



Trees impacted by mountain pine beetle. Credit: www.bugwood.org

Beetles and Severe Fire: Who's on First? A Century of Disturbance in Colorado's Subalpine Forests

Summary

Forests have evolved with and depend on natural cycles of wildfire, insect outbreaks, disease, and extreme weather for periodic rejuvenation. The subalpine forests of northwestern Colorado experienced an unusual sequence of disturbances in succession over the past 125 years. Severe wildfires in 2002 were preceded by stand-replacing fires a century before. These were followed by a record setting wind blowdown, subsequent salvage logging, and two separate bark beetle infestations. This study by University of Colorado researchers was the first to collectively analyze how a century of disturbances interacted with each other to shape ecosystem patterns and processes with regard to fire risk in this forest type. The project evaluated the extent and severity of the wildfires that took place in northwestern Colorado during the extreme drought of 2002 in relationship to the disturbances that took place during the five years prior to the fires, and to the stand-replacing fires of the late 19th century. Many of the findings were quite unexpected. The most surprising result was that neither bark beetle infestation nor salvage logging had detectable effects on fire severity or extent. Increased risk of fire was attributed to drought.

Key Findings

- Fire extent and severity in Colorado subalpine forests are controlled by different variables.
- Fire severity, even during extreme drought, was strongly influenced by pre-fire conditions, especially the legacies of stand-replacing fires and where present, blowdown.
- Pre-fire conditions had little influence on fire extent, with the exception of previous stand-replacing fires.
- Recent beetle outbreak and salvage logging that took place after blowdown had no detectable effect on fire severity or extent.

Disturbances: Take one for the team

Bark beetle infestations, a record setting wind blowdown and stand-replacing fires—the disturbance history of the last century in northwestern Colorado’s subalpine forests reads like a playbook for a very long game: The Elements vs. The Trees. But as destructive as it all sounds, these events aren’t necessarily harmful for forests. Most forests have evolved with natural cycles of wildfire, disease, insect infestations, flooding, avalanches, and windstorms. Periodic disturbances leave a footprint of altered stand structure, composition, density and age class that refresh the life cycle of the forest to varying degrees, depending on their intensity and frequency. So even though disturbances are often perceived as harmful, they improve the score for the forest in the long run.

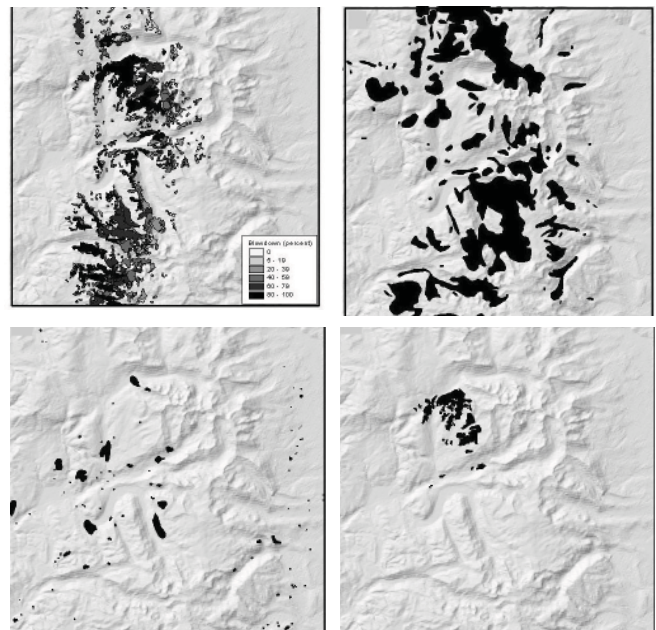
A disturbance is defined as a discrete event in time that has ecological effects on either the biological or physical environment that changes the structure, composition or function of an ecosystem. Changes brought by human management such as salvage logging and timber harvest are considered disturbances as well. Sometimes changes brought by a disturbance shape the spread, severity and effects of disturbances that follow, allowing for good prediction of the effects of subsequent disturbances. This influence is thought to weaken however, as the intensity of subsequent disturbances grows stronger, reducing the ability to predict how one disturbance might shape the effects of the next.

