Restoration of Forest Ecosystem Western Long-needled Pines

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Semantic and philosophical confusion lies at the heart of much of the current controversy over restoration of forest ecosystem health (e.g., see Kolb et al. 1994). Nowhere are these controversies more heated than in the long-needled pine forests of western North America (Clark and Sampson 1995, Covington et al. 1994, Sampson et al. 1994, Williams et al. 1993). To some, the health of the forest is simply the health of the trees. To others, forest health implies the natural functioning of entire landscape ecosystems, including native diversity and natural disturbance regimes. In this paper we examine ecosystem health of western long-needled pine forests and draw conclusions regarding ecological restoration of this widespread forest type in an adaptive ecosystem management framework.

Our paper begins by defining ecosystem health, ecosystem restoration and the concept of the evolutionary environment. Next, we present an overview of the ecological context of ecosystem health declines in ponderosa pine ecosystems. Finally, we close with a discussion of ecosystem restoration in this important forest type.

Ecosystem Health

Ecosystem health *(sensu* Leopold 1949, Callicott 1994) is related to, but distinct from forest health as it often is used today. Although most foresters and others in the conservation professions generally have used the term "forest health" to connote the health of entire forest ecosystems, some in the lay public have used the term "forest health" in a much more restricted sense-all too often to mean merely tree or stand health and as a euphemism for the practice of salvaging trees, including old-growth trees, before they "go to waste" as food for bark beetles or fuel for infernos. We believe that it is important for conservation professionals to be clear on this point. When we refer to a "forest," we should refer to a forest ecosystem-a specified spatial entity-and all that exists, lives and occurs within that area. As used in this paper, the term "forest health" is synonymous with the term "ecosystem health," for those ecosystems that are, in fact, forests.

Ecosystem health refers to the health of ecosystems in their entirety, including humans as members of ecosystems. Taking this metaphor a bit farther, we can define ecosystem medicine as the science and art of dealing with the health of ecosystems, including the prevention, alleviation and cure of diseases, where disease is defined as dysfunctions, such that natural ecosystem structures and processes become disrupted. In this sense, ecosystem restoration as an ecosystem health discipline is analogous to general practice in the field of human medicine. Ecosystem management might be viewed as the science and art of maintaining well-being.

Ecosystem Restoration Defined

Ecosystem restoration is founded upon fundamental principles of evolutionary ecology and conservation biology. A central premise of ecological restoration is that restoration of natural systems to conditions consistent with their evolutionary environments will prevent their degradation, while simultaneously conserving their native plants and animals. Practitioners of ecological restoration recognize that a failure to include human interactions with wildlands is folly and that "pure" restoration goals are appropriate for only a subset of public lands (see below).

Ecosystem restoration consists of a broad variety of practices designed to restore natural ecosystem structure and function. For example, in southwestern ponderosa forests, ecosystem restoration might consist of preserving all of the old-growth trees (those which predate Euro-American settlement), removing most of the trees which postdate Euro-American settlement, raking heavy fuels from the base of the old-growth trees, burning under prescription, removing introduced plants and sowing with native herbaceous seeds.

However, ecosystem restoration should not be construed as a fixed set of procedures not as a simple recipe for land management. Rather, it is a broad intellectual and scientific framework for developing mutually beneficial human/wildland interactions compatible with the evolutionary history of native ecological systems. In other words, ecosystem restoration consists not only of restoring ecosystems, but also of developing mutualistic human uses of wildlands which are in harmony with the natural history of these complex ecological systems.

Evolutionary Environment Concept

The concept of the evolutionary environment is central to understanding ecosystem restoration. The term evolutionary environment is used to refer to the environment in which a species or groups of species evolved-the environment of speciation. Over evolutionary time, species not only adapt to their evolutionary environment, but they also may come to depend on those conditions for their continued survival.

The evolutionary environment of western forest ecosystems is dominated by natural disturbance regimes (e.g., fires, predation, defoliation), which have varied in kind, frequency, intensity and extent (Agee 1993). These disturbance regimes served as natural ecological checks and balances on populations and insured spatial and temporal habitat diversity.

Declining Ecosystem Health in Ponderosa Pine Forests

Short return-interval, fire-adapted ecosystems often are the first indicators of problems that are propagated across landscapes and throughout biomes (e.g., Williams et al. 1993, Covington et al. 1994). In the absence of periodic low-intensity fire, these ecosystems undergo rapid and striking changes in species composition and structure which, in turn, become predisposing factors to undesirable changes in ecosystem health, not only for indigenous biota, but for contemporary humans as well.

