Review of the Forest Service Response:

The Bark Beetle Outbreak in Northern Colorado and Southern Wyoming

A report by
USDA Forest Service
Rocky Mountain Region and Rocky Mountain Research Station
at the request of Senator Mark Udall

September 2011

Executive Summary

A mountain pine beetle outbreak in three national forests in the Rocky Mountain Region (Region 2) of the U.S. Forest Service—the Arapaho-Roosevelt, Medicine Bow-Routt and White River—was initially detected in 1996. By 2010 it had spread to about four million acres. This report examines the ecological conditions and historical land use that contributed to the outbreak, management response to the outbreak, suggested new and extended authorities for addressing the outbreak, and what we might expect as we look forward to the "new forest."

Looking Back: Conditions that Led to the Outbreak

Bark beetles are a natural part of forest ecosystems throughout the world. However, bark beetles are killing trees in larger numbers, at faster rates, over longer time periods, and over larger areas compared to outbreaks recorded over the past century. Moreover, outbreaks are occurring in multiple forest types. Reasons for these changes are unclear, but they include a changing climate affecting both insect and host; previous management practices such as selective timber harvesting and wildfire suppression in some forest types; a maturing forest due in part to changing disturbance patterns; and prolonged drought, which can stress trees and make them more vulnerable to insect attacks.

During the last part of the 20th century, widespread treatments in lodgepole pine stands that would have created age class diversity, enhanced the vigor of remaining trees, and improved stand resiliency to drought or insect attack—such as timber harvest and thinning—lacked public acceptance. Proposals for such practices were routinely appealed and litigated, constraining the ability of the Forest Service to manage what had become large expanses of even-aged stands susceptible to a bark beetle outbreak.

There were other factors that helped set the stage for a large-scale outbreak:

- Consecutive years of severe drought in the late 1990s and through the middle of the first decade of the 2000s, putting already densely populated stands under severe stress.
- Funding for pre-commercial and commercial thinning to reduce stand density during the decade leading up to and including the outbreak did not keep pace with the rate of bark beetle outbreak spread.
- Limited accessibility of terrain (only 25% of the outbreak area was accessible due to steep slopes, lack of existing roads, and land use designations such as Wilderness that precluded treatments needed to reduce susceptibility to insects and disease).
- Decline in public acceptance of large-scale timber management practices in the last part of the 20th century. This lack of public acceptance, compounded by national and international market forces and the relatively low commercial value of lodgepole pine, contributed to a corresponding decline in the timber industry. (The timber industry in the Rocky Mountain Region has declined by 63 percent since 1986).

Management Response in the Aftermath of the Outbreak and Factors that Influenced Response

Region 2 has made mitigation in the aftermath of the outbreak a top priority in its allocation of limited resources. However, funding levels at the outset of the outbreak (mid- to late 1990's) were inadequate to conduct any appreciable level of mitigation work in response to both its scale and rate of spread. Beginning in FY 2008, federal and state lawmakers have responded to the outbreak through increased funding, and legislation to expand authorities.

Collaboration with communities of interest has been a key component of the Forest Service response to the outbreak. These partnerships have helped to increase public awareness of the threat posed by dead and dying trees, and have been instrumental in identifying priority areas in which to conduct mitigation work. The response strategy focuses on protecting human life, public infrastructure and critical water supplies; and on strengthening the ability of communities to adapt to changed conditions on the landscape. What has emerged from collaborative efforts with communities is widespread social acceptance of the treatments needed to mitigate these threats of dead and dying trees.

Authorities such as timber sale contracts and stewardship contracts have proven to be of limited use because of the low value of beetle-killed timber and the declining capacity of the traditional timber industry. Although some new markets have been developed for beetle-killed trees, utilization of large quantities of biomass is still years away. Grants have been made to private wood products companies to stimulate new technologies and increase current efficiencies. The research community and private companies are studying the economics of biomass utilization, as well as the environmental consequences of adding biomass and biological charcoal (biochar) to forest soils.

Significant increases in appropriated funds have been used to accelerate mitigation activities. Sustaining those increased levels of funding will be essential for the Forest Service to continue to prepare for and implement mitigation activities at the level and pace needed to effectively protect life and property from the threat of dead and dying trees.

New or Extended Authorities that Could Help

Two tools that hasten response to emerging outbreaks and improve effectiveness are the Good Neighbor Authority and the Stewardship Contracting Authority. Both are set to expire on 30 September 2013. It would be helpful if they were extended or made permanent.

Looking Forward: the "New Forest"

Developing appropriate management responses to bark beetle outbreaks requires understanding the complexities of interactions between the beetles and host trees. In establishing the new forest, long-term management objectives will include creation of more diversity in terms of both species composition and age classes across the landscape; implementing restoration strategies for high-elevation pine forests; thinning to reduce stand density in forest ecosystems that have highly susceptible conditions; and incorporating climate change considerations when formulating forest management strategies.

However, opportunities to apply a strategy to achieve those objectives will continue to be limited to a small fraction of the infested land base, due to terrain (accessibility), appropriated budgets, economics, and land use designations. Simulations suggest that lodgepole pine will remain the dominant species in harvested stands that have lost their overstory to bark beetles. In untreated stands, simulations suggest that subalpine fir will become the most dominant species.

The complexity of watershed and hydrologic processes make it difficult to predict the effect of the bark beetle outbreak on runoff quantity and quality. Any variation due to the outbreak would be difficult to detect due to other sources of variation that affect water quality and quantity, such as precipitation and climate factors.

Bark beetle outbreaks result in significant changes to forest stand structure, and thus to fire risk and fire behavior.[1] Fire risk and behavior in these stands are complicated by differences in the degree (percentage) of tree mortality, rate of tree mortality, and time since mortality. The specifics of how beetle outbreaks affect the likelihood that a fire will start are a topic of current research.

[1] Fire Risk: the probability of an ignition occurring as determined from historical fire record data. Fire behavior: the magnitude, direction, and intensity of fire spread.

Table of Contents

Introduction

Since 1996, when it was first detected, the mountain pine beetle outbreak in the lodgepole pine forests of northern Colorado and southern Wyoming has grown exponentially. By 2010, aerial detection surveys had estimated that four million acres were affected by mountain pine beetles in the Arapaho-Roosevelt, White River and Medicine Bow-Routt National Forests. A bark beetle outbreak of this scope is historically unprecedented in this area.

The three national forests took early steps to respond to the outbreak. Treatments to thin stands to reduce susceptibility to infestation; salvage infested trees; and reduce the number of susceptible of trees around rural subdivisions were among the actions taken. By the middle of the first decade of the 2000s, it was clear that management actions such as thinning had not stopped the spread of the outbreak, but only slowed its spread into high-value areas. It was not feasible even to remove dead trees to the degree desired by many local residents to reduce wildfire risk.

In November of 2010, Senator Mark Udall wrote to USDA Secretary Tom Vilsack to request that the U.S. Forest Service conduct a review of this mountain pine beetle outbreak (see Appendix One). He asked that the Forest Service document "lessons learned and obstacles encountered" to help determine what more can be done, and what additional tools may be needed to respond to this outbreak and others in the future. This report was produced collaboratively by the Rocky Mountain Research Station (RMRS) and the Rocky Mountain Region (Region 2). It is a compilation of current research information and management experience, using readily available information on administrative and management issues. No additional research or development of administrative data was undertaken for this report.

Part I (Looking Back: Conditions that Led to the Outbreak) addresses the ecological conditions of the lodgepole pine forests that contributed to an outbreak. It also describes uses of the forests in the 19th century that contributed to a forest structure that was highly vulnerable to an outbreak. Finally, this section addresses social, economic and policy issues that constrained vegetation treatments that would have increased resiliency to drought or insect attack.

Part II (The Outbreak: Management Response, and Factors that Affected It) details the response to the outbreak by the Forest Service and its partners. It also examines the social, economic and policy issues that affected the ability of the Forest Service to respond quickly and at the necessary scale.

Part III (Suggested Extended Authorities) suggests extension of authorities, set to expire, that would be useful in responding to an outbreak.

In Part IV (Looking Forward: The "New Forest") touches on post-outbreak conditions, including development of the future forest, how to promote resiliency, impacts to watersheds, and how fire hazard[1] and fire risk will change over time.

[1] Fire Hazard: A fuel complex, defined by volume, type, condition, arrangement and location, which determines the ease of ignition and the resistance to control. A physical situation (fuels, weather, and topography) with potential for causing harm or damage as a result of wildland fire.

Part I – Looking Back: Conditions that Led to the Outbreak

Ecological Conditions

Native bark beetles are a natural part of forest ecosystems throughout the world. We know that bark beetles have been associated with western forests in the United States since at least the Holocene geologic epoch, which began approximately 12,000 years ago. They have probably been a part of the forest ecosystem for much longer.

About 500 species of bark beetles occur in North America, but only a few kill all or a portion of the host trees they infest. These few species are primarily responsible for the large areas of tree mortality seen across the major forest ecosystems in the West. These tree-killers reside in a single family of insects (*Curculionidae*, subfamily *Scolytinae*) and each species has evolved to feed and reproduce in a single conifer group. The mountain pine beetle, the species of primary interest in this report, attacks and reproduces in at least 12 different species of pine, including lodgepole, ponderosa, bristlecone, whitebark, western white, sugar, and limber pine.

Historically in North America, bark beetle populations are cyclical and periodically erupt into outbreaks. Although outbreaks can kill many trees over large areas, they have not "destroyed" forests but have served as positive forces of transformation that redistribute nutrients and growing space. In this role, beetles generally attack larger trees, thus helping to renew the forest by killing older and declining trees while allowing younger, more productive trees to compete successfully for resources. The current bark beetle outbreaks, however, are unprecedented in their intensity, their extent, and their synchroneity (that is, their occurrence at the same time). Bark beetles are killing trees in larger numbers, at a faster rate, over longer time periods, and over larger areas compared to outbreaks recorded over the past century. Furthermore, the outbreaks are occurring concurrently across western North America in multiple forest types. The reason or reasons for these changes are unclear, but the best available science provides some insights. They include:

- A changing climate affecting both insect and host.
- Previous management practices such as timber harvesting, historical use patterns, and wildfire suppression in some forest types; and a maturing forest due in part to management practices that changed the size and frequency of regeneration events. The result was hundreds of thousands of contiguous acres of lodgepole pine in densely stocked, mature stand conditions that were highly susceptible to bark beetle attack.
- Prolonged drought, which can stress trees and make them more vulnerable to insect attacks.

Climate: Bark beetles, like all insects, are ectotherms (an organism whose body temperature varies with the temperature of its environment). Every aspect of the beetle's life is affected by temperature—from the number of eggs it lays, to its ability to disperse, to the rate at which the beetle moves from one life stage to the next (for example, from pupa to adult), to the survival of the beetle during cold periods. Mountain pine beetles, for instance, move from one life stage to another only when temperatures are warm enough—a threshold which varies depending on geographic location.

During the past decade, most years ranked among the warmest since record keeping began in the mid-1800s. Naturally this is also the case in forest ecosystems where bark beetles make their home. Cold winter temperature is a major mortality agent of bark beetles. Warmer winter temperatures foster increased insect survival during the winter, leading to larger populations. Warmer, drier conditions can result in a stressed environment for trees—making them more susceptible to insect attack—and higher temperatures can increase the speed of insect development. However, this will be a factor only if the insect is still able to enter the winter in its cold-hardy stage; this may be occurring in high-elevation forest types such as whitebark and limber pine.

In addition to the direct effects of warming temperatures, there are indirect effects of climate change. A prolonged drought in portions of the western U.S. during the late 1990's and early 2000's, combined with the warming temperatures, weakened trees and made them more susceptible to bark beetle attacks. Forests full of drought-stressed trees, combined with rapidly expanding populations of bark beetles, fueled dramatic increases in the duration, intensity, and extent of tree mortality in these western forests.

