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Defensible Space and Mitigating Mountain Pine Beetle (Dendroctonus ponderosae Hopkins) Damage

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Abstract

Mountain pine beetles **(*Dendroctonus ponderosae* Hopkins)** are an endemic insect of western North American forests. The beetle's range extends north to British Columbia in western Canada, south along the western United States and into northern Mexico. It has moved east into the states of Arizona, Colorado, Idaho, Montana, Nevada, South Dakota, Utah, and Wyoming. Live specimens of lodgepole (*Pinus contorta var. latifolia*), ponderosa (*Pinus ponderosae*), and white bark (*Pinus albicaulis*) Pines are preferred hosts. Climate conditions such as drought create outbreak conditions that last for only a few growing seasons or several years if these drought conditions continue. Mountain pine beetles are univoltine, having one brood per year, and can reproduce in all pine species within their flight range. The mountain pine beetle has a complicated life cycle, and includes a symbiont blue wood staining fungi, which depending on environmental factors could be one of four species, *Grosmannia clavigera*, *Leptographium longiclavatum, Ophiostoma montium,* and *Ceratosystiopis* sp. 1.

The current outbreak began in the late 1990s. Many factors have contributed to the current outbreak, but two are getting majority of blame: overstock of mature hosts of lodgepole, ponderosa and white bark pines, and climate change. A comparison of three locations and how different communities are dealing with the continuing outbreak is discussed. Control and management options, as well as maintaining a defensible space around home in the forest is also discussed.

Introduction

Many research studies have been done over the course of one hundred years determining the cause in decline of several different species of pine tree: lodgepole pine (Pinus contorta var. latifolia), ponderosa pine (Pinus ponderosae), and white bark pine (Pinus albicaulis). A common factor that has been found is that mountain pine beetle (*Dendroctonus ponderosae* Hopkins) is one of many culprits and the focus of this paper, along with its blue staining fungi symbiont, *Grosmannia clavigera*.

Mountain pine beetles are an endemic insect of western North American forests. (Ciesla, 2011; Gibson, 2009; Lynch, 2006; McGarrity, 2005) The beetle's range extends north to British Columbia in western Canada, south along the western United States and into northern Mexico. It has moved east into the states of Arizona, Colorado, Idaho, Montana, Nevada, South Dakota, Utah, and Wyoming. Live, un-infested lodgepole, ponderosa, and white bark pines are the preferred hosts, many other western pine species: limber, coulter, foxtail, pinion and bristlecone are also attacked but to a lesser degree. Climate conditions such as drought create outbreak conditions that can last for only a few growing seasons to several years if drought conditions continue. Elevation was originally thought to be a limiting factor in spread as well, but has been proven incorrect. Wet winters or springs aid the non-infested tree in expelling the beetle using pitch tubes, if the attack is not severe. Mountain pine beetle is not a strong flier and relies on dense stands of host trees to continue the insect's life cycle and continue to spread the infestation. As the beetle spreads to a new host tree, the infested tree will continue to die, first turning orange, then red and finally gray. Once the tree has been attacked by the feeding activity of the beetle, the blue stain caused by the fungal spores, are introduced by the beetle from

specialized structures on the insect's head. Once in the phloem of the target tree, the fungal spores colonize, preventing the uptake of nutrients for the tree further weakening it. There are four species of blue stain fungi: *Grosmannia clavigera, Leptographium longiclavatum, Ophiostoma montium,* and *Ceratosystiopis* sp. 1. *Grosmannia clavigera* is the most common found. (Khadempour, 2012) As the host tree dies, the beetle moves on to a new tree. Studies of wildfire behavior in areas of high mountain pine beetle activity have led to theories that the insect has increased the potential for increased fire danger. (Creeden, 2014; Jenkins, 2008; Jenkins, 2012; Lynch, 2006)

As humans move into less populated areas and build vacation homes in forested areas, these infested, dying or dead trees become a safety problem. In dense forest situations, there could be several homes or cabins in a small (less than 1 mile) area and roads may be limited, water is also limited in these areas as well. Thinning of the host trees would not only lessen some of the infestation potential but would also lessen the potential of fire severity and possible loss of life or buildings. Informed landowners can do visual surveys to the trees on the property, looking for evidence of pitch tubes or exit holes. Consulting with a county extension forester or local forestry professional to determine the severity of an infestation and discussing treatment options will help in saving some of the preferred trees.

There are several treatment options: cutting, thinning (using the harvested tree for firewood or chipping for mulch) or using insecticides. Timber from infested wood is used in construction projects or made into decorative furniture. Some of the wood is not desired due to the blue staining caused by fungi that are introduced to the tree while the beetle is feeding. This stained wood is becoming popular for woodworking projects, however. Valuable trees, for aesthetic purposes, can be treated with an insecticide, but the timing of the treatment is important. The

tree must have no insect activity, and the insecticide must be a persistent variety. These spray treatments must be repeated every year, and can be quite costly.

History

The first reports of damage from mountain pine beetle was recorded in 1906 in forests in the Pacific Northwest south into Oregon. Foresters working the forests of Oregon, east to Idaho were reporting large number of pine trees dying from an attack by what was being called bark beetles. Andrew D. Hopkins had collected a specimen that he referred to as the Black Hills Beetle in Spearfish, SD in 1900. He noted that the beetle appeared to prefer the ponderosa pine of the Black Hills of western South Dakota and called it the Black Hills Beetle, changing the name to *Dendroctonus ponderosae* Hopkins in 1902 after further study with other collected specimens. (Furniss, 2010) With the reports of a similar beetle causing widespread destruction in the Pacific Northwest, Hopkins travelled to the area to survey the damage and collect specimens of this new insect. He then determined that it was the same beetle he had found in the Black Hills, giving it a new common name of mountain pine beetle. (Furniss, 2003) Stakeholder cooperation (timber companies in the area of the outbreak); the U.S. Forest Service and the Bureau of Entomology began the first project to find a control to prevent further loss of valuable timber products. (Burke, 1990)

