

Forest Development Leading to Disturbances

Clinton E. Carlson,¹ Stephen F. Arno,² Jimmie Chew,¹ and Catherine A. Stewart³

Abstract.—Natural disturbance in western U.S.A. forest ecosystems is related to forest succession, growth, and structural development. Natural disturbance may be biotic (insects and diseases) or abiotic (fire, wind, avalanche, etc.). Natural disturbances are more appropriately thought of as natural processes; disturbance is a social connotation implicating economic loss. Forest development influences the amplitude of natural processes, which in turn influences forest development. Understanding balances among ecological processes, and how these processes influence wildlife, timber, and other valued resources is becoming increasingly important for land managers. We can use currently available vegetation management tools and concepts to keep some of the natural disturbances within socially acceptable limits. This is the role and responsibility of silviculture in ecosystem-based forest management.

INTRODUCTION

Forest development occurs through the complex interactions of ecosystem processes. Rock and soil weathering, along with inputs of solar energy, rain, and dust, interact with forest plants producing a myriad of forest structures. Forests are integral in carbon cycles, nutrient cycles, energy fixation, and other ecosystem functions (Mueller-Dombois and Ellenberg 1974). Outputs from forest ecosystems include water, fiber, fauna, and other resources important to humans. During forest development, ecosystem processes may perturb the system; if the process adversely affects a resource important to humans, then the process is often called a "disturbance." Some processes operate insignificantly in very young forests but become very important in older forests; thus, forest development may lead to disturbance. Generally, agents that operate to release carbon are referred to as disturbance agents. In this paper we discuss the relation of forest development to three general agents: fire, disease, and insects, we give examples of influ-

ences of human activities on disturbance processes, and we discuss strategies on how to deal with disturbance by regulating forest development.

FOREST DEVELOPMENT AND FIRE

For thousands of years fire shaped the composition and structure of North American forest, woodland, and shrubland and grassland ecosystems (Pyne 1982). For example, cores taken from pond sediments in a subalpine lodgepole pine site on the Lolo National Forest in western Montana show clear evidence of several severe fires and a few dozen less severe fires during the past 11,000 years (Johnson et al. 1994). Analysis of fire scars on trees in ponderosa pine/interior Douglas-fir forests documents frequent low-intensity fires dating back as far as the late 1400s (Arno 1976). Analysis of fire scars on giant sequoia stumps provides a continuous record of frequent fires extending back 2,000 years (Swetnam 1993).

Historically, most western forest types were characterized by one or more of the following fire regimes based on fire severity: (1) nonlethal understory fires; (2) mixed and variable fires; and (3) stand-replacement fires (Brown 1995). If most of the forest cover (80 percent or more) dies as a result of fire it is considered stand replacement. If most of

¹Project Leader and Forester, Intermountain Research Station, Forestry Sciences Laboratory, Missoula, MT.

²Research Forester, Intermountain Research Station, Fire Sciences Laboratory, Missoula, MT.

³Silviculturist, Bitterroot National Forest, Stevensville, MT.

the forest survives, it is considered nonlethal understory fire. If severity is in between it is classified as a mixed regime.

The pond sediment record from the lodgepole pine site on the Lolo National Forest is suggestive of a mixed severity fire regime. In contrast, fire history evidence from lodgepole pine ecosystems in the greater Yellowstone Park vicinity indicate a stand-replacement fire regime (Romme 1982; Barrett 1994). In Glacier National Park, Montana, lodgepole pine ecosystems represent both these fire regimes (Barrett et al. 1991). The mixed fire regime (having more frequent and less severe fires) is associated with relatively dry environments and gentle topography while the stand-replacement fire regime is associated with a wetter climatic region and steep topography. Fire history from most ponderosa pine/Douglas-fir sites indicates a nonlethal fire regime, although some sites experienced mixed or variable fire regimes (Arno et al. 1995b).

The effect of fires was to favor dominance by fire-dependent tree species. These are early seral species that are fire resistant, regenerate abundantly in response to fire, or exhibit both these attributes. Attempts to exclude fire during this century have lengthened intervals between fires in the nonlethal and in some of the mixed fire regime types (Agee 1993). This allows advanced successional development and accumulations of dead and living fuels in many forests. Most logging treatments fail to counteract the buildup of understory conifers because thinning small noncommercial trees is costly.

