

How do different factors such as temperature, latitude, precipitation, and daylength affect leaf fall of *Acer rubrum* along the eastern coast of the United States from the years 2011-2021?

Cameron E. Simpson

Background:

Phenology is the study of how the seasonal life cycles of natural phenomena are affected by the climate and natural processes of the world (Nord & Lynch 2009). The reason phenology plays such an important role is because it acts as a natural biological clock (Nord & Lynch 2009). This clock is used to alert natural phenomena when phases of their life cycle should occur. Without the timing signals that are the core instances studied in Phenology, natural phenomena would not know how their life cycles work disrupting the balance of every ecosystem (Nord & Lynch 2009).

Different types of natural phenomena which experience phenology include plants, fungi, and animals. Plants and fungi possess very similar phenologies when compared to each other, while animal phenology is very different. Each of these three natural phenomena's phenology depends heavily on the species (Sun et al. 2021). Geographical location of a natural phenomena also has a major effect on the organism's phenology (Nord & Lynch 2009). Plants are more widely studied out of these three phenomena due to how a change in their phenology impacts humans and other natural phenomena like animals.

Plants can be grouped into four different categories. These categories include angiosperms, gymnosperms, pteridophytes, and bryophytes. Angiosperms are plants that produce a flower and have seed contained within a carpel (Classification of Plants). Gymnosperms are plants whose seeds are unprotected by a fruit or an ovary (Classification of Plants). Pteridophytes include vascular plants which disperse spores (Classification of Plants). Lastly, bryophytes are nonvascular plants that have to absorb their nutrients and water through the air (Classification of

Plants). Within these four categories trees will either be an angiosperm or a gymnosperm. Examples of gymnosperm trees include pines, spruces, firs, and cedars (Classification of Plants). These trees contain needles instead of leaves, and have their seeds unprotected (Classification of Plants). Examples of angiosperm trees include oaks, maples, and birches. All of these angiosperm trees have a shorter timeline between pollination and fertilization when compared to gymnosperm trees (Classification of Plants). The phenophase that a tree will fall within is determined by the type of tree it is.

There are eleven phenophases for plants according to the National Phenology Network (USA National Phenology Network). Each of these phenophases helps to describe the life cycle of a plant and its natural processes. These phenophases include leaf growth, young leaves or needles, leaves or needles, colored leaves or needles, falling leaves or needles, open flowers or pollen cones, flowers or pollen cones, pollen release, fruit or seed cones, ripe fruit or seed cones, and recent fruit, cone or seed drop (USA National Phenology Network). Eight of these phenophases occur in the spring/summer seasons, while the other three phenophases happen in the fall/winter seasons. What phenophases a plant will experience depends heavily on the species.

Of the eleven phenophases, six of them deal with flowers or pollen cones, pollen, and fruit or seed cones (Haggerty & Mazer). The time of year these six phenophases occur depends heavily on the location and species of the plant (Haggerty & Mazer). For example, in the northern hemisphere flowers and pollen cones start to appear and open around the beginning of March (Haggerty & Mazer). Flowers and pollen cones usually take approximately seven weeks to fully bloom into open flowers or pollen cones (Haggerty & Mazer). In the northern hemisphere this phenophase would occur in the middle of April through early May (Haggerty & Mazer).

Once these flower and pollen cones open the pollen release phenophase can happen (Haggerty & Mazer). Peak pollen release for angiosperms and gymnosperms in the northern hemisphere occurs in the middle of April (Haggerty & Mazer). As time progresses the flowers and pollen cones can develop into fruit or seed cones which can take anywhere from six to seven months to fully develop (Haggerty & Mazer). For angiosperm trees such as *Malus domestica* and *Pyrus communis* their fruit starts to become ripe in early September. Seed cones take anywhere from eighteen months to three years to fully mature and become ripe (Haggerty & Mazer). Once the fruit or seed cone is completely ripe the cone or seed drop phenophase will take place (Haggerty & Mazer). This most commonly occurs sometime between September to early November. The other five phenophase for plants are associated with the leaves (Haggerty & Mazer).

