Vehicular Emissions and Red Pine Growth

Nick Andrew
Molly Conlon
John Cherry
Molly Phillips

Abstract:
Human actions and decisions can have a critical impact on the environment from overuse of natural resources, development of land, and emission of pollutants. In this study, we looked at the impacts of vehicular emissions on red pine trees along Interstate-75. In order to determine whether there was a difference in growth between trees on the eastern (downwind) and western side of the interstate, we analyzed tree cores from 30 pines on either side of the highway as well as 30 pines from the east and west sides of a less traveled north-south running control road. We found significant differences in the growth of trees on the eastern and western side, with the west side growing more on average than the trees on the east side, leading us to believe that vehicular emissions have an overall negative impact on tree growth. The regulations on emissions put in place by the Clean Air Act and its amendments, conform to the significant differences in growth found in our study.

Introduction

Human decisions and actions regarding the utilization of natural resources to land development to the emission of pollutants into the skies, water, and land have a critical impact on all levels of ecological systems. Point source pollution can damage an area as small as a puddle or spread pollutants over many square miles. Large-scale pollutants can affect an entire lake, such as Lake Erie, which was saturated with phosphorus runoff in the 1970's, or they can have a global impact, such as greenhouse gases and their relationship to climate change.

The current point of interest regarding vehicle emissions focuses on their connection to global warming. Recent regulations, as outlined by the Corporate Average Fuel Economy (CAFE), focus on controlling the carbon that Americans emit into the atmosphere (Mufson, 2007). Vehicle emissions, however, contain carbon monoxide, nitrous oxides and lead in addition to carbon dioxide. The levels of these pollutants have changed according to EPA regulations over the years. In 1970, the Clean Air Act limited hydrocarbon emissions to 0.41 grams per mile but was revised to 0.25 grams per mile by 1996. Carbon monoxide outputs in automobiles were limited to 3.4 grams per mile in the original Clean Air Act, and remain unaltered since. These regulations, which were supposed to go into effect in 1975, were subsequently delayed until 1978 and then until 1981. The maximum allowable release of nitrous oxides was 1 gram per mile by 1981, and was then revised to 0.4 grams per mile by 1996(EPA, 1994). Starting in 2008, a new standard for nitrous oxides will be set at 0.07 grams per mile (EPA, 1999). The 1990 Clean Air Act Amendment made the production of vehicles requiring lead gasoline illegal by 1993, and lead was banned from gasoline in 1996 (EPA, 1994).

Much has already been studied, learned, and written on the localized effects of various vehicle emissions. Nitrous oxide emissions appear in *Picea abies* (Norway spruce) that are within 50 meters of a motorway and could increase growth of trees in nutrient poor soils (Saurer et al., 2004). Carbon Dioxide increases the net primary production of *Pinus taeda* (Loblolly pine) when there are sufficient amounts of other nutrients for it to be the limiting resource (DeLucia, 1999). Ozone exposure (created when hydrocarbons, nitrous oxides, and sunlight combine) results in significant damage to *Betula pendula* (European white birch) and restricts growth (Oksanen, 2003). There is also considerable evidence that ozone formation occurs not just in congested urban areas, but also along rural interstates (Jones et al, 2001). Lead has been shown to affect root development in *Picea sitchensis* (Sitka spruce) although high concentrations are necessary to affect plant yield (Burton et al, 1984). Research attempting to find the cumulative effects of these pollutants is uncommon. The most notable research to date is currently occurring in Wisconsin, where researchers behind the Aspen FACE project are using carbon dioxide and ozone-controlled stands of trees to study the exclusive effect of these gasses on their areas. So far their results indicate that increased concentrations of carbon dioxide and ozone have the general effect of canceling each other out (Karnosky et al., 2003).
The Mackinac County section of the Hiawatha National Forest was established in the 1920's. As a designated national forest, the area is managed by rangers from the United States Forest Service, and is used for economic, conservation, and research purposes.

Originally a forest consisting of white pine and various hardwoods, this area was clear-cut in the early 20th century. Jack pine and red pine were heavily replanted by the Civilian Conservation Corps during the 1930's, and have flourished in the forest since (Christiansen, 2007).

The Mackinac County section of Interstate 75 was constructed immediately in the years following the completion of the Mackinac Bridge, in 1957. I-75, as with all US interstates, is maintained and monitored by the United States Department of Transportation. To our knowledge neither the USDOT nor the USFS has conducted a study in Mackinac County or in any area of the Hiawatha National Forest on the relationship between automobile pollution and tree growth in any tree species (Christiansen, 2007).

There are over 40,000 miles of Interstate in the United States (). If vehicle emissions have an effect on the growth of trees and other plants along these roads there could be a considerable economic cost or conversely an economic benefit to the number of miles that we drive to work and on vacation.

Pinus resinosa (red pine) is a common tree species in the northern timberlands of Michigan's Upper Peninsula, and spans much of the northern United States and Canada. Due to its rapid growth in the first 25 years of life, it is a high demand species for the timber industry. It is also relatively free from insect or disease damage, suffering a low mortality rate. The best predictors for red pine growth are age and site/soil quality, two relatively easy variables to control. The third, less reliable, predictor of growth is stand density, with higher volume trees founding higher density stands (DOA, 2006).

In this study we addressed the impact of vehicle emissions along I-75. For the purposes of this experiment, we limited our focus exclusively to the growth of *Pinus resinosa* through the measurement of tree rings. Specifically, we asked whether vehicle emissions increase, decrease, or have no effect on the rate of growth of red pine. Additionally, we asked whether mobile emissions regulations affect the impact of vehicle emissions on red pine growth, whether traffic can be used as an indicator of vehicle emissions and their impact on red pine growth, and whether fluctuations in climate, as opposed to emissions levels, better explain changes in the growth of *Pinus resinosa*.