Attempts to exclude the fire process from fire-dependent forests have often resulted in a shift in forest composition, structure, fire regime, and susceptibility to insects and diseases. It is common for underburn and mixed fire regime types to be transformed into stand-replacement fire regimes as a result of fire exclusion (fig. 1) (Agee 1993; Arno 1988; Arno et al. 1993; Barrett et al. 1991). By contrast, in historical stand-replacement fire regimes, attempts to exclude fire have had relatively little effect (Hawkes 1980; Kilgore 1987; Johnson et al. 1990; Barrett et al. 1991). Numerous lightning fires have been suppressed while quite small, but this is presumably offset by additional ignitions from

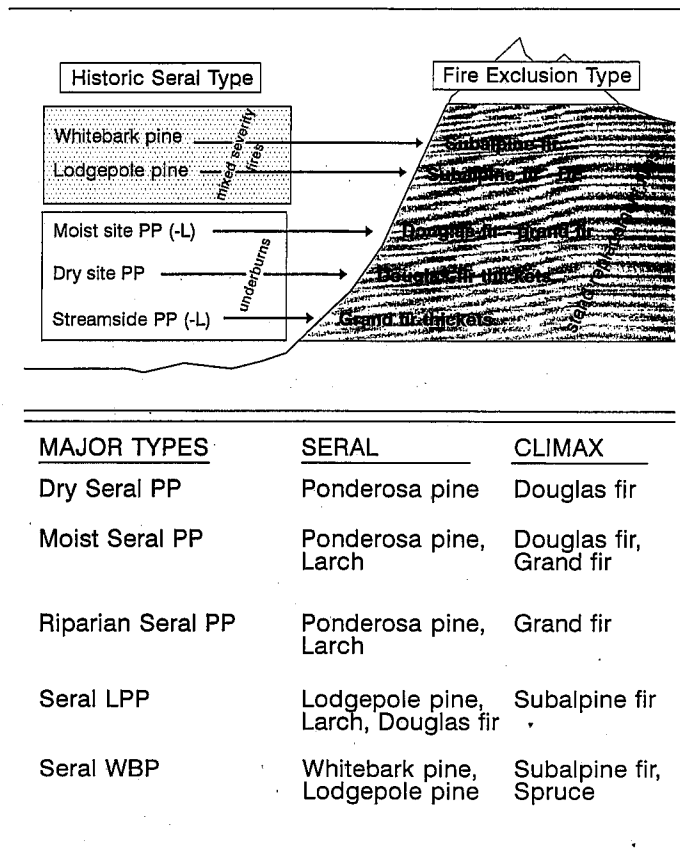


Figure 1.—A schematic representation of pre-1900 and modern forest structure and fire regime types on the east slope of the Bitterroot Range south of Missoula, Montana.

large numbers of human-caused fires. The possibility exists that suppression could have appreciable effects in some geographic areas, especially where units of this type are small, isolated, and surrounded by other kinds of forest or vegetation where fires have been largely excluded.

Ecological ramifications of excluding fire or shifting fire regimes in fire-dependent forest types are only superficially known (Kauffman 1990). There is broad agreement among forest ecologists that effects of fire exclusion practises have been profound in many of the forests formerly characterized by a nonlethal fire regime (Agee 1993). Subtle, long-term effects of fire exclusion might include changes in soil chemistry that upset balances controlling tree growth and pathogen relationships (Hungerford et al. 1991). In wildland forests where management goals emphasize main-

taining biodiversity and ecological processes, various applications of prescribed fire can often be used as a surrogate for the natural fires of the past (Arno and Brown 1991; Hungerford et al. 1991). We are incorporating prescribed fire as a silvicultural component in studies designed to return ponderosa pine/Douglas-fir forests to more natural structures (Arno et al. 1995a).

FOREST DEVELOPMENT, INSECTS, AND DISEASES

Numerous insects and diseases interact with forests in varying stages of successional development and may contribute to altered fire regimes noted above. Forest biomass is the primary substrate for economically important insects and diseases as well as those that are not. Ecologically these agents function to recycle carbon in the ecosystem—they are process agents. For the purposes of this paper, two forest types are considered—interior Douglas-fir, representing low-elevation dry-site conditions, and lodgepole pine, representing mid-elevation moist site conditions. Four important pests—western spruce budworm, Douglas-fir dwarf mistletoe, and *Armillaria* root disease in Douglas-fir forests, and mountain pine beetle in lodgepole pine forests—are considered relative to forest development.

Interior Douglas-fir Forests

Interior Douglas-fir forests for the most part occupy Douglas-fir habitat types (Pfister et al. 1977). As discussed above, these habitat types were formerly dominated by ponderosa pine and western larch, the seral, shade-intolerant fire-adapted species. However, selective harvest of the seral species, along with a dramatic reduction in the frequency of wildfire, have caused a conversion to Douglas-fir and widespread forests of this species now exist in place of western larch and ponderosa pine. The current Douglas-fir forests are highly susceptible to western spruce budworm, dwarf mistletoe, and root disease.

