DISTURBANCE PROCESSES
AND ECOSYSTEM MANAGEMENT

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Executive Summary

"Ecosystems are not defined so much by the objects they contain as by the processes that regulate them"

Christensen and others 1989

Awareness and understanding of disturbance ecology and the role disturbance plays in ecosystem dynamics, and the ability to communicate that information, is essential in understanding ecosystem potentials and the consequences of management choices. Ecosystems constantly change in ways that are only partially predictable. To have an effective ecosystem management policy, resource managers and the public must understand the nature of ecological resiliency and stability and the role of natural disturbance on sustainability. Disturbances are common and important in virtually all ecosystems. The positive effects of disturbance on biodiversity is now recognized. Integrating disturbance ecology into sustainable resource management may be as much a social challenge as it is a biological problem.

Efforts to suppress disturbance, such as lightning-caused fires, floods, erosion, drought, disease, and insects, which have been perceived to be in conflict with economic interests, have resulted in reduced biodiversity and ecosystem health. The more we attempt to maintain an ecosystem in a static condition, the less likely we are to achieve what we intended. We must be willing to bear both the economic and biologic consequences of such management.

Disturbance is pervasive throughout forest and grassland ecosystems. It is not a question of whether disturbance will happen, but when, where, and what kind. Forest Service managers must consider and incorporate the following information on disturbances into the Agency's forest plans: the types of disturbance that are likely within specific ecosystems and criteria for predicting where particular disturbances will occur as well as the probability of occurrence. This information together with a knowledge of the vulnerability of certain areas to particular disturbances and the management objectives for those areas can increase the accuracy of assessments of the impact of disturbance and help managers better determine appropriate alternatives.

Disturbances caused by drought, disease, fire, insects, and wind are common in ecosystems managed by the Forest Service, but are most often viewed as difficult to predict or unpredictable. Because they occur with relative frequency across these ecosystems, the characterization of these disturbance regimes and an understanding of their role in ecosystem dynamics will increase the predictability of their occurrence and their socioeconomic impacts. The "tools" to facilitate this process, such as Global Positioning Systems, Geographic Information Systems, and geo-statistical technologies, are now available. Including disturbance potential in land management plans will increase our capability to respond appropriately following the occurrence of disturbances.

"Nothing is permanent but change"

Heraclitus 500 B.C.

I. INTRODUCTION

This paper is intended to broaden awareness and help develop consensus among USDA Forest Service scientists and resource managers about the role and significance of disturbance in ecosystem dynamics and, hence, resource management. It describes key concepts that will enable the Agency to integrate disturbance ecology into forest planning and ecosystem management within a social context. While much of what is presented here applies to all ecosystems, some language is specific to "wildlands" or "wild-like" lands managed by the Forest Service.

The paper is not a state-of-the-art summary on disturbance ecology. Rather, it presents current hypotheses about roles of disturbance in shaping ecosystem attributes and processes. Just as ecosystems are constantly changing, so are the hypotheses regarding their dynamics. A knowledge of disturbance and its role in ecosystems is critical to ecosystem management and to public understanding of ecosystem dynamics.

Many decisions and activities related to natural resource management are based on perceptions that ecosystems are stable, in equilibrium, and static. Yet, ecosystems and the processes that regulate them are continually changing. In fact, the **only** constant in ecosystems seems to be change. According to Vogl (1983): "When a living thing, community or system ceases to change it is nonfunctioning, decadent, or dead." The world's forests, shrublands, and grasslands are dynamic systems, forever changing in response to successional forces, long-term fluctuations in climate, and the more immediate effects of natural disturbance from disease, drought, fire, insects, storms, and the movements of earth, wind, and water. This paper focuses primarily on the "natural" (nonhuman) disturbance agents: disease, insects, drought, fire, and wind, though a given disturbance rarely is without some human influence. Indeed, some of the most remarkable effects of disturbance result when human-related activities cause or exacerbate disturbance.

Disturbances are commonly viewed negatively as a disruption of ecosystem equilibrium and an interruption of access to resources that otherwise would be available. Although disturbances disrupt socioeconomic expectations, a burgeoning science based on nonequilibrium theory indicates that they are essential ecological processes, necessary at some level of intensity and periodicity for the long-term sustainability and productivity of most, if not all, ecosystems. Vogl (1983) states that contrary to equilibrium theory, "Many organisms exist because of certain catastrophic factors or extreme conditions, and not in spite of them."

The long-term **health of ecosystems**1 is linked to disturbance. Recurrence of disturbance and recovery within ecosystems is an important mechanism for energy flow and nutrient cycling, and for maintaining age, species, genetic, and structural diversity, all attributes of ecosystem health. Disturbance occurs as a continuum from frequent intervals of low intensity to infrequent occurrences of high intensity (White and Pickett 1985). Disturbances typically follow a power law (Waldrop 1992); the average frequency of a given disturbance is inversely proportional to some power of its size. Large disturbances are rare, and small ones frequent. Ecosystems have evolved in response to disturbance-recovery regimes that have recurred over millions of years.

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1 A healthy ecosystem is one in which structure and functions allow the maintenance of the desired condition of biological diversity, biotic integrity, and ecological processes over time (Kaufmann et al. 1994).

