The Status of Our Scientific Understanding of Lodgepole Pine and Mountain Pine Beetles – A Focus on Forest Ecology and Fire Behavior

A synthesis of our current knowledge about the effects of the mountain pine beetle epidemic on lodgepole pine forests and fire behavior, with a geographic focus on Colorado and southern Wyoming.

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Introduction

Major lodgepole pine forest changes and how they affect us. Mountain pine beetle populations have reached outbreak levels in lodgepole pine forests throughout North America. The geographic focus of this report centers on the southern Rocky Mountains of Colorado and southern Wyoming. The epidemic extends much more widely, however, from the southern Rocky Mountains in Colorado in the United States to the northern Rocky Mountains in British Columbia and Alberta, Canada.

Worries about large-scale tree mortality in lodgepole pine forests have created public concerns across the West. The appearance of red trees during the last decade, a clear sign of recent beetle attack, has been followed by bare dead tree skeletons throughout this large area. Unquestionably, millions of dead trees foretell large forest changes in the near future, and more might be anticipated in areas where the mountain pine beetle has not yet reached epidemic levels.

People are concerned for many reasons. At a minimum, the loss of mature lodgepole pine trees will significantly change the present and future appearance of affected forests for half a century or more. Extensive areas of dead trees and snags are not as aesthetically appealing as live forests. Perhaps more seriously, dying and dead trees raise fears of increased fire danger. Some people worry that the dead needles and wood generated by the mountain pine beetle epidemic will lead, perhaps quickly, to severe wildfires that threaten lives, property, wildlife, and watersheds. Many are concerned that trees not yet attacked will succumb to the epidemic. Some people worry that the forest in and around our communities and recreation areas will become sparse or disappear forever, and that these forest changes will affect timber commodities, game habitat, and recreation resources.

Some contend that the current epidemic with synchronous outbreaks at many locations is unprecedented and a clear warning of global climate change impacts on ecosystems around the world. Scientists and others point to other changes occurring in our region – *Ips* beetle-caused mortality of piñon pine in the Southern Rocky Mountains, aspen decline, and large fires in Front Range ponderosa pine forests and elsewhere. It is difficult to prove cause and effect, but all of these changes began during the last 10-15 years, coinciding with recent warm climatic conditions, increasing numbers of large trees, and advancing age of many forests. Whether or not the current epidemic is unprecedented is a question to which there is currently no clear answer because of the lack of precise information on extent and severity of beetle outbreaks prior to the early 1900s. Nevertheless, many in the scientific community believe the probability of a similar event historically over at least the past few 100 years is low.

There are many insights and opinions about lodgepole pine being discussed by stakeholders of all kinds -- forest managers, agency administrators, researchers, policy-makers, politicians, the news media, industries, and the general public. Some concerns and fears are supported by scientific evidence. Others are probably justified given the current status of our scientific knowledge, but lack clear scientific support. Still others are myths with little or no basis in science. A further complication is that some of the information emerging from the science community has appeared on the surface to be somewhat contradictory.

The reason for this report. This document is written to report our current scientific understanding of the ecology and fire behavior of lodgepole pine, with a focus on the direct and indirect effects of the current mountain pine beetle epidemic that is so dominant in our minds. We recognize that important socio-economic implications stemming from the mountain pine beetle epidemic exist, and we hope that examining the status of science will aid in addressing these issues. While this document focuses on lodgepole pine and mountain pine beetles, there are also many other forest types and non-forested systems subject to extreme or at least unexpected impacts of climate, other insect and pathogen species, and other disturbances including fire and wind.

This report results from a meeting in January 2008 convened in Colorado by The Nature Conservancy, bringing together expertise of scientists who study lodgepole pine throughout its geographic range. We hope to provide as much scientific help to stakeholders as possible by sorting out what is known with a high degree of certainty, what we are confident about but with less certainty, and what is truly not understood and in need of more research. While our primary geographic focus during the workshop was Colorado and southern Wyoming, some of the findings may be appropriate for lodgepole pine throughout much of its natural range of distribution. *We urge caution, however, in applying our findings beyond our initial area of focus or to other forest types in the region.*

During the workshop and through subsequent email dialogue, the lodgepole pine team reached consensus on nine key points. As always, science is a work in progress, and uncertainties surfaced during discussion of some key points. For some points we provide what is known with adequate confidence rather than waiting for more definitive information, when this information is useful to interested stakeholders. This report provides the nine key points along with explanatory material intended to help the reader understand the degree of confidence we have from scientific study for these key points. To help the reader, we provide a list of suggested reading at the end of this report for more detailed information on many of the topics discussed. We begin with the obvious.

A. Lodgepole pine forests are being heavily impacted by the ongoing mountain pine beetle epidemic.

From British Columbia to Colorado, forests are experiencing high mortality of lodgepole pine trees from attack by mountain pine beetles. An insect epidemic with multiple outbreaks at this scale has not been observed during the last century of scientific study, though small outbreaks have occurred. This mortality is changing forest structure and composition, and modifying fuels in ways that will affect fire behavior for decades.

Many believe the mountain pine beetle epidemic, now nearly a decade in duration, might be unprecedented at least in recent centuries, stemming from a unique alignment of factors. These factors include extensive forests of trees at the right age, size, and density to support large numbers of mountain pine beetles, and a climate warm enough over the last decade to favor beetle reproduction and survival. But records are short. Modern records cover little more than a century, and for this period there is no account of a similar severe mountain pine beetle epidemic in lodgepole pine over such a large area.