Life cycle

Many research projects and studies later, many things have been learned about the mountain pine beetle. The mountain pine beetle has a complicated life cycle, and includes a symbiont blue wood staining fungi. Mountain pine beetles are univoltine, having one brood per year, and can reproduce in all pine species within their flight range. They prefer lodgepole, ponderosa, and white bark pines. Many others, not common in lower elevations such as

bristlecone pines are also be attacked by the beetles. In general the beetle prefers a specific size of tree, larger than eight inches in diameter and over eighty years old in lodgepole pine and eight to twelve inches in ponderosa pines. Dense stands of the host species is also preferred, the beetles are not strong fliers and when swarming from one host to a new one, the shorter the flight the better. (Gibson, 2009) The bristlecone pine are typically at higher elevations than most of the lodgepole and ponderosa pines, and harsh winter temperatures help slow the beetles down when they do attack, but does not stop their life cycle. The temperatures have to be extremely cold (less than -34° C), for longer than 32 days due to the larva being able to withstand cold temperatures for a portion of their life cycle. (Safranyik and Linton, 1998) A full life cycle of 2 years is possible at higher elevations, while areas in the western U.S. could see 2 generations a year with optimum conditions (i.e.: drought or higher than normal temperatures). Research has lead the scientific community to believe that warming due to climate change is preventing the extreme cold temperatures of winter from slowing or perhaps even stopping the spread of the mountain pine beetles in some areas of the U.S. and Canada.

Female adult beetles initiate the flight and mating process by emitting a pheromone to attract male beetles. She will also construct the vertical egg gallery that is 10 to 120 cm long and use the boring dust to construct the egg chambers where she will lay her eggs singly. The eggs are laid in niches on both sides of gallery. The larvae hatch in 10-14 days and feed in right angles away from the egg galleries. When the larvae are mature, they construct oval pupation cells. Most of the current year's brood will emerge from the pupation cells as adults that will overwinter under the protective bark. (Ciesla, 2011) While construction of the galleries is taking place, the spores of *Grosmannia clavigera*, a species of blue stain fungi are being introduced by the adult beetles.

The fungi spores geminate and produce mycelium which colonizes the phloem of the host tree. The process of colonization of the phloem blocks nutrients from reaching all areas of the tree, beginning with the top of the tree. The blocking of these nutrients and water causes the tree to starve to death. The sapwood of the dead tree becomes discolored with what appears to be a dark blue-gray to blue color, hence the common name of "Blue Stain Fungi". The species that is responsible for this appearance differ from species of tree, but it is commonly *Grosmannia clavigera*. The spores of the fungi, which unlike common fungi that are carried by wind currents, actually rely on special structures on the heads of *Dendroctonus ponderosae*. As the adult beetle constructs their galleries for egg laying and larval rearing, the fungal spores propagate ahead of the larvae feeding on the phloem. The fungi rely on the adult beetle to transport it to a new tree and more nutrients. The adult beetles and larvae feed on the phloem which is high in carbon but low in sterols, nitrogen and vitamins needed by the beetles for growth, molting and reproduction. The fungi produce ergosterol which provides these needed sterols and other nutrients that the beetles need to complete their life cycle. The fungi decreases the moisture content of the phloem, aiding the development of the brood. (Khadempour, 2012; Rice, 2008)

Climate

Mountain pine beetle is a univoltine species and in general has only one generation per year. Changes in climate have adjusted the length of their life cycle. Climate change, whether the temperatures increase or decrease also affects the tree as well. In periods of cool, wet weather, non-infested trees are able to protect themselves from attack by forcing the adult beetles out of the tree using pitch tubes. The infested tree, while the change in temperatures (lower temperatures) won't save the tree from its current infestation, it does extend the life cycle of the insect up to two years. Higher temperatures and drought increase water stress on the host tree,

limiting its ability to uptake any nutrients. Also with the increased temperature the potential for the insect to have more than one generation also increases.

Laboratory research has revealed that under varying temperatures egg development differed. In temperature ranges of 23° C to -25° C, the mountain pine beetle egg to adult time frame was 30 days. The researchers discovered that earlier life stages, eggs and the first two larval instars are able to develop under a wider range of temperatures. However, the later larval instars and pupae require warmer temperatures to complete development. The researchers concluded that this ability in the earlier instars to develop under such a wide range of temperatures is what gives the insect the ability to survive in changing environmental conditions. (Bentz, et al., 1991)

Unfortunately extremely cold temperatures will not kill the adult beetles overwintering under the host tree's bark or the larvae within the phloem. In a controlled testing environment, lodgepole pine logs of varying diameters and dryness were placed in a cold storage environment to determine a mortality level for mountain pine beetles. Size, diameter of the test logs and approximate number of larvae present in each log were noted at the beginning of the experiment. There was some mortality, but at a temperature of -12°C, the super cooling point of the larvae appeared to aid in survival. To test the ability of the larvae to survive even lower temperatures, the lowest temperatures of -34°C were used. Mountain pine beetle larvae are known to be able to produce glycol to aid in surviving freezing temperatures. Some of the test subjects did survive the -34°C for 32 days. The researchers felt that log size and bark thickness aided the beetle larvae's super cooling point, and provided insulation against the extreme cold. (Safranyik and Linton, 1998) Global warming appears from the research article reviewed to be in best interest of mountain pine beetle survival.

