

Final Project Report:
Mountain Pine Beetle Predictive Mapping: Dead-Red Trees 2011-12

Due: April 11th, 2012

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Introduction

In June 2006, the devastating outbreak of mountain pine beetle (*Dendroctonus ponderosae*) overcame the barrier of the Rocky Mountains and spread into the west-central region of Alberta for the first time ever; a flight distance of about 400 km (ASRD 2009). Since then, there has been increasing concern that the beetle will enter the boreal forest and kill vast forests of Jackpine (*Pinus banksiana*), one of the dominant tree species of the boreal ecozone, which span eastward across Canada. Mature lodgepole pine (*Pinus contorta*), is the dominant pine species found in B.C and western Alberta and is the endemic host of the mountain pine beetle (MPB); however recent research has shown that MPB can successfully reproduce in Jackpine (Cullingham *et.al.* 2011). The hybrid pine zone in Alberta, where lodgepole and jackpine interbreed, is primarily where the current MPB outbreak is centered. Pockets of beetles are also located at the south- western Alberta border and found spreading north-east into jackpine forests. Moreover, increasing temperatures resultant from climate change are likely responsible for increasing MPB populations because consecutive cold winter temperatures are required to kill and control population levels of MPB; this phenomenon now rarely occurs.

The MPB will overwinter in a host tree and emerge in the summer and disperse by flying for 7-10 days (Safranyik *et. al.* 1999), travelling distances of 40 – 100 km per day above canopy (Jackson *et. al.*, 2007), and under wind conditions. One-year after the initial attack of beetles on alive trees (green-stage), the pine needles turn red (red-stage) and the trees die. Insect pest surveys performed from fixed-wing aircraft or helicopters usually document the red-stage of the MPB spread. Thus, winter conditions of the previous year, during the green-stage, can be used to estimate over-wintering survival and predict where, and how many, beetles will attack.

Research Objective

My objective was to determine the severity of MPB outbreak in Alberta using known locations of dead trees to predict the expansion of future attacks divided into three suitable habitat types: lodgepole pine, jackpine, and hybrid pine forests. Specifically, I predicted suitable areas of future dispersal using temperature as the major predictor of overwintering survival, as well as habitat foraging criteria and MPB flight characteristics. I implemented these criteria in ArcMap (ESRI 2008) to create digital maps and map predictions. Here, I outline the methods used, including the educated criteria selection in the analysis as well as visual aids to help understand the analysis procedures.

Data Sources

Table 1. Summary of Data Used in the Analysis of Suitable Habitat for MPB Expansion and Mapping Presentation		
Dataset	Purpose	Source
Canadian Ecozones	To make up the gap in potential habitat between the lodgepole and jack pine distribution data	http://sis.agr.gc.ca/cansis/nsdb/ecostrat/gis_data.html
MPB survey point data (06-2010)	Proof of where the MPB has been a is likely to go	http://www.srd.alberta.ca/LandsForests/ForestHealth/ForestPests/ForestPestSurveyData.aspx
Alberta Places	To see if the survey data fit known distribution of MPB in Alberta and use in map display	www.geobase.ca

Climate Stations of Alberta with historical monthly (Dec-Feb) temperature for Winter Years 04-2011	Generate a winter minimum temperature climate model using minimum monthly winter (dec-feb) climate models for winter years 04-2011	http://www.climate.weatheroffice.gc.ca/prods_services/cdn_climate_summary_e.html
Water	Trees can't be in water	http://www.geobase.ca
Lodgepole and Jackpine distribution	Suitable habitat areas	http://esp.cr.usgs.gov/data/atlas/little/
Canadian DEM (30 arc-seconds)	Mask elevation ranges suitable for growth of pine trees	http://www.geogratis.ca
Alberta Provincial Boundary	Use as a clip layer and in mapping presentation	http://www.geogratis.ca

