TESTIMONY OF

Dr. John Ball
Professor of Forestry
South Dakota State University
Forest Health Specialist
South Dakota Department of Agriculture

Before the U.S. House Committee of Natural Resource
Subcommittee on Federal Lands

Hearing on

Seeking Better Management of America's Overgrown, Fire-Prone National Forest

Wednesday, 17 May 2017

The Black Hills, a forested refuge on the Northern Plains, encompasses 3.8 million acres in southwestern South Dakota and northeastern Wyoming. There is about 1.2 million acres of ponderosa pine (*Pinus ponderosa*) in the Black Hills. It is the dominant species across much of the Black Hills regardless of soils type, aspect or elevation.

Landownership of the Black Hills is dominated by the 1.5 million acres within the boundaries of the Black Hills National Forest. National forest system lands comprise about 1.2 million acres and the balance is highly fragmented with more than 300,000 acres of private forest land as inholdings.

The two major natural disturbance agents of ponderosa pine in the Black Hills are fire and mountain pine beetle (*Dendroctonus ponderosae*). One of the recent forest management challenges in the Black Hills was a mountain pine beetle epidemic. The epidemic began in the late 1990s and only recently ended. It resulted in more than 16 million trees being killed by the beetle during the past 17 years.

The mountain pine beetle is a native bark beetle found throughout western North America. The Black Hills has experienced recorded mountain pine beetle epidemics since the 1890s and evidence in the Black Hills and other western states suggests these events have occurred far longer. Ponderosa pine mortality from mountain pine beetle can be 50% or greater in forest stands during these epidemics.

Epidemics, while a natural occurrence, can have negative consequences. The loss of trees on private lands can adversely affect property value. Landowners must also content with large numbers of standing dead trees that increase the risk of fire and are a hazard for falling. Public lands are also impacted but to a greater degree due to the size of ownership. The amount of dead trees across broad landscapes negatively affects view shed. The dead trees are also a fall-hazard along trails and roads. The loss of trees killed by the beetles will affect volume available for sale and harvest in future years. The fallen trees can increase fire severity and complicate suppression actions.

Phases to an outbreak

Mountain pine beetle is generally found at endemic populations. An endemic state is one in which the beetle populations are so small that they are capable of mass attacking only an occasional large-diameter tree, one greater than 12 inches in diameter (diameter is taken at 4.5 feet above the ground and referred to as dbh). The beetles primarily persist within the phloem (inner bark) on smaller diameter trees that are colonized by other borers or stressed by root rot disease or lightning strike.

The incipient-epidemic phase is triggered by some event that allows a larger population of beetles to survive to emerge and colonize increasingly larger diameter trees. Once the MPB population exceeds 400 attacking beetles per acre, the trees chosen for colonization become larger than 10 inches dbh and may not have any signs of previous weakening injury.

As the incipient-epidemic phase continues the distance between colonized trees decreases from 150 feet to less than 20 feet. This is due to male and female mountain pine beetle aggregating pheromones released during initial attack and gallery construction. The density of attacking beetles overwhelms the defenses of the larger, healthier trees in a stand and the epidemic phase begins.

During the epidemic phase, tree vitality no longer becomes a predictor of attack success. Increasingly larger groups of trees are killed. As a mass-attacked tree nears the optimal colonization density, the production of an anti-aggregation pheromone by the beetles induces any additional attracted beetles to switch attacks to neighboring trees so grouping not only increases in area but also concentration. Nearly 100% of the trees within a grouping are killed.

The epidemic collapse phase begins due to depletion of large-diameter trees, the trees needed to sustain mass-attacks. The reduction in available phloem is also due to the rapid colonization and exploitation of infested trees by secondary beetles such as sawyer beetles. The feeding by these borers reduces the food available to mountain pine beetle resulting in poorer survival and fewer emerging as adults. Additionally, increased colonization by bacteria, nematodes, fungi and other insects compete with or feed on the mountain pine beetle.