As more is learned about forest ecology, a recurring theory is the trees that have been attacked by mountain pine beetle are thought be just dead and no longer useful. Lodgepole pines rely on fire to release their seed from the cones, clear the ground cover to aid in rain and snow melt to germinate these seeds to go on to become the new trees. The trees do add fuel to the process, and this is part of the tree's life cycle. Several different host tree species have developed strategies for defense against the beetle's attack (i.e. pitch tubes), but the beetles themselves have also developed new attack strategies as well. The mountain pine beetle utilizes a mass attack strategy when their numbers are high, and are able to attack many trees in a densely populated area. The insects are successful in mounting an attack on healthy, uninfested trees, overcoming the tree's defenses by using many individuals in the attack. However, in areas of less host tree density, this mass attack strategy is not as effective. The distance between host trees to new host tree may be out of the beetle's flight range and will prevent an infestation. This same study also investigated diapauses concerning the Mountain Pine Beetle and found that the beetle life cycle is controlled by environmental conditions and not diapause. (Logan, 2001)

Continuing climate concerns have forest scientists in the western U.S. working to understand the continued mountain pine beetle outbreak. The beetle infestation is moving in a more northern direction and becoming more of a concern in western Canada, specifically in the provinces of British Columbia and Alberta. Recent research is showing that the mountain pine beetle is moving into higher elevations of over 10,000ft elevations that previously were thought to be safe from the insect. The researchers have also noted that flight season has also lengthened, and that many individuals are becoming bivoltine, having more than one generation per year in lower elevations of less than 6,000ft. Egg galleries are being constructed earlier, with adults emerging earlier in the early months of warm summer temperatures, and attacking trees

with the second generation adults either overwintering under the bark of the host tree, or pupation completing early in the following spring. (Mitton and Ferrenburg, 2010)

An example of this warming trend has been found in Yellowstone National Park. In 1988, Yellowstone National Park suffered a catastrophic fire that was at first blamed solely on drought and mountain pine beetle (and other insect) outbreaks. But research conducted in 2010 on white bark pine showed this to be not completely the case. (Logan, et al., 2010) White bark pine is part of its own unique ecosystem in the park. It is considered a foundation and keystone species. The foundation aspect is from the fact that as a higher elevation species (8500ft) it is a nurse tree for other conifers, provides biomass and enhances soil formation. The keystone effects affect snow dynamics; aiding drifting and holding the snow melt in the spring. But most importantly, white bark pine produces large, fleshy seeds that are a critical food source for Clark's nutcracker (*Nucifraga columbiana*), red squirrels (*Tamiasciurus hudsonicusto*) and grizzly bear (*Ursus arctos*). Of all the organisms depending on the seeds, the grizzly bear is most reliant on raiding the seed stored by squirrels in the fall when other nutritious food may be in short supply prior to the bear preparing for hibernation in fall. With increased activity of mountain pine beetle activity being observed at higher elevations of 10,000ft, attack from mountain pine beetle appears to be a serious concern. (Logan, 2010) The cascading effect on the white bark pine ecosystem would be catastrophic. The tree relies on the bird to spread the seed, the squirrels also aid in the spread and planting of seeds, but mostly the grizzly bear relies most on the seed stored by the squirrels. Without the seed from the white bark pine, all three species would suffer from population decline.

Present Outbreak

The current outbreak began in the late 1990s. Many factors have contributed to the current outbreak, but two are getting majority of blame: overstock of preferred mature hosts of lodgepole, ponderosa and white bark pines, and climate change.

The numbers of preferred host trees have ballooned in recent years. Suppression of natural thinning fires has been blamed, with the U.S, Forest Service receiving most of the blame. In fact most, if not all, is on timber companies looking for mature stands of live timber for harvesting. Preferably, non-infested stands, because of the blue stained effect from the symbolic fungi create a lumber product that cracks and warps badly as it dries, making the lumber a lower grade and less desirable for building projects. Climate change has also aided the spread of the beetle. Periods of continued drought aids the beetles by preventing the tree from absorbing enough water to expel the adult beetles at the beginning of the attack using pitch tubes. Warmer temperature aid the larvae in surviving what would normally would be the coldest part of winter. These conditions exist in all of the mountain pine beetle's range.

A main problem with setting policy on management of areas under attack from the mountain pine beetle is public perception of how the management is done. Areas of heavy infestation in the Pacific Northwest and further north into British Columbia, Canada are overstocked with mature lodgepole pine. The lodgepole pine is a favored timber species and in the U.S. these areas of valuable timber, natural occurring fires had been suppressed. Lodgepole pines rely on fire to aid in seed dispersal from the cones, clearing the forest floor to allow water to reach the seed and aid germination. An open forest floor also allows moisture and other nutrients to be taken up by the mature tree and seedling trees. Without these steps, there is no replacement for the beetle killed trees. (Jenkins, 2008)

Man has affected how the forest has survived in many areas for centuries. In the northwestern to north central areas of Montana, the Native American tribes would routinely set fires to the forest to clear areas for grazing for their horses and wildlife (deer, elk, and moose). These fires were never the catastrophic type we see currently, simply because the fuel load wasn't available as it is now. (Arno, 1976) The fuel loads have increased from suppression effort by man to protect areas used for timber and recreation. Timber use is highly profitable and beetle killed trees are viewed by the timber industry as having a short "shelf life". This "shelf life" is described and "the length of time after death that a tree will be useable for a given product". (McGarrity and Hoberg. 2005) Forestry officials in British Columbia found that dead, standing trees could be harvested up to fifteen years after death in drier warmer climates and less than ten years in colder wetter climates. (McGarrity and Hoberg, 2005)

The current outbreak is caused more from climate change or changes in climatic conditions that are cyclic. Drought has been an on-going problem in many areas of the mountain pine beetle's western range. The drought problem also extends into British Columbia and Alberta, Canada. As the outbreak spread north and into higher elevations, several new facts are being confirmed from several researchers: The mountain pine beetle has adapted to its new environment, lower elevations are seeing up to two generations a year and more trees attacked due to on-going drought conditions. Higher, cooler elevations are still seeing only one generation per year; however the numbers of trees attacked appears to be increasing. (Creeden, 2013)

Forest Fires as mentioned several times can be beneficial to the forest: clearing floor of debris and allowing the seed of grasses and other forbs to germinate and grow, feeing herbivores,

the burned trees provide homes for burrowing animals or birds and insects that move in to feed on the dead trees provide food for the birds and animals.