Justification for Data Inclusion

The primary datasets used for analysis in this project (Fig. 1) include Ecozones of Canada, distribution of Lodgepole and Jackpine in North America, MPB aerial survey data for years 2006 to 2010, Environment Canada historical monthly (Dec-Feb) weather summaries for years 2004 to 2011, and water features of Alberta. At the beginning of this project it was unknown that digitized distribution maps of tree species in North America were available and so ecozones of the boreal forest were going to be used to determine potential habitat. The ecozones were kept because there is a gap in tree species distribution where MPB has killed trees. Ecozones would therefore provide an explanation for this phenomenon and suggests that the tree species distribution maps have errors (all data sources have inherent errors). The tree species distribution maps provide the primary source to predict where the MPB could travel; given that they indicate where the MPB food source may be found. The MPB survey data points appeared quite accurate with each point representing several killed pine trees. For example, in the 2010 beetle kill layer there was an average of about 9 trees per point for a total of 575, 674 dead pines counted, although some trees counted may have been counted more than once or been kills from previous years. These layers are used to determine where MPB has been and where it is likely to go based on the 2010 survey data. Historical weather data from Alberta climate stations for years 2004 – 2011 was utilized to create interpolated raster surfaces to model the winter conditions as climate is one of the most important variables limiting MPB expansion. The water layer was used as a buffer and erase layer to remove any water features out of the potential habitat and MPB expansion areas.

Study Area

The study area of the project is located at the west-central region of Alberta near Grande Prairie, Slave Lake and North of Fairview. The scale chosen to display the analysis results is 1 : 5,000 000 because the climate station data was distributed throughout the province of Alberta with a greater concentration of stations surrounding the larger cities like Edmonton and Calgary. Another reason for choosing such a small scale for display is because it is easier to observe how far the MPB has already spread and allows to better visualize where it could possibly expand to in the future.

Criteria

The analysis criteria were selected from prior knowledge of MPB ecology acquired through applied research, from literature and website reviews. Some of the criteria were arbitrarily chosen by comparing various sources of information and by selecting an average or a value that was most probable (e.g. jackpine is likely to be found at 0-800 m above sea-level therefore, 800 m was selected as the upper boundary):

1. MPB Can travel 7-10 days from 40-100 km per day, used buffer of 200 km around 2010 dead-red tree layer but not within 10 km of 2006 20 km integrated points, 10 km of 2007 20 km integrated points, 5 km of 2008 10 km integrated points, 3 km of 2009 5 km integrated points and not within the major 2006-2010 attack polygon (digitized manually around major attack areas).
2. Possible habitat = tree species Jackpine or lodgepole or ecosystem = boreal plain or boreal shield or montaine cordillera or taiga shield or taiga plain
3. At least 100 m from water
4. Not beyond 800 m elevation for Jackpine or beyond 2300 m for lodgepole pine.
5. Overwinter Survival rating not 5 (not colder than -35°C from winter average minimum temperature climate model for years 2010 and 2011).

Methods

The analysis procedures were performed using a combination of vector and raster processing with data in Figure 1. The first step was to create the suitable foraging criteria raster using the tree species distribution and Canadian ecozone polygons. This was done by:

- Merging jackpine distribution to taiga plain, taiga shield, boreal shield, boreal plain, while removing the prairie ecozone
- Merging lodgepole pine distribution to montane ecozone, while removing the prairie ecozone
- Intersecting these two newly create layers to create a hybrid forest type and erase this hybrid area from lodgepole and jackpine
- Buffering the water layer using distance of 100 m and erasing this feature from the lodgepole, jack, and hybrid pine

