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CHAPTER 20

Emulating Natural Forest Disturbance in the Wildland–Urban Interface of the Greater Yellowstone Ecosystem of the United States

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The Greater Yellowstone ecosystem encompasses Yellowstone and Grand Teton National Parks, plus adjacent national forests, other public lands, and extensive tracts of private lands in the American states of Wyoming, Montana, and Idaho (figure 20.1). The area is dominated by high, mountainous terrain, but also includes several lower elevation river valleys and portions of the plains surrounding the mountains (Hansen et al. 2002). Although the ecosystem contains one of the largest tracts of wild country in the continental United States, it also has one of the country's fastest growing human populations and economies (Riebesame et al. 1997; Rasker and Hansen 2000; Hansen et al. 2002). Population growth has been driven by migration from nearly all other regions of the United States, as highly mobile people are attracted to the region's outstanding natural amenities, including the scenery, wildlife, and outdoor recreational opportunities (Hansen et al. 2002). The major areas of economic growth are associated with services, real estate, and sources of nonlabor income rather than the traditional economic activities of mining, agriculture, and timber harvesting—a pattern typical of emerging "New West" economies throughout the Rocky Mountain region (Wilkinson 1993; Power 1998). Associated with this rapid population growth and a shifting economic base is a striking change in land use patterns, as formerly agricultural and grazing land is being converted to low density exurban or rural residential development (Theobald 2000; Hansen et al. 2002).

Research is beginning to demonstrate that these new patterns of land development pose serious threats to the biodiversity and the charismatic wildlife of the ecosystem, in part because the most productive and biologically rich areas are concentrated on or near private lands at lower elevations (Hansen et al. 2000, 2002). Even the large, protected national parks are threatened by the changing land use, because many species of migratory wildlife, such as elk (*Cervus elaphus*), rely on lands outside the parks for critical winter habitat, and populations of other species in the parks are actually maintained largely by dispersal of individuals from more productive habitats outside the parks; for example, this is true of yellow warblers (*Dendroica petechia*) (Hansen et al. 2002).

Another issue that has barely begun to be addressed involves the effects of changing land use patterns on such fundamental ecosystem processes as the natural disturbance regimes of the Greater Yellowstone ecosystem. As we explain below, fire is essential to the diversity and ecological functions of the natural ecosystems in this area. Management policies for the large national parks and wilderness areas emphasize that natural processes should be allowed to occur with minimal human interference. However, implementation of this policy grows ever more challenging as vulnerable homes and other structures become more numerous on private lands adjacent to the nature reserves. In particular, natural fires that would otherwise be allowed to burn in parks or wilderness areas must now be suppressed to prevent the fires from spreading to private lands. Although people are beginning to question the relative responsibilities of the government and the landowners for protecting private property against wildland fires, the western United States has a long tradition of government

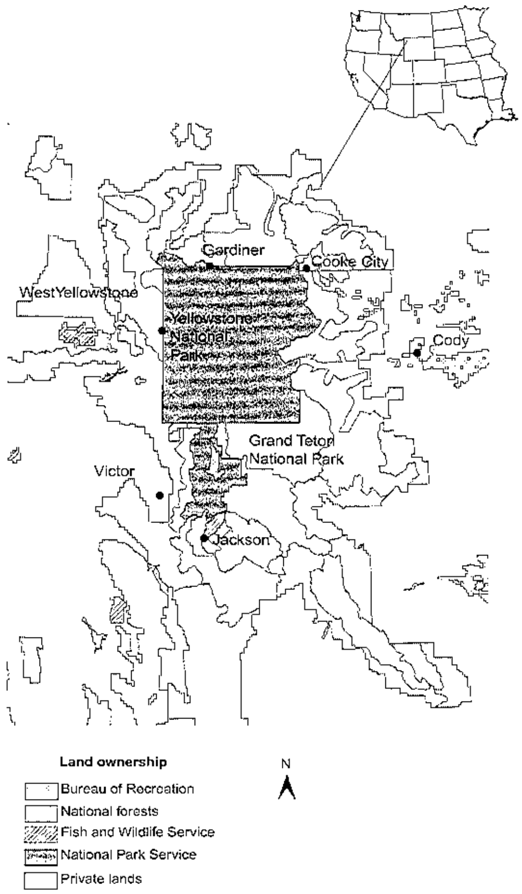

FIGURE 20.1. Location of the Greater Yellowstone ecosystem, United States. Private lands occupy approximately 1.2 million ha, and another 5.5 million ha are included in national parks, national forests, and other public lands, for a total area of approximately 6.7 million ha. Modified from Rasker and Hansen (2000).

