#2296

14. From Ecosystem Dynamics to Ecosystem Management

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Understanding how natural disturbance regimes shape forest ecosystems has become a key element of new approaches to forest management. Indeed, many of the conservation and management problems in the temperate rain forests of western North America relate directly to the differences between the management regimes we have imposed on the forests and the natural disturbance regimes that dominated the forests before the arrival of European settlers and industrial development. A variety of recent initiatives in forest policy in both the United States and Canada have emphasized the processes and structural consequences of natural disturbance as models for management (Swanson et al. 1993; Scientific Panel for Sustainable Forest Practices in Clayoquot Sound 1995a). Implementing this approach, however, is limited by our understanding of natural disturbance regimes, by our ability to make direct management recommendations from what we do know, and by constraints imposed by the social context in which forest management takes place.

The current focus on using natural disturbance patterns as models for management in temperate rain forests is part of a much broader shift toward ecosystem-based management regimes in both Canada and the United States. "Ecosystem management" includes more elements of landscapes than forests, however, and many more considerations than natural disturbance regimes. Key dimensions of ecosystem management include the integration of social and ecological data and values and the application of the principles of adaptive management. Nonetheless, understanding the *processes* responsible for shaping temperate rain forests and maintaining their biodiversity in the past is fundamental to successful ecosystem management.

Ecosystem Dynamics

Over the past few decades, the disturbance regimes to which forests are subjected have emerged as key features distinguishing different types of forests around the world. A forest's natural disturbance regime can be defined as the long-term pattern of the frequency, intensity, spatial extent, and heterogeneity of disturbances (Pickett and White 1985). Some forests, such as those of most boreal regions, are characterized by relatively frequent large-scale disturbances that destroy forest stands, resulting in a coarse-grained mosaic in which relatively young, even-aged stands are distributed in large patches. Other forests experience large-scale disturbances only infrequently, resulting in a finer-grained mosaic of older, often uneven-aged, forest patches. Temperate rain forests generally follow this pattern. When major disturbances are separated by long intervals, the forest's structure, the kinds of habitats it provides, and the suite of animals living in it are all affected (Figure 14.1) Temperate rain forests are especially distinguished by their tremendous accumulations of biomass, by the great longevity of canopy dominants (Table 14.1), and by the widespread distribution of late-successional (old-growth) elements over forest landscapes.

A number of general conclusions about the dynamics of temperate rain forests have been drawn from recent research (Table 14.2). Most of these ideas arise from research on a variety of forest types well distributed over the temperate rain forest region and, at least qualitatively, should apply to all forest

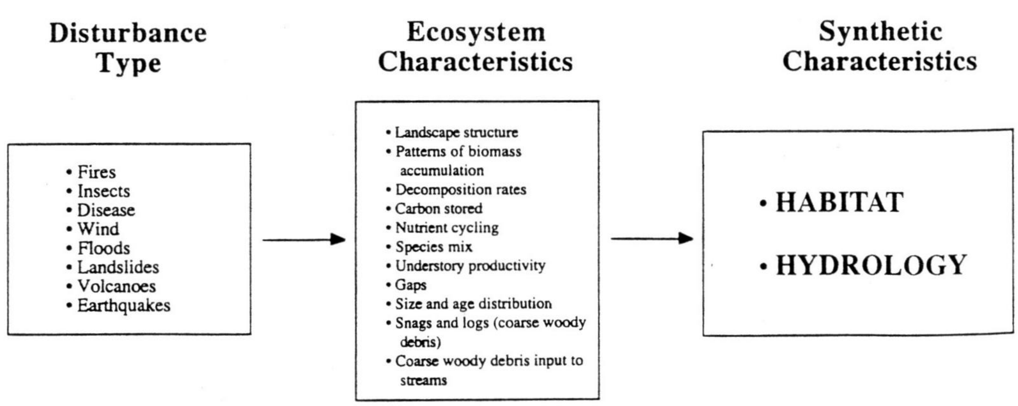

Figure 14.1. The influence of disturbance on temperate rain forests. The forest's hydrological character and its ability to provide habitat are synthetic variables that arise from the combined effects of a number of specific attributes.

Table 14.1. Characteristics of Northwest Trees

	Typical (of productive very old forests)			Maximum		
Species	Age(years)	Diameter(cm)	Height(m)	Age(years)	Diameter(cm)	Height(m)
Pacific silver fir (*Abies amabilis*)	>400	90–110	45–55	750	237	72
grand fir (*Abies grandis*)	>400	90–150	45–60	>500?	202	81
noble fir (*Abies procera*)	>400	100–150	45–70	>500	275	90
Port-Orford cedar (*Chamaecyparis lawsoniana*)	>500	120–180	60	—	359	—
yellow-cedar (*Chamaecyparis nootkatensis*)	>1000	100–150	30–40	1824 (>2000?)	365	62
western redcedar (*Thuja plicata*)	>1000	150–300	40–50	1400 (>2000?)	631	71
Sitka spruce (*Picea sitchensis*)	>500	180–230	60–75	1350	525	95
Douglas-fir (*Pseudotsuga menziesii*)	>750	150–220	70–80	1300	440	100
coast redwood (*Sequoia sempervirens*)	>1250	150–380	75–100	2200	501	—
western hemlock (*Tsuga heterophylla*)	>500	90–120	50–65	1238	275	75
mountain hemlock(*Tsuga mertensiana*)	>500	75–100	35+	>1000	221	59

Sources: Modified from Waring and Franklin (1979) and Pojar and MacKinnon (1994).

Table 14.2. What Key Lessons Have We Learned About Ecosystem Dynamics in Coastal Temperate Rain Forests?