The degree of change created by a disturbance can also be influenced by the condition of a forest at the time of the disturbance event. This includes stand ages, proportions of live and dead biomass, and dominance of different tree species. These elements often reflect the time since the last major disturbance came through. In turn, they may influence the severity or extent of subsequent disturbances such as blowdown, insect outbreak and fire.

This research examined the idea that the history of previous disturbances, both those that have occurred in the past few years and those dating from a century or more ago, have important consequences for the occurrence, spread and severity of subsequent disturbances.

Between 1997 and 2002 extensive areas of subalpine forests in northwestern Colorado were affected by an extensive blowdown of trees, bark beetle outbreaks (spruce beetle and mountain pine beetle) and subsequent salvage logging. Some of these stands were also affected by severe fires in the late 19th century. The severe drought of 2002

brought more wildfires to the region. The Hinman and Burn Ridge fires in the Routt National Forest (RNF) combined to burn over 31,000 acres. Some of this area had been impacted by the blowdown, and was in the midst of a beetle outbreak when the fires occurred. The Big Fish Lake fire burned in the Flat Tops Wilderness Area of the White River National Forest (WRNF), where stand-replacing fires had occurred a century before and a severe beetle outbreak had caused widespread tree mortality in the 1940s. This seemingly relentless matrix of disturbances—within the context of a warmer, drier climate—highlighted some questions about the compounding influences of different disturbances on each other, and on the extent and severity of subsequent wildfire.



Clockwise from top left, maps showing the extent and severity of 1997 Route Divide Blowdown within study area; the extent of spruce beetle outbreaks in 2002; the extent of salvage logging 1997–2002; the extent of mountain pine beetle outbreaks in 2002.

For a group of University of Colorado scientists with a background in disturbance ecology and wildfire, the relatively recent and rapid occurrence of these otherwise infrequent disturbances provided an uncommon opportunity to find some answers. It has long been recognized that different types of disturbances can potentially interact and that the results can be surprising. But there have been few studies that quantitatively show how the extent of a

previous disturbance such as bark beetle outbreak affects the extent or severity of subsequent disturbances such as fire, or vice-versa. Geography Department researchers Dominik Kulakowski, Christof Bigler and Professor Thomas Veblen took advantage of the unique situation in Colorado to help fill the void. They focused on the interactions between the disturbance history of the area, the spread and severity of the 2002 fires, and the most recent stand-replacing fires which occurred some 100 to 125 years before.

The findings of their project, funded by the Joint Fire Science Program and the National Science Foundation, revealed “Nothing but surprises,” according to Kulakowski. The results challenge long-held assumptions about beetle infestation and fire severity in this forest type. In particular, the research found that the assumed link between insect outbreak and subsequent forest fire may be incorrect, or so small as to be inconsequential. Instead, the evidence pointed to drought and warming temperatures as the essential conditions for both beetle infestation and severe fire.

Northwest Colorado

Outbreaks of spruce beetles are often triggered by blowdown or by logging that leaves slash on the ground. The Routt Divide Blowdown may have triggered the current spruce beetle outbreak. The millions of large dead spruce provided an unprecedented feast and an exceptional, protected habitat for the insects. Because the trees were piled on the ground, the insects were sheltered from wind and insulated from the cold by snow cover, so the population was able to survive the winter and continue expanding.



Remnants of the record setting 1997 Routt Divide Blowdown after the 2002 fire. Photo by D. Kulakowski.

During the same period, mountain pine beetles began attacking lodgepole pine in the study site but it's not likely this outbreak was caused by the blowdown. The critical conditions favorable to the current outbreaks of both insects are believed to be drought and warming temperatures, including higher minimum temperatures in winter that otherwise kill beetle larvae. Both the 1940s Flat Top outbreak and the Routt Divide outbreaks were accompanied by drought. Extreme drought parched the

entire state of Colorado from 1998 to 2002 setting record lows for precipitation and preceding the large, severe fires in the study area. January to September of 2002 was the driest period on record since the early 1900s, and was similar to the severe droughts of the late 1800s.

