Disturbance Regimes and Their Relationships to Forest Health

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Abstract.—While planners deal with landscape issues in forest health, silviculturists deal with the basic units of the landscape, forest stands. The silviculturist manipulates small-scale disturbances and needs appropriate management indicators. Disturbance agents and their effects are important to stand development and are therefore useful as management indicators. More studies are needed to improve our understanding of the spatial and temporal patterns associated with various agents. We propose use of a disturbance profile to quantify small-scale disturbance regimes. This multivariate descriptor can assist making decisions on where, when and how to mimic, promote, suppress or tolerate natural disturbance.

INTRODUCTION

New attitudes and concerns for maintaining healthy forests have made planners and silviculturists more aware of the importance of natural disturbances in shaping forest landscapes and stands. Fire, insects and pathogens are no longer considered necessarily undesirable and are now recognized as performing valuable ecological functions and even promoting ecosystem health (Haack and Byler 1993; van der Kamp 1991). Small-scale natural disturbances induced by insects or pathogens at the gap or stand levels could even be used to achieve management objectives (Lundquist 1995b). However, such use of small-scale disturbance requires an good understanding of the spatial and temporal characteristics (disturbance regimes) of vegetation response and recovery (Lundquist 1995a, 1995b, 1995c). For describing and modeling disturbance regimes at the stand level, we have developed the concept of a multivariate, spatially-explicit disturbance profile (Lundquist 1995b). This tool can assist silviculturists in making site-specific decisions on where, when and how to mimic, promote, suppress or tolerate natural, small-scale disturbances.

A HEALTHY FOREST

Forest health can be viewed from a number of different perspectives. The concepts of "tree health" and "stand health" are generally understood as complements of traditional tree and forest pathology. A healthy tree is one without damaging injuries or diseases, and a healthy stand is one without devastating infestations. Here, we use the term "forest health" in the sense of ecosystem health from the utilitarian perspective of satisfying management objectives as well as the ecological perspective of maintaining natural processes and structures (Kolb and others 1994; Shrader-Frechette 1994). Although the analogy of forest health with human health is flawed, it still provides a useful metaphor. All concepts of "health" include two principles: an identified goal and a comparison to some normal standard. In medicine, the goal is determined by ethics as preservation of human life or dignity; the normal standards are determined by clinical studies of selected populations. In forestry,

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the goal on public lands is determined by policy as ecosystem management for sustainability, integrity and diversity; standards and guidelines are proposed by resource specialists and set by managers. The challenge is to determine how these abstract qualities can be measured and what reference sites to use for establishing standards (but see Lemons 1985).

DISTURBANCE

Forest ecologists and managers recognize that disturbance, as well as site factors and competition, determine forest species composition and succession. Disturbance is more than the destruction of vegetation; it is an opportunity for release and reorganization (Holling 1992). Disturbance increases ecosystem heterogeneity and responds to it (Knight 1987). The repetition of overlapping vegetation patches of various sizes and ages across the forest landscape demonstrates that disturbance is frequently recurrent and ubiquitous (see Reice 1994). Disturbance is also scale-dependent; disturbance processes at a lower level of the ecological hierarchy produce the vegetation patterns observed at a higher level (Allen and Hoekstra 1992).

The spatial and temporal patterns associated with the repeated occurrence of a given disturbance agent define its regime (Pickett and White 1985; Pickett and others 1989). These patterns are described by means and variances in location, size and shape of affected area, frequency, synchrony, seasonality, duration, rotation and intensity of the disturbance, the severity of damage, and synergysim among agents. The disturbance regime of a specific agent is spatially and temporally keyed to a characteristic scale: e.g., windthrows at a gap scale and ice ages at a continental scale (Delcourt and others 1983).

The effect of disturbance on landscape dynamics depends on the proportion of the area affected and on the ratio of disturbance frequency to recovery time (Turner and others 1993). Small-scale and large-scale disturbances are distinguished not by the areal extent affected but by the resulting variation in stand age distributions across the landscape. Landscapes with small variation in age distributions over time result from disturbance regimes that operate at fundamentally small scales (canopy gap to stand). Large-scale disturbances (i.e., introduction of exotic species) or significant alteration of a disturbance regime (i.e., suppression of low intensity fires) can induce catastrophic changes into the ecosystem.