agencies—notably the U.S. Department of Agriculture Forest Service—assuming primary responsibility for preventing damage to human life or property caused by wildland fires (Pyne 1982). That basic policy appears likely to continue (U.S. Department of Agriculture Forest Service and U.S. Department of the Interior 2000). Thus, an urgent land management question in the region and other similar regions in the American West is how to maintain such natural disturbance processes as fire while reducing wildfire damage to the dispersed homes and other vulnerable structures being developed so rapidly on private lands in these fire prone natural ecosystems.

In ecosystems formerly characterized by frequent low intensity fires—particularly in the ponderosa pine (*Pinus ponderosa* Laws.) forests of the southwestern United States—mechanized thinning of dense forest canopies followed by low intensity burning is an effective strategy for reducing wildfire hazard and simultaneously restoring natural forest structures and processes (e.g., Hardy and Arno 1996; Covington et al. 1997; Friederici 2003). This strategy is being implemented widely throughout the western United States (e.g., Lynch et al. 2000; Arno 2002; Farnsworth and Summerfelt 2002), and is a key component of the National Fire Plan (U.S. Department of Agriculture Forest Service and U.S. Department of the Interior 2000) that lays out the federal government's overall strategy for wildland fire management over the next decade (e.g., Rains and Hubbard 2002). Unfortunately, natural disturbance regimes in the Greater Yellowstone ecosystem are dominated not by frequent, low intensity fires, but rather by infrequent, high intensity fires, as described later in this chapter. Thus, the mechanized thinning and low intensity prescribed burning that work so well in other kinds of forests fail to emulate the natural disturbance regimes of the very different forests of the region. Consequently, these approaches are unlikely to succeed in this region for a variety of operational and ecological reasons. In this chapter, we first describe the region's natural fire regimes and demonstrate why it would be both impossible and inappropriate to eliminate fire from this ecosystem. We then identify the major problems associated with attempting to apply a southwestern ponderosa pine model to the region's forests. Finally, we suggest an alternative fire management strategy that would more closely emulate the natural disturbance regimes of the region while reducing fire hazards to private property.

Natural Vegetation Patterns and Disturbance Regimes

The Greater Yellowstone ecosystem ranges in elevation from 1500 to 4000 m above sea level (asl), encompasses a variety of geological substrates from crystalline Precambrian rocks to Quaternary lake sediments, and includes rugged, glaciated mountains, as well as broad plains. Consequently, the area is very ecologically diverse (Romme and Knight 1982; Despain 1990; Glick et al. 1991). Broad river valleys and basins at lower elevations (<1800 m asl) are generally dominated by semi-arid sagebrush grasslands (characterized by *Artemisia tridentata* Nutt., *Agropyron spicatum* [Pursh] Scribn., and *Festuca idahoen-*

sis Elmer.) on upland sites, with cottonwood-willow woodlands (*Populus* spp., *Salix* spp.) along streams. Foothills and higher valleys (~1800–2300 m asl) support forests of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), trembling aspen (*Populus tremuloides* Michx.), limber pine (*Pinus flexilis* James), and lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.). The extensive volcanic plateaus of the region are covered by lodgepole pine forests, whereas higher mountain slopes (2300–3000 m asl) are dominated by forests of lodgepole pine, Engelmann spruce (*Picea engelmannii* Parry), alpine fir (*Abies lasiocarpa* [Hook.] Nutt.), and whitebark pine (*Pinus albicaulis* Engelm.).