There are five different types of leaf phenology in plants. Leaf growth typically begins in the middle of March for plants located in the northern hemisphere of the world (Haggerty & Mazer). This phenophase is when the new leaves or needles are starting to emerge and grow. This phenophase will then transition into the next phenophase which is young leaves or needles have fully emerged from the shoot and are beginning to grow (Haggerty & Mazer). Once the leaves or needles have fully grown, the third phenophase of having leaves or needles has begun. The next phenophase for leaves or needles occurs in the middle of September in the northern hemisphere when the leaves and needles start to change colors (Haggerty & Mazer). Once the leaves or needles start changing colors, this will lead into the final phenophase of falling leaves or needles where plants will drop their leaves or needles to be able to stay alive during the colder months (Haggerty & Mazer). Though plants have a time when a specific phenophase occurs there are different factors which can affect a plants phenology (Haggerty & Mazer).

Factors which can affect a plant's fall phenology include temperature, precipitation, photoperiod, latitude, polluted and warming soils (Gill et al. 2015). These are all factors which have changed drastically in the past couple of decades due to climate change. Scientists have found that as temperatures around the globe are rising, places are experiencing extreme droughts or constant floods, and soil is becoming contaminated with excess nitrogen and other pollutants due to human activities (Nord & Lynch 2009). These factors are being studied to determine if one or all of them are having an effect on plants' fall phenologies. How rising temperatures are affecting plants' fall phenology is the area of greatest focus.

The effects that temperature has on fall plant phenology is significant (Nievola et al. 2017). Though not all plants can be grouped into one category it has been found that when compared to other factors temperature has the most drastic effect on plant phenology (Fu et al. 2020). According to another study it was found that a rise in temperatures in temperate regions showed a delay in autumn phenology (Fu et al. 2020). Similarly, in a study done from 1993 to 2010 data was collected from places in the United State, Japan, and Eroupe and showed that October temperatures were the biggest indicator driver of leaf fall in deciduous trees (Box 2021). Furthermore a study done on the species *Acer rubrum* found that leaf fall occurred an average of 7.5 to 13 days later when temperatures were found to have increased by 4°C (Li et al. 2020). In this same study it was also found that earlier warming can also lead to earlier leaf fall because it makes the trees more susceptible to frost when temperatures rapidly decrease in the fall and winter seasons (Li et al. 2020).

Another factor which can affect a plant's fall phenology is precipitation. It has been found that precipitation has a stronger effect on spring phenology than fall phenology (Fu et al. 2020). In the spring season plants, especially in the northern hemisphere, are starting to grow leaves,

flowers, and other structures necessary for growth and reproduction. This requires a lot of nutrients and precipitation. This precipitation also has an affect on fall phenology. Xie et al. found that an increase of precipitation in the summer indicated that fall dormancy in deciduous trees occurred earlier in the autumn season (Xie et al. 2015). When looking at precipitation's effect on plant phenology, extreme weather events, such as drought and floods, need to be considered. As such, these events need to be recorded when studying plant phenology; however, it should be noted that these two extreme weather events can greatly skew results of studies (Xie et al. 2015).

Photoperiod, also known as daylength, is another factor that can have a great impact on plant phenology. Photoperiod is defined as the amount of time during the day period in which an organism is receiving sunlight ((Estiarte & Peñuelas 2015). Location of a plant impacts the amount of sunlight the plant may receive. It was found that, with the exception of temperature, photoperiod has the biggest effect on autumn phenology in plants (Estiarte & Peñuelas 2015). The more uniform a photoperiod is, the more consistent the leaf senescence will be for that plant; if the photoperiod is longer or shorter, impacts on plant phenology may be seen (Estiarte & Peñuelas 2015). For example, an insufficient photoperiod has been found to speed up autumn phenology, making it occur earlier in the year rather than later (Richardson et al. 2013). Photoperiod is usually grouped with latitude (the angular distance of a place north or south of the equator) which impacts the length of photoperiod and can affect fall plant phenology.

. The effects of climate change on plant phenology varies by location due to differences in elevation and latitudes (Nord & Lynch 2009). In a peer review study it was found that in New Hampshire dioecious trees' latitude helped to determine the timing of when leaf fall would take place (Gill et al. 2015). Gill et al. discovered that trees found at a lower latitude had a more

delayed leaf senescence when compared to those at a higher latitude in New Hampshire (Gill et al. 2015). This also means that places with a low latitude, such as Florida and Georgia, will be warmer in the fall seasons compared to locations with a higher latitude, such as New Hampshire and Maine. Thus, locations with a higher latitude will most likely experience fall phenology quicker than locations with a lower latitude.