Materials and Methods

Differing tree growth on the east side and west side of a high and low traffic road

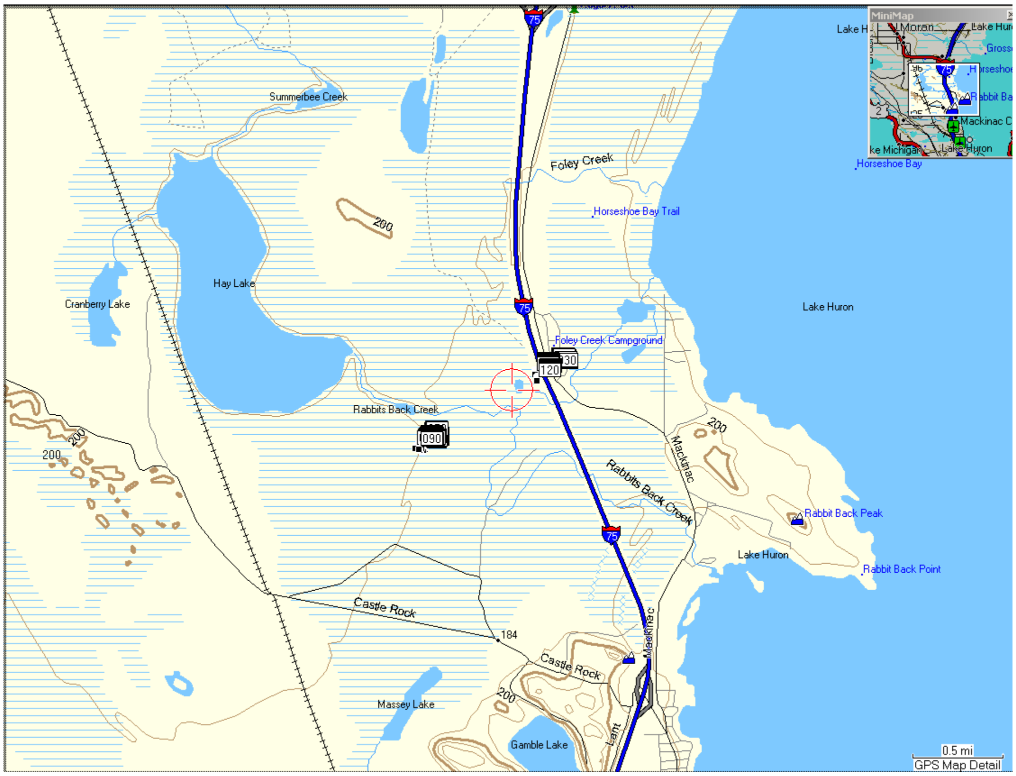


Figure 1

In order to determine the effect of vehicular emissions on the growth of *Pinus resinosa*, we sampled trees at two sites adjacent to interstate 75, a high traffic, north-south highway in the Hiawatha National Forest. We assumed that wind primarily comes from the west, causing the eastern side of the road to receive higher concentrations of vehicular emissions. This assumption is confirmed in data from the closest NCDC weather station in Sault Ste. Marie that has recorded a prevailing yearly wind direction for the past ten years between 300 degrees and 330 degrees with most years having a prevailing direction of 310 degrees (DOC, 2007). The deviations within a year from this pattern happen in the late winter months when traffic over the Mackinac Bridge is at its least. We concluded that differing amounts of sunlight exposure on either side of the road at different times of day could confound our data so we chose a site as a control that conformed to this same pattern of sunlight. In addition to similar sunlight conditions, we selected a control based on similar soil samples and slope. All of the samples from our control sites, and a portion of samples on the west side of the interstate were Onaway loam (tan, see figure 2) on a very small slope, while the remaining samples on both sides of the interstate were Blue Lake loam (pink, see figure 2) on a steeper slope (Whitney and Rodock, 1997). Both soil types are very well-drained, and characteristic of soils found on an outwash plain, which is the geologic landscape of the area. Although Blue Lake loam tends to have a much thicker sand layer before reaching bedrock, the two soils are very similar, and could be expected to find similar results in both species composition and growth rate (DOA, 1999, 2006). We selected an area that is close enough in proximity to receive similar wind and precipitation patterns, but far enough away, and preferably upwind, from the highway to completely avoid its possible effects. This site was located along a low traffic, north-south dirt road west of I-75, still in the Hiawatha National Forest, and is marked in Figure 1 along with the highway sample.