For earlier periods, however, little scientific evidence exists to suggest that severe mountain pine beetle outbreaks either did or did not occur. Forest fires, another important natural disturbance, often scar living trees, which provides physical evidence indicating dates, locations, and severity of fires back through much of the last millennium. Fire-scarred wood is often resistant to rot and may persist for centuries, preserving a record of fire. But mountain pine beetle attacks that might have occurred more than a century ago leave little or no physical evidence helpful for determining dates or severity of such attacks. Wood from trees killed by beetles rots quickly, especially where wood moisture is high (e.g. fallen trees). Both stand-replacing fires and beetle epidemics that kill large numbers of trees allow stands of trees of the same age to establish in the wake of the disturbance. The ages of these trees can be used to estimate the time of the last stand-replacing disturbance, but it is often not possible to tell what kind of disturbance initiated the stand, and disturbances such as beetles, fire, and wind may act synergistically. Thus we cannot exclude the possibility that factors aligning so perfectly to result in the current epidemic could not have aligned equally in past centuries or millennia.

Regardless of whether or not the current mountain pine beetle epidemic and lodgepole pine mortality are within the historical range of variability at some time scale, the epidemic and associated tree mortality are large and are having immediate effects on forest structure and function over a vast area.

B. Not all lodgepole pine forests are the same.

Some forests are composed of nearly pure lodgepole pine established following large fires decades or centuries ago. Others are mixtures of lodgepole pine with subalpine species such as Engelmann spruce, subalpine fir, and aspen at higher elevations, or with mixed conifer species such as ponderosa pine, Douglas-fir, and aspen at lower elevations. Each type of forest has unique features of ecology and fire behavior. And lodgepole pine trees in all three types are vulnerable to attack by mountain pine beetles.

Lodgepole Pine Ecology 101. Lodgepole pine is found over a large area in western North America, from northwestern Canada in the northern Rocky Mountains; Washington, Oregon, and California in the Cascades and Sierra Nevada; Idaho, Montana, and Wyoming in the central Rockies; down to Colorado and even northern New Mexico in the southern Rockies. It comes as no surprise that across this large area and also locally, lodgepole pine trees are found in diverse forest conditions. In Colorado and southern Wyoming, pure stands of lodgepole pine occur. Even where pure stands occur, lodgepole pine forests may range from extremely dense to open and savanna-like. Elsewhere, lodgepole pine is mixed with other species. These differences in species composition of forests influence the way forests are affected by mountain pine beetles and fire, and how forests may change in the future.

Two key features of lodgepole pine are especially important in the way the species interacts with the environment and with other trees. Lodgepole trees are relatively intolerant of shade, and they are adapted to reproduce prolifically after fire. Unshaded lodgepole trees survive and grow more readily than trees overtopped either by larger lodgepole pines or by other species. Fire adaptation in trees occurs in two primary forms: the capacity to survive fire, or the ability to reproduce after fire even if killed. While species like ponderosa pine are adapted to survive fire, lodgepole pine is adapted to reproduce readily after fire.

Many lodgepole pine trees have serotinous cones that remain closed and store viable seeds in the crowns of trees for years, actually requiring the heat of a fire for seed release and dispersal. When crown fires kill trees, the resin sealing the cones melts, allowing the cones to open shortly after the fire. Huge numbers of seeds are released at once to the forest floor, falling on exposed soil that is an excellent seedbed for germination and seedling establishment. It is not uncommon to find 50,000 or more seedlings per acre several years after a stand-replacing fire. Competition then thins out trees naturally as these young forests grow to maturity. After a mountain pine beetle epidemic, lodgepole pine stands also generally regenerate, because serotinous cones on branches that have fallen near the ground heat adequately to release seeds, and seeds previously released from non-serotinous cones may exist in the forest litter. However, the role of serotinous and non-serotinous cones as seed sources, and the effect of cone serotiny on subsequent stand density, are not well understood.

The three most common natural agents influencing lodgepole pine in Colorado and southern Wyoming other than fire are mountain pine beetles, dwarf mistletoe, and wind. Of these, mountain pine beetles have the capacity like fire to change forests at large scales. Beetle populations can occasionally reach epidemic densities over large areas, though not usually as large as the current epidemic. The spatial extent of the current epidemic is probably related to large numbers of suitable host trees existing over much of the range of lodgepole pine in the West. Mountain pine beetles are a native insect that has evolved with lodgepole pine. They normally exist in endemic populations that kill a few trees but are regulated by weather. Endemic populations of beetles typically infest diseased or stressed trees. Because temperature regulates beetle development, prolonged warm periods may help trigger outbreaks. Natural enemies also help regulate endemic bark beetle populations but their role under epidemic populations is not as effective.

Dwarf mistletoe typically occurs in localized patches. While mistletoe slowly spreads, it often remains only locally significant, and trees may live for decades with mistletoe. This native parasite, which also evolved closely with lodgepole pine, is periodically reduced by fires that kill the infected trees. Major wind events may topple trees and create small to large openings. In many places lodgepole pines are shallowly rooted in rocky soils or on steep slopes. Typically even the largest blowdowns affect forests only locally, and while they contribute to the landscape mosaic of forest age and composition, they are unlikely to affect forests regionally unless they become centers of another disturbance agent (e.g. spruce beetle).

Three kinds of lodgepole pine forest. Lodgepole pine forests occur along gradients of elevation and latitude that control the length of growing season, available moisture, and frequency of natural disturbances. Fire and mountain pine beetles affect forest structure and composition differently in each ecosystem, just as environmental conditions regulate the occurrence and intensity of the disturbances. To understand this, it is useful to identify three specific types of forest in which lodgepole pine occurs. In Colorado and southern Wyoming, these are pure lodgepole pine, subalpine forest, and mixed conifer forest.

