PANEL PRESENTATIONS AND DISCUSSION

FIRE, SILVICULTURE, AND ECOSYSTEM MANAGEMENT: WHAT ARE THE ISSUES?

Moderator

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INTRODUCTION

Keith Moser

The first of the three speakers today is Kevin Ryan. Kevin is the Fire Effects Project Leader at the Intermountain Fire Sciences Lab in Missoula, Montana. Kevin has bachelor's and master's degrees from Colorado State University and a Ph.D. in forestry from the University of Montana. He will be talking about issues involving fire and tree physiology. The second speaker today is Jim Vose, who is the research ecologist with the Coweeta Hydrological Laboratory in Otto, North Carolina. He has a bachelor's degree from Southern Illinois University, a master's degree from Northern Arizona University, and a Ph.D. from North Carolina State University. The third person, who will talk about silviculture and land management strategies and their interaction with fire, is Dr. Chadwick Oliver. Chad is a professor of silviculture at the University of Washington in Seattle. He has a bachelor's degree from Suwanee University, The University of the South, and master's and doctorate degrees from Yale University.

Kevin Ryan

Numerous devastating fires in recent years, coupled with the increased understanding of the ecological necessity for fire in some ecosystems, are leading to a shift in the traditional fire management paradigm of attempted total fire exclusion to one where prescribed burning, often coupled with silvicultural treatments, is being proposed. Managers are asserting that prescribed burning can and should be used to overcome certain undesirable forest health conditions, reduce the frequency of severe wildfires, restore vignettes of ancient fire-dependent forests, and improve the overall sustainability of the forests. However, the debate about the need for increased prescribed burning often fails to go beyond the broad conceptual arguments and explicitly address the technological and logistical complexities of the problem. For example, if we are proposing to treat an overstocked stand to restore open parklike conditions, we are talking about killing trees, either with a chainsaw or with fire. The chainsaw may be exact in choosing which trees will die but it does not mimic many desired fire effects. It is important to recognize that fire will not go benignly though a forest and selectively remove the undesirable trees leaving our favored trees unharmed. For fire to achieve our desired end requires that we have a good understanding of how fires of varying behavior will selectively injure trees with certain morphological characteristics. It is necessary that we have a good understanding of how fire injury is related to the death of a tree. It is necessary that we recognize that trees may take 2 or 3 years, occasionally longer, to die following fire and that postfire insect and disease attack are often part of the death process. If we fail to recognize this latter point and clearly convey this message to our public we should not be surprised if we are perceived as causing rather than curing forest health problems.

As professional resource managers, we face a number of issues in dealing with the shifting fire management paradigm. First, we must recognize that past management, regardless of how well intended, has not resulted in healthy, sustainable, fire-safe forests in many areas. Second, we must recognize that the depth of our scientific understanding simply does not go as deep as we would like. These two taken together imply that we need to act based on our best knowledge, monitor the results of our treatments, and adapt our management as new knowledge becomes available. Third, we need to involve our public and honestly convey to them the level of our knowledge and the rationale for proposed treatments, lest they be misled about our intentions and our ability to finesse the problem.

For the remainder of my time I would like to address the second issue: the depth of our scientific knowledge. Specifically, I want to briefly review physiological and morphological factors which need to be considered when developing prescriptions for burning western conifers. A recent "*Far Side*" cartoon by Gary Larson poignantly illustrates the problem at hand. The cartoon shows two loggers looking at the freshly cut stump of a tree. The caption says: "And see here, Jimmy. It's another time when the old fellow miraculously survived some big wildfire." As the fire management paradigm in the West shifts towards more prescribed burning, it is important that managers incorporate not only fire behavior considerations but also fire injury considerations into their prescriptions. And it is important that scientists conduct experiments to improve our basic knowledge of how fires of varying severity interact with plant morphology to cause injury, and on how varying fire injuries affect the physiology, survival, and growth of trees.

Let's look at a somewhat simplistic, idealized tree. It has three main parts: the crown, which is the basic production unit; the stem, which serves as a short-term storage unit and as a conduit for the flow of materials between the crown and the roots; and the roots, which are the resource procurement division of this biological factory.

Each part of the tree performs a fairly unique set of physiological functions. Therefore, injuries to each part have fairly unique consequences to the overall well-being of the tree. Each part of the tree is located in different proximity to the combustion zone in a fire and each has distinctly different morphological characteristics. As a result, differing aspects of fire behavior and different heat transfer mechanisms dominate the injury process.

When developing a silvicultural prescription where cutting is to be followed by fire, it is necessary to explicitly address which trees will be cut, the type and amount of fuel that will be created, and how the altered microenvironment will affect fire potential. When developing a prescription for burning, it is necessary to develop prescription parameters which explicitly address how each part of the tree will be affected by the fire. The process of developing treatment alternatives is, then, an iterative process involving trade-offs. Cutting modifies fuels, which modify fire potential, which modifies tree susceptibility to injury, which in turn needs to be a factor in deciding which trees to cut. It is often impossible to eliminate injury of the desired trees and maintain an operationally feasible window for burning.

