during periods of intensive forestry management (Figure 15.4)(Swanson et al. 1993). Mapping forest conditions or the extent of individual disturbance events through time can help define either the range of vegetation conditions or the disturbance regime.

An even more useful, spatially explicit characterization can be developed by mapping disturbance regime units across landscapes (Figure 15.5). This is accomplished by interpreting event histories for individual sites and then compiling site histories across a landscape. Disturbance regime patterns are interpreted by considering effects of topography, vegetation type, soil, climate, or other relevant factors that exercise long-term controls on the frequency and severity of disturbance processes.

Mapping units for characterizing wildfire disturbance regimes may describe the frequency and severity of disturbances—such as infrequent, stand-replacement wildfires or 60-year rotation clearcutting on private land holdings of the forest products industry. In some areas, landscapes can be stratified by vegetation types (Barrett and Arno 1991, Agee 1993) to provide a basis for mapping fire regimes. Where vegetation types are not highly differentiated with respect to fire regimes, topography may be more useful in interpreting fire regimes over landscapes. In either case, information on landform effects on fire patterns assists in interpreting long-term landscape

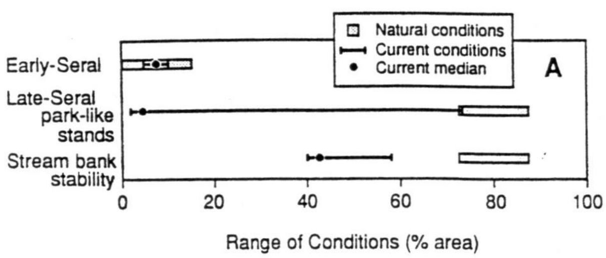


Figure 15.3 Example of range of interpreted natural and present ecosystem conditions for the Silvies River area (from Caraher et al. 1992, p. 22).

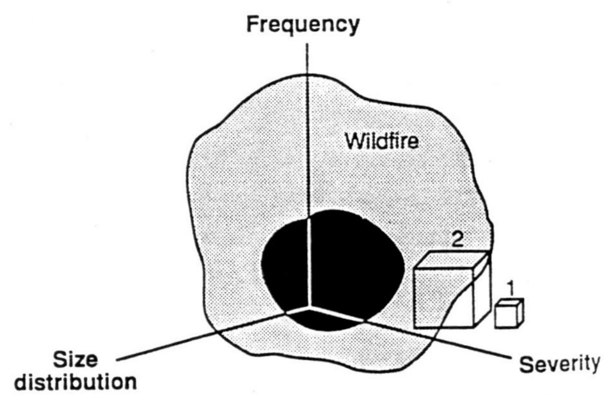


Figure 15.4 Hypothetical representation of a natural disturbance regime as the large, irregular "cloud" showing a probability distribution of wildfire events. Box 1 represents a management system of dispersed clearcuts with broadcast burning, assuming no landscape disturbance by wind or fire. Box 2 represents the disturbance regime resulting from the interaction of the management system (box 1) with disturbance processes that could not be suppressed (e.g., windthrow at stand edges and wildfire). The black area represents a range of conditions resulting from a management system within the range of natural variability, but not a mimic of the full natural range (Swanson et al. 1993).

dynamics beyond the time scale reflected in current vegetation (Figure 15.5).

Disturbance regimes imposed by geomorphic processes are another important aspect of fitting managed biological landscapes with the physical environment. Examples of mapable disturbance regimes include landslide hazards and the potential for lateral change in river channels (Grant and Swanson 1995). Some elements of watershed analysis are designed to provide such information (Washington Forest Practice Board 1992, FEMAT 1993, Montgomery et al. 1995). Information on geomorphic disturbance regimes is used not only to minimize effects of management on accelerated erosion but also to identify parts of the landscape where natural disturbances should not be impeded—such as stream processes that create and maintain secondary channels on wide valley floors.