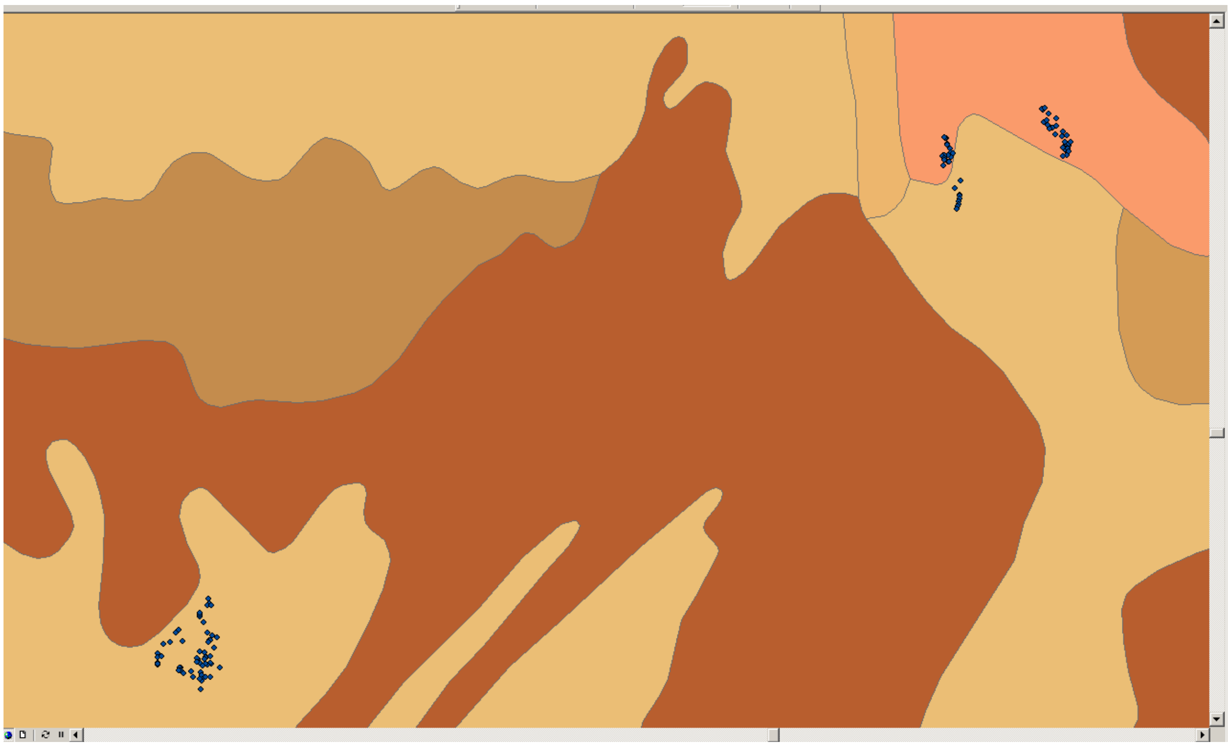


Figure 2

We used red pine because it is abundant in these two areas, and as a softwood species, is easy to core and has distinct annual rings for accurate analysis. After selecting the sites and marking the trees with a Global Positioning System (GPS), we took tree cores from 30 trees from the eastern and western sides of the highway and from the lower traffic road. We assumed that 120 trees would provide a representative sample.

We measured the size of individual tree rings on each core sample to determine yearly growth in order to compare the mean yearly growth among trees on the eastern and western sides of I-75 and our control road between 1948 and 2006. We limited our analysis to years after and including 1948 because our sample size was insufficient prior to 1948.

Large discrepancies in tree age between the east and west sides of the interstate led us to take steps to prevent a confounding variable in our study. To account for this, we ran a univariate test with age as a covariant for every year in both the highway and control samples. For the years in which we found the covariant not significant, we checked for normality by calculating two ratios: skewness/standard error of skewness and kurtosis/standard error of kurtosis. We conducted t-tests on the data that we found to be normally distributed and Mann-Whitney U tests on the years that were not. The results of these tests were used to run 2x1 Chi-square tests for both the control and the I-75 sites to determine if one side of the road had a consistently greater mean growth. A 2x2 Chi-Squared test was run with I-75 and the control road to determine if there was a difference in the frequency of significant growth differences between I-75 and the control road.

Traffic rates and tree growth

There are many factors that could potentially cause differences in growth of red pines on the eastern and western sides of the interstate. Because we reasoned that vehicular emissions might impact plant growth, we wanted to know if traffic could be used as an indicator of the effects on emissions on red pine. To determine if there is a strong correlation between traffic and growth, we obtained Mackinac Bridge traffic data since 1957 (the year it was built) as a measure of the amount of traffic at our site. We averaged the growth of each year from 1957 to 2006 for both the eastern and western side of I-75. We then created a proportion of the mean growth on the eastern and western side of the interstate since 1957. For each year we divide the eastern side by the western side, creating a growth ratio, in order to compare the eastern growth to the western growth. We chose to look at the proportion of means because it would lessen the impact of other potential variables such as weather. Using this data and the Mackinac Bridge traffic data, we ran a regression.

Weather and tree growth

Although our primary research question asked if vehicular emissions impact red pine growth along I-75, we wanted to know if weather could better explain any growth patterns we saw during our analysis. To determine if there is a relationship between weather patterns and tree ring growth, we used data from UMBS climatology records of Mackinac City (compiled by Bob Vande Kopple). Although this data was available back to 1898, we used only from 1957 on, to parallel the traffic rate correlation. In looking at the weather data, we analyzed both mean daytime temperature and cumulative precipitation annually, and then by taking just the seasons of spring/summer together, to focus more closely on what constitutes the growing season. Using proportions of the mean growth of trees on both sides of the interstate congruent to the above procedure, we ran multiple regressions with the different weather data.