So, let us first look at a tree's response to fire injury and return later to look at how fires injure trees. A tree has three possible responses to a given fire. First, it can survive, prosper, and grow well if it is only slightly injured and has gained some kind of competitive advantage. Second, it can survive but do poorly if it has been severely injured. Third, it can die. Which of the three outcomes occurs in a given fire depends on the tree's resistance to being injured, the type and degree of fire injury that the tree suffers, the prefire vigor or physiological condition of the tree, and the tree's ability to repair the injury. It generally is accepted that the postfire environment also plays a role in the response (e.g., if the tree experiences a favorable climate after the fire versus an adverse one, if the postfire climate is conducive to bark beetle flight versus not being conducive, etc.) but such complex interactions have not been demonstrated, cannot be predicted, and generally have no value in developing a burning prescription.

Although there have been a number of studies documenting the effects of fire on tree growth (see Landsberg 1994 for review) and postfire survival (see Ryan 1990 for review), very little research has been done on the physiological consequences of fire injury. The larger body of physiological literature can be used, however, to gain insights into the expected response to fire injury (see Ryan 1993 for review). It is generally accepted that there is a hierarchy of carbon allocation in a tree (Waring and Schlesinger 1985). All living cells respire and the first thing a tree must do is meet its demand for maintenance respiration. As much as half of the carbon fixed by the crown in photosynthesis may be used in the same year to maintain nonphotosynthetic tissues such as stems and roots. Theory and experimental evidence suggest that canopy and root growth are in a dynamic equilibrium. These are the next highest priorities for carbon allocation in the tree. Storage, stemwood growth, and the production of defensive chemicals tend to be a lower priority. Forty to seventy percent of total annual photosynthesis may be available for growth depending on tree age, site, and season. Ranges for the percentage of carbon used in crown versus root versus storage versus stem growth versus defensive chemistry can vary substantially. Injury and environmental stress can be expected to cause short-term deviations in the hierarchy of carbon allocation within a tree.

Looking first at crown injury, in an earlier paper (Ryan 1990) I attempted to carefully exclude trees with potential stem or root injury so I could focus solely on the response of individual trees to fire-caused defoliation (crown scorch). It is apparent that the survival of the tree depends upon both the level of defoliation and the prefire vigor of the tree. Vigorous trees have a much higher likelihood of surviving moderate crown scorch than low vigor trees. High vigor trees have more stored carbohydrates which can be used to heal injuries and replace lost tissues. I also used a physiological process model that calculated daily net photosynthesis from tree and weather parameters. I used this model to estimate how defoliation (0%, 20%, 40%, and 60%) reduces the amount of carbon available to the tree. It appears that even minor crown scorch (20% defoliation) can be expected to greatly reduce the chemical defenses of a tree against insect attack. This observation suggests that either: (1) insect populations frequently are not present to exploit weakly defended trees; (2) we do not really understand hierarchy and relative size carbon allocation in trees; or (3) that the tree can temporarily reorder its priorities when stressed.

Consider a cross section, taken from a ponderosa pine (Ryan 1993). A propane burner was used to artificially remove 80% of the foliage. Cumulative growth in the 2 years following defoliation is less than in the year previous to defoliation. This is consistent with what we would expect from the physiological analysis in the previous slide but the fact that growth did not completely cease illustrates that the tree has considerable ability to modify allocation between competing needs.

Moving on to the response to stem injury, this is a graph of mortality as a function of the percent of the circumference of a tree girdled by fire. It is based on a small amount of experimental data from ponderosa pine (Ryan 1993) and Aleppo pine in France (Rigolot et al. 1994). The data were censored to exclude trees with detectable crown or root injuries. It is apparent that there is considerable variation in mortality associated with the amount of girdling depending on tree age and size. Younger trees appear to be much more resilient to basal girdling than older trees. It is interesting to note, however, that expected mortality for light to moderate levels of girdling is much lower than would be inferred from earlier fire literature (e.g., Wagener 1961). I believe this is because earlier authors poorly quantified actual stem injuries and essentially ignored root injuries. These two are often highly correlated in wildfires but need not be correlated in prescribed burns. Stem injuries are difficult to detect, particularly in trees with thick bark. Current methods of detection require destructive removal of the bark so it is difficult to accurately assess injury without damaging the tree. Bark beetles often attack basally girdled trees (Ryan and Amman 1996). If this fire injury has been overlooked it leads to the false conclusion that bark beetles killed the tree.

We artificially girdled trees in 1987 with heat from a burning wick. In 1988 there was no difference in g_s (stomatal conductance) in trees with 0% versus 70% versus 100% girdling. There was also no difference in g_s in 0% and 70% girdled trees in 1989. However, all but one of the 100% girdled trees died during the second growing season. Seasonal growth for Aleppo pine from the Mediterranean climate of southern France has been analyzed by Rigolot et al. (1994). The trees in that study were basally girdled with heat in March to either 0% (control), 70%, or 100% of the circumference. It is apparent that 70% basal girdling has no effect on diurnal or seasonal growth patterns during the first growing season. The effect of complete girdling does not become apparent or result in the appearance of chlorotic foliage until late July. It appears outwardly that completely girdled trees function normally until just before death, a fact that suggests that postburn monitoring should be conducted frequently during the first 2 years. Fatal basal girdling often does not become apparent visually in western conifers before the second growing season following injury. These trees are often attacked by bark beetles while the foliage is still green. The beetles may accelerate the demise of the tree but are not the cause of death.

