Cold tolerance and seasonal generations of the western pine beetle in California

Talking Points:

- Historical temperature records suggest that episodes of western pine beetle winter mortality in California due to extreme cold temperatures are infrequent and mostly restricted to the northeastern parts of the state.
- Most areas on the west slope of the Sierra Nevada range, especially lower elevations of the ponderosa pine belt, have likely never experienced significant winter mortality of western pine beetle during the period of record.
- Monitoring in 2017 found no increase in the number of generations of western pine beetle on the Lassen and Stanislaus National Forests compared to historic observations when differences in elevation and latitude are accounted for.

Background Information

The west slope of the southern Sierra Nevada range of California recently experienced one of the largest tree mortality events in recorded history. Well over 100 million trees have died since 2010 due to a combination of extreme drought, high stand density and bark beetle infestation. Increasing temperatures, expressed as warmer winters and hotter summers, were also cited as contributing factors by increasing moisture stress in trees, increasing life stage development rate for bark beetles (increase in the number of generations) and increasing bark beetle survival rates (reduction in winter mortality). While it is clear that hotter summer temperatures and longer growing seasons can increase water demand in trees, the effect of recent warmer winters and hotter summers on bark beetle reproduction and survival is not well-known and varies by bark beetle species and location. This report reviews existing information on cold tolerance and the number of seasonal generations of the western pine beetle (*Dendroctonus brevicomis*), the bark beetle species responsible for the recent, exceptionally high level of, ponderosa pine mortality in the south Sierra Nevada range. All historical research is from Miller, J. M.; Keen, F. P. 1960. *Biology and control of the western pine beetle***.** Misc. Pub. 800. Washington, DC: U.S. Department of Agriculture; 381p.

Cold Tolerance

There are large differences in average and extreme winter temperatures within the range of western pine beetle and ponderosa pine in California. Winter temperatures on the eastside of the Sierra Nevada range, in the southern Cascade Range, and across the Modoc Plateau, frequently drop to near or slightly below 0°F, but rarely drop to extreme sub-zero levels (less than -20°F). These infrequent sub-zero temperatures tend to occur only at night alternating with above-zero daytime temperatures. Winter temperatures on the west slope of the Sierra Nevada range are generally much warmer with very infrequent sub-zero events and only one known extreme sub-zero temperature recorded (Table 1).

Western pine beetle larvae feed within tree bark which provides some protection from cold temperatures. Depending on bark thickness, internal bark temperatures can be up to 8° to 20°F warmer than the ambient air temperature. Overwintering larvae also develop cold hardiness due to the formation of glycerol in their bodies that acts as anti-freeze. Sub-zero winter temperatures occurring for a couple of nights are not likely to cause larval mortality unless they drop below -15°F. When winter temperatures drop below -15°F or remain slightly below zero for several days, internal bark temperatures can become cold enough to kill overwintering larvae.

Western pine beetle larvae begin to develop cold hardiness by the end of October and reach the same level of cold tolerance regardless of the severity of winter temperatures. Laboratory studies have determined that -
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Table 1. Select temperature records for locations within the range of ponderosa pine in CA.

Location	Elev (ft)	Average Winter Low Temp (°F)	Lowest Recorded Temp (°F)	Date	Average # days <= 0 degrees (°F)	Period of record
Northeastern California						
Sierraville	4975	16.6	-29	2/13/1949	11.2	1909-2012
Alturas	4400	18.5	-34	2/5/1989	7.7	1905-2012
Portola	4850	19.3	-28	1/4/1971	4.8	1915-2012
Burney	3198	20.6	-26	1/25/1949	3.4	1948-2012
Susanville	4212	22.2	-23	1/18/1952	2.4	1893-2012
Adin	4195	22.6	-26	1/22/1962	3.1	1894-2012
McCloud	3280	24.7	-12	1/8/1937	0.5	1909-2012
Quincy	3420	25.5	-28	12/12/1972	1.5	1895-2012
West slope Sierra Nevada						
Huntington Lake	7020	22.8	-18	2/13/1949	1.6	1915-2012
Giant Forest	6414	24.4	-5	1/21/1937	0.3	1921-1968
Grant Grove	6600	25.8	-6	2/13/1949	0.2	1940-2012
Yosemite NP HQ	4018	26.3	-6	12/30/1911	0.1	1905-2012
Calaveras Big Trees	4695	27.9	-4	12/11/1932	0.1	1929-2012
Springville Tule HD	4070	29.1	-2	1/21/1937	0.0	1896-1955
Nevada City	2781	30.8	-1	1/21/1937	0.0	1893-2012
Georgetown	3001	35.4	9	12/11/1972	0.0	1946-2012
Northwestern California						
Fort Jones	2725	24.9	-23	1/8/1937	2.1	1936-2012
Hayfork	2300	27.3	-4	12/11/1932	0.3	1914-2006
Southern California						
Lake Arrowhead	5205	29.5	5	2/14/1949	0.0	1941-2011