The Forest Service is committed to applying "good science" in all resource management decisions. However, such decisions are made in an environment in which science itself is constantly changing. Management decisions are made in a social, political, and economic environment where judgments are guided not only by alternative beliefs about science but also by certain perceptions and illusions. The scientific community increasingly recognizes the nonequilibrium status of ecosystems. However, such a theory of constant change often is in conflict with socially imposed mandates that expect or are based on stable ecosystems. The science of disturbance ecology challenges the way in which the public perceives natural disturbances and their influence on the environment, and their attitudes about controlling and/or coexisting with them. Integrating disturbance ecology into **sustainable**2 resource management may be as much a social challenge as it is a biological problem.

Within the Forest Service we need to better understand the biological effects of disturbances, their patterns of occurrence and predictability, and their socioeconomic impacts. Current programs and policies are based on the perception that all disturbance is "bad" and that every disturbance, no matter the type or intensity, must be controlled. As a result, there is a lack of knowledge about the effects of disturbances and a lack of appreciation of their benefits.

Thus, the Forest Service needs to communicate that disturbances often occur as normal and essential forces of ecosystem dynamics and are not always catastrophic events that solely cause damage. The Agency also needs to communicate that attempts to control disturbances seem to operate within a power law, that is, actions that cause disturbances to occur less frequently often increases their magnitude when they do occur.

Ecosystem management3 requires the Forest Service to understand the complex concepts of ecosystem dynamics while meeting often competing demands for resources with other than politically based solutions. Our beliefs, perceptions, and illusions are deeply rooted and largely based on how we perceive ourselves in relation to our environment. We now appreciate and can now measure the impact of human activities on ecosystems. Integrating disturbance ecology into ecosystem management to sustain healthy and productive ecosystems could challenge the very notions of who we are and how we fit into the world around us.

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2 Sustainability means that desired ecological conditions or flows or benefits can be maintained over time (A National Framework For Ecosystem Management, USDA Forest Service, Washington, DC, 1994).

3 Ecosystem management is the skillful, integrated use of ecological knowledge at various scales to produce desired resource values, products, services, and conditions in ways that also sustain the diversity and productivity of ecosystems (R-5 Ecosystem Management Guidebook, Vol. 1, USDA Forest Service, Pacific Southwest Region, San Francisco, CA, 1994.)

II. NATURAL DISTURBANCE AND ECOSYSTEM DYNAMICS

DEFINITIONS

Disturbance--White and Pickett (1985) define disturbance as "any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment." As defined, disturbance includes both environmental fluctuations and destructive events and precludes whether or not an event is "normal" (White and Pickett 1985). The Forest Service defines disturbance as "a discrete event, either natural or human induced, that causes a change in the existing condition of an ecological system" (Interim Directive, USDA Forest Service, 1994; Kaufmann et al. 1994). This definition distinguishes between natural and human-induced disturbance and recognizes that resource management can cause disturbance.

While the importance of human-induced disturbances in ecosystem dynamics is recognized, it is beyond the scope of this paper to discuss fully their impacts. Likewise, this paper does not debate the "naturalness" of anthropogenic disturbance. However, disturbances caused by diseases, drought, fire, insects, and wind, do not always occur independent of human activities, and the human dimension is discussed when it is significantly related to disturbance caused by natural factors.

Although all biological systems are dynamic because of the processes of birth, growth, death, and replacement, most biological systems are dynamic because of additional factors, of which natural disturbances are paramount (White 1979). Reice (1994) states that: "most biological communities are always recovering from the last disturbance." In the traditional ecological view of disturbance, a clearly exogenous factor occurs at a single point in time, creates a "patch" with abrupt or clearly defined boundaries, and increases resources available for new growth through decreased biological use, increased decomposition, or both (White and Pickett 1985). However, disturbances can be caused by endogenous or exogenous factors that in natural ecosystems may not be readily distinguishable.

Disturbance results in the release of nutrients, light, moisture, and space and makes these available for new growth by existing or replacement species. The occurrence of these events in ecosystems relative to the lifespan of the biotic components can be fairly frequent or rare depending on the biota, disturbance factor(s), and the ecosystems.

A major effect of disturbance in ecosystem dynamics is a change in successional pathways. As a consequence, dominance of a site by one or several individual species can be reduced and diversity increased. In some ecosystems, disturbance is the critical factor in maintaining coexisting species. Effects of disturbance can be temporary or long term, but time is relative. Disturbance can cause the elimination of a species and result in major changes in species composition.

Regimes--Disturbance regimes are used to characterize the spatial scale and temporal patterns of disturbance and subsequent response and recovery of ecosystems. "Mosaics" of flora and fauna in an ecosystem reflect the temporal and spatial distribution of disturbance and its relationship to geographic, topographic, environmental, and plant-community gradients. The frequency of disturbance is measured over time. Frequency, the mean number of events per time period, is used to express the probability of an event occurring in a given year. The return interval (cycle or turnover time) is the mean time between disturbances on a given site, and the rotation period is the mean time needed to disturb an entire area. Rotation periods are longer than return intervals and are useful in explaining the distribution or abundance of a species in a landscape. Frequency of disturbance can have a major effect on species composition depending on the scale of the event. Generally, frequent disturbance favors shade-intolerant species while shade-tolerant species are typical of ecosystems disturbed infrequently.