But more recent wildfires, whether natural or part of a man-made controlled procedure have on several occasions become extremely violent and destructive. What could have only been a few dozen or so acres affected, turned into thousands of acres destroyed, and possibly even homes destroyed. Several research studies have been done using climate data, insect outbreak data and forest pathogen data. (Arno, 1976; Jenkins, 2008; Lynch et al., 2005; McGarrity and Hoberg, 2005; Platt et al. 2011), all of the research had a common denominator: dense forest populations of host trees of similar ages.

Comparison of Three Areas

Colorado

Jefferson County, Colorado is the fourth largest county in the state. Residents live in the larger metropolitan areas, the Rocky Mountain foothills and in many unincorporated smaller communities. In the summer residents and visitors alike enjoy many outdoor activities: biking, camping, and hiking. There are three national forest areas in the county: Arapahoe, Pike and Roosevelt and two state parks.

With all of this activity in summer, the danger for fires is always a concern. Lodgepole and ponderosa pines, douglas fir and gramble oak are the primary tree species in the county, but not the only ones by far. The county has an average of fifteen inches of precipitation per year in rain and snow. Starting in 1996, while undergoing several years of drought, Jefferson County began to see an increase in wildfire activity. This increase in fire activity led to an increase in community action in preventing fires in and around homes, banning cedar shake roofs in favor of steel roofing material or other fire resistant materials, and promoting defensible space around

homes of not less than thirty feet or more. The Colorado state forestry service developed a forest agriculture program for landowners with forty or more acres to promote not only thinning potential timber products but to aid in creating defensible space around buildings as well as clearing potentially infested host trees. These work plans for the annual program worked well for several residents in the unincorporated areas. One couple, Lowell and Linda Dietz live in Pine, CO and had begun the Forest Ag. Program twenty years ago and reported that though they no longer are participating in the program, the experience and things that they have learned still aids them in surveying their property every summer. They have been very kind in answering my question and are sharing a few before and after photos with me. (Dietz, personal communication. 2/3/2014)

Tree farmers are not immune from mountain pine beetle attack either. One farmer, Wes Rutt, that was contacted, stated that he noted that the mountain pine beetles were not just sticking to mature host trees or trees of a specific diameter. The beetles on his property were attacking all ages and sizes of ponderosa pine up to 7500' ft. in elevation, and all ages and sizes of lodgepole pine in the higher elevations. He shared that he also experienced several years of drought, and the beetles spread rapidly. (Rutt, personal communication. 6/10/ 2015)

I had several emails from contacts in Colorado. Lisa Mason, an outreach forester with the Colorado State Forest Service gave me lots of contacts in several different counties. I did email Mr. Rutt as referenced above and he was quite helpful and answered my questions and passed on several other resources that were very helpful. He was affected by the High Park fire in 2012. He stated that he had already lost many of his trees to the beetles and drought, but after the fire he also lost several buildings, and a total of 70% of his trees. His home was not lost, due in part to preparing defensive space around it. He said that as a volunteer firefighter, he knows

that the defensible space practices worthwhile and are what will save a home in tinder dry forests; he just had not done the same treatments around the outbuildings that he lost. He and his wife have since rebuilt and the new buildings have more fire resistant plantings around them and the addition of steel roofs as well.

The Dietz family were also evacuated out of their summer home in 2000 due to the Hi Meadows fire. The fire was determined to have been started by a lit cigarette thrown from a vehicle near Bailey, CO. Mr. and Mrs. Dietz have only one road into their property, so when the evacuation order came, Mrs. Dietz who was home at the time grabbed a tote packed for just such an occasion and prepared to leave. A fire crew from the local fire station arrived to see if the home was cleared, and upon arrival asked Mrs. Dietz if it would be possible to use their property as a lookout. The property has an unobstructed view of the Pine, CO valley. Mrs. Dietz gave permission and informed the crew that they were to help themselves to anything in the house, food, water, etc. The fire started to run up the hill below the property, but died down quickly thanks in part to their forest Ag program that resulted in thinning out many of their trees. Many of their neighbors also participate in the forest Ag program as well. (Dietz personal communication. 2/3/2014)

Montana

The Mountain Pine Beetle outbreak in Montana began later than it did in Colorado and South Dakota, starting in 2000. Climatic changes in the winter storms and drought were contributing factors to the outbreak. Normal Montana early fall temperatures will fall to -10°F several times and for a week or two at a time before warming back up to above freezing. Mountain pine beetle larvae can survive temperatures of sub-freezing cold for up to 30 days, due the ability to produce glycol to prevent them from freezing. Since the current outbreak began in

2000, these frigid cold snaps have not been as frequent as they once were, and the duration of the cold spell is shorter. Drought continues to be a problem as well, with snow levels even in the Rocky Mountains declining. The mountain pine beetle prefers the lodgepole pines of the upper elevations of Montana, and in the age range of eighty years old. 71% of Montana's lodgepole pines are in this age zone, on an estimated 2.2 million acres. On private land the ages are the same include another 116,000 acres. Of the state owned forest, there are many areas that have a serious overstock of host tree species. Wildfire suppression in these areas have led to trees with low vigor, close together and competing with each other for sunlight, water and vital nutrients. These factors make them defenseless to attack from mountain pine beetle. The beetles spread quickly and move from host to host with no difficulty. In 2007, the city of Helena, MT instituted an open space plan starting with the removal of dead or dying pine trees around the city. The city parks and recreation department personnel were in charge of selecting which of the trees to remove. The result has been much more open areas, the remaining trees are healthy, and the residents of the city have discovered new hiking trails. Part of the problem with the city's beetle problem was on-going drought and a century of fire suppression leading to a large overstock in host tree species. This is a common combination of factors in all beetle damaged areas.