The relationship of climate factors and epidemics

What triggers the change from the endemic to the incipient-epidemic phase and eventually an epidemic are still being studied. Climatic factors such as temperature variability and precipitation regimes are thought to play important roles in regulating mountain pine beetle populations. Cold winter temperatures, -35^{o}F, can cause sufficient mortality to end an epidemic but these are rare events. Extreme cold temperatures, -20 to -35^{o}F can reduce overwintering survival and subsequent emergence. The beetles require air temperature between 72 to 90^{o}F for flight. They also prefer bark temperatures between 65^{o} and 80^{o}F for investigating host suitability so more attacks on north sides of trees than south and more attacks in dense, cooler forests than open, warmer forest stands. Warmer temperatures during the beetle flight period, August for the Black Hills, can increase mortality and decrease flight activity.

Precipitation regimes can have an indirect effect on mountain pine beetles. Moisture stress is a critical agent in predisposing pine to successful colonization by bark beetles. Limited precipitation during the time period the tree is growing, as well as moisture stress during the flight period can reduce defenses, resin flow being the primary defense for pines. However, it is not a linear relationship to stress and defense. While severe moisture stress reduces defense, moderate moisture stress can actually increase defenses.

The Black Hills is unique among western forests in having detailed information on tree mortality from mountain pine beetle during the past 125 years as well as weather data going back to the early 1900s.

There have been four large landscape-scale epidemics recorded since the 1890s. These are epidemics that resulted in losses throughout the Black Hills and the accumulated tree mortality exceeded one million trees. There have also been several smaller, more localized outbreaks but the losses during these were limited to thousands of trees, rather than millions.

While it is impossible to have accurate numbers on tree mortality during the past 125 years due to differing means of counting (e.g. board feet, acres, and tree count) and survey methodology (e.g. horseback to aircraft, to high resolution aerial photography) a reasonable approximation can be made from the various data sources.

A review of the key climatic factors and the epidemics do not show a strong correlation between climate and epidemics (Table 1). The most recent epidemic occurred during a time period that was only slightly warmer but wetter than average. The 1990s, when the most recent epidemic began, was a decade of wetter than average climatic conditions, the wettest since the 1930s. There were two episodes of drought, 2000-2002 and 2005-2007.

The most noticeable difference in the data is the gradual warming, not of summer temperatures, but the January minimum temperature. Winter temperatures do have an influence on bark beetle survival. Mountain pine beetles are not freeze tolerant so must avoid freezing by hardening; eliminating much of the free water from cells and creating an antifreeze-like substance to prevent any remaining body fluids from freezing. Phloem temperatures must be maintained for several days at -20^{o}F during late autumn to kill 50% of the population. The bark also provides insulation and the temperature in the phloem is often 5 to 10^{o}F warmer than that of the air during short cold periods. The phloem and air temperatures only become equal if the cold persists for several days.

The relationship of forest conditions and epidemics

Bark beetle epidemics are not cyclical, at least as cycles are defined for insect populations. Epidemics do not occur at regular intervals, every 10 years for example. Instead they appear when there are sufficient resources to sustain an increasing beetle population. The small-scale epidemic of the 1930s was the first one following the 1890 epidemic that claimed more than 12 million trees. The 1930s epidemic losses were only about 500,000 trees. While the decade was drier and warmer than average, the standing timber volume on the forest was not high due to the lingering impact of the previous epidemic and harvests for homesteads and mining.