Wildfire Suppression: Since the early 20th century, when the United States implemented a policy of suppressing fire on public land, many fire-prone ecosystems such as ponderosa and lodgepole pine have experienced long fire-free intervals. Often the species composition and structure of those forests changed, resulting in dense forests full of the mature trees that bark beetles favor.

The role of fire suppression in bark beetle outbreak dynamics is a topic of much discussion among scientists, reflecting the need for additional research. Although the effect of fire suppression on bark beetle outbreaks varies by forest type, region, and the level of forest management (such as timber harvest), it is fair to conclude that fire suppression policies have helped create a landscape that is more homogeneous over vast tracts of forest, and therefore more susceptible to large-scale bark beetle attacks.

Historical Use

The tie hacking industry in the area of Wyoming and Colorado that is now the Medicine Bow National Forest began in 1868 with the construction of the Transcontinental Railroad. During the peak construction years, 1868 to 1870, timber for 3 million railroad ties was removed. Between 1869 and 1902 (the year the Medicine Bow National Forest was established), timber for another 10 million railroad ties was taken, representing 90-95% of the total volume of forest products.

In Colorado, construction of railroads was more localized, supporting the mining industry that sprang up along the mineral belt after the discovery of gold in 1858. The boom years for railroad construction began in 1880 and ran until 1892, supporting the silver boom. The mining industry was the most significant industry in Colorado in the nineteenth century. It used vast amounts of forest resources. All materials for local railroads, mining supports, and construction in mining towns and camps came from local forests. Placer mines and mill waste came to dominate many landscapes. Often entire mountainsides were completely denuded to provide milled lumber for construction, supports for mines and cribbing, and fuel. Industrial mining on a landscape scale peaked around 1900 and then retreated to only the most profitable mines.

This scale of tree removal, and the clearing of large areas to expose the geology for mining exploration and extraction, resulted in a "regeneration event" in thousands of acres of pine forests—in other words, whole forests started over with seedlings. This contributed to the current stand structure where a mature overstory is the prevalent condition.

Social, Economic, and Policy Issues

Public Acceptance of Treatments

Forest conditions susceptible to mountain pine beetle infestation in pine forests were recognized by Forest Service personnel as early as the mid-1990s. These conditions were noted as the rationale for vegetation treatments in Purpose and Need statements for disclosure documents required under the National Environmental Policy Act (NEPA). In the 1990's, vegetation treatments in lodgepole pine stands that would have increased resiliency to drought or insect attack (timber sales and stand improvement projects such as thinning) lacked public acceptance. These practices, which increase growth rates and vigor of individual trees by reducing competition, were routinely appealed and litigated. This hampered the ability of the Forest Service to address stand conditions susceptible to outbreak.

Moreover, people were skeptical about the potential spread of the insects. Many did not believe, looking at green trees that had been attacked by bark beetles, that they had actually been killed. That realization came a year later, when the trees turned red. Public acceptance of active forest management (also called social license) increased as people witnessed the scope of the outbreak and its rapid rate of spread, but by then it was too late to implement active preventive forest management measures. Rather, the social license allowed the Forest Service (and other partners) to implement large mitigation projects in the aftermath of the outbreak to address threats to public safety from wildfires and falling dead trees.

Funding

Funding for pre-commercial and commercial thinning to reduce green tree stocking was extremely low for the decade leading up to and including the outbreak. As the infestation progressed, appropriated funds did not keep pace with the outbreak sufficiently for Region 2 to take early measures to effectively detect and remove infested trees (brood trees) or to thin stands of lodgepole pines ahead of the predicted beetle infestation expansion (see Appendix 2).

Scale of Possible Treatments

Funding levels were not the only limiting factor in maintaining forest stands. The Forest Service was able to access less than 25 percent of the suitable timber base. Limited access is attributed to several factors:

- Forested slopes that exceed 35% to 40% are too steep for conventional forest management practices.
- Many wildand urban interface (WUI) areas, particularly in Colorado, are adjacent to inventoried roadless areas. Since the Roadless Rule was promulgated in 2001, it has been repeatedly litigated, and judicial decisions have differed. Court decisions have changed the legal landscape for project planning. Fuel treatment projects in the WUI require additional analysis and in some cases have been controversial. In some areas fuel loadings are so great that effective fuel treatment cannot occur without removing some of the fuel using a temporary road. Commercial access on a large scale that would support a long-term supply of wood to industry and allow increased management of watersheds is difficult outside of the WUI and at-risk communities.
- In general, mechanized treatments are prohibited in designated wilderness areas. The Arapaho,

Roosevelt, White River, and Routt National Forests in Colorado have a combined total of over one million acres of wilderness; the Medicine Bow National Forest in Wyoming has more than 78 thousand acres. A large portion of these wilderness acres have been impacted by the current bark beetle outbreak.

Capacity of the Traditional Timber Industry

The timber industry in the United States has been in decline for at least the last two decades. One factor in this decline has been public pressure to reduce the supply of green live timber from National Forest System (NFS) lands (public opposition to tree cutting); another has been national/international market forces. In Region 2, the timber industry has declined by 63% since 1986. (In 1989, the Region sold 190 million board feet; in 2005, the Region sold 58 million board feet.) Consequently, few industrial resources were or are available to help the Forest Service in applying management practices in response to the bark beetle outbreak.

Use of Federal Authorities

As the outbreak emerged, Region 2 was limited in its ability to reduce stocking of low-value lodgepole pine because it cost more to remove it than it was worth. The Forest Service does not have authority to assign no-value or salvage rates to the healthy, green standing trees.

Stewardship Contracting

Stewardship contracts[1] can be a valuable tool for thinning stands where the value of the extraction activity (timber harvest) is equal to or greater than the cost of thinning. In R2, there often is not enough value in the material being removed to offset the cost of removal of the material or to offset the cost for other restoration activities within the contract area. Short-term contracts were frequently used in Region 2, but they were generally used on areas of less than 2,000 acres, and only a fraction of the area in those contracts involved thinning stands. Previous contracts didn't affect enough acres in the three national forests to measurably improve resiliency of lodgepole pine stands on large landscapes.

[1] Stewardship contracting combines restoration and extraction activities on NFS lands into contract or agreement packages. It provides for trading goods for services, and allows a national forest to retain receipts from forest products that need to be removed to meet restoration objectives, and apply the receipts to needed service work in the stewardship project area. Stewardship contracts may be short-term contracts that last for 1 to 5 years or they may be long-term contracts, often referred to as Long-Term Stewardship Contracts or LTSCs, which can have 10-year duration.

Part II – The Outbreak: Management Response and Factors that Affected Response

Management Response

Collaboration

As the outbreak expanded to affect millions of acres, the Forest Service recognized that neither it nor any other entity could respond effectively on its own—so the agency convened partners in 2006 to suggest a collaborative approach. The partners agreed, and created the Colorado Bark Beetle Cooperative (CBBC), an organization that takes concerted and strategic action to address the outbreak. The CBBC, composed of federal, state and local governments, non-governmental organizations and private businesses, has cooperated on projects and public education efforts ever since. These partners have been involved in general awareness and public education, identification and prioritization of areas for mitigation work, and watershed assessments.

In 2007, Region 2 established a Regional Incident Management Team to coordinate hazardous tree removal among the three forests and promote cooperation with partners. Soon afterward, the Northern Front Range Mountain Pine Beetle Working Group was formed to coordinate efforts along the Front Range of Colorado. In the research community, the Western Bark Beetle Research Group (WBBRG)[1] was formed to serve as an ad hoc umbrella organization aimed at fostering communication, and enriching scientific interactions among Forest Service bark beetle researchers in the western United States. WBBRG's goal is to enhance the responsiveness, delivery, and impact of bark beetle research. It has provided Forest Insect and Disease Tally (FIDT) software for analyzing insect and disease population information taken during stand surveys; a research bibliography, extending back into the 1960's and including current research; and databases of historical mountain pine beetle outbreaks.

Mitigation

The response strategy developed by the Forest Service and its partners focuses on public and employee health and safety; protection of public infrastructure and critical water supplies; and community resilience to adapt to changed conditions on the landscape. (There was not the funding, capacity, nor public support to address backcountry areas.) The strategy identifies values at risk:

---

1 The web site address for the WBBRG is (http://www.usu.edu/beetle/wbbrg_bark_beetle.htm.

- 215,000 acres of wildland urban interface (WUI) ;
- 3,700 miles of forest system roads;
- 1,300 miles of trails;
- 460 developed recreation sites;
- 16 ski areas; and
- 550 miles of powerlines.

In addition, essential water supplies are at risk from falling trees because of the damage wildfires can cause to watersheds, and because falling dead trees can obstruct water infrastructure (such as ditches, gates, pipelines, and storage facilities). Within the heart of the outbreak in Colorado and Wyoming are the headwaters for rivers that supply water to 13 western states.

In 2009, Regional Forester Rick Cables, recognizing that the outbreak had become a safety emergency that exceeded regional capability, signed a Delegation of Authority that transferred management of public health and safety actions to the Boise National Incident Management Organization (NIMO) for a duration of two years. The NIMO developed a "theatre-level" management strategy for the area comprising the three "bark beetle forests."[2] The NIMO also developed an Incident Action Plan and an incident management organization. Management has since transitioned back to a Regional-level team that continues to focus mitigation efforts. Projects are directed in four major activity areas:

- Hazardous tree removal from roads, trails and campgrounds.
- Hazardous tree removal from administrative sites and the WUI.
- Work with permittees who are removing hazardous trees from infrastructure such as powerlines, ski areas, and recreational residences.
- Public information about the hazards of falling trees.

The need for mitigation grows as risk grows. Necessary accelerated activities include environmental analysis, contract preparation and administration, layout of contract units, and hazard tree removal and hazardous fuels reduction work. Region 2 has made mitigation of the outbreak its top priority, shifting allocated funding to this effort to the fullest extent possible. The "bark beetle forests" are using innovative approaches to perform critical work. For example, interagency hot shot crews, youth crews, and prison crews augment the capacity of the forests' workforce. Forest Service Enterprise Teams and employees from other national forests also help to temporarily increase capacity. Contracts are used to implement work projects, providing jobs in the private sector.

Through these efforts, the following have been accomplished to date:

- 12% of roads mitigated for hazard trees
- 12% of trails mitigated for hazard trees
- 61% of recreation sites mitigated for hazard trees
- 18% of wildland urban interface (WUI) acres mitigated for hazardous fuels reduction

See Appendix Three for further details.

[2] Medicine Bow-Routt, Arapaho-Roosevelt and White River National Forests.

At the national level, the Forest Service has developed a multi-region bark beetle strategy to identify and accomplish work needed across NFS lands in the West. This will aid in establishing a consistent and sustainable budget plan for bark beetle mitigation efforts in the longer term.

Forest Service State and Private Forestry Assistance

The State and Private Forestry branch of the U.S. Forest Service has provided funding to the Colorado State Forest Service (CSFS) to help address the outbreak. CSFS provides technical assistance to landowners, and treats thousands of acres for hazardous fuel reduction. For example, Cooperative Fire Protection program funding supported planned fuel reduction treatments on more than 4,000 acres in 2009, and more than 5,550 acres in 2010.

Public Information/Education

The Forest Service and its partners in Colorado have conducted a coordinated bark beetle education and information campaign. The campaign has evolved from explaining why trees are dying (the changing forest, the biology of the bark beetle) to raising awareness of safety threats, especially falling dead trees and wildfire (practices for safe camping and hiking, creating defensible space around private properties, etc.) The campaign is directed at the general public, specific categories of stakeholders such as homeowners in the wildland urban interface (WUI), and state and federal legislators.