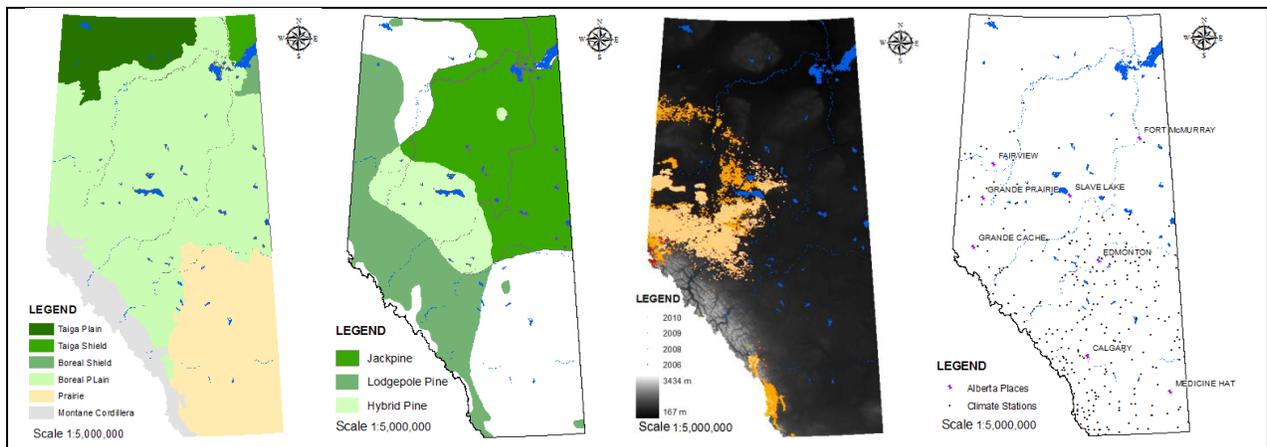


Figure 1. Data used in the analysis procedure to create potential MPB attack areas for three tree-host forest types

Google earth was used to determine the elevation of the tree line in the Canadian Rocky Mountains. This was determined to be about 2300 m and was therefore used as the criteria for lodgepole pine. The digital elevation model was used to remove the elevation areas that were not likely to contain either lodgepole or jackpine This was accomplished by:

- Clipping the Canadian DEM using the Alberta provincial boundary
- Using the raster calculator to create two rasters with areas that are ≤ 2300 m and ≤ 800 m

Once the elevation rasters were created the habitat layers were converted to rasters using the polygon to raster tool and the following simple additive equation was used in the raster calculator to extract a raster that met the elevation and habitat criteria:

$$\text{final_habitat} = [\text{elevation_criteria}] + [\text{habitat_criteria}]$$

The second step involved using the 2006-2010 infected trees to create distances that could be attacked in summers 2010 and 2011; where dead-red trees are likely to be found in 2011 and 2012, respectively. Some of these survey data also included green attack data but these were ignored; only red-trees were used in the analyses. Initially, the intent was to create dissolved buffers using all the data, however, the dataset was too large, taking too long to create buffers and unable to dissolve. Therefore, it was necessary to reduce the point layers and create dissolved buffers that were simplified. This was done by:

- Integrating (integrate tool) MPB survey points using distance of 20, 10, 10, 5, and 20 km's for years 2006 to 2010, respectively.
- Dissolving the points for all years
- Using the multi-part to single-part tool to create attributes for all points that remain after integrating
- Buffering and dissolving the new point files using a distance of 10, 10, 5, 3, and 200 km's for years 2006-2010, respectively
- Merging the buffers of years 2006-2009 and erasing them from the 2010 buffer polygon
- Using the Alberta boundary as a clip layer to clip the 2010 distance buffer polygon.

To reduce the area further, it was necessary to create additional polygons around major point clusters of dead trees. This was done by simply creating a new polygon feature class, starting an editing session and digitizing polygons around major attack clusters. This layer was then erased from the final buffer layer from the step above to create the most likely areas that MPB could spread to.

The fourth step was to create interpolated climate raster models for winter years 2004-2011. The data were downloaded from Environment Canada historical weather summaries for all climate stations in Alberta. The winter climate data that was used was the minimum recorded monthly temperature for December, January, and February. A kriging interpolator was used as kriging accounts for proximity by assigning a greater influence for climate stations that are closer. Here are the procedures to create the minimum winter average climate models:

- Bring up an HTML results page for the weather data that you want to download (minimum monthly temperature recorded at all the climate stations in Alberta for months dec-feb and years 2004-2011)
- Highlight all the data from the webpage table for December 2006, copy, and past into an Excel spreadsheet (Microsoft 2007) while deleting all unnecessary information (keep the headers and all the data delete the rest)
- Follow the same steps for January and February but paste them separately in their own tabs and save the document in an older format (97-2003)
- Add the table to ArcMap and add XY data using the columns lat long for Y and X, respectively and assign a geographic projection such as North American Datum 1983
- Right-click on layer and export data to a point feature class in a geodatabase and save projection as the dataframe in NAD_83_UTM_Zone11N
- Open the Spatial Analyst toolbar and set your environment to a cell size of 500, extent to Alberta Boundary, and the default folder
- Interpolate to Raster with Kriging: input points = climate stations, z value = Tn (min monthly temp), kriging method = ordinary, Linear semivariogram model, search radius type = variable, search radius settings: number of points = 12, maximum distance = 500 km
- Create a surface for Dec, Jan, and Feb for a certain year

