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Chapter 17
Emulating Natural Disturbance Regimes: An Emerging Approach for Sustainable Forest Management

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Abstract Sustainable forest management integrates ecological, social, and economic objectives. To achieve the former, researchers and practitioners are modifying silvicultural practices based on concepts from successional and landscape ecology to provide a broader array of ecosystem functions than is associated with conventional approaches. One such innovation is disturbance-based management. Under this approach, forest practices that emulate natural ecological processes, such as local disturbance regimes, are viewed as more likely to perpetuate the evolutionary environment and ecosystem functions of the forest matrix. We examine how this concept has been applied in three U.S. forest types: Pacific Northwest temperate coniferous, Western mixed-conifer, and Northeastern northern hardwood forests. In general, stand-level treatments have been widely used and often closely mimic historic disturbance because forest structure and composition guidelines have been well defined from reconstructive research. Disturbance-based landscape management, however, has not yet been closely approximated in the three forest types we examined. Landscape implementation has been constrained by economic, ownership, safety, and practical limitations. Given these constraints we suggest that disturbance-based management concepts are best applied as an assessment tool with variable implementation potential. Silviculture practices can be compared against the frequency, scale, and level of biological legacies characteristic of natural disturbance regimes to evaluate their potential impact on ecosystem sustainability.

17.1 Introduction

Recent landscape ecology texts (Turner et al. 2001; Lindenmayer and Franklin 2002) and some U.S. regional management plans (FEMAT 1993; SNFPA 2004) have proposed using natural disturbance as a model for sustainable forest management. This

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chapter examines how forest managers can use natural disturbance patterns and processes as a coarse-filter model by manipulating forest structure and development, and the spatial distribution of treatments. Although management plans implementing these ideas vary regionally, most have the common goals of increasing forest structural complexity, maintenance of landscape connectivity and heterogeneity, and protection or restoration of riparian and watershed integrity. Most plans also focus on the matrix, the area between reserves that constitute most of the managed forest landscape. In this chapter we first summarize the concepts of disturbance-based management that are generally applicable to maintaining a sustainable forest landscape. Next we provide examples of disturbance-based management as applied in three distinct forest types: Pacific Northwest temperate coniferous forests, Western mixed-conifer forests, and Northeastern northern hardwood-conifer forests. For each of these examples, we describe existing forest conditions, summarize historic disturbance regimes, and then examine current management practices designed to emulate forest conditions produced by natural disturbance regimes. Finally we evaluate the strengths and weaknesses of using disturbance-based management in each of these forest types and identify lessons that may be useful for forest managers in other regions of the world.

17.2 Disturbance-Based Forest Management Concepts

17.2.1 Managing the Matrix

Concepts of forest sustainability have changed as the social perception of forests has shifted (Harrison 2002). Forest landscape sustainability, once measured as a constant supply of timber, has become a more complex concept where social, ecological, and biodiversity needs must be met in addition to economic revenues (Hunter 1999). This range of values cannot be fully sustained if forest landscapes are strictly segregated into reserves and production lands. Parks, wilderness areas, and reserves alone will never be able to sustain biodiversity and all the ecological services that society now demands of its forests. A significant majority of global forest lands, by one estimate about 88% (Dudley and Phillips 2006), have no formal protection. As the dominant element of the landscape, managed forestlands have a controlling influence on ecological processes, such as biological connectivity, watershed functioning, and carbon sequestration. Consequently, sustainable management of "matrix forests" is increasingly viewed as an essential complement to other conservation approaches (Lindenmayer and Franklin 2002; Keeton 2007). Matrix management incorporates concepts from the field of conservation biology. Lindenmayer and Franklin (2002) developed a framework for conserving forest biodiversity that we believe also provides appropriate metrics for assessing landscape sustainability, particularly if used in conjunction with protected areas based strategies. They list five core principles: (1) maintenance of stand structural complexity; (2) maintenance of connectivity; (3) maintenance of landscape heterogeneity; (4) maintenance of aquatic ecosystem integrity, and (5) risk spreading, or the application of multiple conservation strategies.

The first principle recognizes that intensive forestry practices usually simplify stand structure, resulting in less vertical complexity in the forest canopy, less horizontal variation in stand density, and fewer key habitat elements like large dead trees and downed logs (Swanson and Franklin 1992; Franklin et al. 1997). Thus, an alternative is to promote greater structural complexity (e.g. vertically differentiated canopies, higher volumes of coarse woody debris) in actively managed stands (Hunter 1999; Keeton 2006), which may benefit those organisms not well represented in simplified stands, as long as sufficient habitat is provided across multiple stands to support viable populations. The second principle, maintenance of connectivity, allows organisms to disperse, access resources, and interact demographically. Connectivity strategies include protection of terrestrial and riparian corridors, and restoration of linkage habitats. There are also non-corridor approaches, such as retention of well distributed habitat blocks and structures that provide "stepping stones" across harvested areas. Maintaining a diverse landscape, principle three, supports an array of ecological functions while also increasing ecosystem resilience to disturbance and stress (Perry and Amaranthus 1997). Principle four relates to minimizing deleterious forest management effects on riparian and aquatic ecosystem interactions (Naiman et al. 2005; Keeton et al. 2007b). Delineation of riparian buffers, riparian forest restoration, and ecologically informed forest road management are essential elements of matrix management (Gregory et al. 1997). Finally, "risk-spreading," principle five, deals directly with the scientific uncertainty associated with over-reliance on any one forest management approach. Uncertainty and risk are reduced if multiple management and conservation strategies are applied at different spatial scales and on different portions of the landscape (Lindenmayer and Franklin 2002).

17.2.2 Emulating Natural Disturbance

The central concept in disturbance-based management is that forest practices which are consistent with natural ecological processes, such as local disturbance regimes, are more likely to perpetuate the evolutionary environment and ecosystem functions of the forest matrix. Some of the negative ecological effects of forest management actions can be reduced if operations attempt to stay within the bounds of these natural disturbance regimes (Attiwell 1994; Bunnell 1995). Several useful indicators have been suggested as measures of differences between natural disturbance regimes and the effects of forest harvest. These include: (1) disturbance frequency, (2) disturbance magnitude (intensity and spatial attributes), and (3) the density and type of biological legacies persisting post-disturbance (Hunter 1999; Lindenmayer and Franklin 2002; Seymour et al. 2002). To evaluate the congruence between human and natural disturbances, managers need information on the frequency of historic disturbance events (e.g. local fire history; wind storm return interval), their patch size and distribution (e.g. fire extent; average sizes and formation rates of canopy gaps), and the number and arrangement of legacies structures (e.g. live and dead trees, and coarse woody debris left after natural disturbances).

An important informational need in disturbance-based management is an understanding of ecosystem recovery following disturbances and long-term processes of stand development (Franklin et al. 2002). Research and evolving forest practices in Scandinavia (Vanha-Majamaa and Jalonen 2001), Canada (Beese and Bryant 1999), and several regions of the U.S., including the Pacific Northwest (Franklin et al. 2002; Keeton and Franklin 2005), upper Midwest (Palik and Robl 1999), Southeast (Palik and Pederson 1996; Mitchell et al. 2002), and New England (Foster et al. 1998; Seymour et al. 2002), have fostered a growing appreciation for the role of biological legacies in ecosystem recovery following disturbances. Biological legacies are "the organisms, organic materials, and organically-generated patterns that persist through a disturbance and are incorporated into the recovering ecosystem" (Franklin et al. 2000). Biological legacies "lifeboat" organisms through the post-disturbance recovery period, ameliorate site conditions in stressed, post-disturbance environments, and promote accelerated and complex recolonization and successional pathways. To emulate these functions in managed forest stands, structures can be retained in varying densities/volumes and in different spatial patterns (e.g. aggregated vs. dispersed, Aubry et al. 1999). Retention schemes can mimic the landscape level patterns created by natural disturbances, such as, in some cases, greater tree survivorship within riparian zones in areas burned by wildfire (Keeton and Franklin 2004). Permanent retention of legacies, such as living trees, can influence (Zenner 2000) and even accelerate (Keeton and Franklin 2005) long-term stand development processes and recovery from disturbance.

An extension of this research has investigated effects of natural disturbances in mediating late-successional stand development (Abrams and Scott 1989; Lorimer and Frelich 1994). The objective is to develop silvicultural systems that provide a broader range of stand development stages, including old-growth forest habitats and associated functions (Franklin et al. 2002; Keeton 2006). These systems accelerate rates of stand development in young, mature, and riparian forests through underplanting, variable density thinning, crown release, and other methods (Singer and Lorimer 1997; Harrington et al. 2005).