During many fires more than one type of injury occurs. The combined effect of crown scorch and basal girdling on stem growth has been overlooked until recently (Ryan 1993). Partial girdling (70%) had no effect on growth the first year but a significant reduction in growth occurred with 40% and 80% defoliation. In the second growing season there is more stem growth in partially girdled and defoliated trees than in control trees. This shift in carbon allocation to stem growth suggests that less carbon was allocated to root growth. If this is true, we would expect less fine root production in the third growing season. Thus, physiological effects of injury such as moisture stress, altered growth, and reduced insect resistance probably last into the third postfire year and beyond.

There are also differences in mortality as a function of crown scorch for thin-barked (e.g., Engelmann spruce, subalpine fir, lodgepole pine, western hemlock) versus thick-barked (e.g., western larch, Douglas-fir, ponderosa pine) trees (Ryan 1990). Bark thickness increases with diameter at a rate that depends primarily on species, and to a lesser extent, on the site. Most fires that are intense enough to cause significant crown scorch are of sufficient duration to kill phloem and cambium of thin-barked trees. Thus, even large diameter trees of thin-barked species are highly likely to die at relatively low levels of defoliation. Small diameter trees of thick-barked species may be killed by either crown scorch or stem injury. In contrast, surface fires in natural fuels are rarely of sufficient duration to cause phloem and cambium injury to all sides of large diameter trees of thick-barked species. Crown scorch or root injury are the major causes of mortality in thick-barked trees.

Fire-caused root injury is very difficult to quantify. Virtually nothing is known about its effects on physiology, survival, or growth. The primary source of heat to injure roots comes from the smoldering combustion of the duff (fermentation and humus layers). The easiest place to detect injury is at the root crown. Examples of ponderosa pine from Glacier National Park illustrate a dilemma we face when reintroducing fire into such stands. After 70 years of fire exclusion a 28 centimeter mound of duff has accumulated beneath the tree. The duff is generally deepest at the base of the tree. Also, because the canopy of the tree intercepts precipitation, this duff is often drIer than in the stand as a whole. This situation is conducive to root crown injury. Temperature data from smoldering duff mounds indicate that temperatures in excess of 400°C may last for up to 30 hours. Such temperatures can be expected to cause lethal temperatures up to 20 centimeters into the root crown. I routinely find root crown injury in ponderosa pine following prescribed fires and wildfires. Where these injuries are discontinuous around the circumference of the tree they appear to have little effect on short-term (up to 3 years) mortality. Ponderosa pine is a deep-rooted tree. The bottom of lateral roots often survive when the top has been killed. Examples from a wind-thrown ponderosa pine from Devil's Tower, Wyoming show evidence of repeated root crown injury from fire. But there is no evidence of stem injuries (cat-faces) which commonly are used in fire history studies.

The logistics and destructive nature of below-ground (root) sampling has precluded our understanding of how fire injury affects tree physiology. However, we can get a glimpse of its potential importance by reducing the rooted volume parameter in our physiological process model while holding the amount of foliage constant. This is analogous to root pruning by a lethal heat pulse into the ground (Ryan 1990). The results lead us to suspect that root injury is potentially a very significant fire effect. Root pruning can be expected to result in moisture stress, reduced photosynthesis, and major shortfalls in carbon allocation to lower priority processes. As the degree of root pruning increases, cumulative net photosynthesis begins to decline earlier in the growing season. At higher levels of root pruning (40% and 60%), onset of the decline (the point where the respiration demand of the tree exceeds photosynthesis) coincides with the period of major bark beetle outbreak in the northern Rocky Mountains.

Our physiological modeling suggests that root-pruned trees may be very susceptible to attack by insects. Clearly this is a provocative speculation at this point. However, the field of fire injury, physiology, and insect interactions should be a fertile research field. We have begun with extensive observation of postfire insect attack following the Yellowstone fires and others. And we have initiated pheromone studies to better understand which species of insects are most attracted to fire-injured trees, and the extent to which insects are major contributors to mortality versus opportunists dining on mortally injured trees. The carry home message for managers is that you should expect to see increased bark beetle and wood borer activity following fire treatments. The results of our studies indicate that this increased activity is relatively short-lived, usually three years or less in most cases.

Let's return for a moment to our idealized tree. We've looked at the response to fire injury. Now let's look at the causal factors associated with fire injury. Active plant tissues are killed by exposure to temperatures on the order of 50°C for one hour, 60°C for one minute, and 70°C for one second. These temperatures are one-tenth those routinely measured in surface fires. The fire's behavior (intensity and duration), interacting with plant morphology in complex and imperfectly understood ways, dictates how much and what kind of tissues will be killed.