- Disturbances have had major impacts on ecosystem dynamics, and disturbances play varying roles in forests.
- Disturbances vary in their importance at several spatial scales.
- General patterns of structural development have emerged, but there are diverse pathways of ecosystem change in response to disturbances.
- Ecosystem structure is strongly linked to biodiversity at multiple spatial scales.
- Late-successional elements are significant in temperate rain forest landscapes.
- Terrestrial and aquatic ecosystems are strongly interconnected.
- Considering large scales of time and space is critical.
- Intensive plantation forestry does not maintain late-successional elements of ecosystems.

ecosystems in the region. Logs and snags, for instance, are important habitat elements in all forest types, irrespective of variations in tree species, soils, climate, or natural disturbance regimes. Some forest types are less well studied than others, however, and much more research is required before quantitative statements can be made about many of the ideas discussed here. Several of these conclusions (especially the first four in Table 14.2) apply not only to temperate rain forests but to a great variety of other ecosystems.

Ecosystem Management

The emerging cluster of concepts known as ecosystem management carries with it a gestalt of holism rather than reductionism, a subordination of human desires to ecosystem health, and recognition of a broader range of values in ecosystems than past practices have acknowledged (Grumbine 1994). The goal of ecosystem management is to manage for the long-term integrity of whole ecosystems, not for the production of single resources. This goal is easier to state than to implement, of course, and is tied to a broad range of social and institutional issues. As nations have begun to articulate commitments to "sustainable development" (Scientific Panel for Sustainable Forest Practices in Clayoquot Sound 1995b), ecosystem management provides scientific, social, and institutional concepts that set a context for thinking more broadly about sustainability in land use planning and management. A hallmark of current thinking about ecosystem management is that, much more than past approaches, it recognizes that people and their values are part of the system to be managed.

The application of ecosystem management is much broader than just forest management or conservation. Indeed, it incorporates many ideas other than

Table 14.3. Dominant Themes of Ecosystem Management

- *Hierarchical context:* Ecosystem management requires consideration of all levels in the biodiversity hierarchy—genes, species, populations, ecosystems, landscapes—and managers must seek connections between all levels.
- *Ecological boundaries:* Ecosystem management requires working across administrative and political boundaries and defining ecological boundaries at appropriate scales.
- *Ecological integrity:* Managing for ecological integrity means protecting all elements of native diversity and the ecological processes and patterns that maintain it.
- *Data collection:* Ecosystem management requires more information about natural systems and better use of existing information in management.
- *Monitoring:* The consequences of decisions and actions must be tracked in order to evaluate success or failure quantitatively.
- *Adaptive management:* Ecosystem management recognizes our uncertainty about the dynamics of natural systems and acknowledges that our management actions are experiments that must be designed, monitored, and used to change future management.
- *Interagency cooperation:* No single agency or interest group has a lead role in management. Managers and others must work together to integrate conflicting mandates and management goals.
- *Organizational change:* Making ecosystem management a reality will require diverse changes in institutional structure and behavior that range from minor to fundamental.
- *Humans as part of nature:* People and their actions cannot be separated from nature. Their mutual influences on each other must be recognized.
- *The importance of values:* Regardless of scientific knowledge, human values play a fundamental role in determining our goals for managing ecosystems.

Source: Modified from Grumbine (1994).

ecosystem dynamics (Grumbine 1994) (Table 14.3). Despite the eclecticism, ecosystem management has become the central concept around which new approaches to forest management and conservation are being organized. (See FEMAT 1993; Scientific Panel for Sustainable Forest Practices in Clayoquot Sound 1994, 1995a.) Though visions of ecosystem management vary substantially (Franklin 1993b; Swanson et al. 1993; Carpenter 1995; Malone 1995), the primacy of maintaining ecological integrity is a consistent component. There is also general agreement on some of the requirements of "ecological integrity" (Table 14.4). Understanding ecosystem dynamics and incorporating that understanding in management is essential for meeting these requirements for ecological integrity in coastal temperate rain forests. Managing forest ecosystems based on their natural dynamics means considering not just silvicultural or harvesting systems but landscape planning and design, rates and types of disturbance to the hydrological system, and the system of riparian and other

Table 14.4. Ecological Integrity as a Goal of Ecosystem Management

Objectives Within the Overall Goal of Sustaining Ecological Integrity
• Maintain viable populations of all native species in situ.
• Represent, within a system of protected areas, all native ecosystem types across their natural range of variation.
• Maintain evolutionary and ecological processes (disturbance regimes, hydrological processes, nutrient cycles, and the like).
• Manage over periods of time long enough to maintain the evolutionary potential of species and ecosystems.
• Accommodate human use and occupancy within these constraints.

reserves to be maintained within a planning unit. We have indentified, and will discuss, six key ideas about natural disturbance regimes and forest dynamics that set the context for ecosystem management.

Ecosystem dynamics and patterns that maintained biological diversity and ecological function in the past are our best model for doing so in the future. We have inherited forest landscapes produced not by centuries of stability but by a long and variable history of ecosystem change. These same landscapes provide ecological services and habitats for diverse communities of plants and animals that vary over time in any given location and vary geographically within the region. The life forms present today have obviously been able to survive the range of past variation in environmental conditions. We tend to take ecological services for granted because they have been present throughout the history of our interaction with coastal rain forests. The more forests diverge from their historical range of ecosystem states, the less certain we can be that they will continue to provide the habitats and services they have conferred in the past. In theory, ecosystem management should maintain forests within the range of variability they have experienced over the preceding centuries and even millennia. For landscapes and ecosystems that have already been substantially modified by human activities, however, this goal may no longer be attainable at large spatial scales. Our knowledge of the dynamics of temperate rain forest ecosystems is so limited that a precautionary approach to management is imperative. This approach should have two components: an effort to emulate conditions that we know did not compromise biodiversity or ecological function in the past, and a commitment to adapt our practices as we learn more about the behavior of temperate rain forest ecosystems.