Western spruce budworm is native to western North American coniferous forests. Primary hosts are grand fir, Douglas-fir, white fir, subalpine fir,

and Engelmann spruce. When weather conditions, forest structure, and parasite and predator populations are favorable to budworm, populations expand rapidly to high levels (Carlson and Wulf 1989). At epidemic levels, nearly every host tree may be defoliated by this insect during any given year of the outbreak. Outbreaks usually last from 7–10 years; during this time significant numbers of host trees may die. Understory trees seem to be most vulnerable; larger overstory host usually survive except under the most severe outbreaks (Johnson and Denton 1975). Outbreaks subside due to interactions of limited food base, adverse weather, increasing effects of parasites and predators, and other factors (Campbell 1985).

Serious budworm outbreaks—those that last several years—kill trees, causing significant accumulations of dead material that can fuel wildfires. If a forest is spared from fire, Douglas-fir will regenerate and start the cycle again. If wildfire does occur, it tends to be far more intense and severe than those that occurred pre-1900 and may cause significant changes in soil structure, soil nutrient profiles, and may induce serious sedimentation in streams. Providing that some old seral veterans are left, the site may seed back to larch or ponderosa pine. In most cases, however, Douglas-fir is the sole remaining conifer and the site eventually will regenerate to this species.

Dense Douglas-fir stands are highly susceptible to *Armillaria* root disease as well as budworm (Hagle and Shaw 1991; Kile et al. 1991). The two agents may even function together. *Armillaria* is often found on trees defoliated for several years—overstory and understory. *Armillaria* centers live for extremely long periods of time (Shaw and Roth 1976), and the fungus is opportunistic. When suitable substrate is available i.e., moisture/nutrient-stressed Douglas-fir, *Armillaria* centers can expand rapidly and kill trees over large areas. As with budworm, this dead material serves to fuel the severe wildfires that are most certain to come. And, as with budworm, in the absence of fire the root disease centers will regenerate to Douglas-fir; the cycle continues.

Douglas-fir forests are also highly susceptible to dwarf mistletoe (Hawksworth and Wiens 1972; Baranyay and Smith 1972). The complex structure

of these forests—several crown layers—increases the chances of successful infection by dwarf mistletoe seeds in comparison to open grown stands dominated by seral species. Mistletoe is even more insidious in its effects than root disease. It takes a long time, 100 years or longer, for significant mortality of the host to occur. Nevertheless, this disease, like budworm and root disease, recycles carbon and helps set the forest up for serious wildfire events.

Lodgepole Pine Forests

Lodgepole pine forests are an interesting contrast to Douglas-fir forests. Lodgepole pine is highly shade-intolerant and is nearly always seral whereas Douglas-fir is shade-tolerant and mostly climax (Pfister et al. 1977). The largest, most continuous lodgepole forests occur on subalpine fir habitat types (Volland 1985). Lodgepole pine typically regenerates following stand-replacing or mixed-severity fires (Lotan et al. 1985). It grows rapidly and dominates the site, but subalpine fir, the shade-tolerant cohort, regenerates well under the canopy of lodgepole; lodgepole forests older than 60 years typically have an understory of alpine fir.

Mountain pine beetle is a serious pest of lodgepole pine. Forests become susceptible to the beetle when average tree diameter is 8 inches or more and stand age is over 80 years (Safranyik et al. 1974). This insect is the most serious insect/disease process agent known to lodgepole pine forests (Amman et al. 1977). Mortality of lodgepole under siege by the beetle is spectacular. Infestations and associated mortality may cover hundreds of thousands of acres at a given time.

In an ecological context, the insect functions in recycling carbon. Large areas of dead pines are a huge concentration of fuel, whether standing or fallen, setting the stage for a continuing cycle of stand-replacing or mixed-severity fires (Lotan et al. 1985). If fire is removed from lodgepole pine forests, succession will lead to a forest dominated by subalpine fir. Subalpine fir forests are highly susceptible to western spruce budworm at elevations below 7000 ft m.s.l. (mean sea level). So, in either case—lodgepole or subalpine fir—forest development sets the stage for other ecological

processes, in these examples the carbon-cycling agents. *Armillaria* root disease may predispose lodgepole pine to infestation by the beetle during periods when the beetle is endemic (Tkacz and Schmitz 1986). The interactions among process agents—insects and disease—is complicated and poorly understood, and deserves further study in light of current interest in ecosystem-based management.

MODELING INTERACTIONS AMONG ECOSYSTEM PROCESSES

The conceptual context of relating forest development to other processes, or “disturbances”, is reasonably straightforward. In today’s environment of high-speed computers, data bases, Geographical Information Systems, and other software, we are in a position to model forest development so we can use results in forest management planning. Modeling interactions influencing forest development interactions is problematic.

