**A Plant’s Life: Mapping Growing Degree Days Over Time at NEON’s Terrestrial Field Sites in Relation to Deciduous Broadleaf Tree Phenology**

Plants make up 80 percent of the total carbon content of all living things on the planet, with land plants being the largest contributor. We rely on plants for many things: transforming the carbon dioxide we emit into oxygen we breathe, providing us with food and resources, shading us on hot summer days, and helping with flood control, to name a few. Plants are also the basis of all the beautiful landscapes around the world.

One of the most picturesque landscapes is that of forests of trees displaying beautiful red, orange, and yellow colors in their leaves, marking the change in seasons of summer into fall. These iconic forests are comprised of deciduous broadleaf trees. Deciduous broadleaf is a large grouping of many familiar trees that can be found across the United States and the world, including oak trees and maple trees.

Deciduous broadleaf trees are exceptionally abundant in the eastern part of the United States. Here, they establish their importance in the ecosystem by providing food to herbivores like the white-tailed deer and the gray squirrel, omnivores like the raccoon and the black bear, and many birds including blue jays and woodpeckers. Many mammals, birds, and insects rely on these trees not only as a source of food, but also for habitat. One special species of insect that depends on deciduous broadleaf trees is the gypsy moth.

Maybe a map of the US with NEON sites that have DBL trees marked

Gypsy moths primarily feed on the leaves of deciduous broadleaf trees, and they can be known to completely defoliate entire trees when larvae feed. The gypsy moth is of European decent, and it was first introduced into the north eastern part of the United States in the late 1800s, making it an invasive species. Because it is an invasive species, the gypsy moth does not have many natural predators in the United States, allowing the species to continue breeding and dominating where it inhabits.

Contributing to the breeding cycle of gypsy moths is the emergence of earlier springs due to an increase in climatic temperature over time. Higher temperatures lead to accelerated development in these insects, allowing for the appearance of multiple generations in the same season. With the opportunity to create more larvae, more damage can be done to the leaves of these deciduous broadleaf trees in the spring, leaving no leaves to change color once it’s time for autumn to arrive, resulting in a landscape that isn’t as beautiful as was expected.

(picture from NEON aquatic site with canopy cover over a stream or algae bloom)

(image of a gypsy moth)

(picture of NEON DBL trees changing colors)

A disappointing fall vacation isn’t the only thing that may result from the severe defoliation of the deciduous broadleaf trees, especially with the accumulation of higher temperatures. When the gypsy moths invade and feed on the leaves of these trees, competition between other organisms that rely on the food that these trees provide, like the squirrels that feed on the nuts, increases. This can possibly lead to decreases in survival rates of certain species, causing other effects within the food web.

When too many leaves are consumed, the ecohydrology and local weather in the area may be affected by the loss of the canopy. With less canopy coverage over water sources, increased algae blooms may occur due to exposure to more sunlight. Algae blooms can negatively affect the whole aquatic ecosystem as other organisms in the water that need sunlight can’t get it due to the abundance of algae. This can cause a decrease in food supply for aquatic animals and can create a domino effect within the aquatic food web. When the time comes for the leaves of these trees to fall, which supplies a source of carbon to the microbes in the soil that are important regulators of the carbon cycle, but there are no leaves, then important ecosystem cycles are affected.

It may seem like the only fate for the forests of deciduous broadleaf trees is complete defoliation and the imminent doom of entire ecosystems, but by observing the way in which these plants grow throughout time in relation to changing temperatures, we can at least predict the changes that may occur.

Images of DBL individuals in each of the phenophases

*Phenology and Temperature*

Phenology is the study of cyclic and seasonal natural phenomena, especially in relation to climate and plant and animal life. Plant phenology is the transition of plants through phenophases, or observable stages of their life cycle that have a defined starting and ending point. Deciduous broadleaf trees have six main phenophases: breaking leaf buds, increasing leaf size, leaves, colored leaves, open flowers, and falling leaves.