By 2002, over 34,000 acres of forest were affected by spruce beetle and 2,400 acres were affected by mountain pine beetle. Both insect species have co-existed with their host tree species for thousands of years. Earlier studies conducted by Veblen showed that previous spruce beetle outbreaks in the region weren't much different in scope and severity than those occurring today. In the case of the mountain pine beetle, however, it remains unknown how current outbreaks (which had affected 600,000 acres in Colorado as of late 2006) compare to those of the past. Scientists know that previous mountain pine beetle outbreaks were severe and widespread, but it has yet to be determined if the extent of current infestations is unprecedented. Bark beetles increase fine and coarse dead fuels either by killing trees or feasting and breeding in dead trees. But whether or not this makes a landscape more flammable varies with topography, weather and forest structure. There are few studies that causally link increased fire occurrence or severity with bark beetle outbreak.

Salvage logging is often implemented after blowdown based on the assumption that removing the fuel will reduce the risk of large, severe fires. Portions of the Routt Divide Blowdown area were logged beginning in 1999 with this intention. By 2002 almost 2,000 acres had been logged within the study area even though the relationship between blowdown debris and subsequent fire risk wasn't clear at the time. Though blowdowns can add a lot of dead fuel there are few documented cases of fires occurring in the years or decades afterward. The effect of salvage logging on severe fire behavior likely varies with the extent of the logging, whether or not slash is removed, and the climatic conditions after the operation.

Stand-replacing fires completely consume entire stands of trees, creating new generations of young, resilient stands. New stands grow in patches scattered across the landscape that can be less susceptible to most major types of disturbances than stands of older trees. Young trees are more resistant to beetle attack because their bark is too thin to sustain hungry beetle larvae, and some post-fire successional species are known to be less flammable. After the late 1800s stand-replacing fires in the WRNF portion of the study area, new stands of fire resistant lodgepole and aspen replaced older spruce-fir stands, reducing overall flammability. However, this protective influence is thought to weaken with increasingly severe fire weather.

A double play for beetles and fire

Severe fire weather was certainly the name of the game leading up to the 2002 fires in Colorado—and at the same time beetle populations were exploding. Bark beetle infestations have periodically taken place under similar conditions in these forests for millennia. Like severe fire,

beetle outbreaks are a natural and necessary disturbance in this ecosystem. Both disturbance types need warm, dry conditions in order to become extensive or severe. According to Kulakowski, wildfires will be severe under these conditions in this forest type whether or not the beetles get there first.

“We know that there are certain climatic conditions that predispose forests to outbreak of bark beetles,” Kulakowski explains. “These conditions are very similar to those that predispose subalpine forests to severe fires. So even though the risk of both fires and outbreaks may increase during similar climatic conditions, the actual causal effect of outbreaks on subsequent fires appears to be minor.”

It’s common for people to assume that trees killed by bark beetles increase fire hazard, but the risk of fire in Colorado was actually very high before the outbreaks. People simply weren’t aware of it. Even though a drought was in progress, the landscape was still filled with green trees. Impacts on forest structure from drought were invisible compared to the beetle damage that came later.

Colorado’s forests are dense with large, older trees that beetles require for successful reproduction. This high density in stands of lodgepole pine and spruce-fir is normal for these forests, which have historically been shaped by severe fires occurring on the order of centuries. Fire exclusion over the last century has contributed to the longevity of these stands. Lack of fire has allowed them to reach the age where they’re most susceptible to beetle attack. In addition, the forests have been pre-stressed by drought and warmer temperatures making trees of all ages somewhat more vulnerable to beetles.

Conditions were warm and dry before and during the 1940s Flat Top and Routt Divide outbreaks. Yet fires in the Flat Tops area were no more frequent or severe during the decades following the 1940s outbreak, while they raged in the Flat Tops and at the Routt Divide fifty years later. This paradox begged the question: Why did one beetle ravaged area burn severely soon after outbreak and the other didn’t?

Results throw some curveballs

This research found that it was drought that made the difference. The weather following the 1940s outbreak was not conducive to fire. The fire weather during and preceding the Routt Divide outbreak was record setting in its severity.