Disturbances vary in magnitude depending on the intensity and severity of the disturbance. For physical disturbance, intensity is equivalent to the physical force (windspeed, BTU's, etc.) per area per time. For biological disturbances such as those caused by insects and diseases, intensity is closely related if not equivalent to population or inoculum levels and host susceptibility. Severity of a disturbance is described as its effects on the organism, community or ecosystem. Severity can be measured in terms of numbers lost from the populations in question or biomass destroyed, and in more subtle changes in carbon, nutrient, and water cycles and allocation among community members, changes in species composition, and changes in susceptibility and vulnerability to other disturbance agents.

The scale of a disturbance has a major effect on the composition of plant species and associated animal species. Small-scale disturbances favor shade-tolerant plant species while large-scale disturbances favor intolerant ones. Both large- and small-scale disturbances can operate simultaneously, resulting in mosaics with patches of varying size, species composition, and age structure within a landscape (Thompson 1978, Pickett and Thompson 1978). The patchiness within a landscape reflects: (1) the type or types of disturbance, their interaction if any, and their frequencies and magnitudes; (2) landscape elements of topography, substrate conditions and organisms, and resource base available to organisms; and (3) life histories and assimilative capacities of species present or potentially available to colonize a disturbed site (Forman and Gordon 1981).

Specific disturbances are not limited to specific ecosystems but they may occur more frequently in some ecosystems than in others. The response to disturbance in these different ecosystems may differ depending on disturbance, site, and species relationships. Ecosystems are not equally **resilient**4 and will not respond uniformly to a particular disturbance. Ecosystems that are disturbed frequently are considered less stable than those disturbed infrequently because of short intervals between events (Holling 1973; Reice 1994). Long-term relationships between species and frequent disturbance have resulted in ecosystems containing species that are adapted to variable environmental conditions and high rates of mortality. Because of this relationship, these less stable but resilient communities are more likely than more stable ones to return quickly to their existing composition and species interactions after disturbance. By contrast, ecosystems that are relatively stable because they are not disturbed frequently are not as resilient. Changes in their species composition, structure, distribution, etc. may be severe, and these ecosystems have a lesser chance of returning to their former composition, structure, and species interactions or will require a long time.

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4 Resiliency is the ability to recover quickly to conditions and relationships existing prior to the disturbance (Holling 1973).

DISTURBANCE AGENTS

Disease, drought, fire, insects, and wind are some of the most pervasive causes of disturbance affecting terrestrial ecosystems. They occur in most ecosystems, but not with equal frequency, as individual events or in concert with other disturbances. For example, insect outbreaks frequently are associated with drought, which, in turn, can exacerbate the adverse effects of insect activity. Drought also can enhance the ignitability of fuel and create a greater potential for fire, especially in ecosystems rarely affected by fire. Root diseases can predispose trees to attack by insects such as bark beetles, which can subsequently be triggered to outbreak levels by other disturbance agents. Trees affected by root disease also are more prone to windthrow. Loss of root-diseased trees by windthrow increases the risk of adjacent trees to windthrow during the same or future wind events. Increased tree mortality can enhance the amount of ignitable fuel and increases the chances of fire and its intensity when it occurs.

Drought

Drought can affect all terrestrial ecosystems. However, in contrast to xeric ecosystems, drought can be more severe in mesic forested ecosystems where available moisture usually is adequate and where severe drought is infrequent. In a mesic ecosystem, natural selection for species that avoid, tolerate, or resist drought is more site than regionally related. In xeric ecosystems, the limited water supply results in selection at a regional and site level for species that are adapted to restricted water availability and are resistant to drought (Mooney et al 1991). Drought, however, can predispose xeric ecosystems to more intense effects from other disturbance agents such as insects, disease, and fire.

Fire

Fire is a major disturbance factor in most terrestrial ecosystems. The frequency with which fire occurs in an ecosystem and its intensity influences and is influenced by the vegetation within it. Fire frequencies vary depending on climate and site characteristics such as weather, aspect, elevation, fuel accumulation and decay rates, and ignition sources. Each ecosystem has a unique combination of responses to fire frequency, intensity, and duration.

Ecosystems maintained by surface fire (commonly those found in more xeric areas such as Pondersoa pine in the West and longleaf pine in the Southeast) result from primary and secondary succession. These areas contain persistent successional species that generally are shade intolerant, have developed adaptations to survive fire, and maintain a constant or fluctuating population in response to disturbance. In these fire-regulated ecosystems, fires are frequent but are less intense in behavior and effects. Fire occurrence usually is patchy, and age and species diversity are common characteristics. In the absence of fire beyond the normal return interval, these fire adapted species are replaced by late successional species that are predominantly shade tolerant but less fire tolerant. This change in species composition and stand structure results in development of fuel ladders which alter fire behavior and effects.

