Simulating Mountain Pine Beetle Outbreaks in Stands of Lodgepole Pine

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Abstract

Mountain pine beetle (Dendroctonus Ponderosae) is a species of bark beetle native to the western US, and a key factor in maintaining healthy forests. Their primary hosts include lodgepole, ponderosa, western white sugar, limber and white bark pines. Beetles will mass attack a host, boring into the bark, girdling the phloem layer of the tree. Responsible for the transportation of nutrients throughout, this layer is vital to the tree's survival, and if girdled it will likely die. While these beetles do play a role in a harmonious forest ecosystem, mass outbreaks in the last two decades have caused significant damage to pine forests in western US as well as western Canada. These outbreaks can be attributed to a combination of factors, including warming temperatures, more common drought conditions, and high forest density that provide an ideal breeding ground for pine beetle. The impacts of these outbreaks can be detrimental both ecologically and economically. The main objective of this study was to use basic factors that contribute to forest health, and beetle spread dynamics, to build a cellular automaton model that represented mountain pine beetle outbreaks in stands of Lodgepole pine. Modeling and simulation of these outbreaks could aid in predicting factors that lead to susceptible forests and help inform forest management strategies.

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I. Introduction

Between 1997 and 2010 more than 5 million hectares were affected by bark beetle in the western US and upwards of 18 million hectares, with the inclusion of British Columbia (Barbara Bentz, Kier Klepzig, 2014). It is predicted that Mountain Pine Beetle alone has attacked 50% of the total volume of commercial lodgepole pine in British Columbia since 1990 (Natural Resources Canada, 2022). Efforts to mitigate the effects of beetle outbreaks have included monitoring and early detection programs, as well as forest management strategies focused on reducing tree density and the promotion of resilient tree species.

Forest health is a key, if not the primary, factor in outbreak severity. Two of the main factors in determining the health of a given stand are age and stand density (Mellen-McLean, 2017). Once a tree species reaches a certain age its growth begins to slow and health declines. If a stand is relatively even aged this can mean a large percentage of the stand will reach this age at a similar time, resulting in a stand of poor health. Stand density is often measured in trees per acre. If trees per acre is high, competition for resources is increased, resulting in more suppressed unhealthy trees. Naturally occurring recycling agents such as fire, fungi, and pests like mountain pine beetle, help to restore forest health. Unfortunately, due to the pressures of climate change we are experiencing warmer summers and winters which promotes beetle regeneration and places more stress on tree health, the combination of which leads to larger, more detrimental beetle outbreaks. This project was an exploration of how these factors of forest health play a role in the severity of beetle outbreaks.

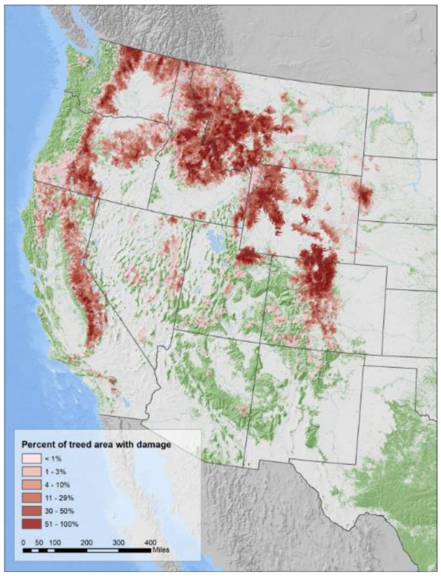

Figure 1. map of tree mortality from Mountain Pine Beetle 2000-2020 (fs.usda.gov)

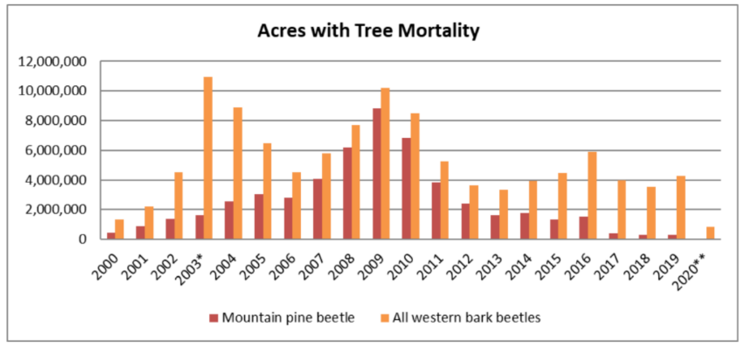

Figure 2. (fs.usda.gov)