The soil in which a plant is grown can also affect that plant's fall phenology. Soil health is a huge driver of a plant's phenology (Nord and Lynch 2009). Nord and Lynch found that if the soil had a higher nitrogen content the phenology of the plant was affected (Nord and Lynch 2009). In a similar study, it was found that soils with a higher nitrogen content showed a delay in a plant's fall phenology (Weih 2009). The pH of soil also was shown to have an effect on the time of leaf fall in the species *Acer rubrum* (Anderson & Ryser 2015). Plant phenology is also affected by soil warming which is caused by warming temperatures around the globe (Wheeler et al. 2017). *Acer rubrum* in the northeastern United States which were exposed to warmer soil temperatures showed a delay in leaf fall compared to other *A. rubrum* trees in soils with a normal temperature range (Wheeler et al. 2017).

Introduction:

Many of the studies discussed previously were done on a species of tree called *A. rubrum*, commonly known as the Red Maple because during the fall their leaves turn a vibrant bright red color (Burns & Honkala 1990). *A. rubrum* is most commonly found in eastern North America (Burns & Honkala 1990). This species of tree is considered to be extremely durable and can live in a wide variety of soils and climates (Burns & Honkala 1990). Still this does not mean that the *A. rubrum*'s fall phenology goes unaffected by factors such as temperature, precipitation, photoperiod, latitude, polluted and warming soils (Burns & Honkala 1990). As *A. rubrum* is one

of the most common trees studied, this work focuses on using the national phenology network to conduct an analysis on the leaf fall of *A. rubrum* trees from the years 2011-2021 along the Eastern Coast of North America. The goal of this research was to see if there was any correlation between factors such as temperature, latitude, precipitation, and photoperiod on the leaf fall of the *A. rubrum*.

Data for this project was collected using the Nation Phenology Network. The United States of America- National Phenology Network brings together volunteer observers, government agencies, non-profit groups, educators and students of all ages to monitor the impacts of climate change on plants and animals in the United States (USA National Phenology Network). To compile the data used for this project the National Phenology Network visualization tool was used. The visualization tool helps users access the National Phenology Network database and all of the information stored within it for animal and plant phenology (USA National Phenology Network).

The National Phenology Network is a useful tool for evaluating plant behavior because it allows any member of the community to record observational data. In the fall of 2021, I shared a plot located at Meredith College with two other students. Each week during the fall semester our group would record data at least three times a week on the ten trees located in our plot. On our group's plot we had two different Red Maples for which we recorded data. This data from the fall of 2021 is included in my independent research. After becoming so interested in the National Phenology Network, I decided to continue with my own personal research and help others as well by becoming a teaching assistant.

As a teaching assistant, I helped other students understand the importance in taking proper data through the National Phenology Network. If data is not taken correctly it can skew

results and mess up data sets. Each week both I and a fellow teaching assistant would go through the data sets of the class to see if any data was entered incorrectly. If data was entered incorrectly it was corrected and fixed.

Methods:

To gather data for this research project, the Nation Phenology Network database and data visualization tool were used. This tool allows anyone to access all of the information within the database. To gather the data used for this project the type of visualization used was the scatter plot. Once the scatter plot visualization was selected the next step was to select the boundary. The boundary for this project was all of the states located along the Eastern coast of North America. The states Florida, Georgia, South Carolina, North Carolina, Virginia, Maryland, Delaware, New Jersey, New York, Connecticut, Rhode Island, Massachusetts, New Hampshire, and Maine. Once all of these states were selected the next step for using the data visualization tool was to select the date range for the data set.

For this data set, the date range used was from 2011-2021. The reason this date range was selected was because the years prior to 2011 had little to no data available. After the data range was selected, the next step was to pick the species and phenophase to be studied. For this project the species selected was the Red Maple (*A. rubrum*) and the phenophase was falling leaf or needles. After selecting all of these options the visualization tool will automatically make a scatter plot graph, but these are not fully accurate. To get the most accurate result the data needs to be combed through to get rid of outliers and inaccurately entered data. For example, if a student entered that leaves were falling in April this would be incorrect and need to be fixed. To be able to get rid of the “bad” data all of the datum were downloaded into a file. This downloaded file contained all of the data for the research parameters for falling leaves for the *A.*

rubrum from the years 2011-2021 for the fourteen states selected.

The data which were downloaded is in the form of a spreadsheet. There were about twenty thousand data points that were downloaded into this spreadsheet. This spreadsheet also included data that were not needed for this particular research project, so points needed to be combed through to find the data that were needed. Throughout the spreadsheet the data were separated into categories based on phenophases such as falling leaves, leaves, increasing leaf size, colored leaves, and breaking leaf buds. Once all of the categories were organized by phenophase all of the data for the falling leaf phenophase were copied and pasted into a new spreadsheet. This next spreadsheet was then organized to see if any of the data points were entered inaccurately.