> *Pure lodgepole pine forests* may occur where environmental conditions are poorly suited for other tree species, or where human impacts such as logging followed by burning eliminate other species. Lodgepole pines are tolerant of cold, dry conditions and poor, rocky soils. Individuals rarely live more than 400 years. Typically, pure lodgepole pine stands result after stand-replacing fires have killed all or most trees, leaving behind lodgepole seeds stored in serotinous cones as the only significant seed source. Alternatively, fire-killed stands without serotinous cones may still reproduce if lodgepole pine seeds are blown in from unburned trees nearby. Stand-replacing fires may occur in healthy, green forests under extreme weather conditions. Similar fires might occur under more moderate conditions when mountain pine beetle mortality or mistletoe infestation in stands creates additional dry fuels, though there is no firm evidence thus far confirming this. Pure lodgepole pine stands are often established within a few years after the fire and have one dominant age class or cohort for the life of the new stand, although some stands may develop continuously over longer periods of time and have multiple age classes. However, if aspen is present even in small amounts before large fires, its sprouting capability may lead to aspen patches which often give way over time to slower-growing lodgepole pine.
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> The spatial extent of pure lodgepole pine forests typically reflects the size of the fires that established them. As a general rule, pure lodgepole pine forests occur more commonly at upper elevations in the mixed conifer (upper montane) zone and the lower portion of the subalpine forest zone, between 9,000 and 10,000 feet elevation in Colorado and southern Wyoming. Less commonly, pure stands exist because sites are unsuitable for other tree species. Historically, past fires may have been tens to hundreds of thousands of acres in size, resulting in large lodgepole pine stands that dominate the landscape for several hundred years. However, even large intense fires do not burn uniformly, and within a fire perimeter, some patches of trees or individuals may survive intact. The 1988 Yellowstone fires are a good example of this. Alternatively, smaller crown fires may have created patches of pure lodgepole pine as small as an acre or less.
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> If not renewed by fire every few centuries, pure lodgepole pine stands often but not always experience ingrowth by other tree species, especially those tolerant of moderate shade. Ingrowth of other species depends strongly on site suitability for the other species, and availability of seeds. Eventually these species may replace lodgepole pine as the dominant

trees in the stand. Lodgepole pine may persist in these mixed stands even if only a limited number of seedlings become established periodically, usually as a consequence of minor local disturbances such as very small fires, wind, insects, or disease.

Subalpine forests at higher elevations (usually above 10,000 feet elevation but as low as 9,000 feet) often include lodgepole pine as a component along with Engelmann spruce, subalpine fir, and aspen. Stand-replacing fires may occur in subalpine forests, but intervals between fires are usually several to many centuries (compared to one to several centuries for pure lodgepole pine forests). After stand-replacing fire, lodgepole pine seedlings grow faster than spruce or fir seedlings and may dominate stands during early developmental stages, even when spruce and fir seeds are available nearby. When aspen is present, however, creation of openings by fire or other disturbances may shift species dominance to aspen because of its sprouting ability.

Mixed conifer forests at lower elevations (usually between 7500 and 9000 feet elevation) often include lodgepole pine along with ponderosa pine, Douglas-fir, aspen, and perhaps small amounts of subalpine fir, Engelmann spruce, and limber pine. Large stand-replacing fires can occur in mixed conifer forests and may lead to pure lodgepole pine stands. More typically, however, mixed-severity fires create smaller openings providing opportunities for patches of lodgepole pine establishment and persistence within the complex landscape mosaic of mixed conifer. Once again, aspen may become temporarily dominant if it existed prior to the fire.

C. Forests are living systems subject to constant change.

It is normal and expected that many natural agents, including mountain pine beetles, fire, and wind, change forests over time. Some changes are so gradual that we barely notice them, while others are relatively sudden and extensive. The forests that are presently losing many trees to insect attack will not look the same in our lifetimes, but healthy and vigorous forests will eventually return in most locations.

We tend to think of forests as static over time because their change is slow relative to human time scales. Yet forests are non-equilibrium systems, and we should expect them to change. Our adult human experience is measured in years or decades at most, and we often fail to notice all but the more dramatic changes that occur in forests. Thus we may believe that the structure and composition of forests typically do not (and even should not) change, and, when they do, it means something alarming has happened. However, lodgepole pine and other tree species live several centuries or more and during their life cycles a number of very natural, and ecologically predictable, forest-changing events or processes often occur. The 1988 Yellowstone fires are often cited as an example of natural change in lodgepole pine ecosystems.

Taking this more comprehensive view, it is clear that combinations of fire and other natural disturbance agents, along with differences in ecological characteristics of the various tree species suited for the landscape, result in frequent changes in forest landscapes over time. The overall forest mosaic is in fact not static, but rather experiences significant shifts and adjustments, all a part of the natural ecology of forests. Thus at any location in a given landscape, the species composition, distributions of tree sizes and ages, and stand density all are subject to change, even if in our memory they do not appear to.

Understanding and predicting the consequences of natural disturbance effects on landscapes is difficult. All of the natural disturbance factors – fire, insects, pathogens, wind, drought, etc. – are capable of affecting forest landscapes at various scales and may act individually or in combination. In the current mountain pine beetle epidemic, interactions between fire and beetle effects are certain, because the insects are changing fuel characteristics of forests significantly.

D. Lodgepole pine will not disappear from the southern Rocky Mountains.

The make-up of our forests is already changing where mountain pine beetles cause high mortality of lodgepole pine. However, this event will not cause the extinction or disappearance of lodgepole pine, and forests dominated by or including lodgepole pine will persist in the southern Rockies, though they may look different from those of the past due to changing climate. Future forests will continue to provide valuable ecological services and aesthetic and recreational benefits.

When viewed from a distance, it may appear that many pure lodgepole pine forests in Colorado and southern Wyoming are being completely killed. It even appears that in some places all the lodgepole pine trees in subalpine or mixed conifer forests are being killed. Yet there is wide variability in the amount of tree mortality, and even where all the mature trees have died, understory saplings may be released and new lodgepole pine seedlings are likely to emerge. Thus it is untrue that lodgepole pine will disappear from our forests.