SIMPPLLE is an object-oriented modeling system recently developed for simulating ecosystem processes (Chew 1995). Simulations with SIMPPLLE on the 55,000 acre Stevensville West Central Integrated Resource Analysis unit in the Bitterroot Valley provide examples of these interactions. Levels of stand-replacing fire for five stochastic simulations without fire suppression activities, starting from current conditions are shown in figure 2. Figure 3 shows the occurrence of stand-replacing fire for five other simulations that include the continuation of our current fire suppression activities. The level of the severe western spruce budworm process that corresponds with each set of fire simulations is shown in figure 4. Continuing to manage the current landscape with fire suppression produces a significantly higher level of budworm activity. Increased budworm activity causes an increase in fuel accumulation, eventually resulting in a higher probability of stand-replacing fires. The continuing increase in the buildup of fuels unquestionably sets the stage for severe stand-replacing fire. This projected increase in stand-replacing fire is shown in figure 5 which is a summary of 30 stochastic simulations. The long term cycling between fires and budworm activity is shown for a 20 decade simulation in

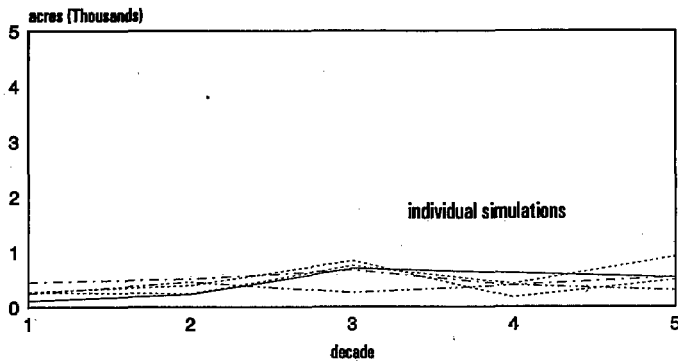


Figure 2.—Acres of stand replacing fire for five stochastic simulations without fire suppression starting from current conditions for Stevensville West Central.

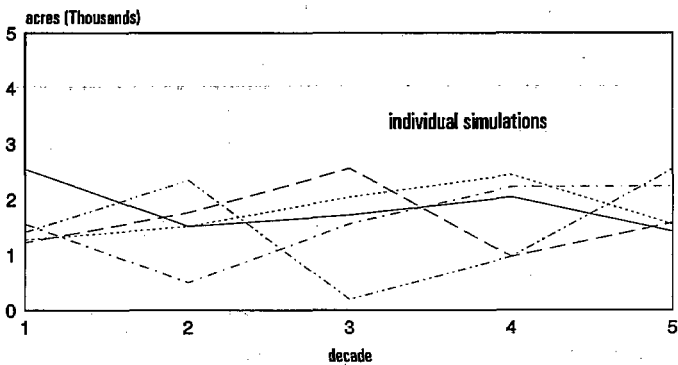


Figure 3.—Acres of stand replacing fire for five stochastic simulations with fire suppression starting from current conditions for Stevensville West Central.

figure 6 on Coram Experimental Forest, a 3030 hectare area in NW Montana. With fire at a low level the shade-tolerant budworm host species increase creating stand structures that favor budworm survival and peak feeding activity. The increase in budworm activity creates a fuels buildup that eventually results in fires reducing the suitable host conditions. A similar relationship for fire and root disease on the 9094 hectare Alden Creek area in North Idaho is shown in figure 7. The amplitude and frequency of the processes in these long term cycles are linked to stand development.

The level of budworm activity that is simulated to occur even without fire suppression is still higher than what has been simulated from historic landscape conditions. Relaxing our fire suppression efforts as a management alternative can have an impact on other processes (fig. 8), but in and by

itself, not enough to create desired future conditions that feature insect/disease resistant dry-site forests with low frequency of stand replacing wildfire. Budworm and root disease will continue at high levels and species composition will not shift quickly enough from shade-tolerant to intolerant. Species groups relative to historic conditions are shown in figure 9. Management alternatives that advocate natural stand development with no intervention by managers, or that maintain the current fire suppression policy, or even not suppressing wildfire, will cause a major gain in the shade-tolerant species (grand fir and Douglas-fir) at the expense of ponderosa pine and western larch. Clearly, some combination of intermediate harvest combined with underburning will be necessary to restore the seral species in a meaningful way.