To see if data were entered incorrectly the data was first organized by the last “yes” day of the year. The last “yes” day of the year is the day of year, ranging from 1 to 366, of the last "yes" record of the series. In this example, it was when there was a last yes that leaf fall occurred. According to the National Phenology Network leaf fall starts to occur in late September to November. There are some instances where leaf fall will occur in December, so these data points were kept in the data set. All of the data that fell outside of this range of months were deleted as leaf fall is not likely to occur in the winter and summer months. Once these data were deleted from the data set, the next step was to delete outliers from the data set.

When something is not entered into the National Phenology Network database it will automatically fill that part of the data with the number -9999. For example if the minimum or maximum temperature is not recorded for a day when data is being entered a -9999 fills that place in the data set. To keep the data as accurate as possible the -9999 in the data set had to be deleted. There were approximately two hundred data points which had a -9999 in this particular

data set. Once these were deleted from the data set it was finally time to make the graphs for the data set.

To make the graphs, the scatter plot graph was used. Factors such as minimum and maximum temperature, precipitation, daylength, or latitude were placed on the x-axis with the last “yes” day of the year on the y-axis was. Once the graph was created for the factor, a trend line was added. The linear equation and the R^2 value was also added onto the graph to describe the mathematical correlation between the factor and the last “yes” day of year and the strength of that relationship (R^2). After making a chart for each factor and comparing it to the last “yes” day of year, the graphs showed the results if there is a correlation between the factors and the leaf fall of *A. rubrum* from the years 2011-2021 along the Eastern coast of North America.

Results:

To find if there is a relationship between a factor and the last recorded “yes” day of leaf fall of *A. rubrum*, the R^2 value was calculated. The R^2 value is the squared value of the correlation coefficient. The correlation coefficient determines how strong of a linear relationship value two values share. For an R^2 value to be considered strong it needs to have a value of .75 or above, while a value of .3 or below indicates a weak correlation. The average last “yes” day of the year was 296 which is October 22nd. The standard deviation for the last “yes” day of the year was 21. This means that 95% of the data points fell between the date range of October 1st and November 12th.

The association between maximum fall temperature on the last “yes” day of year had the second strongest correlation out of all the factors. The correlation came out to be .106 on a scale from zero to one (Figure 1). The average maximum fall temperature was 17.25 °C for the 2,865 data points. The correlation between maximum fall temperature and the last “yes” day of year for

leaf fall is fairly weak. When compared to the minimum temperature versus the last “yes” day of year graph the correlation was 0.097, and the average minimum fall temperature was 5.99 °C (Figure 2). The R² value between these two factors shows that the minimum fall temperature had less significance of *A. rubrum* leaf fall when compared to the maximum fall temperature.

The R² value on the graph for latitude versus the last “yes” day of year was 0.071 (Figure 3). This correlation was weaker than both minimum and maximum temperatures. The average latitude came out to be approximately 40.43. This latitude falls in the middle of the state of New Jersey. The precipitation versus the last “yes” day of year was also fairly small with a value of 0.023 (Figure 4). The average amount of precipitation was 334 millimeters. (13.1 inches).

The final factor that was studied was the day length otherwise known as photoperiod. The R² value on the graph for daylength versus last “yes” day of year was 0.29. Out of all the factors this is the strongest correlation (Figure 5). The average time of day length was 40884 seconds or 11 hours and 21 minutes. Even though the correlation for daylength was still minimal, it still showed that there is a correlation between when leaves of the *A. rubrum* will fall and the daylength.

Conclusion

Based on the data, numerous factors have an impact on *Acer rubrum*. The data suggest that minimum and maximum temperature, photoperiod, precipitation, and latitude all contribute to leaf fall of the *A. rubrum* tree (Estiarte & Peñuelas 2015). Based on the results, it can be inferred that minimum and maximum temperatures seemed to have the second and third largest effect on leaf fall of the *A. rubrum*. In previous studies, temperatures were also one of the biggest predictors of when leaf fall would occur (Gill et al. 2015). Yet, the correlations in this study are not as strong, suggesting that multiple factors influence when leaf fall will occur (Xie et al.

2015).

