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Summer Climate and Western Spruce Budworm Outbreaks in the Pacific Northwest

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Abstract

Western spruce budworm outbreaks occur yearly with devastating effects for forests across Oregon, Washington, and British Columbia. However, as of yet, the relationship between these outbreaks and summer climate is poorly understood. In this study, I compared western spruce budworm outbreak records from Oregon, Washington, and British Columbia with June-August temperature and precipitation records between 1975 and 1995. This research reveals interesting patterns in the correlation between drought conditions and western spruce budworm outbreaks. My results necessitate further study examining the potentially significant relationship between summer drought conditions and western spruce budworm outbreaks.

Introduction

The western spruce budworm (WSB) (*Choristoneura occidentalis*) is one of the most widespread and destructive North American forest pests (Kemp *et al*, 1985). In western North America, where the budworm is endemic, the Douglas fir (*Pseudotsuga menziesii*) and true firs (*Abies spp*.) are the main hosts of WSB (ibid). WSB outbreaks have a profound effect on forest ecosystems over the long term. They often kill numerous understory trees and reduce growth rates and cone crops in forests (Kemp *et al*, 1985). WSBs target younger trees and seriously inhibit regeneration, particularly in younger stands (Fellin and Dewey, 1993). In the short term, small outbreaks can increase nutrient cycling in areas of infestation (Swetnam and Lynch, 1983). Furthermore, WSBs regulate primary productivity by consuming photosynthetic tissues as well as redistributing biomass and resources (Ryerson *et al*, 2003). Thus, WSB may have as much ecological significance as fires. However, not very much is known about longer term dynamics, particularly the relationship between WSB outbreaks and climate (Ryerson *et al*, 2003).

Past studies of WSB in the northwestern U.S. and Canada (Thomson *et al* 1984 and Kemp *et al* 1985) have found that WSB outbreaks generally occur in warmer and drier conditions. This is in keeping with the "plant stress hypothesis" or the idea that in stressful conditions, plants have a higher food quality for insects because of decreased amounts of defensive secondary compounds and/or increased soluble nitrogen and carbohydrates (Kemp *et al*, 1985). In other words, the stress of drought conditions may lead to insect outbreaks. It is important to keep in mind that the response to climate varies based on normal climatic conditions in a particular area.

Winter climate is known to have little impact on WSB outbreaks (Thomson *et al*, 1984). When temperatures are cold enough to limit their food supply in late spring or early summer, larvae are often killed directly (Fellin and Dewey, 1993). Past studies in the Western U.S. have found that cool summer temperatures may slow development, increasing the time where the population is vulnerable to parasites and predators (ibid). However, the impact of summer climate on WSB outbreaks in Oregon, Washington, and British Columbia has not been widely investigated (ibid). Thus, my study seeks to gain a greater understanding of the relationship between summer climate and WSB outbreaks. The first goal of my study is to create a unified international dataset for WSB outbreaks in the Pacific Northwest region. Most prior studies have looked at a single state or province. Given that ecosystems do not follow country boundaries, conducting an international study is vital to the understanding of the large-scale factors influencing WSB outbreaks.

I chose to conduct my study over the period 1976-1995 because of the data availability (British Columbia did not do an aerial survey for the years 1996-1997) and because of the large outbreak the occurred in the mid to late 1980s. Given this outbreak, I decided to investigate a 20 year period surrounding the years of the outbreak in order to gain a better understanding of this outbreak. Furthermore, I decided to focus on summer climate (June-August) because this is the time where WSBs go through the majority of their life cycles and when the defoliation takes place (Fellin and Dewey, 1993). To understand the drought conditions, I looked at both summer temperature and precipitation.

My study seeks to increase the understanding of the relationship between summer climate and WSB outbreaks in the Pacific Northwest region.