Foliage is poorly insulated. The dominant mechanism killing foliage is the convection of hot gases above the flames. The peak convection is associated with the passage of the flame front. Flame length, a measure of the fire's intensity or rate of energy release, air temperature and wind speed determine how high in the canopy lethal temperatures will occur. The amount of fine fuels (approximately <5 millimeters diameter), their moisture content, the rate they are ignited, wind, and slope determine the intensity of the surface fire. Prescription parameters need to be defined such that the expected scorch height is below the limit associated with high survival of those trees which are intended to survive.

Phloem and cambium are insulated by dead outer bark. The thickness of the dead outer bark determines the resistance of a tree to stem injury. Resistance to stem injury increases with the square of the bark thickness roughly at the rate of 3 minutes per centimeter squared of bark. Trees with very thin bark may be killed by brief flame contact. Such trees are poor candidates for prescribed burning unless supplemental measures (e.g., artificial insulation or fuel removal) are applied. The dominant heat transfer mechanism associated with stem injury is conduction. The dominant factor determining stem injury is the duration of burning of fuels larger than approximately 5 millimeters (branches and coarse woody debris). The amount and moisture content of these fuels dictate how much injury will occur on a given tree. Prescription parameters need to be developed that explicitly address the likelihood of stem injury. Unfortunately, only a handful of experienced burners have developed their art to the point where they can predict the duration of flaming in their fuels. Careful observation of flame duration followed by sampling of cambium vitality will help managers develop rules of thumb for use until science tackles and solves the problem.

Prediction of root injury is not possible at this time. Little is known about how roots are distributed in the soil relative to soil heating during a fire. Factors affecting the depth of lethal heat penetration in the soil are the duration of smoldering of the duff, the moisture content of the soil, and, to a lesser extent, soil texture. Managers can minimize root injury by minimizing duff consumption to the degree that this is compatible with other burn objectives. Guidelines for predicting duff consumption are widely available in the West.

General species-dependent patterns of rooting depth may be of some use in predicting which species will survive best. For example, western larch and ponderosa pine are deeper rooted than the equally thick-barked Douglas-fir. The latter species survives more poorly after extensive duff-consuming fires. Shallow rooting co-occurs in trees with thin bark and is commonly associated with less fire-resistant, late successional-stage species. Such trees survive only in marginal discontinuous surface fires where duff consumption is patchy. The term "mixed-severity fires" is currently in vogue to describe such fires.

The science of predicting the behavior and effects of fires is relatively robust. However, it should be apparent from the foregoing discussion that there is still a great deal of art involved in the application of fire. As we move forward with implementation of this new paradigm in fire management, we need to be careful observers and document our treatments and results. As we formulate silvicultural and fire treatments we must constantly ask the question, "Will this combination of treatments yield the desired species composition and stand structure?" In other words, "Will the right trees survive?" We need to recognize that it will take time and often it will take multiple treatments to achieve the desired conditions. We need to recognize the complexity and accept the uncertainty. And, we need to convey the magnitude of that uncertainty to decision-makers and the public. It is time to get beyond the conceptual paradigm shift and get on to the actual paradigm shift. We need to act, monitor, adapt, and communicate.

James Vose

Today I will discuss my perspectives on what I consider to be some of the more critical issues related to the use of fire in ecosystem management. My primary point of reference will be the southern Appalachian region; however, I think that many of the issues in this region are similar to those of other areas in the East. My objectives are to raise questions and describe why these questions are important to the use of fire in ecosystem management.

Fire has a long history of use in the southern U.S. as a forest management tool. These fires have been used primarily for the traditional silvicultural purposes of site preparation and fuel load reduction. For example, many southern states (Georgia, Alabama) prescribe burn as much as 400,000 hectares of forest land annually. This long history of extensive fire use, and corresponding research, has led to a relatively good understanding of fire effects on silvicultural responses (i.e., regeneration success, fuel load reduction, etc.) in southern pine forests. The use of fire in an "ecosystem management" context is a much more recent phenomena. We understand considerably less about the use and effects of fire outside the domain of traditional silvicultural objectives. In particular, there has been growing interest in using fire to restore and/or maintain ecosystems (i.e., longleaf pine, Table-mountain pine, pitch pine) or regenerate other species (i.e., oak). In the context of the new "ecosystem management" based uses of fire, I pose three questions.

1. What type of ecosystem are we trying to restore or maintain; i.e., what do we choose as the "baseline" condition?

In contrast to many forests in the western U.S., contemporary forests in the eastern U.S. are legacies of both extensive and intensive human disturbance. These disturbances include prehistoric burning, Native American burning, European settler land clearing and burning, logging, and fire exclusion. Under current (i.e., the past several thousand years) climatic regimes, human fires were and are much more important than lightning-ignited fires in the southern Appalachians. Researchers are just beginning to establish fire and vegetation chronologies for the southern Appalachians using pollen and charcoal analyses. Some of the initial results indicate that over the past 4000 years, forest composition has varied substantially in response to the various fire regimes imposed by the different inhabitants of the region (Delcourt and Delcourt, *in press*). Clearly, the composition of the historical forest was a moving target. However, restoration implies that the management objective is to restore the ecosystem to a previous condition. Philosophically, the fire ecologist and land manager must communicate to the public which baseline condition they are trying to restore and maintain. Alternatively, the option is to forego the notion of restoration and reintroduce fire to create an ecosystem with characteristics quite different than under a "natural fire regime."