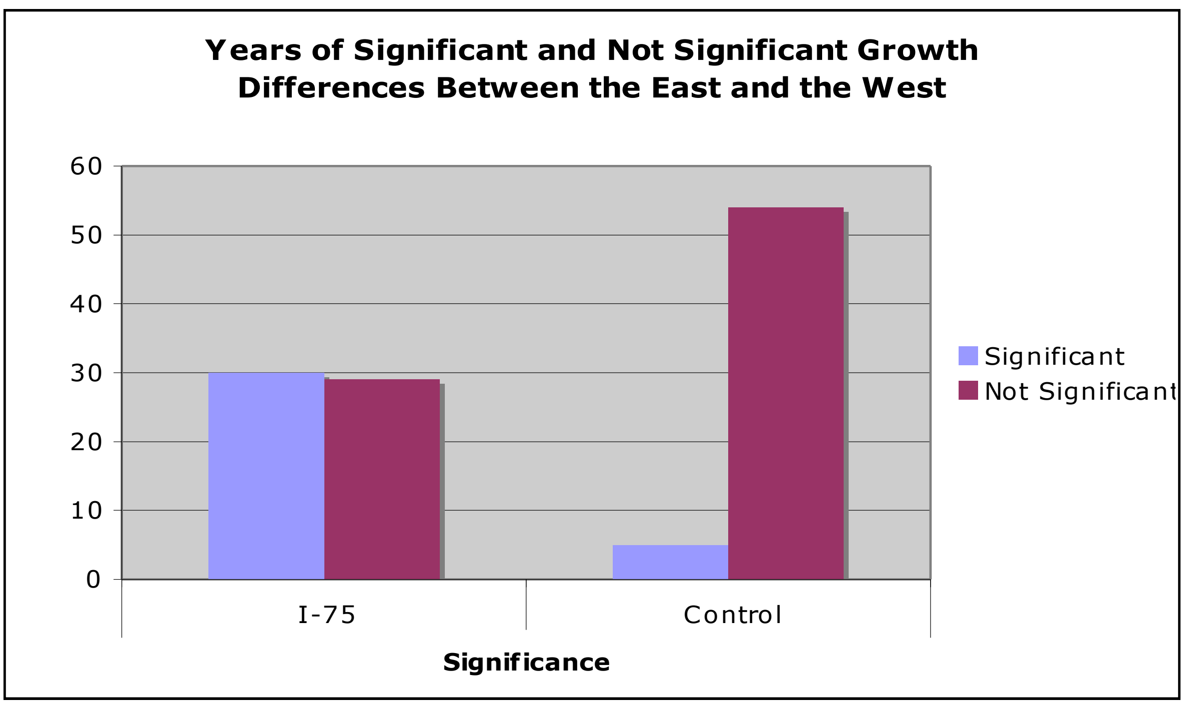
Results

Differing tree growth on the east side and west side of a high and low traffic road

In 30 of the 59 years that we surveyed, mean growth of red pine differed significantly between the east and west sides of I-75. In all 30 cases showing a significant difference, mean growth was greater on the west side of I-75 than on the east side. Every year from 1959 to 1988 showed a significant difference in growth between the east and west sides of the interstate except for one year, 1987. (See graph below)

In contrast, our control site showed five years of significant differences in the growth of east and west sides of the control road. (See graph below) For each of these years showing a significant difference, the mean growth on the east was greater than the mean growth on the west side of the road. Four of the five years that showed significant differences in growth between the two sides occurred within the past decade.

Our Chi-Squared tests determined that the frequency of results that show mean growth on the west is greater than on the mean growth on the east is significantly greater than the frequency of results that showed mean growth on the west was less than on the east. This is true for both I-75 and our control road. The 2x2 Chi-Squared test, at a p-value less than .0005, showed that there was a difference in the frequency of significant years showing mean growth differences between I-75 and our control road. The comparison of significant and non-significant years between the two roads is shown graphically below.



Effect of Traffic Rates on Tree Growth

In order to accurately represent the differences in growth between the east and west side of the two different roads of interest, we created a mean growth proportion for each year of interest in our study. In order to compare the growth of the east to the west, we divided the mean growth of the east for each year by the mean growth of the west for each year.

The linear regression analysis between traffic volume and our calculated mean proportion showed a significant correlation with a p-value less than 0.0005. However, the R^2 value was relatively low; therefore, there is not a strong linear relationship between traffic and our calculated mean proportion.

The graphs below show traffic volume and the calculated proportion (as mentioned previously) as a function of time. The graph of the traffic volume follows a general trend—as time passes the traffic volume increases as well. However, in more recent years, the traffic volume declines. The graph of the mean proportion of growth begins at higher proportion then drops to a very low proportion for about 15 years then begins to climb again after 1980. Because traffic generally increases over time, we would expect the east side to receive more pollutants, and in turn, inhibit growing capabilities. If the east side growing capabilities are inhibited, it would grow proportionally less than the west side. This would result in a lower calculated proportion as observed on the graph roughly between the years 1965 and 1981. As shown on the graph, the proportion begins to increase showing that the east side is beginning to catch up to the growth of the west side. There could be less of an inhibition on the growth of the east side due to regulations on vehicular emissions that had been previously passed and began to take effect.

Weather and tree growth

In analysis of the temperature and precipitation throughout the last half century, we found a significant association between spring and summer temperatures and the difference in growth between trees on the east and west sides of the interstate. However, the R^2 was very low, with a value of 0.10, showing that the linear correlation between spring and summer temperatures is not strong. There was no correlation between seasonal or annual precipitation levels and the mean difference in growth on the interstate or the control.