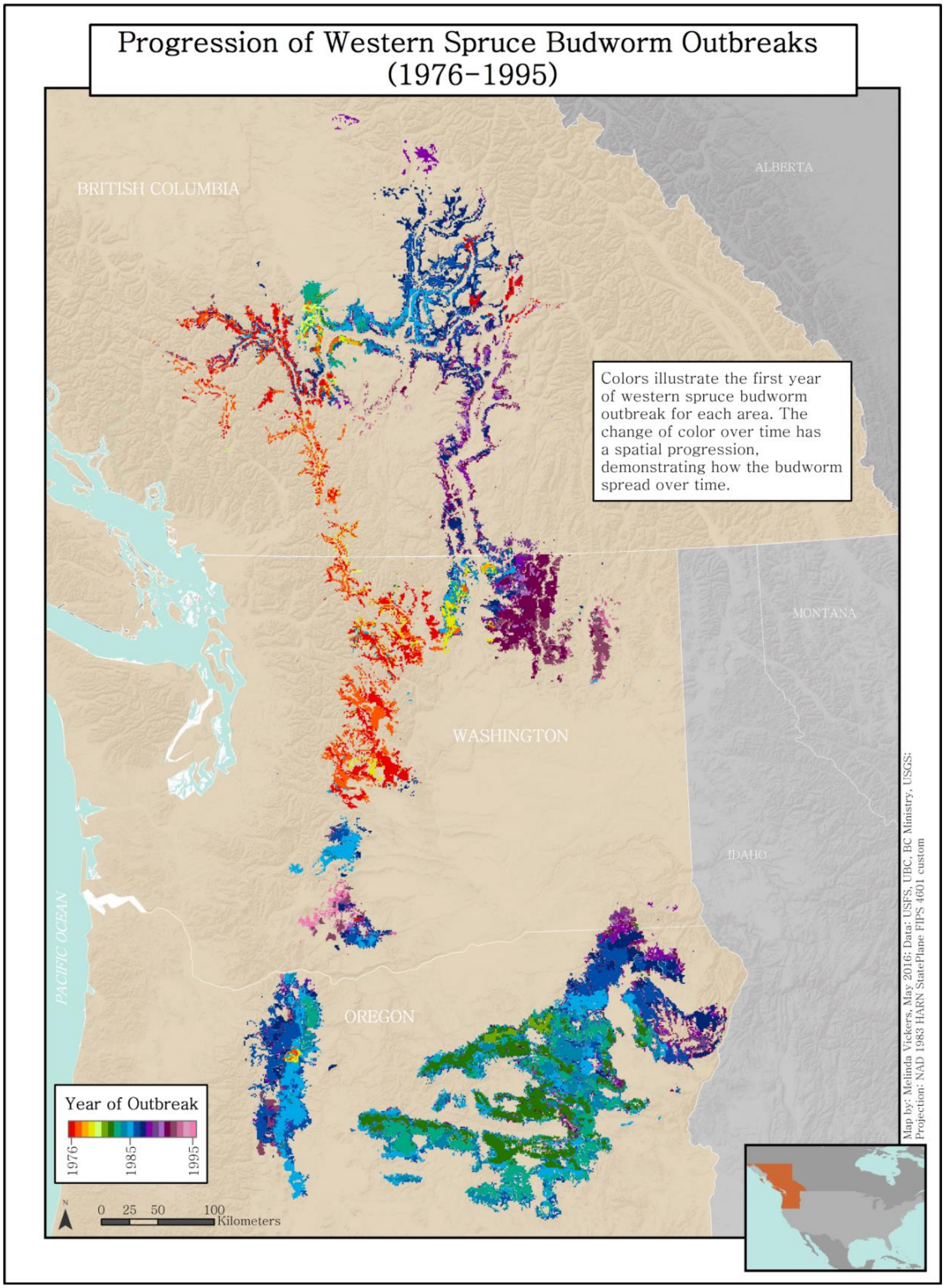

Fig. 1— Map illustrating the progression of outbreak over time for the study area. Colors represent the first year of outbreak in each location (see Methods).

Methods

My analysis utilized two main datasets: western spruce budworm (WSB) outbreak records and summer climate variables (June-August) for the years 1975-1995. The outbreak records were obtained from digitized aerial survey data by the U.S. Forest Service and the B.C. Ministry. For my analysis, I created one unified dataset for all the Oregon, Washington, and British Columbia data projected in a custom State Plane projection. From this dataset, I took just the WSB data and converted these to rasters for each year. In order to understand the impact of climate on outbreaks, I had to find a way to represent just the outbreaks. I reclassified the raster files to give every cell a value of 1 and made a second file where the area around the outbreaks were given a value of 0. Then, using the conditional tool and 1975 as a baseline year, I created new raster files where cells with new outbreaks for each year were given a value of 1 and cells with continued outbreaks were given a value of 0 (see Fig. 1 above).