Fire is most severe in ecosystems where it is infrequent but at high intensity. (Examples include the more mesic hardwood and coniferous forests of the East and coniferous forests of the Coastal West). Here, a greater amount of biomass is available for consumption, so fires burn with greater intensity. Fire effects generally are greater on these more mesic sites in conjunction with drought. When fires burn in these ecosystems, they are stand replacement fires which result in major vegetational changes on the site. However, severity of fire may be even greater on more xeric sites where suppression has altered the fire regime. On these sites, fires burn hotter and for longer durations than under the historic fire regime, causing severe effects on the vegetation and soil and result in long-term site degradation.

Forests of the world have been burned for many thousands of years (Spurr and Barnes 1980). Recent evidence in Kenya and South Africa suggests controlled use of fire by hominids about 1.4 million years ago. Neolithic man first acquired reliable fire-making techniques around 7000 B.C. Native peoples regularly burned the world's forests, including rain forests, to clear underbrush, improve grazing, drive game, and combat insects.

Fire has been responsible for the development of heathlands and moors of western Europe and the British Isles, savannas of the tropical forest belts, upland meadows within forests of the American mountains, Douglas-fir in the Rocky Mountains and Pacific Northwest, eucalyptus in Australia, two- and three-needled pines (red, jack, and pitch) in the northeastern United States and southeastern Canada, aspen in the central and southern Rocky Mountains, giant sequoia and redwood forests, the mixed hardwood forest complex of the eastern United States (particularly oak on dry sites), the taiga, and grassland areas on upland sites within forest regions (Spurr and Barnes 1980). Around the world, the dominance of pine and oak forests of virtually all species and in virtually all regions is due primarily to fire. Lowlands, such as swamps, bogs, marshes, and prairies, and semitropical forests of high humidity also have burned (and their vegetation markedly affected). Even the vast areas of spruce in the boreal forest of North America and Eurasia are structured to a great extent by past fires. And nowhere is the dependence of the pine forest on recurring fires more evident then in the southern pine belt of the Southeast.

Wind

Disturbance from wind also occurs in most terrestrial ecosystems. Wind is the major force in "patch dynamics" of some ecosystems and creates gaps of varying size by blowing down large overmature trees, those affected by root disease, and trees exposed on the edges of existing gaps. Tornados cause considerable damage in areas that are prone to the development of such storms. Areas of disturbance are larger along or near coasts when tropical storms with high-velocity winds make landfall. Damage by large-scale storms is strongly related to elevation, aspect, and vegetation structure (Foster and Boose 1992). Susceptibility to blowdown in forested ecosystems is related to the amount of crown sway and, hence, mutual crown support.

Wind also can cause chronic damage that results in progressive disturbance over time. In some forested ecosystems, fronts of waves of tree mortality can be created that move progressively through the stand as trees succumb to the continued effects of wind over time (Sprugel 1976; Marchand et al. 1986).

Diseases and Insects

Disturbances caused by diseases and insects occur in all terrestrial ecosystems and as a group probably are the most ubiquitous. Observations suggest that most pathogens and insects are ecosystem/species specific, although some can occur in several different ecosystems on related or entirely different species. Some pathogens and insects cause disturbance by attacking healthy host species. Others affect only hosts that have been weakened by a predisposing stress caused by another disturbance agent, while still others act in both capacities. Pathogens and insects, alone or together, are important causes of small gaps, particularly in deciduous forests. These agents also can disturb large areas resulting in major structural or species changes within an ecosystem. Examples are disturbances in western lodgepole pine forests caused by the mountain pine beetle and in the former chestnut/oak forests of the East due to chestnut blight.

Pathogens and insects that kill individuals or groups of plants that have been stressed by other disturbance agents function as ecosystem scavengers. Many individual plants become marginal producers because of competition or as they age or are stressed, yet they continue to "tie up" large pools of resources--light, space, water, carbon, and nutrients. Stress-induced pathogens and insects eventually kill these weakened plants, and nutrients and other favorable growth factors are released for the rapid colonization by replacement vegetation.

Regimes

Although often perceived as occurring chaotically, disturbances from disease, insects, drought, fire, and wind occur with sufficient regularity in some ecosystems that their frequency, intensity, and severity can be measured from historical information and used to predict future occurrences.

The Palmer Drought Index (Palmer 1965), the Z-T Method (Zehenhasic and Salvai 1987), and the Keetch-Byram drought index (Keetch and Byram 1968) are used to predict the frequency, severity and potential impacts of drought. Fire regimes described by Heinselman (1981) indicate the frequency, intensity, and severity of fire and its biological impact. Historical information on fire occurrence in specific ecosystems can be used in conjunction with fire regimes to predict occurrences and impacts.

Because short-term weather events that result in wind damage are not easily predicted and because they are sporadic and their effects are mostly local, there have been few measurements of the frequency or severity of these events. However, areas that are highly susceptible to wind damage can be identified and their risk determined or predicted. For large storms of tropical origin, models such as HURISK (Neumann 1987) can be used to estimate the return period of a storm of varying intensity. Such information along with data on vegetation structure, age, species, soil type, topography, and aspect can be used to plan for potential storm impacts.