There was also a very small correlation between the latitude of where the *A. rubrum* was located and when leaf fall occurred. When looking at latitude it makes sense that *A. rubrum* trees located at a higher latitude will drop their leaves sooner than those located at a lower latitude. As seen in a meta-analysis done by Gill et al. trees found at a lower latitude had a more delayed leaf senescence when compared to those at a higher latitude in New Hampshire. This could be because the trees located at higher latitudes will most likely experience colder temperatures sooner than the trees located at a lower latitude.

Another factor which showed a very minimal correlation on *A. rubrum* leaf fall along the Eastern coast of North America was precipitation. Previous studies suggest that precipitation has a stronger effect on spring phenology rather than fall phenology (Fu et al. 2020). During the fall *A. rubrum* are trying to conserve energy because the days are getting shorter. To conserve energy the tree will get rid of parts of the tree which require a lot of nutrients, such as the leaves (Robertson 2012). Since the trees are shedding the leaves in the fall the trees do not need as much water in order to keep the leaves alive (Robertson 2012).

The final factor which had the strongest correlation was the day length (photoperiod). As the days in the fall in the winter become shorter there is less sunlight. Trees need sunlight to perform photosynthesis, so as the days get shorter the trees will start to shed their leaves to help conserve energy in the winter (Robertson 2012). Though the correlation for daylength was very small, it still does have an influence on the leaf fall of *A. rubrum* (Estiarte & Peñuelas 2015). This demonstrates that the date of leaf fall for the species *A. rubrum* from the years 2011-2021 along the Eastern coast of North America is influenced by multiple factors rather than just one.

There were a few limitations for this research project. One of the limitations encountered

was how the National Phenology Network is a citizenship science project. With this Network being a citizenship science project there is always the chance that data will be entered into the database incorrectly. This was seen in the outliers and some of the data points which had to be deleted from the data points used for this particular project. This is something which can be easily prevented by asking for help and paying close attention when entering data into the National Phenology Network's database. Another limitation for this project is that natural disasters such as hurricanes, floods, and windstorms are not taken into account when entering data.

Natural disasters are something which have a large effect on plant phenology especially fall phenology of *A. rubrum*. For example, in the fall of 2019 North Carolina was hit by Hurricane Florence. This Hurricane devastated North Carolina with severe flooding and strong winds which had a large impact on plant life including the *A. rubrum* (Cooper-Ellis et al. 1999). Many trees lost their leaves early this year due to these conditions, yet it could not be recorded into the database. If there was some way to be able to report natural disasters into the National Phenology Network's database it would help show why these trees experienced earlier leaf fall that year. This is something that is relatively simple, but would be extremely beneficial to add into the database system.

For future directions the best thing which can be done is to encourage others to participate in this citizenship science project. The more people who are encouraged to participate in the National Phenology Network results in more data which can be gathered. The more data that is gathered the more accurate the findings will become, giving scientists a better understanding of the effect certain factors have on plant and animal phenology.

Going forward, expanding the research parameters to more states or throughout more years and perhaps even looking at the whole *Acer* genus instead of focusing on just one species can improve the study by.... These are things which can be done to continue this project and increase the scope of this research project.

Figures:

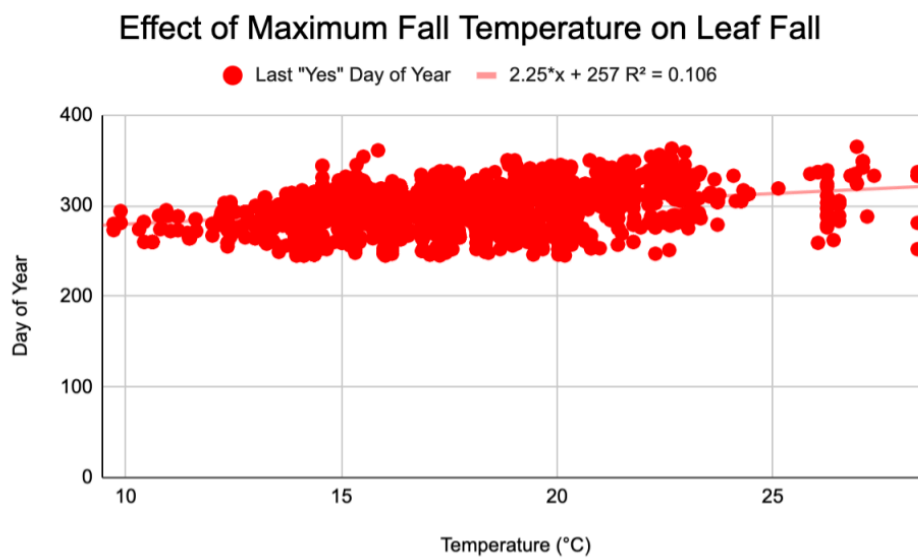


Figure 1: Figure 1 shows the correlation between the maximum fall temperature and leaf fall date in *Acer rubrum* along the Eastern coast of North America a from the years of 2011-2021.