My attempts to make contacts with Montana landowners, county extension agents, and federal individuals were unsuccessful. What contacts I did make were very brief in answers in emails. Amy Gannon, Entomologist with the Montana Department of Natural Resources and Conservation was helpful in referring a couple of research articles by Christopher Fettig. I also made contact with Crystal Beckman, also with the Montana Department of Natural Resources and Conservation Office. She is the Fire Prevention and Invasive Species Program Coordinator. She was able to refer me to the Firewise.org website for information on defensible space.

South Dakota

The first recorded interception of mountain pine beetle (formally named Black Hills Beetle) was in Lead, SD in 1898. (Hopkins, 1905) by William Pratt. A.D. Hopkins renamed several specimens of beetles collected prior to this date, after discovering that they were all the same species. The beetles had been collected and stored at the United States National Museum in Philadelphia, PA. Mr. Hopkins compared the new specimens with the old and determined that the specimens collected in Colorado, South Dakota and Utah were the same species. During several field collecting trips in the western U.S., Mr. Hopkins was able to determine that the beetles were not just endemic to the Black Hills, and renamed them "Mountain Pine Beetle" due the fact that the beetles appeared to attack pine trees in mountainous areas. (Hopkins, 1905) Many outbreaks of the beetles have occurred over time in the Black Hills. The dominate host tree is ponderosa pine. The elevation of the Black Hills is 7200 ft. which is within the growth range of the ponderosa pine which grows quickly in the Black Hills. Many outbreaks have occurred in the Black Hills National Forest including areas of four counties: Custer, Fall River, Lawrence and Pennington. Rapid City, SD is located in Pennington County, and is directly east of the main concentration of beetle outbreak in Custer and Lawrence Counties.

The city of Rapid City started receiving complaints from private landowners about declining ponderosa pines on the outskirts of town in 2012. An investigation done by South Dakota state foresters and extension foresters determined that mountain pine beetles had made their way into town for the first time. The South Dakota Department of Agriculture has massive amounts of information to aid landowners in identifying the signs of mountain pine beetle damage. Most of the residents already know this information; the area has been battling the beetles in the current outbreak since 1996. The beetles have infested or killed trees on over

430,000 acres of Black Hills forest land. (Brian Garbisch, personal communication, 2/6/2014) Lawrence and Custer Counties of South Dakota are timber production areas. Many of the logging operations in the two counties have been focusing on contract work with the state forestry office, county extension offices and landowners in removing the infested trees or treating more valuable and as yet un-infested trees for the beetles with a pheromone spray to mimic current infestation.

While on a brief vacation during the summer of 2013, I noticed that the ponderosa pines in the Hill City, SD area were predominantly red in color. After living in the area for well over a decade, I knew what this meant. I was distressed thinking that even a small fire in the area of the town would be catastrophic in scope, since there are many homes in the woods all around the city proper. I paid another visit to the area in 2014 and noticed a remarkable difference in the condition of the trees in the Hill City area. I stopped in at the Hill City, SD Chamber of Commerce and chatted with Mary Thomas, the office manager and all around volunteer of the day. We chatted for quite a bit in between tourists stopping in for information on sites to see in the area. I asked a couple of questions that I had, first did the local U.S. Forest Service office do any thinning in the area lately? Mrs. Thomas said "Oh yes! They started about a year ago, and with a couple of crews from the state and reservation, cleared out quite a few beetle trees all around town!" I could tell, and explained that I had been in the area the previous summer, and noticed a surprising difference. She also mentioned that two years of heavy wet snow and wet springs had also helped some trees green back up. I asked if any of the tourists had asked about the trees. She said that several of the returning visitors for the Sturgis Motorcycle Rally had noticed the difference as well. I found this interesting, I did not think about chatting with any of

the motorcycle riders in the Black Hills for the rally for my research paper. There were several taking a break in the chamber's parking lot, and I walked over to speak to a couple resting.

Bob and Mary Johnson visiting the area from Minneapolis, MN are Sturgis Rally veterans, participating for the 10th year. I asked how they were enjoying their visit, and explained I was doing a few on the spot interviews for my Master's degree final project. Mr. Johnson stated they would be happy to help. I asked what they had noticed most about the Black Hills in their last several visits. Mrs. Johnson brought up the numbers of "sick" trees. I asked her to explain what she meant, and she said that they had both noticed a general decline of many trees, even more so around the Mt. Rushmore area. I asked if they had heard of mountain pine beetle, and Mr. Johnson said that he had, and was hoping that it wouldn't make across South Dakota to the forests of Minnesota. Mrs. Johnson asked if I knew where the beetle had come from. I explained that they are native to the area. She then asked if there was anything that could be done to save the forest in the Black Hills, and I explained that the beetles would die back on their own eventually, but in the meantime thinning of the ponderosa pines was on-going and would help the healthy trees. The rest of their group had arrived by then, and we said our good-byes and I wished them a good visit.

Another area that I had visited in 2013 was the town of Custer, SD, just a short 30 minute drive down the highway. As I drove, I noticed more slash piles of ponderosa pine limbs waiting for winter burning along the highway. It's an annual event in the Black Hills, as soon as the first snow falls, the U.S. Forest Service lifts burning restrictions in the hills, and the timber companies go out and burn their slash/scrap piles.

Arriving in Custer, I stopped in at the Chamber of Commerce office and spoke to Karen Huber the office manager. I explained what I was doing for my master's project and asked if she

would mind answering a few questions. I asked her if any of the visitors had mentioned the trees around town looking "sick". She said, "Oh they ask all the time! We tell them about the bark beetles and explain that some of the hiking trails around town are closed because trees may fall". I asked if it appeared that visitor numbers were down. She said that several of the local Campgrounds that were normally booked for the entire week of the Sturgis Motorcycle Rally had several spots open, and a few groups had cancelled reservations at the state park. This was something new. I had not thought of checking with the campgrounds for their input.