A concerted effort must be made to identify the physiological, spatial, and temporal conditions that affect risk and hazard from diseases and insects. Cycles of biotic agents of disturbance are more difficult to determine and predict than those of physical agents because of the many interrelated biotic and abiotic factors that control their population dynamics. However, many insect outbreaks are keyed to the onset of specific changes in climate and weather or to the maturity of vegetation, all of which can be monitored. Information on the distribution, abundance, and potential impacts of insects and pathogens must be linked with data on landscape structure, species composition, potential successional pathways, and other disturbance regimes. This information along with data on the effects of soil, climate, and topography on ecosystems will be necessary to adequately predict the severity and duration of epidemics as well as their effects and recurrences. Models of biology and impacts for insects such as the spruce budworm, tussock moth, southern pine beetle, gypsy moth, and for pathogens such as dwarf mistletoe and *Armillaria* and *Phellinus* root fungi are examples of useful information that is now available.

III. DISTURBANCE IMPACT

Disturbance impact includes both an ecologic and socioeconomic component. For example, Averill et al. (1982) described insect disturbance as having an ecological impact, the cumulative net effects of the disturbance on the affected site, and a socioeconomic impact, the values assigned, decision criteria, and land management objectives. Disturbances not only have on-site impacts but also can cause off-site impacts such as downstream siltation or faunal movement that increases the density of a species in a particular habitat. Off-site effects also must be considered when assessing ecological and socioeconomic impacts.

The process of disturbance, response, and recovery changes the current state of the ecosystem. Whether this change is good or bad depends on the socioeconomic values that are applied to the ecosystem being considered. Disturbance has both short- and long-term effects. In the short term, the socioeconomic impact may dominate and then lessen as other goods, services, and amenities replace ones that were lost. Long-term impacts usually are biological as, for example, one species replacing another that was reduced or lost in response to disturbance. Because long-term biological and ecological impacts may have socioeconomic consequences related to sustainability, the socioeconomic impact cannot be fully assessed until the ecological impact is understood. The magnitude and frequency of a disturbance are important factors in determining impact.

Some resource outputs such as timber volume or animal unit months are readily measurable and the effect of disturbance events on the availability and sustainability of these outputs can be quantified. The closer the planned output level is to the capability of the land to provide the outputs, the greater the effect of the disturbance event on changing the planned output. If the planned resource outputs are below the capability of the land, the disturbance event may have little or no impact on the sustainability of the output level.

Disturbance also affects resource outputs that are more qualitative, such as scenic value. Although the immediate effect of a disturbance event on a scenic vista often is a reduction in scenic value, the long-term value may be enhanced. However, people seldom make the connection between a pleasing vista and the past disturbance(s) that created it. Disturbance caused by windstorm, wildfire, and outbreaks of pests generally are considered only in the short term as obtrusive to scenic views because people usually focus on dead trees.

Direct impacts of disturbance events on faunal populations vary widely. Mortality of vertebrates usually is negligible due to their mobility. Effects on invertebrate populations may be short or long lasting depending on the life stage that is impacted and the intensity of the event. The immediate effect of a disturbance event on fauna is a sudden and sometimes drastic modification of habitat and microclimate. Disturbance provides a change in the habitat that favors some species over others, and generally increases biodiversity.

The impact of disturbance on threatened and endangered species is mixed. Organisms that require disturbance become less abundant in the absence of disturbance. In general, disturbance results in greater diversity of flora and fauna, so management that focuses on preventing disturbance to maintain single species or groups of species is not without significant cost. For example, the highest mammalian extinction rate in the world occurs in the Spinifex ecosystem of Australia and is due to forest management-related reduction of fire following its widespread use by aboriginal people (Gill and Bradstock in press). For many species we lack a sufficient understanding of their relationship to disturbance.

Prediction of disturbance events and the potential negative and positive impacts of these disturbances on threatened and endangered species must be incorporated into management plans. For example, hurricanes always will be important in the long-term management of the red cockaded woodpecker (RCW). Most of the RCW recovery areas are vulnerable to the effects of winds of hurricane force, and this bird could be extirpated in some designated recovery areas. At least one RCW recovery area always will be in some form of recovery from disturbance by hurricanes (Hooper and McAdie 1993), so any long-term management plan for the RCW must consider the potential impact of this disturbance process.

The introduction of "new" plant and animal species into ecosystems is a continual process. The rate of introduction of exotic species has increased as the capability of humans to travel ever increasing distances in shorter periods has improved. Whether or not an introduced organism will survive depends on whether the new environment will meet its needs and whether the organism has the genetic capability to compete successfully. Because of the tremendous diversity of species, we often are aware only of the successful introductions. Such introductions are deliberate for a specific purpose to meet human needs or "accidental", and many exotic species are recognized only after they become well established. The literature abounds with records of organisms that were introduced to new continents and caused change in ecosystems: chestnut blight, Dutch elm disease, and white pine blister rust; gypsy moth, hemlock woolly adelgid, and beech scale; leafy spurge, purple loose strife, and cheat grass; and ringnecked pheasant, starling, and house sparrow are examples of introduced species that have had or will have a significant impact on terrestrial ecosystems in North America. The impacts of disturbance caused by these introduced organisms often are greater than those caused by native organisms, particular where an exotic species gains a competitive advantage in its new ecosystem.