Fire is the major natural disturbance agent in most of the vegetation types of the region (Romme and Knight 1982; Despain 1990). Fires of mixed severity, with patches of high tree mortality interspersed with patches of low mortality, occurred at intervals of 20–50 yr prior to the twentieth century and maintained a mosaic of Douglas-fir forests that included dense, closed-canopy stands and open savannalike stands (Houston 1973; Arno and Gruell 1986; Littell 2002). Some of these stands, especially at the lower forest-grassland ecotone, have increased in density over the past 100 yr—a scenario similar to that in southwestern ponderosa pine forests (e.g., Covington et al. 1997). However, this pattern of a natural fire regime dominated by frequent, low intensity fires, subsequently disrupted by twentieth-century fire exclusion efforts, is a conspicuous exception to the region's more general pattern. Most of the forested area in the Greater Yellowstone ecosystem, including lodgepole pine, spruce–fir, and whitebark pine forests, was influenced primarily by infrequent, but large, stand-replacing fires before the twentieth century, and this natural fire regime has not been altered substantially by recent fire exclusion efforts (Romme 1982; Romme and Despain 1989). Ignitions occur every summer, but most are extinguished naturally by wet weather. Only a handful of ignitions, caused by either lightning or humans, occur during weather dry enough to permit fire spread, but these few fires account for most of the area burned during any given time period (Renkin and Despain 1992). Differences in fuels related to stand age and site productivity influence fire activity during relatively moderate fire weather, but have little effect on fire behavior or its effects during extreme weather conditions—as occurred in 1988 (Renkin and Despain 1992; Turner and Romme 1994). Based on the fire history during the past 250 yr, Romme and Despain (1989) concluded that twentieth-century fire suppression has had little effect on the infrequent large fires that dominate the fire regime of the lodgepole pine forests in the Greater Yellowstone ecosystem.

Fire Effects and Ecological Responses to Fire

Although fires in the Greater Yellowstone ecosystem tend to be severe and stand replacing, the natural ecosystems are very resilient to fires of this kind. Much of our understanding of fire effects in the area comes from studies initiated after the 1988 fires, which burned for more than 4 months, often under extreme fire weather conditions, and ultimately affected nearly 300,000 ha (Christensen et al. 1989). The fires burned at variable intensities and created a complex mosaic of patches through crown fires, severe surface fires, and low intensity surface fires, although forested areas were affected mainly by stand-replacing fires (Turner et al. 1994a). Research has focused mostly on lodgepole pine forests and grasslands, which are among the most extensive vegetation types in the Greater Yellowstone ecosystem. Postfire responses in other forest and nonforest types are probably similar to the responses described later in this chapter for lodgepole pine and grassland ecosystems.

Burned grasslands resprouted from surviving belowground plant parts, quickly restored the prefire cover in most places, and exhibited increased aboveground productivity for at least 2–3 yr after the fire (Van Dyke et al. 1991; Turner et al. 1994b; Wallace et al. 1995). Forest floor herbs (e.g., *Epilobium angustifolium* L., *Lupinus argenteus* Pursh.) also survived as rhizomes and roots, even where intense fire consumed nearly all aboveground herbaceous vegetation and litter (Anderson and Romme 1991). These survivors sprouted after the fire, and contributed most of the living biomass during the first 2 yr after the fire (Turner et al. 1997b). A flush of flowering and seedling establishment occurred in many forest floor species 3–5 yr after the fire and combined with the continued sprouting to rapidly increase total plant cover. Because so many individual prefire plants survived the fire, species composition was remarkably similar in burned and unburned forests—aside from several native annual species (e.g., *Collinsia parviflora* Lindl., *Gayophytum diffusum* T.&G.) that are rare in mature forests but flourished for a few years in the early postfire forests (Turner et al. 1997b). Most areas were overwhelmingly dominated by native species. Some nonnative species (e.g., *Cirsium arvense* L. Scop., *Lactuca serriola* L.) became established in the burned forests, but their distribution was patchy, apparently because of the general scarcity of nonnative seed sources in Yellowstone Park at the time of the fire (Turner et al. 1997b).