2. Should fire be used as an "ecosystem management" tool in systems which are not ecologically adapted to fire?

Forests in the eastern U.S. are undergoing considerable change. For example, in the southern Appalachians and elsewhere, there has been a noticeable reduction in oak regeneration and an increase in the relative abundance of red maple. In addition, rhododendron appears to be expanding into midslope positions from the riparian zone. Fire exclusion has been advanced as a reason for these changes, so discussion and research have been accelerated on the potential uses of fire to reduce red maple and rhododendron and increase oak regeneration. At present, however, there is no clear evidence that fire exclusion is the sole cause of these changes. For example, the loss of American chestnut in the early part of this century and changes in forest grazing patterns have also been implicated as causal mechanisms for some of the observed changes. Whatever the causal mechanisms, fire may be a useful tool to reduce the vigor of both red maple and rhododendron (which is thin-barked, generally fire intolerant) and improve the competitive ability of oaks. However, the frequency, location, and intensity of the fires may be very different compared to "natural fire" regimes. The implications of introducing a new disturbance regime to these ecosystems are uncertain and will require careful evaluation prior to widespread prescription and application.

3. Do we know enough about ecosystem responses to use fire as a management tool?

There is a considerable body of knowledge on the effects of fire on ecosystem components in the southern pine forests; considerably less is known about hardwood ecosystems. In addition, these studies often have a short-term, narrow focus (i.e., fuel consumption). Even in southern pine forests, there are few integrated, long-term studies of the effects of fire on ecosystems. The long experience of using fire in southern pines contributes to the knowledge base of observed responses, but this experience is not necessarily applicable to hardwood ecosystems. Reintroducing fire into ecosystems which have not been burned for nearly a century poses considerable uncertainty and challenges. Widespread application of fire in hardwood forests will also need to be accompanied by long-term ecosystem research. In addition, I believe that fire ecologists and land managers will be faced with increasing pressures regarding secondary effects, especially smoke emissions. Increased use of fire will mean greater inputs of both particulates and chemicals into the air. Restrictions imposed to maintain air quality standards in the eastern U.S. may be a considerable constraint on where and when fire is used.

Chad Oliver

I am going to talk about the silvicultural aspects of use of fire. I'll build on the concepts outlined by the other two speakers.

To put silviculture in perspective, if we look at what we are trying to manage in terms of an ecosystem, we are not looking at managing a single direction. If this is our forest, we are looking really at a number of interactions between biodiversity, the global environment, commodities, human well-being, and how these interact with each other. If we had a single objective (like we used to have in many areas of commodity management) then we had one way to manage our forests, and it was fairly straightforward. At that time, what we thought, in terms of biodiversity, was the "natural forest" existed in a steady state, so what we began doing was just setting aside individual areas and letting those places be our natural forests. This approach began very early in this century, and to give you an example to refer to, I'll describe an area set aside by the Harvard Forest in New Hampshire. It was assumed to be an old-growth forest functioning at a steady state, and that it would perpetuate the species that were found here naturally because it was assumed to be all old growth. Then the 1938 hurricane blew down one half a million acres of forest in New England.

What we began to realize is that the forests everywhere go through dynamic and constant change. The Ecological Society of America Annual Meeting in 1990 confirmed this change in paradigms from a steady state to the dynamic one. Participants agreed that we are going to have to rethink our ways of managing our forests as a result of this new paradigm. Now, what we realize, is that the forest changes over time through disturbances that back it up and then move it forward in different ways.

What we also realize is that each of these different forest structures have different values for wildlife. So, what we are looking at is a diversity of conditions. We also appreciate that each stage has certain tendencies, risks for fire, and certain risks for insects and other such things.

Now to give you examples, consider the stand-initiation stage in the Inland West. As it grows, you get very little understory. This is a stem-exclusion stage, a stand about 90 years after stand initiation. Eventually, some of the overstory trees die. You start to get a partial understory. This is the understory-reinitiation stage. If you do not get a disturbance before then, some trees die, others grow into the understory, and we end up with what we call old-growth structure. Depending on topography and other factors, disturbances often occur before this condition. And in different places we can have other structures as well. This is a savanna-like structure that you used to find in ponderosa pine stands in the West and longleaf pine stands in the Southeast.

Now, what we realize is we can classify these different forest structures in a number of different ways. We appreciate that the forest grows naturally from one condition to another and that disturbances set it back and change it from one structure to another. In addition to which, as I'll show, our silvicultural manipulations can be used to mimic, avoid, and recover from the natural disturbances so that we create a certain distribution of these structures across the landscape.

Here we are planning to manipulate different stand structures. We do so through individual management operations, which means everything from prescribed fire to planting to thinning. We interact with physiologists to determine how we are affecting individual plants. We interact with ecologists to determine what types of conditions we can achieve. But, in order to know what structures we want, we have to look at the landscape pattern as a whole.