Even fifty years later, the remnants of the 1940s Flat Tops beetle outbreak had only minor influence on the 2002 Big Fish Lake fire. This is consistent with the suggestion that any increased flammability caused by beetle infestation in these subalpine forests is short term, lasting only several years after an outbreak, until the fine fuels completely decay. After that period it’s possible that the likelihood of a fire burning extensively may actually decrease for decades due to a lack of fine fuels (needles, leaves, etc).

The study showed that severe fires burn in this forest type during prolonged periods of heat and drought and it doesn’t matter much if the trees are living or dead. When drought is severe, the impacts of disturbances can be



Dead trees from 1940s White River National Forest beetle outbreak are still visible. Photo by T.T. Veblen.

uncharacteristically severe, trumping many of the residual effects of previous individual disturbances.

“We were really shocked at the findings,” Kulakowski explains. “Here we had this ideal situation—where we were really going to quantify the degree to which ongoing beetle outbreak increases fire extent and severity—and as it turns out it’s not even detectable.” Changes in fuels generated by beetle outbreak did not appear to influence fire severity or extent in these subalpine forests even in the midst of outbreak or during the years immediately following.

Pre-fire conditions were generally poor predictors of fire extent, with the exception of stand-replacing fires. Cover type was the most important predictor of extent in that spruce-fir stands were more likely to have burned than expected. Aspen, lodgepole and other post-fire stands that were expected to burn, burned less than anticipated. Blowdown and elevation were of secondary importance. Record setting blowdown, ongoing insect outbreak, and salvage logging had almost no detectable influence on extent of the 2002 fires.

In contrast, pre-fire conditions were powerful predictors of fire severity even during extreme drought, with blowdown being the prominent contributor. 90% of the stands that experienced severe blowdown burned severely. Crown cover and elevation were of secondary importance. In stands that were less severely blowdown, those with dense crown cover were more likely to burn severely. Tree mortality caused by bark beetles and salvage logging impacts had no detectable effect on fire severity.

The salvage logging operations removed primarily large timber, and left enough slash that neither fire severity or extent during extreme drought were affected. Results from the Hinman and Burn Ridge fires portion of the study area imply that efforts to mitigate against large, severe fires after blowdown don’t always reduce the likelihood of severe fire. This was especially evident in forests like the subalpine zone study area where fire may be driven more by weather than fuels. In this forest type, during severe drought, these salvage practices didn’t appear to be effective at influencing either fire extent or severity. They may be more effective, however, during years with average precipitation.

Previous stand-replacing fires affected both the extent and severity of the 2002 fires. Young (<120 year) postfire stands were less likely than expected to have burned (71% less than expected) or severely burned (58% less than expected). Areas that were burned even though they weren't expected to occurred more in old (~300-400 year) postfire stands and old growth stands over 400 years old. Stand replacing fires substantially reduce both fine and coarse fuels which reduces forest susceptibility to large or severe fires. It's likely that the areas burned by the 2002 fires will buffer the forest against severe fires and severe impacts from most other disturbances for the coming century.

No one-size-fits-all scenario

"To sum it up," explains Kulakowski, "it's easier to make predictions about how severely a fire will burn in a given area of subalpine forests than it is to predict how extensive a fire will be. How large a fire becomes is not so much a function of pre-fire vegetation or disturbance history as it is of climatic variables. In contrast, how severe a fire will become is much more a function of these pre-fire vegetation conditions."

The researchers emphasize that these results can only be applied to subalpine forests dominated by spruce, fir and to a lesser extent lodgepole pine. They also point out that more studies about the effect of bark beetle outbreaks on fire behavior are needed, possibly combining remote sensing with ground surveys to determine a more accurate measure of the duration of infestations.

Kulakowski stresses that there is no universal blueprint that can be used to predict the effects of various disturbances in all forest types. He strongly cautions against taking these findings and applying them to a different forest type and location.

"I think that the lesson here is that when we are talking about what constitutes a "normal" or "natural" fire regime we don't have a one-size-fits-all scenario. We need to be very careful to look closely at what forest type we're talking about, and where it's located geographically. Even if we have the same composition of tree species we may have very different fire regimes depending on whether we're talking about Colorado, Arizona or Montana."