Products that have been created to share information include brochures, flyers, media releases and editorials, interpretive signs, newspaper inserts, DVDs, door hangers, table tents, and lapel buttons. (These products were shared with partners in Wyoming as they began to experience effects of the outbreak.) Signs warn forest visitors of the danger of falling trees, and Forest Service employees also make personal contacts in the woods to share information with visitors.

To raise awareness among lawmakers at the federal and state levels, partners provide briefings locally and in Washington, D.C., and host several field tours each summer.

Federal and State Legislative Action

Federal lawmakers, in responding to the threat to public safety, critical infrastructure, recreation activities, and water supplies, have introduced legislation to help the Forest Service address the outbreak. Senator Mark Udall's National Forest Insect and Disease Emergency Act of 2009 is an example. None of these bills have passed to date.

Federal lawmakers have also secured additional funding, either directly, as Senator Wayne Allard did when he provided $13 million through the Senate Appropriations Committee in FY 2008, or through reprogramming. At the request of concerned western lawmakers in FY 2010, USDA Secretary Tom Vilsack directed Region 2 to prioritize $40 million to address bark beetle mitigation.

Colorado lawmakers have passed 25 forestry-related bills in the past three years, ranging from loan programs to state income tax breaks for homeowners working to create defensible space (notably HB 1199, the Colorado Healthy Forests and Vibrant Communities Act of 2009). In addition, Governor Bill Ritter established the Colorado Forest Health Advisory Council in 2008 to advise state and federal government on actions to promote forest health.

Factors Affecting Response

Authorities to Remove Trees

Authorities available to the Forest Service to manage forests were developed in the post-war period (1960s and 1970s) for "normal" environmental conditions and "business as usual."[3] They are based on the assumption that the wood products available for removal have enough value to cover the cost of removal, pay for reforestation, and still return money to the U.S. Treasury.

Current conditions are far from the "normal" conditions under which these authorities and regulations were promulgated. Today stand mortality far exceeds stand growth; current estimates are that over six million acres of forests in Region 2 have some level of insect-caused tree mortality. Dead standing trees and most green standing trees in the Colorado and Wyoming outbreak area have little or no commercial value due to size, condition, accessibility or marketability. In fact, they have negative value because they must be removed at a cost.

Region 2 has done as much as possible to accelerate the removal and disposal of dead and dying trees. In 2004, Region 2 was allowed to increase the delegated authority for Personal Free Use[4] and Administrative Free Use[5] to remove trees that were "killed, infested, or anticipated to be infested with insects or disease…." This authority was delegated to Forest Supervisors in October 2007. The Region has maximized delegation of administrative use and timber settlement authorities, enabling forest supervisors and district rangers to dispose of larger quantities of dead and dying material. Timber designation and appraisal procedures have been streamlined to respond more expediently to requests for removing material.

Stewardship Contracting

Although stewardship contracting authority has been available for many years, Region 2 was unable to take advantage of large Long-Term Stewardship Contracts (LSTCs) during the early years of the mountain pine beetle outbreak for two reasons:

1. *The cancellation ceiling for multiyear contracts (part of the Federal Acquisition Regulations):* The cancellation ceiling is essentially a bond funded by the Forest Service to cover the maximum amount of a contractor's investment in the event the agency cancels a long–term stewardship contract. The appropriated funds needed to fulfill the cancellation ceiling requirement are encumbered. In most cases, the cancellation ceiling is more than $500,000 (held in reserve annually). This requirement has been clarified and should not be a barrier to using stewardship contracts in the future.
2. *Goods for services:* Under a stewardship contract, the contractor doesn't pay for the value of merchantable material harvested; instead, the contractor provides services of comparable value to the Forest Service. This is not useful for areas where the value of the removed material is much less than the cost of the removal—such as lodgepole pine stands killed by bark beetles. Most treatments in the outbreak area require appropriated funds to implement.

Region 2 currently has an LTSC that covers parts of the Arapaho-Roosevelt and Pike National Forests. Approximately 4,000 acres per year are treated.[6]

[3] Normal environmental conditions include predictable mortality from endemic beetle populations in green stands and predictable growth and mortality of forested stands based on accepted models of forest development. "Business as usual" means that there is adequate milling capacity and funding to remove wood products on a schedule that reflects a compromise between growth rates and mortality rates (an allowable sale quantity assessment would balance natural tree mortality and growth with a complementary harvest quantity).

[4] Personal Free Use: Small quantities of wood cut for firewood or fence posts for private individuals when removal of the material is in the government's interest.

[5] Administrative Free Use: Special-use permittees are allowed to cut wood products to support the purposes of their permit. For example, a range permittee would be allowed to cut wood for fence posts used on the permitted range allotment.

[6] Region 2 is exploring opportunities for another LTSC in western Colorado, and evaluating responses to a Request for Information.

Emergency Planning Authorities
Region 2 has found the expanded authorities in the Healthy Forest Restoration Act (HFRA) very helpful in addressing the outbreak because they streamline the environmental analysis process. These authorities provide that:

- Only the proposed action and no-action alternative be identified for projects within 1 ½ miles of an at-risk community, or in the WUI as defined in a community wildfire protection plan (CWPP).
- Only the Proposed Action, No-Action and Action Alternative be identified for projects farther than 1 ½ miles outside an at-risk community or CWPP-defined boundary.

Two other emergency authorities have been analyzed for use in mitigating the outbreak: a Governor's emergency or disaster declaration and a USDA Secretarial disaster designation. These authorities are used to respond to natural disasters that have overwhelmed the capabilities of local and state governments, or caused the loss of at least 30% of one crop. The relief provided is in the form of assistance to private landowners; therefore, these types of emergency measures do not affect federal agency responses.

Evolving Public Acceptance of Treatments
Experience has shown that some forest management practices that involve cutting trees are more accepted by the public than others. For example, practices that reduce hazardous fuels or encourage the restoration of pre-settlement ponderosa pine stands are more acceptable than practices that are undertaken as commercial forest products management. Project proposals that are viewed as "cutting trees for the sake of cutting trees" or "feeding the timber industry" are routinely appealed; consequently, the projects are negotiated down to reduced levels of harvest or affected acres.

Current Funding
As noted in Part 1, low funding levels were a contributing factor to low levels of stand density management in the past. Sustained high-level funding allocations are necessary to accelerate activities for public and employee safety, and hazardous fuels reduction in the WUI. These activities include additional NEPA preparation, layout of contract units, and appropriate contract administration. Appropriated funds have been inadequate to "staff up" to the level needed for these accelerated activities.

In 2008 the Region identified a $10 million shortfall in the timber program to address impacts of the outbreak. That year, Regional Forester Cables formally requested emergency funding to implement a public safety strategy, largely due to falling trees. However, program priorities for Forest Health Protection, Forest Management, Hazardous Fuels, and Road Maintenance are aligned around issues other than hazard tree mitigation. Programs are designed to deal with a recurrent program of work, not a long-term, evolving incident like the bark beetle outbreak. Hazard tree mitigation, especially at a large scale, is not a focus of any Forest Service program area. Budget line items (BLIs) tend to be aligned around functional resource areas, and their relationship to the bark beetle epidemic is not straightforward.

Additionally, the constrained budget leads to only marginal changes in regional allocations, and the budget process and structure only address year-to-year rather than multi-year funding. The budget process favors a steady-state program of work and lacks a mechanism for Regions to ask for additional funding for emergencies. Generally speaking, there is no clear mechanism in the budget process to ask for special recognition or emergency considerations. The constrained budget approach coupled with high fixed costs effectively prevents any but the most marginal changes in Regional requests and therefore allocations. Thus, R2 did not have enough discretionary budget after fixed costs to show how much of a shift was needed to address the impacts of the bark beetle outbreak.

The budget amounts for bark beetle mitigation through FY 2010 are displayed in Appendix Two. In FY 2011, a total of $33 million is being directed to mitigation efforts.

Scale of Possible Treatments
The factors that limited access to many areas for treatments to maintain forest stands—steep slopes, adjacency to inventoried roadless areas, prohibition of mechanical treatments in designated wilderness—are still applicable today.

Capacity of the Traditional Timber Industry
Intermountain Resources LCC (IMR), located in Montrose, CO, is in receivership. The last large mill operating in Colorado, IMR processes material from both Colorado and Wyoming. Like other forest product companies across the nation, it is facing an extended downturn in forest product markets. The company is seeking relief from Forest Service contract requirements for emergency removal of green and dead trees.

There are 25 small operators in Colorado, each with 5 to 10 employees. These small operators do not have the financial or physical capacity to respond to the huge number of acres affected by the outbreak. The material to be removed and processed is expensive to transport relative to the value of the product. These small operators primarily produce items such as pellets, fence posts, rails, rough lumber, and specialty products.

In Wyoming, a now-closed mill in Saratoga, which has a 36-million board foot capacity, will cost $4 million to modernize.

Biomass
Some new avenues have been developed for utilization of dead standing material, but utilization of large quantities of biomass material is still years away. The benefit/cost ratio for converting municipalities to biomass-fueled heat or power does not favor use of biomass when compared to natural gas because natural gas costs less at this time. With the exception of a biomass heating unit in Boulder County, there are no large biomass utilization units in proximity to the outbreak.

Region 2 has been approached by 17 companies investigating their ability to utilize biomass. This demonstrates the high level of interest in the private sector in utilizing this material. The national forests in the Region cannot provide the volume of wood necessary to meet the capacity of all the new companies seeking certainty of supply. Also, Region 2 has been contacted by many individuals and companies wanting a guarantee of long-term supply and exclusive rights to wood volume. Federal contracting rules do not allow entering into sole source contracts when there is clear interest from multiple qualified potential contractors. As an alternative, Region 2 has proposed a nontraditional “stewardship agreement” with the State of Colorado. This agreement would give the State an opportunity to access much of the available beetle-killed material and dispose of it according to State procurement and acquisition rules.

There are three active pellet mills in Colorado: Rocky Mountain Pellets in Walden, Confluence Energy in Kremmling, and EE Pellets in Silverplume (mobile technology). Rocky Mountain Pellets and Confluence Energy are each capable of producing about 100,000 tons per year. EE Pellets produces about 20,000 tons per year. It is working on building four or five portable mills (Colorado manufactured).

Small private wood products companies within Region 2 have benefitted from grants provided through the Forest Service’s Forest Products Laboratory. (See Appendix Four for details.) Although some operators have received financial and technical assistance to upgrade or expand their businesses, business capacity is still insufficient to address the needs of forest management on a very large scale.

In the research community, the Rocky Mountain Research Station, university collaborators, and private partners are studying the economics of biomass utilization, as well as the environmental consequences of adding biomass and biological charcoal (biochar) to forest soils.

Studies of the economics of biomass utilization are investigating options for utilizing forest treatment residues for bioenergy production. This includes using either ground wood or processed wood to co-fire a coal-powered electricity generating facility, and quantifying net greenhouse gas emissions, carbon balance, and energy balance associated with various configurations. These alternative configurations help determine the conditions under which utilization of biomass from forest treatments delivers the greatest net economic and environmental value. Economic development impacts, as well as the social acceptability of biomass removal and utilization, are a part of these analyses. Studies to investigate alternatives for, and economic efficiencies of, transporting forest treatment residues from locations that are not accessible to standard chip vans (which are not designed for use on forest roads) are also informing results.