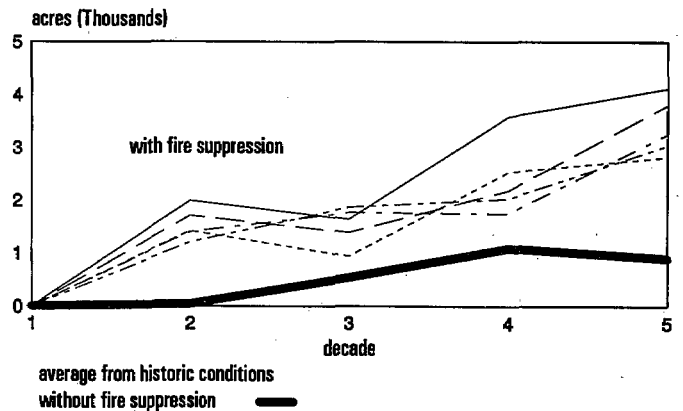
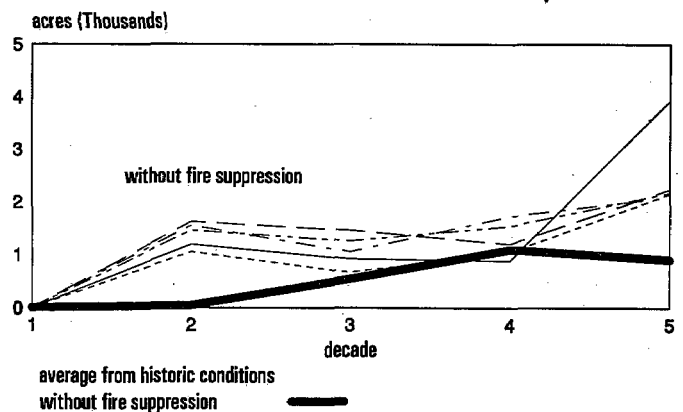


Figure 4.—Acres of severe western spruce budworm for stochastic simulations with and without fire suppression, starting from current conditions for Stevensville West Central.

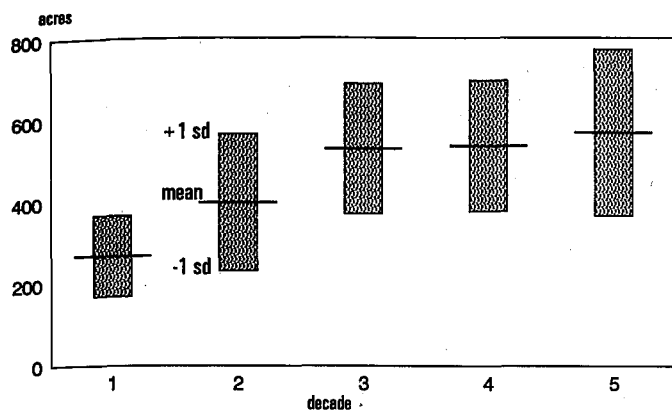


Figure 5.—Means and standard deviations for stand replacing fire based on 30 stochastic simulations with fire suppression from current conditions for Stevensville West Central.

MANAGING ECOSYSTEMS FOR MULTIPLE BENEFITS: THE ULTIMATE PROCESS

We are beginning to better understand the complex interactions that occur among ecosystem processes and forest development. This understanding should lead to better management of our forests. In light of our new knowledge and understanding, there appear to be two major schools of thought concerning ecosystem management: ecocentric and utilitarian. One school advocates that ecosystem structure, process, and function need to be maintained in order to assure long-term ecosystem viability, without defining output levels needed by human beings. This approach, that we label the “ecocentric” approach, rapidly becomes fuzzy in that it is difficult to decide which, and at what levels or ranges of variations, the various structures, processes, and functions need to operate. In fact, this is impossible to do without invoking social parameters to define suitable indicators of ecosystem health because ecosystems undergo continuous change. For example, consider the mountainside adjacent to the smelter at Kellogg, Idaho. For many years this smelter emitted large quantities of heavy metals and sulfur oxides. Soils near the smelter are now highly acid ($\text{pH} = \text{ca } 3.0 - 3.5$) and are laden with lead, cadmium, and zinc. The original conifer forest is gone. Nevertheless, there is still an ecosystem, and it has structure, function, and process. If one attempts to disregard human values (which is quite impossible) and consider this ecosystem as an entity unto itself

(anthropomorphic?), then the two states of the ecosystem—before smelter and after—simply exist. A similar case can be made for natural interventions such as glaciation, or, in a longer time frame, land-form modification due to tectonic activity.

The alternative approach, the “utilitarian” approach, is to consider ecosystems as important reservoirs of resources valuable to human beings. In this approach we can *define what we want and need* from ecosystems, and then structure management to produce these resources within the capability of the system. We can define sustainable levels of wildlife, esthetics, wood, water, or whatever. This approach has high merit in view of an expanding and demanding world-wide human population. We can define acceptable structures and desirable process levels that will meet management objectives. Forest management will hopefully adopt this approach. However, there is plenty of doubt that it will. Forest managers are under pressure both from groups advocating extreme environmental viewpoints to protagonists for extreme utilization, and decisions are difficult to make.