The biological consequences of disturbance is change from the status quo; this change is neither "good" nor "bad". However the socioeconomic impact is seen as **both** good and bad. A tenet of the Forest Service's philosophy on resource management is preventing or minimizing bad impacts resulting from disturbance events to levels deemed acceptable under the objectives established for a management unit. There are significant economic costs associated with preventing these losses from occurring. Willingness to pay, as well as **who** pays, to prevent and/or mitigate disturbance events becomes a concern. Disturbance events that result in loss of resources, dwellings, and life suggest that such costs of protection are acceptable. However, unwillingness and/or inability to pay for the full range of treatments necessary to prevent disturbance impacts caused by fire, insects, or diseases, for example, requires significant prioritization of treatments and often results in losses incurred that were valued but not protected.

Understanding the role of disturbance in ecosystem dynamics and planning for its occurrence will help resolve problems related to good and bad impacts and help prioritize prevention and mitigation efforts. The cost of mitigation and prevention always must be weighed against the value of the resource value saved or protected. Socioeconomic gains are maximized when the activities are consistent with the functioning of the ecosystem, including its disturbance, and decline when in conflict with ecosystem processes.

There is substantial evidence that in some situations, the elimination or reduction of disturbance creates larger problems than it solves. For example, fire exclusion from some cover types has resulted in a shift from fire-tolerant to fire-intolerant species. This leads to a change from stand maintenance fires of low intensity to stand replacement fires of high intensity. The latter are less controllable, more dangerous and costly to suppress, and more damaging to the ecosystem. This scenario represents a growing problem where development is occurring at an increasing rate in the wildland/urban interface.

Suppression of fire in fire-regulated ecosystems also can result in serious insect and disease problems. For example, the fire-adapted ponderosa pine ecosystems in the western United States historically were relatively resistant to insects and disease organisms. Forest management practices and fire suppression in these ecosystems have resulted in the replacement of pine with fire intolerant, but more shade tolerant, Douglas-fir. This change in species composition and structure created several major problems: (1) Douglas-fir forests are susceptible to and capable of supporting high populations of the western spruce budworm, resulting in severe defoliation and mortality; (2) Douglas-fir trees are infected and killed by root pathogens and dwarf mistletoe; and (3) higher fire hazard conditions (high amount of fuel wood and flame ladders) have resulted in increased fire intensity and a change from surface to crown fires (Monnig and Byler 1992). These consequences may lead to a reduction in site quality and species composition that may last for many decades.

Insect outbreaks in forests dominated by lodgepole pine also have resulted from the suppression of fire (Monnig and Byler 1992). For example, the mountain pine beetle is a major pest on mature and overmature lodgepole pine in the West. In the past, frequent disturbance by fires in these forests resulted in mosaics of stands of different ages and, hence, different susceptibilities to beetle infestation. Fire suppression, however, has created large expanses of generally homogenous stands of similar age that when mature are uniformly susceptible to beetle attack. As a result, massive epizootics of the mountain pine beetle can occur in these stands. The subsequent heavy mortality creates highly flammable conditions which, when fire does occur, result in large burn areas and eventually expansive regeneration of even-aged lodgepole pine stands. In the absence of fire, these stands mature and again become susceptible to large-scale attack by the mountain pine beetle.

If disturbance events and their potential impacts are neither predicted nor incorporated into land management plans, the expected flow of outputs from a forest may be disrupted and management objectives may not be met. Knowing the impact of a disturbance event and its probability of occurrence allows managers to develop reasonable outputs at realistic costs.

IV. WHY IS IT IMPORTANT TO UNDERSTAND DISTURBANCE-RECOVERY REGIMES?

Alvin Toffler calls these times of turbulent change, "the hinge of history." Indeed, we have witnessed many paradigm shifts. In science we have gone from the age of Newton and an obsession with reductionism to the emergence of quantum mechanics, chaos, and complexity. In organizational theory we have seen a shift from Fredrick Taylor's concept of "scientific management" to the idea of "quality" as expressed by Deming, Juran, Fiegenbaum, and others, as well as the rise of the "learning organization." In ecology, we have moved from the ideas of Clementsian succession and equilibrium theory to a recognition of the ecology of patch dynamics and the importance of disturbance-recovery regimes in nonequilibrium theory. It is not that the previous ideas are wrong and these new ideas are right, but that today's theories extend the limits of yesterday's view of the world. There are several consistent themes inherent with each of these new ideas. Chief among them are flux, nonequilibrium, uncertainty, sustainability, and learning/adapting.

Sustainable development increasingly is recognized as a major goal of world societies. The Bruntland Commission defined sustainable development as that which "meets the needs of the present without compromising the ability of future generations to meet their own needs." The popularity of this term stems from the melding of the interrelated objectives of environmental protection and economic growth. Biological diversity (the variety of life forms, the ecological roles they perform, and the genetic diversity they contain) is rapidly being diminished by habitat change and destruction and other damaging influences resulting from human population growth, pollution, and economic expansion. As stated in Mooney (1988): "Data on diversity at a given site indicate its structural dynamics as related to both evolutionary history and pattern of disturbance...such knowledge is essential for understanding and hence managing a given level of diversity." If we have a goal of sustainable development and the conservation of biodiversity, and ecosystem management and adaptive management are the means by which we achieve that goal, then we must have a thorough understanding of disturbance-recovery systems. If we ignore the lessons of disturbance and recovery, the concepts of sustainable development and the conservation of biodiversity are meaningless.