Lodgepole pine's seeds were released from cones in the burned canopy, and became established in the greatest numbers during the first 2 years after the fire. The resulting seedling density ranged from more than 10,000 seedlings ha^{-1}, where a high proportion of the burned canopy trees had serotinous cones and the fire burned at moderate intensity, to fewer than 100 seedlings ha^{-1}, where no trees were serotinous and the fire was very severe (Tinker et al. 1994; Romme and Turner, in press). Despite this variability, seedling density was sufficient to restock most of the burned forest at densities equaling or exceeding those under the prefire conditions. Burned trembling aspen forests resprouted after the fire (Romme et al. 1995a), and aspen seedlings were unexpectedly discovered in burned coniferous forests—many in places outside the prefire range of the species (Romme et al. 1997).

Associated with the rapid recovery of the original plant cover and species composition was a rapid recovery of ecosystem functions. Within 10 yr after the fire, some dense stands of lodgepole pine saplings (>60,000 stems $\cdot$ ha^{-1}) exhibited aboveground net primary productivity and leaf area index equal to that in mature lodgepole pine forests (Reed et al. 1999). Although lower density postfire stands have lower productivity and leaf area, the rapid accumulation of new biomass occurring throughout nearly all of the burned area also resulted in the conservation of nutrients. We detected very low nitrate concentrations (0.04–0.12 $mg \cdot L^{-1}$) in the streams draining several severely burned watersheds 8 yr after the 1988 fires, as well as 1 yr after a smaller but nevertheless stand-replacing fire that occurred in 1996 (Romme and Turner, in press). Less is known about the specific soil changes and biogeochemical cycling processes after fire, but we have initiated research to investigate these aspects of ecosystem function.

Over the long term, many of the new forests that emerged after the 1988 Yellowstone fires may remain very dense for many decades or centuries before natural mortality begins to occur extensively in the canopy, in the absence of fire. It is important to recognize that dense lodgepole pine stands are a normal part of postfire succession in this ecosystem (Romme and Despain 1989; Despain 1990)—and are decidedly not an artifact of twentieth-century fire suppression, as are the dense stands of southwestern ponderosa pine and some other forest types (e.g., Covington et al. 1997).

Alternative Fire-Management Strategies

Given the natural role of fire in the forests of the Greater Yellowstone ecosystem, how can or should we attempt to manage this powerful ecological process? In this section, we briefly discuss two possible strategies that we believe are inappropriate for both operational and ecological reasons, and then suggest the broad outlines of a preferred management approach that would emulate this ecosystem's natural disturbance processes (Swetnam et al. 1999; Romme et al. 2000).

Inappropriate Strategy 1: Complete Fire Exclusion

Federal land management agencies have attempted to exclude fire from most western ecosystems throughout much of the twentieth century, and achieved some success early on (Pyne 1982). However, complete fire exclusion over the long term now appears unattainable from an operational standpoint, and is ecologically undesirable as well.

Operational problems

Recent severe fire seasons have demonstrated unequivocally that fire cannot be excluded for long in the Greater Yellowstone ecosystem and many other ecosystems. The vegetation and climate of the Greater Yellowstone ecosystem are such that fire is inevitable, even with modern fire suppression technology. We can control fires during relatively moderate fire weather, but have little influence on fire behavior or spread during the severe fire weather that recurs periodically, as happened in 1988 and 2000 (Despain and Romme 1991).