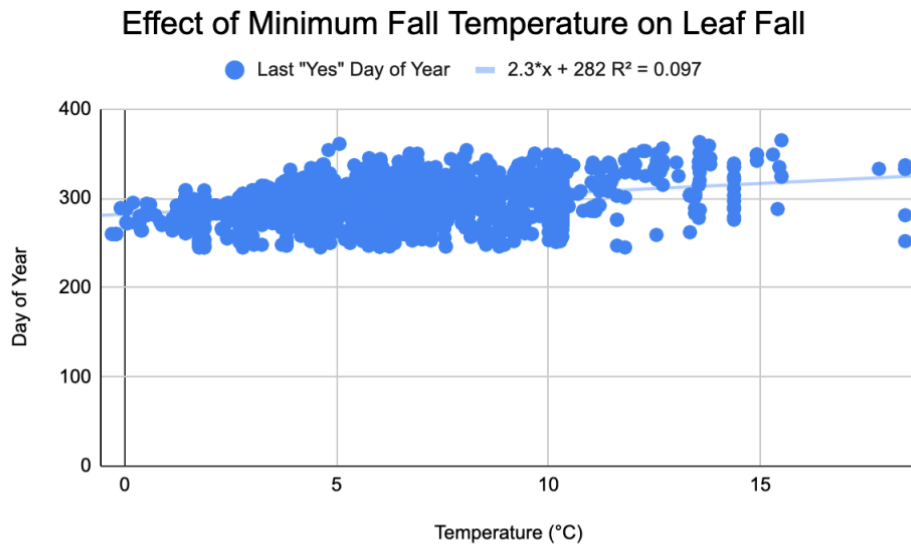


Figure 2: Figure 2 shows the correlation between the minimum fall temperature and leaf fall date in *Acer rubrum* along the Eastern coast of North America a from the years of 2011-2021.

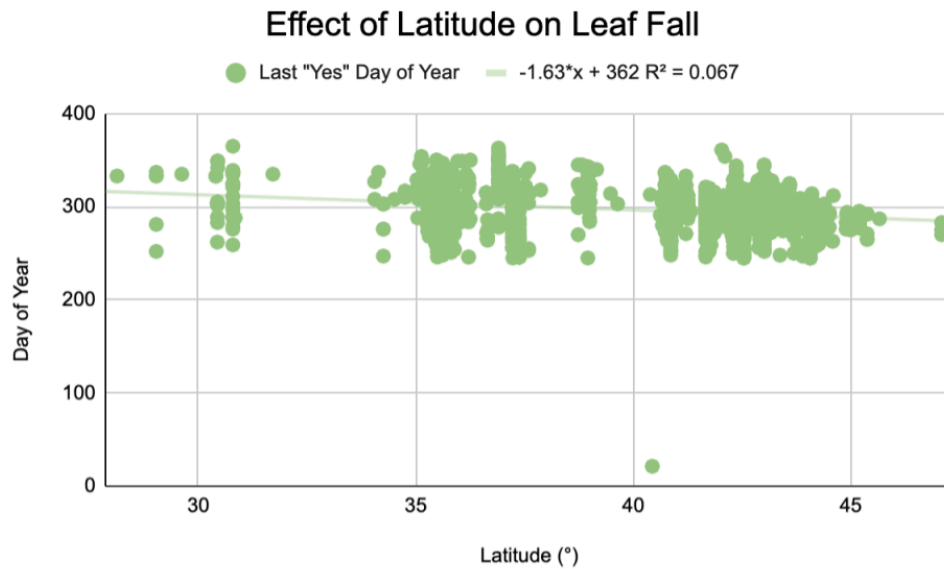


Figure 3: Figure 3 shows the correlation between the latitude and leaf fall date in *Acer rubrum* along the Eastern coast of North America a from the years of 2011-2021.