Ecosystems and the economy are examples of complex adaptive systems, a collective designation for nonlinear systems defined by the interaction of large numbers of adaptive agents (Holland 1992; Waldrop 1992). Each ecosystem is a network of many agents (biological, chemical, physical) acting in parallel in an environment produced by its interactions with the other agents in the system. Agents are constantly acting and reacting to what the other agents are doing; thus, change is constant. The control of ecosystem dynamics tends to be highly dispersed--there is no master agent in ecosystems, including humans. A functioning ecosystem arises from competition and cooperation among the agents themselves. Ecosystems have many levels of organization that are constantly being revised and rearranged over time, and they adapt in anticipation of potential future conditions (adapted from Waldrop 1992, p 147 - characteristics of complex adaptive systems).

In managing complex adaptive systems such as ecosystems, we must address the concepts of constant change, decentralization, multiple levels of organization, nonequilibrium, the futility of optimization, prediction, feedback, and learning. The following are some of the implications that result from managing complex adaptive systems:

Constant change rather than static equilibrium. It is meaningless to discuss equilibrium because complex adaptive systems are continually unfolding and in transition. Managers must learn to adapt to this constant change.

Improvement rather than optimization. The space of possibilities is too vast, so there is no practical way of finding the optimum. The most we can do is change and improve. Prediction, feedback, and learning, that is, adaptive management, is essential.

Mitigation rather than control. The ability to control complex adaptive systems in general and disturbance phenomena in particular is limited. Managers must work within this limitation.

Nonlinear rather than linear. Complex adaptive systems require appropriate management models and thinking that addresses their nonlinearity.

Integration rather than fragmentation. Complex adaptive systems are integrated. As a result, reductionist thinking does not work.

Understanding disturbance and recovery is vital for managing both land and effective organizations. The metaphor of living ecosystems is supplanting clock-like machine metaphors for organizations of the past (Wheatley 1992). Just as a knowledge of disturbance-recovery regimes is the key to understanding ecosystem structure and process, the lessons learned can be applied to the death and rebirth of organizations. Managing healthy ecosystems and developing effective learning organizations requires a knowledge of self-renewal found in disturbance ecology.

V. CONCLUSION

How successful the Forest Service is in fulfilling its mission to manage the multivalued systems on our national forests and grasslands begins and ends with people and their choices. Ecosystem management is predicated on public land managers making natural resource management choices and decisions with greater public involvement. Our awareness and understanding of disturbance ecology, the role of disturbance in ecosystem dynamics, and our ability to communicate that understanding internally and to the public is essential.

Ecosystems are constantly changing in ways that are only partially predictable. Salwasser (1994) maintains that contrary to some views, "We cannot hold ecosystems constant or regulate them precisely to produce constant flows of desired outputs or conditions--whether those outputs be scenery, water, 'old-growthedness', wildlife diversity, or wood products." As we learn more about ecological process, we must counter long-held ecological views and public policy which have ignored the consequences of disturbance and presumes a constant environment where systems are at equilibrium and overall species composition and relative abundancies are stable through time.

To have an effective ecosystem management policy, managers and the public must understand the nature of ecological resiliency, stability, and the impact of natural disturbance factors on sustainability. Attempts to thwart, circumvent, or otherwise shield natural systems and organisms from natural and often essential disturbances such as fires, floods, erosion, drought, diseases, and insects fail to recognize that the organisms in a given ecosystem may be there because of those very disturbances.

Efforts to suppress disturbances, which have been perceived to be in conflict with economic interests, have resulted in reduced biodiversity and ecosystem health. The more we attempt to maintain an ecosystem in a static, constant condition, the less likely we are to achieve what we intended. We must be willing to bear both the economic and biologic costs of such management. Ecosystems in which the major disturbance regimes and natural processes have been significantly altered are unduly stressed and extremely vulnerable to upset by the slightest perturbation. Understanding and incorporating disturbance processes--whether natural or human induced--in resource management is essential to meet the resource needs of future generations.

Disturbance is pervasive throughout forest and grassland ecosystems. It is not a question of whether disturbance will happen but when, where, and what kind. Forest Service managers must consider and incorporate the following information on disturbances into the Agency's forest plans: the types of disturbance that are likely within specific ecosystems and criteria for predicting where particular disturbances will occur as well as the probability of occurrence. This information together with a knowledge of the vulnerability of certain areas to particular disturbances and the management objectives for those areas can increase the accuracy of assessment of the impact of disturbance and help managers better determine appropriate alternatives.

Disturbances caused by drought, diseases, fire, insects, and wind are common in ecosystems managed by the Forest Service but are most often viewed as difficult to predict or unpredictable. Because they occur with relative frequency across these ecosystems, the characterization of these disturbance regimes and an understanding of their role in ecosystem dynamics will increase the predictability of their occurrence and their socioeconomic impacts. Including disturbance potential in land management plans will increase our capability to respond appropriately following the occurrence of disturbances.

"Nothing is permanent but change"

Heraclitus 500 B.C.

LITERATURE CITED

Averill, R.D.; Wilson, L.F.; Fowler, R.F. 1982. Impact of the redheaded pine sawfly (Hymenoptera: Diprionidae) on young red pine plantations. Great Lakes Entomologist. 15: 65-91.