While environmental conditions, such as mild winters that reduce over-wintering mortality of the beetles and drought that increases tree stress may play a role in determining the severity of an epidemic, forest stand factors are the primary driver. The two key characteristics are tree diameter and stand density. Stands most susceptible to mountain pine beetle infestations have more than 75% of their trees at the 7 to 13 inch dbh range and the stand density is over 120 square feet of basal area per acre (basal area is the cross-sectional area of a trunk at 4.5 feet above the ground). The importance of stand density over environmental conditions such as drought is evidenced by the fact that the drought that occurred during the 1930s did not result in a widespread epidemic since stand densities were still low following the wildfire and beetle mortality from the early 1900s. It is generally recognized by forest pest managers that stands of older, larger diameter, less vigorous trees are essential for an outbreak of bark beetles to develop. This is why silvicultural treatments to thin out trees are considered an important strategy for reducing stand susceptibility to bark beetles.

Large trees ($\geq$ 10 inches dbh) are essential to sustaining an epidemic. They attract beetles into a stand and their colonization begins a chain reaction. Smaller trees may be attacked, but cannot sustain an outbreak. The reason for this is related to the food resources in a tree. A 14-inch dbh tree has 1.8 times the surface area of a 10-inch dbh tree, twice the basal area but three times the net production of beetles. In other words, far more beetles emerge from the tree than attacked it the previous summer. Substantial numbers of pine larger than 10 to 12 inches are required to build an epidemic as trees of these sizes or larger can have more beetles emerge than attacked. A stand of 6 to 8 inch trees may be attacked, but cannot sustain an epidemic as the amount of food-supplying phloem is insufficient for large broods to develop.

The stand density, how many trees per acre and their size, is also a key factor. However, the reason is not that a dense stand reduces the health of the trees. Stand density alone does not significantly reduce defenses – quality and pressure of pitch – to retard successful attacks. Instead, dense stands create a more favorable micro-climate for bark beetles to navigate and mass attack trees.

Mountain pine beetle must attack a tree in mass to overcome the resin defenses. If only a few beetles attempt an attack they will be overwhelmed by resin as they burrow into the tree. Instead large numbers of beetles must attack within 4 to 5 days of the initial attack if their efforts are to be successful.

A coordinated attack requires a means of communication and bark beetles produce pheromones, chemical messengers, to call other beetles in for attack. The pioneer female beetles produces a pheromone to attract males and females. The pheromone is synthesized from terpenes in the tree. The larger the tree, the thicker the phloem, the more terpenes, hence larger trees will produce a greater "calling card" than smaller trees.

The pheromone is most effective as an attractant if the air is stagnant and the pheromone does not disperse. Open stands experience more air flow and the unstable air disrupts orientation of the beetles to odor plumes, which guide mass attacks to suitable hosts.

The unstable air also interferes with beetle navigation to the targeted tree. Mountain pine beetles are not strong flyers and have an average flight speed of about 1 to 2 miles per hour (mph). Wind speeds of greater than 5 mph interfere with flight and instead the beetles are pushed by the wind. Open stands have higher wind speeds so are more disruptive to navigation. Furthermore, convection caused by mid-day heating results in beetles being carried by updrafts.

Closely spaced trees provide the ideal environment for concentrating attacks on nearby trees. Most beetles fly less than 300 feet to find a new host as long as suitable host material is available hence attacks often appear as slowly enlarging pockets that coalesce as the epidemic continues. If the stands are open, some of the beetles, about 2 to 3%, will be carried above the canopy by the turbulent air. They "surf" the drafts by folding their wings and dropping to lower altitudes as temperatures cool below the threshold for flight. They can be carried downwind 18 to 62 miles, and occasionally hundreds of miles. The beetles cannot actively determine their landing location; they are subject to the wind. The landing location is as likely to be a prairie as a forest. Several years ago a flight appeared in the prairies of western Nebraska that is thought to have originated in Colorado.

Stand density clearly has a major influence on the beetles' success at colonizing suitable pines. Open stands have only about 20 to 30% of the capture rate of adult beetles compared to dense stands. Open stands may also experience about 5 to 10% of the pine mortality of dense stands. The most susceptible ponderosa pine stands to mountain pine beetle colonization have 20% of their basal areas in pines 10 inches dbh or greater, have a basal area greater than 110 ft^2/acre with more than 97% of that basal area occupied by pines.