- Create an average surface raster for that winter year using simple additive formula in raster calculator (eg. Winter06 = [dec] + [jan] + [feb])
- Reclassify the raster to get an over-winter survival rating: 1 = 0 to -20 °C, 2 = -20 to -25°C, 3 = -25 to -30°C, 4 = -30 to -35°C, and 5 = < -35, representing high to low over-winter survival.
- Export these winter average rasters to the default geodatabase ensuring that the projection is in NAD_83_UTM_Zone11N
- Create the climate limitation model by calculating the areas with survival rating of 1 to 4 in raster calculator (winter2011 not 5)

The final step in the analysis was to combine all the raster surfaces to achieve the final areas for MPB expansion in 2011 and 2012. Only 2010 and 2011 winter average climate models were used in the analysis and the only area to exclude from the analysis was survival rating = 5.

Another meaningful last step was to calculate a measure of area for each of the host-tree regions using the attribute table field called COUNT (number of cells with a classification) and multiplying this value by the cell size in square meters. This was done with the field calculator. An area measure in hectares was also derived by dividing the area in m² by 10000.

Results

The climate models, representing the overwinter survival of MPB (Fig.2), show that the winter monthly minimum temperature average for 2010 and 2011 was rarely lower than -35°C (survival rating of 5). These results suggest that consecutive cold winter temperature necessary to kill MPB likely did not occur. Thus, population survival was likely high. Furthermore, by observing the 2004 to 2009 climate models (separate map document), it can be seen that minimum winter temperature averages for most years were suitable to MPB spread into Alberta, with spatial correlation of low survival ratings and following-year dead pine trees.