Each landscape has some type of distribution of different forest structures. The other thing that is important is that these structures are not static.

We are looking for strategies for management so that we mimic, avoid, and recover from our natural disturbances, and maintain these different conditions. And we are developing ways to use different tools to project across a landscape and develop these different structures. We need (and are developing) tools for telling us what different operations to do.

Right now, in every region of this country we have an imbalance of structures of one sort or another, not always the same type. I'll give you a couple of examples. In coastal Pacific Northwest we have done a lot of clear-cutting and regrowing the stands, so we have an awful lot of this stem-exclusion structure relative to the others. Now we don't know what the historical range was, but rather than wait until we know exactly what that is, we are safe to assume that this forest structure is in excess, so we probably want to find a way to get more of a balance of structures.

In the Inland West, we know that our fire exclusion policy plus a high grading policy has created two things. We have reduced the number of openings. We have gotten rid of that stand-initiation structure and moved to a lot of stem-exclusion structure. In fact, the interesting thing is that stem-exclusion structure is caused by small diameter, overly crowded stems. We are growing a lot of dense stands.

If we have overly crowded dense stands, we can do either active management or passive management. Before determining which alternative to use, we have to look at our different objectives in terms of biodiversity, commodities, human well-being, etc. Then we can look at these different values, looking at the different alternatives, which are: 1) commodity value and management, and; 2) some type of a landscape management.

We can rank how well those strategies will achieve each of our goals. We also need to rank how certain we are that each of these strategies will achieve our goals. People often default to the idea of if we don't know it will work, we should do nothing. We also need to ask, what is the probability that we will achieve our objective if we do nothing?

As we decide, we can look at how stand structures change naturally through time. We can even determine whether they change naturally, and their relative degree of susceptibility to fire. There are two ways we need to look at fire and how should we protect certain areas from fire and where can we use it as a manipulation tool. I'll describe a number of these manipulations. Some of our silvicultural diagnostic tools allow us to predict when an area is in danger of a fire.

Consider a dense lodgepole pine stand that we predicted would burn up. First we predicted there would be insects in it, after which it would burn. Then the question is, should it burn or not? Should we thin or remove the trees before we burn it, or should we not? It's possible we won't get regeneration. On the other hand, if there are houses in this area we need to look at the dangers there.

But a silvicultural tool may allow us to get out of a situation. We may want to first remove as much of the wood as possible to meet two objectives, both the wood value and getting rid of the fire danger. Consider an area that in the late 1800's was known as Antelope Flats, on the Coconino Plateau of the Grand Canyon. We know from our diagnostic tools, for example, that forest stands are so dense now we can expect at anytime to have insects in it and then fires. If we got fires, it would not go back to an open parklike stand. In all probability, the fires would be so hot that we would burn up even the large trees.

Therefore, what we may want to do is use our silvicultural operations first to thin the number of trees to leave it more parklike. Then we would have to work with the physiologists about how could we reintroduce prescribed fire without getting the fire so hot it gets into the duff layers and kills the big trees we are trying to retain. In other areas, we can predict that our stand was so crowded that, sure enough, they did burn excessively. And then we get into the question of how do we restore our stands?

Consider a stand with a stem-exclusion structure that would stay in this structure for about the next 60 years if left alone, with no understory and very little wildlife value. However, we could prune it and thin it to about one third of the existing stems per acre. Three years later we have a lot more wildlife in the understory. This is not a particularly fire-prone area, but by our pruning operation and our opening it up we have reduced the fire danger. There is also an economic advantage to this that I'll show you later that would help offset the cost.

We can also thin stands later in their life. Consider a stand that is 65 years old. Three years after we thinned it, we produced a lot more understory. Now, the question of fire is whether it is a good thing or a bad thing. So, in terms of silvicultural operations, part of our question is to what extent should we salvage to prevent these reburns from being so drastic?

Now, at the same time, and in many places, we have used silviculture as an active management tool. For a while we used it to reduce the fuel damage in western Washington and also to create planting areas. As we found with better utilization standards, and with our concern about having light-seeded species come in a fire area, we reduced our amount of prescribed fire. In fact, I am beginning to think that from an ecological perspective, we may want to reintroduce fire in some places because we may actually not have some understory species that were dependent on fires.

There are other things about the stand-initiation stage we can manipulate. On the surface this looks like a very effective regeneration of an area; however, we often plant too densely. We end up then with overly crowded small diameter stands that get insects and diseases in them. We can do very little about it because the wood is so small and often burns completely. We have diagnostic tools we use in silviculture that tell us what spacing will give us what sized trees so that we can know when our stands are the right spacing.

Now, we can diagnose how stands can behave by using some of our silvicultural knowledge. If we understand stands, then we can manipulate them accordingly. You see a lot of stands that have two or more layers in them that we always assumed were natural succession, uneven-aged stands. Our silvicultural research is showing, in fact, that these are often a single age and they started after a single disturbance. Now knowing that, we can manipulate the stand in such a way that we just have to be sure we don't have too many trees in each of our layers. This will create, very often, the structures that we want. If we keep the spacings where we want we also reduce our fire hazard there. Not knowing that, we very often look at our young stands and either assume: 1) we have too many trees per acre and spend a lot of time getting rid of them, or; 2) we assume we have too many of the wrong species and spend a lot of effort where it's not necessary.