One method of assessing disturbance-based practices has been to compare managed forests to their "historic range of variability" (HRV). Although ecosystem structure and function vary over time and space, HRV suggests there is a bounded range to these conditions that can be compared against the range of conditions produced in managed forests (Aplet and Keeton 1999). There are examples of forest management plans based on reconstructions of HRV (e.g. Cissel et al. 1999; Moore et al. 1999). In practice, however, HRV-based management is difficult to implement. To begin with, the feasibility of quantifying HRV for a given landscape varies greatly depending on data availability and modeling requirements (Parsons et al. 1999). There is the added difficulty of finding appropriate historical reference periods (Millar and Woolfenden 1999). Third, forest managers must determine whether HRV offers a realistic target for management, considering the extent to which conditions within the HRV are compatible with contemporary management objectives as well as altered ecosystem conditions and dynamics attributable to land use history. HRV, however, can provide an informative benchmark or reference for understanding landscape change.

The concepts of disturbance-based forestry have intuitive appeal because they take a cautious, less intrusive approach to management, one that attempts to stay within the bounds of historic conditions and "natural" variability. A central concern, however, is whether these concepts can be implemented in practice. Managers' best efforts to mimic natural disturbance regimes will inevitably involve tradeoffs between economic, social, and ecological objectives. The case studies that follow explore the basis, evolution, and limitations of disturbance-based forest management in the U.S, beginning with the Pacific Northwest where many disturbance-based forestry concepts were first developed.

17.3 Case Studies

17.3.1 Pacific Northwest Forests

Distribution and Current Condition – Temperate coniferous forests in the U.S. Pacific Northwest (PNW) and Canada extend over 2000 km from southeastern Alaska to northern California in a narrow band ranging from 60 to 200 km in width (Franklin and Halpern 2000). Low to mid elevation forests in this region are dominated by large conifers, including most commonly Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), Sitka spruce (*Picea sitchensis*), Pacific silver fir (*Abies amabilis*), noble fir (*Abies procera*), and in northern California, coast redwood (*Sequoia sempervirens*). The climate is strongly maritime influenced, having very wet (80–300 cm annual precipitation) mild winters, and warm, dry summers. The forests are noted for having some of the greatest biomass accumulations and highest productivity of any forests in the world. Historically, landscapes in Pacific Northwest were dominated by large areas of continuous forest cover. By some estimates roughly 60–70% of forests were in an old-growth condition (greater than 150 years of age) at any one time (Vogt et al. 1997). Stand structure in PNW forests changes dramatically in response to disturbance and with processes of stand development (Franklin et al. 2002), yielding an array of different biodiversity values and ecosystem functions (Hunter 1999). Therefore, the initial focus of disturbance-based forestry was on managing stand structure and age class distributions in this region (e.g. FEMAT 1993). Young to mature forests, especially in managed stands, tend to have single-layered canopies and low structural complexity, although young stands may have a high carryover of coarse woody debris if they originated from natural disturbances (Spies et al. 1988). Old-growth stand structure is typified by a range of tree sizes, including very large trees, exceptionally high volumes of coarse woody debris (both standing and downed), and vertically continuous canopies which have very high leaf area index values (Gholz 1982) (Fig. 17.2, upper left). The largest trees can reach diameters over 300 cm and heights over 90 m. Understory light availability can be limited beneath closed canopy forests, often producing a sparse or patchy herb and shrub community, extensive moss mats, and saplings and mid-canopies dominated by shade-tolerant tree species (Van Pelt and Franklin 2000). Tree mortality processes shift from density-dependent competition during early stand development to density-independent or disturbance-related mortality late in stand development. Thus, horizontal complexity associated with gap dynamics is a defining characteristic of old-growth forests in the PNW (Franklin et al. 2002; Franklin and Van Pelt 2004).

In the 1980s and '90s, controversy over the PNW's declining late-successional/ old-growth (LS/OG) forests and associated biological diversity eventually led to changes in forest management both there and across much of the United States. After several decades of widespread clearcut logging (Fig. 17.2, lower left) and replanting, the majority of LS/OG forest was converted into short rotation (e.g. <60 year) plantations. Today less than 10% (or about 1.8 million ha) remains of the late-successional forest cover extant at the time of European settlement (FEMAT 1993). Loss and fragmentation of habitat at landscape scales has contributed to significant population declines in northern spotted owls (*Strix occidentalis caurina*), marbled murrelets (*Brachyramphus marmoratus*), and other LS/OG associated species. Loss of LS/OG and related high quality spawning and rearing habitats along headwater streams has been one of several factors causing declines in anadromous salmonid populations. By one estimate (FEMAT 1993), over a thousand species of plants, animals, and fungi are associated with LS/OG forests in the PNW.

Historic Disturbance Regimes - Wind and wildfire are the main disturbance agents in PNW forests, although floods, insects and pathogens are important at smaller scales. Though infrequent, large intense fires exert a strong influence on the age-class structure and development patterns of these forests. Historically fire return intervals generally increased along precipitation gradients varying, for example, from about 200 years in central Oregon to over 1000 years in coastal Washington (Agee 1993). Under the right weather conditions, tens of thousands of hectares can burn within a short period. Typically not all trees are killed even during extreme, large-scale wildfires (Morrison and Swanson 1990; Gray and Franklin 1997). Fires usually leave small groups of survivors on landforms providing refugia or dampening effects on fire intensity and spread (Camp et al. 1997). Standing dead trees and scattered live trees, varying by species-specific fire resistance traits, are often widely distributed throughout burn areas, depending on fire intensity, and stand age and structure at the time of disturbance (Keeton and Franklin 2004).

Wind is also an important disturbance in PNW forests at two scales and intensities. Large, catastrophic windstorms strongly influence coastal forests in particular. These storms can blow down large swaths of forests, particularly when soils are saturated after weeks of winter rain. For example, the 1962 Columbus Day windstorm caused a timber blow down in excess of 25 million cubic meters in western Oregon and Washington (Lynott and Cramer 1966). Another windstorm in 1921 blew down approximately 19 million cubic meters of timber along a 110 km long, 50 km wide swath on the west side of Washington's Olympic Peninsula (Guie 1921). Wind is also a chronic disturbance creating small- to moderate-sized gaps within closed canopy forests (Spies et al. 1990; Lertzman et al. 1996). Fine-scaled wind disturbance interacts with trees weakened by fungal pathogens, such as stressed trees, opening up the canopy and increasing understory light availability. Wind disturbances in the PNW typically leave fewer standing trees, compared to wildfires, and greater densities of snapped and up-rooted trees (Franklin et al. 2000).

Disturbance-based management - forests in the PNW have been extensively altered by over 100 years of logging and clearing for development. Following World War II clearcut logging became the dominant type of regeneration harvesting in the region. Clearcutting removes nearly all aboveground structure, whereas wind and fire typically leave abundant biological legacies, including live trees and very large accumulations of coarse woody debris (Kohm and Franklin 1997; Franklin et al. 2000). Studies have documented many differences in plant succession (Halpern and Spies 1995; Turner et al. 1998), soil erosion and nutrient loss (Sollins and McCorison 1981; Martin and Harr 1989) and biodiversity responses (Hansen et al. 1991) in clearcuts compared to wind and fire created openings. The frequency of large disturbances also differs considerably from harvesting, which is generally practiced on 40–60 year rotations in the Douglas-fir region (Curtis 1997). At the landscape level, dispersed patch clearcutting practiced by the U.S. Forest Service on national forest lands left much of the PNW's forests highly fragmented, with a significant increase in forest edge (Franklin and Forman 1987) and a reduction in interior forest microclimate and habitat conditions (Chen et al. 1990) (Fig. 17.2 bottom left). In response to these changes, some researchers proposed a "new forestry," one which significantly lengthens rotations (Curtis 1997) and retains large green trees, snags, and logs in harvest areas to more closely mimic historic disturbance (Swanson and Franklin 1992; Franklin et al. 1997). With the implementation of the Northwest Forest Plan (NFP) in 1994, redevelopment of LS/OG within reserves established by the plan became a central objective, requiring innovative silvicultural approaches that would accelerate rates of stand development and promote eventual recovery of LS/OG structure and functional conditions (DeBell et al. 1997). Researchers are testing silvicultural systems designed to meet this need, such as variable density thinning (Harrington et al. 2005) and creation of variably sized gaps (Wilson and Puettmann 2005) in young and mature stands. These approximate and accelerate stand development processes, such as spatially variable density-dependent and disturbance related tree mortality, that reduce stand densities, increase light availability, and allow for understory reestablishment of shade-tolerant conifers (Keeton and Franklin 2005). Collectively these processes influence both overstory tree growth rates and redevelopment of the vertically and horizontally complex structure characteristic of late-successional temperate forests (Franklin et al. 2002). Another experimental study, called the "Demonstration of Ecosystem Management Options" (DEMO), is testing the "Variable Retention Harvest System" proposed by Franklin et al. (1997). DEMO is evaluating variable levels of post-harvest retention (ranging from 15 to 70% of basal area) in two spatial patterns, aggregated vs. dispersed (Aubry et al. 1999) (Fig. 17.1). Trees are retained