Notes - Coldest California temperature ever recorded = -45°F, Boca (near Truckee) 1/20/1937
- A temperature of -21°F was reported on the west side of the Sierra Nevada at Wawona, CA in January 1937

cold tolerance regardless of the severity of winter temperatures. Laboratory studies have determined that -7.5°F will kill most larvae in a couple of hours, -5°F will kill >50% of larvae and even 0°F for an extended time will cause some larval mortality. For overwintering larvae to experience these temperatures in a tree, ambient air temperatures would have to be substantially lower and sustained (e.g. -15° to -20°F). Western pine beetle larvae are also thought to be less susceptible to sudden short-term cold temperatures in the fall due to insulating properties of ponderosa pine bark, and in the spring because larvae maintain their cold hardiness.

Mortality of western pine beetle larvae due to cold temperatures has been documented four different years (1924, 1932, 1933 and 1937) in central Oregon and northeastern California. The winter of 1932-1933 was especially damaging to an ongoing outbreak; causing up to 90% larval mortality in some locations. However, this cold event only reduced the infestation for one year and did not end the outbreak. The general consensus of researchers monitoring western pine beetle infestations during these historic cold temperature events was that anything less than 50% reduction in beetle populations had little to no effect.

Only one report of western pine beetle mortality is known to exist for extreme cold periods that have occurred since 1937. Dead western pine beetle larvae were observed in infested ponderosa pine on the Lassen National Forest in 2013 after January temperatures dropped to -26° and -21°F on consecutive nights

in Pine Creek Valley. However, it is likely that several other cold temperature events recorded in northeastern California since 1937 resulted in some level of western pine beetle mortality. Only one record of western pine beetle mortality due to cold temperatures is known to exist for the west slope of the Sierra Nevada. Western pine beetle mortality was estimated at 15% on a single tree near Bass Lake, CA during a survey of insect mortality after the record cold temperatures of January 1937. This survey concluded that western pine beetle mortality was restricted to cold air drainages and that most weather stations within the west side ponderosa pine sub region did not record temperatures low enough to produce lethal conditions for a large part of the overwintering forest insect population. The survey also found no abnormal mortality of forest insect broods in southern California (Salman, K.A. 1937. *Reconnaissance of 1936 and 1937 winter mortality of forest insects in California*. USDA Bureau of Entomology and Plant Quarantine, Berkeley, CA; 3 p.). Weather records dating back to the late 1800's and early 1900's suggest that winter mortality events would have been rare to non-existent in most locations within this region.

Seasonal Generations

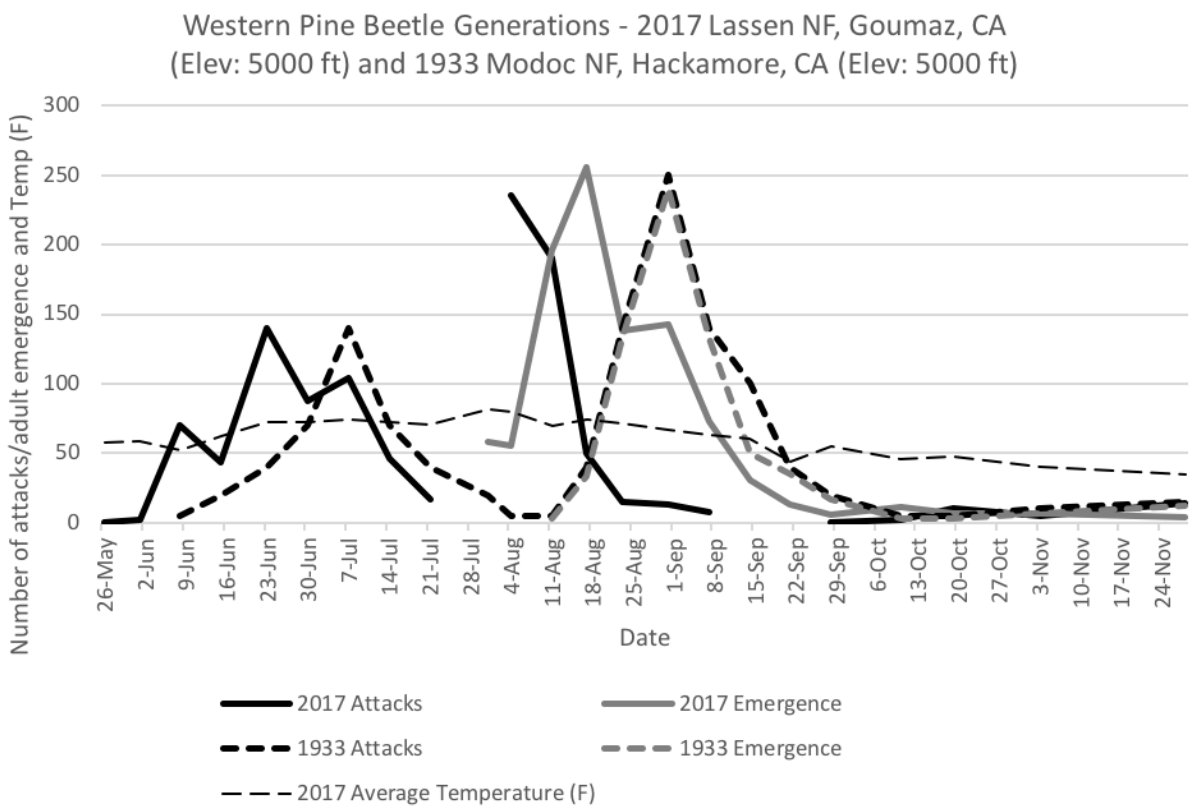
Most of the literature on western pine beetle life stages and development describes from two to four generations per year depending on location. In the northern part of their range and at higher elevations, the beetles produce two generations each year, with attacks in early June and late August. In the south and at lower elevations, the beetles produce three and sometimes four generations each year, with attacks as early as March and as late as November. The third and fourth generations are typically described as "partial" generations and make up a smaller percentage of the total population. Year to year variation in temperature can influence the rate of life stage development but likely results in no more than one extra partial generation. Researchers monitoring western pine beetle outbreaks in the 1920's and 1930's concluded that the level of tree mortality in any particular region or year seem to have little relation to the number of beetle generations produced per year.