We already know enough about natural disturbance regimes to design silvicultural disturbance practices that incorporate key aspects of natural disturbance better than past practices have done. This is especially true at the forest stand level. Many researchers have proposed forest practices informed by natural ecosystem dynamics. (See Franklin et al. 1986; Hansen et al. 1991; Hopwood 1991; Swanson and Franklin 1992; Franklin 1993a, 1993b; McComb et al. 1993.) These proposals, however, have mostly been based on research in the Douglas-fir forests of the southern part of the bioregion. Although the factors of concern are generally similar across the coastal rain forest region—planning for biological legacies, for example, and maintaining the integrity of riparian networks—differences in management are indicated by regional gradients in disturbance regimes (Figure 14.2).

Three caveats are important. First, while these new approaches to forestry are based on a substantial body of research and are being tested widely through the temperate rain forest region, they remain highly experimental and have not been practiced long enough to demonstrate that they will indeed maintain biodiversity. Second, given our rudimentary knowledge of linkages between forest dynamics and biological diversity, formal and informal reserves are a key component of an overall conservation strategy. Third, natural processes, both known and unknown, should be allowed to operate in such reserves—so they can serve both as refugia for life forms that do not find suitable habitat in the more heavily managed matrix and as models for management in matrix landscapes.

The idea that new approaches to silviculture based on natural disturbance will introduce and maintain late-successional elements of biological diversity in managed forests remains a largely untested hypothesis. Novel silvicultural practices complement, rather than replace, the need for reserves of a variety of sizes. Unfortunately, though most proposals for maintaining biological diversity in managed landscapes emphasize the interdependence of stand-level and landscape-level level strategies (Franklin 1993c), the background science and detailed management recommendations for new stand-level approaches are substantially better developed than our ability to understand and manage at the landscape scale.

At the stand level, forest harvesting occurs on a gradient of the removal or retention of trees: clearcuts are at one end of the gradient and nearly undisturbed forest is at the other (Scientific Panel for Sustainable Forest Practices in Clayoquot Sound 1995a). The greater the proportion of trees removed, the more other components of the forest (such as understory vegetation and forest floor biota) will be disturbed. Silvicultural prescriptions for Douglas-fir forests with a history of stand-initiating disturbances emphasize retaining certain trees and patches of forest as biological legacies (McComb et al. 1993). Such prescriptions have generally proposed that a fairly low level of retention (perhaps 5 to 15 percent) is sufficient to produce structurally complex stands made up of older, multiaged remnants in an even-aged matrix. As they develop,

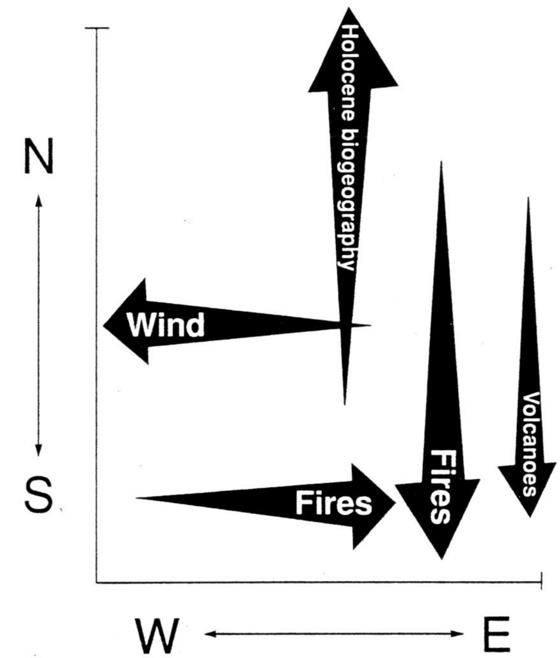

Figure 14.2. The variation of disturbance influences on North American coastal temperate rain forests along gradients of latitude and longitude. Broadly influential, but expressed differently over gradients, are Pleistocene glaciation, erosion, landslides, floods, and stream channel geomorphology.

stands of this type will resemble unmanaged old-growth forest more than intensively managed plantations. Recent research comparing such retention harvests with traditional clearcutting supports this expectation. Retained trees and forest patches—and the structurally complex forests they will become—are likely to retain a greater variety of mid- to late-successional species of various taxa than are clearcut areas (Hansen et al. 1995; Schowalter 1995).

In wetter types of forest, a higher level of retention is more likely to be appropriate. After studying patterns of forest structure in wet temperate rain forest on the west coast of Vancouver Island, Lertzman et al. (1996) suggested a management regime that would maintain late-successional character in managed stands by creating small gaps within a matrix of old forest. This approach should better maintain conditions similar to the continuous, uneven-aged, late-successional forest characteristic of wetter types of coastal temperate rain forest and, moreover, would provide settings for regeneration similar to those responsible for many of the current canopy trees.

The proposal by the Scientific Panel for Sustainable Forest Practices in

Clayoquot Sound (1995a) to implement a "variable retention" silvicultural system can incorporate both the lower levels of retention appropriate in the southern part of the coastal temperate rain forest region and the higher levels of retention that may be required in the northern parts of the region. Similarly, McComb et al. (1993) describe an approach to developing desired future conditions for managed stands based on stand-initiating disturbances that produce a one-story canopy with old-growth remnants, stand-maintaining disturbances that produce a multistoried, multiaged stand with patchy gaps, and disturbances that are intermediate in intensity, producing stands with two to three distinct age classes.