Scientific knowledge is not complete, however, and there is considerable uncertainty about the composition of future forests after the epidemic. Clearly, major changes in these forests are occurring, but multiple factors will affect what kind of new forest will result. A high proportion of larger lodgepole pine trees (diameters greater than six inches) are dying, and in many places many smaller trees are being killed as well. Mortality may approach 100% in pure lodgepole pine stands having few small trees.

Recovery of lodgepole pine forests following previous beetle outbreaks suggests, however, that in many places significant numbers of lodgepole seedlings and small saplings will survive. These may produce new pure stands of lodgepole pine if no other species are present, or help sustain a lodgepole component in stands of mixed species. Height growth of Engelmann spruce or subalpine fir seedlings is slow compared with that of lodgepole seedlings. Where small seedlings of spruce or fir existed beneath a pure lodgepole pine overstory, lodgepole pine may still predominate after the first decade because of their more rapid growth. However, if saplings of spruce and fir trees are left under the dead pines, they may grow quickly into the canopy and dominate the site. If aspen is present, sprouting and rapid early growth may result in an aspen forest, perhaps with the shade tolerant conifer species in the understory. However, aspen sprouting after mountain pine beetle mortality is not as well understood as it is for disturbances that more directly affect aspen trees or roots.

In pure lodgepole pine forests with few or no surviving trees, it is reasonable to expect a new lodgepole forest to regenerate on suitable sites, but difficult to predict with certainty. The existing seed bank (seeds stored in cones of dead trees and in the litter) or seeds produced by non-serotinous trees near the time of tree death may produce enough new seedlings to regenerate a new lodgepole pine forest. It is also possible that other species will colonize the sites, including other wind-dispersed trees such as spruce and fir, ponderosa pine and Douglas-fir, or bird-dispersed trees such as limber pine. Grasses, forbs, and shrubs may flourish in the new openings for periods of time, and tree establishment may be limited or slowed. Under such conditions, the landscape is likely to become more diverse than it was in the previously pure, single-aged lodgepole forests. This in itself may be beneficial for reducing the risk of a future large-scale mountain pine beetle epidemic or other monolithic disturbance.

E. Active vegetation management is unlikely to stop the spread of the current mountain pine beetle outbreak.

Mountain pine beetles are so numerous and spreading so rapidly into new areas that they will simply overwhelm any of our efforts where trees have not yet been attacked, and no management can mitigate the mortality already occurring. However, judicious vegetation management between outbreak cycles may help mitigate future bark beetle-caused tree mortality in local areas.

In the current epidemic, it is impractical to expect that silvicultural treatment of lodgepole pine forests will prevent or even impede the advance of the epidemic in Colorado and southern Wyoming. There are simply too many suitable host trees over too large an area, and unusually high insect populations. Unless climatic conditions become less favorable for beetle reproduction and spread, the most likely scenario is that the epidemic will be sustained until host trees are depleted.

Preventive spraying of high-value trees with insecticides is effective in protecting trees from bark beetle attack. Direct control measures such as removing infested trees may provide some mitigation on a small local scale but are not be effective at a landscape scale.

The current epidemic is so extensive and severe in part because large areas of lodgepole pine forest are suitable hosts for mountain pine beetles. As noted earlier, it is unclear if epidemics occurred at such a large scale historically, though smaller-scale or less severe epidemics most likely did occur and are expected in the future. Active vegetation management *between* periods when lodgepole pine forests are vulnerable to a mountain pine beetle epidemic may reduce the magnitude of future landscape-scale outbreaks, if that is chosen as a management objective. Creating diverse patch ages and sizes (including young patches) and perhaps more mixed-species forests across the landscape may or may not reduce the spread of future mountain pine beetle outbreaks, but it likely would reduce the amount of forest susceptible through time to a monolithic disturbance, including mountain pine beetle attack or fire. Thus while unproven, this increased landscape heterogeneity may be effective for limiting the scale and severity of future mountain pine beetle impacts. The effectiveness of such measures cannot be assured, nor are all the ecological consequences known, though even in the current epidemic, stands and patches of younger lodgepole pine trees appear to have survived the epidemic with no or only limited mortality.

F. Large intense fires with extreme fire behavior are characteristic of lodgepole pine forests, though they are infrequent.

Very dry and windy conditions can lead to large intense fires in lodgepole pine forests. Such fires are a natural way for lodgepole pine to be renewed and are largely responsible for extensive pure lodgepole pine forests.

Fire history studies based on fire scars and stand structure evidence extending over at least the past 500 years show that large, severe fires (often involving multiple ignitions) occurred in subalpine lodgepole pine forests of Colorado and southern Wyoming during periods of exceptionally warm and dry weather. These studies also show that long intervals (e.g. of 80 to 100 years) during which large fires were absent from study areas extending over 10,000 or more acres were common during the past five centuries in subalpine lodgepole pine forests. Climatic variation at annual and multi-decadal time-scales has been the major driver of fire occurrence in these forests and is the key explanation for the non-equilibrium behavior of these ecosystems. Large fires shaped the amounts and locations of extensive lodgepole pine forests on the landscape and this process is relatively well understood, but additional research would be helpful to characterize stand history in local areas, especially in relation to past climate.

Fire is complex, and its behavior varies with variations in weather, ignitions, fuel amounts and arrangement, and fuel moisture. Historically, most ignitions in lodgepole pine forests were caused by lightning. The role of Native American ignitions is unknown, but given that extensive fire occurs in these forests only under dry and windy conditions, their contribution was probably small. Young and mature stands of pure lodgepole pine are relatively unlikely to burn except under the most extreme weather conditions. Unless residual fuels remain from the effects of previous fire or insect epidemic, fuels commonly are sparse in the understory, and closed canopies help keep the forest floor cool and somewhat moist. The snow-free period above 9000 feet elevation is relatively short, leaving little time for fuels to dry. The term “asbestos forest” has been applied to these forests, attesting to their low probability of an intense crown fire except under extreme weather conditions.