Fig. 17.1 Examples of disturbance-based silvicultural practices. The *upper right* is an example of both dispersed and aggregated retention in the U.S. Pacific Northwest (photo credits: Jerry F. Franklin). Shown on the *left* is a group selection cut with retention (both live and dead trees) within small (0.05 ha) harvested patches on the Mount Mansfield State Forest in Vermont (northeastern U.S.) (photo credit: Jeremy Stovall). Shown on the *bottom right* is mixed conifer in which understory trees were first thinned to reduce fuels and then the stand was prescribed burned to mimic historic low-intensity fire (photo credit: Malcolm North)

permanently to provide legacy functions and multi-aged structure; biodiversity and regeneration responses will be monitored over the long-term (Aubry et al. 2004). The NFP requires management practices that increase the level of biological legacies which historically were associated with natural disturbance regimes. For instance, where regeneration harvests are employed (i.e. in 1.6 million ha of "matrix" areas), the NFP requires retention forestry practices that leave individual large trees and forest patches within harvest units. In addition, 15% of each 5th field watershed must be left in intact patches of mature and old-growth forest to provide residual structure across large matrix areas. The intent is to provide biological legacies and some degree of habitat connectivity (also achieved using riparian buffers) across managed landscapes. In late-successional reserves created by the NFP, development of late-successional forest structure is the management objective and thus regeneration harvests are prohibited. Only thinnings in stands less than 80 years of age are allowed to accelerate rates of stand development. This strategy addresses the need for large, well distributed, and connected blocks of habitat across the landscape, in which natural disturbance dynamics will play a formative role. The NFP also encourages development of innovative approaches, particularly in Adaptive Management Areas. In this spirit Cissel et al. (1999) proposed an alternative management

Fig. 17.2 *Top left* is a typical Pacific Northwest old growth forest. *Bottom left* is a Pacific Northwest landscape fragmented by clearcut logging. *Middle top* is mixed conifer forest in Yosemite Valley, California in 1890. *Bottom middle* is the same forest in 1970 after many years of fire suppression with an inset photograph of the forest in 1990 (pictures from Gruell 2001). At *top right* is a structurally complex, old-growth northern hardwood stand in New York's Adirondack State Park. *Bottom right* is a young, structural simple secondary northern hardwood forest in Vermont's Green Mountains

plan for one watershed covered by the NFP. Rotation periods and harvesting patterns were based on reconstructions of spatially-explicit fire return intervals, including stand replacement events in riparian forests. The projected result was a less fragmented landscape pattern over time compared to the harvesting pattern required by the NFP, in which placement of harvest units is constrained by the extensive network of riparian reserves.

17.3.2 Western Mixed-Conifer Forests

Distribution and current condition – the classification "mixed conifer" has been loosely applied to many coniferous forest types in North America that have a combination of species in which no one species clearly dominates. In the western United States, mixed conifer usually has a combination of shade-tolerant (e.g. cedars and true firs) and -intolerant (e.g. pines) conifers and is often a mid-elevation forest type, bounded at lower elevation by ponderosa pine (*Pinus ponderosa*) and at higher elevation by fir (e.g. *Abies magnifica*, and *A. lasiocarpa*), spruce (e.g. *Picea engelmanii*) or lodgepole pine (*Pinus contorta*) forests. Mixed conifer is widely distributed in the western U.S. but is most prevalent in the northern Rockies (northeastern Oregon, central Idaho and western Montana), the western slopes of California's Sierra Nevada, central Colorado, and the southern Rockies (northern Arizona and New Mexico). Stands that were not heavily harvested can contain 300–500 year old trees and some species, such as sugar pine and Douglas-fir, can reach diameters of over 250 cm and 75 m in height.

Across a landscape, mixed-conifer conditions are highly heterogeneous not only due to historic fire regimes (Fig. 17.2 top center) but also because they occupy an elevational band where significant changes in precipitation form (rain vs. snow) and availability (immediate soil wetting vs. snow pack banking) occur over small scales. Spatially variable physiographic and microclimatic conditions can have strong influences on the size of vegetation patches, patch complexity and pattern, and horizontal fuel continuity, which collectively influence fire spread (Taylor and Skinner 2004). A century of fire suppression has homogenized forest patterns at landscape scales making delineation of patches and restoration of patch complexity a central challenge for disturbance-based management.

Historic disturbance regime – historically fire was the key disturbance agent with an average return interval of 15–35 years (Arno 1980; Agee 1991; McKelvey et al. 1996). Across much of the western U.S. this fire regime changed in the late 19th century concurrent with a cooling trend in global climate, an increase in grazing (which reduces herbaceous fuels), and a reduction in Native American ignitions. Beginning in the late 1930s with increased forest road construction and development of effective fire fighting methods, fire suppression also contributed to the reduction in burned acreage. Many mixed-conifer forests have not burned in the 20th century and one study, using the amount of acreage annually burned by wildfire in different forest types, estimated California's mixed conifer now has a fire return interval of 644 years (McKelvey and Busse 1996). Historically, mixed-conifer fires were usually low-intensity surface fires that consumed surface litter and fine fuels, and killed small, thin-barked trees. Researchers have found some evidence of higher intensity burns in the past but it appears these crown fires were infrequent events (>400 years) possibly driven by extreme weather (Stephenson et al. 1991).

Historically fire produced a highly heterogeneous landscape. Within a watershed, riparian areas and valley bottoms had longer fire return intervals, developing higher stem densities and fuel loads than adjacent upland forest (Bisson et al. 2003; Dwire and Kauffman 2003; Stephens et al. 2004). Midslope forests generally experienced frequent fires (8–20 years) and forest conditions were strongly influenced by slope, aspect and soil conditions. Ridgetops characterized by shallow soils and open forest conditions often slowed or contained surface fires because of low fuel loads. Reconstruction of past landscape patterns (Hessburg et al. 2005, 2007) suggest this high degree of heterogeneity was a defining characteristic of low-intensity fire regimes. This heterogeneity is self-reinforcing. The behavior of each successive fire is influenced by the spatially variable fuel conditions left by previous fires, thereby perpetuating patchy stand structures and patterns.

In the absence of fire, current forest conditions have become more homogeneous at all scales (Fig. 17.2 bottom center). When wildfires do occur in these conditions they are often higher severity than they would have been historically, because increases in surface and ladder fuels can sustain crown fires across large areas. Over the last 5 years, Arizona, Colorado, and Oregon have had the largest fires in their recorded histories, with much of each burn area experiencing crown fire and high tree mortality (>75%). The frequency of large high intensity fires is predicted to increase further over the 21st century in mixed-conifer forests due to climate change (Keeton et al. 2007a).

Other disturbance agents (i.e., wind, avalanches and flooding) are present in mixed conifer but historically their impacts have been localized or infrequent. In the absence of fire pests have become the principal mortality agent in mixed conifer attacking high-density, moisture-stressed stands (Ferrell 1996). As an ecological process, however, pests do not replace fire because their mortality is more clustered and does not select for smaller, thin barked trees (Smith et al. 2005). Pest mortality has reduced the number of large, old-growth trees, and increased fuel loading in many forests, exacerbating the potential for high-intensity wildfire.

Disturbance based management – Management of mixed-conifer forests has evolved as desired conditions have changed and research has demonstrated the importance of maintaining critical ecological processes, such as fire. This evolution, however, has produced hybrid management approaches, including practices that reflect past priorities while incorporating new concepts. For example, another subspecies of spotted owl is found in Californian and Southwestern mixed-conifer forests, where logging has reduced the extent of old growth. Consequently management became focused on retaining old-growth structures and providing suitable owl habit. Unlike the Pacific Northwest, however, western mixed-conifer forests are characterized by frequent, low to moderate intensity disturbance rather than long periods of old-forest conditions. Managers often find it difficult to reconcile the emphasize on providing undisturbed habitat for spotted owls and developing large, old trees, because increasing fuel loads threaten to eliminate both if high-severity wildfires burn across the landscape. Fire history studies have long established the frequency of historic burns (Biswell 1973; Agee 1991; McKelvey et al. 1996), and research has identified low-intensity fire as a "keystone" process for restoring and maintaining the ecological functions associated with forest "health" (Falk 2006; North 2006). Low-intensity fire shapes mixed-conifer ecosystems by reducing the understory canopy, slash, litter, and shrub cover, all of which open growing space, provide pulses of soil nutrients, and increase the diversity of plants and microhabitat conditions (Wayman and North 2007; Innes et al. 2006; North et al. 2007).