A truly ecosystem-based management regime will require detailed information on forest structure and disturbance history at several scales. It will also require a substantial commitment to monitoring in order to determine if its objectives are being met (FEMAT 1993; Scientific Panel for Sustainable Forest Practices in Clayoquot Sound 1995a). In designing silvicultural practices that incorporate natural ecosystem dynamics, ecosystem-specific information on the following variables should be considered:

- The range of disturbances and causes of tree mortality (windthrow, fire, physical damage)
- The range of intensitiy of disturbances
- The range of sizes and shapes of disturbed patches
- The internal heterogeneity of disturbed patches
- The spatial relationships of disturbed patches to one another
- The temporal frequency of disturbances
- The spatial variability in disturbance intensity and frequency

Knowledge of historical dynamics is a fundamental aspect of implementing an ecosystem dynamics approach to management. Ecosystem-based silvicultural disturbance regimes cannot be designed without understanding the natural disturbance regime for the ecosystems in question. While certain ideas are likely to apply to most ecosystem types—such as the importance of biological legacies at all scales of analysis—even nearby watersheds experiencing similar climatic conditions may exhibit substantial variation in disturbance history. For instance, Morrison and Swanson (1990) concluded that topography was important in how the natural disturbance regime was expressed in the two watersheds they compared. Local information in such detail is unavailable, however, for much of the coastal temperate rain forest region.

Managers should not refrain from applying ideas about ecosystem dynamics to the design of management regimes simply because their information about local disturbance histories is limited. The art of management consists of combining the known, however incomplete, with professional judgment to achieve management goals. This requires a willingness to proceed from general principles to specific practices in the absence of hard rules—a willingness that is rare among managers in both the United States and Canada. Nevertheless, acting with incomplete information, while acknowledging its limitations, will be an essential component of professionalism in future forest management. A challenge to ecosystem management is to strike a balance between giving managers the freedom to adapt practices to complex ecosystems and creating policies that provide for basic ecological protection.

We know enough to begin structuring management around various types of natural disturbance regimes. The *Biodiversity Guidebook* of the Forest Practices Code of British Columbia provides a good example (British Columbia Ministry of Forests 1995). In this guidebook, management recommendations for maintaining biological diversity are stratified by the "natural disturbance type" (NDT) of the forest being considered: NDT 1 refers to ecosystems in which stand-initiating events are rare; NDT 2 refers to ecosystems in which stand-initiating events are infrequent; NDT 3 refers to ecosystems in which stand-initiating events are frequent; NDT 4 refers to ecosystems in which stands are maintained by frequent fires. For instance, the distribution of seral stages to be maintained in a landscape planning unit varies from more emphasis on early seral stages in NDT 3 to more emphasis on mid to later seral stages in NDT 1. This framework is a significant step toward a more ecologically based approach to management. Even under such guidelines, of course, both the stand-level and landscape-level characteristics of the forest are substantially modified from their natural state. Natural disturbances may kill trees, but they do not remove the bodies—which is, after all, a major objective of forestry.

The approach we describe here is intended to maintain key ecological processes in managed forests, not to maintain completely unmodified ecosystems. A forest managed for timber production will always differ in significant ways from a forest subject solely to natural disturbances. Our objective is not merely to "mimic" natural disturbances, but to incorporate the attributes of natural disturbance that allowed species and ecological processes to persist through or recover from disturbances in the past. Managers must always be aware of the degree to which they are generalizing from other ecosystems. The problem of limited local information on disturbance histories is exacerbated by the substantial variation in disturbance regimes over the coastal temperate rain forest region. Disturbance ecologists, managers, and landscape modelers must work together to design and implement management regimes that reflect both local ecological conditions and general concepts of forest dynamics.

A focus on ecosystem dynamics forces management to consider not only ecosystem states but trajectories. One important consequence of the focus on ecosystem dynamics is its shift in emphasis from the current state of a forest to the trajectory the forest will follow over the course of time. Because forests change so slowly compared with human time scales, it is easy to ignore the substantial changes they undergo over several centuries. Placing forests in their historical context allows us to better assess their current state and encourages us to look beyond current conditions to projected future trends. Consider, for example, an area where a stand of old-growth forest was recently cut but some snags were retained. These snags will provide habitat for cavity-nesting birds over the short to medium term. But if no large living trees were left and the stand is scheduled to be cut again in eighty years or less, it will be on a trajectory of declining habitat for species that depend on large snags. Once the initial cohort of snags has decayed, they will not be replaced. It is much more important to plan for the structural characteristics that will develop over the full rotation (and more) than it is to produce some desired condition immediately after harvest.

The dispersion of logged patches in space is a good example of the difference between states and trajectories at the landscape scale. Distributing logging in small dispersed clearcuts has been a common response to concerns about the cumulative effects of logging on both sides of the international border. This policy has created the checkerboard patterns now so familiar on federal lands in the U.S. Pacific Northwest (Spies et al. 1994). Dispersed clearcuts have often been implemented, however, without any change in the overall rate at which the forest is cut. Yet the consequences of an excessive rate of logging in a watershed will be the same in the long term, whether the cut is dispersed in many small patches or in a few large ones, and may be worse in the short term under a dispersed cut scenario because more roads must be built and the remaining forest is fragmented more rapidly. Eventually, cut patches will coalesce, residual forest patches will be small, and continuity among forest patches will be lost (Franklin and Forman 1987; Spies et al. 1994). The trend (historically in the U.S. Pacific Northwest and currently in British Columbia) to disperse cut patches masks these consequences, but only temporarily. In general, forest landscape planning has been plagued by too little analysis of the long-term and large-scale consequences of planning rules conceived with small-scale, short-term variables in mind.

Natural states and processes are sometimes undesirable. Should we emulate all naturally occurring processes or patterns? No. This is both a scientific question and a matter of social values. Natural events, such as large landslides, can be extreme; life forms and ecosystems are unlikely to have well-developed adaptive responses to events that occur only rarely in their evolutionary or ecological histories. Moreover, the extremes of natural disturbance intensity, frequency, or spatial extent will also often have undesirable social or ecological consequences—disruption to hydrological regimes with resulting impacts on fish stocks, for example, or private property put at risk by large wildfires. The effects of natural and human-induced disturbances are cumulative, and many components of temperate rain forest ecosystems are already stressed by human activity (for instance, by overfishing of anadromous fish). The current state of such systems constrains future trajectories that we may consider acceptable. In general, desired states or trajectories for management should be bounded by the range of conditions resulting from natural disturbance regimes, but they need not represent all the states or trajectories possible under those disturbance regimes (Figure 14.2).

