Effects of precipitation changes on mountain pine beetle populations in the Arapaho Roosevelt National Forest

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Introduction

Across North America, mountain pine beetle populations in pine forests are a widespread source of tree mortality (Carroll et al., 2003). As a result of the beetles infesting and reproducing in living trees, the beetles are lethal to the living trees and have negatively impacted over 5 million hectares of forest in the western United States between 1997 and 2010 (Bentz & Klepzig, 2014). While they are detrimental to forests and create long-term damage, the life span of the beetle is just about one year, with a generally specific life cycle during the year (Ministry of Forests, Lands & Natural Resource Operations, n.d.). According to the Ministry of Forests, Lands & Natural Resource Operations in British Columbia, female beetles emerge and find a suitable host tree when temperatures are above 16 degrees Celsius, with male beetles then joining them to create an "egg gallery" beneath the bark where blue-stain fungus can emerge (n.d.). Blue-stain fungus in the egg gallery creates a mechanism which prevents the trees from defending themselves against the beetle infestation (Ministry of Forests, Lands & Natural Resource Operations, n.d.). The larvae of the beetles spend winters underneath the bark and complete the transformation as pupae into June and July, followed by the young adults collecting blue-stain fungal spores in the egg gallery chambers; the adults emerge from the infested trees in the summertime or early into the fall while temperatures are still not too low (Ministry of

Forests, Lands & Natural Resource Operations, n.d.). A large component of their life process is due to climate factors, allowing for the mass attacks on suitable host trees driven by synchronized emergence from climate-influenced life cycles (Bentz & Klepzig, 2014).

Climate change has implications on the changing prevalence of mountain pine beetle populations, due the beetles' reliance on climate factors for emergence and growth in suitable host trees. Creeden et al. report in their study that outbreaks of the beetle population occurred in years that lacked low winter temperatures, and drought was an important factor at each location for a duration of the outbreak (2014). Pine trees that are unstressed from drought conditions possess increased capability to defend themselves against mass attacks by producing toxin resin, and drought conditions inhibit their ability properly undergo this mechanism (Preisler et al., 2012). During the 2001-2002 drought in the Southern Rocky Mountains, declining levels of precipitation caused a large increase of mountain pine beetle populations (National Science Foundation, 2012). Outbreaks have recently been more severe, and strong evidence supports the idea aimed towards climate change being a leading component in outbreak severity (Preisler et al., 2012). As the climate continues to change, pine trees will become more susceptible to conditions that weaken their defenses against the beetle populations, allowing for increases in mass attack severity and tree fatality (Bentz & Klepzig, 2014).

Understanding the impacts of climate change on mountain pine beetle outbreaks is incredibly important to forest ecology. These outbreaks greatly disturb forests, as tree mortality affects wildlife populations, reduce the quality of the watershed, create timber losses, and decrease recreational use of forests (Walter & Platt, 2013). Buotte et al. report that pine trees are a keystone species in high-elevation forests, promoting community diversity, providing shelter for species, allowing for snow melt regulation, and creating stability in soils which reduces erosion (2016). As climate change has shown evidence of increasing outbreak severity in mountain pine beetle populations, detrimental losses within forest communities could result. Within Colorado, this could mean great amounts of loss to the ecosystem as the climate crisis continues. Colorado is heavily forested, with forest coverage being approximately 23 million acres, and about one third of the land mass of the state (Rocky Mountain Research Station, n.d.). Precipitation levels in Colorado impacted by climate change likely have large implications on the health of forests and on the overall forest ecology due to its effects on mountain pine beetle outbreak severity.

In this paper, the effects of precipitation levels in a given year in comparison to the average area of the nearest mountain pine beetle infestation in the Arapaho Roosevelt National Forest located in Colorado are investigated. Due to implications of drought conditions leading to worsened tree defense mechanisms and more severe outbreaks in mountain pine beetle populations, I hypothesize that as precipitation levels increase, the average area of the nearest mountain pine beetle infestation decreases.

Methods

To further investigate the effects of precipitation on mountain pine beetle infestations, I gathered data from a research study conducted by Walter and Platt (2013). Walter and Platt surveyed the Arapaho Roosevelt National Forest in Colorado in 2003, 2005, 2006, 2009, and 2010 using remote sensing satellite images to compile data on predictors of mountain pine beetle outbreaks. Their data included several categories for determining predictors of MPB infestations, including dominant size class of trees in each surveying site, the aspect within the forest including north, south, east, west, and all other possible combinations, percent cover of the lodgepole pine and the ponderosa pine, the area of the nearest MPB infestation in hectares for each year, distance to the nearest MPB infestation for each year, and the infestation code to determine whether it was a red attack or non-red attack for each year. Since I was interested in the effects of precipitation on the size of MPB infestations, I decided to narrow down the data to look just at the area of the nearest MPB infestation in order to understand whether precipitation has any effect on this category. There were over 2000 data points for the area of nearest MPB infestation for each year due to the many surveying locations with differing elevations and location aspects. I decided to calculate the average area of the nearest MPB infestation for each year to make the data easier to work with, and to get a sense of the overall size of the area of the nearest infestation in the Arapaho Roosevelt forest for each year.