To obtain summer climate variables, I clipped a digital elevation model (DEM) to my study area using a cell size of 2500 x 2500 m. In this file, I used the elevation values in addition to latitude and longitude (calculated by adding columns and calculating x and y coordinates in decimal degrees) to generate climate data for each year using the application Climate WNA (Western North America) from the University of British Columbia. From these datasets, I extracted total summer precipitation and average summer temperature to create rasters (by joining the Climate WNA data to the DEM point file, exporting them individually as new point files, and converting the point files to rasters) that represented both of these variables for the 20 study years plus 1975 (see Fig. 2).

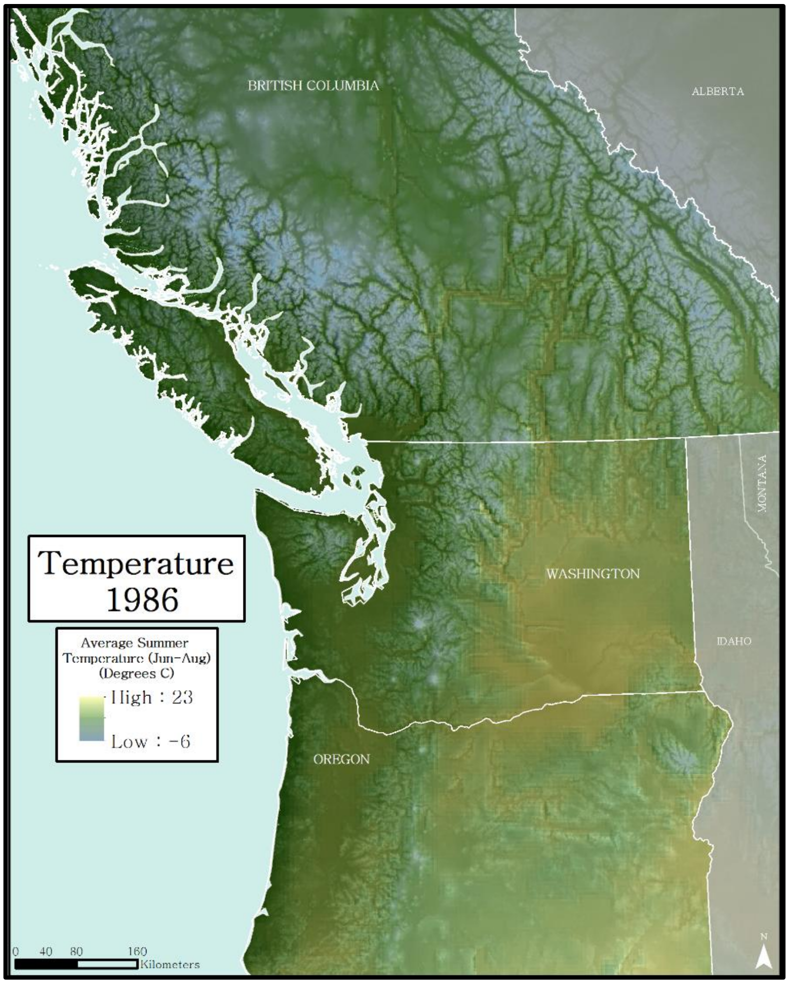

Fig. 2— Map illustrating one year of the temperature data extracted from Climate WNA.

For an initial comparison, I graphed the area of outbreak, calculated from the new outbreak raster files, with the precipitation and temperature over time. For the graphs, I clipped vector (point) climate data to a merged file of all the outbreaks over the 20 year period and used the resulting area to calculate summer temperature and precipitation. I also compared the precipitation and temperature from the prior year to the outbreak area.