The sequence of these undesirable changes is becoming widely acknowledged but poorly documented. Fire exclusion leads to tree population irruptions (including conversion from fire-resistant species to fire-intolerant species), steadily accumulating forest floors, impoverishment of herbaceous and other non-arboreal vegetation, shifts away from indigenous wildlife diversity, epidemic insect and disease outbreaks, severe stand-replacing crown fires, degradation of human habitat values (e.g., esthetics, biodiversity, watershed condition and wood products), and threats to human life, health and property (Clark and Sampson 1995, Covington et al. 1994, Williams et al. 1993). To all of these other undesirable costs must be added the rapidly accelerating cost in firefighter life and health and the exponentially increasing direct costs of fire suppression. Continuation of these trends is intolerable.

Although there is an increasing consensus among ecologists and natural resource professionals that these undesirable changes have been and are occurring throughout North America's short-interval, fire-adapted ecosystems, many, including most of the lay public, are skeptical about the magnitude and extent of these changes in ecosystem conditions and disturbance regimes. Furthermore, even among natural resource scientists, debate is heated over what, if anything, can be done to alleviate these problems. Some argue that these systems will recover rapidly to natural conditions following insect, disease and crown fire epidemics. Others argue that these synchronized large-scale catastrophic disturbance regimes will tend to be self-perpetuating. Still others argue that thinning alone can be used to restore ecosystem health or that prescribed burning without mechanical thinning can restore natural conditions. Currently, there is a great need for quantitative data to illuminate these debates.

Long-needled pine forests extend over more than 20 million hectares of western North America (Bailey 1995, Brown 1982), constituting the majority of the commercial pine forests of the continent. Ponderosa pine *(Pinus ponderosa)* alone accounts for more than 1.1 billion cubic meters of growing stock (Van Hooser and Keegan 1988). These forests are highly valuable as sources of wood products, water, livestock forage, wildlife habitat, recreation and conservation of biological diversity. However, a century or more of human-caused disruption of the frequent low-intensity fire regimes and elimination of the open, parklike forest structures characteristic of these ecosystems prior to Euro-American settlement has led to extensive ecological degradation, reduction in social and economic values, and the development of dense forest and fuel structures that are highly susceptible to insect outbreaks and high-intensity crown fires of unprecedented scale (Everett et al. 1994, Covington et al. 1994). Although Euro-American settlement occurred at varying times across North America, our functional definition is the time when long-term patterns of fire disturbance regimes were disrupted, often associated with major structural changes (e.g., grazing, harvesting). By this definition, some unharvested forests in northern Mexico are in presettlementlike condition due to the ongoing frequent fire regime, despite 400 or more years of Spanish colonization (Leopold 1937, Fule and Covington 1994a, 1994b). To provide quantitative information essential to address the growing concern over sustainable management of these ecosystems, we propose to investigate the effects of high-intensity wildfire, prescribed fire, understory thinning and bark beetle-induced tree mortality "treatments" on *key* ecosystem and human resource characteristics of long-needled pine ecosystems of the cordilleran region of North America.

The long-needled pine forest and savannah ecosystems of western North America are dominated by an ecological group of closely related pines *(Pinus ponderosa, P. durangensis, P. engelmannii., P. arizonica, P. jeffreyi, P. washoensis)* in the section Ponderosae characterized by thick bark, insulated buds and other adaptations to frequent fire regimes (Conkle and Critchfield 1988, McCune 1988, Barton 1993). Frequent fire, recurring every 2 to 20 years in these forests prior to Euro-American settlement (Weaver 1943, Biswell 1972, Dorey 1979, Kilgore 1981, Arno 1985, Knight 1987, Mast 1993, Covington et al. 1994, Swetnam and Baisan in press), has played a key role in the evolution of the biota of these widespread ecosystems. In fact, Mutch (1970) hypothesized that natural selection in ponderosa pine has produced characteristics such as long needles with high resin content and exceptionally slow decomposition rates which function to encourage fires, thereby reducing establishment of and competition from other trees (e.g., *Abies* spp., *Picea* spp.*)* that are not adapted to frequent fires. Frequent fires appear to be essential for maintaining open, parklike forests, by controlling pine tree population irruptions and forest floor accumulations (Covington et al. 1994), and by maintaining a high level of nutrient availability Covington and Sackett 1984, 1990).