Because forest insects and pathogens are sensitive to host distribution, size and physiological condition, which are relatively uniform within patches, they are primarily agents of gap- or stand-level disturbance. In analyzing or treating infested stands, the silviculturist needs to be especially mindful of their effects on tree reproduction, growth and mortality within stands. The planner, concerned with the landscape patterns, should be aware of how insects and pathogens modify long-term succession and induce stand replacement. Both levels of the ecological hierarchy are relevant to ecosystem management and forest health (Allen 1994). Both levels are influenced directly or indirectly, respectively, by the small-scale disturbances caused by insects and pathogens.

Because agents such as fire, stem rust, bark beetles, root disease and mistletoe spread by different means and cause different types of damage, they have distinctive disturbance regimes that vary by forest type and condition. These differences can be illustrated by examples pertinent to the forests of the Sacramento Mountains, New Mexico (Mescalero Apache Indian Reservation and Lincoln National Forest).

Fire in the Southwestern Mixed Conifer Forest

One of our study sites in the mixed conifer forest of the Sacramento Mountains is the Delworth plot. This mesic, south-facing stand of Douglas-fir, white fir, ponderosa pine, and southwestern white pine was logged in the 1930s and again in 1969. The canopy is multistoried and contains many large-size trees. All recorded fires occurred before 1879, at a mean interval of 10 years; and these fires usually occurred early in the growing season (Huckaby and Brown 1995). This pattern of frequent, low-intensity fires in the previous century and their relative rarity in this century is typical of fire regimes in the Southwest (Swetnam and Baisan 1995). In contrast to the earlier low-intensity fires which cleared undergrowth and maintained open stands of large-size trees, most recent fires in the surrounding forest have been high-intensity, stand-replacing crown fires. Fire regimes are influenced by forest conditions and management practices which affect fuel loading. Although fire has not occurred recently at the Delworth site, stand density and composition are suitable for a damaging fire.

Stem Rusts of Pine

The most important stem rust in the Sacramento Mountains is the recently introduced white pine blister rust (*Cronartium ribicola*). Because the outbreak is still expanding, the character of its disturbance regime has not yet been established here (Geils 1995). However, comandra blister rust (*C. comandrae*) in the lodgepole pine forests of Wyoming, a native rust with a well described epidemiology, can illustrate its likely spatial and temporal behavior (Jacobi and others 1993). Spores that infect pines are produced on an alternate host species (comandra) and wind-dispersed to pine hosts when suitable environmental conditions of high humidity exist. Incidence is high where pine hosts are in close proximity to alternate hosts (<200 m); moderate incidence levels occur many kilometers downwind of alternate host populations. Episodes of severe infestation appear at irregular intervals but are frequent enough that serious outbreaks can occur each decade. Infected trees may become girdled by a rust canker; girdled trees are killed or spike-topped. Where alternate hosts are in close proximity to the pine, the disease appears to have a contagious distribution on the pine; but where spores have been dispersed over a long distance, distribution on pine appears random. Local features of the disturbance regime of stem rusts result from interactions of host distributions, landforms, and meso-scale climate. These factors in the Sacramento Mountains are favorable for the severe outbreak of white pine blister rust developing there.

Bark Beetles

Bark beetles (Scolytidae) are important mortality agents of pine and other conifers throughout the southern and western United States (Schowalter and Filip 1993). At endemic population levels, mortality is usually restricted to weakened, diseased, or otherwise stressed single or small group of trees. Upon emerging from a brood tree, adults disperse to either nearby or distant trees. Epidemics arise when significant amounts of the preferred host become stressed by droughts, windstorms, or biotic agents such as mistletoe or root disease. When these conditions comprise a large proportion of the forest, outbreaks occur. During expanding outbreaks, beetle populations increase to numbers sufficient to kill trees which would have otherwise not been attacked. Disturbance regimes are determined by the abundance, distribution, size, and condition of the hosts; weather, predators and parasites also influence the timing of outbreaks. The roundheaded pine beetle (*Dendroctonus adjunctus*) is now epidemic in the Sacramento Mountains; the previous outbreak occurred in the mid–1970's (Parker and others 1975).