In line with the utilitarian approach, if we are to alter processes that adversely influence social amenities related to forest development, then we must consider traditional and non-traditional silviculture along with prescribed fire. Fire is an essential process of western North American ecosystems, and can be and is used in an applied sense to alter structural development, recycle nutrients, maintain seral species, and minimize impacts of forest pests. Where chainsaws are prohibited (wilderness, for example), prescribed natural fire may be the tool of choice. For those areas with approved Prescribed Natural Fire (PNF) programs in the Northern Region, 193,460 acres have burned within the parameters of the programs since 1972. However, there are many more wilderness acres where fire is not used due to risk to adjoining private lands. Prescribed manager-ignited fire is another potential tool for use in wilderness areas. However, use is limited due to interpretations of management restrictions in the Wilderness Act of 1964. Consequently, fire will function in an unnatural role in Wilderness landscapes lacking a PNF program.

Prescribed ignited fire, not associated with intermediate cutting, also has strong potential as a

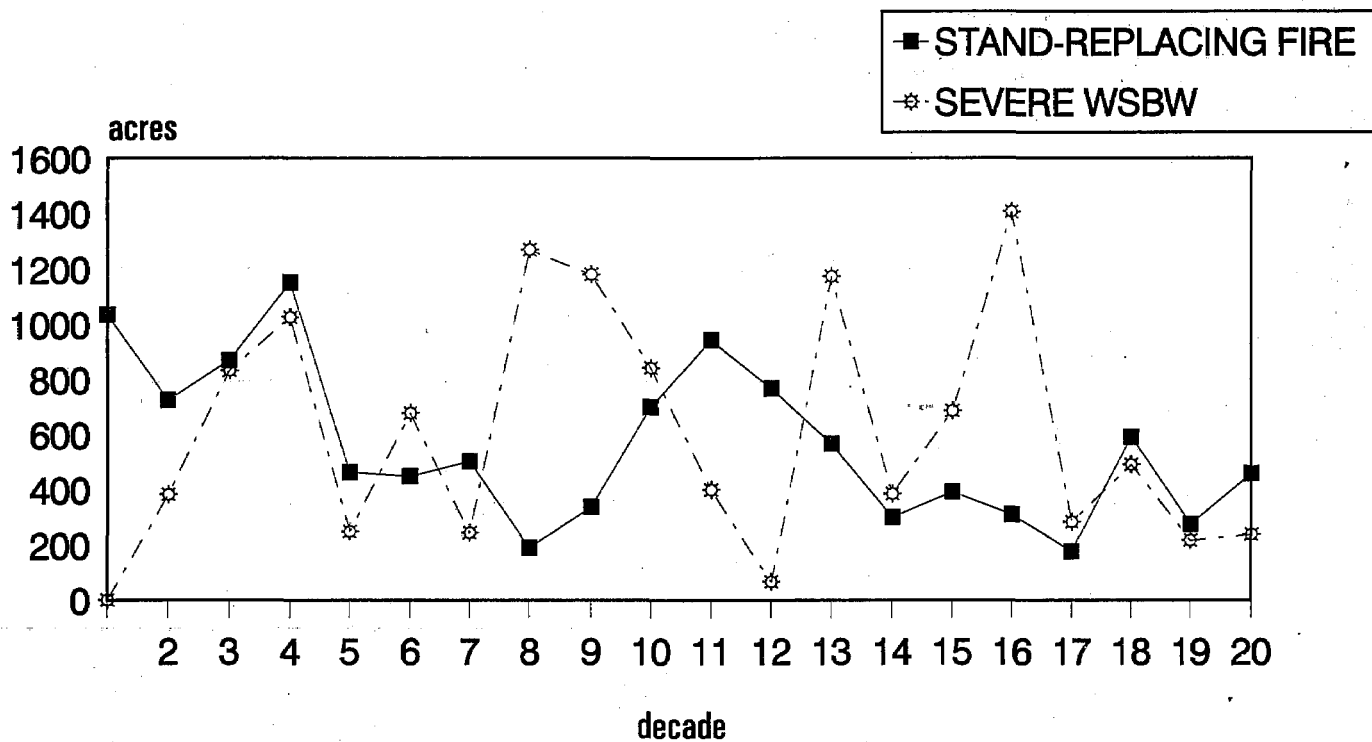


Figure 6.—Acres of stand replacing fire and severe western spruce budworm processes for a 20 decade simulation for Coram Experimental Forest in NW Montana.