Since Pliocene times, these forests have provided important evolutionary habitat for an exceptionally diverse biota, much of which appears to be dependent on frequent fire. For the past 10 to 30 thousand years these forests have been vital resources for numerous human cultures, most recently (1850 to present) for Euro-American industrialization. Early human cultures in North American forests supplemented lightning ignitions by using fire as a hunting, gathering and agricultural tool (Pyre 1982); however, soon after Euro-American settlement of the region, heavy livestock grazing broke the continuity of grass fuels and active fire suppression eliminated the presettlement fire regime. In the absence of frequent fires, striking changes occurred: tree species less adapted to frequent fire have invaded (at the expense of other plants), and pine tree biomass, both live and dead, has steadily accumulated, contributing to progressively declining biodiversity, increasing susceptibility to insect and disease epidemics, and supporting a shift from frequent, low intensity surface fires to larger and larger crown fires (Cooper 1960, Covington and Moore 1994 Covington et al. 1994).

To a society with high demands for wood products, the increase in tree density at first seemed beneficial to many. However, after 50 to 70 years of fire exclusion, foresters and ecologists, beginning with Aldo Leopold in the 1930s, began sounding the alarm that fire exclusion in these long-needled pine forests was leading to rapidly accelerating ecological degradation. For example, in 1943, Harold Weaver summarized conditions in eastside Washington ponderosa pine: "Dense, even-aged stands of ponderosa-pine reproduction have developed...enormous areas are growing up to dense, even-aged stands of white-fir [sic], Douglas-fir, and incense-cedar [sic) reproduction under the merchantable ponderosa pines ... for the past 20 years epidemics of the western pine beetle have killed and are continuing to kill billions of board feet of ponderosa pine worth many millions of dollars. Because of these ecological changes, which are continuing to take place, the fire hazard has increased tremendously. Fires, when they do occur, are exceedingly hot and destructive and are turning extensive areas of forest into brush fields."

Soon, other researchers pointed out additional undesirable consequences of fire exclusion in ponderosa pine forests. Studies in Utah (Madany and West 1983, Stein 1987), Montana (Gruell et al. 1982), Idaho (Steele et al. 1986, Barrett 1988), Washington (Weaver 1943, 1957), California (Laudenslayer et al. 1989) and the Southwest (Cooper 1960, Covington and Sackett 1984, 1992, Covington and Moore 1992, 1994) have shown that increased tree density, fuel loading and crown fire occurrence are common consequences of fire exclusion throughout the ponderosa pine type (Kilgore 1981).

Various authors (e.g., Leopold 1924, Arnold 1950, Cooper 1960, Biswell 1972, Weaver 1974, Kilgore 1981, Covington and Moore 1994a, 1994b) have inferred that associated with these increases in tree density, forest floor depth and fuel loading in ponderosa pine ecosystems have been: 1) decreases in soil moisture and nutrient availability; 2) decreases in net productivity and diversity of herbaceous plants and shrubs; 3) decreases in tree vigor, especially in the oldest age class of pine; 4) decreases in animal productivity; 5) decreases in stream and spring flows, particularly dry-season or base stream flows; 6) increases in susceptibility to pine bark beetles; 7) increases in fire severity and size; and 8) large homogenous landscapes that, in the absence of frequent fires, will tend toward large-stand replacing fires in perpetuity. In sum, the implication is that today's tree densities and fuel loads in ponderosa pine ecosystems are not sustainable, and that virtually every aspect of the ecosystem, not just the trees, is either adversely affected or placed at greater risk as a result. However, with few exceptions, these inferences have not been supported by intensive ecosystem management-oriented research.

Public recognition of the severity of these ecological changes has led to considerable debate over implications of various management scenarios (including no action) on ecosystem health and sustainability (e.g., Kolb et al. 1994, Salwasser 1994, Mutch 1994). Furthermore, researchers, other natural resource professionals and the lay public are embroiled in an often rancorous debate over what, if anything, should be done. Concerns about overcutting of old-growth trees (or, for some factions, practically any commodity uses of forestlands) has led some environmental groups and some scientists to argue against any role for mechanical treatments in restoration of ecosystem health. However, others point to evidence that, without mechanical treatment to reduce unnatural fuel loads, the ensuing fires, even under controlled conditions, can kill old-growth trees and other vegetation, and cause such intense soil heating that restoration of natural conditions is retarded, if not precluded, for the foreseeable future (see review by Covington et al. 1994).