As lodgepole pine forests mature they become increasingly vulnerable to natural disturbances such as mountain pine beetles and wind. Even with only partial overstory mortality, openings created in the forest canopy allow more air circulation beneath the canopy, and drying of surface fuels. In addition, fuel amounts may be increased by the localized tree mortality, including fuel ladders provided by fallen trees, young understory trees, and shrubs that may help fire reach the overstory. Such changes may increase the probability of fuel ignition from lightning and may alter fire behavior in several ways. Fire behavior in maturing stands is not fully understood, however, and more research would be beneficial.

These remarks about fire behavior apply especially to pure lodgepole pine forests. In subalpine mixed forests, the likelihood of dry fuels is even less as the snow-free period is shorter. In mixed conifer forests below 9000 feet, the complexity of the landscape, greater productivity and longer and more frequent fire season encourages mixed-severity fires which have both surface and stand-replacing components. Even in the mixed conifer forests, however, fire extent is highly variable due to climatic variation, and fire-scar studies show that years of widespread fires during past centuries were dependent on exceptional drought. Typically, lodgepole pine occurrence can be suppressed with shortened fire intervals because its long-term presence depends on seed germination after fire and trees growing to reproductive maturity before the next fire. In general, fire history and potential fire behavior are less well understood in mixed conifer forests than in pure lodgepole pine forests.

G. In forests killed by mountain pine beetles, future fires could be more likely than fires before the outbreak.

Large intense fires with extreme fire behavior are again possible.

There is considerable uncertainty about fire behavior following a mountain pine beetle epidemic on this scale. In pure lodgepole pine forests, crown fires are possible both before an epidemic and after while needles are still on trees. Intense surface fires are possible after most dead trees have fallen to the ground. The probabilities of such fires are uncertain, and more research is needed to learn in what ways and how long the fuels and fire environment are altered by the beetles. Nevertheless, protection of communities and other values at risk continues to be imperative.

More research is required to fully understand fire behavior over time following a mountain pine beetle attack. Nonetheless, the extensive epidemic now occurring is precipitating enormous changes in fuel structure over large areas in Colorado and southern Wyoming, through changes in the condition and arrangement of the forest biomass (which is fuel for forest fires). The mature lodgepole pine trees that provided abundant but moist living fuels are now dead, dry, and falling, and have the potential to contribute to extreme fire behavior in post-beetle forests similar to historical fires in lodgepole pine forests. However, the realization of that potentially extreme fire behavior will depend on a number of contingencies, particularly future climatic conditions.

Empirical data are very limited. One study of fire extent and severity of wildfires that burned in subalpine forests in Colorado in the extreme drought of 2002 did not find that fire extent or severity were greater in stands recently killed by mountain pine beetle. The authors cautioned, however, that the conclusions regarding the influence of the recent beetle outbreak on fire extent and severity are limited by spatial and temporal limitations associated with aerial detection of the outbreak. More importantly, any broader applications of this case study would need to be tested by additional studies considering different initial forest (fuel) conditions and especially weather conditions that drive fire behavior. Even though only limited scientific information is available to predict likely fire behavior during and in the decades following a mountain pine beetle epidemic and under varying climate conditions, we believe that both field observations of fire behavior and modeling provide some insights into what could be expected. We offer these insights as preliminary guidance for those concerned with management of beetle-killed forests, even as new research is being conducted to clarify our scientific understanding.

Pure lodgepole pine. In the initial phases of the epidemic when trees are being killed, needles die, turn red and dry out but persist on trees for two or three years. During this phase, needles and small branches provide dry fine fuel that could burn in a crown fire. The amount of fuel is relatively unchanged compared with the pre-epidemic forest. However, fuel moisture is lower, and some think it likely that a crown fire could ignite and spread under somewhat less extreme fire weather conditions than were required for initiating a crown fire in an equivalent forest of live trees.

The fuel structure of dead lodgepole pine stands changes significantly when needles fall to the ground. During this phase, little fine fuel remains in the forest canopy to support an active crown fire that spreads from tree to tree. Furthermore, the fallen needles lie close to the ground surface and, in the absence of other fuels near the ground, provide a relatively poor fuel bed for generating significant flame heights. Increased growth of grasses, low shrubs and forbs may create a moist fuel bed during the growing season but provide dry fine fuels near the end of the growing season. However, large amounts of biomass in the boles and branches of standing trees remain well above typical flame heights, and without needles these canopy fuels are relatively unlikely to burn. Thus surface fires in years following needle fall may not be intense and crown fires may be nearly impossible (assuming the forest is relatively pure lodgepole pine and most or all large trees are dead). In some areas, rapid development of a tall shrub community (which may precede tree regeneration) may provide shade and protection from drying of fuels on or near the ground. However, this is unlikely in most lodgepole pine forests in Colorado and southern Wyoming (the focus area of this report), because few tall shrub species occur in these relatively dry forests. Instead, low shrubs such as huckleberry and buffaloberry are more common.

Trees killed by mountain pine beetle may remain standing for a number of years, but as they progressively decay and fall to the ground (often aided by wind), the fuel structure changes once again. In this phase (typically 10-20 years or more after death), a large amount of biomass becomes available as fuel within flame heights that can be generated by the fine surface fuels. Some of the biomass is elevated above the ground where it dries out more easily and becomes available to support intense fire with a large release of heat. Such a fire is relatively hard to control and nearby structures may be hard to protect. Furthermore, fire intensities under these conditions could cause high mortality of young trees that survived or regenerated after the mountain pine beetle attack. If widespread fire mortality occurs before trees have matured to cone production age, rapid re-establishment of lodgepole pine on this site is less likely.

At the scale of a stand, none of the changes in fire behavior that we have described would be outside the historical range of variability for this ecosystem. Even in stands with tremendous wood accumulation on the ground, fire behavior may differ little from historical fires within blow-downs or areas recently burned by stand-replacing fires. However, we are uncertain about fire behavior at landscape or regional scales because we have not seen systems with such heavy fuel loads over such extensive areas; and we know little about the ecological consequences of such fires at these scales.