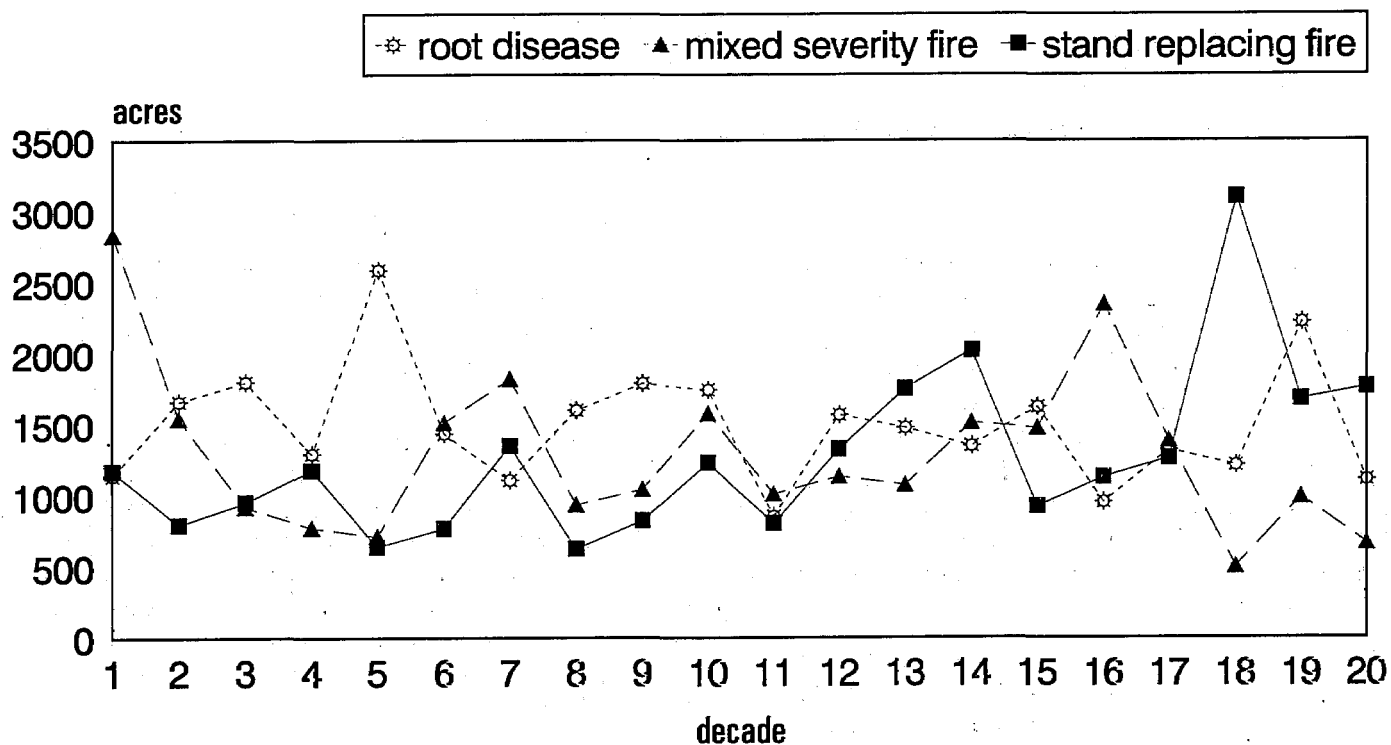
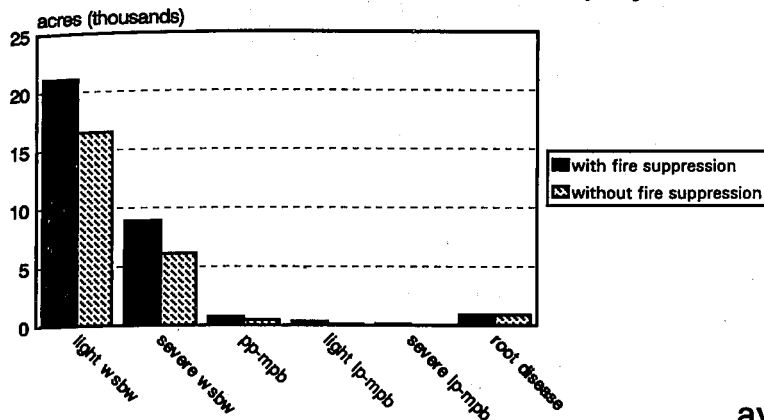


Figure 7.—Acres of the fire and root disease processes for a 20 decade simulation for Alden Creek in North Idaho.

INSECT & DISEASE PROCESSES

accumulated acres for a 5-decade projection



FIRE PROCESSES

average acres per decade

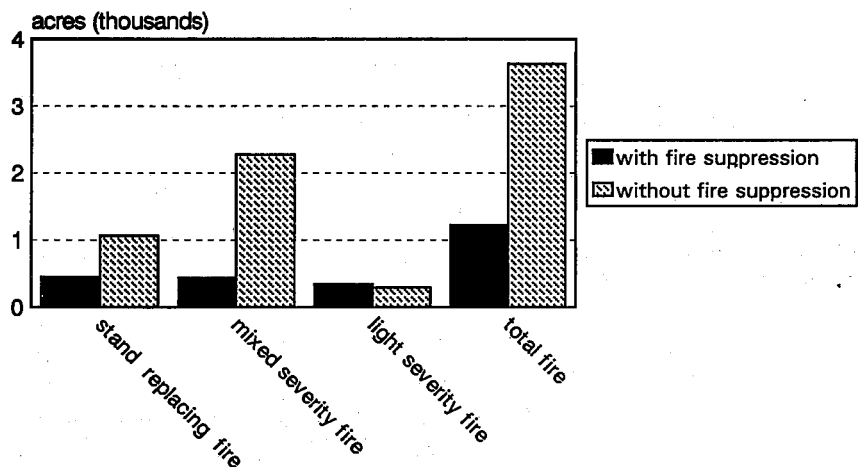


Figure 8.—Comparison of acres of insect and disease and fire processes from simulations with and without fire suppression for Stevensville West Central.

