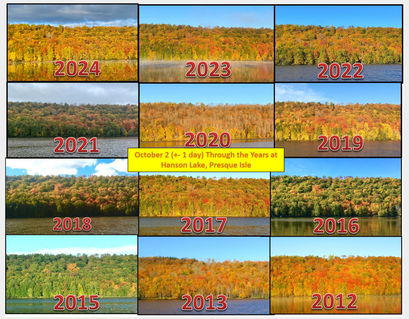
An Investigation of the Impact of Temperature and Precipitation Patterns on the Phenology of Deciduous Trees in Maine

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Introduction

The timing of seasonal biological events has been shown to be changing on a global scale in response to meteorological and climate-related factors. Several studies have shown changes in phenology of various species in the state of Maine over time, including shifts in the timing of deciduous tree spring leaf out and autumn peak foliage, resulting in longer growing seasons. Peak fall foliage in the state of Maine has been documented to be occurring almost two weeks earlier since 1950 in Acadia National Park[8]. With increased summer rainfall and warmer summers, trees also tend to have less colorful peaks and lose their leaves faster. Although some studies have shown a strong correlation between temperature and deciduous tree phenology[1, 6], results from other studies suggest variation was tied more closely to microclimate and year-to-year temperature changes[5].



Mosaic of images taken from Hanson Lake, ME on 2 October over the past 13 years (missing 2014). Photo credit: Todd Foisy



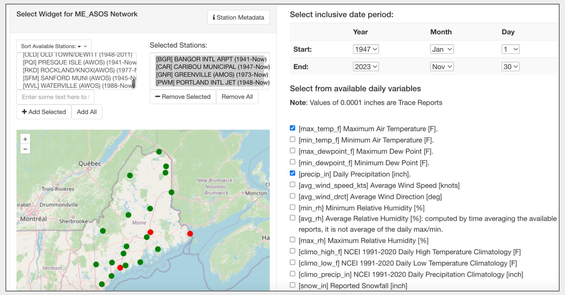
MODIS Satellite Image of Northern Maine on 9 October 2024 showing foliage from a visible satellite image.

This study looked at the changes in temperature and precipitation and their effects on the timing of spring leaf out dates and peak foliage dates in four, geographically separated Maine locations. Satellite imagery and weather station data from the different regions of the state allow for conclusions to be drawn about how much tree phenology has shifted over time. Future climate projections predict continued shifts in tree phenology patterns. These changes have the potential to negatively impact tourism, a major economic sector, in the state of Maine in the future.

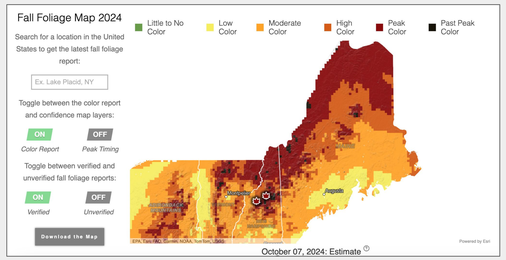
Conclusions

- A comparison between the first and last 15 years of historical average monthly temperature datasets shows increases at all locations between 0.4-4.4 degrees Fahrenheit in October and 1.2-3.3 degrees Fahrenheit in April, while comparisons of average monthly precipitation were variable, but showed increases in some locations. Spring leaf out dates were directly compared with average April temperatures between 1981-2023, where a positive trend was found for all locations, with warmer temperatures correlated with earlier leaf out dates.
- More historical data is available for spring leaf-out dates compared with autumn peak foliage dates. The limited availability of autumn peak foliage data made analysis difficult; no correlation was shown between increasing temperature and later peak foliage dates over the 9 year dataset that was available.
- In order to more clearly understand the possible effects of climate and meteorological factors on tree phenology in Maine and to predict future patterns, additional sites should be studied within the state and the region, including the analysis of both direct and remote sensing data.
- Phenology has been shown to be a sensitive biological indicator of climate change[7]. Phenology data is a valuable addition to more traditional meteorological and climate datasets for future studies and climate modeling.

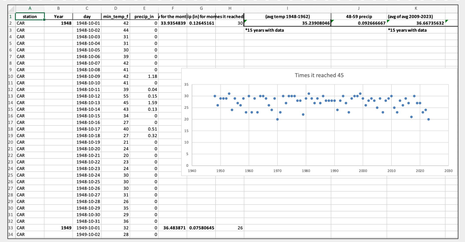
Methods



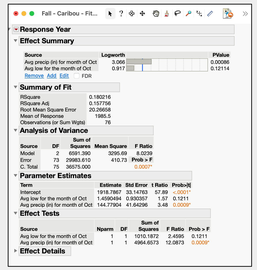
Iowa Environmental Mesonet (https://mesonet.agron.iastate.edu/request/daily.phtml?network=ME_ASOS) daily temperature and precipitation observations from Maine weather stations as far back as record go in Bangor (1942), Caribou (1948), Portland (1948), and Greenville (1973) were used to compare both leaf-out and peak foliage dates between regions.