Our fire prevention regime has allowed a lot of grand firs and Douglas-firs to grow up in the understory in the West and hardwoods to grow up in the East. In fact, the invasion and the increase in grand fir in the West is very similar to the increase in red maple in the East, also exacerbated by high grading in the name of selective cutting.

In very many places in the western United States we did high grading. We took the best trees and left the others. This did not produce very good wood quality, but as the trees regrew it produced a lot of the old-growth structure. We ended up then in the West with very large contiguous areas of this old-growth structure.

Unfortunately, what we have done historically is create this habitat over such a large contiguous area that it is highly flammable. Then the areas that we found that used to be old-growth habitat down along the streams will burn up too and we will go from a case of feast to famine. We can use our silvicultural techniques to avoid that. I want to emphasize just very quickly that we can do selective cutting if we do the right techniques. Consider a 65-year-old stand in western Washington that has many of the old-growth structures from selective cutting where we have avoided those other problems. If we leave too much overstory or understory, however, it is suppressed and we've basically lost our desired conditions. This is another diagnostic tool we can use.

So, we have a variety of techniques. We can use silviculture in many ways both to enhance the structure that we want and to protect a desired structure from fire. We can use silviculture to recover from wildfires as well. The choice of whether to do something or not gets to be the question, in the face of uncertainty: Will doing "nothing" be better or will doing "something" be better?

Keith Moser

Thank you all for your insights. Now let's take a few questions from the audience.

Audience member

What are the consequences of reintroducing fire into areas where fire has been kept out for a long period of time?

Kevin Ryan

I'll use our own example. I showed two slides that dealt with ponderosa pine in Glacier National Park. What we were trying to do when we reintroduced fire at Logging Creek in 1983 was to cause mortality of Douglas-fir and a hybrid spruce that grows in that part of the North Fork drainage. We were largely unsuccessful because, although we burned on the driest day in the two years, it was still too moist. We did not consume enough fuel, did not kill enough trees, and did not create an adequate seedbed for ponderosa pine seedlings. In the burned area shown in that slide, Mother Nature put the second treatment in for us in 1994 under much drier conditions. The interesting thing was that we had, unwittingly, created a few small spots where ponderosa pine regenerated where a log had burned up in our 1983 burn. Fortunately, there wasn't enough fuel around those sites to kill those trees when the area burned in a prescribed natural fire in 1994. Basically, what we were trying to do in 1993, I now realize is probably going to take us at least two or three treatments to get to where we want to be.

Jim Vose

An example I'll use is from one of yesterday's talks, and that is using fire to restore the only real fire-dependent ecosystem in the southern Appalachians: the pitch pine-hardwood and Table-mountain pine ecosystems. Since about the early 1980's, foresters have been using a combination of silviculture and high-intensity fires, what they call the fell and burn technique. With this technique, they chainsaw-fell all the material. If there is any merchantable product, they will take it off. Otherwise, they will leave it in place and then burn it with a high-intensity/low-severity fire. This method is used to restore both the native yellow pines on the site. They would then also plant white pine in a wide spacing and try to increase the resistance to insects and increase the productivity. They've been doing that about 15 years or so and we initiated an ecosystem-level study to try and understand the environmental consequences of that.

Now as a result of some of the conclusions of the previous study, we initiated a stand-replacement fire where, instead of chainsaw felling the material, the pitch pine system was lit with a helicopter over standing vegetation in an attempt to mimic wildfire. In this case, what we consider as the potential negative effects of the fire will be much, much less. There will be about a five-fold reduction in nitrogen loss from the site and equal, if not more, regeneration and restoration of the pine component. It is definitely a work in progress. You learn as you go in terms of appropriate ways to reintroduce fire into fire-dependent systems.

Chad Oliver

They are now reintroducing fire in the Pacific Northwest but doing it with spring burns which has certain advantages in terms of smoke mitigation. Since spring wildfires were not a common part of the natural fire cycle in this region, is that causing some adverse or unbalanced effect to the vegetation? This is a very good question. We probably are changing which species have a competitive advantage after the fire, so we are probably changing the relative abundance of different species by doing the spring burn. We have to look at how we are probably changing the relative abundance of species when we don't burn, when we do a spring burn, or when we do a late summer burn. If we look at the pre-Columbian times, it is highly probable that most of the fires were in the late summer or fall. There may have been occasional ones started by the Native Americans in the spring, as well. I think this is an unknown question, one we ought to monitor by all means. You pointed out that the advantages are not only less carbon in the atmosphere. Also, I think it is a good opportunity to take some of these areas that have had a very high accumulation of woody fuel material and duff, and burn them under less than severe conditions. Then these sites will not burn so hot that the fires kill the roots of the trees or damage the soil very much. So it may be a way for us to reintroduce a natural fire regime. I think the concern you expressed is a real concern and one that should be monitored. My guess at this point is it is not enough of a concern for us to stop but it is something we should monitor.