In mixed conifer, disturbance-based management has begun to focus on process restoration and the importance of influencing fire behavior (Fig. 17.1). In fire-dependent forests management practices are evaluated based on what kind of fuel conditions they create. Modeling software is used to estimate how different post-treatment fuel loads and weather could affect local fire intensity (Stephens 1998; Stephens and Moghaddas 2005). Fuels are reduced until the crowning and torching index (the wind speed needed to produce an active and passive crown fire) for the treated stand are higher than conditions that are likely to occur even under extreme weather events. With air quality regulations, increasing wildland home construction, and limited budgets, many forests cannot be prescribed burned, at least as an initial treatment. Yet restoration of these forests is still dependent on modifying fuels because they control wildfire intensity when the inevitably fire does occur, and in the mean time can produce stand conditions that simulate some of fire's ecological effects.

Disturbance-based management with a focus on process has two potential benefits that traditional silvicultural practices often lack: variability and adaptation to current conditions. Managers have often focused on structural targets, such as thinning all trees up to a maximum diameter limit, consistently applied throughout a treated area. This uniform application, however, is unlikely to produce the variable stand structures and composition that fire would have in the past (Hessburg et al. 2005). Management keyed to manipulating disturbance processes, however, produces different stand structures across a landscape because thinning prescriptions, designed to affect fire behavior, vary depending on a locale's slope position (i.e., riparian, midslope or ridgetop), aspect, and moisture conditions. A second benefit of process-based management is that forest structure and composition are allowed to re-establish to modern dynamic equilibrium by using fire under current climate and ignition conditions (Stephenson 1999; Falk 2006). Annual fluctuations in temperature and precipitation are expected to increase with global warming (Field et al. 1999). Process-focused management lets forests reach their own equilibrium in response to the interaction of fire with current climate conditions.

Landscape level management in mixed conifer is focused more on fire control than strictly mimicking historic disturbance patterns. Mechanical treatments of fuels vary depending on slope position. Riparian areas are usually left alone. Midslope forests are often thinned following process-focused management. Stands are thinned from below (removing the smallest trees first), and ladder and surface fuels are reduced until a wildfire burning through the stand is likely to stay on the ground rather than climbing into the overstory canopy. The location of treatment units, called "Strategically Placed Area Treatments" or SPLATs, follows model predictions about how a fire might move through a burnshed (Finney 2001). Treated units are placed in a stepped herringbone pattern, like speed bumps designed to reduce the rate of fire spread. Ridgetops and forests near wildland urban interfaces (WUIs) are considered control points and are heavily thinned to defensible fuel profile zone (DFPZ) standards to dramatically reduce fuels.

These landscape treatments were largely developed from fire simulation models (Finney 2002, 2003) and do not necessarily match historic landscape patterns. For example, current management practices that avoid riparian areas do not replicate natural fire patterns, because historically fire often reduced fuels and thinned stand structure, albeit not as frequently as adjacent upslope areas (Olson 2000; Dwire and Kauffman 2003; Everett et al. 2003). Another departure from historic landscape patterns is thinning prescriptions along ridgetops. Thinning in these areas reduces canopy cover to 40% by evenly spacing leave trees and separating their crowns. Research, however, has suggested there is limited reduction in crown fire potential through overstory thinning and tree crown separation (Agee et al. 2000; Butler et al. 2004, Agee and Skinner 2005). Furthermore, studies in active fire regime forests (Stephens and Fry 2004; Stephens and Gill 2005), and stand reconstructions (Bonnicksen and Stone 1982; North et al. 2007) indicate forest structures (live trees, snags, logs and regeneration) were highly clustered in forests with frequent low-intensity fire. Even spacing of leave trees produces a regular distribution which significantly departs from historic spatial patterns (North et al. 2004, 2007). Managers, however, have not attempted to reproduce historic conditions because even a small potential gain in fire intensity reduction is considered a priority in these key control areas. Disturbance-based management in mixed conifer is generally mimicking historic stand conditions but failing to replicate landscape-level patterns because of concern over fire containment.

17.3.3 Northern Hardwood Region

Distribution and current condition – the northern hardwood region of eastern North America[1] is characterized by evenly distributed annual precipitation and relatively fertile soils on post-glacial landscapes. The region's forests are thus both generally productive and diverse, comprised primarily of two dominant forest groups, the northern hardwood forest (beech-birch-maple) and the northern coniferous forests (spruce-fir-hemlock, but also white-red-jack pine). Central hardwood forests (oak-hickory) finger northwards through major valleys and along a transition zone in southeastern portions of the region. In New York and the New England states these major formations have been classified into 40 different cover types (Eyre 1980) and four type groups that collectively cover approximately 89% of the northeastern U.S. (Seymour 1995). The later include the northern hardwood or American beech-yellow birch-sugar maple (*Fagus grandifolia-Betula alleganiensis-Acer saccharum*) type; the red spruce-balsam fir (*Picea rubens-Abies balsamea*) type; the eastern white pine-eastern hemlock (*Pinus strobus-Tsuga canadensis*) with mixed hardwoods type; and the oak type (mostly red oak [*Quercus rubra*], but also white oak [*Quercus alba*], black oak [*Quercus velutina*], and others).

A post-European settlement history of land-use exceeding 300 years creates a unique and complex context for application of disturbance-based forestry concepts. Forest cover, composition, age class distribution, and structure in the northern hardwood region have changed dramatically since the 17th and 18th centuries (Cogbill et al. 2002; Lorimer and White 2003). Geophysical heterogeneity, climate variability, and disturbances, which included aboriginal clearing and burning, maintained a dynamic and diverse landscape in which forest structure and composition were spatially and temporally variable (Foster and Aber 2004). The landscape was nevertheless dominated by late-successional and old-growth forests (uneven-aged, >150 years in age), with young forests (up to 15 years old) representing <1–13% of the landscape on average (Lorimer and Frelich 1994; Lorimer and White 2003). Nineteenth century clearing, followed by land abandonment, secondary forest redevelopment on old-fields, and 20th century forest management, resulted in the current predominance of young to mature forests.

[1] Includes all or portions of Minnesota, Wisconsin, Michigan, New York, Vermont, New Hampshire, and Maine in the United States, and Ontario, Quebec, New Brunswick, and Nova Scotia in Canada. Delineations sometimes also include portions of Pennsylvania and the southern New England states.

Research in remnant eastern old-growth over the last two decades has substantially broadened our understanding of structure and composition in pre-settlement forests. These studies have been conducted across a wide range of sites representing a significant portion of the region's biophysical diversity (see review in Keeton et al. 2007b). They tell us that forest structure, both in terms of landscape level patch complexity (Mladenoff and Pastor 1993) and stand structure (Tyrell and Crow 1994; Dahir and Lorimer 1996; McGee et al. 1999) (Fig. 17.2 top right) differs considerably between old-growth forests and the young to mature forests which currently dominate the landscape. Forest management has tended to convert landscapes with complex patch mosaics shaped by wind and other disturbances to simpler configurations (Mladenoff and Pastor 1993). Forest patches are now less diverse in size and less complex in shape. At the stand level younger, secondary forests tend to have less differentiated canopies, lower densities of large trees (both live and dead), lower volumes and densities of downed logs, smaller canopy gaps, and less horizontal variation in stand density (Fig. 17.2 bottom right). These relate both to the limited time over which secondary forest development has occurred, through predominately old-field succession, and forest management practices which tend to set back or hold in check late-successional stand development processes (Keeton 2006). The relative abundance of dominant tree species and their landscape position have also shifted as a result of land use history (Cogbill et al. 2002).

With changes related to land-use history have come shifts in the types of ecosystem goods and services provided by forested landscapes. For instance, young to mature northern hardwood forests provide lower quality habitats for late-successional species (see reviews in Tyrell and Crow 1994; Keddy and Drummond 1996; McGee et al. 1999), lower levels of biomass and associated carbon storage (Krankina and Harmon 1994; Strong 1997; Houghton et al. 1999), and reduced riparian functionality in terms of effects on headwater streams (Keeton et al. 2007b). Interest in disturbance-based forestry has developed as managers look for new approaches offering a broader array of ecosystems goods and services. Rehabilitation of forestlands degraded (e.g. poor stocking and genetic vigor) through intensive high-grade logging, a practice particularly widespread on former industrial timberlands, is another major concern (Kenefic et al. 2005). Disturbance-based approaches have great potential for restoring structural complexity at both landscape and stand scales. This would be achieved using harvesting approaches that emulate both natural disturbance effects and their interaction with processes of stand development, leading to provision of a range of stand structures, developmental stages, and associated ecosystem functions.