Christiansen, N.L.; Agee, J.K.; Brussard, P.F.; Hughes, J.; Knight, D.H.; Minshall, G.W.; Peek, J.M.; Pyne, S.J.; Swanson, F. 1989. Interpreting the Yellowstone fires of 1988. Bio. Sci. Am. Inst. Biol. Sci., Washington, DC: The Institute, 39(10): 678-685.

Forman, R.T.T.; Gordon, M. 1981. Patches and structural components for a landscape ecology. BioScience. 31: 733-740.

Foster, D.R.; Boose, E. 1992. Patterns of forest damage from catastrophic wind in central New England. Journal of Ecology. 80: 79-98.

Gill, A.M.; Bradstock, R.A. In press. Extinctions of biota by fires. In: Conserving Biodiversity: threats and solutions. Bradstock, R.A. et. al. (eds.). Surrey Beatty and Sons, Sydney.

Heinselman, M.L. 1981. Fire intensity and frequency as factors in the distribution and structure of northern ecosystems. In: Proceedings, fire regimes and ecosystem properties. GTR WO26.

Holland, J.H. 1992. Adaptation in natural and artificial systems. Cambridge, MA: MIT Press.

Holling, C.S. 1973. Resilience and stability of ecological systems. Annual Review of Ecology and Systematics. 4: 1-23.

Hooper, R.G.; McAdie, C.J. 1993. Hurricanes and the long-term management of the red-cockaded woodpecker. In: Proceedings, third red-cockaded woodpecker symposium; 25-28 January 1993; Charleston, SC. (in press)

Kaufmann, M.R.; Graham, R.T.; Boyce Jr., D.A.; Moir, W.H.; Perry, L.; Reynolds, R.T.; Bassett, R.L.; Mehlhop, P.; Edminster, C.B.; Block, W.M.; Corn, P.S. 1994. An ecological basis for ecosystem management. Gen. Tech. Rep. RM-246. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Keetch, J.J.; Byram, G.M. 1968. A drought index for forest fire control. Res. Pap. SE-38. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station.

Marchand, P.J.; Goulet, F.L.; Harrington, T.C. 1986. Death by attrition: a hypothesis for wave mortality of subalpine Abies balsamea. Canadian Journal of Forest Research. 16: 591-596.

Monnig, E.; Byler, J. 1992. Forest health and ecological integrity in the Northern Rockies. FPM Report 92-7. U.S. Department of Agriculture, Forest Service.

Mooney, H.A. 1988. Lessons from Mediterranean-climate regions. In: E.O. Wilson and F.M. Peters (eds). Biodiversity. Washington, DC: National Academy Press: 157-165.

Mooney, H.A.; Winner, W.E.; Pell, E.J., eds. 1991. Response of plants to multiple stress. San Diego, CA: Academic Press.

Neumann, C.J. 1987. The National Hurricane Center risk analysis program. NOAA Tech. Memorandum NWS NHC 38. Coral Gables, FL: National Oceanic and Atmospheric Administration, National Weather Service, National Hurricane Center.

Palmer, W.C. 1965. Meteorological drought. Res. Pap. No. 45. U.S. Department of Commerce, Weather Bureau.

Pickett, S.T.A.; Thompson, J.N. 1978. Patch dynamics and the design of nature reserves. Biological Conservation. 13: 27-37.

Reice, S.R. 1994. Nonequilibrium determinants of biological community structure. American Scientist. 82: 424-435.

Salwasser, H. 1994. Ecosystem management: can it sustain diversity and productivity. Journal of Forestry. 92: 6-10.

Sprugel, D.G. 1976. Dynamic structure of wave-generated Abies balsamea forests in the northeastern United States. Journal of Ecology 64: 889-911.

Spurr, S.H.; Barnes, B.V. 1980. Forest ecology, 3rd ed. New York: John Wiley & Sons.

Thompson, J.N. 1978. Within-patch structure and dynamics in Pastinaca sativa and resource availability to a specialized herbivore. Ecology. 59:443-448.

Vogl, R.J. 1983. A primer of ecological principles. Cypress, CA: Pyro Unlimited.

Waldrop, M.M. 1992. Complexity: the emerging science at the edge of order and chaos. New York: Simon & Schuster.

Wheatley, M.J. 1992. Leadership and the new science. San Francisco, CA: Berrett-Koehler Publishers.

White, P.S. 1978. Pattern, process, and natural disturbance in vegetation. Botanical Review. 45: 229-299.

White, P.S.; Pickett, S.T.A. 1985. Natural disturbance and patch dynamics: an introduction. Chapter 1. The ecology of natural disturbance and patch dynamics. San Diego, CA: Academic Press: 3-13.

Zelenhasic, E.; Salvai, A. 1987. A method of streamflow drought analysis. Water Resources Research. 23(1): 156-168.

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Abstract:This paper is intended to broaden awareness and help develop consensus among USDA Forest Service scientists and resource managers about the role and significance of disturbance in ecosystem dynamics and, hence, resource management. To have an effective ecosystem management policy, resource managers and the public must understand the nature of ecological resiliency and stability and the role of natural disturbance on sustainability. Disturbances are common and important in virtually all ecosystems.

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