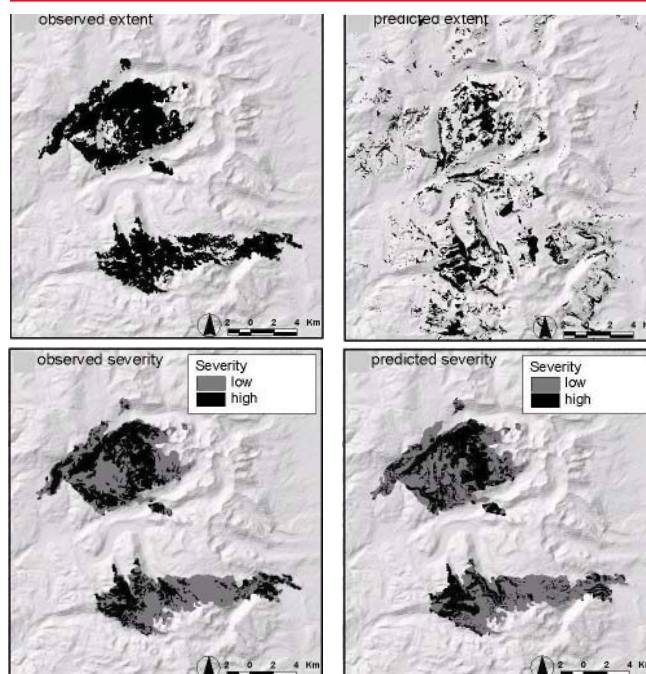
"The more we can adapt our management policies to fit individual forest types across the western U.S.," he continues, "The better off we'll be." And when it comes to severe fire in Colorado's subalpine forests—don't be too quick to blame the bugs.

Further Information: Publications and Web Resources

Effects of Blowdown, Beetle Outbreak, and Fire History on the Behavior and Effects of the 2002 Fires in Western Colorado. 2003. T. Veblen, D. Kulakowski, C. Regan. *JFSP final report*: http://www.firescience.gov/projects/03-2-2-01/03-2-2-01_final_report.pdf

Management Implications

- No evidence was found to support the assumption that bark beetle outbreak or salvage logging influenced either fire severity or extent in Colorado subalpine forests.
- Fire-hazard mitigation may not reduce fire extent following blowdown or outbreaks of spruce beetle in these areas because fires there may be primarily driven by weather as opposed to fuels.
- Fire extent is not strongly influenced by prefire vegetation conditions associated with previous beetle outbreaks, but is strongly influenced by previous stand-replacing fires from the late 1800s.
- Fire severity, even during extreme drought, is strongly tied to pre-fire conditions, especially the legacies of blowdown and stand-replacing fire (but not to beetle outbreak or salvage logging).



Clockwise from top left, observed fire extent; predicted extent; predicted fire severity; observed fire severity.

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Scientist Profiles

Dr. Dominik Kulakowski is now an Assistant Professor at the Graduate School of Geography at Clark University in Worcester, MA. His professional interests center on the biogeography and ecology of subalpine forests. Previously, he was a Research Associate and Lecturer with the University of Colorado and a Research Associate with the Swiss Federal Institute for Snow and Avalanche Research in Davos, Switzerland.



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Effects of Blowdown, Beetle Outbreak, and Fire History on the Behavior and Effects of the 2002 Fires in Western Colorado

Written By: Lara Durán

Purpose of this opinion piece

Manager's Viewpoint is an opinion piece written by a fire or land manager based on information in a JFSP final report and other supporting documents. This is our way of helping managers interpret science findings. If readers have differing viewpoints, we encourage further dialogue through additional opinions. Please contact Tim Swedberg to submit input (timothy_swedberg@nifc.blm.gov). Our intent is to start conversations about what works and what doesn't.