Furthermore, I used zonal statistics to see if there was a significant climatic difference between areas that experienced outbreak and those that did not for the year of the outbreak and the year before the outbreak. Using a shapefile that represented all of the outbreaks experienced over the 21 year period, I created a 50 km buffer around the outbreak area. For each new outbreak file, I reclassified the data so that areas with a continuing outbreak received a value of 1, those with new outbreaks received a value of 2 and areas with no data received a value of 0. I then used raster calculator to add the reclassified outbreak data to the raster buffer (value = 1). The final buffer files gave the buffer area a value of 1, continuing outbreaks a value of 2, and new outbreaks a value of 3.

I then ran zonal statistics for each year (1976-1995) comparing average summer temperature and total summer precipitation with the buffer files both for the year of the outbreak (e.g. outbreak buffer 1976 with 1976 precipitation) and for the prior year (e.g. outbreak buffer 1976 with 1975 precipitation). Finally, I ran a T test at a p value of 0.05 (n = 20) for each of the zonal statistics comparisons.

Results

Based on the initial graphing of total summer precipitation (TSP) (Fig. 3) with yearly outbreaks and the zonal statistics (Fig. 4), there seems to be a correlation between lower TSP and outbreaks. However, there are years with dips in TSP, such as the dramatic dip in 1994, that are not correlated with outbreaks. Thus, TSP does not appear to be a consistent predictor of outbreaks. Based on my zonal statistics analysis, areas with no outbreak have an average of 29.81 mm more TSP than areas with an outbreak. In every year, TSP was higher in areas with no outbreak ranging from a 0.67 mm difference to a 71.69 mm difference. However, because of the high variance, after running a T test, I cannot reject the null hypothesis that there is no significant difference because the T observed (0.002813) was lower than the T critical at a P value of 0.05 (3.850).

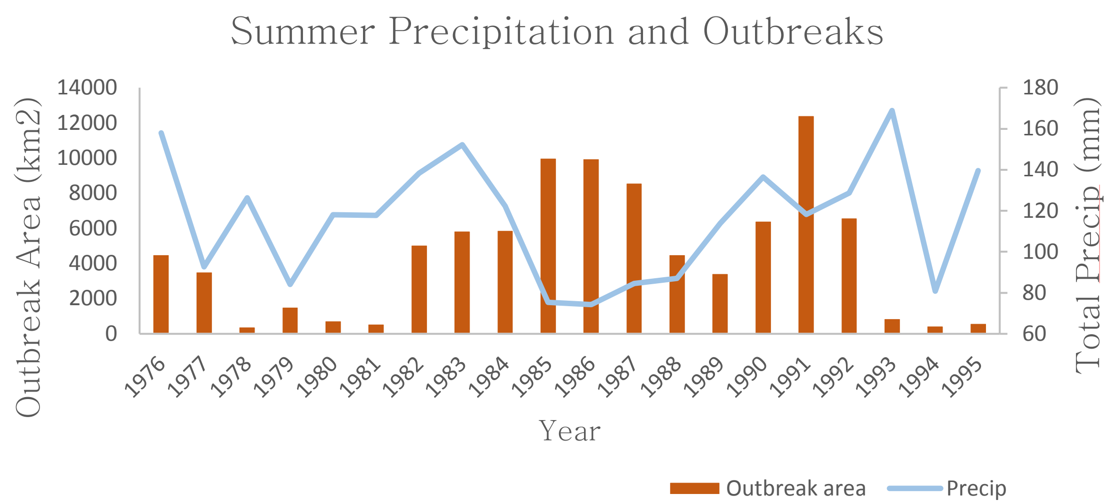

Fig. 3— A comparison of the total new outbreak area and the total summer precipitation (June-August) for the year of the outbreak over the study period.