Historic disturbance regimes – development of disturbance-based forestry practices begins with an understanding of natural disturbance dynamics and their influence on ecosystem structure and function. In the northern hardwood region, a variety of disturbance agents, including wind, ice, insects, fungal pathogens, beavers (*Castor canadensis*), floods, and fire, have shaped forested landscapes for centuries. Wind disturbances are generally dominant, occurring most frequently as low intensity wind storms that result in fine-scaled canopy gaps. The region also experiences a variety of other types of wind events, including hurricanes, straight line winds and microbursts, and tornadoes. In New England, hurricane frequency and intensity decrease along a gradient running inland from the southeast to the northwest (Boose et al. 2001). Susceptibility to wind disturbance varies with topographic position and orientation relative to wind direction (Foster and Boose 1992), adding to patch complexity at landscape scales. High intensity wind events leave significant accumulations of downed wood debris as well as standing biological legacies, primarily snapped and uprooted stems (Foster 1988). Retention of legacy structure is, therefore, an appropriate way to emulate this type of disturbance.

Seymour et al. (2002) reviewed the literature and found a discontinuity in both frequency and spatial extent of natural disturbances in the northeastern U.S. They concluded that natural disturbances have been either relatively high frequency (e.g. returns intervals of 100 years) with small extent (e.g. 0.05 ha) or very low frequency (e.g. return intervals approaching or exceeding 1000 years) with large extent (e.g. $>$10 ha). However, recent studies suggest that intermediate intensity disturbances, such as ice storms and microburst wind events, may be more prevalent than previously recognized (Ziegler 2002; Millward and Kraft 2004; Woods 2004; Hanson and Lorimer 2007). These events tend to produce partial to high canopy mortality across a moderate to large sized area, but they can leave abundant residual live and dead or damaged trees (Keeton unpublished data). Remnant trees together with regeneration and release effects, can result in multi-aged stand structures. Multi-cohort silvicultural systems are thus analogous, in some respects, to the age structure produced by intermediate intensity disturbances.

The important role of canopy gap forming disturbances in stand dynamics and related ecosystem functions is well established (Dahir and Lorimer 1996; Runkle 2000). Disturbance gaps usually involve death or damage to individual or small groups of trees. Depending on size and orientation, gaps can result in regeneration of intermediate to shade tolerant species, release of advanced regeneration, and/or competitive release and accelerated growth in proximate overstory trees. In mesic, late-successional forest types, disturbance gaps form at the rate of about 1% of stand area per year on average (Runkle 1982). Gap patterns in northern hardwood stands are often highly diffuse, with individual gaps having irregular form and encompassing scattered residual or legacy trees, both live and dead. Sequential disturbance events can cause gap expansion over time (Foster and Reiners 1986). Gap phase processes are important drivers of both vertical and horizontal structural diversification, particularly late in stand development. Consequently, many late-successional habitat attributes depend on disturbance originated canopy gaps (Keddy and Drummond 1996). Hence, disturbance based forestry practices are often designed to emulate gap processes, especially where management objectives include regeneration of intermediate to shade-tolerant species and maintenance of multi- or uneven-aged structure.

Fire was far less prevalent, historically, in the northern hardwood region in comparison to western coniferous forests, although there were important exceptions. There are a number of fire dependent/fire maintained plant associations, such as pine barren, pitch pine (*Pinus rigida*)/oak communities, and the jack pine (*Pinus banksiana*) seral type in the upper Midwest. Many of these have declined as a result of fire exclusion. Restoration of stand structure and species composition characteristic of historic fire regimes remains an important management objective on appropriate sites. There is debate regarding the geographic extent of Native American burning prior to European settlement, with some authors stressing the amount of grassland and early successional shrubland/forest maintained for berries, game, and agriculture (DeGaaf and Yamasaki 2001, 2003). However, historical evidence suggests that aboriginal fire in the northeastern U.S. was primarily restricted to the vicinity of settlements and travel routes (Russell 1983).

Native insects and pathogens, such as defoliators (e.g. eastern spruce budworm [*Choristoneura fumiferana*]) and root rots (e.g. *Armillaria* spp.), historically had important influences on stand dynamics and habitat complexity at gap and stand scales. Introduced organisms, including beech bark disease (*Nectria* spp.), ash yellows (caused by a mycoplasma-like organism), pear thrips (*Taeniothrips inconsequens*), and hemlock woolly adelgid (*Adelges tsugae*), are among the greatest current threats to forest ecosystem sustainability in the northern forest region. Two exceedingly important species, American chestnut (*Castanea dentate*) and American elm (*Ulmus americana*), were functionally extirpated by exotic pathogens in the 20th century, although efforts are underway to reintroduce hybrid varieties bred for disease resistance. Declines in native tree species impacted by exotic organisms, together with a changing global environment, limits our ability to manage within the HRV and necessitates an adaptive, forward looking approach.

Disturbance-based management – application of disturbance based forestry concepts in the northern hardwood region has a number of things working in its favor. First, the region has had long experience with partial cutting and selection harvesting that in many ways mirrors the relatively frequent and low intensity, fine-scaled disturbances endemic to northern hardwood systems. Secondly, many of the commercially valuable hardwood species, and some of the commercial conifers, have intermediate to high shade tolerances and thus respond favorably, both in growth and regeneration, to low intensity harvests that might emulate natural disturbance effects. However, closer examination of the region's disturbance regime indicates a far greater degree of structural and compositional complexity – with respect to the range of effects associated with different disturbance types, frequencies, intensities, spatial patterns, etc. – than is afforded through conventional silvicultural systems. Hence, developing systems that produce and maintain complexity becomes a central objective of disturbance based forestry.

There are several examples of disturbance based silvicultural systems developed in the northern hardwood and southeastern boreal forest regions (e.g. Harvey et al. 2002; Seymour 2005; Keeton 2006; Seymour et al. 2006). These share a number of concepts that may have broader relevance outside the region. First, some of these systems emulate gap processes, but strive for variety in gap size and shape in a manner similar to heterogeneous disturbance effects. Secondly, they stress retention of biologically legacies to maintain and enrich stand structural complexity over multiple management entries. Restoration and management for stand structural complexity in general is an explicit objective. Thirdly, management for multi- or uneven-aged structure best emulates the dominant structural condition associated with natural disturbance regimes in these regions. Fourth, harvest entry cycles, desired stand age distributions, and percent of stand area harvested at each entry can be modeled on natural disturbance frequencies and scales. And fifth, carefully designed intermediate treatments can emulate the accelerating effect of low intensity natural disturbances on rates of stand development. This is true so long as they maintain and promote development of structural complexity (vertical, horizontal, dead and dying trees, etc.) rather than homogenizing structure, as is typical of conventional thinnings.

To guide disturbance-based forestry in the northeastern U.S. Seymour et al. (2002) proposed a "comparability index" based on their analysis discussed in the preceding section. The index depicts the correspondence between conventional harvest systems and natural disturbance frequencies and scales. Conventional even-aged approaches, such as clearcut logging, are not in synch with natural disturbance frequencies for northern hardwoods if practiced on short rotations (e.g. $<$ 100 years). Extended rotations (see Curtis 1997) would move closer to this benchmark. Entry periods associated with uneven-aged forestry did show a close correspondence with natural frequency; scales were similar but typical group selection openings are generally slightly larger than natural gaps. While Seymour et al. (2002) identified two general regimes using frequency and scale (see preceding section), the various studies reviewed showed considerable variation around the means. This supports the need to vary opening sizes, levels of canopy retention, and spatial patterns to emulate the complexity inherent to natural disturbance regimes.

The principles described above primarily address stand level management. Yet in the northern hardwood region there are questions regarding whether landscape scale age class distributions should be shifted closer to that associated with natural disturbance regimes (Lorimer and White 2003; Keeton 2006). Given the current over abundance of young to mature stands, an artifact of land-use history, this would require a greater emphasis on management for late-successional forest characteristics. Late-successional forests are dramatically under-represented relative to HRV (Lorimer and White 2003). Others have advocated managing for early-successional forest habitats due to declines in some disturbance dependent wildlife species. Proponents of this approach favor patch-cut or large-group selection harvesting methods (Hunter et al. 2001; King et al. 2001; DeGaaf and Yamasaki 2003). Although early successional habitats represented something less than 10% of the landscape historically, there are concerns that grassland/shrubland habitats may be approaching this level in some locales (DeGaaf and Yamasaki 2003). Thus, a disturbance based approach in this region will require consideration of these differing, though not mutually exclusive, proposals for managing age class distributions.