Problem

In the 1940s and 1990s, northwestern Colorado subalpine forests experienced large-scale bark beetle and spruce beetle outbreaks followed by windthrow. In 2002, the Big Fish Fire burned through portions of the bug kill. Today, bark beetles are impacting much of northwestern Colorado again—even more extensively and at higher elevations. Subalpine forest managers in northwestern Colorado are facing challenging management choices with recent bark beetle outbreaks and climate change predictions, though have little empirical studies from which to draw. Managers need to determine how best to balance the socio-political values with the physical dynamics of fire and subalpine forest ecology.

Application for Land Managers: How Best to Apply the Results of this Study

Using remotely sensed data, this study attempted to understand the temporal and spatial relationships within northwestern Colorado's subalpine endemic bug-killed areas that influenced the Big Fish Fire extent and severity during drought (Jenkins et al. 2008). In doing so, however, it did not

give full consideration to one very important environmental factor that influenced fire behavior and hence fire effects: local fire weather.

The Big Fish Fire was managed as a "wildland fire use" incident while other large Colorado fires were also occurring. According to archived National Incident Management Situation Reports, fire behavior on the incident was highly variable (FireLine 2002). Therefore, for forest managers to truly apply the results of this study, it needs to be considered along with other recent publications on fire-bug-forest dynamics, and not taken as a stand alone project (Jenkins et al. 2008, Lynch 2006s, Page and Jenkins 2007a, Page and Jenkins 2007b).

Fuels Complex

By observing fire severity and extent in subalpine forests in Colorado, this study attempts to consider which leg of the fire environment triangle is stronger and better correlated. In general, this project illustrates the importance of the whole fuels complex for determining fire effects—even during extreme drought in subalpine systems. In Colorado's subalpine western slope forests, managers can therefore expect to generate higher vegetation mortality from fire when the following dynamics co-occur: beetle outbreaks, windthrow, Englemann spruce-subalpine fir cover type, old-growth seral stage, and intermediate elevations.

It can be argued, however, that these results are intuitive to most fire and fuels managers. Previous fires, bug kill, and wind throw all contribute to, diminish, or otherwise change the fuel complex and ultimately change fire behavior and its effects. Lodgepole pine and aspen generally have higher canopy base heights and lower canopy bulk densities than Englemann spruce-subalpine fir, and burns with greater intensity during extreme drought. Most useful to forest managers are quantitative stand descriptions, such as basal area, surface fuel loading, or snags per acre—and how they correlated with observed and calculated fire effects.

A word of caution: The deliverables from this project generally over simplify the role of post-mortality conditions in fuel complex and subsequent fire behavior, partly due to the nature of the research methods used. This is acutely evident as most fire managers believe fires in all North American ecosystems—especially during the past five years—are growing increasingly intense, severe, and large (Westerling et al. 2006). Furthermore, this study's authors do not address how changes to the fuel complex from bug outbreaks or past fire influenced actual fire weather or fuel conditions—such as wind speed, solar radiation, and shading of surface fuels.

“The deliverables from this project generally over simplify the role of post-mortality conditions in fuel complex and subsequent fire behavior.”

For instance, Page and Jenkins found a tremendous difference in the fuel complex, fire behavior, and fire effects of lodgepole pine stands between endemic stands, current epidemic stands, and post epidemic stands (2007a, 2007b). Concurrence between Page and Jenkin's research with the findings from this project lie in the variables: time since last outbreak and last fire.

Fire Weather

In addition, the investigators did not mention looking at daily progression maps, fire behavior documentation, incident fire weather from the Remote Automated Weather Station, ICS-209s, or other incident products developed by the assigned Fire Use Team. While researchers might not immediately consider this data source, it is readily on the minds of fire and fuels managers because of the pressure to be hyper vigilant of fire behavior under predicted and expected fire weather.

Daily fire weather could explain some of the study's results. And while it is one thing to study just the ecological effects from natural records (tree rings, dead and down woody transects, cover type percent, etc.) because those are the only records available, it is quite another when a plethora of other data on fire behavior and correlated fire weather exists but is not considered in the science. Consequently, managers could view the results with some skepticism.

Furthermore, when studying fire effects in subalpine systems influenced by bug kill, the deliverables from this project suggest regional climate and drought can be used as a surrogate for local daily and clearly variable fire weather. Hence, while this study supports the importance of extreme drought, managers must consider variable daily fire weather first and foremost, even when planning effective fuel treatments in any ecosystem.