Root Disease

Root diseases are caused by various fungi (e.g., *Armillaria*) which spread by root contact, root-feeding beetles, rhizomorphs or spores (Shaw and Kile 1991). Although infected trees eventually die, mortality is usually precipitated by other agents (wind or bark beetles). Although random individual trees may harbor and die of root disease, distinctive root disease pockets are common in some forests. These mortality pockets increase slowly, except where expansion is accelerated by partial cutting, and persist for decades, even following stand replacement. Proliferation and extinction of pockets is rare. Trees differ in their mortality rates from root disease by species and age; therefore root disease disturbance regimes are strongly influenced by stand composition and structure. Root diseases are important mortality agents in the Southwest (Wood 1983), and were commonly observed on the Delworth site.

Mistletoe

Dwarf mistletoes (*Arceuthobium*) spread primarily by short-range (<20 m), ballistic dispersal of seeds; rare long-distance dispersal (kilometers) which establishes new infection centers is effected by birds (Hawksworth and Wiens, 1995). As the infestation builds within centers, severely infected trees are stunted, broomed, topped, and eventually killed. Mortality rates accelerate exponentially as the mistletoe population increases. Because of its long life-cycle, centers expand only meters per year; nonetheless, well-scattered seed trees with mistletoe infections can re-infest a regenerated stand after only several decades. The distribution and abundance of mistletoe is strongly influenced by the fire regime and management practices. Mistletoe is very abundant and damaging in the Sacramento Mountains (Hawksworth 1959; Hessburg and Beatty 1986).

Other Disturbances and Interactions

Fire, stem rust, bark beetles, root disease, and dwarf mistletoes are not the only natural disturbance agents that affect forest stands of the Sacramento Mountains; decay fungi and defoliating insects (e.g. western spruce budworm) are also locally or occasionally important. The predisposing factors, damages, dynamics and interactions with other agents of each of these disturbances are different and complex. Root disease and dwarf mistletoe are persistent and by weakening trees often predispose those trees to attack by bark beetles. Trees broomed by mistletoe or recently killed by other agents provide fuels to carry fire from the surface to the canopy; but devastating crown fires can eradicate mistletoe from a stand (Alexander and Hawksworth 1975). The dynamics of mistletoe infection centers are intermediate between the sudden appearance of bark beetle spots and long-term site occupancy of root disease pockets. Southwestern white pine which is less damaged by fire, bark beetles, root disease and dwarf mistletoe had often filled-in following the mortality of other species from these agents and had therefore formed a buffer on their spread. By removing the southwestern white pine, blister rust may have an indirect effect of increasing the activity of other disturbance agents.

These complex relations can be quantified as a disturbance pathway composed of a predisposing factor, mortality agent, and tree response (Lundquist 1995a). Associations and sequences of pathways are recognized as networks and the importance of various pathways determined by the frequency with which they occur. Because different agents are associated with different spatial and temporal dynamics and interactions and because multiple agents are active in most forest stands, disturbance can not be treated as a single, generic process that simply kills trees uniformly over a given area at a certain return frequency. Managing stands and landscapes requires a site-specific knowledge of the effects and dynamics of the various disturbance agents which determine forest health.

A MANAGEMENT INDICATOR

The principal difficulty in relating the complex regimes and interactions of these disturbance agents to forest health is the lack of a suitable, quantitative, management indicator. Measures of stocking and commercial volumes appropriate for timber production are not adequate where the management goals are sustainability, integrity, and diversity. We have identified five attributes required of a satisfactory metric for relating disturbance and forest health:

1. sensitivity and responsiveness to effects of disturbance and recovery;
2. relationship to patterns and processes on the scale at which silviculture is practiced;
3. provides linkage to higher and lower spatial scales;
4. indicates the status and trend of resource values and ecological functions; and
5. reflects and responds to management activity in modeling exercises and implementation.

Research Strategy

The management indicator we propose is the disturbance profile (Lundquist 1995b). Our current research studies with the disturbance profile includes development of survey methods, summary and analysis procedures, descriptive and predictive models, experimental verification and management implementation (Lundquist and others 1995). Beatty and others (1995) describes the methods used to collect data and compute the disturbance profile; Lundquist (1995b) describes application of the profiling technique. Here, we introduce a basic strategy for integrating the spatial patterns and dynamics of multiple disturbance agents, vegetation responses and their interactions.