Ecological problems

Even if we were capable of suppressing all fires, we probably should not do so. As explained earlier in this chapter, fire does not threaten the natural ecological integrity of the Greater Yellowstone ecosystem. On the contrary, it appears to be essential for long-term persistence of at least some important species, communities, and ecosystem functions. Several species are known to be more or less fire dependant; for example, Bicknell's crane bill (*Geranium bicknellii* Britt.) appears to persist primarily as dormant seeds and to germinate only in response to a fire induced stimulus (Abrams and Dickmann 1984), and the three-toed and black-backed woodpeckers (*Picoides tridactylus* and *P. arcticus*) breed primarily in recently burned forests (Hutto 1995). Large, infrequent fires also shape the landscape's dynamic mosaic of patches, which influences wildlife habitat, hydrology and other important ecosystem properties (Romme and Knight 1982; Christensen et al. 1989; Knight and Wallace 1989). Periodic large, severe fires may have additional subtle effects that have only begun to be recognized. For example, sexual reproduction in trembling aspen and many forest floor herbs appears to occur primarily in the aftermath of severe fires (Romme et al. 1995b, 1997). Although these species persist between fires via asexual sprouting, the fire stimulated infusion of new genotypes into these populations of long-lived clonal plants may be critical for persistence of the species in the face of climatic and environmental variability on the scale of centuries (Eriksson 1992; Tuskan et al. 1996). Thus, we argue that a primary goal of fire management in the Greater Yellowstone ecosystem should be to let fire play its natural ecological role to the greatest degree possible, recognizing that fire is a key process in maintaining the resilience and ecological integrity of this ecosystem.

Inappropriate Strategy 2: The Southwestern Model of Thinning and Low Intensity Burning

Mechanized thinning of dense stands followed by low intensity prescribed burns in fall or spring has been shown to accomplish the goals of ecological restoration and mitigation of the fire hazard in southwestern ponderosa pine forests and other forest types characterized by pre-1900 fire regimes of frequent, low intensity fires. This approach is called the *southwestern model* (Covington et al. 1997). However, the approach is not likely to succeed in the forests of the Greater Yellowstone ecosystem, where infrequent, high intensity fires have long been the norm, for both operational and ecological reasons.

Operational problems

Prescribed burning in lodgepole pine forests, the most extensive forest type in the Greater Yellowstone ecosystem, is a challenging enterprise. Because of typically late snowmelt and frequent summer rain showers, suitably dry conditions for ignition occur only infrequently (Brown 1991; Renkin and Despain 1992). Once the fuels do dry, however, only a small amount of additional drying is needed to push them into a state where crown fires become likely. Unlike the fuel bed in ponderosa pine forests, that in lodgepole pine forests is not conducive to extensive spread of surface fires. On the contrary, fires in lodgepole pine forests tend to move via crown-to-crown spread and wind-driven spotting, rather than spreading diffusely through surface fuels (Brown 1991). Thus, burning extensive areas of lodgepole pine forest with low intensity controlled burns would be very difficult, and perhaps impossible.

Ecological problems

Mechanized thinning of dense lodgepole pine forests would be problematic for at least two reasons. First, lodgepole pine is usually not very windfirm, and most of the residual stand left after a heavy thinning could easily blow down over a few years after this treatment. Second, many herbs and low shrubs on the forest floor are adapted to shady understory conditions and may be unable to tolerate the increased light, wind, and temperature variation associated with an open canopy structure; for example, this is true of the fairyslipper orchid (*Calypso bulbosa* L.), whitevein pyrola (*Pyrola picta* Sm.), and twinflower (*Linnaea borealis* L.). Although the native species are well adapted to infrequent, severe fires, they may not fare well under a novel disturbance regime composed of frequent, low intensity fires. Juvenile and adult individuals of lodgepole pine, Engelmann spruce, and alpine fir are not very fire resistant, and are easily killed by even a low intensity fire. Most forest floor herbs and shrubs would readily resprout after a single fire, but they may be incapable of repeated sprouting after repeated fires. The resprouting response probably requires substantial energy reserves, and we do not know how long it takes for roots and rhizomes to replenish these reserves after a fire. The density and vigor of the postfire sprouts of gambel oak (*Quercus gambelii* Nutt.), a common perennial shrub in the southwestern United States (but not present in the Greater Yellowstone ecosystem), were substantially reduced following repeated, short interval burning (Harrington 1985). Thus, frequent, low intensity burning could potentially cause initial stimulation but may ultimately lead to local extirpation of at least some of the forest floor species of the Greater Yellowstone ecosystem. Loss of these native herbs and shrubs, coupled with increased light and nutrients in burned forests, would create a condition in which the burned forests were vulnerable to invasion by nonnative plant species—which thrive in environments with high availability of light and nutrients and frequent disturbance (e.g., Mooney and Drake 1986). Much of this discussion is somewhat speculative, as research to test these hypotheses has not been conducted. However, this analysis does indicate that hasty implementation of mechanized thinning and low intensity prescribed burning over large areas could lead to very undesirable results, in part because such a disturbance regime would be so different from that which the organisms have experienced in their evolutionary history.