Explore Fall (https://www.explorefall.com/fall-foliage-map) map of present and historical Maine peak foliage data, showing the movement of colors throughout the state of Maine in October and November. Archive data was collected and used in this project from: 1942 (Bangor), 1948 (Caribou and Portland), and 1973 (Greenville).



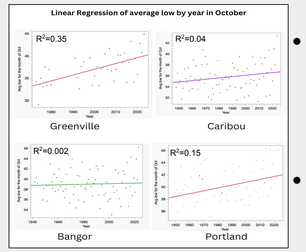
For fall foliage, temperature and precipitation data collected from Explore Fall and Iowa Mesonet, were combined in Excel to create preliminary graphs and average counts of data per year and for the first and last 15 years of each dataset. Spring leaf-out data from Iowa Mesonet in April were analyzed using the same protocol.



JMP Statistical Software was used to create final graphs and analyze both peak foliage and spring leaf-out data. From the Fit Y by X feature, graphs of Year vs. Average Low for Month of October (April) and Times it Reached 45ºF (65ºF) vs. Average Low for Month of October (April) were created.

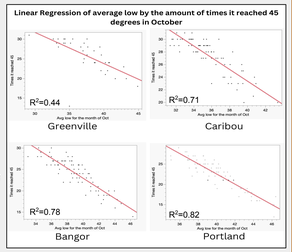
Also, using the Fit Model feature, linear regression models were created to show the p-value, F Ratio, R^2, and other measures of statistical significance for both temperature and precipitation per year for all locations.

Results



Fall

- The p-values for all four locations in peak foliage were <.0001, rejecting the null hypothesis that there is no correlation between how many times it reached 45ºF and average low in October.
- While the regions had a large F ratio for times it reached 45ºF vs. average low, the value was not as large for year vs. average low.



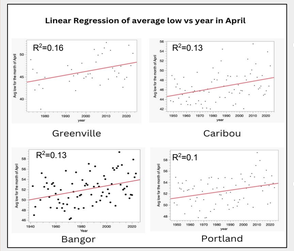
- The largest average temperature increase for October was in Greenville with a 4.4ºF difference between the first and last 15 years of the dataset. Bangor had a 0.4ºF increase, smallest of the regions studied.
- The largest average precipitation increase for October was in Bangor and Greenville with 0.15 inch between the first and last 15 years of the dataset. Caribou had a 0.04 inch increase, lowest of the regions.

Portland	Source	Logworth	PValue
	Avg low for the month of Oct	2.993	0.00102
	Avg precip (in) for moth of Oct	2.066	0.00859

Bangor	Source	Logworth	PValue
	Avg low for the month of Oct	2.001	0.00998
	Avg precip (in) for moth of Oct	0.324	0.47449

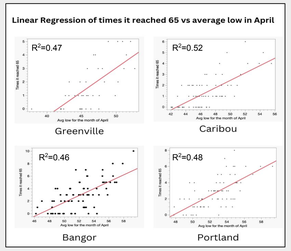
Caribou	Source	Logworth	PValue
	Avg precip (in) for month of Oct	3.066	0.00086
	Avg low for the month of Oct	0.917	0.12114

Greenville	Source	Logworth	PValue
	Avg precip (in) for month of Oct	3.370	0.00043
	Avg low for the month of Oct	1.860	0.01381



Spring

- The p-values for all four locations in peak foliage were <.0001, rejecting the null hypothesis that there is no correlation between how many times it reached 65ºF and average low in April.
- While most regions had a large F ratio for times it reached 65ºF vs. average low, the value was also not as large for year vs. average low.



- The largest average temperature increase for April was in Greenville with a 3.3ºF between the first and last 15 years of the dataset. Bangor had a 1.3ºF increase, smallest of the regions studied.
- The largest average precipitation increase for October was in Bangor with 0.11 inch between the first and last 15 years of the dataset. Portland had a 0.02 inch increase, smallest of the regions.

Portland	Source	Logworth	PValue
	Avg low for the month of April	1.941	0.01147
	Avg precip (in) for moth of April	1.279	0.05260

Bangor	Source	Logworth	PValue
	Avg precip (in) for moth of April	12.019	0.00000
	Avg low for the month of April	1.155	0.06992

Caribou	Source	Logworth	PValue
	Avg low for the month of April	2.543	0.00286
	Avg precip (in) for moth of April	1.685	0.02066

Greenville	Source	Logworth	PValue
	Avg precip (in) for month of April	1.803	0.01575
	Avg low for the month of April	1.146	0.07142

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