Two examples of experimental research help illustrate the application of disturbance-based forestry concepts to the northern forest region. The first is a project called the "Acadian Forest Ecosystem Research Program" (Seymour 2005; Saunders and Wagner 2005; Seymour et al. 2006). It provides an example of "area based" prescriptions. The study is testing two silvicultural systems, an irregular group shelterwood with reserves (or retention) and a "small gap" group selection with reserves (Fig. 17.3). Both systems emulate "natural disturbance rates, patterns,

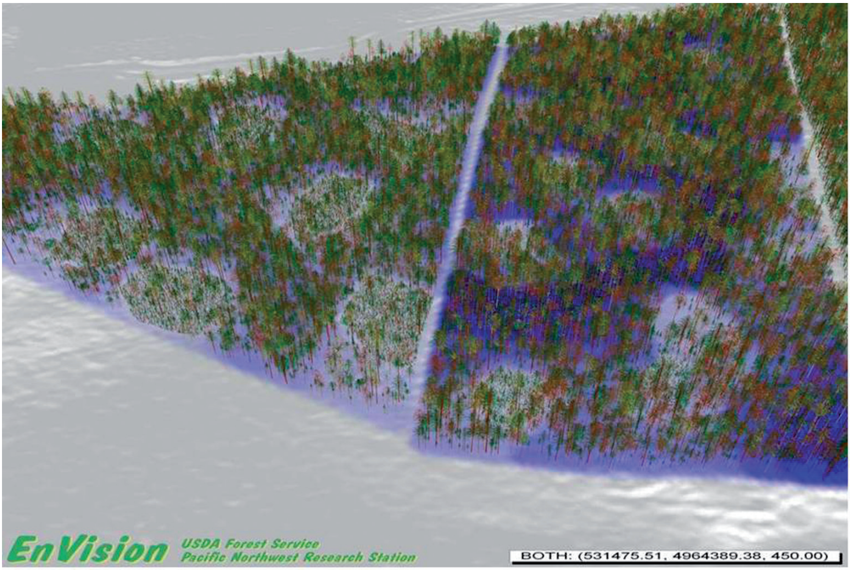


Fig. 17.3 Simulated view of the Acadian Forest Ecosystem Research Project areas on the Penobscot Experimental Forest, Maine. Shown is year 11 following treatment for group shelterwood with retention (*left*) and group selection with retention (*right*). The first group expansion has just occurred for the group shelterwood. Gaps are positioned based on actual GPS locations. Visualization of regeneration and reserve trees is based on tally data. Overstory structure is averaged across the blocks. Figure courtesy of Robert Seymour, University of Maine

and structural features of natural forests" by adjusting cutting cycles, removal rates, and reserve tree retention levels (Seymour 2005: 45). They approximate the 1% annual disturbance rate and partial mortality (i.e. persistence of biological legacies) typical of gap dynamics in this region. The first (large gap) treatment is modeled after the German *Femelschlag* or "expanding gap," in which large group harvests (each about 0.2 ha in size) expand previously created openings at each entry. This emulates observed natural gap dynamics (Runkle 1982). Under this approach 20% of stand area is cut every 10 years over 5 entries, followed by 50 years with no harvesting. If advanced regeneration is lacking, 30% of overstory basal area is retained within gaps; at the next entry this is reduced to 10% for permanent retention. The second (small gap) system is a half speed version of the first. It harvests and regenerates 10% of stand area in roughly 0.1 ha patches every 10 years. Individual gaps are expanded every 20 years; the within group retention prescription matches the first treatment. Both systems shift initial single cohort structures to "diverse, irregular within-stand age structures." Long-term retention of reserve trees within groups ensures that legacy large tree structure is maintained throughout the management unit.

A second example is provided by the Vermont Forest Ecosystem Management Demonstration Project (FEMDP) (Keeton 2006). This study is evaluating the ability of modified uneven-aged silvicultural approaches to accelerate rates of stand development. Prescriptions are based primarily on tree diameter distributions.

Biodiversity responses (McKenny et al. 2006; Smith et al. in press) and economic tradeoffs (Keeton and Troy 2006) are of key interest. Modified single-tree selection and group-selection are compared against an alternative approach called "structural complexity enhancement" (SCE). Both of the selection systems include higher levels of post-harvest retention than is typical for the region. The group selection treatment employs small (mean 0.05 ha) but variably sized groups, with light retention of individual live and dead trees within groups, to emulate the scale and structural diversity associated with natural gap dynamics (Fig. 17.1). Compliance with worker safety regulations is maintained by topping large snags within groups and through the use of fully enclosed harvesting machinery. SCE is a restorative approach that promotes development of old-growth structural characteristics (Keeton 2006). It combines a number of disturbance-based silvicultural approaches, including variable density marking to create small gaps, crown release to promote development of large trees, enhancement of coarse woody debris (standing and downed) densities, including pushing or pulling trees over to create tip-up mounds, and an unconventional marking guide based on a rotated sigmoid diameter distribution. The latter reflects the growing appreciation for the disturbance history-related diversity of diameter distributions found in late-successional forests (Goodburn and Lorimer 1999; O'Hara 2001).

Application of disturbance-based forestry at the landscape scale is complicated in the northern forest region because the majority (93%) of forests are privately owned and held in small parcel sizes (now averaging < 4 ha). Mean parcels sizes have been trending downward for several decades due to increasing rates of subdivision and exurban housing and commercial development. This contrasts with many regions of the western U.S., where large proportions of the landscape are in public ownership and can be managed holistically, for instance to plan patch dynamics at large scales. Meeting large scale objectives in highly parcelized landscapes, such as management of age class distributions and scheduling the frequency and spatial pattern of harvests to achieve desired patch configurations, can only be achieved through the collective or combined actions of many individual landowners operating on a parcel by parcel basis. Public land holdings in the region, including national and state forests, offer larger contiguous forest tracts where disturbance-based forest management is directly applicable.

There are, however, policy instruments that could be used to promote broader adoption of disturbance-based management objectives. Increasingly forest conservation on private lands in the Northeast, including large blocks of former and current industrial timberland, is achieved through a combination of incentive based and market mechanisms as well as limited acquisition of high conservation value forests. Conservation easements and tax incentive programs, such as current use value appraisal, provide a means for conserving working forests and promoting sustainable management practices. As former industrial timberlands are transferred to new ownerships under easement, there is the potential to build disturbance-based forestry requirements into conservation agreements and revised management plans. Forest certification offers another potential avenue for explicate incorporation of disturbance-based forestry concepts into management planning. Finally, community based forestry can help achieve disturbance based objectives through the aggregate contribution of multiple landowners. Community-based initiatives involving multiple landowners provide strength in numbers. Landowners, in effect, voluntarily pool their resources and, to some degree, coordinate management across a larger area. This gives participants access to market opportunities not readily available to individuals. If conducted under a set of agreed upon standards there is an opportunity for disturbance-based forestry through community forestry.

17.4 Lessons

Disturbed-based forest management is increasingly used in forest types across North America to enhance the range of ecosystem goods and services provided by managed forests. Although specific silvicultural systems and implementation vary depending on regional disturbance regimes (Table 17.1), several common advantages and limitations to disturbance-based forestry have emerged.

17.4.1 Limitations

Before regionally specific disturbance-based management systems can be implemented, researchers need to provide comprehensive information on historic and current disturbance regimes, including disturbance frequencies, intensities, patterns, and associated biological legacies. With this information, managers may find that efforts to closely emulate natural disturbance regimes face social and economic constraints. For example, in the Pacific Northwest, large tracts of contiguous forest would need to be treated to emulate the scale of historic wind and fire disturbances. Management has been able to extend the rotation period between harvests and leave more structural legacies, but the public is not receptive to treating large (>400 ha) blocks of forest at one time. This would also carry significant ecological risk due to the current scarcity of late-successional forests (Aplet and Keeton 1999). In mixed-conifer forests, fuels need to be reduced every 15–30 years with either repeated applications of prescribed fire or service contracts that hand thin and pile burn small unmerchantable trees that have accumulated with fire suppression. Both practices can be expensive (e.g. > $200 and >$1000/ha, respectively). Managers are also constrained from mimicking historic landscape patterns because past practices (logging in riparian areas), public health (prescribed fire smoke), and safety concerns (rural homes) limit options. In Northeastern forests, extensive private ownership and a general skepticism of land use regulation makes coordination of landscape-level management difficult.