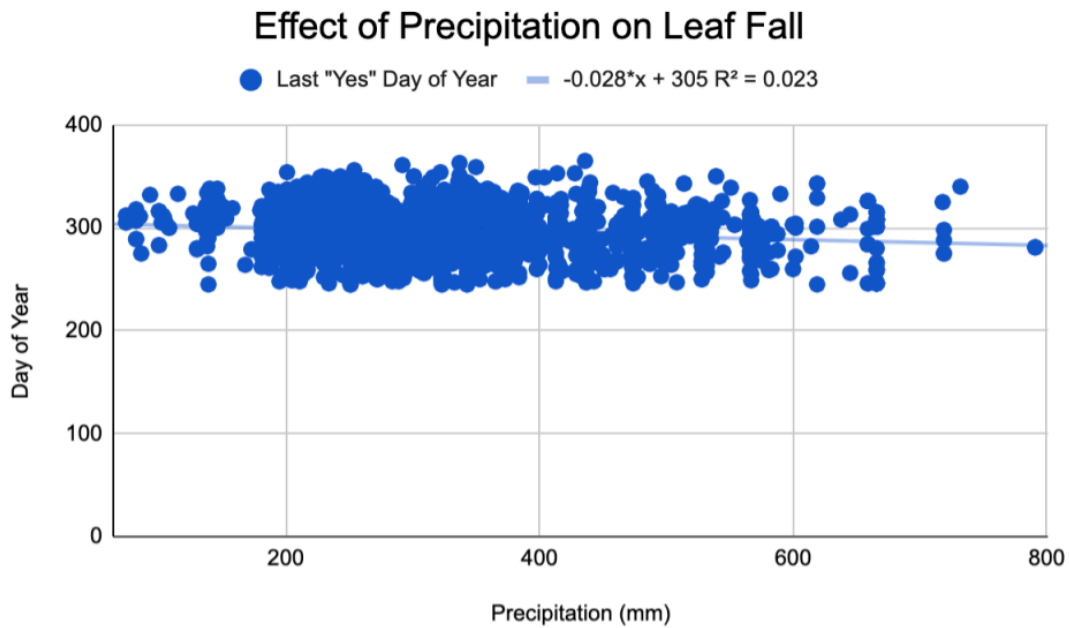


Figure 4: Figure 4 shows the correlation between the precipitation and leaf fall date in *Acer rubrum* along the Eastern coast of North America a from the years of 2011-2021.

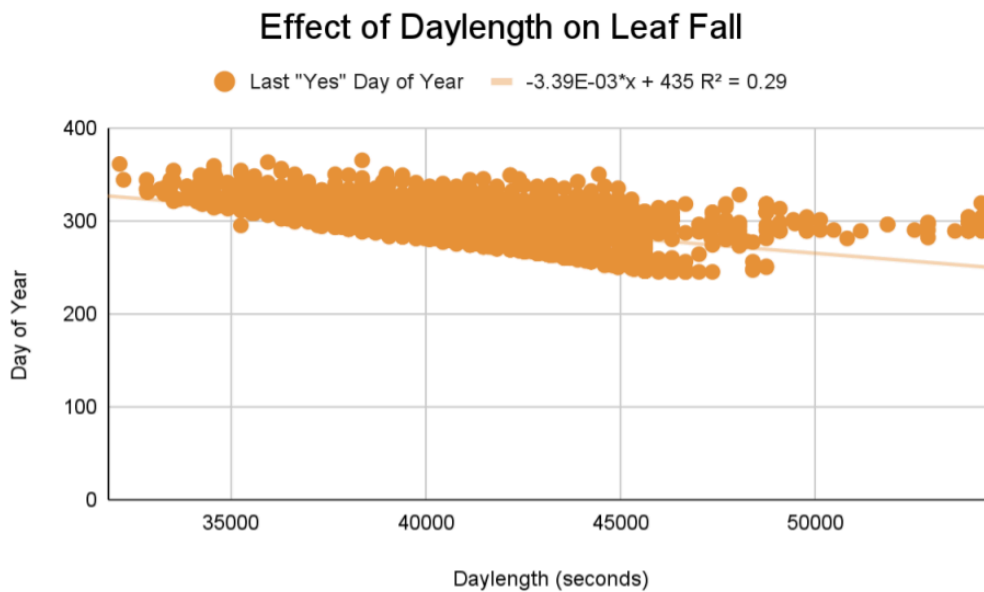


Figure 5: Figure 5 shows the correlation between the daylength and leaf fall date in *Acer rubrum* along the Eastern coast of North America a from the years of 2011-2021.