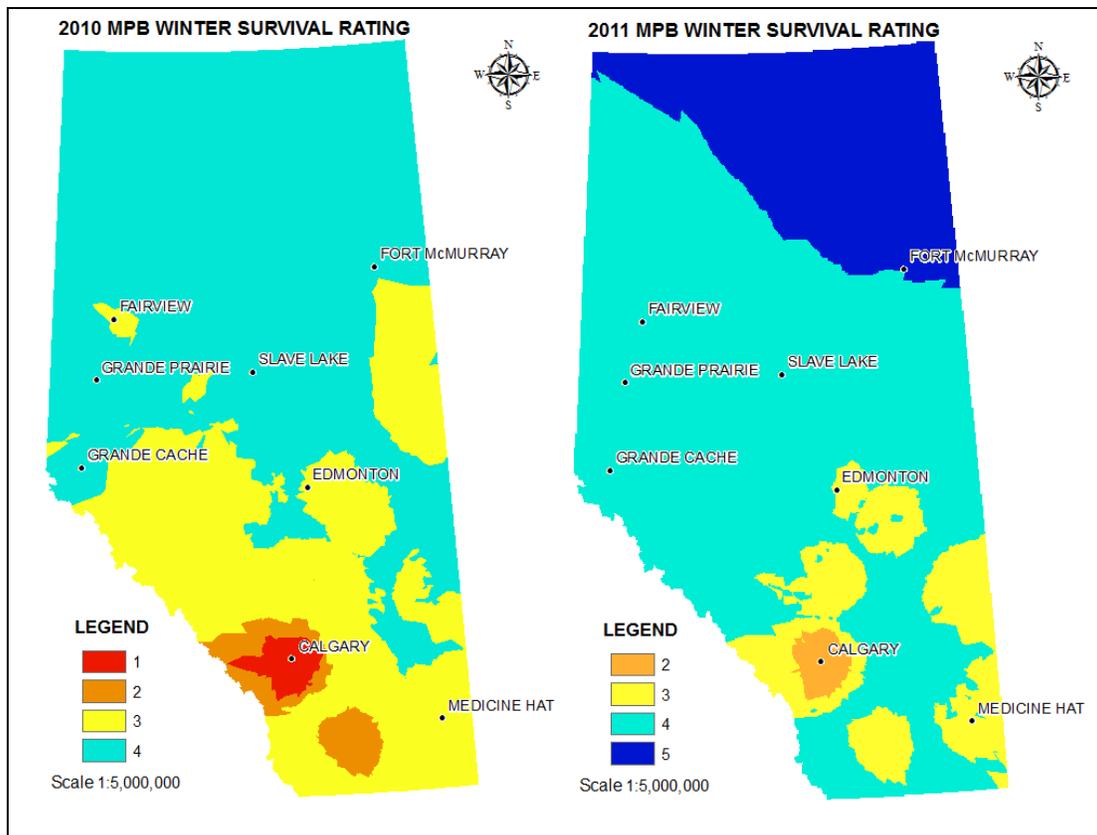


Figure 2. Winter survival ratings for 2010 and 2011 based on minimum monthly temperature models.

The estimated area of lodgepole, hybrid and jackpine forest (Fig. 3) was 5942608, 4967350, and 6089075 hectares, respectively. This area represents the suitable habitat for MPB expansion and where dead trees are likely to be found in 2011 and 2012, and beyond.

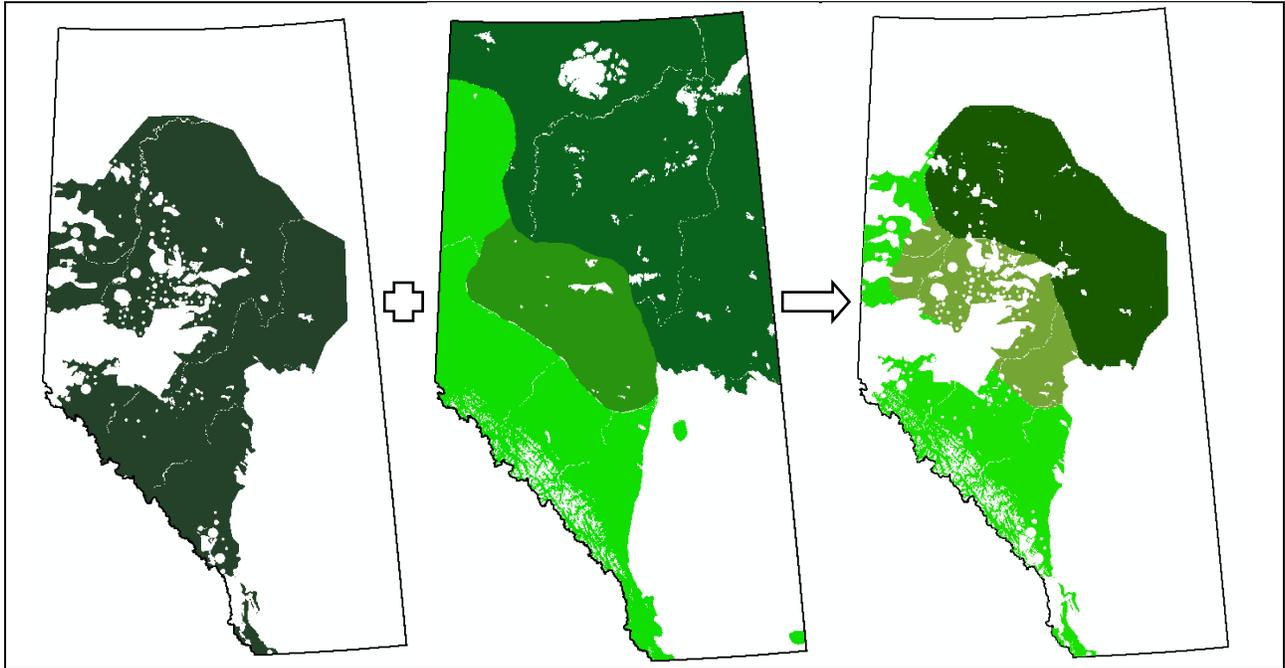


Figure 3. Left is the MPB flight range raster showing area that are within 200 km from 2010 20 km integrated points, middle is the suitable habitat raster showing area of lodgepole, hybrid and jack pine in Alberta, right is the final raster that meets criteria from both rasters to the left and climate criteria.