Preferred Strategy: Emulating the Natural Fire Regime

We suggest that the only fire management strategy likely to be effective over the long term will be one that accepts and incorporates infrequent, large, severe fires throughout much of the landscape. Such fires are a natural part of this ecosystem, they probably are unavoidable, and they have the ecological benefits described earlier in this chapter. Naturally ignited fires in the extensive wilderness portions of the Greater Yellowstone ecosystem can probably be allowed to burn with minimal interference under most conditions. However, an overall strategy must also deal with the risk posed by such fires to homes, watersheds, and other human property and values. Full development of this kind of fire management strategy will require much additional work on the part of managers, researchers, and the public, but here we sketch out three of the strategy's major elements.

Create defensible spaces around homes and other vulnerable elements

The quickest and most effective method for reducing losses of homes and property to wildfire is to reduce fuels in the immediate vicinity of vulnerable structures. Although local fuel reduction does not guarantee full protection, thinning dense forests within 30–60 m of a home can aid firefighters attempting to protect the home and at least reduces the probability of serious damage or loss when fire occurs (Cohen 2000; Arno 2002). To be effective, thinning treatments must be accompanied by the use of fire resistant building materials, the removal of pine needles from roof gutters, and other similar actions. Although we argue against broad-scale thinning of forests in the Greater Yellowstone ecosystem, we believe that the use of thinning to create a defensible space around vulnerable structures is appropriate, and is necessary before any prescribed burning can be conducted safely (Brown 1991). Specific information and guidelines for protecting homes and other structures from wildland fire are readily available (e.g., Firewise, undated; Dennis, undated). Moreover, homeowners can take responsibility for accomplishing the work themselves or by contracting with private companies, and the overall costs that result from this approach are relatively low for individuals and society. Color plate 22 illustrates a recent fuel reduction project in Grand Teton National Park of the kind that we advocate here. This treatment is unlikely to stop the advance of an intense fire across the landscape, but it will probably increase the survivability of buildings in the immediate vicinity, which is the explicit and appropriate objective of the treatment.

Clear or burn larger areas near vulnerable structures

A large, intense forest fire burning into a housing development during extreme fire weather may cause great damage, even if homeowners have taken appropriate steps to reduce fuels around their homes. Therefore, it may be appropriate in some locations to treat the surrounding vegetation (especially dense forests) so as to reduce the intensity of any future fire that burns into the area (Brown 1991). Where homes are surrounded by dense Douglas-fir forests, which had a more open structure before 1900, mechanized thinning and low intensity prescribed burning (something like the southwestern model) may be feasible and appropriate. However, lodgepole pine forests probably should not be treated in this way over extensive areas. Rather, effective treatment of lodgepole pine forests should probably involve either clearcutting or prescribed burning.

Clearcutting is relatively easy and effective in reducing fuels and retarding fire spread, and clearcut patches can be designed to mimic the shape and size of natural fire created openings. However, the ecological effects of clearcutting are very different from the effects of natural fire with respect to coarse woody debris, biogeochemistry, soils, and wildlife habitat. The focus of this chapter is on fire rather than timber harvesting, but the idea of making harvesting more closely emulate the ecological effects of natural stand-replacing fire in the Rocky Mountains is explored in Romme et al. (2000).