Management

An array of direct and indirect actions were utilized throughout western North American to manage the mountain pine beetle during this latest epidemic. Direct actions are those employed to reduce beetle populations, while indirect actions are aimed at manipulating stand conditions to reduce susceptibility to an infestation. It is believed these actions do not necessarily bring an end to an epidemic which is driven by a host of biological factors, but instead protects trees and stands.

The objective of direct actions is to kill the beetles before they emerge as adults. The intent is to reduce the population enough to limit mass attacks. Direct actions include removal of infested trees, lethal baiting (pheromone-baited trees sprayed with an insecticide), and solar treatments.

Indirect actions center on reducing stand density. The objective is to reduce the basal area to between 40 and 80 ft^2/acre. This action creates a more open forest environment that is less favorable to the beetles' attempts to mass attack trees. A combination of direct and indirect actions are recommended when infestation are widespread.

A wide array of mountain pine beetle management actions have taken place across the Black Hills during the course of this epidemic from indirect actions, reducing stand density by thinning, to direct actions such as sanitation harvests to solar treatments. There is no better example of the application of these direct and indirect actions than Custer State Park located in the southern Black Hills of South Dakota. Custer State Park is located south of Rapid City, SD. The 2400 acres in the northwestern corner of Custer State Park, known as the Needles, experienced an incipient-epidemic mountain pine beetle population transitioning to an epidemic population beginning in the early 2000s. During this epidemic indirect actions, including thinning, were conducted to reduce stand susceptibility as well as direct actions, such as sanitation harvests and solar treatments. In addition, semiochemcials have been employed with aggregation pheromones used as barrier and grid baiting as well as lethal baiting. High-value trees in campgrounds and near resort buildings have been treated with carbaryl or permethrin to protect individual trees from successful attack.

What makes Custer State Park an ideal site to evaluate the efficacy of mountain pine beetle treatments in the Needles area is that it bordered the Norbeck Wildlife Preserve, including the Black Elk Wilderness Area in which no actions were implemented during the epidemic. There were many similarities between the stand conditions on each side of this boundary before the epidemic began with each dominated by ponderosa pines with many of these stands composed of mature pines greater than 12 inches dbh.

However, now almost 14 years later, the appearance between the two forests is very striking (Figure 1). The ponderosa pine mortality from mountain pine beetle in the Black Elk Wilderness Area is nearly 80%, while within the adjacent lands of the Custer State Park the accumulated mortality from mountain pine beetle over the 14 year period is slightly less than 20%. The pine mortality due to mountain pine beetle is even lower in the main body of the Park, generally less than 10%, than along the western and northern portions of the Park that border the Norbeck.

Furthermore at the end of the epidemic, not only were nearly four out of five trees in the Wilderness Area killed by mountain pine beetle, the average diameter had been reduced as well as the basal area (Table 2).

The efforts to actively manage mountain pine beetle extended beyond Custer State Park. A "Black Hills Regional Mountain Pine Beetle Strategy" was developed by a coalition including the USDA Forest Service, USDI Bureau of Land Management, USDI National Park Service, South Dakota Department of Agriculture and Game, Fish and Parks, the seven Black Hills Counties, the Black Hills Forest Resource Association and private landowner representatives.

The South Dakota Department of Agriculture was the lead agency for coordinating efforts on private lands. Appropriations totaling $10 million were provided by the South Dakota legislature for this effort to survey, mark, and treat federal, state and private land. Addition source included $600,000 from Landscape Scale Restoration Competitive grants from the US Forest Service State & Private Forestry, and Western Bark Beetle funds from USDA Forest Service Forest Health Protection. Since 2012, an average of 600 to 1,000 private landowners were able to treat and protect their lands.

Private landowners were provided with assistance in marking infested trees and a cost-share program was initiated to assist in treating these trees. A cooperating agreement with the Forest Service allowed landowners to treat infested trees on National Forest System lands that were within 300 feet of their property.