Disturbance-based forestry practices have been legitimately criticized for carrying significant uncertainty when it comes to producing the process effects induced by natural disturbances (Lindenmayer et al. 2007). For instance, foresters

Table 17.1 Historic disturbances, disturbance-based silviculture, example projects, and management challenges for three regional forest types in the United States

	Pacific Northwest coniferous forests	Western mixed conifer forests	North hardwood forests
Dominant historic disturbances:	Fine-scaled canopy gaps	Low-moderate intensity wildfire	Low intensity wind; fine-scale canopy gaps
Stand scale			
Landscape scale	Infrequent, high-intensity fire and windstorm	Moderate intensity wildfire	Intermediate intensity microbursts and ice storms Infrequent, high-intensity hurricanes
Disturbance-based silvicultural systems:	Variable density thinning and underplanting	Fuels reduction that varies by landscape topographic position:	Variable density thinning; crown release
	Group selection/gap creation	Ridgetop: remove understory fuels and leave overstory trees with widely separated crowns	Selection harvesting with structural retention within variably sized groups
	Regeneration harvesting with aggregated and dispersed green tree retention	Midslope: thin from below up to 50–75 cm dbh	Expanding gap systems
	Variable retention harvest system	Riparian: no entry	Multi-cohort systems
Examples of experimental projects:[1]	Demonstration of Ecosystem Management Options	Fire and Fire Surrogate Study	Acadian Forest Ecosystem Research Program
	Olympic Habitat Development Study	The Teakettle Ecosystem Experiment	Vermont Forest Ecosystem Management Demonstration Project
	Montane Alternative Silvicultural Systems	Southern Utah Fuel Management Demonstration Project	
	Variable Retention Adaptive Management Experiments		
Challenges:	Large scale of dominant disturbances	Human constraints on treatment types and intensities	Extensive private ownership of small parcels

[1]For literature describing the project examples see Peterson and Maguire (2005).

can approximate the structural legacies and patterns associated with wind throw, but they may not achieve (or may only achieve in part) the same effects on soil turnover, soil carbon dynamics, and nutrient cycling. Similarly, thinning can restore the stand and landscape structures that historically supported low to moderate intensity fire regimes, but may fall short when it comes to the full range of effects on ecosystem processes associated with frequent natural fire (North 2006). Lindemayer et al. (2007) point out that the specific sequence of disturbances over time, their timing, intensity, type, and pattern, can result in complex process effects that may be hard to approximate through management.

These limitations, however, do not mean that disturbance-based forest management is fundamentally impractical or scientifically flawed. But they do suggest that forest managers often cannot fully or directly emulate historic disturbance patterns at the stand level, and are particularly limited at landscape scales. Rather, knowledge and inferences based on natural disturbance regimes can be used to guide and modify silvicultural manipulations to achieve a more limited set of objectives.

17.4.2 Modifying Silviculture to Better Match Disturbance Regimes

Silviculture has traditionally focused on manipulating stands (Oliver and Larson 1996) to influence forest succession while extracting wood products (Smith 1986). Thinning guidelines are developed to achieve a desired age structure, diameter distribution, species composition, and spatial pattern. This approach can attempt to engineer forest structure to fit a concept of stand dynamics that may not match disturbance processes. For example, to produce "semi-natural" forest conditions silviculturists have sometimes relied on the principles of uneven-aged silviculture (Smith 1986), which suggest cutting to a negative exponential or reverse-J shaped diameter distribution to produce a multi-aged structure. This was the shape of the diameter distribution North et al. (2007) found in unmanaged, fire-suppressed mixed conifer (Fig. 17.4, pretreatment bar) and which was maintained with diameter-based thinning prescriptions (Fig. 17.4, understory and overstory thinning bars). However, a reconstruction of the same forest in 1865, when it had an active fire regime, found an almost flat diameter distribution (Fig. 17.4, 1865 reconstruction bar), probably resulting from pulses of mortality and recruitment associated with fires and wet El Nino years (North et al. 2005). O'Hara (2001; O'Hara and Gersonde 2004) has pointed out that seral development and local disturbance patterns can produce a wide variety of diameter distributions in natural stands. Similar variability in age class structure has been documented in the Pacific Northwest (Zenner 2005) and the northern hardwood region (Goodburn and Lorimer 1999). Thus, modified silvicultural practices might manage for a broader range of diameter distributions and age-class structures more characteristic of local disturbance regimes (O'Hara 2001; Keeton 2006).

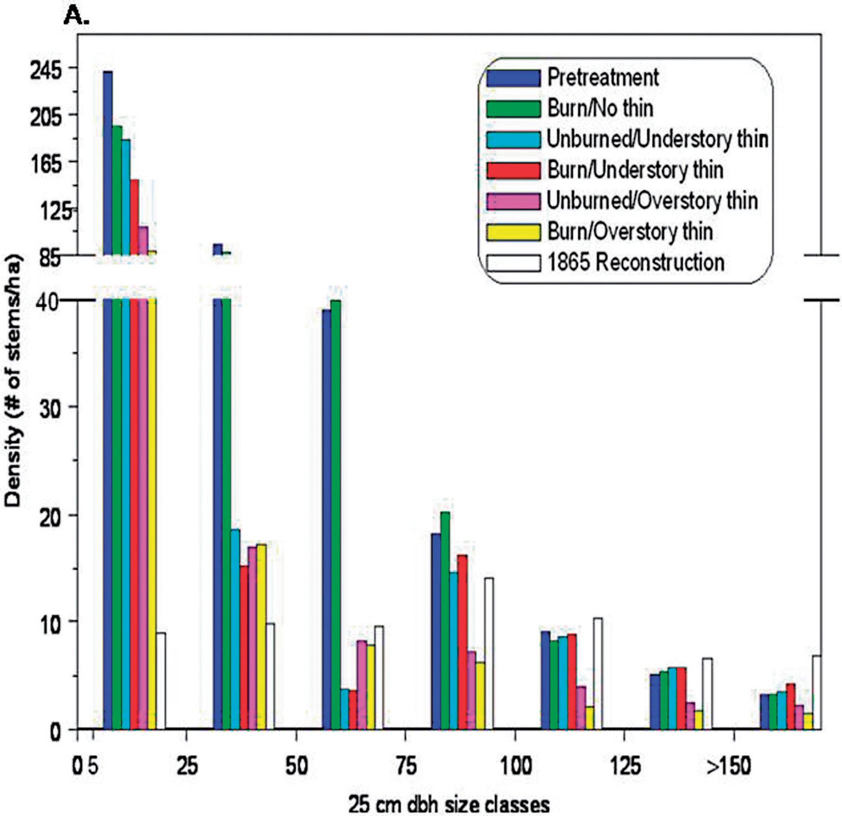
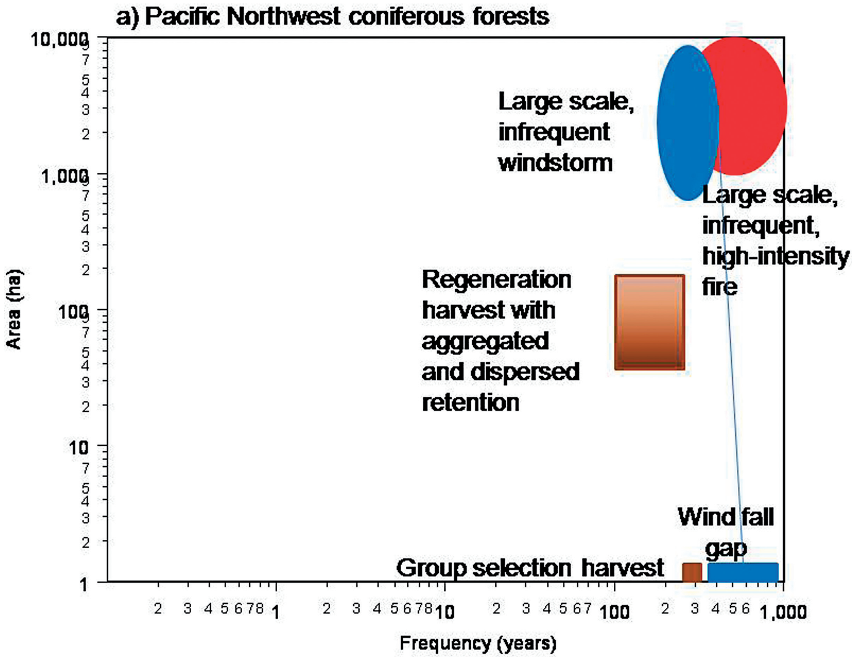