In 2017, Region 5 Forest Health Protection monitored western pine beetle development at two locations. One monitoring site was on the Lassen National Forest near Susanville, in northeastern California, the second site was on the west slope of the Sierra Nevada, on the Stanislaus National Forest, near Strawberry. Five trees were baited at each site in early to mid-May to initiate mass attack by adult beetles. The number of attacks within a predetermined section of the bole were recorded weekly (Lassen NF) or biweekly (Stanislaus NF). After trees were fully colonized, cages were placed on the trees to capture and record emerging adults. A second set of five trees were then baited at the beginning of August to repeat the monitoring cycle. A third set of trees were baited in late September and monitored on the Lassen NF site. Temperatures were recorded at 1-hour intervals for the entire season.

The Lassen National Forest monitoring revealed one full seasonal generation, an overwintering second generation (overwintering larvae) and a very small partial third generation (overwintering eggs). These results are nearly identical to studies on the Modoc National Forest in 1933 (Figure 1). The Modoc study site was at the same elevation (5,000 ft) and one degree north in latitude. The timing and number of generations on the Stanislaus National Forest (5,400 ft) was similar to the Lassen. The main differences being an earlier date of attack initiation by the adult beetles (May 22 for Stanislaus NF and June 8 for Lassen NF) and the emergence of a larger partial third generation. The number of generations recorded at the Stanislaus site were fewer than determined by researchers at lower elevation sites (3,000 - 4,000 ft) near North Fork on the Sierra National Forest from 1926 to 1933. Results of that historic effort revealed two full seasonal generations and large partial third and small partial fourth overwintering generations. Winter temperatures in 2017 were generally above the long term average but cooler than 2014, 2015 and 2016 respectively. There were likely a few earlier attacks initiated by overwintering adults (April and early May) that were not detected by this monitoring effort.

Temperature data loggers at both the Lassen and Stanislaus sites recorded hourly temperatures during the hottest summer on record in California. Monitoring will continue in 2018 to capture year to year variation and develop a predictive model for western pine beetle life stages and development.

Figure 1. Timing of western pine beetle attack and emergence (Lassen 2017 & Modoc 1933)



Summary

Historical temperature records suggest that episodes of western pine beetle winter mortality in California due to extreme cold temperatures are infrequent and mostly restricted to northeastern parts of the state. Historical observations of larval mortality during extreme cold events in the 1920's and 1930's indicated that 90% mortality only slowed an outbreak and at least 50% of the population had to be killed to have any effect at all. Most areas on the west slope of the Sierra Nevada range, especially lower elevations of the ponderosa pine belt, have likely never experienced significant winter mortality of western pine beetle during the period of record.

Recent monitoring of western pine beetle development on the Lassen NF showed a strong similarity to observations made in 1933 for northeastern California. The timing and number of generations was nearly identical to historic observations, even during the hottest summer on record. The number of generations on the Stanislaus NF was also consistent with historic observations when differences in elevation are accounted for. More observations are needed in other parts of California over a longer timeframe to better describe year to year variation and detect any differences from the historic record. Continued monitoring will also provide the data necessary for modeling western pine beetle development to predict potential life cycle changes with increasing temperatures.

Climate change is likely to impact bark beetle life cycles and tree health in California for the foreseeable future with the general consensus that conditions will become warmer and drier. While the impacts to bark beetle development and survival are unclear, drought stress on California's forests is likely to increase. Under this scenario, reducing tree density and creating stand heterogeneity in species composition and size class will be critical to increasing the resiliency of California's forested landscapes.

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