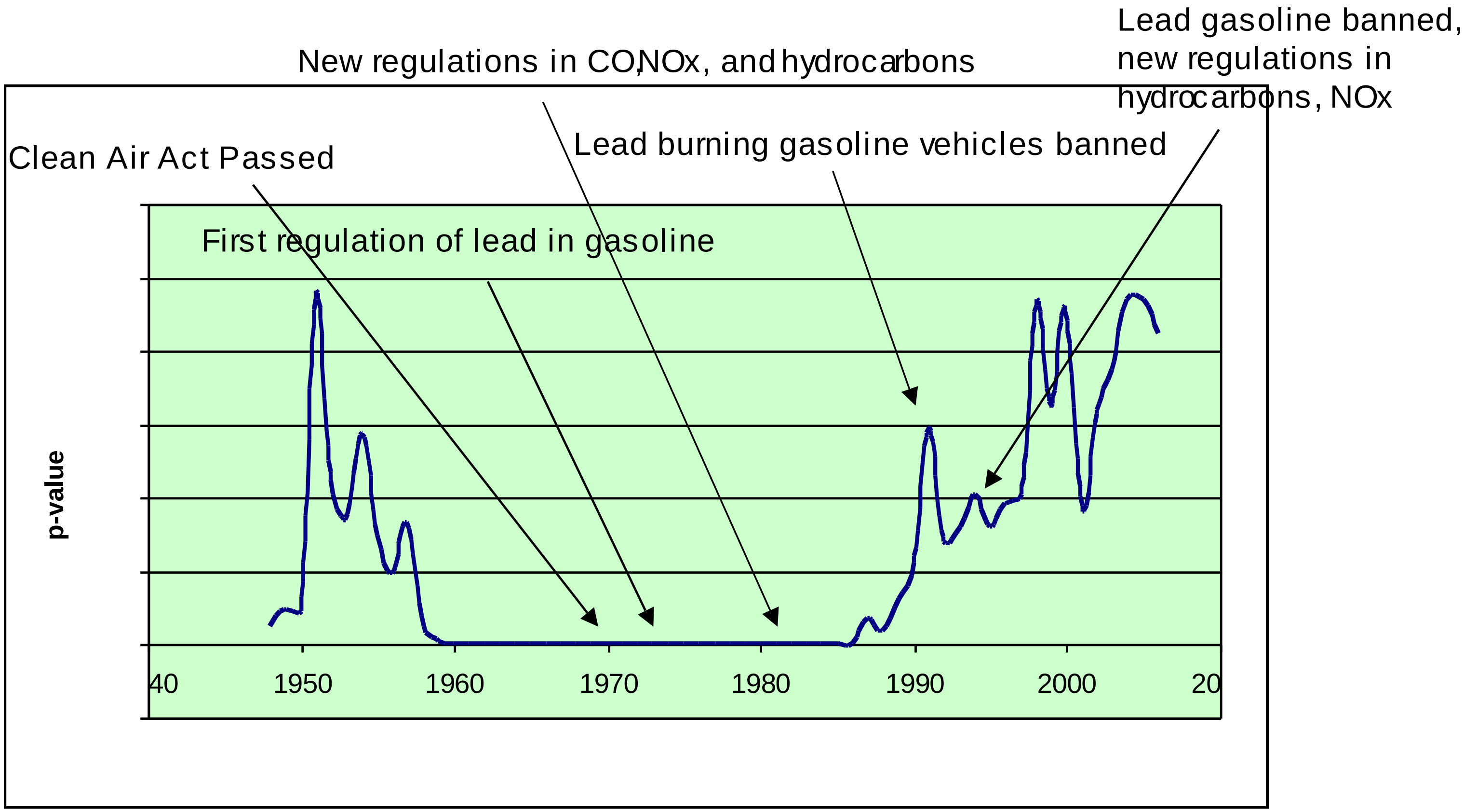
According to the data we found a significant relationship and near significant relationship between the mean differences in growth of the east and west sides of the control road.

This data supports the theory that emissions would have a significant impact on growth for both the interstate and the control.

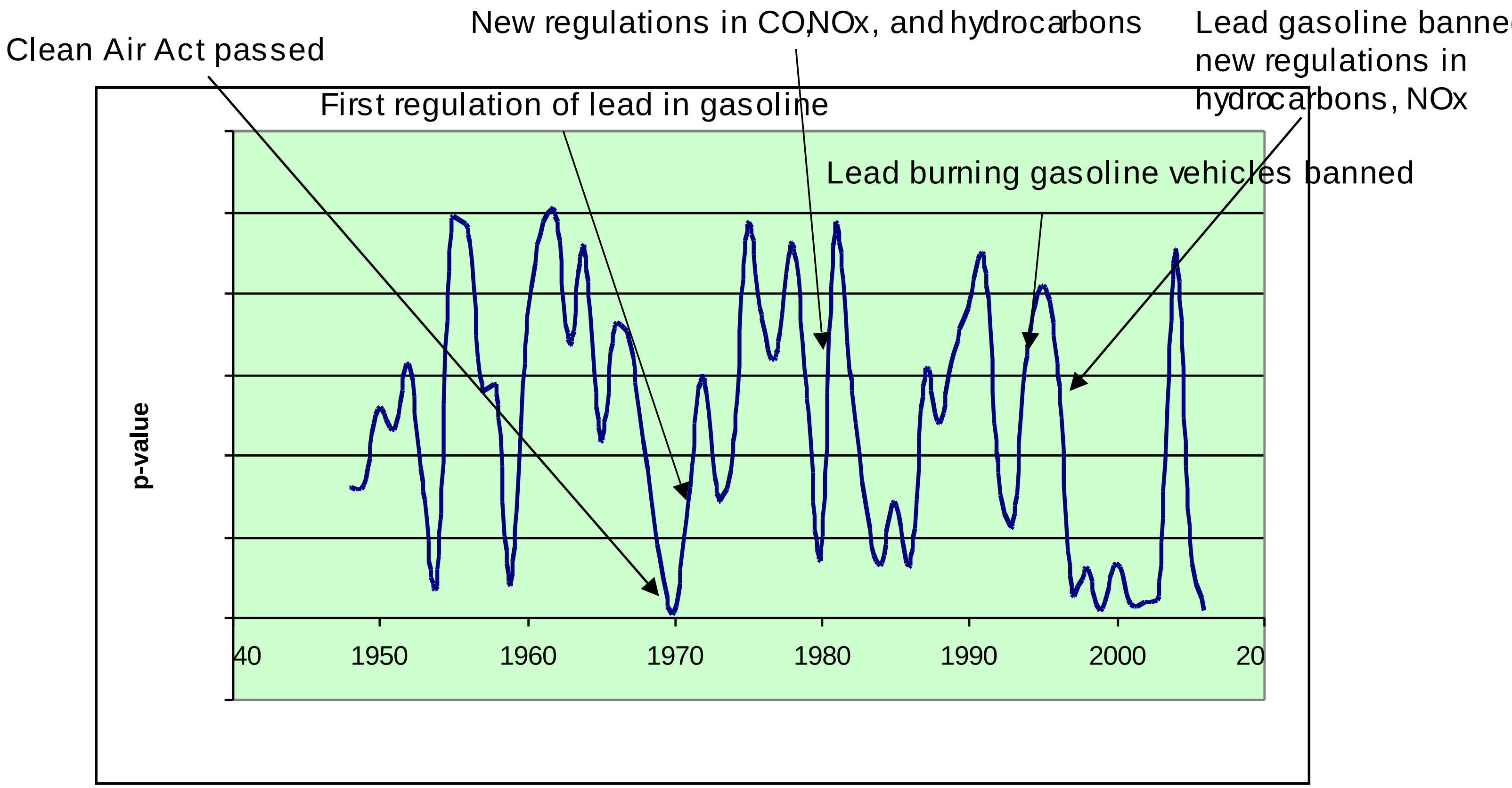
I-75:	**p-value**
Annual Precipitation:	0.298
Annual Temperature:	0.287
Spring and Summer Temperature:	0.050