Since Walter and Platt's study did not gather data on precipitation levels during their study, I used data from the Northwest Alliance for Computational Science and Engineering to get precipitation data in the Arapaho Roosevelt National Forest in the years 2003, 2005, 2006, 2009, and 2010 (n.d.). After gathering this data, I plotted the average annual precipitation in inches with the average area of the nearest MPB infestation for 2003, 2005, 2006, 2009, and 2010 in Microsoft Excel. I then created a scatter plot with this data to identify any relationship between these two variables. Once I created this plot, I ran a regression analysis to determine the significance of the data and the relationship I saw. I felt that a regression analysis was appropriate since I was investigating a potential linear relationship and determining the significance of the effect of the independent variable "precipitation" on the dependent variable "average area of the nearest MPB infestation" (Northwestern University, n.d.)

Results

The plotted data resulted in an apparent negative correlation between precipitation and average area of the nearest MPB infestation, as the plot shows that as precipitation increases, the average area of the nearest MPB infestation decreases. I hypothesized that as precipitation levels increase, the average area of the nearest mountain pine beetle infestation decreases. The plotted data would indicate that my hypothesis is correct, and that higher levels of precipitation results in smaller average areas of the nearest MPB infestation.

Figure 1

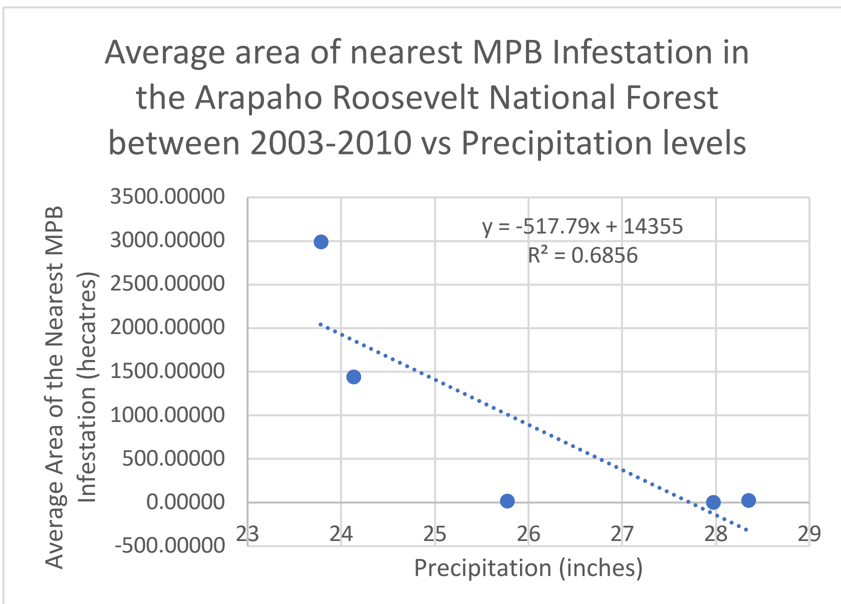

Figure 1 depicts the graphed results comparing data collected from the Walter and Platt study (2013) on the nearest mountain pine beetle infestations in hectares between 2003 and 2010 versus data on precipitation levels in the same year from the Northwest Alliance for Computational Science and Engineering at Oregon State University (n.d.). Results are reflected by data collected in the Arapaho Roosevelt National Forest in Colorado.

The regression analysis run on this data however resulted in a P-value of 0.08339332. Since this value is greater than 0.05, I fail to reject the null hypothesis and cannot conclude anything definitive from this data since the relationship between these two variables is deemed not significant.

Regression Analysis

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	14355.2321	5277.83596	2.71990873	0.07255498	-2441.1975	31151.6616
X Variable 1	-517.79483	202.458852	-2.5575312	0.08339332	-1162.1093	126.519595