II. Modeling/Simulation

The first steps in simulating the spread of mountain pine beetle was accurately representing a stand of lodgepole pine. Forest Health Protection and State Forestry Organizations calculate a stand susceptibility Index as: Susceptibility = P x A x D x L. P is percent of susceptible pine, A is age factor, D stand density factor, and L location factor (Gibson, 2010). Apart from the location factor (held constant for the purposes of this project), these would be the primary factors in determining stand composition. An additional Beetle pressure factor would determine the number of initially infected trees. Given these variables, the model randomly populates a 2d grid, with values between 0 and 1 representing the susceptibility of the tree, 0 being a dead or empty cell, and ~1 being good health and not susceptible. A cell with a value of 1 would represent a currently infested tree. On average Mountain Pine beetle attack lodgepole pine of 8 in. DBH (Diameter at Breast Height) and greater. SDI (Stand Density Index) is a metric used to determine the optimal stand density for a given species and maintain stand health. For Lodgepole an optimal SDI for even aged stands with an average dbh of 8 in. is approximately 250 trees per acre (USDA Forest Service). To account for a varying stand density the grid size was held constant at

5041 (71*71) cells, meant to represent a 10 acre plot with a maximum stand density of approximately 500 trees per acre. Meaning if trees per acre is 500 nearly every cell is populated with a tree, vs a trees per acre of 250, more cells are left empty (see figure 3).

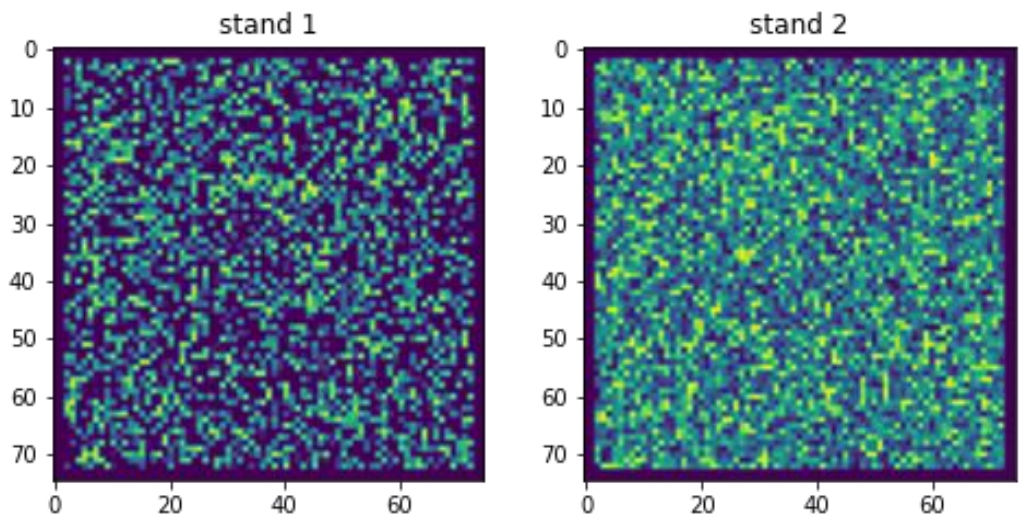

Figure 3: Two populated stands of varying stand density, stand 1 = 250 trees per acre, stand 2 = 500 trees per acre

In figure 3 you will also notice a larger percentage of cells are colored yellow in stand 2. This is due to a larger number of initially infested trees.

Once a stand is accurately generated then begins the process of simulating beetle spread dynamics. Mountain pine beetle in general, have a one-year life cycle. This includes four stages, egg, larva, pupa and adult. Once females reach adulthood, they leave there host trees in search for a new one. Females are most successful at attacking suppressed and aging trees as they are less resilient and have fewer defenses against an attack. Once an attack on a tree is initiated, they release a pheromone that attracts other males and females. If a tree is overpopulated with beetles, incoming beetles will often attack surrounding trees resulting in patches of dead trees within a stand. To simulate this all initially infected trees search the two layers of cells immediately surrounding them (see figure 4). Those that are below the health factor are then sorted and the tree with the lowest value becomes the new host tree, while the previous host dies. The tree of the second lowest health will also become a new host tree if it is below the health threshold divided by a factor of 1.2 (see figure 4).