Lodgepole pine with other species. Similar transitions in fuel structure also will occur in the lodgepole pine-dominated component of subalpine and mixed conifer stands. But the mixture of dead lodgepole pine with live trees of other species creates a more complex fuel structure. An important effect of lodgepole pine mortality in mixed stands is a change in the environmental conditions and thus the fuel moisture near the forest floor. Prior to beetle mortality of the overstory, solar radiation is largely intercepted by the forest canopy, and air movement beneath the forest canopy is moderated by the overstory. The understory beneath the canopy remains relatively cool and moist.

When lodgepole pine trees die and needles fall from dead trees, radiation reaching the forest floor and air movement beneath the residual live tree canopy are increased, and both contribute to fuel drying. More open canopies also contribute to greater understory vegetation growth. The consequences of these changes on fire behavior are not fully understood, but such conditions may favor ignition and spread of fire more readily than in forests having few canopy gaps or fuels created by mountain pine beetle mortality, particularly later in the growing season when fuels near the ground become drier. Because several associated species, firs and spruces, typically have low crown bases due to poor self-pruning, higher surface fire intensity from added lodgepole pine fine fuels coupled with drier, warmer, windier surface conditions, could lead to an increase in potential for passive crown fire (torching). Furthermore, increased human activity in today's forests has increased fire ignitions compared with the historical period.

H. Mountain pine beetle outbreaks are not likely to cause increased erosion.

Soils are not disturbed and protective ground cover is not reduced when mountain pine beetles kill lodgepole pine trees. If anything, understory plants may grow more vigorously in the increased light and with the higher available soil moisture and nutrients. Where tree mortality is high, annual streamflow may increase and the timing of water delivery may be changed, because of reduced canopy interception of precipitation and reduced water uptake by the trees.

Interactions between forest structure and hydrology have been studied extensively, and there is little question that major changes in the structure of Colorado and southern Wyoming forests alter several key hydrologic characteristics of these forests. Forests are widely viewed as important for protecting sloping terrain in watersheds from extreme runoff and erosion. Wildfire severe enough to kill forests is viewed as a major threat to watersheds, because protective vegetation, litter, and duff are often consumed. In many cases, fire exposes soils directly to precipitation, and runoff during heavy precipitation events (often exacerbated when fire makes soils temporarily hydrophobic) can result in extreme erosion for several months following a fire.

Soil type, steepness of slope, precipitation intensity and duration, and timing of understory vegetation recovery all affect the severity of erosion after fire.

Death of forest trees during a mountain pine beetle epidemic affects the forest floor and soil much differently than fire. Tree mortality caused by beetles leaves behind protective layers of litter and duff, and often quickly results in more productive understory vegetation. Thus severe erosion events are not expected as a result of the mountain pine beetle epidemic. In fact, mulching and seeding after fire often are used in attempts to mimic the stabilizing effects of litter, duff, and understory vegetation found after overstory mortality by beetles.

The potential for erosion from wildfire still exists, however, if extensive fire occurs in the decades following the epidemic, when large amounts of fuel are on the ground. Thus while the mortality of trees does not increase erosion significantly, erosion remains a possibility if a post-beetle fire occurs with heavy fuel loading on the ground. We note, however, that erosion is a natural process, and concerns about extreme erosion may be more a human issue than an ecological one.

There may be other hydrologic effects of mountain pine beetle mortality. Paired watershed studies around the world support the conclusion that substantially decreasing forest density results in increased runoff, though many factors affect the degree to which this occurs. Subalpine forest studies in Colorado and elsewhere are among the best examples supporting these findings. While no empirical studies of runoff in relation to the current mountain pine beetle epidemic have been completed in Colorado and southern Wyoming, it is reasonable to expect that the total annual runoff will increase where pure stands of lodgepole pine are killed by mountain pine beetles. More research is needed to determine how the hydrologic features of watersheds change during and after such epidemic changes in forest structure.

I. Climate changes will most likely contribute to substantial forest changes in the decades ahead.

Given the climate changes in the last several decades and projected changes for coming decades, large fires and other natural disturbances and shifts in vegetation composition and distribution are anticipated in many ecosystems of Colorado and southern Wyoming. These large disturbances and other changes in growing conditions will likely contribute to restructuring many forest landscapes.

Many uncertainties about climate and vegetation exist for the years, decades, and centuries ahead. As noted in our introduction, we have seen a number of significant ecological events in the last decade, including the mountain pine beetle epidemic in lodgepole pine. All of them coincide with warmer climatic conditions than were typical for the past century or more for which we have records. Warming temperatures (especially winter minimum temperatures), longer growing seasons, and growing season drought may be playing major roles in the widespread bark beetle outbreaks in Colorado and southern Wyoming and elsewhere. Fuel quantity and arrangement and fire behavior may be influenced directly or indirectly by the same variables. Germination and establishment success of new seedlings may be affected. However, it is difficult to prove whether climate changes, consequences of past forest management practices on forest conditions, or both are the primary causes of these ecological changes.

Implications for future forests. Models for predicting future climates have progressed dramatically in recent years, but their accuracy is questionable for planning purposes, particularly at local levels. Nonetheless, model predictions suggest significant alterations in climate from past observed patterns. These predictions are supported by recent climate events that themselves had largely been predicted several years ago. Therefore, the potential for future changes justifies thinking about future ecosystem dynamics that are very different from what we have seen in the last few centuries, including vegetation responses involving natural disturbance agents, species distribution, habitat suitability, and conservation of biodiversity. Areas at the elevational and latitudinal edges (ecotones) of lodgepole pine distribution may be the most likely to experience notable changes following the beetle epidemic.