Conclusions

Natural fire regimes were particularly important in shaping the communities present at the time of Euro-American settlement. Exclusion of natural fires in the forests and woodlands of the West, coupled with global climatic fluctuations and changes in atmospheric chemistry, has led to tree population explosions, dead fuel accumulations and landscape-level fuel continuity to such an extent that the niches of some species of plants, animals and microbes have become threatened. In many cases, the natural functioning (e.g., successional processes, recycling processes) of these ecosystems has been severely impaired. Parallel decline in resource conditions for humans have occurred to a greater or lesser extent in all types.

As a result of increased tree densities in the ponderosa pine type, the increase in late successional species in the mixed conifer climax type and the increasing landscape homogeneity in all types, catastrophic disruption of these systems by either large crown fires or large insect and disease epidemics is certain. And the resulting homogenous landscapes will tend to be self-perpetuating unless something is done to restore more nearly natural conditions.

The ongoing crash of old-growth tree populations is almost as great a concern as is the irruption of postsettlement trees. Although logging and "sanitation" cutting probably remain principal causes of old-growth mortality in some ponderosa forestlands, insects, diseases, drought and crown fire now predominate as sources of mortality. Given the severe population crash of old-growth trees and their importance to both biodiversity and esthetics, it is essential that we reinvigorate and protect them by thinning competing postsettlement trees and removing other fuels from around their bases.

These changes, in concert with ongoing global changes in atmospheric carbon dioxide and climate, imply the need for extensive ecosystem restoration and management to prevent wide-scale collapse of existing ecological systems. Ironically, this is especially true for wilderness areas and nature reserves where unnatural tree densities often exceed that of surrounding wildlands.

While some might quibble over the exact magnitude of the changes, the general trajectory seems unequivocal. Continued climate changes, coupled with fire regime disruption, are likely to lead to increased tree seedling establishment (especially of shade-tolerant species), intensified competition among established trees, further deterioration of tree vigor, and increased tree mortality from insects, disease and drought. Thus, we should anticipate an acceleration of historical changes in the West, including increased fuel accumulations, lengthened fire seasons and intensified burning conditions, all contributing to larger and more catastrophic wildfires. The threats to natural ecosystem structures and processes, human lives, and resource values are great. Given current trends, the consequences of inaction far exceed those of well-reasoned and scientifically based ecosystem restoration (Sampson et al. 1994). Nonetheless, we must be cautious that increased publicity and alarm cries about ecosystem health not lead to ill-conceived and haphazard solutions, with the possible result that the “cure” may be worse than the “disease.” There has been a lot of wishful thinking from different quarters that there might be some simple solution to ecosystem health problems, that thinning, prescribed fire, wildfire, bark beetles or tree diseases alone will restore natural conditions. Today's severe crown fires are a far cry from an ecosystem restoration process. In fact, any disturbance (e.g., logging, bark beetle attack, tree diseases) which kills old-growth trees sets the system on a long path to recovery, one that will take at least as long as the time it takes to regrow the dead old growth (perhaps 300 to 700 years for ponderosa pine ecosystems).

Although uncontrolled disturbances may restore portions of ecosystems under specific circumstances of site, ecosystem condition and disturbance environment, it is likely that the more general case is that these individual disturbances, in isolation, will run contrary to comprehensive restoration goals. It is far more likely that some combination of management actions and natural recovery processes will be necessary. Integrated ecosystem management is essential.

Given the diversity of human needs and goals for western wildlands, it seems unlikely that vast areas will be restored to natural conditions. In fact, keeping some areas in a somewhat artificial state may be desirable. Areas dedicated to wood fiber production, livestock grazing or human settlements might fall into this category, with the caveat that it is generally safer to manage in harmony with natural tendencies. Such departures from managing within the natural range of variability should be made judiciously.

Fortunately, recent calls for applied systems approaches for dealing with undesirable environmental changes are beginning to be heeded by both resource interest groups and governmental organizations (e.g., USDA Forest Service's recent policy change toward ecosystem management and the U.S. Department of the Interior's shift toward ecosystem approaches to conservation of biological diversity).

According to Callicott (1994), Aldo Leopold suggested several lines of evidence for a potential synergy between innovative commodity resource uses and restoration and maintenance of ecosystem health: "Accordingly, Leopold set out to define conservation in the following terms: as ‘a universal symbiosis with land, economic and aesthetic, public and private;’ as ‘a protest against destructive land use;’ as an effort ‘to preserve both utility and beauty;’ as ‘a positive exercise of skill and insight, not merely a negative exercise of abstinence and caution;" and, finally, as 'a state of harmony between men and land."'

Systematic adaptive ecosystem management can provide a sound scientific basis for evaluating the consequences of various ecosystem restoration options and help us to define innovative mutualistic roles for humans in wildland ecosystems.

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