The potential for manufactured products using pyrolysis (the heating of organic matter to create biochar, synthetic gas, or bio-oil from forest residue) offers an additional value-added use for residual or waste material from forest thinning and wood processing. Biochar appears to be useful as a soil amendment; it can enhance the absorption of heavy metals and toxins, suggesting potential uses in mine reclamation; it's a precursor to activated carbon for water filtration; and it can potentially be used as a stable form of carbon in future carbon markets. Field, laboratory and greenhouse studies are examining the properties of biochar, as well as how it can be part of an integrated utilization strategy, or added to a wood processing facility as an additional product line.

Myriad conversion technologies are emerging, including new pyrolysis systems. State and federal land and resource managers, as well as county and municipal managers, need to understand the costs and benefits of biomass utilization at a variety of scales. Technology demonstrations can be an effective part of outreach programs to increase exposure to new knowledge and emerging results.

While many studies are ongoing, researchers are confident that, in some cases, collecting, processing, and hauling forest treatment residues off site for thermal energy production can substantially reduce greenhouse gas and particulate matter emissions. (This is in comparison to burning those residues on site, and using either natural gas or fuel oil to provide the same amount of usable thermal energy in a boiler.)

Part III – Suggested Extended Authorities

Extension of Temporary Authorities

Congress could extend, or make permanent, two authorities that have been very useful in responding to the outbreak. Both are set to expire on 30 September 2013:

- The Good Neighbor Authority allows Colorado Forest Service employees to act as agents for the federal government to mark and remove trees on NFS land when the work is performed in conjunction with similar treatments on adjacent non-NFS land.
- Stewardship Contracting Authority allows a "goods for services" arrangement with a contractor.

Part IV – Looking Forward: The "New Forest"

Creating a Resilient Forest

Developing appropriate management responses to bark beetle outbreaks requires understanding the complexities of species-specific, multi-scale interactions between beetle and host tree occurring within the targeted forested area. It also requires understanding the long-term influences of these management actions at the larger landscape and regional levels. The unprecedented nature of the current mountain pine beetle outbreak in Colorado and Wyoming makes management decisions more difficult because the appropriate management response cannot necessarily be formulated based on previous events. Using lessons learned from this outbreak can help forest managers in the future develop management strategies to ameliorate stand conditions which would be predisposed to large-scale insect outbreak.

There are some general guidelines, however, that can be used in developing management strategies for future forests:

- In areas severely affected by recent outbreaks, land managers may consider creating more diverse forests through modifying species composition and age classes across the landscape. Greater diversity of species and age structure may reduce susceptibility to massive outbreaks in the future. Treatments such as these must be initiated early during stand development and continued with relative frequency as stands mature; in other words, proactive stand regeneration is required to maintain age class diversity across large landscapes.
- Restoration strategies for high-elevation pine forests affected by mountain pine beetle and blister rust are needed to ensure perpetuation of these critical ecosystems.
- Forest ecosystems that have highly susceptible forest conditions, but are currently unaffected by bark beetles, may benefit from thinning to reduce stand density. This is particularly true in lodgepole and ponderosa pine stands where research has shown that thinning can reduce susceptibility. For example, in a diameter-limit thinning study in lodgepole pine on the Shoshone National Forest in Wyoming, the investigators found that 26% of trees were killed by mountain pine beetle in untreated control plots compared to less than 3% in the thinning treatments.
- Policy makers and forestry professionals can incorporate different climate change scenarios—as well

as the direct and indirect effects of this change on both potential hosts (the trees) and the pest (bark beetles)—when formulating future forest management strategies. A greater investment in research is critical to generating new knowledge and incorporating research results into managers' decision making.

It may make sense to practice intensive management, such as applying insecticides on high-value trees on a small scale in areas such as campgrounds or near homes, but such practices are not feasible on a landscape scale. At larger scales, lodgepole pine forests affected by mountain pine beetles will regenerate naturally and a new forest will emerge with time. While dead trees on a mountain slope may not be visually appealing, the forest has been reset—not destroyed.

The Role of Natural Regeneration

In Colorado and Wyoming, land managers and the public are concerned about the extent of poor seedling establishment in beetle-killed lodgepole forests. Other concerns relate to potential changes in species composition after the outbreak, and to the length of time it will take these forests to recover.

These concerns are justified. Owing to the unprecedented nature of the outbreak, it is unknown if the forests that regenerate after this outbreak will differ from those that regenerated in the past. There are no systematic surveys of regeneration in beetle-killed forests, nor do we have comprehensive information about the number, size, and species of surviving trees where beetles have caused extensive mortality. Both types of information are critical to charting a course following the outbreak and assuring investments in regeneration are strategic.

Owing to terrain, and to budgetary, economic and regulatory limitations—such as prohibitions on entering roadless areas and designated wilderness—active management will be applied to a small fraction (probably less than 15%) of the forest area killed by mountain pine beetles. Research studies conducted on the Sulphur Ranger District of the Arapaho-Roosevelt National Forest help us understand the implications of this situation.

Recent studies conducted by the RMRS in forest stands near Fraser, CO suggest that lodgepole pine will remain the dominant species in harvested stands over the next century, but subalpine fir will become the most abundant species in untreated areas. The long-term consequences of the outbreak will be most dramatic in untreated areas, where the shift in tree species composition will influence timber and water production, wildfire behavior, wildlife habitat and other forest attributes. Another RMRS study suggests that the density of seedlings is at least as high in stands affected by extensive pine beetle-caused mortality as in stands having healthy pre-outbreak conditions. Care must be taken when drawing conclusions for the broader infestation area. Similar studies on-going at a network of sites will complement the need for additional work across the range of physical and biological conditions to provide a more robust data set from which we can begin to predict the future forest and begin to plan how to manage it.

Research gaps in understanding future forest composition and resilience include the impacts of mechanical fuel reduction treatments and post-harvest site preparation in beetle-killed forests on seedling establishment and growth, plant nutrient and moisture relations, and biogeochemical and hydrologic processes; and the influence of continuing climate change on forest regeneration and species composition in mountain pine beetle-impacted areas.

Impacts to Watersheds

Water supply in western North America is controlled primarily by snow accumulation and melt in forested headwater basins. Watershed health and function in the subalpine zone are controlled by climate, physiography,[1] forest cover, and land use. Recent impacts from the widespread mountain pine beetle outbreak are exerting a profound effect on forest cover, structure, and species composition. These impacts, in turn, are driving changes in water quantity and quality—two important ecosystem services provided by federally managed forests.

The mountain pine bark beetle began to attack lodgepole pine at the long-term Forest Service watershed research site at the Fraser Experimental Forest (FEF) in 2002. By 2007, bark beetles had killed between 50% and 80% of the overstory pine in Fraser's research watersheds. The suite of scientific records at the FEF provides a unique opportunity to quantify the impacts of this widespread disturbance. Consequences of the mountain pine beetle outbreak result from a combination of short-term and longer-term changes in hydrologic and biogeochemical processes that control delivery of clean water from forested catchments. In general terms, canopy mortality from bark beetles influence watershed processes in ways similar to logging or stand-replacing fire. However, the impacts of beetle outbreaks to downstream users—associated with the magnitude, timing, and duration of watershed change—are likely to differ dramatically from logging or fires because of the lack of impacts to understory vegetation and soils.

Stream Water Quality: Higher stream water nitrate concentration and export were detected during six years following bark beetle mortality; this is likely the result of decreased nutrient demand following mortality of overstory pines (dead trees don't require nutrients). The increase in concentration and export in the years following the bark beetle outbreak was small and does not pose a risk to human or stream health.

Stream Water Quantity: Trees impact runoff by returning water to the atmosphere through two important mechanisms. First, trees use soil water during the growing season through transpiration[2], which moves water from the soil back to the atmosphere. Second, tree canopies in snow-dominated regions intercept snowfall, a portion of which then sublimates directly back to the atmosphere before reaching the snowpack. The magnitude of beetle-related changes in transpiration, interception, and runoff will depend on three things: the amount of mortality in the stand, the species composition of the remaining overstory, and finally, basin physiography. Earlier empirical work on water yield effects of both harvest and lesser-scale beetle kills provides some basis for predictions.

The best empirical information we have for the region is from harvesting studies, although limited research on beetle kill has shown similar magnitudes of effect. Our hypothesis is that beetle kill will result in less yield increase than harvesting. Harvesting typically removes the mature timber and the understory over a short period of time, so impacts are immediate and profound—on the order of a 40% increase in yield averaged over 30 years post-harvest. Beetle-killed mature stands often leave a healthy understory behind. This understory still consumes water through summertime transpiration and still causes some interception losses of snowfall. It is important to note that the current bark beetle outbreak is unprecedented in magnitude and extent, and there may be significant departures in impacts from previous beetle infestations.

Future detection of changed streamflow may be difficult, as well. In the harvest studies, researchers were able to maintain control watersheds to isolate climate versus land cover changes. Because the beetle kill

---

[1] Physiography: physical features of the earth's surface

[2] Transpiration is the evaporation of water from plants. It occurs chiefly at the leaves.

has been so widespread, the traditional paired watershed approach cannot be used to separate the effects of climate variations from land cover variations as readily as where scientific control is retained. In the future, with longer statistical records, and studies using semi-deterministic models, there is a greater probability of detecting and quantifying the effects of the beetle infestation on stream flow and water quality.

Improved knowledge and understanding of how canopy loss and tree death following mountain pine beetle infestation alters snow accumulation in winter, and snowmelt, transpiration, nutrient release, and runoff processes in spring and summer would improve the precision of water yield predictions and detection.

For more detailed information on watershed impacts, see Appendix Five.

Fire Risk and Behavior

Bark beetle outbreaks can result in significant changes to forest stand structure, and thus to fire risks and fire behavior. Regardless of beetle activity, fire risk and behavior are shaped by:

- The amount, type, and condition of vegetation or fuels on site.
- The fuels' dryness and exposure to sun and wind.
- Topography, elevation and weather.

The presence of beetle activity adds additional variables to the challenges of predicting and managing fire risks based on:

- Species of beetle.
- Intensity and rate of tree mortality.
- Time since mortality.

Bark beetle mortality modifies canopy fuels, surface fuels (such as grasses, forbs, shrubs, and downed-woody material), and ground fuels of dead litter and humus. Localized weather conditions such as increased sun, wind, and rain or snow are also modified in proportion to the number of trees killed. These changes are directly linked to changes in the forest water balance that are known to affect fuel moisture relationships, and therefore fire behavior.

The specifics of how beetle outbreaks affect the likelihood of a fire are poorly understood; this is a topic of current research. The increased presence of fine, dry surface fuels implies a greater number of successful ignitions and can affect fire spread. The degree to which mortality affects fire potential depends on the stand structure[3] prior to the bark beetle outbreak, and the level of stand mortality. Owing to the complexity of the number of sites, beetle outbreak dynamics, and scientific limitations, it is possible to describe expected future fire potential in only a general way. Real-time fire management decisions should be based on local expert knowledge informed by the context of the specific wildfire situation.

Will the beetle outbreaks lead to more frequent fires in impacted watersheds?

Basic fire science principles suggest that opening the forest should lead to dryer surface fuels, more sunshine, and more wind, which will favor increased ignitions and early fire spread resulting in more fires requiring management.

---

[3] Stand structure: The quantity, distribution, and horizontal and vertical arrangement of live and dead trees, understory vegetation, woody debris, litter, and humus within a given area.

Will the bark beetle outbreaks lead to more or less extreme fire behavior?
Past experience is largely anecdotal but decades of firefighter wisdom suggest fires will be more intense for an indeterminate amount of time following attack. Current operational fire behavior models were developed for "normal" healthy forests; they do not include variables that address the phases of beetle attacks: attacked green, attacked yellow, dead-red. (See Appendix Six.)

The physics and chemistry of fire and fire weather/climatology suggest all fire behavior measures should increase during the attack phase. Following attack, forest composition and structure are fundamentally altered. The "time-since-outbreak" is important in differentiating effects on fine fuels (and thus fire spread) and larger fuels (which relate to fireline construction and often safety).