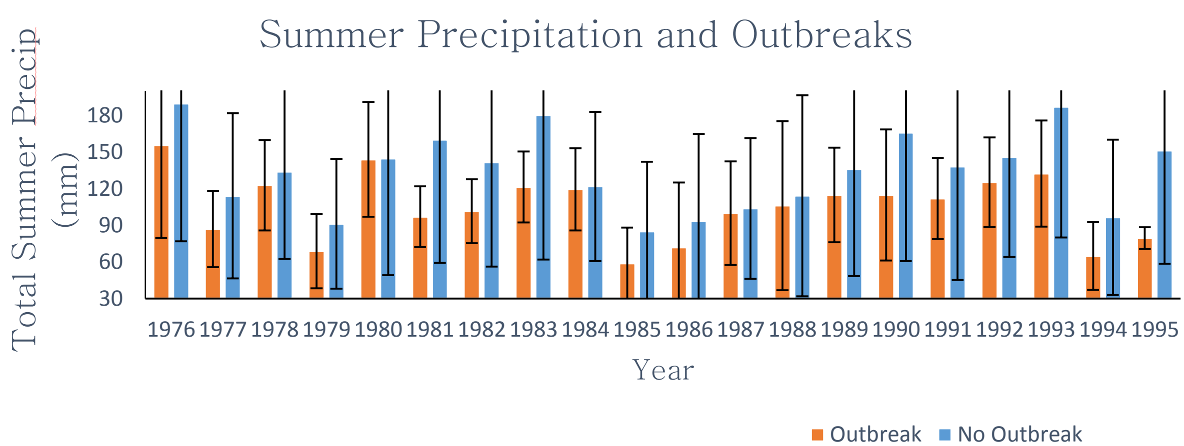

Fig. 4— A comparison (based on the zonal statistics analysis) of the total summer precipitation within the area of new outbreak and the rest of the buffer area.

Average summer temperature (AST) does not appear to have as apparent of a correlation with outbreak area as TSP (Fig. 5). The mid-1980s outbreak occurred in a year with higher temperatures while high temperatures in 1977 and 1994 were not correlated with higher temperatures. AST does not appear to be a consistent predictor of outbreaks. My zonal statistics analysis (Fig. 6) gives the opposite result: areas with no outbreak are on average 0.43°C hotter than areas with an outbreak. For all but two years, AST was higher in areas with no outbreak ranging from a 0.01°C difference to a 1.24°C difference. After running a T test for AST, I am unable to reject the null hypothesis that there is no significant difference between AST in areas with an outbreak and areas surrounding an outbreak.

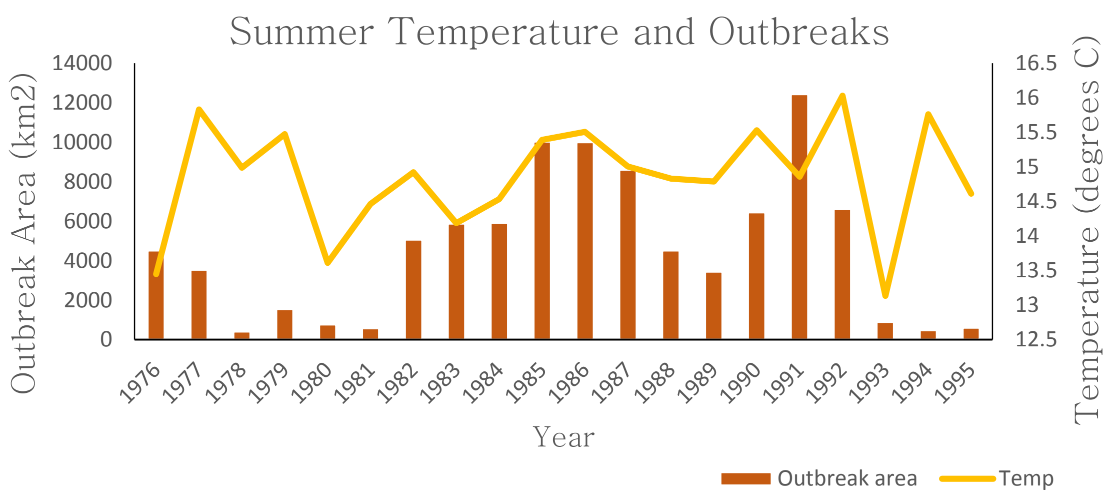

Fig. 5— A comparison of the total new outbreak area and the average summer temperature (June-August) for the year of the outbreak over the study period.