Discussion

Similar research studies provide implications as to how precipitation and drought do have significant impacts on mountain pine beetle infestations (Creeden et al., 2014), and is predicted to be due to the increased defense mechanism by means of toxic resin that trees have with increased precipitation (Preisler et al., 2012). While my results did show an apparent correlation in the graphed data between precipitation and average area of the nearest MPB infestation, my P-value would reflect that this relationship is not significant enough to draw any conclusions. I am not surprised to have seen this negative trend in my data, but I am surprised that the relationship was deemed not significant. I however think that there are several reasons for getting the P-value I did which could come from errors in my methods. I did only use five data points for my data analysis, which could have resulted in the high P-value. But considering the fact that my P-value was just about 0.03 too high to be significant, I feel that more data points used for analysis could result in a lower P-value if the study was done again. I think it was appropriate to use only the averages of the area of the nearest MPB infestation from each given year from the Walter and Platt (2013) study since there were thousands of data points from each surveyed location, but in future studies it could be greatly beneficial to use more than five years' worth of averages in order to have more data points. I also think there may have been errors in the data I collected from Northwest Alliance for Computational Science and Engineering (n.d). To get data from this source, I had to select a very small grid square from the map of the Arapaho Roosevelt forest, and there was no option to select a larger area. I chose a very central gridded location within the Arapaho Roosevelt forest to use for my data points for the five selected years. While I feel that the data points I gathered are representative of a general average precipitation level in the Arapaho Roosevelt Forest in each given year, I don't think that the data is entirely representative of the entire forest. In the future, if possible, it would be better to align the selected grid square precipitation averages specifically with the Walter and Platt MPB infestation averages from that same area using coordinates or something similar.

Other studies have found that precipitation is not the only indicator or predictor of mountain pine beetle infestations. Sambaraju et al. found that while precipitation does have some effect on MPB infestations, colder temperatures and lower minimum winter temperatures had a significant effect on the probability of infestation, as colder temperatures reduced the probability of infestation (2012). Carroll et al. similarly report that temperature is an important factor in MPB infestations because of their biological reliance on temperature for their life cycles (2003). I think that temperature data along with precipitation data in a similar future study could provide interesting implications for MPB infestations. Additionally, I think that investigating further into the time of year at which precipitation levels are highest or lowest could provide interesting and informative data. A study conducted by Thomson and Shrimpton found that dry periods during the summer with low levels of precipitation were associated with the beginnings of MPB infestation outbreaks (1984). Gathering data on precipitation levels during a specific time of year, such as in the summer, may provide interesting results in terms of MPB outbreaks in future studies.

If I were to replicate this study in the future, I would gather MPB infestation data similar to how Walter and Platt (2013) collected their data, making sure I have thousands of surveyed sites within the Arapaho Roosevelt forest to provide very accurate averages of the nearest MPB infestation for each year that is representative of the entire forest. I would instead however collect data over a period of 10-15 years, making sure that I collect data for every single year so that I have several more data points to work with. I would additionally try to gather both precipitation and temperature averages for the Arapaho Roosevelt forest in each year using a more representative model which encompasses the entire forest, rather than a small area within the forest solely for precipitation. I think it would be beneficial to investigate both precipitation and temperature effects on MPB infestations for more comprehensive results.

Looking into predictors and environmental factors such as precipitation and temperature which could lead to mountain pine beetle infestations may be extremely beneficial to incorporate preventive measures. If we can better understand what factors cause outbreaks in forests, we can be more prepared to protect our forests and work towards creating resistance against these factors to prevent outbreaks. Pine trees are incredibly crucial to high-elevation forests for several reasons including species shelter, diversity, regulation, and stability; mass morality of trees could cause incredible harm to forest ecosystems (Buotte et al., 2016). Maness et al. also report that high levels of tree mortality have effects on evapotranspiration rates and ultimately alters the surface energy balance and can change the regional atmospheric layer above the forest, leading to consequential alterations in the usual formation of clouds and precipitation levels (2012). MPB infestations have resulted in severe tree mortality (Carroll et al., 2003), which could then consequently damage entire forest ecosystems and further negatively disrupt climate factors like cloud coverage and precipitation. This is a potentially very harmful positive feedback loop because low precipitation levels may lead to increased rates of MPB outbreaks, which then results in mass tree mortality, which could ultimately decrease precipitation levels even further by disruptions in the evapotranspiration rates.

Another consequential aspect of mass tree mortality from MPB infestations is the release of carbon from the dying trees. One study conducted by Ghimire et al. investigated carbon impacts of MPB outbreaks and found that tree mortality in western US forests has caused a reduction in net ecosystem productivity and report that carbon is emitted back into the atmosphere via biological processes once trees are killed (2015). This has great implications for climate change and global atmospheric CO2 levels. Climate change also reportedly increases the rate of MPB outbreaks (Preisler et al., 2012), so this is another positive feedback loop that could be incredibly consequential.

I think however that it’s extremely difficult to say definitively, with complete confidence, how climate change will impact MPB infestations. Polley et al. describe how warming in the biosphere is predicted to alter the amount and distribution of precipitation and also will likely increase both drought and storm severity, but on the contrary, increased atmospheric CO2 levels can directly stimulate plant growth and reduce other consequences (2013). To complicate matters even further, reduction in soil water availability due to precipitation changes can counteract CO2-stimulated plant growth (Polley et al., 2013). I feel that while a study such as the one I have conducted can provide important implications for how certain climate and environmental factors influence mountain pine beetle infestations, it’s nearly impossible to say how climate change in the future will impact MPB infestations even further. However, we can use our knowledge on the subject matter to the best of our abilities to protect our forests and develop strategies of resistance and resilience against our changing climate.

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