The harvest of trees, including infested trees, increased greatly during the 2000s and 2010s (Table 3). The annual harvest more than doubled from the rate in the 1990s. The combination of thinning susceptible stands and removing infested trees greatly reduce further losses in the treated stands (Figure 2).

The fourteen cooperators in the "Black Hills Regional MPB Strategy" from 2012 to 2016 conducted beetle surveys and treatments on a cumulative 800,000 acres, harvested 155,000 acres of beetle-infested and over-grown trees, and thinned 58,000 acres of small (non-commercial) trees. These efforts were significant in direct control of beetle populations in key private and public lands and in creating more resilient forest over broad landscapes for the long-term. Forest resources were protected in important areas like Mount Rushmore National Memorial, Custer State Park and national forest recreation areas. In this effort the cooperators invested nearly $90 million from 2012 to 2016, about 30% for direct control and 70% for long-term forest resilience. The commercial harvest sustained about 1,200 direct jobs and returned about $120 million to the local economy.

Conclusion

The 1997-2016 epidemic was predicted back in mid-1980s based on the trend that harvests were being reduced as volume increased. The key to an epidemic is sufficient food resource to allow the beetle population to continue to expand.

Ponderosa pine forest regeneration and growth is prolific in the Black Hills. Almost every acre of the Black Hills has been cut at least once during the past 125 years. The 5th billion board foot of timber was harvested in 1997. At that time there was estimated to be about 5 billion board feet on the forest; in 1899 there was an estimated 1.5 billion.

There are three means of reducing the density of the forest, fire, bark beetles and timber harvest. While each can reduce stand density, they differ in fundamentally important ways. Fire can thin, and in some instances eliminate, a forest stand. Bark beetles can do the same. Only timber harvest can be regulated to a finer degree to reduce stand densities to a target level and not beyond in a landscape of intermixed private and state/federal lands.

Selected references

Allen, K.K. and D.F. Long. 2008. Evaluation of mountain pine beetle activity in the Norbeck Area, Black Hills National Forest. Forest Health Evaluation RCSC2-08-03, U.S. Department of Agriculture, Forest Service, Rocky Mountain Region, Renewable Resources. 8 p.

Ball, J. and C. Taecker 2013. Survival of Mountain Pine Beetle in Unpeeled Logs. *Western Journal of Applied Forestry* 28: 154-157.

Carroll, A.L., T. L. Shore and L. Safranyik. 2006. Direct control: theory and practice, pp. 155-172. *In* Safranyik, L. and B. Wilson (eds). *The Mountain Pine Beetle: A Synthesis of its Biology and Management in Lodgepole Pine.* Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC, Canada. 304 p.

Harris, J. L. (comp.); R2 FHP staff, and State Forest Health Specialists, 2014. 2013, *Forest Insect & Disease Conditions, Rocky Mountain Region (R2)*. USDA Forest Service. State, Private Forests, Tribal Relations, & Forest Health Protection (SPF-TR-FHP), R2-14-RO-32. 77 pp.

Lessard, G. 1986. Mountain pine beetle mortality in ponderosa pine, Black Hills of South Dakota and Wyoming. Biological Evaluation R2-86-02. Lakewood, CO; U.S. Department of Agriculture, Forest Service, Rocky Mountain Region. 7 p.

Riva, R.J. 2009. South Dakota's Forests 2005. U.S. Department of Agriculture Forest Service, Resource Bulletin NRS-35. Northern Research Station, Newtown Squares, PA. 96 p.

Six, D.L., E. Biber and E. Long. 2014. Management for mountain pine beetle outbreak suppression: Does relevant science support current policy? *Forests* 5: 103-113.