Fire behavior can be expected to decline somewhat in the post-attack phase but not return to pre-fire conditions. Conditions for surface fire spread are exacerbated, whereas conditions for crown fire spread are reduced. However, snags (standing dead trees) present unique fire behavior problems, principally as a source for, and recipient of, embers which start new fires ahead of the main fire.

Will the bark beetle outbreaks lead to larger or more severe fires?
Past experience regarding whether fires are naturally larger or smaller, or more or less severe, is anecdotal and inconclusive. Snags constitute a major safety hazard for firefighters. Snag mitigation concerns may reduce firefighter effectiveness, leading to larger fires.

Heavy downed logs slow fireline construction. Moreover, they are associated with extended burning, greater soil heating, sustained smoke production and extended fire mop-up, particularly in warmer, dryer forests. Increased resistance to control implies that fires will either grow larger or require more suppression resources.

Intense scientific interest in bark beetle-fire interactions is relatively recent and ongoing. It is clear that beetle infestations have a direct effect on wildfire potential, and that the degree of influence can be categorized by phases of the infestation: Are the attacked trees still green? Are there standing dead trees with red needles? Are there fallen dead trees that have lost all their needles?

In addition, given that operational fire models are not able to account for low fuel moisture, newly developed physics-based models are exploring how attack intensity and patterns, along with variable winds, influence fire spread. Since many of the scientific studies are not yet complete, research can inform, but the expert local knowledge of a fire suppression practitioner is needed to guide management.

Gaps in knowledge and understanding of fire risk and behavior in beetle-killed stands include the observable changes in fire behavior in beetle-killed stands and how can these observations be efficiently and accurately obtained (can these observations be used to further develop predictive models?); how fuel dynamics (i.e., spatial and temporal changes in fuels: mass, chemistry, moisture, and size distribution) change in beetle-killed stands; how flammability simulation models can be adequately parameterized using these observations; and , finally, the implications of insect and disease attacks on public and fire fighter safety.

For more detailed information on fire risk and behavior, see Appendix Six.

Appendices

Appendix One- Senator Udall's Request

MARK UDALL
COLORADO

SUITE SH-317
SENATE HART OFFICE BUILDING
WASHINGTON, DC 20510
(202) 224-5941

United States Senate
WASHINGTON, DC 20510

November 15, 2010

The Honorable Tom Vilsack
U.S. Department of Agriculture
1400 Independence Ave., SW
Washington, D.C. 20250-0003

Dear Secretary Vilsack:

As you know, we have been experiencing an unprecedented insect epidemic in the forests of Colorado and Wyoming. The vast scale of tree mortality brought on by the mountain pine beetle has affected over 3.5 million acres of National Forest Service land in Colorado and Wyoming over the past decade. When it finally runs its full course, it is estimated that the vast majority of mature lodgepole pine in these areas will have died.

We are now dealing with the aftereffects of dead trees that present a serious hazard to people and property when they eventually fall down, and can present decades of increased fire threats due to the accumulation of the dead, downed trees. We are also dealing with impacts to watersheds, power lines, ski areas, tourism, and many other facets of an epidemic of this scale.

As you also know, I have been working with my congressional colleagues to secure additional resources and legislative tools so that the Forest Service, the state and private property owners can reduce the hazards and threats posed by these dead trees.

I believe that much more can and should be done to address this epidemic and eventually help manage our forests so that they can be healthier and better able to withstand future stresses such as insect infestations. While I applaud the work of the Forest Service to address many of these concerns, I stand ready to do all that I can to help.

In that regard, I am writing to request that the U.S. Forest Service conducts a study or review of this epidemic—especially in the forests of Colorado and Wyoming—to highlight the lessons learned and the obstacles encountered in addressing and responding to it.

I understand that we are still experiencing and responding to this epidemic. However, I believe that now would be a good time to take stock and review what is working, what more needs to be done, and what additional tools may be needed. This seems especially timely, as it is my understanding that the mountain pine beetle, albeit a natural part of our forest ecosystems, is now spreading across our Western forests in similar epidemic proportions.

Specifically, I would suggest that this study examine the following issues (this is not intended to be an exhaustive list, but rather to identify the sorts of topics that I believe could be useful in responding to this and future epidemics):

- the preemptive actions taken—or that could have been taken—by the Forest Service to address this epidemic so as to reduce or mitigate its severity;

- the obstacles (such as fiscal, regulatory, legal, administrative, economic) that the Forest Service has encountered that may have hindered—and may continue to hinder—responses that could reduce wildfire and hazardous tree threats and promote healthier future forest conditions;

- the availability—or lack of availability—of any "emergency" authorities to allow the Forest Service to respond to this epidemic in an expeditious and responsible manner;

- the availability—or lack of availability—of resources and facilities (such as private timber extraction and milling capacity) external to the Forest Service that could help respond to the threats through tree removal and reuse;

- the administrative contracting mechanisms and whether these mechanisms are adequately flexible to respond to this epidemic given the low commercial value of the timber;

- any special issues related to the impacts to watersheds;

- any issues related to implementing policies and projects that will help improve natural forest regeneration; and

- the estimated costs associated with addressing the threats and impacts from this epidemic.

I believe an epidemic of this scale and scope can provide a useful learning experience to help address not only this incident in my region, but also help identify ways that we can better respond to future epidemics and in areas where the current one may eventually spread. In addition, it can help me in my continuing efforts to help the Forest Service better respond to this issue and promote healthy and safe forests for the enjoyment and benefit of the nation.

Thank you for your consideration of this request. Please feel free to contact my office if I can be of further help in initiating and conducting this study.

Sincerely,

Mark Udall

Mark Udall
United States Senator

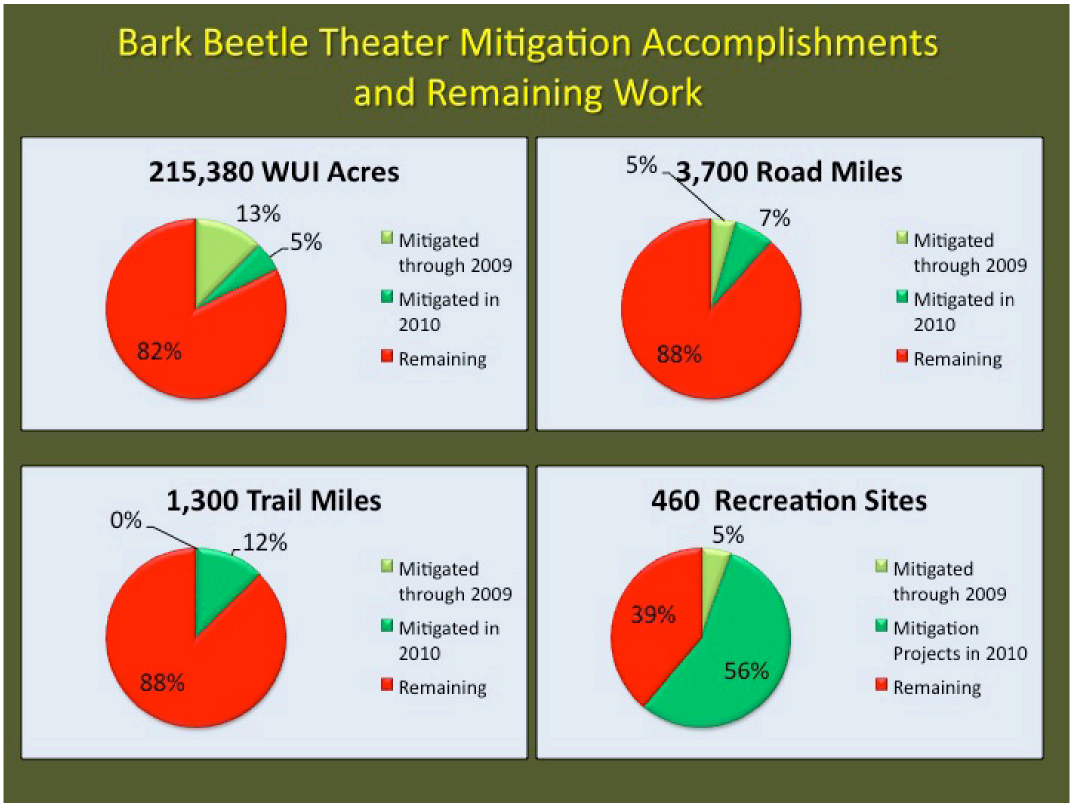
Appendix Two – Funding History of the Rocky Mountain Region (Region 2)

SPFH – Forest Health Federal Lands
SPS4 – Forest Health Federal Lands, National Fire Plan

	2003	2004	2005	2006	2007	2008	2009	2010
SPFH % USFS Omnibus	5%	3%	5%	4%	3%	5%	5%	4%
SPFH R2 $	$2,481,000	$1,693,000	$2,883,000	$2,109,000	$1,876,000	$2,656,000	$260,500	$2,327,000
SPS4 % USFS Omnibus	22%	31%	12%	10%	12%	10%	14%	15%
SPS4 R2 $	$1,492,000	$4,544,000	$1,824,000	$1,436,000	$1,775,000	$1,496,000	$2,490,000	$3,210,000
SPS5 % USFS Omnibus	12%	11%	9%	9%	14%	12%	13%	8%
SPS5 R2 $	$1,201,000	$1,111,000	$850,000	$850,000	$1,418,000	$1,176,000	$1,271,000	$ 897,000
NFVW % USFS Omnibus	6%	6%	6%	8%	7%	6%	7%	6%
NFVW R2 $	$11,079,00	$12,165,000	$11,799,000	$14,313,000	$12,116,000	$10,761,000	$11,928,000	$12,071,000
NFTM % USFS Omnibus	5%	6%	7%	8%	5%	5%	6%	6%
NFTM R2 $	$14,452,000	$16,388,000	$18,269,000	$21,447,000	$16,868,000	$17,351,000	$18,760,000	$19,974,000

SPS5 – Forest Health State Lands, National Fire Plan
NFVW – Vegetation and Watershed, Federal Land
NFTM – Timber Management, Federal Land
Omnibus – annual federal funding legislation

Appendix Three – Accomplishments and Remaining Work



Appendix Four—Forest Service Biomass Grants in the Rocky Mountain Region (Region 2)

American Reinvestment and Recovery Act Wood-to-Energy grants: Three grants were funded and awarded to upgrade and improve wood processing equipment.

- Colorado Springs Utilities: $250,000 for equipment that will facilitate wood chip co-firing at rates up to 20 percent in the Drake Power Plant (coal-fire).
- Boulder County Parks and Open Space: $250,000 for installation and refurbishment of wood-fired steam heat system at a county facility, and for equipment that will facilitate better handling of wood waste streams coming from the forest.
- Confluence Energy: $250,000 for wood processing equipment to facilitate conversion of beetle-killed wood into pellets for commercial and home heating use.

Forest Products Lab grants for 2009: Three companies in Colorado received funding for wood utilization grants.

- Intermountain Resources LLC (Montrose) received $250,000 for a chipper/grinder to increase efficiency in biomass utilization.
- Independent Logging (Alamosa) received $250,000 to expand mill operations and equipment.
- Rouge Resources (Steamboat Springs) received $250,000 for in-woods operations and milling equipment.

Forest Products Lab grant for 2010:

- West Range Reclamation received $350,000to purchase a log delimber/debarker and log loader for use in creating a product and market for residual biomass from the Front Range Long-Term Stewardship Contract.

