Methods

**Study Area**

**Data Sources**

We acquired interpolated daily minimum and maximum temperature data covering the study area for the years 1980 - 2016 from the Daily Surface Weather And Climatological Summaries (DAYMET) project (THORNTON et al., 2017). The DAYMET data sets are distributed as raster tiles in a Lambert Conformal Conic projection with 1km x 1km grid cells. We retrieved daily temperature records for 8 weather stations in Idaho (USA) from the National Oceanic and Atmospheric Administration (2018; Table 1) for model verification.

For MPB tree mortality, we retrieved raster data containing the estimated number of trees killed due to MPB in both ponderosa and lodgepole pines for the years 1997 - 2010 (Meddens and Hicke, 2014). [Brief description of their datasets…]. To determine which raster cells to use for analysis, we calculated the set of raster cells that had nonzero tree mortality in any of the sample years. We then converted the retained raster cells to point data, each point associated with a vector of counts of MPB-associated tree mortality in each of the years.

Range maps for Pinus ponderosa and P. contorta were those in Little(Little, 1971).

**MPB Survival Model**

To estimate the potential MPB overwinter survival rates, we implemented an object-oriented version of the physiological process-based model of MPB cold tolerance created by Régnière and Bentz (Régnière and Bentz, 2007) in Java (version 1.8). Their model uses daily temperatures to track the proportions of MPB in one of three physiological states. The states each represent different phases of individual beetles’ cold hardening processes. The population-level cold hardening status (state variable C in Régnière and Bentz, 2007) status tracks the daily temperatures. This allows for rapid drops in temperature to catch more beetles in a less cold-hardened state, resulting in reduced survival. Slowly decreasing temperatures allow a greater proportion of the population to transition to the most cold-hardened state to better withstand cold temperatures. To verify the correctness of our model implementation, we compared survival estimates using temperature data from the weather stations to those found in Table 1 of Régnière and Bentz (2007)

Github page for model code: <https://github.com/michaelfrancenelson/RegniereBentz_ColdTolerance.git>

* Repository is private for now, but when we publish I’ll create an official public release.

**Time Lag Analysis**

We used our model to calculate yearly MPB overwinter survival rates for each raster cell in the daily climate data to create a stack of yearly MPB overwinter survival rasters. For each point in the tree mortality data, we then extracted the MPB yearly survival values from the raster cell containing the point’s coordinates. For each of the years 1997 - 2010, we determined the set of points that had nonzero tree mortality. Points with zero MPB tree mortality for the year were assumed to correspond to areas without MPB activity or missing data. To perform the time lag analysis we compared the tree mortality count for the year to the modeled MPB overwinter survival for each of the years from four years before the tree mortality to five years after. For example, tree mortality data from 2005 were compared to MPB overwinter survival for the years 2001 – 2010. (This describes the ‘regular’ plots, the ‘delta’ plots had a slightly more complicated procedure.)

[We’ll have to think about whether any statistics are possible for the time lags…]

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Station Name | Lat | Lon | Station ID | Date Range | Reference Survival | Survival | Diff |
| Fairfield Ranger Station | 43.34 | -114.79 | USC00103108 | 1960 – 2017 | 0.353 | 0.408 | 0.055 |
| Ketchum Ranger Station | 43.68 | -114.36 | USC00104845 | 1974 – 2017 | 0.556 | 0.550 | 0.006 |
| Stanley | 44.17 | -114.93 | USW00004112 | 1963 – 2017 | 0.184 | 0.205 | 0.021 |
| Banner Summit | 44.30 | -115.23 | USS0015E11S | 1980 – 2017 | 0.510 | 0.602 | 0.092 |
| Galena | 43.88 | -114.67 | USS0014F17S | 1988 – 2017 | 0.547 | 0.533 | 0.014 |
| Dollarhide Summit | 43.60 | -114.67 | USS0014F08S | 1988 – 2017 | 0.698 | 0.777 | 0.079 |
| Galena Summit | 43.87 | -114.71 | USS0014F12S | 1988 – 2017 | 0.613 | 0.652 | 0.039 |
| Vienna Mine | 43.80 | -114.85 | USS0014F04S | 1988 - 2017 | 0.610 | 0.623 | 0.013 |

Table 1: Model verification: The Reference Survival column are the mean survival values obtained from simulated weather created using the 30-year normal climate average data at the locations (from Table 1 in Regniere and Bentz, 2007). The Survival column is the mean of the estimated MPB survival outputs of our model implementation using daily temperature data from the stations during the date ranges shown. The Diff column is the magnitude of discrepancy between the two estimates.