Discussion

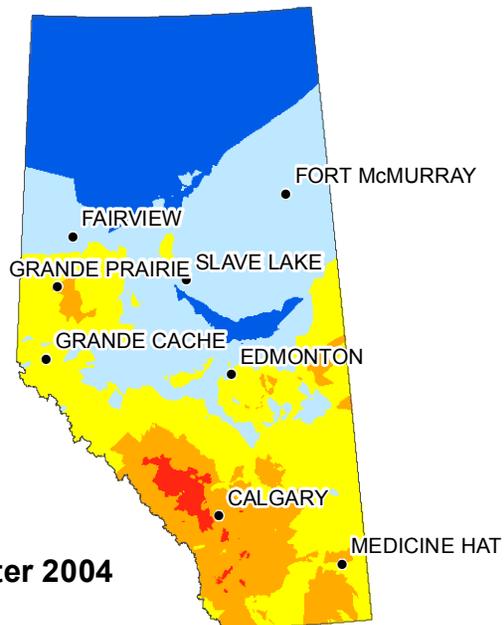
The resulting suitable habitat expansion model is a generalistic model based on several assumptions and data that is likely out of date and inherent to errors. There are several ways that the model could be improved: using satellite imagery to classify polygon areas of dead read trees as these areas could be masked out of the analyses. Satellite images would also allow for the removal of features such as urbanized, clear-cut, or barren areas. Furthermore, by incorporating past spread rates and density estimates of MPB population dynamics as well as forest stand characteristics (e.g. age class and tree diameter) the model would better be able to predict where beetles are likely to spread to next. The climate models could be further improved by incorporating daily minimum temperatures for the entire winter and using animation to display them. Also, simply because the climate models show a survival rating of 5 (< -35°C), it does not necessarily mean that there was low winter survival. Consecutive negative temperatures of such a magnitude would be necessary to significantly reduce MPB populations. Radar could be a powerful tool to analyze flight characteristics of MPB as done by Jackson *et. al.*, (2007), but this was not attempted in this analysis. It was interesting to note the processing limitations of the dissolve tool with large datasets. Integrating these large dataset into a simplified one resulted in a loss of information and manually digitizing and removing large areas of outbreak from potential habitat was more effective in reducing the amount of suitable habitat for MPB expansion. If integrating data in the future, it is recommended to start with a smaller integrating distance, as there are greater data losses with increasing distance. Only time will tell whether or not the model holds true?