My final stop was at the U.S. Forest Service District Office in Rapid City, SD. I talked to Ranger Kim Simpson, the visitor specialist for the day. When I asked about the thinning activity around Hill City, she said that it is part of an ongoing project along with another in the Custer State Park area and two more in the Wind Cave area as well. She also told me that the ranger district further northwest in Lead, Deadwood and Spearfish also had several projects that were going on as well. When I asked about hiking trails being closed in the Custer area, she explained the trails were closed as a precaution in the Black Elk Wilderness due to heavy outbreak activity and past infested trees in danger of falling down. Many had already fallen due to the blizzards in 2013, the storm she said had knocked down thousands, but because of the rugged terrain, there was little salvage or tree thinning going on in the area. When I asked about the beginning of the current outbreak, she responded with "it began about 1995, but really blew up in 1997 after several years of drought". I asked what was being done with the trees that were being cut down. She said quite a bit were being used as "cut and chunk" where the trunks are cut in two foot sections, and de-barked. The wood is left for the winter and in spring is available for picking up as firewood. Several tribal crews from the closest Native American reservation in Pine Ridge were coming up quite often and collect several loads to take back and pass out to residents for

heating fuel. I communicated with Brian Garbisch by email; our schedules didn't work out for a meeting. Mr. Garbisch works as a forest health professional for the South Dakota Department Agriculture, Resource and Conservation Forestry Office based in Rapid City. He was able to share some more contacts with me: Private Professional Foresters and Consulting Foresters in the Black Hills and a few private contractors as well. Unfortunately this was all the information that I was able to get from him, and the Pennington County Extension Office only had handouts.

Management and Control

Custer State Park, SD is home to not only a captive herd of American Bison, but is also a gathering place for other wildlife such as elk, mule deer, and antelope. It is also one of the busiest state parks in the state park system of South Dakota because of its location to Mt. Rushmore National Monument, Wind Cave National Park, Jewel Cave National Park and Devil's Tower National Monument, WY. Several other popular tourist stops are scattered in the area as well. Custer State Park was also the site of the Galena fire of 1988. After several years of drought, a storm system moved into the area and a lightning strike ignited the fire in the Grace Coolidge Drainage area on July 5, 1988 and it burned out of control in the Black Elk Wilderness until .75" of rain from another storm system aided firefighters in extinguishing it. After an aerial survey of the burned area, it was estimated that 16,788 acres were burned. The trees involved were predominately ponderosa pine. (Driscoll, 2004) The forest conditions in Custer State Park were similar to the conditions of the Yellowstone fires in 1988. However, the comparisons as far as mountain pine beetle is concerned differ as far as host tree. Years of drought, but unlike Custer State Park, the host trees in Yellowstone were lodgepole and white bark Pines. The elevations were different, however geographic layout was similar; there was more fuel on north facing hillsides than on the southern exposures. Water is retained on north slopes due to a lack

of solar radiation and heating causing evaporation. (Lynch, 2006) Another aspect of the Galena fire, was that it burned so hot that there were reports from firefighters of rocks exploding. (Driscoll, 2004) Several areas of northern Montana have also burned, but unlike the fires in Custer State Park that affected tourists to the area, the fires in Montana often effect timber production activities. There have been several fires in the Glacier National Park areas that have involved the evacuation of campers and tourists to the area. The predominate tree species are lodgepole pines that have been attacked by mountain pine beetles a decade or more previous. What is left, are "gray ghosts" of trees that have a tendency to burn quickly and fall in high winds. These "ghost" trees also occur in the ponderosa and white bark pines as well. Even with the destruction of forest fires, some good does come from the effects. With the thinning or falling after effects of affected trees, seed from cones are released and with cleared areas with moisture available, the tree seed from host species are able to germinate, take root and grow. The effects of fire also release needed nutrients into the soil as well, including carbon. Another regeneration activity that may be used includes replanting of specific species of trees for timber production or for their growth factors. A plan that may be in place for replanting is spacing of seedlings to prevent the re-introduction of mountain pine beetle into a new growth area. With planning these replanted areas for timber production will grow quickly and be available for harvest fairly quickly. (Griesbauer and Green, 2006) The amount of growth of these new plantings will depend on climate factors, namely occurrence of precipitation.

A few management options for the infested trees are classified as "direct control" and "indirect control". Direct control includes the use of fire, insecticides, sanitation harvests or a combination of several of these options. One of the direct options that were originally used in the Black Hills in 1901-02 was in the fall, locating the heaviest infestations, mark the trees, and

cut these infested trees down, then de-bark the tree. Without the bark, it was assumed by A.D. Hopkins that the beetles and larvae would not survive the winter. The wood was thought to be protected from further attack, and could be removed the following spring to be used for commercial building, the same as a cut, living tree. He did not advocate clear-cutting as a treatment, but selectively cutting the severally infested areas. (Hopkins, 1905) Another way of looking at this treatment is a localized treatment, and is now limited by budget, time, personnel, and equipment. Other considerations include environment and market conditions and logistical constraints. These controls work well on private lands, but on the public lands such as the National Forest System, the process can take years to implement while environmental groups fight a control plan with appeals and litigation. (Fettig, et al., 2014) Sanitation falls into the "locate, cut, and remove" treatment. A research study conducted by Christopher Fettig determined that following four criteria would aid in reducing the mountain pine beetle a more manageable level in numbers: 1) Early detection, the sooner the infested trees are located the better, 2) Rapid response, get the crews out to survey and determine the level of infestation of surrounding host trees. Implement the control process: cut and de-bark, cut and chunk or grind to mulch. 3) Continue to monitor the infested trees to see how quickly the insects are spreading or if they are spreading, and 4) Follow up treatments may be required to bring the numbers of beetles back to the desired manageable numbers. (Fettig, et al., 2014) Sanitation can be time consuming with ground surveys, aerial surveys and fresh infestations hard to see the first summer. Often the determination of attack is by the condition of nearby host trees.