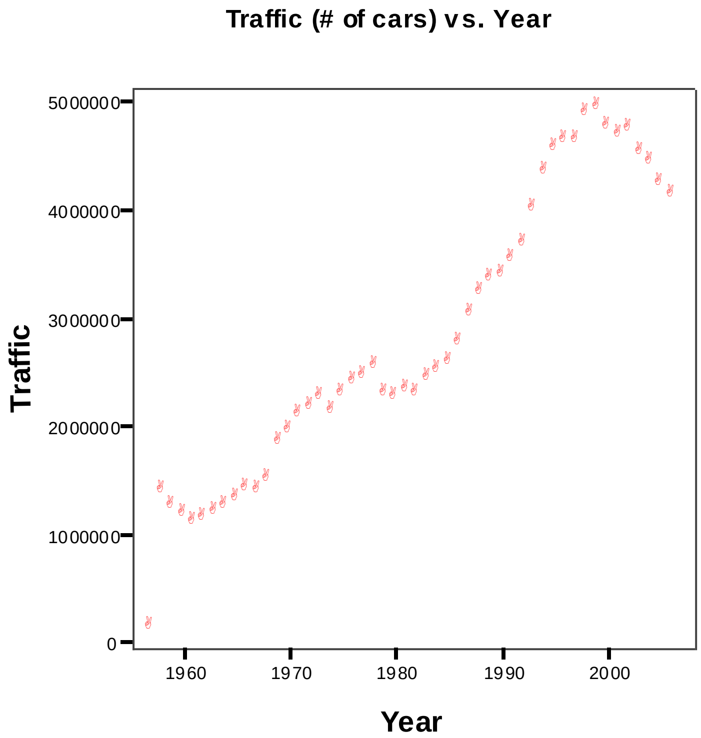
Control:	**p-value**
Annual Precipitation:	0.907
Annual Temperature:	0.043
Spring and Summer Temperature:	0.054

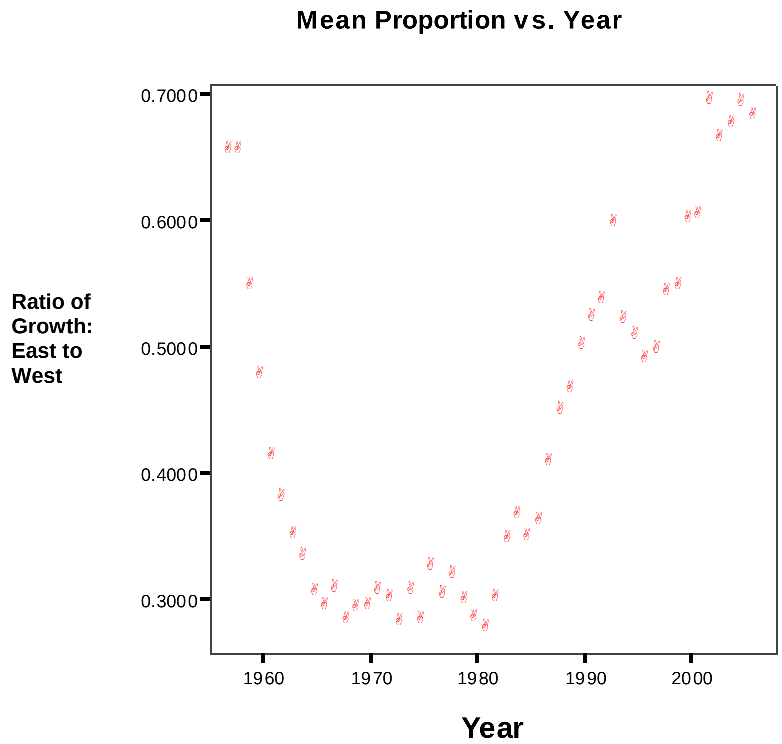
Significance of the Growth Difference Between East and West: Interstate-75