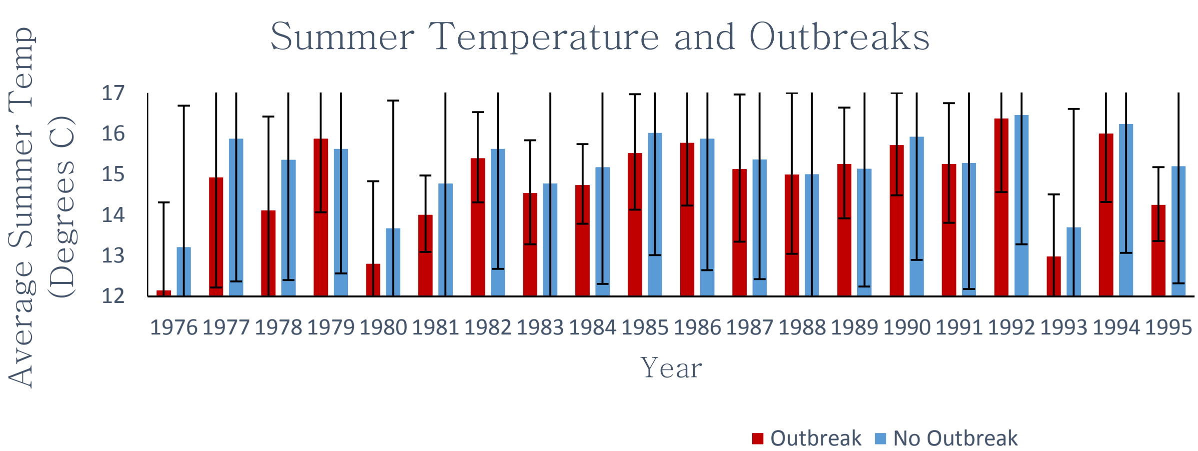

Fig. 6— A comparison (based on the zonal statistics analysis) of the average summer temperature within the area of new outbreak and the rest of the buffer area.

Based on the initial graphing of previous total summer precipitation (PTSP) (Fig. 7) with yearly outbreaks and the zonal statistics (Fig. 8), there seems to be a correlation between lower PTSP and outbreaks. However, like TSP, there are years with dips in PTSP, such as the dramatic dip in 1995, that are not correlated with outbreaks. Thus, PTSP does not appear to be a consistent predictor of outbreaks. Based on my zonal statistics analysis, areas with no outbreak have an average of 30.38 mm more PTSP than areas with an outbreak. In all but one year, PTSP was higher in areas with no outbreak ranging from a 3.46 mm difference to a 78.04 mm difference. Based on the T test, I am unable to reject the null hypothesis that there is no significant difference between PSTP in areas with no outbreak and areas with an outbreak.

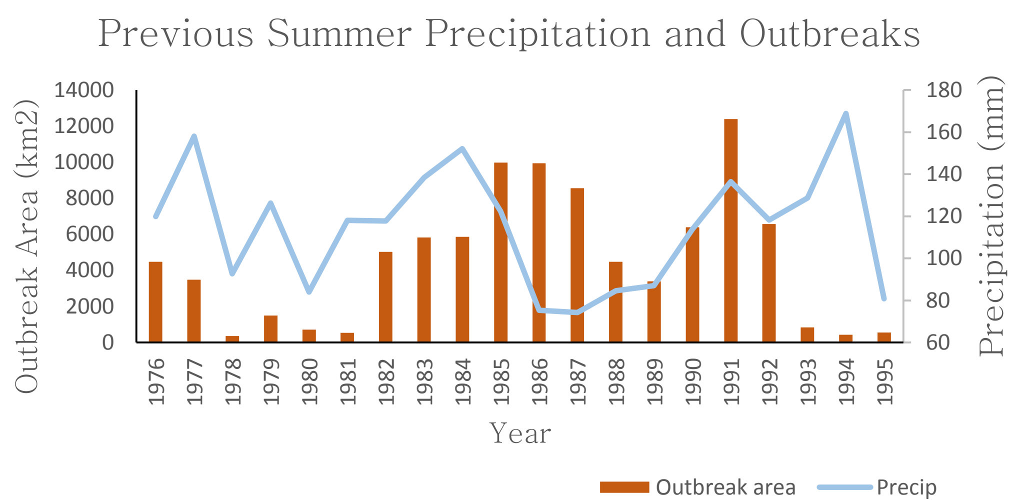

Fig. 7— A comparison of the total new outbreak area and the total summer precipitation (June-August) for the before the outbreak over the study period.