There are, however, some important challenges to defining natural ranges of variability and disturbance regimes: First, interpretation of past disturbance regimes has limitations. Second, native people influenced fire regimes to varying extents for much or all of the period that the present dominant forest species have been significant components of the flora of the region. And finally, exotic species, such as undesired

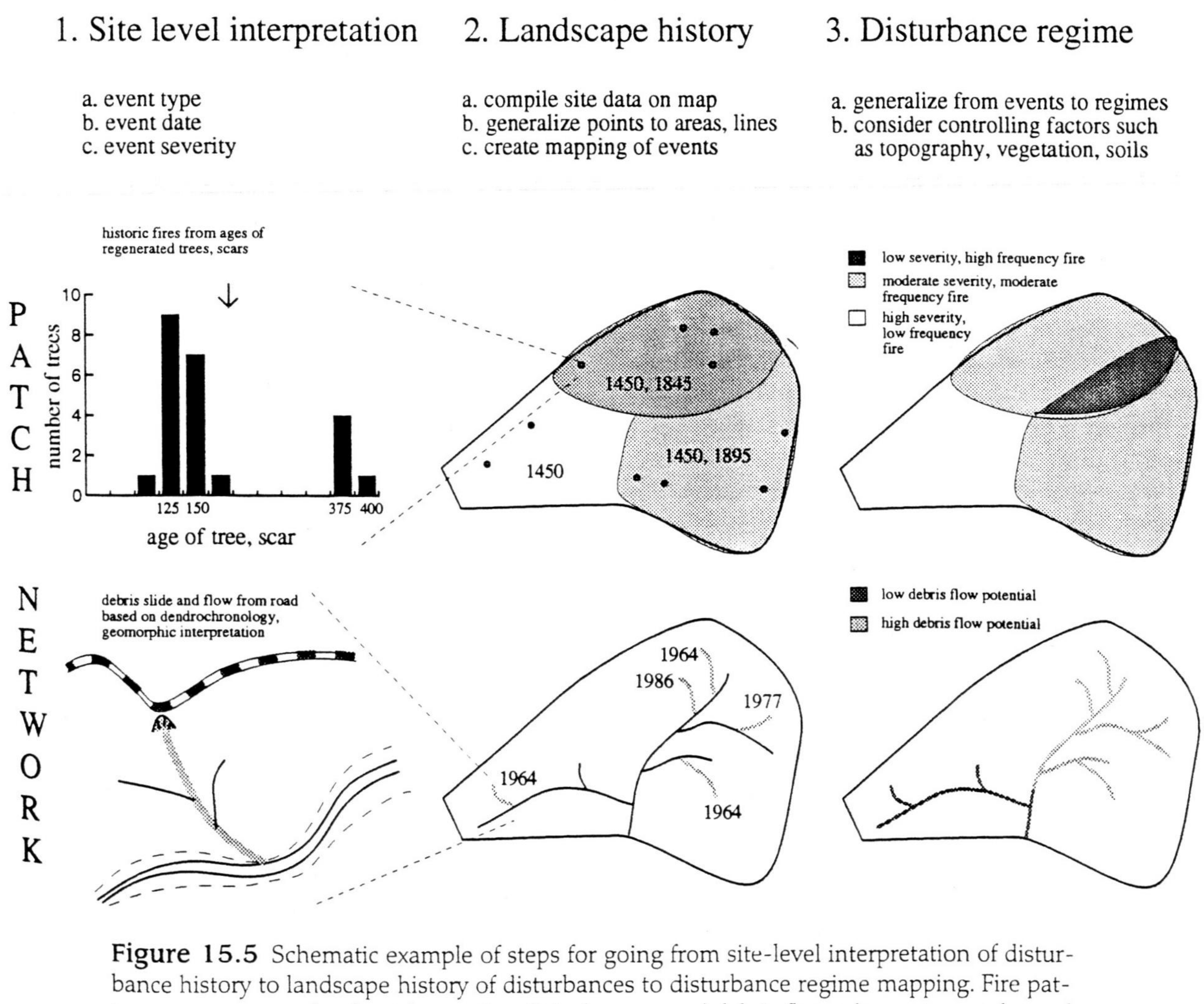


Figure 15.5 Schematic example of steps for going from site-level interpretation of disturbance history to landscape history of disturbances to disturbance regime mapping. Fire patterns are an example of patch-creating disturbances, and debris flows down stream channels are an example of disturbances in networks.

weeds and planted fish stocks, and engineered structures, such as roads and dams, are unnatural parts of the ecosystem that are likely to stay in most cases; hence, they must be accommodated in managing ecosystems at large scales (Swanson et al. 1993). There are concerted efforts to improve understanding of each of these factors. Although some uncertainty surrounds each of these considerations, we believe that the range of natural variability concept for management remains important and viable.