Fig. 17.4 Density of trees in 25 cm diameter classes in old-growth, mixed conifer at the Teakettle Experimental Forest. The pretreatment forest (fire suppressed modern conditions, *blue bar*) has a reverse-j shaped diameter distribution, as do the five silvicultural treatments used in an effort to reduce fuels and restore historic stand conditions. The reconstruction of stand conditions in 1865 (*white bar*), however, indicates a fairly flat diameter distribution and a greater number of large trees. Figure from North et al. 2007

17.4.3 Comparing Management Practices to Natural Disturbances

One potential method for evaluating silvicultural practices is to examine their congruence with historic disturbance events. For example Seymour et al.'s (2002) comparability index evaluates the size and rotation length of management treatments against the scale and frequency of regional natural disturbance patterns. This interesting approach builds on two of the three characteristics of disturbance that some researchers (Hunter 1999; Lindenmayer and Franklin 2002) have suggested using to evaluate management activities. In addition to Seymour et al.'s (2002) choice of scale and frequency, we suggest a third evaluation criterion, the level of biological legacies left by historic disturbances. We compared current silvicultural practices in the three regional case studies against the historic disturbance regimes



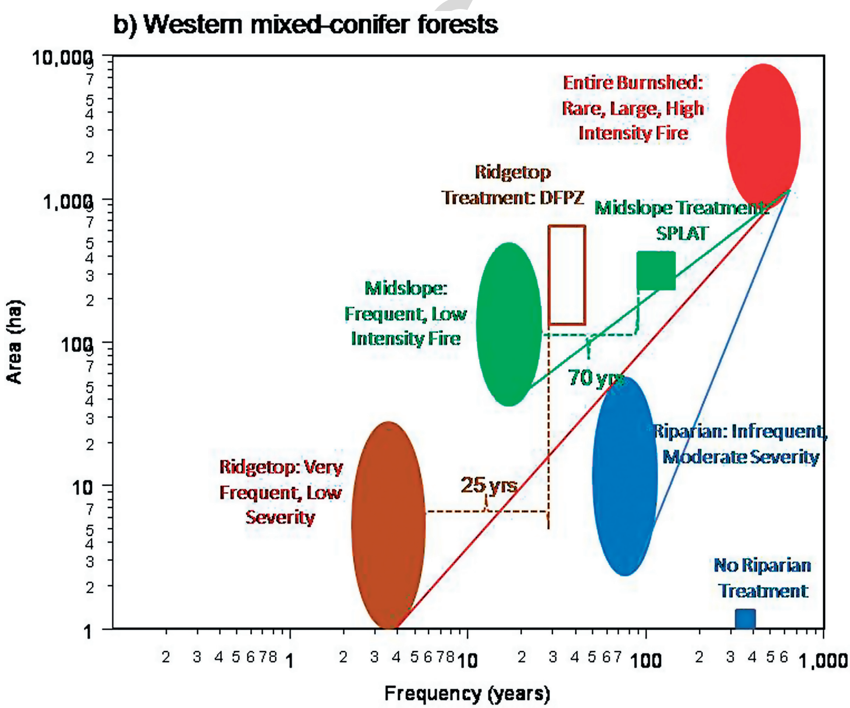


Fig. 17.5 (continued)

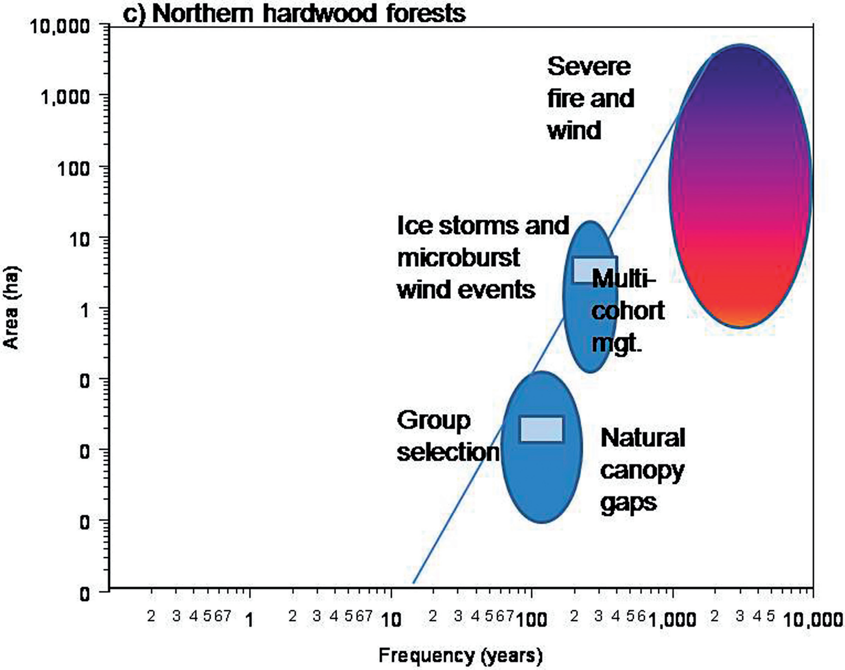


Fig. 17.5 A comparison of natural disturbance regimes and management treatments based on concepts in Seymour et al. (2002) in (**a**) Pacific Northwest coniferous forests; (**b**) Western mixed-conifer forests; and (**c**) Northeastern hardwood forests. The *x* axis is a logorithmic scale of the frequency of events in years and the *y* axis is a logorithmic scale of the size of events in hectares. Ovals represent historic disturbance regimes and rectangles represent management practices. For each oval and rectangle, shape width is the frequency range (*in years*) for a disturbance type, shape height is the range of scales (*in hectares*) and shape fill (*shaded* for aggregated, *non-shaded* for dispersed) is the pattern of biological legacies. The diagonal lines between the rare, large-scale and more frequent, small-scale ovals are a reference for the bounds (longest return interval and smallest scale) of each forest type's natural disturbance regime. The Northeastern hardwood diagram modifies one in Seymour et al. (2002), adding a hypothesized intermediate disturbance regime suggested by recent research (Millward and Kraft 2004; Woods 2004; Hanson and Lorimer 2007)

for those forest types (Figs. 17.5a, 17.5b, 17.5c) using Seymour et al.'s (2002) concept. The Pacific Northwest case study illustrates the difficulty in using disturbance-based management at the landscape level. Fire and high-intensity wind disturbances generally affected large areas (>1000 ha), which managers cannot directly emulate due to competing management objectives (Fig. 17.5a). In mixed conifer, managers are attempting to vary their treatments across the landscape, depending on topographic position, but with varying success (Fig. 17.5b). The most significant management departure from historic disturbance patterns is for riparian zones which are currently not being treated and may act like wicks to spread crown fire throughout the landscape. Ridgetop treatments, the creation of defensible fuel profile zones, are conducted on a much larger scale than historic ridgetop fire sizes and are leaving trees regularly spaced rather than grouped together. Group selection cutting in Northeastern hardwood forests approximates fine-scaled gap disturbances but there is little opportunity to coordinate this approach at landscape scales because of extensive private, small-scale ownership (Fig. 17.5c).

Our case studies suggest that social values, competing ecological objectives, and encroaching human settlement sometimes constrain our ability to emulate natural disturbance dynamics at landscape scales. Although managers may not be able to meet all landscape objectives, by comparing silvicultural treatments against the scale, frequency, and biological legacies characteristic of historic disturbances they can understand where compromises are made and risks accrue.

Disturbance-based forest management is a conceptual approach where the central premise might be summarized as "manipulation of forest ecosystems should work within the limits established by natural disturbance patterns prior to extensive human alteration of the landscape" (Seymour and Hunter 1999). Although such an objective seems like a simple extension of traditional silviculture, it fundamentally differs from past fine filter approaches that have manipulated forests for specific objectives such as timber production, water yield, or endangered species habitat. Some critics have argued that this approach leaves managers without clear guidelines because the scale and processes of ecosystems are poorly defined, making it difficult to directly emulate the ecological effects of natural disturbances (Oliver and Larson 1996). Disturbance-based management, however, readily acknowledges these uncertainties. It emphasizes a cautious approach, targeted at those specific management objectives, such as provision of complex habitat structures, reduced harvesting impacts, and landscape connectivity, that can be achieved. Although this approach will require changes in how management success is evaluated, disturbance-based management is likely to minimize adverse impacts on complex ecological processes that knit together the forest landscape.

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