Table 1. Mountain pine beetle epidemics in the Black Hills and key climate factors

Time period	Tree mortality	January average minimum temp (°F)	August average maximum temp (°F)	Precipitation April -June (inch)	Precipitation April -Sept (inch)
1895-1908	12.1 million trees	na	na	na	na
1946-1955	2.9 million trees	-18.9	79.6	9.9	15.9
1968-1984	4.8 million trees	-16.7	79.2	10.5	16.5
1997-2016	16.7 million trees	- 8.0	79.4	14.1	17.6
Average (1909-2015)		-14.1	79.0	9.9	16.3

Table 2. Stand characteristics in the Black Elk Wilderness Area before and after the epidemic.

Epidemic	Trees/acre	Average diameter (inches)	Basal area (ft^2/a)
Before	230	10.1	137
After	61	6.9	18

Table 3. Annual harvest in the Black Hills in million board feet (MMBF).

Year	Total Harvest (MMBF)	Harvest of Infested Trees (MMBF)
2012-2013	130	23
2013-2014	121	15
2014-2015	130	18
2015-2016	134	6

Figure 1. Aerial photograph taken of the Needles area of Custer State Park and the adjacent Black Elk Wilderness Area.

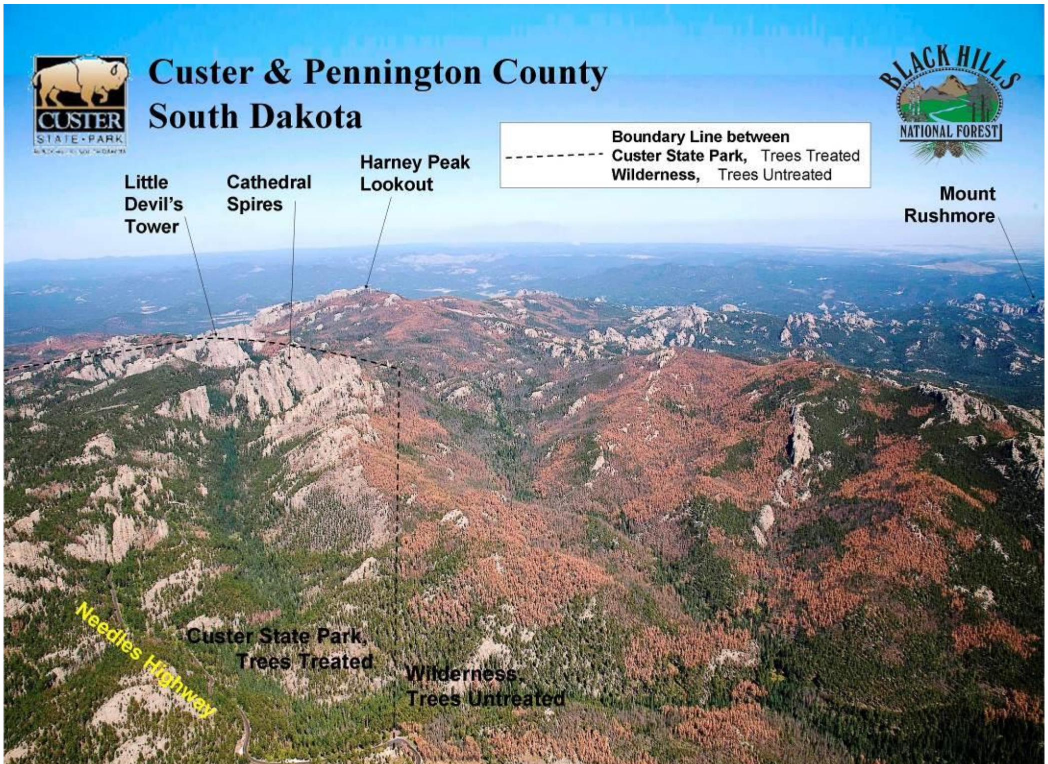

Photo looking north September 10, 2009

Figure 2. Aerial photograph of Forest Service timber sale surrounded by infested trees.