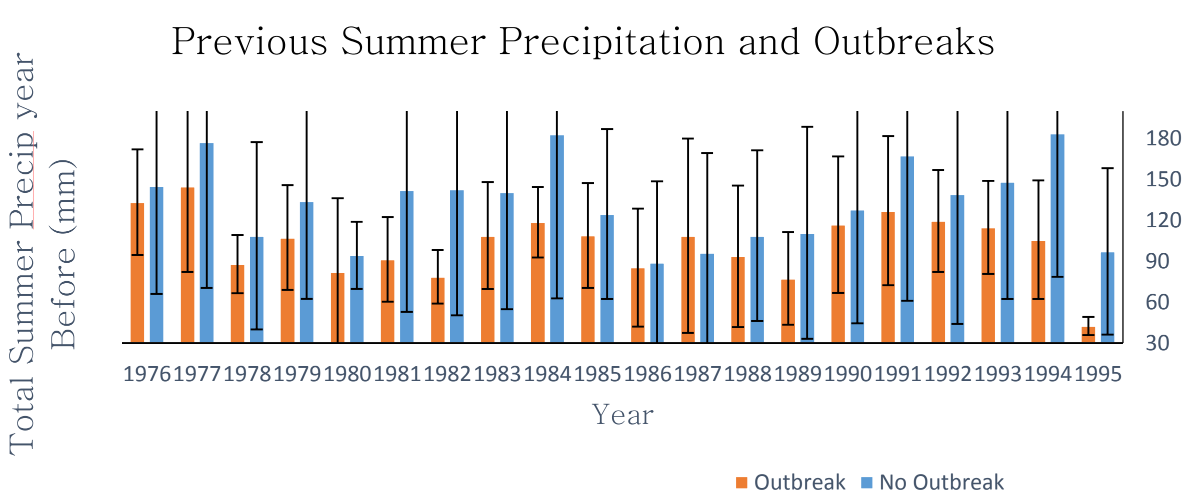

Fig. 8— A comparison (based on the zonal statistics analysis) of the total summer precipitation for the previous year within the area of new outbreak and the rest of the buffer area.

Previous average summer temperature (PAST) does not appear to have as clear of a correlation with outbreak area as PTSP (Fig. 9). The mid-1980s outbreak started before the dramatic increase in PAST. PAST does not appear to be a consistent predictor of outbreaks. My zonal statistics analysis (Fig. 10) gives a different result: areas with no outbreak are on average 0.44°C hotter than areas with an outbreak. For ¾ of the years, PAST was higher in areas with no outbreak ranging from a 0.20°C difference to a 1.28°C difference. Based on a T test, I was also unable to reject the null hypothesis that there was no significant difference between PAST in areas with an outbreak with areas with no outbreak.

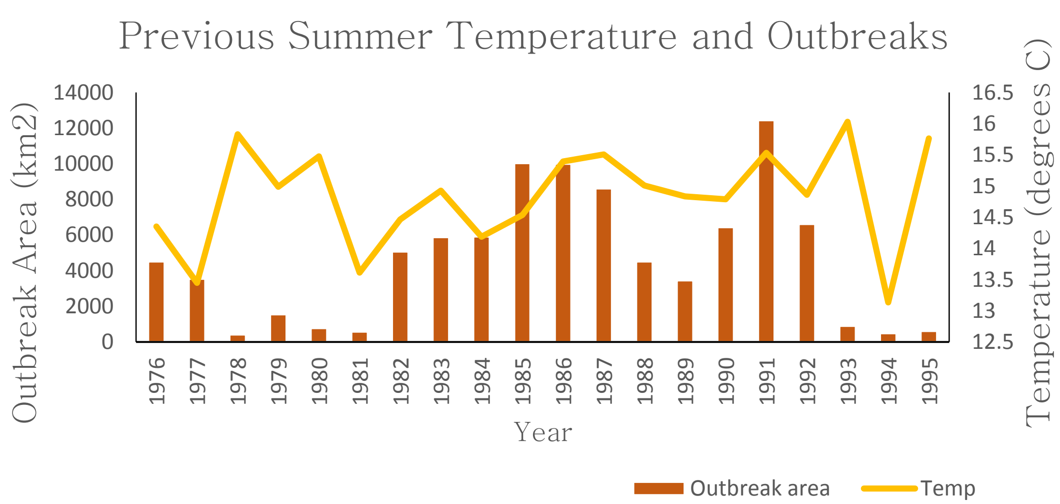

Fig. 9— A comparison of the total new outbreak area and the average summer temperature (June-August) for the year before the outbreak over the study period.