A focus on ecosystem dynamics leads to a consideration of whole landscapes. With the shift in focus from managing timber to managing whole ecosystems comes an explicit need to assess and plan for whole landscapes. The emphasis on planning for those parts of the landscape where logging does not occur is a keystone of ecosystem management in both British Columbia (Scientific Panel for Sustainable Forest Practices in Clayoquot Sound 1995a) and the northwestern United States (FEMAT 1993). In both countries, this focus has led to increased emphasis on the integrity of riparian networks and the importance of riparian ecosystems for both aquatic and terrestrial life forms (Chapters 5 and 6).

Landscape elements—riparian zones, mid-slope forests destined for harvest, late-successional reserves—cannot be treated independently. These elements are functionally linked by numerous physical and ecological processes (Swanson et al. 1988). Conservation, once primarily concerned with reserves, now must address the whole landscape. From a conservation standpoint, a landscape can be thought of as reserved areas plus a surrounding matrix of managed forest. The matrix plays at least three key roles in conserving biological diversity (Franklin 1993c; FEMAT 1993):

- The matrix can provide habitat elements (such as logs and snags) well distributed in space.
- Management of the matrix can increase the effectiveness of reserved areas.

- The matrix controls landscape connectivity, which influences such processes as the movement of animals between reserves.

Conservation biology initially treated reserves as islands in a sea of inhospitable terrain, functionally the equivalent of oceanic islands (Simberloff 1988). From this perspective, concerns about continuity across the landscape take on an almost artificial air—like building bridges between islands that were never linked ecologically (Simberloff et al. 1992). But in temperate rain forests, habitat islands are remnants of what was once more-or-less continuous forest. Matrix management in such landscapes should emphasize maintaining significant elements of continuity by reducing the contrast between the reserves and the surrounding matrix, or "softening the matrix" (Franklin 1993c). This approach has tremendous appeal and is a cornerstone of ecosystem management on federal lands in the U.S. Pacific Northwest (FEMAT 1993). The trade-offs between investing in matrix management versus reserves, however, remain largely unexamined and need substantial research.

Ecosystem management provides a context for ecosystem-focused as well as species-focused conservation. Traditional approaches to conservation have focused on species or populations of particular interest. Four key problems with the species-based approach have emerged:

- Species cannot be maintained in situ without their habitat or the ecosystems that provide it.
- Species-specific plans are too expensive, time-consuming, and labor-intensive to implement for more than a very small fraction of the species known to inhabit temperate rain forests.
- The vast majority of species in temperate rain forests are little known, as are their ecological relationships.
- Because many species have conflicting needs, a management regime designed for one species is likely to have negative impacts on others.

If our objective is to conserve biological diversity, adopting a conservation strategy that places more emphasis on ecosystems and landscapes is the only feasible approach (Franklin 1993c). The *Biodiversity Guidebook* of the British Columbia Forest Practices Code (BC Ministry of Forests 1995) is predicated on this idea: one of its key elements is the delineation of "forest ecosystem networks" (FENs). FENs contain specified distributions of seral stages of forest that represent the distribution of ecosystems in an unmanaged landscape and maintain some of the connectivity inherent in the landscape before logging. This idea is, in general, consistent with the approach we describe here, though the quantitative prescriptions for the amount of area in FENs have more to do with policy objectives than with disturbance ecology. FENs are intended to provide habitat or refugia for the majority of species that require natural forest conditions—without adopting species-focused management plans. Species with special requirements beyond what FENs provide are treated separately, not as part of the strategy for biological diversity in general. Although society will continue to demand special treatment for some species of special concern, such attention will continue to be limited to a very small portion of the temperate rain forest biota. Such an approach is unsustainable in isolation from a broader conservation strategy.

Key Problems

We have learned a tremendous amount about the dynamics of temperate rain forests and are beginning to apply that knowledge to management and conservation. Predictably, our understanding highlights a number of unresolved issues. We know enough to identify problems, and sometimes enough to propose solutions, but rarely can we assess the long-term consequences of specific management actions.

Ecological dogmas and assumptions, including those of ecosystem management, need continous testing and revision. But much of this testing can be done through management. Forest management in temperate rain forests has always been a large-scale experiment. We now have to design the experiment so that it tests our hypotheses more effectively. In the near future, new tools will exert a strong influence on research on ecosystem dynamics and on the management prescriptions that evolve from that research. By combining remotely sensed data, geographic information systems (GIS), and spatially explicit simulation models, we can address fundamental questions at larger scales than ever before.

We expect ten problems in temperate rain forest ecology and management to dominate the research agenda over the next decade (Table 14.5). As with the lessons outlined earlier in Table 14.2, many of these problems are not restricted to temperate rain forests, or even to forests in general.

Key Linkages Between Ecosystem Structure, Biodiversity, and Ecosystem Function

We understand well the biology of habitat dependence for a few significant temperate rain forest species, but even basic habitat relationships remain poorly described for many groups. Furthermore, we rarely know the extent to which the few well-known species are representative of a fauna or flora as a whole. Issues such as functional redundancy (Walker 1995) or keystone taxa and processes (Willson and Halupka 1995) in temperate rain forests remain

Table 14.5. What Are the Outstanding Problems in Ecosystem Dynamics and Ecosystem Management in Temperate Rain Forests?