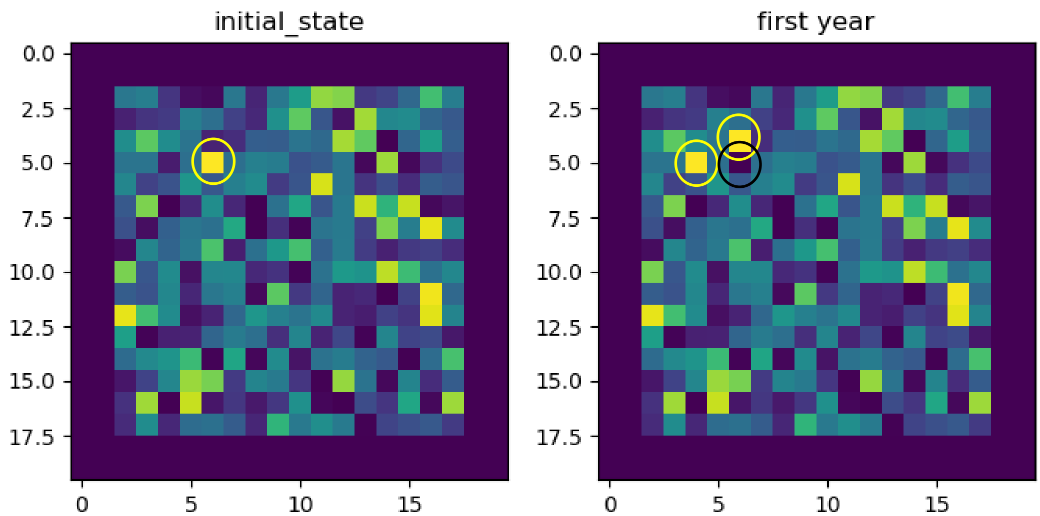

Figure 4. A toy example showing an initially infested tree dying while two others surrounding it become infested

This process continues until infested trees can find no susceptible trees surrounding them. Because beetles typically infest a new tree each year, each iteration represents a year. To determine the percentage of mortality given different stand compositions, beetle pressures, and time spans, the simulation is duplicated, generating a different stand given the same initial conditions.

III. Results

Once the simulation was built, the goal was to explore the outcomes of various combinations of initial conditions, and see if it was possible to replicate common beetle kill statistics. For example, it is estimated that in stands of even-aged lodgepole older than 80 years old, mountain pine beetle are responsible for 80% of tree mortality, in a period of 3-4 years (Mellen-McLean, 2017). This was replicated with a stand density of 200 trees per acre, 90% of trees below the health threshold of 0.3, and 350 initially infested. After 1000 trials approximately 78% tree mortality was observed (figure 6).