Appendix Five—Impacts to Watersheds

Water supply in western North America is controlled primarily by snow accumulation and melt in forested headwater basins. Watershed health and function in the subalpine zone are controlled by complex relationships between climate, physiography, forest cover and land use. Recent impacts from widespread mountain pine beetle infestation are exerting a profound impact on forest cover, structure, and species composition. These impacts are driving changes in water quantity and quality --two important ecosystem services provided by federally managed forests. The expectation is the infestation will result in quantifiable changes in streamflow and water quality, as well as forest composition and structure.

While there is a desire to predict the effect of the beetle infestation on runoff quantity and quality, the complexity of watershed and hydrologic processes suggests that such predictions are premature and subject to considerable uncertainty. In addition to complexity of processes, inter-annual variability in meteorology, especially precipitation, makes detection of changes due to the infestation problematic. In the future, with longer statistical records, and studies using semi-deterministic models, there is a greater probability of detecting and quantifying the effects of the beetle infestation on streamflow and water quality.

The mountain pine bark beetle began to attack lodgepole pine at the long-term USFS watershed research site at the Fraser Experimental Forest in 2002. By 2007, bark beetles had killed 50% to > 80% of the overstory pine in Fraser's research watersheds. The hydrologic, climatic, biogeochemical and vegetation records available at the Fraser Experimental Forest provide a unique opportunity to quantify the impacts of this widespread and poorly-understood disturbance. The consequences of the current MPB outbreak will result from a combination of short and longer-term changes in hydrologic and biogeochemical processes that control the delivery of clean water from forested catchments. In general terms, canopy mortality from bark beetles will influence watershed processes in ways similar to logging or stand-replacing fire. However, the relevance of beetle outbreaks to downstream users, associated with the magnitude, timing and duration of watershed change are likely to differ dramatically from logging or fires

Stream Water Quality

Water flowing from most undisturbed lodgepole pine ecosystems has a low nutrient content because of the combination of f of low soil nutrient supply and high nitrogen (N) demand and retention by vegetation and soil microbes (Fahey et al. 1985; Knight et al. 1985; Stottlemyer et al. 1997). Mortality of the forest overstory is sure to lessen N demand, but it is unclear to what extent this will result in measurable changes in nutrient transport to stream water. In fact, change in stream nutrients following bark beetles may signal ecosystem response to disturbance rather than a symptom of impaired water quality.

During the first six years following the onset of bark beetle activity and in basins where bark beetles killed more than 70% of the overstory, spring and late fall stream water nitrate were elevated compared to pre-outbreak concentrations Figure 1). Since few physical changes have altered forest structure at this point, the higher stream water nitrate concentration and export are the likely result of decreased nutrient demand following mortality of overstory pine. However, the increase in concentration and export in the years following the MPB outbreak were small and do not pose a risk to human or stream health. Indeed the changes from extensive MPB-related canopy mortality were less than the scale of natural seasonal fluctuations and they were < 2% the annual N input in precipitation.

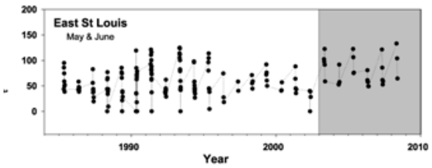


Figure 1. Stream nitrate concentrations at the USDA Forest Service, Fraser Experimental Forest prior to and during (shaded area) the current mountain pine beetle outbreak.

These findings from the long-term Fraser watershed record are substantiated by independent monitoring efforts led by the University of Colorado and the US Geological Survey that also find measureable but small changes in stream water nutrients following bark beetles (Clow et al. 2011; Lewis et al. 2011).

Stream Water Quantity

Trees impact runoff by returning water to the atmosphere through two important mechanisms. First, trees use soil water during the growing season through transpiration, which moves water from the soil matrix back to the atmosphere. Transpiration may account for losses of up to 50% of the annual precipitation in subalpine basins (Leaf, 1975; Kaufman, 1985). Second, tree canopies in snow-dominated regions intercept snowfall, a portion of which then sublimates directly back to the atmosphere before reaching the snowpack. Canopies may intercept up to 60% of the annual snowfall (Hedstrom and Pomeroy, 1998; Storck and Lettenmaier, 1999), and 20% to 50% of the annual snowfall may sublimate directly back to the atmosphere without producing runoff (Troendle and Meiman, 1986; Pomeroy and Gray, 1995; Montesi et al., 2004) The magnitude of beetle related changes in transpiration, interception, and runoff, will depend on three things – the e amount of mortality in the stand, a, the species composition of the remaining overstory, and finally basin physiography.

Research at FEF shows that transpiration declines rapidly following a successful beetle attack and that tree water use stops completely by the beginning of the following growing season. As part of an experiment that implicated beetle induced blue stain fungi as the primary cause of tree mortality following beetle attack, researchers showed that transpiration is affected just seven to thirteen days after beetles first infect a tree (Figure 2). By the end of the first growing season, "beetle- attacked" trees used 50% less water than trees unaffected by beetles and blue-stain fungi. This rapid decrease in tree water use means that residual vegetation will have greater access to soil water and that more water will potentially be available for runoff. The magnitude of these responses remains uncertain but ongoing studies at FEF are quantifying changes in tree and stand water use over a range of site conditions.

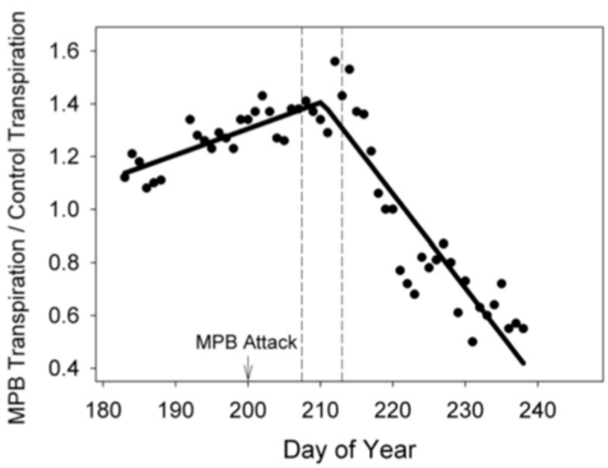


Figure 2. Change in tree water use for mountain pine beetle attacked trees (MPB Transpiration) versus trees not affected by beetles or blue-stain fungi (Control Transpiration). Dashed vertical lines indicate 95% confidence intervals around the date that a significant decrease in transpiration occurred.

Change in forest structure following forest disturbance has the potential to significantly alter snow interception during the winter months. Following mountain pine beetle infestations, lodgepole pine trees killed by beetles lose their needles within three to five years and fall to the ground five to ten years later (Mitchell and Preisler, 1998). Reduced leaf area and openings created by falling trees reduces snow interception and allows more snowfall to reach the ground where it accumulates until spring melt and subsequent runoff. Data from forest inventory plots at FEF show tree basal area declined by 50% in managed basins as a result of the current mountain pine beetle infestation. However, because Engelmann spruce and subalpine fir have more leaf area per unit stem diameter, leaf area losses from the same basins averaged only 24% (Figure 3).

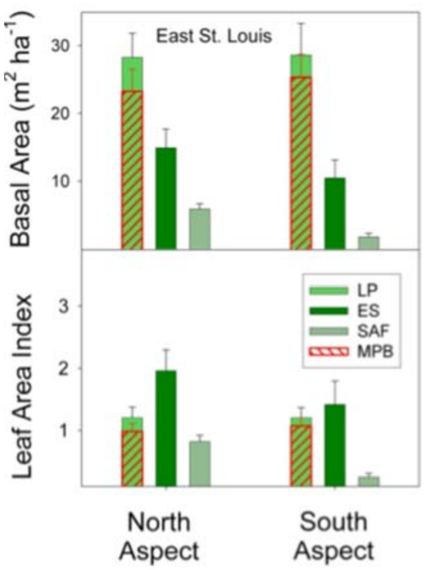


Figure 3. Lodgepole pine Basal area and leaf area losses due to mountain pine beetle (MPB) in the East Saint Louis Creek watershed at Fraser Experimental Forest. (LP = Lodgepole Pine, ES = Engelmann Spruce, SAF = subalpine fir).

A complex relationship exists between changes in interception and transpiration and streamflow. Other complicating factors include forest structure, species composition, local meteorology, and basin physiography (slope, aspect, elevation, etc.). Previous management studies provide general insights to potential changes in streamflow, because there are important similarities between harvest through management and tree mortality from beetle infestation. There are decades of research in the subalpine zone that show that tree removal results in increased runoff (e.g. Wilm and Dunford, 1948; Van Haveren, 1981; Bosch and Hewlett, 1982; Troendle and King, 1985; Troendle and Meiman, 1986; Troendle and King, 1987). In general, increased streamflow will result from harvesting and the magnitude of the increase will be proportional to the basal area removed. At the Fraser Experimental Forest, a 50% removal of the timber from the Fool Creek basin resulted in a 40% increase in flow over the first 30 years of post-treatment record (Troendle and King, 1985). A a 29% increase has been recorded over a 50 year post-treatment period (Elder, unpublished data).

There are, however, complicating factors that make simple prediction of increased flows subject to considerable uncertainty. In order to detect the change in flow, there must be a minimum mean annual snowfall of about 800 mm (water equivalent). Too much basal area removal may result in snowpack loss due to redistribution and sublimation. Differences between harvest methods and impacts versus beetle-related mortality further cloud our ability to accurately predict changes in streamflow resulting from the current infestation. Harvesting typically removes the mature timber and the understory over a short period of time, so impacts are immediate and profound. Beetle-killed mature stands often leave a healthy understory behind. This understory still consumes water through summertime transpiration and still suffers interception losses of snowfall. There is also a multi-year lag between tree infestation and eventual tree removal. The tree may maintain a green canopy for up to a year, followed by red needles, needle loss, branch loss and eventual tree fall. This progression may last several years and will produce a slow change in the tree's ability to intercept snow. At the stand or basin level, this progression will result in a slow change in sublimation loss and runoff generation. At the same time, the understory water consumption may be increasing through transpiration, thus offsetting water savings from reduced snowfall interception. There are few studies that have quantified streamflow changes following MPB infestation (Love, 1955; Bethlamy, 1975; Potts, 1984), and their results suggest variable, but similar results to some effects of forest harvesting. However, it is important to note that the current MPB outbreak is unprecedented in magnitude and extent, a there will likely be significant departures from both previous beetle infestations and harvests.

In addition to the complexity of processes described above, inter-annual variability in meteorology, especially precipitation, makes detection of changes due to the infestation problematic. Figure 4 shows a graph of a relationship between a heavily infested basin (East St Louis), and a control basin (Brush Creek) that had little beetle presence for the period graphed. The years following the infestation in East St. Louis Creek (2003) are shown with different symbols (2004-2007). Note that the values all fall well within the 95% confidence interval that indicates no significant change from the previous relationship.