Phenology is highly affected by temperature. Higher temperatures cause earlier springs. While gypsy moths develop more rapidly with higher temperatures, plant phenology can be negatively affected. When springs occur earlier, plants are more susceptible to freezes that can come after the beginning of false springs, especially when the plants have already started to transition to their next phenophase, leading to negative long-term effects on the plant.

Perennial crops, like deciduous broadleaf trees, may be affected if temperature shifts affect the chilling requirements of fruit or nut production. Chilling requirements are related to heat requirements. If the winter is long and cold, then less warmth is needed in the spring to bring most plants out of dormancy. But when the winter is warm, plants need more warmth in the spring to prompt leaf growth. When many woody plants are not exposed to cold temperatures in the winter to reach their chilling requirement, then delays in leaf-out may follow.

Though the delay in the development of leaves of deciduous broadleaf trees may benefit them by delaying the destruction of the gypsy moth, if fruit or nut production is delayed, then there may not be enough food for the animals that rely on consistent production of nuts or fruit.

If flowering plants don’t flower when other organisms expect them to, then pollinators that rely on these flowers may have to find other sources of pollen. When the time comes for these flowers to be pollinated, the pollinators may have moved on, leaving the plants to rely on other ways of pollinating. Each phenophase that is observed in plants are important to systems and organisms at different times.

Examining how plant phenology changes over time, especially in relation to temperature and heat accumulation, is important to humans in: optimizing when to plant, fertilize, and harvest crops; managing invasive species, like the gypsy moth; predicting human health-related events like the timing and severity of allergies; understanding the timing of ecosystem processes, such as carbon-cycling; and assessing the vulnerability of species and ecological communities to ongoing climate change.

Timelapse of plant phenology images????

*NEON Data*

NEON has been collecting data on [plant phenology](https://data.neonscience.org/data-product-view?dpCode=DP1.10055.001) at NEON terrestrial sites across the United States since late 2013. Part of the data follows deciduous broadleaf trees as they change through their phenophases. NEON employs status-based monitoring in which the phenological condition of an individual is reported any time that individual is observed. Status and intensity data are reported per phenophase per individual or patch, for each day observed.

[Air temperature data](https://data.neonscience.org/data-product-view?dpCode=DP1.00002.001) is also collected at NEON field sites using Single Aspirated Air Temperature (SAAT) assemblies on deployed towers. With air temperature data, growing degree days can be calculated, which link temperature and its effect on plant phenology. Growing degree days (GDDs) are the number of degrees the average daily temperature exceeds the temperature below which the organism will remain developmentally inactive.

For many plants, a specific number of growing degree days must accumulate to trigger a change in phenological status. This minimum number of GDDs is referred to as a plant’s growing degree threshold. If a growing degree threshold for a phenological transition is known for a particular organism, it is possible to investigate how soon that transition is likely to be reached by calculating accumulated growing degree days (AGDDs) over the course of a year.

By mapping this heat accumulation in the form of AGDDs days and comparing it to the transitions in phenophases for deciduous broadleaf trees, the relation between the two can be observed, and by comparing across years and NEON field sites, it is possible to make predictions for changes in the climate and changes in phenology in years to come using the data.

Shiny app

*The Future of NEON Phenology Data*

With evidence supporting the green wave hypothesis, which states that migrating herbivores should track the leading edge of green-up, where forage quality is the highest, then changes in the timing of green-up may lead to changes in patterns in their migration or eating habits and could be detrimental in their ability to adapt to the changes.

Climate change can also lead to phenological mismatches in mutualistic interactions between plants and animals. With phenological shifts in plants happening sooner or later than shifts in animals that usually occur at the same time, the interactions between these organisms may be much briefer, which may end their mutualistic relationship altogether.

High temperatures may cause non-perennial crops to develop more quickly and have a shorter life cycle, resulting in smaller plants, shorter reproductive duration, and lower yield potential. Expediated development of pests can further contribute to the lower potential of these crops.

While the Observatory continues to collect phenology and air temperature data over the course of 30 years, it may be possible to make better predictions for future seasonal changes with a larger dataset. These predictions can then help us in controlling parts of the food web and ecosystems that may be affected negatively by a changing climate over time.