Keith Moser

If I could add to that point, one of the things we are faced with in the Georgia-Florida region is going from dormant-season burns, which we tend to use for hardwood control or wildlife issues, and moving towards lightning-season or growing-season burns. Workers have pointed out that while dormant-season winter burns were not as prevalent as lightning-season burns, they were still part of the historic fire regime. So having an occasional dormant-season burn is part of the sort of natural stochastic behavior that occurred within the range of natural variation. It's not like burning has to be growing season, it has to be "here," it cannot be "there." But the whole idea, as I think Chad and Jim talked about, is figuring out what is the range of natural variation and that gives you a lot of wiggle room when you put in the fires.

Chad Oliver

Peter Cole asked the question, given the increase of carbon dioxide in the atmosphere and our concern right now of going to some type of range of variability of vegetation, how do we balance these two conditions against each other?

First of all, in terms of what conditions do we want across the landscape, we have to realize that in pre-Columbian times, there was still quite a bit of fluctuation in amounts of different stand structures, different disturbances and the way they changed over time. So what we have used, and this was discussed at a conference that Neil Sampson of American Forests was in charge of, is that we like to use historical range of variability just to be sure that we have not lost certain species or overlooked certain vegetation types. But exactly knowing what is the appropriate balance is something that we don't know, and we may never know. Therefore, all we can do is work away from the extremes, where we have too much of a single type. Now, relative to the carbon dioxide balance, there are several interesting perspectives. Some people point out the amount of CO_2 that's stored in the standing trees. Keep in mind that these areas will burn. The question is, are we better off letting them burn in wildfires or are we better off letting them burn in controlled fires? In many of our ecosystems, "stopping them from burning" is not very likely. If we were to stop the fires, the sudden catastrophic release of carbon dioxide would cause decomposition which would emit the same amount of CO_2, only more slowly.

Now, if you're looking for a way for forests to mitigate the CO_2 problem, wood use as a substitute for steel, aluminum, brick, and concrete is very efficient in terms of the amount of CO_2 required to produce the product. We are most efficient by using the wood and using it to substitute for other products so that the fossil fuels used to make these or refine these other products are kept in the ground. That's where we store our carbon, by keeping the fossil fuels in the ground. Now one way we can manipulate our forests is that, historically, you realize you've got a little bit of fuel every few years in a periodic burn. Well we've let that fuel accumulate excessively so if we let a natural fire burn or we burn it without removing some of the fuel, we will have gone somewhat back to our natural range of variability, only in very large pulses.

Let's say we remove much of that wildfire fuel from the ground and utilize it as substitutes for these other products. Then we move back towards some type of regular, periodic burning of the remaining material. We will then be in a position where we've prevented x amount of CO_2 from getting into the atmosphere from burning and we will have prevented y amount of CO_2 from getting into the atmosphere by use of fossil fuels.

Audience member

We've talked a lot about structure and composition and natural processes. How do we go about determining the proper method for restoration of these historical forest structures? In fact, how do we determine what the historical structures were at all?

Kevin Ryan

We can use historic photographs to determine species composition and stand structure. We can use fire history data to understand the processes associated with the historical conditions. We can then use our ecological process models to simulate how management can be expected to alter current stand conditions. In this way, we can design treatments which will, hopefully, restore the stand to conditions similar to those in the photographs. I do not think, however, that you can use the models to tell us what the historic landscape looked like.

Jim Vose

I think it's really difficult and I agree, we need to look at structure and we need to look at composition, but I think the key is the function. Unfortunately, it is a lot harder to get historical information about function. I think that our best bet is to use the subset of ecosystems that are out there that may have, for whatever reason, experienced a long-term fire regime that may be close to what is natural. I suspect that there are some people, who for whatever reason, continue to burn on a regular cycle. There are some forests in the South that continued to be burned for quail production through the historical period of fire suppression.

The only other way to do it is with shorter-term studies in combination with modeling and, hopefully, produce a paradigm that is somewhat representative of how a particular system functions. Then we use a simulation model to predict what 200 years or 100 years of a particular fire regime would do to the ecosystem. We don't really know all of those answers yet, but I think it is critical, and I think it's where we need to go.

Chad Oliver

The main way we currently measure process is by evaluating structure at two points in time, so that we can get some handle on what the processes were. We have to be cautious, because now we tend to think in terms of relatively benign processes. But if you go just to the Canadian border, you realize that 14,000 years ago it was all under a mile-deep sheet of ice. So if you want to imitate that process you start with bulldozers. Yes, on the one hand that was "natural," although I don't think that's within the range of what we want to do.

Keith Moser

As a quick comment, I think Neil's question is very important for those of us in the East trying to look at restoration of natural systems. The vast majority of the central hardwoods were dominated by the American chestnut, which rarely exists as mature trees anymore, therefore any question about "natural" oak regeneration is an academic one. I consider oak to be an ecological "flash in the pan" in this region, prevalent in such numbers only because chestnut is no more. Trying to re-create some sort of pre-European process is very much an artificial exercise.

In closing, I would like to thank our panelists for speaking today, and the audience for contributing excellent questions.

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