Adopting a management approach based on disturbance regimes has rather different implications in terrestrial habitats of uplands areas than it does in stream and riparian networks. Stream and riparian networks are potentially affected not only by direct local disturbances, but also by disturbances in upland areas that may have effects transported downslope by streamflow and other processes. Furthermore, disturbances that may be limited in uplands areas may have substantial effects on the disturbance regime of stream and riparian networks. Roads, for example, may affect less than 5 percent of uplands, but they may significantly alter the size distribution of peak flow events (Jones and Grant 1996).

These concepts actually can be applied to real landscapes. One example is the Augusta Landscape Project on the Willamette National Forest in Oregon, a test area for ecosystem management planning (Cissel et al. 1994, in preparation, Wallin et al. in press). Planning for this 7,600-hectare area began with mapping disturbance event histories for wildfire, based on dendrochronology (A.D. 1500–1900) and landslides and the use of field and aerial photograph interpretation (1950–1994). To develop maps of disturbance regimes, event histories have been interpreted in light of landform influences on disturbance patterns. This information, combined with information on present landscape conditions and land-use designations, has been used to develop a landscape management plan that sustains aquatic and terrestrial habitat more within the range of historic variation. Moreover, the plan has been modeled for several centuries into the future.

Key features of this disturbance-based Augusta landscape design include variable rotation lengths (100–300 years), varying levels of tree removal at each cutting, and size distribution of cutting units. Selection of silvicultural prescriptions is based on wildfire frequency, severity, and geographic patterns of the past. The range of cutting rotations, levels of live trees retained, and unit sizes are much more variable under this management system than they were under earlier patch clearcut systems or the Northwest Forest Plan.

Approaches to riparian zone management also differ significantly. The Willamette National Forest Plan and the Northwest Forest Plan prescribe streamside buffer strips throughout the stream and riparian network. The Augusta landscape design uses a small number of large reserves to protect aquatic and riparian species. These are connected by wide buffers along only the major channels. Some cutting is permitted within other riparian areas.

The result of the Augusta landscape design is a future landscape with forest habitat patterns more similar to the historic patterns than would be the case under the previous patch clearcut system or the Northwest Forest Plan (Wallin et al. in press, Cissel et al. in preparation). This conclusion has been examined in a variety of respects, including the extent of interior forest habitat in mature and old-growth classes and the density of edge between forest and open areas. Edge density is a useful measure of landscape pattern because it may serve as an index of blowdown potential—that is, freshly exposed forest edges are susceptible to wind damage. Also, some species that favor interior forest habitat, such as northern spotted owls, may be more susceptible to predation in landscapes with higher edge densities. The Augusta landscape design, therefore, has a higher likelihood of sustaining terrestrial and aquatic species.

Conclusions

The use of understanding of the physical environment, including natural disturbance regimes, has evolved through the stages of helping to repair damage to commodity production systems, to minimizing effects of further management, to using the physical environment and ecosystem dynamics as a basis for management design. In the 21st century, we expect land management to better fit the managed biologi cal landscape with the physical landscape and its historic disturbance processes and patterns. The major impetus for doing so is that past poor fits have proven socially untenable; consequences of poor fits include the actual or potential listing of threatened or endangered species as a result of habitat alteration well outside the historic range of conditions.

Prototypes of landscape management designs are being developed that illustrate use of natural disturbance regimes and other aspects of the physical environment to plan ecosystem and watershed management. In some regions, however, the need to provide for habitat recovery following a prolonged period of intensive land use may slow implementation of an ecosystem-based approach to management. This seems to be the case in the range of the northern spotted owl. In areas where landscapes have been strongly influenced by suppression of wildfire, a focus on restoring the disturbance regime through management may be more immediately acceptable.

Viewed from the mid-1990s, it is interesting to consider how difficult changing to a more ecosystem-based approach to management may be. The recent growth of understanding about how ecosystems and watersheds function and the major revamping of natural resource management approaches would seem to set the stage for improving the fit of managed landscapes to natural landscape patterns and functions. However, it may be well into the 21st century before much progress is made. Social changes are critical—such as increased public understanding of the role of disturbances in ecosystems. Changes in policy also are needed to direct planning to regional and watershed scales, rather than restricting it to the scales of projects (e.g., timber sales) and agency management units (e.g., an individual national forest) where cumulative ecological and watershed effects may be obscured.

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Creating a Forestry for the 21st Century

The Science of Ecosystem Management

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Foreword by Jack Ward Thomas

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