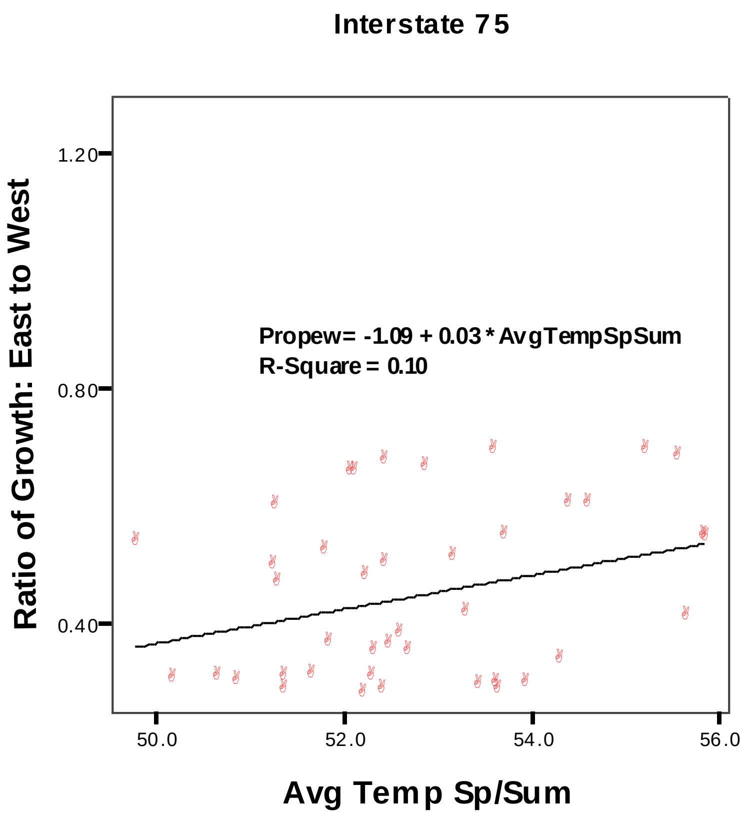


Significance of the Growth Difference Between East and West: Control




Traffic (# of cars) vs. Year
Traffic
5000000
4000000
3000000
2000000
1000000
0
1960
1970
1980
1990
2000
Year


Mean Proportion vs. Year
Ratio of Growth: East to West
0.7000
0.6000
0.5000
0.4000
0.3000
1960
1970
1980
1990
2000
Year


Interstate 75
Propew= -1.09 + 0.03 * AvgTempSpSum
R-Square = 0.10
1.20
0.80
0.40
Ratio of Growth: East to West
50.0
52.0
54.0
56.0
Avg Temp Sp/Sum

Discussion

After statistical analysis we found a significant trend of greater annual growth in red pines on the west side of Interstate-75 than the east side. These results are based on a consistent tendency towards higher tree growth on the western side between 1959 and the present day. Even when we removed the difference in tree ages on either side of the highway, we still found statistically significant differences in growth between the pines on either side between 1959 and 1988. In contrast, we saw less difference in growth between the two sides of the control road.

In analysis of traffic data since 1957, we found no linear correlation between the number of vehicles that had passed the site and the differences in growth between trees on the eastern and western side of the interstate. Although we saw a trend towards a wider gap between tree growth on either side of the road as traffic increased in the years immediately following the construction of the bridge and road, we also saw a shift in the opposite direction beginning in the 1980s; as traffic continued to increase, the mean difference in growth decreased. This tells us that while the levels of emissions within vehicles may have been a factor, the number of vehicles actually passing through the area is not.

One potential explanation for these mean differences in growth alongside either side of the highway involves the aforementioned topic of automobile emissions. Soon after the Mackinac Bridge and I-75 were completed in 1957, we began to see shifts in tree growth on the east side, with differences in growth on the eastern and western sides becoming greater. Likewise, once emissions regulations became stricter, we again saw a shift in downwind tree growth. Over this same time period, our control site, which experienced the same temperature, sunlight and soil conditions, saw little difference in growth between trees on either side of the road. The only statistically significant differences were seen in the last eight years. The only major factor separating these two sites is the increased exposure to automobile emissions that occur in our test site along the interstate.

The results of our spring and summer temperature's effects on the highway sites support this explanation. The results showed a significant, yet small, correlation between hotter spring and summer temperatures and larger proportions (or smaller differences in growth) between the east and west sides of the highway. Research has confirmed that trees tend to photosynthesize earlier in the daytime, and then close their stomata as the temperature increases, to avoid moisture loss (Martin, 2000). Therefore in seasons with more peak hot days, trees would close their stomata earlier and more often. One side effect of this would be that trees downwind from the highway would take in less of the emissions from automobiles, and would exhibit less diminishing growth as compared to those upwind in those seasons. This correlation with the weather data suggests that this would be true.

Another possible explanation for the differences in growth is that the eastern edge forest on the western side of the road could grow better than the western edge on the eastern side of the road. As previously explained, trees photosynthesize earlier in the day. Therefore, it would be beneficial for a tree to receive most of its sunlight in the morning, as would occur for trees on the eastern edge of the forest. In turn, trees on a western edge would close their stomata before they see an optimal amount of sunlight to assist them in photosynthesis, and its resulting growth. Before the highway was built through this part of the forest, it is likely that this was an undisturbed patch of forest. Therefore this pattern would not become evident until the construction of the road in the 1950s created this edge effect. The control may appear to contradict this, however, if the less traveled road was not built until the last decade because we would not see this effect until recent years. The date of this road's construction has not been confirmed.

The significance of our results is quite large in scope. Although our study has focused on the localized effects of automobile emissions, there are over 40,000 miles of interstate in the United States (DOT, 2007). If vehicle emissions have an effect on the growth of trees and other plants along these roads there could be a considerable economic cost or conversely an economic benefit to the number of miles that we drive to work and on vacation. Additionally, forests in the US are responsible for a great deal of carbon sequestration; by limiting their growth we limit their sequestration ability. This is another example of a localized effect having consequences toward a global problem such as climate change. Finally, as a general trend many developing countries, whether due to a lack of access to modern technologies or a greater emphasis on economic stimulation rather than economic handicaps, are far behind the United States and other developed countries in both engine and gas emissions regulations. As we have seen, the United States only decades ago had far less stringent laws on the emissions in automobiles, and these negative effects of emissions could be far greater in developing countries well into the future.

Conclusion

Upon completion of this study, we believe that vehicle emissions have an overall negative effect on the rate of tree growth in *Pinus resinosa*. This is an important finding not only in terms of the scope of impact that we discussed previously, but also in terms of the potential effects that have yet to be explored in relation to this study. Although numerous studies have been noted that analyze the effect of one specific chemical or compound on trees or other species, little has been done to analyze the overall effect of vehicular emissions on these same species. We would hope to find continued research into the effects of vehicles on localized tree populations, particularly in more populated urban areas.