Disturbance Profile

The disturbance profile is a multivariate descriptor of distributions of live vegetation, canopy density, course woody debris and disturbance pathways within a forest stand (for detailed examples see Beatty and others 1995 or Lundquist 1995b, 1995d). The specific variables which quantify vegetation, canopy structure and composition, woody debris, and disturbance pathways are chosen for their relevance to the ecological patterns and processes at the gap and stand levels. These variables are also screened to determine their utility for tracking the effects of specific silvicultural treatments on stand dynamics and resource values. The selection of variables is also guided by an identified management objective; these objectives and variables provide specific definition to the general goals of sustainability, integrity, and diversity. The designated management objective also helps identify the population from which standard norms can be determined. In the study we are conducting on the Sacramento District the objective is "enhance habitat for the small mammal prey of the Mexican spotted owl." The disturbance profile is designed to be a silvicultural tool for monitoring and projecting the trends and effects of small-scale natural disturbances and their responses to management intervention.

We use a multi-scale approach for studying disturbance to develop an understanding of the underlying ecological processes at the gap level and to determine the distribution patterns of vegetation, canopy, and woody debris at the stand level. Small-scale disturbance is emphasized because associated predisposing factors and agents are more easily subjected to silvicultural treatment and because cost-benefit risks are more predictable and favorable. The dynamics and interactions of small-scale disturbance agents usually determine the patterns of stand heterogeneity and development and may influence vulnerability to a stand-replacing event.

The multi-scale approach to developing the disturbance profile involves two phases. First, we intensively study disturbance and recovery to observe the initiation, expansion and recolonization of canopy gaps on a series of 4 ha plots. This observation scale and extent is appropriate for the important disturbance agents such as fire, stem rust, bark beetles, root disease, and mistletoe. Then, we extensively survey a number of stands (10 to 200 ha) to determine the distribution patterns of gaps (and subsequent re-vegetated patches) by cause and age. These surveys provide detailed information on how various gaps and patches are interrelated and integrate into the stands designated by silviculturists for management. Distribution patterns of vegetation, canopy gaps, woody debris, and mortality agents are characterized in both of these exercises with spatial statistics and methods adapted from landscape ecology.

The field data collected during the intensive plot study and the extensive stand survey provides spatial and temporal information on 1) live trees and regeneration (vegetation), 2) horizontal canopy structure (gaps), 3) snags, logs, and stumps (coarse woody debris), and 4) biotic and abiotic mortality agents and associated predisposing factors (disturbance pathways). Vegetation, gaps, and coarse woody debris are the basic structures which comprise the stand as seen from resource and ecosystem management perspectives. The disturbance pathways identify the dominant processes active in the stand and therefore indicate likely trends of future development.

Disturbance Profile for Forest Health

The disturbance profile provides a operational method for defining forest health and determining how well a stand or proposed treatment meets forest health goals. The disturbance profile is intentionally constructed from measurable variables which reflect those ecological processes and structures related to sustainability, integrity, and diversity. Key to identifying the specific variables which comprise the profile is recognition of the management issue or context from which forest health is to be judged.

Forests are evolving biological systems with complex and ever-changing dynamics and structures. Knowledge of the range of variation in presettlement stands and of contemporary, unharvested stands is useful for indicating previous and potential realizations of forest conditions. But these conditions are not necessarily required or appropriate in the sample population which typifies the healthy forest stand. Reconstruction techniques provide only a portion of the description of disturbance regimes; relict, unharvested stands may persist as such because they were atypical. Most stands that have not been cut or grazed have nonetheless been subjected to suppression of fire or pests or indirectly affected by these activities in adjacent stands. One would not use the range of cholesterol levels from Eskimo populations to set the normal range for an American white male (see Beatty and others 1995). An overmature stand of climax species may not be appropriate standard for rating the health of spotted owl habitat on the Sacramento District. Finally, there are important differences in the disturbance regimes of various agents which have subsequent consquences on stand development.

Although there may be no universal standard conditions represented by some imaginary "undisturbed" stand for determining forest health, there are stands which can be recognized as desirable conditions for specific management objectives. Because these objectives can include ecological functions as well as commodity production, healthy forests in the broadest sense can represented by these stands. The disturbance profiles of these reference stands provides a standard and range of variability for assessing other stands or tracking their performance following treatment. By choosing stands which meet specific criteria of sustainability, integrity, and diversity as a standard, the profile can relate these qualities to the dynamic processes and complex patterns of various small-scale disturbance agents.

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