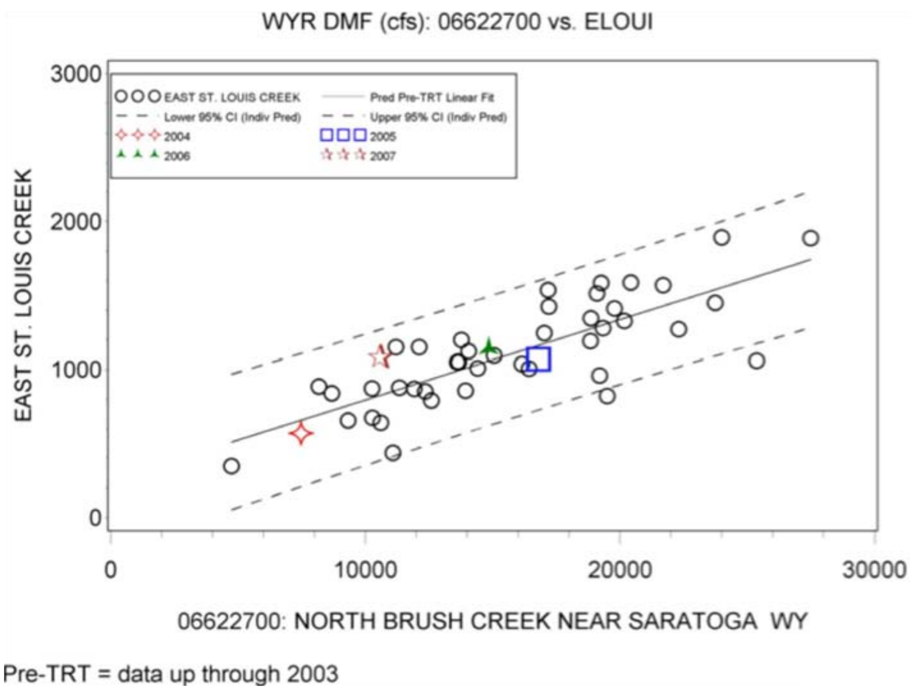


Figure 4. Predicted annual flow from East St. Louis creek from observed flow in Brush Creek. Mountain pine beetle infestation was first observed in 2003 in the East St. Louis Creek watershed. Brush Creek was not significantly affected through the period shown. The 95% confidence limits were calculated based on the pre-infestation record.

Appendix Six—Fire Risk and Behavior

Bark beetle outbreaks can result in significant changes to forest stand structure and thus, to fire risks and fire behavior.

Factors shaping fire risk and behavior

Regardless of beetle activity, fire risk and behavior are shaped by:

- The amount, type and condition of vegetation, or fuels, on site,
- The fuels' dryness and exposure to sun and wind, and
- Topography, elevation and weather.

The presence of beetle activity adds additional variables to the challenges of predicting and managing fire risks based on:

- Species of beetle,
- Intensity and rate of tree mortality, and
- Time since the mortality.

Bark beetle mortality modifies the canopy fuels, surface fuels such as grasses, forbs, shrubs, and downed-woody material, and ground fuels of dead litter and humus. Localized weather conditions such as increased sun, wind, and rain or snow are also modified in proportion to the number of trees killed. These changes are directly linked to changes in the forest water balance which are known to affect fuel moisture relationships, and therefore fire behavior.

Intense scientific interest in bark beetle-fire interactions is relatively recent and is ongoing. It is clear that beetle infestations have a direct effect on wildfire potential, and that the degree of influence can be categorized by the phase of the infestation: attacked green, attacked yellow, standing dead red, standing/fallen dead grey, and fallen gray/new green.

Since much of the scientific studies are not yet complete, research can inform, but expert local knowledge is needed to guide management.

Summary of research and findings pertaining to the relationship between beetle outbreaks and fire risk and behavior

Will the beetle outbreaks lead to more frequent fires in impacted watersheds?

- Basic fire science principles suggest that opening the forest should lead to dryer surface fuels, more sunshine, and more wind which will favor increased ignitions and early fire spread resulting in more fires requiring management.

Will the bark beetle outbreaks lead to more or less extreme fire behavior?

- Past experience is largely anecdotal but decades of firefighter wisdom suggest fires will be more intense for an indeterminate amount of time following attack.
- Current operational fire behavior models were developed for "normal," healthy forests and do not include variables that address the phases of beetle attacks: attacked green, attacked yellow, dead-red.

- The physics and chemistry of fire and fire weather/climatology suggest all fire behavior measures should increase during the attack phase.
- Following attack forest composition and structure are fundamentally altered. Fire behavior can be expected to decline somewhat in the post attack phase but not return to pre-fire conditions. Conditions for surface fire spread are improved whereas conditions for crown fire spread are reduced. However, snags, standing dead trees, present unique fire behavior problems, principally as a source for, and recipient of, embers which start new fires ahead of the main fire.

Will the bark beetle outbreaks lead to larger or more severe fires?

- Past experience regarding whether fires are naturally larger/smaller or more/less severe is anecdotal and inconclusive.
- Snags constitute a major safety hazard for fire fighters. Safety concerns will reduce fire fighter effectiveness leading to larger fires.
- Heavy downed logs slow fireline construction. The increased resistance to control implies fires will either grow larger or require more suppression resources.
- Heavy downed logs are associated with extended burning, greater soil heating, sustained smoke production and extended fire mop-up, particularly in warmer-dryer forests.

Additional Information

The specifics of how beetle outbreaks affect the likelihood that a fire will start is poorly understood and a topic of current research. The increased presence of fine, dry surface fuels implies greater number of successful ignitions. The degree to which mortality affects fire potential depends on the stand structure[1] prior to the bark beetle outbreak, and the level of stand mortality. Owing to the complexity of the number of sites, beetle outbreak dynamics, and scientific limitations it is only possible to describe expected future fire potential in a general way. Management decisions should be based on local expert knowledge cognizant of the context for the decision. Scientific limitations are less critical in vegetation management planning decisions than in real-time fire management actions.

Phase I – Attacked **Green**

Prior to beetle attack foliage is green and moisture contents are 'normal,' around 100 to 110 percent by weight. Shortly after successful beetle attack, within one- or two-weeks, fungal associates of the beetles disrupt sap flow in the tree limiting the normal cycle of nighttime replenishment of canopy moisture. Once attacked foliar moisture drops slightly and needle chemistry changes (Jolly and Parsons, in progress and Gibson and Negron, 2009). At least by the start of the first full year following successful attack, trees lose the physiological capacity to limit moisture loss, needles die and rapidly dry. Evidence suggests ignition time, the amount of heat and time required to ignite a fuel, decreases even before symptoms are visible.

[1] Vegetation Structure: The quantity, distribution, and horizontal and vertical arrangement of live and dead trees, understory vegetation, woody debris, litter and humus within a given area.

Condition	Color	Foliar Moisture Content (%)	Ignition Time (sec.)
Unattacked	Green	100 - 110	30 - 42
Attacked (Initial)	Green	90 - 100	18 - 32
Attacked (Dying)	Yellow to buff	90 to 50 (rapid decline)	15 - 28
Dead	Red	10 - 19	11 - 15
Snag	Grey	n.a. (no foliage)	n.a.

Phases II and III – Attacked **Yellow** and Standing Dead **Red**

Initially ignition time drops by about one-third and crown fire potential increases somewhat. Once foliage transitions to visibly yellowed needle moisture content is half that of normal foliage, with a comparable reduction in ignition time. The decrease in foliar moisture content effectively reduces the crown base height of a tree (Keyes 2006). Thus, fires can more easily transition from a surface fire to a crown fire at lower flame lengths and fireline intensity (Keyes 2006, Gibson and Negron 2009). The corresponding increase in fire intensity and spotting implies that firefighter safety zones need to be larger and defensible space around infrastructure and homes (home ignition zone) (Cohen 2000) needs to be wider.

Changes in fire behavior depend on the severity and sequence of beetle attack. For reasons not fully understood some attacks are relatively uniform over large areas and most trees are attacked over a short time. In contrast in other areas beetles attack and kill trees to varying degrees over three to seven years. The severity and sequence determine how much live vs. dead fuel is in the forest canopy at any point during the outbreak, and thus the fire potential.

Phase IV – Standing and Fallen **Grey**

Once the dead needles fall from trees fuel and fire dynamics change. Initially more soil moisture is available to keep ground fuels (humus and rotten logs) and surface vegetation/fuels moist. While more sunlight increases the drying rate of dead surface fuels the understory fuels beneath more open forests are also more exposed to rainfall and humidity events during the fire season. It is also reasonable to expect that live understory vegetation would experience less competition for water after large trees are killed, which could alter their growth, development, and susceptibility to drought, all of which affect their flammability. Thus, the combined effect on fire potential must be assessed on a site by site basis.

Snags, standing dead trees, have long been known to present special fire behavior problems. Snags are both the source of embers starting spot fires ahead of the main fire or across fire lines, and are themselves receptive to embers that land on them. Fire intensity can be expected to be less during the snag phase as compared to the red-dead phase. In addition, snags pose extreme fire fighter safety issues. Falling and rolling snags hamper day-time fire fighting and preclude many nighttime operations. Snags on both sides of the fireline pose hazards not only from falling but also spotting. Recent Canadian experience indicates fire lines may need to be twice as wide to protect firefighters on the lines.

Phase V – Fallen **Grey** and New **Green**

Once the majority of snags have fallen, fire behavior will vary depending on the new forest structure, and should be assessed accordingly. The immature trees reforesting beetle-killed areas typically have foliage close to the ground and are thus susceptible to crowning and spotting. The downed logs present three problems. First, their contribution to fire intensity is not well understood nor represented in current fire behavior models. This is the subject of current research. Second, fireline construction rates are reduced to as little as one-fourth depending on the density of downed logs. Third, as logs age they become increasing receptive to ignition by embers. The effect of heavy deadwood is to increase resistance to control which implies a trade-off between increasing suppression forces or accepting larger fires.

Research Opportunities and Needs:

- Current operational fire behavior models were developed for “normal,” healthy forests. The models are not valid to address the beetle attack phases of attacked green, attacked yellow, dead-red.
- Current crown fire prediction models are not valid in recently beetle-killed forests.

Bibliography

Bark Beetles and Forests, Creating a Resilient Forest

Bentz B, Nordhaus H, Allen CD, Ayres M, Berg E, Carroll A, Hansen M, Hicke J, Joyce L, Logan J, MacFarlane W, MacMahon J, Munson S, Negrón J, Paine T, Powell J, Raffa K, Régnière J, Reid M, Romme W, Seybold S, Six D, Tomback D, Vandygriff J, Veblen T, White M, Witcosky J, Wood D (2009) Bark beetle outbreaks in western North America: Causes and consequences. University of Utah Press, ISBN 978-0-87480965-7, 42 p.

Fettig C, Klepzig KD, Billings RF, Munson AS, Nebeker TE, Negrón J, Nowak J (2007) Review: The effectiveness of vegetation management practices for prevention and control of bark beetle infestations in coniferous forests of the western and southern United States. Forest Ecology and Management 238: 24-53.

Negrón, JF, Bentz BJ, Fettig CJ, Gillette N, Hansen EM, Hayes JL., Kelsey RG, Lundquist JE, Lynch AM, Progar RA, Seybold SJ (2008) US Forest Service bark beetle research in the western United States: Looking toward the future. Journal of Forestry 106: 325-331.

Raffa, KF, Aukema B, Bentz B, Carroll A, Erbilgin N, Herms D, Hicke J, Hofstetter R, Katovich BS, Lindgren J, Logan J, Mattson W, Munson AS, Robison DJ, Six DL, Tobin P, Townsend P, Wallin K (2009) A literal use of 'forest health" safeguards against misuse and misapplication. Journal of Forestry 5: 276-277.

Gibson K, Skor K, Kegley S, Jorgensen C, Smith S, Witcosky J (2008) Mountain pine beetle impacts in high-elevation and five-needle pines: current trends and challenges. USDA Forest Service, Forest Health Protection, R1-08-020

Timber Harvest and Historical Use Patterns

Wroten, 1955

Biomass

Price, JI, D.W. MCCollum and R.P Berrens (2010). Insect infestation and residential property values: A hedonic analysis of the mountain pine beetle epidemic. Forest Policy and Economics. 12. 415-422.

Jones, Greg; Loeffler, Dan; Calkin, David; Chung, Woodam. 2010. Forest treatment residues for thermal energy compared with disposal by onsite burning: Emissions and energy return. Biomass and Bioenergy 34(2010): 737-746.

