Plant phenology is the transition of plants through phenophases, or observable stages of their life cycle that have a defined starting and ending point. For example, one phenophase observed in deciduous broadleaf trees is “Breaking leaf buds,” which begins once a green leaf tip is visible at the end of the leaf bud and ends once the plant is in its “initial growth” phenophase in which new growth of the plant is observed. This phenophase is also sometimes referred to as “budburst”.

Plant phenology is highly affected by climate change, directly through the impacts on temperature and precipitation, and indirectly through the timing and duration of pest infestations and disease outbreaks, water fluxes, nutrient budgets, carbon dynamics, and food availability. The impacts of temperature on plant phenology is particularly important. High temperatures, for example, 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 (Hatfield, Prueger 2015). Along with high temperatures comes earlier springs. When springs occur earlier, plants are more susceptible to freezes that can come after the beginning of a false springs, especially when the plants have already started to transition to their next phenophase, leading to negative long-term effects on the plant (Carter et al. 2017).

Perennial crops may also be affected, if temperature shifts affect the chilling requirements of fruit or nut production (Hatfield, Prueger 2015). 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 (Fu et al. 2015).

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 aggregated growing degree days over the course of a season.

Predicting phenological changes in plants due to the climate is important to humans in: managing invasive species; predicting human health-related events like the timing and severity of allergies and when mosquitos are most abundant; optimizing when to plant, fertilize, and harvest crops; understanding the timing of ecosystem processes, such as carbon-cycling; and assessing the vulnerability of species, populations, and ecological communities to ongoing climate change (USA NPN). When phenological transitions occur earlier or later than average, the timing and impacts of allergies change, crop production may suffer because of poorly timed application of fertilizers and pesticides, and animals at various trophic levels may have reduced survival or fecundity rates as their own life cycles become out of sync with the plant phenological transitions on which they rely (USA NPN).

Invasive species are usually better at adapting to fluctuating climates, so while native species may be affected negatively by earlier springs and a changing climate, invasive species are more likely to dominate the native species in their habitat (Monahan et al. 2016). By being able to predict when springs will likely start using phenology data over time, controlling invasive species in an area would be easier. Ragweed is known to produce extremely allergenic pollen, and it can only reproduce in areas where its seeds can mature before the winter frost (Chapman et al. 2014). As the climate warms, ragweed will be able to grow in more places and could possibly cause worse allergies, so knowing when ragweed releases its pollen could help humans avoid reactions to it.

Changes in normal plant phenology can also have major impacts on the food web and interactions with other organisms. 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 (Merkle et al. 2016). 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 (Rafferty et al. 2014). Though some animals may be able to adapt and use other plants for survival, the plant may be affected negatively, and other animals that depend on the plant may be affected negatively as well.

Deciduous trees are among the USA-NPN regional species list to monitor due to their dominance in their habitat, their conservation value, association with health issues such as allergens, and their importance to ecosystem services such as food supply. The National Ecological Observatory Network (NEON) has been collecting data on plant phenology at NEON terrestrial sites across the United States since late 2013. Part of the data follows deciduous broadleaf trees as they change through their breaking leaf buds, increasing leaf size, young leaves, leaves, colored leaves, open flowers, colored leaves, and falling leaves 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.

This project focuses on the phenology of deciduous broadleaf trees, a perennial plant, within several NEON domains throughout the United States. Specifically, the deciduous broadleaf “green-up” period, the amount of time it takes leaves to reach full size, will be compared to accumulated growing degree days throughout a season to observe how phenophases change as heat accumulates. By using data collected by NEON, deciduous tree leaf growth throughout time at a field site within one season will be graphed along with the temperature over the season, so that comparisons can be made across the Observatory and throughout time. The accumulated growing degree days for the sites will also be displayed so that the changes in phenophases can be compared to the heat accumulation at the site, further allowing for the exploration of plant phenology and its relation to climate change.

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