Citations:

- Anderson R, Ryser P. 2015. Early Autumn Senescence in Red Maple (*Acer rubrum* L.) Is Associated with High Leaf Anthocyanin Content. *Plants*. 4(3):505–522.
doi:10.3390/plants4030505.
- Box O. 2021 Oct 8. Will We Lose Fall Foliage to Climate Change? *JSTOR Daily*.
<https://daily.jstor.org/will-we-lose-fall-foliage-to-climate-change/>.
- Burns RM, Honkala BH. 1990. *Silvics of North America / Vol. 2, Hardwoods*. Washington: United States Department Of Agriculture.
- Classification of Plants | 4 Major Types of Plants | BioExplorer.net. Bio Explorer.
<https://www.bioexplorer.net/plants/>.
- Cooper-Ellis S, Foster DR, Carlton G, Lezberg A. 1999. Forest Response to Catastrophic Wind: Results From an Experimental Hurricane. *Ecology*. 80(8):2683–2696.
- Estiarte M, Peñuelas J. 2015. Alteration of the phenology of leaf senescence and fall in winter deciduous species by climate change: effects on nutrient proficiency. *Global Change Biology*. 21(3):1005–1017. doi:10.1111/gcb.12804.
- Gill AL, Gallinat AS, Sanders-DeMott R, Rigden AJ, Short Gianotti DJ, Mantooth JA, Templer PH. 2015. Changes in autumn senescence in northern hemisphere deciduous trees: a meta-analysis of autumn phenology studies. *Annals of Botany*. 116(6):875–888.
doi:10.1093/aob/mcv055.
- Fu Y, Li X, Zhou X, Geng X, Guo Y, Zhang Y. 2020. Progress in plant phenology modeling under global climate change. *Science China Earth Sciences*. 63(9):1237–1247.
doi:10.1007/s11430-019-9622-2.
- Haggerty B, Mazer S. *The Phenology Handbook A guide to phenological monitoring for students, teachers, families, and nature enthusiasts*.

- Li L, Manning W, Wang X. 2020. Effects of Elevated CO₂ Concentrations on Leaf Senescence and Late-Season Net Photosynthesis of Red Maple (*Acer rubrum*). *Water, Air & Soil Pollution*. 231(9):N.PAG–N.PAG. doi:10.1007/s11270-020-04828-z.
- Nievola CC, Carvalho CP, Carvalho V, Rodrigues E. 2017. Rapid responses of plants to temperature changes. *Temperature*. 4(4):371–405. doi:10.1080/23328940.2017.1377812.
- Nord EA, Lynch JP. 2009. Plant phenology: a critical controller of soil resource acquisition. *Journal of Experimental Botany*. 60(7):1927–1937. doi:10.1093/jxb/erp018.
- Richardson AD, Keenan TF, Migliavacca M, Ryu Y, Sonnentag O, Toomey M. 2013. Climate change, phenology, and phenological control of vegetation feedbacks to the climate system. *Agricultural and Forest Meteorology*. 169:156–173. doi:10.1016/j.agrformet.2012.09.012.
- Robertson B. 2012. Q: Why do leaves fall off trees in the fall? *Science and Children*. 49(7):68-9.
- Sun C, Beirne C, Burger JM, Howey T, Fisher JT, Cole Burton A. 2021. Simultaneous monitoring of vegetation dynamics and wildlife activity with camera traps to assess habitat change. *Remote Sensing in Ecology and Conservation*. 7(4):666-84.
- USA National Phenology Network | USA National Phenology Network. 2019. Usanpnorg. <https://www.usanpn.org/usa-national-phenology-network>.
- Weih M. 2009. Genetic and environmental variation in spring and autumn phenology of biomass willows (*Salix* spp.): effects on shoot growth and nitrogen economy. *Tree Physiology*. 29(12):1479–1490. doi:10.1093/treephys/tpp081.
- Wheeler JA, Gonzalez NM, Stinson KA. 2017. Red hot maples: *Acer rubrum* first-year phenology and growth responses to soil warming. *Canadian Journal of Forest Research*. 47(2):159–165. doi:10.1139/cjfr-2016-0288.

Xie Y, Wang X, Silander JA. 2015. Deciduous forest responses to temperature, precipitation, and drought imply complex climate change impacts. *Proceedings of the National Academy of Sciences*. 112(44):13585–13590. doi:10.1073/pnas.1509991112.