Jones, Greg; Loeffler, Dan; Butler, Edward; Chung, Woodam; Hummel, Susan. 2009. Emissions, energy return and economics from utilizing forest residues for thermal energy compared to onsite pile burning. In Proceedings of the 2009 National Silvicultural Workshop, June 15-18, Boise, ID, USDA Forest Service Proceedings RMRS-P-61, pp. 145-158.

The Role of Natural Regeneration

Collins BJ, Rhoades CC, Hubbard RM, Battaglia MA (under revision) Tree regeneration and future stand development after bark beetle infestation and harvesting in Colorado lodgepole pine stands. Forest Ecology and Management.

Collins BJ, Rhoades CC, Underhill J, Hubbard RM (2010) Post-harvest seedling recruitment following mountain pine beetle infestation of Colorado lodgepole pine stands: A comparison using historic survey records. Can. J. For. Res. 40: 2452-2456.

Rocca ME, Romme WH (2009) Beetle-infested forests are not "destroyed." Frontiers in Ecology and the Environment 7(2): 71-72.

Impacts to Watersheds

Bethlamy, N. 1976. A Colorado episode: beetle outbreak, ghost forests, more streamflow. Northwest Science. 49: 95-105.

Bosch, J.M., and J.D. Hewlett. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. Journal of Hydrology. 55: 3-23.

Clow, D.W., C.C. Rhoades, J. S. Briggs, and M. Caldwell. Responses of soil and water chemistry to Mountain Pine Beetle induced tree mortality in Grand County, Colorado (in preparation manuscript).

Elder, K. 2009. Fool Creek Watershed study: 50 Years later. Unpublished Report, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Fahey, T.J., J.B. Yavitt, J.A. Pearson, and D.H. Knight. 1985. The nitrogen cycle in lodgepole pine forests, southeastern Wyoming. Biogeochemistry. 1: 257-275.

Hedstrom, N. and J. Pomeroy, 1998. Measurements and modeling of snow interception in the boreal forest. Hydrological Processes. 12: 1611-1625.

Kaufman, M. 1985. Annual transpiration in subalpine forests: large differences among four tree species. Forest Ecology and Management. 13: 235-246.

Knight, D.H., T.J. Fahey, and S.W. Running. 1985. Water and nutrient outflow from contrasting lodgepole pine forests in Wyoming. Ecological Monographs. 55: 29-48.

Leaf, C. 1975. Watershed management in the Rocky Mountain subalpine zone: the status of our knowledge. USDA Rocky Mountain Forest and Range Experiment Station, Research Paper RM-137.

Lewis, Jr., W.M., J.H. McCutchan, Jr., L. A. Cooper, T.M. Detmer, C.C. Rhoades, D.W. Clow, J.S. Briggs, and J.D. Stednick. Biogeochemistry of beetle kill: Explaining a weak nitrate response (in preparation manuscript).

Love, L.D. 1955. The effect on streamflow of the killing of spruce and pine by the Engelmann spruce beetle. Transactions of the American Geophysical Union. 36: 113-118.

Mitchell, R. G. and H. K. Preisler. 1998. Fall rate of lodgepole pine killed by the mountain pine beetle in central Oregon. Western Journal of Applied Forestry. 13: 23-26.

Montesi, J., K. Elder, R.A. Schmidt, and R.E. Davis. 2004. Sublimation of intercepted snow within a subalpine forest canopy at two elevations. Journal of Hydrometeorology. 5: 763-773.

Pomeroy, J. and D.M. Gray, 1995. Snowcover accumulation, relocation and management. NHRI Science Report 7, National Hydrology Research Institute, Environment Canada. 134 pp.

Potts, D. 1984. Hydrological effects of a large-scale mountain pine beetle (Dendroctonus ponderosae Hopkins) outbreak. Water Resources Bulletin. 20: 373-377.

Storck, P and D. Lettenmaier. 1999. Predicting the effect of a forest canopy on ground snowpack accumulation and ablation in maritime climates. Proceedings of the 63rd Western Snow Conference. Lake Tahoe, CA. Western Snow Conference, 1-12.

Stottlemyer, R., C.A. Troendle, and D. Markowitz. 1997. Change in snowpack, soil water, and streamwater chemistry with elevation during 1990, Fraser Experimental Forest, Colorado. Journal of Hydrology. 195: 114-136.

Troendle, C., and R. King. 1985. The effect of timber harvest on the Fool Creek Watershed, 30 years later. Water Resources Research, 21(12): 1915-1922.

Troendle, C., and R. King. 1987. The effect of partial and clearcutting on streamflow at Deadhorse Creek, Colorado. Journal of Hydrology, 90: 145-157.

Troendle, C. and J. Meiman. 1986. The effect of patch clear-cutting on the water balance of a subalpine forest slope. Proceedings of the 54th Western Snow Conference. Phoenix, AZ. Western Snow Conference, 93-100.

Van Haveren, B. 1981. Wagon Wheel Gap watershed experiment revisited. Proceedings of the 49th Western Snow Conference. St. George, UT. Western Snow Conference, 131-138.

Wilm, H.G., and E.G. Dunford. 1948. Effect of timber cutting on water available for streamflow from a lodgepole pine forest. USDA Technical Bulletin 968, Washington, DC, 43 pp.

Fire Risk and Behavior

Bentz B, Nordhaus H, Allen CD, Ayres M, Berg E, Carroll A, Hansen M, Hicke M, Hicke J, Joyce L, Logan j, Macfarlane W, MacMahon J, Munson S, Negrón J, Paine T, Powell J, Raffa K, Regniere J, Reid M, Romme W, Seybold S, Six D, Tomback D, Vandygriff J, Veblen T, White M, Witcosky J, Wood D (2009) Bark beetle outbreaks in western North America: Causes and consequences. University of Utah Press, ISBN 978-0-87480965-7, 42 p.

Cohen, J. D. (2000). Preventing disaster, home ignitability in the wildland-urban interface. Journal of Forestry 98(3): 15-21.

Cruz, M. G. and M. E. Alexander (2010). Assessing crown fire potential in coniferous forests of western North America: a critique of current approaches and recent simulation studies. International Journal of Wildland Fire 19(4): 377-398.

Deeming, J. E., R. E. Burgan, et al. (1977). The National Fire Danger Rating System – (1978). Ogden, Utah, US Forest Service Intermountain Forest and Range Experiment Station: INT-GTR-39 63p.

Fahnestock, G. R. (1970). Two Keys for Appraising Forest Fire Fuels. US Forest Service, Pacific Northwest Forest and Range Experiment Station: PNW-RP-99. 26p.

Fettig c, Klepzig KD, Billings RF, Munson AS, Nebeker TE, Negrón J, Nowak J (2007) Review: The effectiveness of vegetation management practices for prevention and control of bark beetle infestations in confierous forests of western and southern United States. Forest Ecology and Management 238: 24-53.

Finney, M. A. (1998). FARSITE: Fire Area Simulator -- model development and evaluation. US Forest Service Rocky Mountain Research Station: RMRS-RP-4. 47p.

Finney, M.A. (2002). Fire growth using minimum travel time methods. Canadian Journal of Forest Research 32: 1420-1424.

Finney, M.A. (2006). An overview of FlamMap Modeling Capabilities. In: Andrews, Patricia L.; Butler, Bret W., comps. 2006. Fuels Management-How to Measure Success: Conference Proceedings. 28-30 March 2006; Portland, OR..U.S Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-41. p. 213-220.

Finney, M. A. (2007). A computational method for optimising fuel treatment locations. International Journal of Wildland Fire 16(6): 702-711.

Gibson, K. and Negron, J.F. (2009). Fire and bark beetle interactions. In: Hayes, J.L.;Lundquist, J.E., comps. The Western Bark Beetle Research Group: A Unique collaboration with Forest Health Protection: Proceedings of a symposium at the 2007 Society of American Foresters Conference. US Forest Service, Pacific Northwest Research Station: PNW-GTR-784. 51-70.

Heinsch, F. A.; Andrews, P.L. (2010). BehavePlus fire modeling system, version 5.0: Design and Features. US Forest Service, Rocky Mountain Research Station. RMRS-GTR-249. 111 p.

Keyes, C.R. (2006). Role of foliar moisture content in the silvicultural management of forest fuels. Western Journal of Applied Forestry 21: 228-231.

Klutsch, J.G., Negron, J.F., Costello, S.L., Rhoades, C.C., West, D.R., Popp, J., and Caissie, R. 2009. Stand characteristics and downed woody debris accumulations associated with a mountain pine beetle (Dendroctonus ponderosae Hopkins) outbreak in Colorado. For. Ecol. Manage. 258: 641–649.

Klutsch, J.G., M.A. Battaglia, D.R. West, S.L. Costello, and J.F. Negrón. Evaluating potential fire behavior in lodgepole pine-dominated forests after a mountain pine beetle outbreak in north-central Colorado. In Press, Western Journal of Applied Forestry.

Klutsch, J.G. 2008. Fuel and stand characteristics in ponderosa pine infested with mountain pine beetle, Ips spp., and southwestern dwarf mistletoe in Colorado's Northern Front Range. 2008. M.S. Thesis, Bioagricultural Sciences and Pest Management Department, Colorado State University and Rocky Mountain Research Station.

McArthur, A. G. (1966). Weather and grassland fire behaviour. Department of National Development, Forestry and timber, Bureau, Canberra, Australia, Commonwealth of Australia. Leaflet 100 23p.

Neary, D. G.; Ryan, K. C.; DeBano, L. F. (2005). Wildland fire in ecosystems: Effects of fire on soils and water. US Forest Service, Rocky Mountain Research Station, RMRS-GTR-42-vol.4. 250 p.

Negrón JF, Bentz BJ, Fettig CJ, Gillette N, Hansen EM, Hayes JL, Kelsey RG, Lundquist JE, Lynch AM, Progar RA, Seybold SJ (2008) US Forest Service bark beetle research in the western United States: Looking toward the future. Journal of Forestry 106: 325-331.

Raffa, KF, Aukema B, Bentz B, Carroll A, Erbligin N, Herms D, Hicke J, Hofsteter R, Katovich BS, Lindgren J, Logan J, Mattson W, Munson AS, Robinson DJ, Six DL, Tobin P, Townsend P, Wallin K (2009) A literal use of 'forest health' safeguards against misuse and misapplication. Journal of Forestry 5: 276-277.

Rothermel, R. C. (1972). A mathematical model for predicting fire spread in wildland fuels. USDA Forest Service, Intermountain Forest and Range Experiment Station: INT-RP-115 40p.

Ryan, K. C. (2002). Dynamic interactions between forest structure and fire behavior in boreal ecosystems. Silva Fennica 36(1): 13-39.

Sandberg, David V.; Ottmar, Roger D.; Peterson, Janice L.; Core, John. 2002. Wildland fire on ecosystems: effects of fire on air. USDA Forest Service, Rocky Mountain Research Station. RMRS-GTR-42-vol. 5. 79 p.

Scott, J. H.; Reinhardt, E. D. (2001). Assessing crown fire potential by linking models of surface and crown fire behavior. USDA Forest Service, Rocky Mountain Research Station: RMRS-RP-29 59 p.

Stocks, B. J.; Lawson, B. D.; Alexander, M. E.; Van Wagner, C .E.; McAlpine, R. S.; Lynham, T. J.; Dube, D. E. 1989. The Canadian forest fire danger rating system: an overview. The Forestry Chronicle. 65(4): 258-265.

van Wagner, C. E. (1977). Conditions for the start and spread of crown fire. Canadian Journal of Forest Research 7: 23-34.

West, D.R., 2010. Mountain pine beetle-caused lodgepole pine mortality from the 1980's and subsequent fire occurrence In Colorado. M.S. Thesis, Bioagricultural Sciences and Pest Management Department, Colorado State University and Rocky Mountain Research Station.