Prescribed burning in proximity to houses and other structures will require great skill and understanding, given the nature of fire in this ecosystem, and specific treatments will need to be modified according to local conditions. Brown (1991) provides guidelines for this kind of prescribed burning in the context of protecting visitor centers and other developments in Yellowstone National Park, but the principles apply more broadly. Young lodgepole pine stands developing after a clearcut or a stand-replacing burn are less likely than older stands to ignite or allow fires to spread under all but the most extreme fire weather (Renkin and Despain 1992; Turner et al. 1994a). Such stands would provide at least some protection from uncontrollable wildfires for several decades (Brown 1991). We stress that such treatments as the prescribed burning we propose would be most appropriate in close proximity to developed areas. In the extensive wilderness portions of the Greater Yellowstone ecosystem, naturally ignited fires can and should be allowed to burn with minimal interference under most conditions. The exception would be fires that show a high likelihood of encroaching into developed areas; for example, fires that are burning during extreme fire weather or in the absence of natural fire barriers.

Encourage responsible development patterns

Most land development in the western United States is minimally regulated by government or other entities, and fire hazard is rarely a major consideration in decisions about where or how to build homes and other structures in wildland areas. Consequently, many homes are located in places that are extremely vulnerable, such as near the top of a steep, brushy slope at the head of a shallow ravine and facing the prevailing wind direction. Such structures probably cannot be protected from wildfire, even by using the measures outlined above. The best strategy would be to not build homes in such vulnerable locations in the first place—or if the homeowner insists on building at this site, then it should be clearly understood that the community has minimal obligation to attempt to save the house from wildfire. A variety of means are available to encourage responsible development patterns in wildfire prone ecosystems. These include formal zoning regulations, tax incentives by governments, and reduced insurance rates for building at safer locations and creating a defensible space around homes. Clustering of homes could also be encouraged in an effort to increase the cost effectiveness of treating surrounding vegetation and protecting homes when a wildfire does occur. Clustered homes, with protected tracts of open space between clusters, would also reduce the fragmentation of natural vegetation (Romme 1997) and create greater opportunities for fires to burn in more natural patterns over greater areas, thereby enhancing fire's beneficial effects on biodiversity and ecosystem processes.

Conclusions

Fire is a key natural process in the Greater Yellowstone ecosystem, and is essential to the ecosystem's long-term biodiversity and ecological integrity. Living with fire in this system is especially challenging for the human members of the community, however, because the most ecologically important fires are infrequent, large, and severe. As the human population continues to grow in the Greater Yellowstone ecosystem and similar places throughout the American West, wildfire hazards to life and property will also grow, and fire management will become increasingly urgent and difficult. In this chapter, we evaluated and rejected two possible strategies for fire management in the Greater Yellowstone Ecosystem: (1) complete fire exclusion and (2) a southwestern model, based on mechanized thinning and low intensity prescribed burning of dense forests. Instead, we recommend a strategy that emulates the region's natural disturbance regime by accommodating stand-replacing fires, while acting locally to protect lives and property.

The technical challenges associated with our recommended approach are daunting: fires in this ecosystem are inherently difficult to control, and the art and science of conducting prescribed, stand-replacing fires in lodgepole pine forests are in their infancy. The sociopolitical challenges are also substantial. Collaboration among many agencies, both governmental and nongovernmental, will be required. Many local residents have a poor understanding of the fire regimes in this ecosystem, as well as unrealistic expectations about the government's ability to protect them from fire and a general resistance to formal regulation of land use. We believe that the measures we call for can be accomplished by means of incentives from governments and perhaps from the insurance industry, rather than by regulation. Moreover, we envision that the people of the American West can gradually move toward a view that living in such a grand landscape as the Greater Yellowstone ecosystem is not merely a right, but also carries with it a responsibility to protect ecological integrity for the benefit of residents and nonresidents alike.

As Aldo Leopold (1934) wrote, "every landowner is the custodian of two interests . . . the public interest and his own." We believe that maintaining at least the major elements of a natural fire regime in the Greater Yellowstone ecosystem is in the public's long-term interest, and will ultimately prove to be the most effective way of protecting human life and property while maintaining biodiversity and ecological integrity.

Acknowledgments

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