Insecticide use has been used on non-infested high value trees in campgrounds, on private land or in city parks. It is sprayed directly on the tree, and has to be applied annually. The

treatment can be expensive, and if it needs to be done more than once a season, cost prohibitive. (Fettig, et al., 2013)

Fire has been used as to burn infested areas as a control method. A main deterrent to this management practice is the temperature of the fire needed to attain control would kill the adults and larvae, and still kill the tree. Several studies have been done on the effectiveness of using prescribed burns to control the mountain pine beetle, and have found that in ponderosa pine it actually increased the tree's death. Other studies found no effect at all. (Fettig, et al., 2014)

Indirect controls include clear cutting, thinning, and prescribed burns. Using clear cutting practices in only small blocks creates differing ages of host trees. With differing ages of lodgepole and ponderosa pine, mountain pine beetles struggle to find phloem thickness that will sustain the insect larvae until adult emergence. Many people find the idea of "clear-cutting" to be a negative effect on the view of the forest in general. Thinning by selecting for diameter limit in the lodgepole pines lowers the numbers of mountain pine beetle until the smaller trees have grown to the optimum diameter. Ponderosa pine thinning has the same effect, and increases the host tree's vigor and increases the amount of nutrients and moisture available for the remaining trees. (Mitchell, et al., 1981; Fettig, et al., 2014)

Management using any of the above direct controls during an outbreak of massive populations as has been the case for the last 18 years has been of limited value. The staggering of ages and diameters of lodgepole pine and thinning of ponderosa pine work better. Utilizing the clear cut blocks aids in natural re-seeding of lodgepole pine and would help in slowing the outbreak from spreading. The direct controls of sanitation, cut-chunk, and thinning aid in slowing local infestations of mountain pine beetle from spreading in ponderosa pine. (Ciesla, 2011)

Safety

Knowing your surroundings, especially at the vacation home or cabin in the woods is vital. For example, what trees are around the property? Do they seem to be dying or have a disease? This would be a good time to check with the local county extension office and pick up a guide to trees in the area, if you are not familiar with them. If you are and something looks out of place or odd, then contact the extension office for an inspector's contact name and number. There are several ID cards or handouts available on the internet to give the landowner some basic idea of what the exit holes, pitch tubes, boring dust and most importantly, woodpecker damage looks like. The South Dakota Department of Agriculture, Division of Forestry has an excellent one at: http://www.beatthebeetles.com.

Emergency Access is important. Often in a fire evacuation, areas will have one way in and out. Having second way out in case the main exit becomes blocked is a great plan. If the landowner chooses to stay until the last possible minute to try and help save the house/cabin, the only exit could be blocked or impassible. Emergency crews may not be able to assist in escape either. If possible, have an alternate route of escape and rally point for family members in a safe location or evacuation shelter.

Falling trees are a constant safety concern. A dead tree may be blown down in strong winds or fall from the weight of snow on the remaining branches. There is no warning when the tree will fall.

Defending the space sounds fairly simple, and there are lots of tips available online. The main safety tip would be to thin vegetation around the home. Firewise.org has a list of basic tips. There are three zones to consider when determining what vegetation to remove or trim;

Zone 1: Includes the house, wood decks, fences, etc., anything within 30ft in a circle around the house. Plants should be low growing, widely spaced of a species that does not burn easily. Some suggestions would be: Wild roses or wood roses, snowberry, bearberry. Keep the lawn mowed, tall grass dries out and burns fast. Prune trees up to 10ft from the ground, check and make sure trees do not overhang the roof.

Zone 2: Moving out 100ft from the house, if there are more trees or trees in general, make sure there is at least 30ft between clusters of trees or 20ft between individual trees. This is a helpful tip if planning on updating or adding to landscaping. Mix deciduous and coniferous trees. This aids in preventing insect pests from attacking all the trees. Create a fuel break using gravel walkways around the house and yard and with gravel or cement driveway. Trim the trees to 10ft from the ground.

Zone 3: Moving out another 100ft from the house (230ft total), thin small conifer seedlings or saplings in between the taller trees. These add fuel to a wildfire. Clean excessive ground litter: leaves, pine needles, pine cones. This is all extra fuel. Examine the tall trees closely. Are any of the tree tops/canopies touching? If so, contact a tree trimming professional about trimming the trees so they do not touch.

In all three zones it's vital that watering take place, especially in times of drought. (www.firewise.org)

Doing one or two of these things will help in a fire situation. The Firewise.org website also has a list of fire resistant plants as a suggestion for landscaping.

Alternate Uses for Damaged Wood

Firewood: this is easy, especially in cases where firewood may be used as a heating source in the home. An important thing to remember is that the wood should not be stored

anywhere near host trees, there is a possibility of the adult emerging beetles moving into an un-infested tree and spreading. Removing the bark removes the ability for the adult to use it for overwintering cover. Chipping the wood to use as mulch around flower beds, but away from the house aids in weed control and aids in retaining water as well.

Building material: 2 x 4s and other wood building parts can still be made from infested trees. The shelf life of some trees is 10 years, so it can be used for plywood. The blue stained wood that has been stained by the fungal feeding activities actually become popular to use as wood flooring material, cabinetry, furniture and wall paneling. There are several companies that specialize in finding a uses for this stained wood.

Economics

An aspect that the mountain pine beetle as also affected is the loss of jobs and money earned from recreational activities in infested areas. Many tourists go to the forested areas to enjoy green trees, wildflowers, hikes along creeks, etc. When arriving in an infested area, they are more prone to shorten their visit, or leave completely. Mountain communities that rely on tourism dollars are not able to survive a long winter without this money coming in. Jobs from seasonal positions in communities in the vicinity of forested areas with a severe outbreak may not last the entire season, or if a wildfire strikes the area, may not recover for many years. The use of any of the direct controls mentioned above would aid in keeping these tourists in the area. (Rosenberger, et al., 2013)

Employment in the timber harvest areas however has seen an increase in employment. These individuals are working as contractors to aid in thinning projects for the federal government or to working to aid landowners in removing infested trees. This new employment

may end with the end of the current outbreak in some areas, but for the time being, these jobs appear to be secure. (Nielsen-Pincus, et al., 2013)

Custer, SD has come up with way to celebrate the mountain pine beetle in a way that lets the townspeople and tourists learn more about the beetles. The organizers called it a celebration and renewal. The Bark Beetle Blues holds its celebration in January and includes parades, cook out (or in, depending on the weather), concluding the weekend with a burning of a bark beetle effigy. It's a small gathering of residents in Custer that is gaining in popularity in western South Dakota.