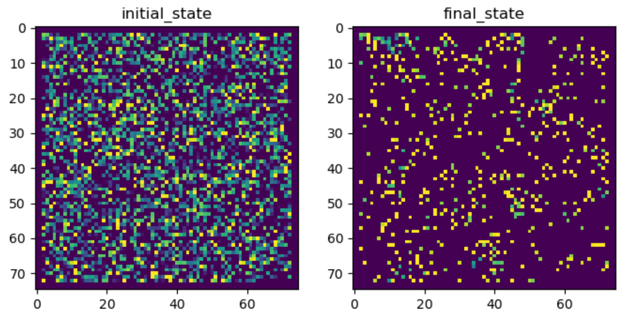

Figure 5. Initial and final states the simulation

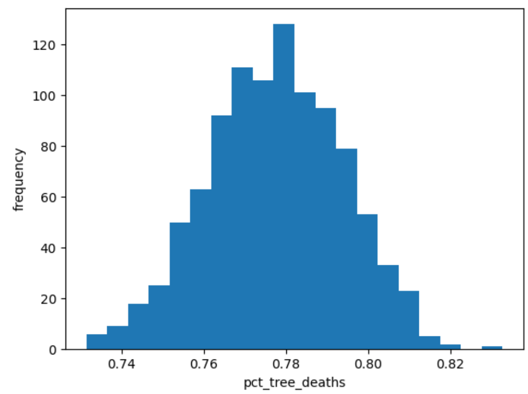

Figure 6. Histogram of percent tree mortality after 1000 trials

In contrast a healthier stand was modeled with the same initial conditions but only 30% below the health threshold, and observed only 25% tree mortality. To compare different conditions a baseline was established as 100 initially infested, 80% of the stand below 0.3, 250 trees per acre, over 10 years. This baseline yeilded 47% tree mortality. Changing the number of initially infected yeilded expected results causing more tree mortality with rising infestation values (figure 7). The percentage of susceptible trees also resulted in a postively sloped relationship, however it plateaued at a value of 0.7 with approximatly 50% tree mortality (figure 8). If the number of years is increased this pushes this plataeu higher untill it reaches a maximum of 68% mortality after approx. 25 years. Trees per acre had a negetivley sloped relationship, which can be explained by the fact that holding everything else constant and increasing the number of trees in the grid will lower the mortality percentage.

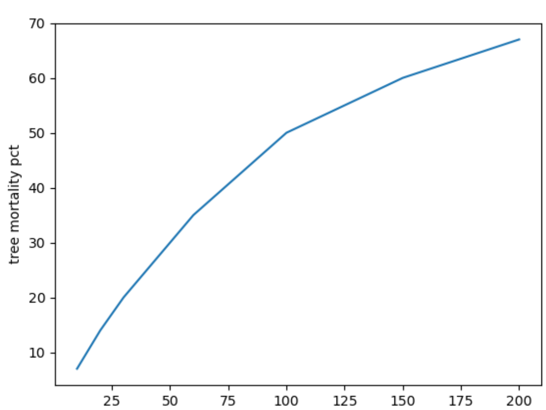

Figure 7.

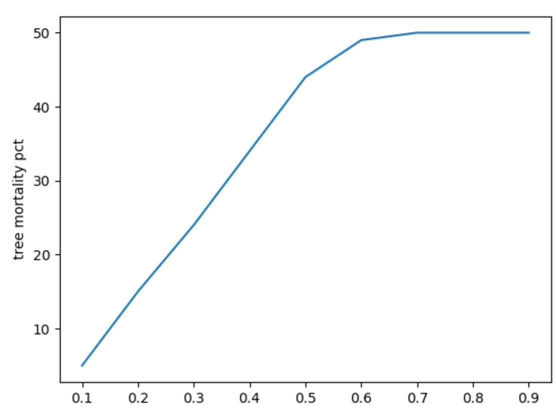

Figure 8.

IV. Discussion

While this model allows one to explore the effects of various stand conditions on mortality, it is still rudimentary in nature. More variables, as well as more interaction between variables, would provide a more accurate and dynamic simulation. For instance, the number of trees per acre should be related to the percent of unhealthy trees. Representing this relationship algebraically rather than manually could be more accurate. Additionally, this model holds the given health values of each tree constant when in reality this is a dynamic variable. In particular the health of a lodgepole pine stand can change drastically over the course of 50+ years, which would effect the beetle infestation. The success rate of beetle attacks on their host could also be more informed as well. Mountain pine beetle does often attack multiple trees after leaving their host, but how many and how successful they are is hard to quantify. Currently they infest a second tree as long as that second tree is below the threshold divided by 1.2. This factor was used for this model but is likely more dynamic. Again, this variable is probably dependent on other variables like stand density and stand health. Finally, with longer warm seasons mountain pine beetle will have more than a single life cycle each year meaning each iteration may represent more than one year.

V. Conclusion

This model serves as an initial exploration of stand dynamics and their effect on the severity of beetle outbreaks. It has shown that forest health plays a key role in the severity of beetle infestation. To improve the model additional factors that play a role in forest health should be integrated. Although this model is only preliminary it has the potential to be a comprehensive tool that could help asses forest susceptibility to mountain pine beetle outbreaks.

VI. Works Cited

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