Our understanding of natural disturbance phenomena such as fire, drought, and insect epidemics under new climatic scenarios is inadequate for us to judge the likely consequences of future climatic conditions. We all observe and acknowledge that natural disturbances can be major change agents regardless of their cause. Climate warming may be contributing to substantial forest changes now, but there may be more subtle changes in the future as well. Through time forest species (including insect associates and other animal species, shrubs, grasses, and forbs as well as trees) may shift to other elevations and latitudes where habitats have become more suitable for them. Some species with rapid generation times, such as mountain pine beetle, may adapt to the changing climate. Alternatively, without adaptation local extinction in bark beetle populations could occur with increased warming due to a disruption of their tightly coupled developmental timing with local weather. Groups of species may migrate together or separately, perhaps leading to unanticipated new forest communities. We cannot make firm predictions about the makeup of future forests or the biodiversity associated with these forests. Regeneration and plant community restructuring in the landscape may follow novel pathways. Information is lacking, however, and extensive research (including use of monitoring data and reconstructions of past changes) is needed to relate potential future climate and the requirements and environmental amplitudes of species and communities.

Is re-establishment of lodgepole pine assured after the mountain pine beetle epidemic? Undoubtedly, but subtle or even large shifts in its location and plant associations are not out of the question. Nonetheless, most of the area experiencing a mountain pine beetle epidemic will likely remain forest. Even if future forests differ from those of today, such forests are likely to provide valuable (if different) benefits and opportunities, both ecologically and socially. Monitoring of changes in forests as they occur is important for enabling research on such changes, and to allow managers to adapt practices to achieve desired effects as conditions change and consequences of past actions are better understood.

J. Summary

The current mountain pine beetle epidemic affecting lodgepole pine forests is an important ecological event with significant socio-economic implications. What will be the consequences for the affected ecosystems? How do we protect our communities and other human values at risk in ways that are socially and economically (as well as ecologically) feasible? These are difficult questions. This report has focused specifically on the ecology and fire behavior issues associated with lodgepole pine and the mountain pine beetle epidemic. We recognize that the socio-economic aspects are as important as the ecological issues, but they are beyond the scope of this report.

Ecologically, much is known about lodgepole pine and mountain pine beetles. Even though the scale of the current epidemic is unprecedented over the past approximately 100 years of reliable observations, beetle-caused tree mortality at some scale has long been part of the dynamics of the lodgepole pine ecosystems. Similarly, fire behavior and its role in ecological processes and fuel management practices are relatively well understood. While we are confident about our general understanding, we have identified at least some scientific uncertainties about lodgepole pine, mountain pine beetle effects, and fire behavior that should be acknowledged and further researched.

We are most concerned about several wildcard issues that create some uncertainty in applying what we know from science. The scale of this epidemic is larger than any mountain pine beetle epidemic studied thus far. We do not fully understand if or how the magnitude of this ecological event will affect future forests in terms of regeneration of the present species or transitions to different vegetation types. Furthermore, there is the question – both tantalizing and troubling – about possible climate change (including its rate, direction and magnitude) and the degree to which scientific findings need to be qualified as they are applied.

If humans were not a part of the equation, forests would simply mature, die, and regenerate or be replaced by other vegetation types, following ecological trajectories over time driven by climate, environment, and species capabilities.

Because humans cause changes in forests by choosing to live there and deriving economic services from them, our communities are impacted by forest changes, whether they are natural or not. Thus both the scale of the mountain pine beetle epidemic and the uncertainties about future forests leave us with questions that are important to us but may not be answerable with the knowledge we have now.

Knowledge from scientific research about lodgepole pine and mountain pine beetles is valuable in two ways. It offers answers to some of the questions we have about forest ecology and provides valuable insight for management of these forests for ecological and community protection purposes. It also clarifies what we do not know. This is valuable not just to direct new research, but also to inform stakeholders of the degree of confidence they should have as land and natural resource management practices are considered.

As noted in the introduction, science is a work in progress. Many of the scientific uncertainties discussed in this report already are receiving attention in the research community. Even as research continues, however, the scientific knowledge already available is usable by a wide variety of stakeholders and in the collaborative and adaptive management process. Adaptive management is perhaps best described as managing while learning on the fly. In this report, the scientific community provides information to managers and other stakeholders, but the scientific community also will help advance the knowledge base through lessons learned as management practices are planned, implemented, monitored, and evaluated. We humans must decide how to manage forests based upon their intrinsic value and natural processes as well as some desired future condition contingent on human wants and needs. We must be realistic about the degree to which we as observers, managers and stewards of the forest can affect what is happening now and what will happen in the future. Whatever we do from here should be done together.

Further Reading

Barclay, H.J., C. Li, C., L. Benson, S.W. Taylor, and T.L. Shore. 2005. Effects of fire return rates on traversability of lodgepole pine forests for mountain pine beetle (Coleoptera: Scolytidae) and the use of patch metrics to estimate traversability. The Canadian Entomologist 137: 566-583.

Bentz, B.J., J.A. Logan, and G.D. Amman. 1991. Temperature dependent development of mountain pine beetle and simulation of its phenology. Canadian Entomologist 123:1083-1094.

Bigler, C., D. Kulakowski, and T.T. Veblen. 2005. Multiple disturbance interactions and drought influence fire severity in Rocky Mountain subalpine forests. Ecology 86: 3018-3029.

Fettig, C.J., K.D. Klepzig, R.F. Billings, A.S. Munson, T.E. Nebeker, J.F. Negrón, and J.T. Nowak. 2007. The effectiveness of vegetation management practices for prevention and control of bark beetle outbreaks in coniferous forests of the western and southern United States. Forest Ecology and Management 238: 24-53.