There were many limits of our study. Not only were we looking at the effects of a relatively isolated highway, albeit a well-traveled one, but also a road that is somewhat young in comparison to much of this country's road infrastructure. Although many of the interstates in this country were built at the same time as I-75 or later, the effect of US highways and large-scale urban road infrastructures occupied long before then. If tested, we would expect to see much greater localized effects on the tree population in more densely populated areas. This would include both interstates that are subject to a higher traffic volume, as well as highways and roads that are located in more urban areas. We would also expect to see greater effects near older roads, since vehicles were in widespread use before 1957, and operated with almost no emissions regulations whatsoever during that time.

Most important of all, we would expect to see the effects of emissions present in *Pinus resinosa* to parallel those of other tree and plant species. *Pinus resinosa* is a fast-growing tree that engages in high levels of photosynthesis, particularly in its early years. It is our best estimation that more stable slower growing trees such as *Fagus grandifolia* (American beech) would be less affected by emissions, as they would see fewer effects from outside factors in general (Wied, 2007). On the other hand, other fast-growing trees, not to mention other fast-growing perennials would be affected similarly to *Pinus resinosa*.

Perhaps most affected by these outside effects would be annuals, which lack the stability of most tree species, and whose populations would fluctuate more from year to year based at least partially on effects within their ecosystem. A major impact of emissions on annuals would require a study of both growth and population changes from year to year over time. A connection that links both other tree species as well as annuals to the effects of vehicle emissions would add to the importance of this study. We would hope that others begin to address the various implications of study in their research, and gauge the intensity and range in which emissions may be having an effect, at a localized as well as a global level.

Works Cited

Mufson, Steven. "Senate, House Turn Focus to Energy Bills." Washington Post 12 June 2007, sec. D: 01.

United States. Office of Mobile Sources. Environmental Protection Agency. Milestones in Auto Emissions Control. Aug. 1994. June 2007.

United States. Office of Mobile Emissions. Environmental Protection Agency. Motor Vehicles and the 1990 Clean Air Act. Aug. 1994. June 2007.

United States. Office of Mobile Sources. Environmental Protection Agency. EPA's Program for Cleaner Vehicles and Cleaner Gasoline. Dec. 1999. June 2007.

Saurer, M., P. Cherubini, M. Ammann, B. De Cinti, and R. Siegwolf. 2004. First detection of nitrogen from NOx in tree rings: a 15N/14N study near a motorway. Atmospheric Environment 38:2779-2787.

DeLucia, E.H., J.G Hamilton, S.L. Naidu, R.B. Thomas, J.A. Andrews, A. Finzi, M. Lavine, R. Matamala, J.E. Mohan, G.R. Hendry, and W.H. Schlesinger. 1999. Net Primary Production of a Forest Ecosystem with experimental CO2 Enrichment. Science 284: 1177-1179.

Oksanen, E. 2003. Responses of selected birch (*Betula pendula* Roth) clones to ozone change over time. Plant, Cell and Environment 26: 875-886.

Jones, Steven L., Michael J. Demetsky, and Jose D. Fuentes. Ozone Formation Attributable to Emissions From Rural Interstate Traffic. Center for Transportation Studies, University of Virginia. Charlottesville, VA: Mid-Atlantic Universities Transportation Center, 2001.

Burton, K.W., E. Morgan, A. Roig. 1984. The influence of heavy metals upon the growth of sitka-spruce in South Wales forests. Plant and Soil 78: 271-282.

Karnosky, D.F., D.R. Zak, K.S. Pregitzer, C.S. Awmack, J.G. Bockheim, R.E. Dickson, G.R. Hendrey, G.E. Host, J.S. King, B.J. Kopper, E.L. Kruger, M.E. Kubiske, R.L. Lindroth, W.J. Mattson, E.P. McDonald, A. Noormets, E Oksanen, W.F.J. Parsons, K.E. Percy, G.K. Podila, D.E. Riemenschneider, P. Sharma, R. Thakur, A. Sober, J. Sober, W.S. Jones, S. Anttonen, E. Vapaavuori, B. Mankovska, W. Heilman, J.G. Isebrands. 2003. Tropospheric 03 moderates resonses of temperate hardwood forests to elevated CO2: a synthesis of molecular to ecosystem results from the Aspen FACE project. Functional Ecology 17:289-304.

Christianson, Steven. Personal interview. 30 May 2007.

United States. Federal Highway Administration. Department of Transportation. Interstate System. June 2007 <http://www.fhwa.dot.gov/programadmin/interstate.cfm>.
Buckman, Robert E., Badege Bishaw, T.J. Hanson, and Frank A. Benford. United States. Forest Service. Department of Agriculture. Growth and Yield of Red Pine in the Lake States. Nov. 2006. June 2007.

United States. National Climatic Data Center. Department of Commerce. Meteorological Data Sault Ste Marie. June 2007.

Whitney, Gregory D., and Stephen Rodock. Soil Survey of Mackinac County, Michigan. Washington, D.C.: The Service, 1997.

United States. Natural Resources Conservation Service. Department of Agriculture. National Cooperative Soil Survey: Blue Lake Series. July 2006. June 2007.

United States. Natural Resources Conservation Service. Department of Agriculture. National Cooperative Soil Survey: Onaway Series. July 1999. June 2007.

Martin, Timothy A. Water and Carbon Relations of Pinus Elliottii Flatwoods Subjected to Drought. North American Forest Commission Conference, 2000, School of Forest Resources and Conservation, University of Florida. 14 June 2007 <http://64.233.167.104/search?q=cache:cJtwUOyUUUwJ:www.fs.fed.us/global/>.

Wied, Ann. "Selecting the Right Tree for Your Yard." University of Wisconsin Department of Horticulture. 14 June 2007 <http://www.hort.wisc.edu/mastergardener/Features/woodies/treeselection/treeselect.htm>.