management tool outside Wilderness but on lands unsuitable for timber as a primary output. Over 11 million acres fall into this category in Forest Service Region 1 alone. Fire very much needs to be re-introduced into these landscapes, but may be limited due to air quality standards and declining funding. Nevertheless, Ranger Districts are building programs and increasing requests for alternative funding and are building partnerships with non-federal organizations, such as the Rocky Mountain Elk Foundation, to accomplish goals.

There is ample opportunity to invoke combinations of harvest and prescribed burning to restore fire as a process and decrease the amplitude and frequency of insect/disease outbreaks on tens of millions of acres defined as suitable for multi-

resource management on national forest lands of the inland west. Funds from timber sales can help with costs associated with burning, the burning will reduce fire hazard, especially important at the urban/wildland interface, and other resource amenities will be enhanced. For these actions to be truly effective, harvest and burning) need to be conducted on landscapes, not individual small stands. There exists an incredibly large volume of intermediate-size, commercially saleable, Douglas-fir and grand fir in the northern Rocky Mountains that needs to be harvested as an integral part of ecosystem-based management that has a utilitarian focus.

Research is currently underway to support landscape-level management that deals with forest

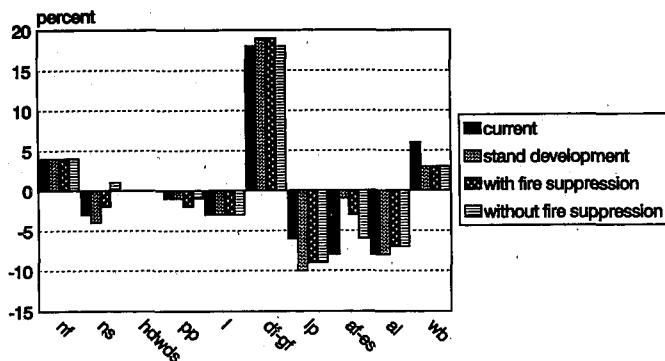


Figure 9.—Comparison of percent change in species groups from historic conditions for current conditions and simulations of stand development only, and with and without fire suppression for Stevensville West Central.

development and disturbance agents. One example is the Bitterroot Ecosystem Management/Research Project (BEMRP), a research/development project to restore social values to an ecosystem adversely affected by unnatural forest development associated with exclusion of low-intensity fire. Although the Project is focused on the Bitterroot National Forest in the northern Rocky Mountains in Montana, it addresses a problem affecting much of the 40-million acre ponderosa pine type in the western U.S.A. and Canada. The problem, stated before in this paper, is that reduced frequency of fire and logging selective for high-value seral species for the last 100 years or so has caused a major shift in species composition and stand structure. Formerly dominated by ponderosa pine and larch, with scattered Douglas-fir and grand fir, the forests are now dominated by the two latter species. The major goal of BEMRP is to develop landscape alternatives to convert the dense stagnated Douglas-fir/grand fir forests to a more natural ponderosa pine/western larch condition, utilizing intermediate harvest and prescribed burning.

BEMRP, currently funded for five years, is an interdisciplinary project. New studies include the relationships of fauna to forest development and detailed analyses of historic fire regimes in relation to forest development. Modeling will simulate forest development affected by various ecological processes such as fire, insects, and disease and to optimize vegetation management given varying resource objectives. Importantly, studies are underway to determine better ways of assessing social wants and needs and to more efficiently involve

diverse publics in forest management planning. More than 25 individual studies have been started under BEMRP. BEMRP involves five units of the Forest Service Intermountain Research Station, the University of Montana, the State of Montana, the Bitterroot NF, and the Northern Region, Forest Service. Detailed information on BEMRP is available on request (Carlson 1994).

CONCLUSION

Disturbances will happen in forests whether we plan for them or not, but there are many potential benefits to society in guiding forest development over large landscapes. Desired future conditions must take into account the needs and wants that society will demand from forested lands. It seems prudent for mankind to regulate forest development and disturbance so that social benefits can be realized in an organized and predictable fashion. If we don't, then nature will do it for us, with a high probability that the outcome will not be positive for human beings.

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