Hawkes, B.C.; S.W. Taylor, C. Stockdale, T.L. Shore, R.L. Alfaro, R.A. Campbell, and P. Vera. 2004. Impact of mountain pine beetle on stand dynamics in British Columbia. In T.L. Shore, J.E. Brooks, and J.E. Stone (eds.). Mountain Pine Beetle Symposium: Challenges and Solutions. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia, Information Report BC-X-399. Pp. 177-199.

Hawkes, B.C., S.W. Taylor, C. Stockdale, T.L. Shore, S.J. Beukema, and D. Robinson. 2005. Predicting mountain mine beetle impacts on lodgepole pine stands and woody debris characteristics in a mixed severity fire regime using PrognosisBC and the fire and fuels extension. In L. Lagene, J. Zelnik, S. Cadwallader, and B. Hughes (eds.). Mixed Severity Fire Regimes: Ecology and Management. Washington State University Coop Extension Service/ The Association for Fire Ecology, Pullman, Washington, Vol. AFE MISC03. Pp. 123-135. http://warehouse.pfc.forestry.ca/pfc/25427.pdf

Hoerling, M. and J. Eischeid. 2007. Past peak water in the Southwest. Southwest Hydrology. Jan-Feb. 2007:18-35.

Jenkins, M.J., E. Hebertson, W. Page, and C.A. Jorgensen. 2008. Bark beetles, fuels, fires and implications for forest management in the Intermountain West. Forest Ecology and Management 254: 16–34.

Kashian, D.M., M.G. Turner, W.H. Romme, and C.G. Lorimer. 2005. Variability and convergence in stand structure with forest development on a fire-dominated landscape. Ecology 86: 643-654.

Kashian, D.M., D.B. Tinker, F.L. Scarpace, and M.G. Turner. 2004. Spatial heterogeneity of lodgepole pine sapling densities following the 1988 fires in Yellowstone National Park, Wyoming, USA. Canadian Journal of Forest Research 34: 2263-2276.

Kennedy, R.G. 2006. Wildfire and Americans: How to Save Lives, Property and Your Tax Dollars. Hill and Wang, NY.

Kulakowski, D. and T.T. Veblen. 2007. Effect of prior disturbances on the extent and severity of wildfire in Colorado subalpine forests. Ecology 88: 759-769.

Logan, J.A., and J.A. Powell. 2005. Ecological consequences of climate change altered forest insect disturbance regimes. In F.H. Wagner (ed.). Climate

Change in Western North America: Evidence and Environment Effects. Allen Press.

McCullough, D.G., R. A. Werner, et al. (1998). Fire and insects in northern and boreal forest ecosystems of North America. Ann. Rev. Entomol. 43: 107-27.

Negron, J.F. and J.B. Popp. 2004. Probability of ponderosa pine infestation by mountain pine beetle in the Colorado Front Range. Forest Ecology and Management 191: 17-27.

Page, W.G. and M.J. Jenkins. 2007. Predicted fire behavior in selected mountain pine beetle–infested lodgepole pine. Forest Science 53: 662-674.

Page, W.G. and M.J. Jenkins. 2007. Mountain pine beetle-induced changes to selected lodgepole pine fuel complexes within the Intermountain Region. Forest Science 53: 507-518.

Renkin, R.A., and D.G. Despain. 1992. Fuel moisture, forest type, and lightning-caused fire in Yellowstone National Park. Canadian Journal of Forest Research 22: 37-45.

Romme, W.H., J. Clement, J. Hicke, D. Kulakowski, L.H. MacDonald, T.L. Schoennagel, and T.T. Veblen. 2006. Recent forest insect outbreaks and fire risk in Colorado forests: a brief synthesis of relevant research. Colorado Forest Restoration Institute, Fort Collins, CO.

Romme, W.H., D.H. Knight, and J.B. Yavitt. 1986. Mountain pine beetle outbreaks in the Rocky Mountains – regulators of primary productivity. American Naturalist 127: 484-494.

Schoennagel, T., M.G. Turner, D.M. Kashian, and A. Fall. 2006. Influence of fire regime on lodgepole pine stand age and density across the Yellowstone National Park (USA) landscape. Landscape Ecology 21:1281-1296.

Shore, T.L., L. Safranyik, B.C. Hawkes, and S.W. Taylor. 2006. Effects of the mountain pine beetle on lodgepole pine stand structure and dynamics. In L. Safranyik and W.R. Wilson (eds.). The Mountain Pine Beetle: a Synthesis of Biology, Management, and Impacts on Lodgepole Pine. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia. Pp. 95-114. http://warehouse.pfc.forestry.ca/pfc/26041.pdf

Turner, M.G., W.H. Romme, R.H. Gardner, and W.W. Hargrove. 1997. Effects of fire size and pattern on early succession in Yellowstone National Park. Ecological Monographs 67: 411-433.

Thrower, J.S., R. Willis, R.D. Jong, D. Gilbert and H. Robertson. 2004. Sample plan to measure tree characteristics related to the shelf life of mountain pine beetle-killed lodgepole pine trees in British Columbia. Mountain Pine Beetle Initiative, working paper. Natural Resources Canada, Victoria, British Columbia, Canada.

Veblen, T.T. and J.A. Donnegan. 2006. Historical Range of Variability of Forest Vegetation of the National Forests of the Colorado Front Range. USDA Forest Service, Rocky Mountain Region and the Colorado Forest Restoration Institute, Fort Collins. Pdf available from: http://www.cfri.colostate.edu/reports.htm

Whitehead, R.J. G. Russo, B.C. Hawkes, S.W. Taylor, B.N. Brown, H.J. Barclay, and R.A. Benton. 2006. Effect of a spaced thinning in mature lodgepole pine on within-stand microclimate and fine fuel moisture content. In P.L. Andrews and B.W. Butler (compilers). Fuels Management - How to Measure Success. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado, Proceedings RMRS-P- 41. Pp. 523-536. http://warehouse.pfc.forestry.ca/pfc/26362.pdf

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