Discussion

What is understood about mountain pine beetle is that it is univoltine, relies on changing environmental factors (drought) to expand its range, and has a wide variety of host trees. It attacks pine trees of 80 years old and larger than 8 inches in diameter. Currently the most affected trees are lodgepole, ponderosa, and white bark pines. Lodgepole and white bark pine are found in higher elevations (5000ft-12,000ft) with the ponderosa pine only growing up to 9000ft in elevation with good climatic conditions, usually found below 7000ft. The mountain pine can produce two generations (bivoltine) in lower elevations in optimum environmental conditions with non-infested host trees close by.

The mountain pine beetles rely on a symbiotic relationship with a blue stain fungus. The adult beetle transports the spores of the fungi into the new host tree, where the fungi produces mycelium in the phloem and begins to interrupt the flow of water and nutrients to the tree. The most common species of blue stain fungi is *Grosmannia clavigera*. The spreading fungi creates the blue stain to the wood which is visible after the tree has been cut down. The beetles and larvae feed on the phloem which is high in carbon, but low in sterols, nitrogen and other

nutrients required for growth and molting of the insect larvae. The fungi produces ergosterol which provides the needed sterols and other nutrients that the insect requires. The mycelium produces the spores which the new adult beetles will transport to the next host tree.

Climate change and drought were both referred to in much of the literature reviewed for this paper. Rising temperatures of 2-5 °C is enough to aid in the survival of larvae over winter, and aids the overwintering adults under the bark as well. The larvae produce glycol from feeding on the phloem and receiving sterols from the blue stain fungi as well. This glycol aids in supercooling the larvae and prevents it from freezing during subfreezing temperatures of -25 °C for less than 30 days during winter. In order for the insect to be controlled by climate alone, subfreezing temperatures need to occur with more frequency and duration of longer than 30 days. Many areas seeing the severest effects of the current outbreak, have not seen low temperatures as these in five to ten years. Many areas are seeing abnormal warm winters, which will slow the life cycle of the mountain pine beetle in higher elevations, but does not stop it. Catastrophic fires such the 1988 Yellowstone fire had many blaming the whole fire on mountain pine beetles and the U.S. Forest Service letting the fire burn uncontrolled. This was not the case. The fire was found to have been caused by an electrical storm, several years of drought, overstocked fuels and insect damage. Not just the mountain pine beetle.

Management decisions of various governmental entities were brought up by several of the authors of reviewed materials. Some pointed at fire suppression activities of the U.S. Forest Service as the reason the mountain pine beetle numbers were so high. Others claimed it was the legal actions of environmental groups that were preventing the U.S. Forest Service from thinning areas of overstocked host tree species. What was agreed on was that thinning, selective cutting and creating chunks of de-barked wood to be used as firewood, or chipping the wood for mulch

were all feasible management options. Spraying has also been done, but it can be very expensive and is only useful on un-infested trees and must be applied every year. Because of the cost, this is only recommended on high value trees, such as home landscaping or in selected areas of campgrounds. Fire as a management option has been used in the past, with mixed results. The temperature of the fire required to kill the beetles and larvae would still kill the host tree. Plus the danger of having a fire in an extreme drought situation is not ideal. The potential for the fire to escape control of the officials in charge could be devastating to private property and losses to timber companies in lost trees is inestimable.

Creating a defensible space and safety around a home in the forest is important as well. Several interviews of individuals who live or work in the forest were conducted. Two of the interviews were with residents in Colorado. Both had experience with fire in their immediate area with different views. The Dietz family had bought 40 acres of land in the Pine, CO area 30+ years ago. They joined the Colorado State Forestry Agriculture program to harvest some of the useable trees and had other mountain pine beetle trees and *Ips* infested trees chipped for mulch around the area of the house. Mr. Rutt and his family also employed a defensible space around their house, and had been harvesting trees as a business for several years. Mr. Rutt is a volunteer firefighter, and had been called out on the High Park fire. After the fire, he returned to find his house intact, but several outbuildings destroyed. He had not cleared enough space around them. In both situations, the clearing around the property saved the home. Many times this is not done, and firefighting resources are called to save homes that could be working on stopping the fires from spreading. Many areas in Montana have also had large fires, and fortunately due to the sparsely populated areas, most homes are naturally equipped with a defensible space. The areas of high population are commonly tourist areas, and precautions must

be taken. In many communities in the Helena, MT area, several properties have at minimum a 30ft clearing around the home and many have some sort of fire resistant roofing material, many of the homes have steel roofing. The Black Hills of western South Dakota is a busy summer destination location with several national parks, Mt. Rushmore National Monument and several local communities have activities all summer long. There have been many thinning projected over the years and this has helped reduce the number of dying or dead trees, and may even be slowing the spread of the beetles. Along with communities in Colorado and Montana, the communities in the Black Hills are also following defensible space requirements and have evacuation plans in place in case of fire.

There have been media reports that the current mountain pine beetle numbers may be dropping in some areas of Colorado, but no research into this claim has been published at this time. Western South Dakota has had excessive amounts of moisture in the last two years with being ground zero for Winter Storm Atlas 2013, followed by very wet springs in 2014 and 2015. With this abundant moisture, new infestations of host tree species in the Black Hills are sure to be down. Moisture has been increasing in Colorado as well with two wet winters and springs. Montana, however is still in a drought situation and getting worse. Lowering mountain pine beetle numbers there may be a long way off.

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