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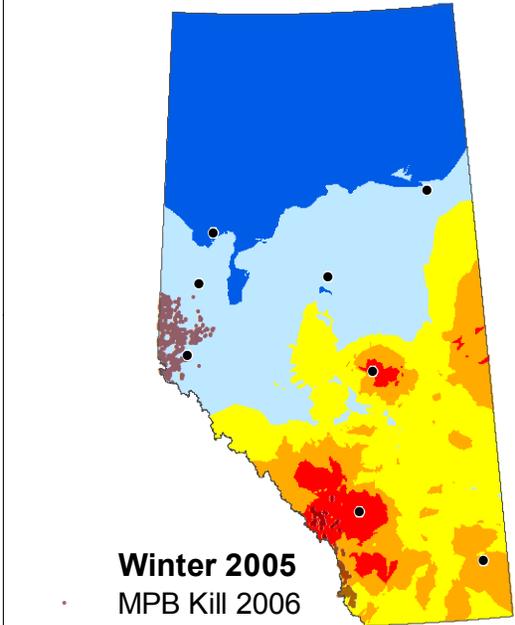
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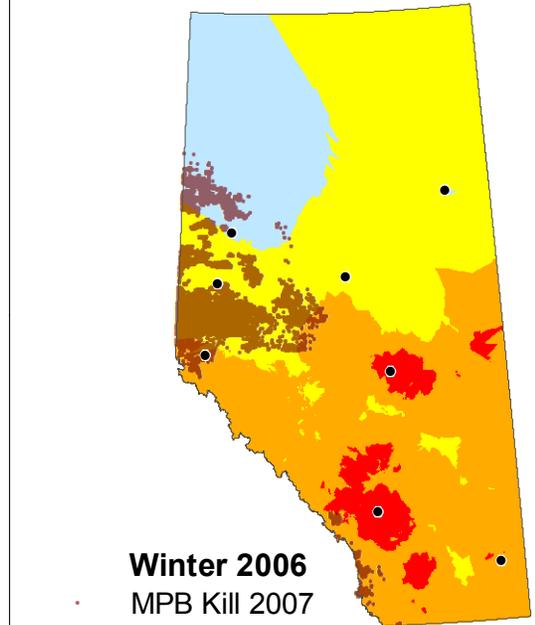
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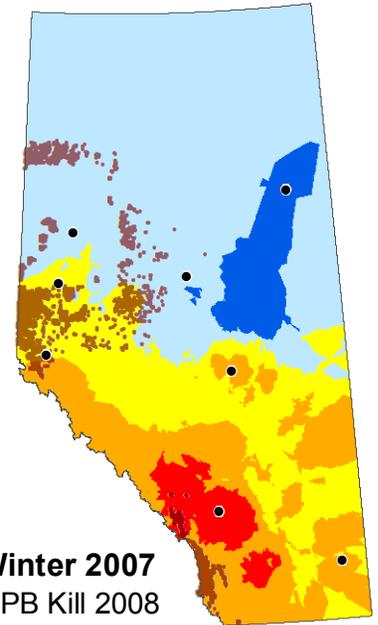
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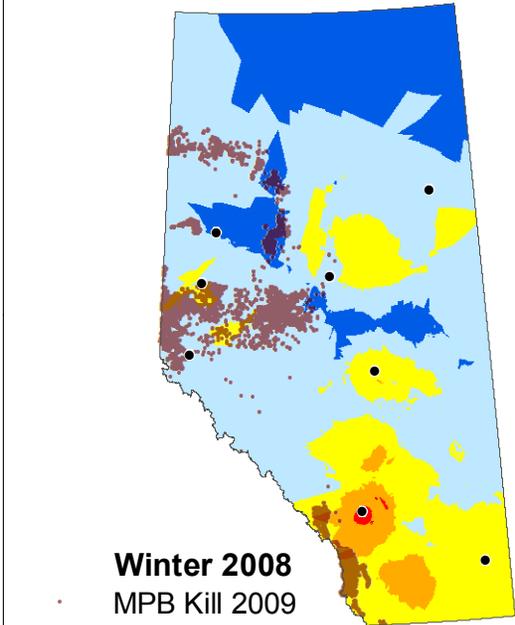
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MPB Kill 2006



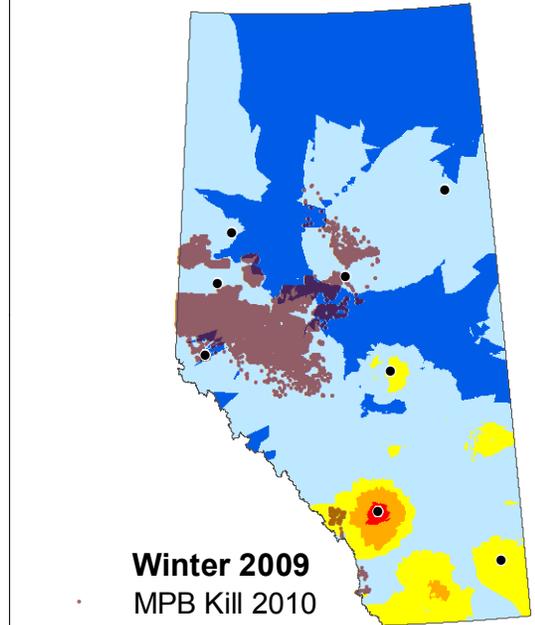
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MPB Kill 2007



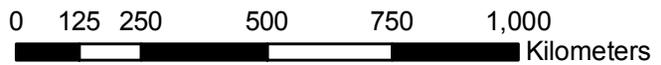
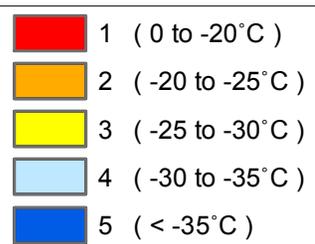
Winter 2007
MPB Kill 2008



Winter 2008
MPB Kill 2009



Winter 2009
MPB Kill 2010



1:15,000,000

Datum: North American Datum 1983
Projection: Universal Transverse Mercator, Zone 11N

MPB Overwinter Survival Rating from Minimum Winter (Dec-Feb) Temperature Model-Years 2004 to 2009 Including Beetle Kill of the Following Year

Map Produced by Simon Allard April 11, 2012