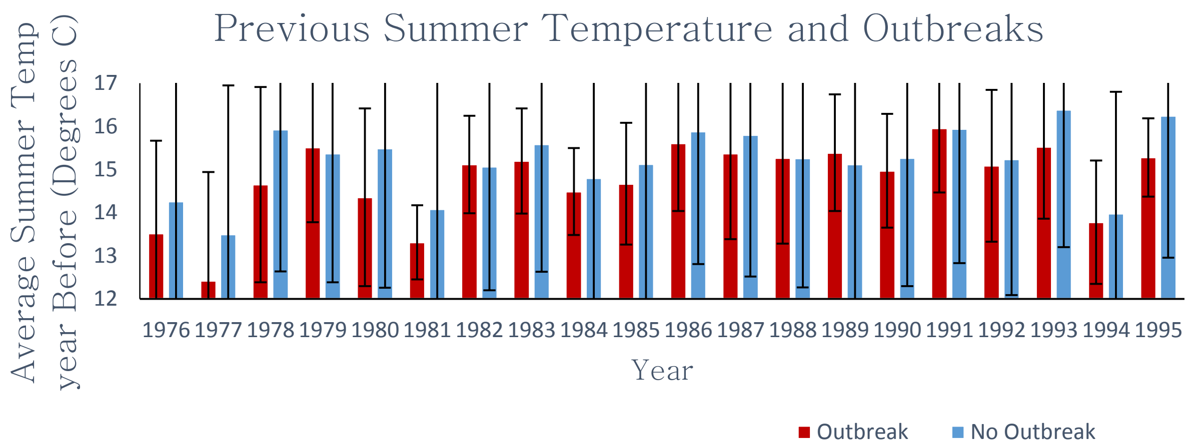

Fig. 10— A comparison (based on the zonal statistics analysis) of the average summer temperature for the pervious summer within the area of new outbreak and the rest of the buffer area.

Discussion

Western spruce budworm outbreaks in the Pacific Northwest may be correlated with summer drought conditions. Lower TSP and PTSP are both lower in years and areas of outbreak. AST and PAST have less of an obvious correlation with WSB outbreaks. Based on zonal statistics, the outbreaks tend to take place in areas with lower temperature than surrounding areas. However, because of the large variance of the results, my results did not find any significant difference from the zonal statistics analysis. Longer term studies using higher quality data may able to find conclusive results based on the trend that my graphs illustrate.

Because of the large study area and the limited time of this research, there are multiple limitations to this research. Firstly, higher resolution climate data would lead to more precise results. Additionally, because the insect outbreak data come from digitized aerial survey data, it may have limited accuracy. For the zonal statistics, given more time, it would be more accurate to compare areas with outbreaks to areas with no outbreaks within a particular species range envelope based on tree species and other factors that limit the expansion of WSBs. For example, my study, though the 50 km buffer encompassed a reasonable area for expansion and fell within a general range of tree species, did not fully account for tree species, water bodies, cities, or any other factors that limit the expansion of WSBs.

To take this research forward, I would compare the results from zonal statistics on a temporal scale. Furthermore, I would increase the time frame of the study. Further studies should also investigate other variables that have an impact on summer drought conditions such as winter snowfall and moisture content. Additionally, drought is relative to the average climate. As such, further studies should also investigate climate anomalies based on a 30 year average.

These results necessitate further research. With a predicted decrease in summer precipitation and an increase in summer temperatures in this region due to climate change, understanding the relationship between climate and WSB outbreaks will become even more important in the years to come. If summer drought conditions are in fact correlated with WSB outbreaks and the future climatic trends lead to more summer drought conditions, land managers will need to find a way to deal with the widespread outbreaks. Otherwise, WSBs have the potential to destroy large areas of forest ecosystems.

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