- Key linkages between ecosystem structure, biodiversity, and ecosystem function
- Understanding the structure and dynamics of late-successional ecosystems
- Historical contingency
- Structure and dynamics of large ecosystems
- Active management for conservation objectives
- Whole landscapes = reserves + matrix
- Adaptive management
- Dynamics of recovery in dysfunctional landscapes
- Natural dynamics + anthropogenic changes + global change = ?
- Ecosystem management: more than science

largely unexamined. Although we know that the structure of forest ecosystems relates to their ability to provide habitat and maintain various ecological processes, we are far from fully understanding the nature of this relationship.

Understanding Late-Successional Ecosystems

Late-successional (old-growth) ecosystems have received a lot of attention, but much of it has focused narrowly on individual species, such as the spotted owl, or on policy-motivated efforts such as ecosystem-specific definitions of "old growth." We have just begun to understand the dynamics *within* late-successional ecosystems. Forests are routinely labeled old-growth whether they are 200 or 1000 years old, yet we know that substantial structural and compositional change occurs between these ages. Relatively little is known about changes in soil biology that occur late in succession, for instance, or about changes in the forest canopy structure and canopy biodiversity. Some general ideas have been proposed about how the dynamics of late-successional forests vary across landscapes and over the temperate rain forest region as a whole, but the details of this variation have not been described. The role of late-successional remnants in the recovery of disturbed landscapes is a problem of obvious importance, but one about which we know almost nothing.

Historical Contingency

The analysis of natural disturbance regimes is generally limited to a description of what happened in a particular place during a particular period. Many aspects of natural disturbance processes are stochastic; that is, they have probabilistic components, such as the coincidence of particular wind patterns with a lightning storm. Many patterns of events *could* have happened; the landscape we see, however, is contingent on a particular history. The extent to which alternative histories were possible remains largely unexplored. For instance, a single, intense stand-initiating fire may shift stands from one trajectory of structural development or another. How contingent are our conclusions on a particular history of prior events? Our ability to answer this question is limited. Yet the ability to answer such questions is important in our quest to design landscape management policies: we want those policies to reflect fundamental aspects of ecological process, not historical accidents. These problems of historical contingency cannot be resolved without models of landscape dynamics more refined than the ones we currently have.

Structure and Dynamics of Large Ecosystems

Research on patterns and processes at scales from landscapes to regions is becoming more common (Spies et al. 1994; Wallin et al. 1994), but the science of large ecosystems remains in its infancy. Although the need to characterize, measure, and predict the cumulative ecosystem consequences of different land use practices is widely acknowledged, we have done so in only a few cases. We are not yet able to say how management regimes interact with other ecological processes to determine large-scale patterns of dynamics.

Future research in both managed and unmanaged ecosystems must focus on processes that integrate ecosystems across large scales. The large, relatively pristine ecosystems still found in some parts of the coastal temperate rain forest region therefore represent an internationally significant scientific resource (Ecotrust et al. 1995). They represent, for instance, some of the few undisturbed river systems in the world where it is still possible to study interactions between the drainage network and the surrounding forests.

Active Management for Conservation Objectives

Traditional approaches to ecosystem conservation have, for the most part, been passive. In large landscapes little modified by human activity, merely refraining from intervention is sometimes sufficient to conserve species or features of interest. But such landscapes are rare. In many cases, active manipulation may be necessary to push ecosystem change in desired directions. Active management may be particularly necessary where past human intervention has caused ecosystems to follow a trajectory substantially different than they would have in the absence of human activity. Circumstances likely to require active intervention include the reintroduction of fire to fire-dependent forests, the restoration of degraded riparian zones, and vegetation control in ecological reserves that have been invaded by exotic weeds. This approach demands caution because, in the past, such interventions have caused problems as often as they have solved them.

Whole Landscapes = Reserves + Matrix

The idea of whole landscapes or watersheds as units for study or planning is now a central focus for both research and management (FEMAT 1993; Scientific Panel for Sustainable Forest Practices in Clayoquot Sound 1995a). At present, however, we have little basis for quantitative projections of the consequences of alternative management scenarios. Evaluating the consequences of varying degrees of emphasis on reserves versus matrix management is a good example. Ecosystem-based landscape planning at present relies on a set of working hypotheses that, by necessity, will be tested in their application. We will learn the most from these applications if they are formally designed as hypothesis tests in an adaptive management approach. Taylor (1995) shows how experimental design can be incorporated into the planning of FENs in the southern interior of British Columbia.

Adaptive Management

Adaptive management is the implementation of policy or planning decisions as experiments intended to test hypotheses about the system being managed (Walters and Holling 1990; McAllister and Peterman 1992). This form of management is a particularly important approach to decision making when there is substantial uncertainty regarding the dynamic behavior of the system and its responses to management: information is as much a product of adaptive management as are the commodities or resources that are the more familiar focus of management activities. Adaptive management has become a critical component of ecosystem management because we do not yet understand the dynamics of diverse ecosystem components at larger scales of space and time (FEMAT 1993; Scientific Panel for Sustainable Forest Practices in Clayoquot Sound 1995a). While formal adaptive approaches to management have a substantial history in fisheries (McAllister and Peterman 1992) and forest managers have long implemented silvicultural practices as experiments at the stand level, there have been few attempts to apply formal experimental management approaches to the larger scales and longer time frames we describe here.

Dynamics of Recovery in Dysfunctional Landscapes

Throughout the coastal temperate rain forest, numerous landscapes can be described as dysfunctional with regard to various ecological processes. Though public attention has focused more on the protection of less disturbed landscapes, the restoration of disturbed landscapes will command substantial public and scientific focus in the future. Restoration has been attempted at the scale of forest stands or stream reaches, but neither the dynamics of landscape recovery nor practical efforts to restore whole landscapes have received much attention. Just as the response times of landscapes are slow (Wallin et al. 1994), managing their recovery will be commensurately slow and challenging. The role that late-successional legacies may play in the recovery of disturbed landscapes deserves particular emphasis in research.

Natural Dynamics + Anthropogenic Changes + Global Change = ?