“While this study supports the importance of extreme drought, managers must consider variable daily fire weather first and foremost.”

Fire Risk Versus Fire Hazard

Concerning bug mortality, forest managers are primarily managing for fire hazard, not fire risk as the deliverables suggest (Langowski 2006, [Western Forestry Leadership Coalition 2007](#)). The term “fire risk” comes loaded with management baggage. Recent publications explain the complexity and problems associated with managing for fire risk ([Finney 2005](#), [Hardy 2005](#)). Most managers realize that they cannot manage the likelihood of a fire event occurring. Proving on-the-ground actions in an attempt to affect fire risk is even more problematic. The public and community leaders appear to be concerned with fire risk, however, perhaps not truly understanding the limitations or objectives of management. Hence, the arguments posed about the effects to fire risk are not immediately relevant to forest managers.

In fact, this study could be strengthened by using new geospatially based burn probability tools with fire weather streams to compare the simulated burn probabilities at different time steps against the geostatistical autocorrelation results and field analysis (Finney 2005). Fire spread patterns during the 1988 Yellowstone fires were significantly correlated with the 1972-75 mountain pine beetle outbreak, which increased the burn probability by 11percent (Lynch et al. 2006). Sustained mountain pine beetle activity, drought, and aspect were the three significant variables influencing fire spatial patterns.

Management Strategies

The mantra of this project really exerts that there is no ecological need to treat bug-killed areas in subalpine systems in northwestern Colorado. While the study argues that the current bark beetle epidemic is within historic range of variability, it simultaneously proposes that the current bug extents are hitting trees at elevations not previously recorded. Yet, without further consideration of a fundamental abiotic factor that contributed to bug-fire ecology (Big Fish fire weather), managers are going to find it difficult to believe the simulated geostatistical results from this study.

This, along with the spatial extent ranging not just across Colorado, but across British Columbia to New Mexico ([Kurz et al. 2008](#)), along with predicted and currently observed abrupt climate changes and recent large wildland fire behavior, are what really makes forest managers, the public, and elected officials nervous. For instance, Brunnell et al. discovered from Holocene records during the 8200 year event, abrupt climate change was associated with large bark beetle outbreak in Idaho and Montana, lasting from 10 to 30 years, and made comparisons to the bug outbreak event seen today across much of North America ([2008](#)).

Multiuse agencies in northwestern Colorado must consider the ecological as well as the socio-political and physical environments in managing bug-killed and wildland fire landscapes. Given

the current management situation in northern Colorado, this project raises two important questions: What does being out of historic range of variability in subalpine systems bug-killed areas really look like? And, how will we know when those systems have departed from it? Perhaps when we find answers to those tough questions, the ecological reasons for treating bug-killed landscapes will be in sync with the physical fire behavior and the socio-political values that these and other subalpine forest managers will be facing with climate changes.

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Manager Profile

Lara Durán is a Fire Planner for the Sawtooth National Forest in Idaho. Her previous positions included Fuels Specialist, Fire Prevention, and Wildlife Technician for the U.S. Forest Service in Colorado. Lara contributed to the JFSP Risk Roundtable, Manager's Reviews, and participated in the national pilot program Integrated Landscape Design to Maximize Fuel Reduction Effectiveness.

She earned a BA in Ecology from the University of Colorado at Boulder where she earned a National Science Foundation grant for undergraduate research in alpine plant development. She was a Wildlife and Plant Ecology Research Assistant at the University of Colorado, contributing to long-term studies on ponderosa pine, Abert squirrels, dwarf mistletoe, elk, American marten, and yucca plants. Since then, she's completed graduate courses in wildlife and plant ecology, law, and administration. She is interested in disturbance ecology and the effects to wildlife.



The information for this Manager's Viewpoint is based on JFSP Project 03-2-2-01, Effects of Blowdown, Beetle Outbreak, and Fire History on the Behavior and Effects of the 2002 Fires in Western Colorado; Principal Investigator was Claudia M. Regan.