Natural disturbance regimes and forest dynamics are driven by changing climate. The many possible interactions and feedbacks between climate, patterns of land use, and various agents of disturbance in forests (such as fires and insects) create substantial uncertainty about the ecological changes to expect over the next two to four decades (Kasischke et al. 1995). Research on the interactions among processes that cause change in ecosystems (disturbances, biological invasions, habitat loss, disease, and physiological stresses) and processes that buffer change (community "inertia" and competition, the self-stabilizing microclimatic feedbacks in massive forests, active management efforts) can reduce this uncertainty. Forest management policy and planning processes have yet to deal seriously with the degree of uncertainty they face due to the combination of long time scales, rapid climate change, and many biological feedbacks, both positive and negative.

Ecosystem Management: More Than Science

Ecological science is only one aspect of the design of management practices in coastal temperate rain forests. Social responsibility, economic feasibility, political acceptability—all will shape the management paradigm that leads to ecological sustainability. Land management is not a scientific process. Though it should incorporate scientific ideas and information, it inevitably reflects substantial elements of consensus and compromise achieved in political and social settings. Ecological science has often played a smaller role in natural resource decision making than we would like, sometimes with disastrous consequences.

If ecosystem management is to fulfill its promise, ecosystem scientists must be prepared to create and accept roles in the management process. These roles should reflect both our knowledge and our uncertainty about ecosystem dynamics. We should use all the tools we have to project and understand the consequences of alternative management actions. Ecosystem scientists must also be willing to step beyond the confines of ecosystem science to work with social scientists and managers to build management options. Ecological, social, and economic criteria for managing ecosystems have nowhere been effectively combined. Success could come in the coastal temperate rain forest. But it will require unprecedented cooperation, and humility, from scientists, managers, and citizens alike.

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World Wide Web Home Page Addresses

Andrews Forest LTER:
http://www.fsl.orst.edu/lterhome.html

B.C. Ministry of Forests. For Forest Practices Code:
http://www.for.gov.bc.ca/

Reports of the Scientific Panel for Sustainable Forest Practices in Clayoquot Sound:
http://conservation.forestry.ubc.ca:8080/panel/clayhome.html

References

Agee, J. K. 1993. *Fire Ecology of Pacific Northwest Forests.* Washington, D.C: Island Press.

British Columbia Ministry of Forests. 1995. *Biodiversity Guidebook.* Forest Practices Code of British Columbia. Victoria, B.C.

Bunnell, F. J. 1995. "Forest-dwelling vertebrate faunas and natural fire regimes in British Columbia: Patterns and implications for conservation." *Cons. Biol.* 9:636–644.

Carey, A. B., and M. L. Johnson. 1995. "Small mammals in managed, naturally young, and old-growth forests." *Ecol. Appl.* 5:336–352.

Carpenter, R. A. 1995. "A consensus among ecologists for ecosystem management." *Bull. Ecol. Soc. Am.* 76:161–162.

Ecotrust, Pacific GIS, and Conservation International. 1995. *The Rain Forests of Home: An Atlas of People and Place.* Part 1: *Natural Forests and Native Languages of the Coastal Temperate Rain Forest.* Portland, Ore.

Forest Ecosystem Management Assessment Team (FEMAT). 1993. *Forest Ecosystem Management: An Ecological, Economic, and Social Assessment.* Washington, D.C.: U.S. Departments of Agriculture, Commerce, and the Interior, and the Environmental Protection Agency.

Franklin, J. F. 1993a. "Lessons from old-growth." *J. Forestry* 91:10–13.

———. 1993b. "The fundamentals of ecosystem management with applications in the Pacific Northwest." In G. Aplet, N. Johnson, J. Olson, and V. Sample, eds., *Defining Sustainable Forestry.* Washington, D.C.: Wilderness Society and Island Press.

———. 1993c. "Preserving biodiversity: Species, ecosystems, or landscapes?" *Ecol. Appl.* 3:202–205.

Franklin, J. F., and R.T.T. Forman. 1987. "Creating landscape patterns by forest cutting: Ecological consequences and principles." *Landscape Ecol.* 1:5–18.

Franklin, J. F., and T. Spies. 1991. "Composition, function, and structure of old-growth Douglas-fir forests." In L. F. Ruggiero, K. B. Aubry, A. B. Carey, and M. H. Huff, tech. coords., *Wildlife and Vegetation of Unmanaged Douglas-fir Forests*. Gen. Tech. Rep. PNW-GTR-285. Portland: USDA Forest Service, Pacific Northwest Research Station.

Franklin, J. F., T. Spies, D. Perry, M. Harmon, and A. McKee. 1986. "Modifying Douglas-fir management regimes for non-timber objectives." In C. D. Oliver, D. P. Hanley, and J. A. Johnson, eds., *Douglas-fir: Stand Management for the Future*. Symposium proceedings. Seattle: College of Forest Resources, University of Washington.

Gregory, S. V., F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. "An ecosystem perspective of riparian zones." *BioScience* 41(8):540–551.

Grumbine, R. E. 1994. "What is ecosystem management?" *Cons. Biol.* 8:27–38.

Hansen, A. J., T. A. Spies, F. J. Swanson, and J. L. Ohmann. 1991. "Conserving biodiversity in managed forests: Lessons from natural forests." *BioScience* 41(6): 382–392.

Hansen, A. J., W. McComb, R. Vega, M. Raphael, and M. Hunter. 1995. "Bird habitat relationships in natural and managed forests in the west Cascades of Oregon." *Ecol. Appl.* 5:555-569.

Harmon, M. E., J. F. Franklin, F. J. Swanson, P. Sollins, S. V. Gregory, J. D. Lattin, N. H. Anderson, S. P. Cline, N. G. Aumen, J. R. Sedell, G. W. Lienkaemper, K. Cromack, Jr., and K. W. Cummins. 1986. "Ecology of coarse woody debris in temperate ecosystems." *Adv. in Ecol. Res.* 15:133–302.

Hopwood, D. 1991. *Principles and Practices of New Forestry*. Land Management Report 71. Victoria: British Columbia Ministry of Forests.

Huff, M. H. 1995. "Forest age structure and development following wildfires in the western Olympic Mountains, Washington." *Ecol. Appl.* 5: 471–483.

Kasischke, E., N. L. Christensen, Jr., and B. Stocks. 1995. "Fire, global warming, and the carbon balance of boreal forests." *Ecol. Appl.* 5:437–451.

Kusel, J. and L. Fortmann. 1991. *Well-Being in Forest-Dependent Communities*. Berkeley: Department of Forestry and Resource Management, University of California.

Lertzman, K. P. 1992. "Patterns of gap-phase replacement in a subalpine, old-growth forest." *Ecology* 73:657-669.

———. 1995. "Forest dynamics, differential mortality rates and variable transition probabilities." *J. Veg. Sci.* 6:191–204.

Lertzman, K. P., and C. J. Krebs. 1991. "Gap-phase structure of a subalpine old-growth forest." *Can. J. For. Res.* 12:1730-1741.

Lertzman, K. P., G. Sutherland, A. Inselberg, and S. Saunders. 1996. "Canopy gaps and the landscape mosaic in a temperate rain forest." *Ecology* 77:1254–1270.

Malone, C. R. 1995. "Ecosystem management: Status of the federal initiative." *Bull. Ecol. Soc. Am.* 76:158–161.

McAllister, M. K., and R. M. Peterman. 1992. "Experimental design in the management of fisheries: A review." *North Am. J. Fish. Mgmt.* 12:1–18.

McComb, W. C., T. A. Spies, and W. H. Emmingham. 1993. "Douglas-fir forests: Managing for timber and mature-forest habitat." *J. Forestry* 91:31–42.

Morrison, P., and F. J. Swanson. 1990. *Fire History and Pattern in a Cascade Range Landscape.* Gen. Tech. Rep. PNW-GTR-254. Portland: USDA Forest Service.

Pickett, S.T.A., and P. S. White. 1985. *The Ecology of Natural Disturbance and Patch Dynamics.* New York: Academic Press.

Pojar, J., and A. MacKinnon. 1994. *Plants of Coastal British Columbia.* Vancouver, B.C.: Lone Pine Publishing.

Scientific Panel for Sustainable Forest Practices in Clayoquot Sound. 1994. *Progress Report 2: Review of Current Forest Practice Standards in Clayoquot Sound.* Victoria, B.C.

———. 1995a. *Report 5: Sustainable Ecosystem Management in Clayoquot Sound: Planning and Practices.* Victoria, B.C.

———. 1995b. *A Vision and Its Context: Global Context for Forest Practices in Clayoquot Sound.* Victoria, B.C.

Schowalter, T. D. 1995. "Canopy arthropod communities in relation to forest age and alternative harvesting practices in western Oregon." *For. Ecol. and Man.* 78:115–125.

Simberloff, D. 1988. "The contribution of population and community biology to conservation science." *Ann. Rev. Ecol. and Syst.* 19:473–511.

Simberloff, D., J. A. Farr, J. Cox, and D. Mehlman. 1992. "Movement corridors: Conservation bargains or poor investments?" *Cons. Biol.* 6:493–504.

Spies, T. A., J. F. Franklin, and T. B. Thomas. 1988. "Coarse woody debris in Douglas-fir forests of western Oregon and Washington." *Ecology* 69:1689–1702.

Spies, T. A., W. J. Ripple, and G. A. Bradshaw. 1994. "Dynamics and pattern of a managed coniferous forest landscape in Oregon." *Ecol. Appl.* 4:555–568.

Swanson, F. J., and J. F. Franklin. 1992. "New forestry principles from ecosystem analysis of Pacific Northwest forests." *Ecol. Appl.* 2:262–274.

Swanson, F. J., J. A. Jones, D. Wallin, and J. Cissel. 1993. "Natural variability: implications for ecosystem management." In M. Jensen and P. Bourgeron, eds., *Eastside Forest Ecosystem Health Assessment II: Ecosystem Management Principles and Applications.* Report PNW 89-103. Portland: USDA Forest Service, Pacific Northwest Research Station.

Swanson, F. J., T. K. Kranz, N. Caine, and R. G. Woodmansee. 1988. "Landform effects on ecosystem patterns and processes." *BioScience* 38(2):92–98.

Taylor, B. 1995. "Forest ecosystem networks: A decision-making framework and its application in the Nehalliston landscape unit." Master's thesis, Simon Fraser University, Burnaby, B.C.

Vannote, R. L., G. W. Minshall, K. W. Cummins, et al. 1980. "The river continuum concept." *Can. J. Fish. and Aqua. Sci.* 37(1):130–137.

Walker, B. 1995. "Conserving biological diversity through ecosystem resilience." *Cons. Biol.* 9:747–752.

Wallin, D. O., F. J. Swanson, and B. Marks. 1994. "Landscape pattern response to changes in pattern generation rules: Land-use legacies in forestry." *Ecol. Appl.* 4:569–580.

Walters, C. J., and C. S. Holling. 1990. "Large-scale management experiments and learning by doing." *Ecology* 71:2060–2068.

Waring, R. H., and J. F. Franklin. 1979. "Evergreen coniferous forests of the Pacific Northwest." *Science* 204:1380–1386.

Willson, M. F., and K. C. Halupka. 1995. "Anadromous fish as keystone species in vertebrate communities." *Cons. Biol.* 9:489–497.

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Edited by

Peter K. Schoonmaker, Bettina von Hagen, and Edward C. Wolf

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M. Patricia Marchak and Jerry F. Franklin

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