Tracking Flowering Times Along the Appalachian Trail

Using iNaturalist to Study Plant Phenology

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Appalachian Trail National Scenic Trail

2025

Acknowledgements

This project is managed by the Appalachian Mountain Club and has been funded by the Forest Ecosystem Monitoring Collaborative (FEMC), Roy Foundation and the Wild East Action Fund through the Appalachian Trail Conservancy. We thank AMC staff members Hailee Gibadlo, Larz Von Huene, Maya Sheyvitch, and Kyler Phillips as well as Danielle Guttman at AMC's Mid-Atlantic office for assisting in data collection and outreach. AMC staff Morgan Southgate assisted in developing R scripts for data analysis, and Cathy Poppenwimer assisted in GIS data and maps. We thank the over 11,000 iNaturalist observers and curators who have contributed their time, photos, and interest to this project and the broader effort to understand biodiversity in ecosystems in our region and around the world.

Appalachian Mountain Club (AMC)

Conservation Research

Report # AMC 2026-01

January 27, 2026

Contents

Executive Summary

Plant phenology, or the timing of seasonal growth, flowering, and fruiting, is a critical bioindicator of ecological responses to climate change[1]. Shifts in phenological timing can cascade through ecosystems, influencing species interactions, migration, and resilience. The Appalachian Trail (A.T.) corridor, stretching 2,198 miles through 14 states and spanning nearly 2,000 meters in elevation, serves as a "mega-transect" for studying these changes across broad climatic gradients. The Appalachian National Scenic Trail, consisting of the treadway and approximately 300 meter buffer, is part of the National Park system and benefits from long-term federal protections to conserve natural and cultural resources across the trail. The Appalachian landscape has been recognized nationally as an important migratory corridor and a key region for biodiversity and building resilience to climate change[2]. Monitoring plant phenology long-term across broad spatial scales and mountainous terrain presents challenges, but community science provides a practical solution.

Since 2018, the Appalachian Mountain Club's iNaturalist project *Flowers and Fauna along the Appalachian Trail Corridor* has leveraged crowdsourced observations from naturalists, biologists, and community volunteers to track flowering patterns of commonly found plant species. Our goal with this work is to:

1) utilize crowdsourced phenology data for a set of target plants,
2) examine how the timing of flowering varies across the A.T. corridor, and
3) as data amass, determine if there are shifts in response to climate change.

Between January 1 and December 31, 2025, participants contributed 11,241 new observations from 2,819 unique observers, including 219 new project members. This brought the project total to 72,762 observations from 11,267 unique observers, including 1,026 members. Curator volunteers also helped expand the dataset, adding over 4,700 phenology-tagged observations to the project, including over 1,000 for the newly included species, mayapple (*Podophyllum peltatum*).

Analyses focused on nine target species spanning early-, mid-, and late-season flowering. Flowering patterns across all species shifted predictably across elevational and latitudinal gradients, with peak flowering occurring approximately 27 days later in

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[1] https://www.usanpn.org/files/shared/files/phenology%20as%20an%20indicator%20of%20Environmental%20Variation%20and%20Climate%20change.pdf

[2] https://appalachiantrail.org/wp-content/uploads/2022/07/Appalachian-Landscape-Corridor-Report_July-2022.pdf

the North than in the Mid-Atlantic and South, and 12 days later at high elevations compared to low elevations. Linear regression analyses revealed that warmer spring temperatures were associated with earlier flowering across species, with early-flowering species showing the strongest temperature sensitivity, and the northern region showing greater temperature sensitivity than the mid-Atlantic or southern regions.

As climate change continues to reshape ecosystem seasonality across the Appalachian landscape, understanding how latitude and elevation influence plant phenology is increasingly urgent. Warming temperatures are expected to drive both northward and upslope shifts in species distributions, making the protected Appalachian Trail (A.T.) corridor a uniquely powerful mega-transect for tracking these changes while weaving together a network of people across thousands of miles. This project, alongside other iNaturalist projects facilitated by AMC, demonstrates that iNaturalist is a robust tool for gathering research-grade biodiversity data while engaging the community in conservation science.

We recommend continued monitoring, with a focus on well-distributed and phenologically predictable species as bioindicators of climate change. Future work could incorporate additional focal species as more observations are curated, allowing investigation of species-specific responses across a broader taxonomic range. We also continue to recommend expanded outreach and education to improve spatial and temporal coverage of data and to increase community participation in curation, strengthening the long-term value of this dataset for climate-change research.

Introduction

Phenology is the study of life cycle events and their relationship with weather and climate (Sparks et al. 2013). In recent years, phenology has come to the forefront of ecology research as it is believed that plants are experiencing shifts in first bloom due to anthropogenic climate change. Plants can therefore be used as bioindicators, species that assess the condition of the environment and identify shifts over time (Holt and Miller, 2010). Long-term phenological monitoring over large-scale distance is necessary to determine shifting seasonality in response to warmer temperatures (Monahan et al. 2016). Community science, or community science, is the practice of engaging the community to participate and collaborate in scientific research (Ullrich, 2022). This method of data collection is a useful tool to expand spatial monitoring coverage and prolong monitoring projects that would be hindered by funding and resources. Additionally, community scientists find deeper meanings in their hobbies, support conservation efforts, and build meaningful connections to their community and natural environment (Bonney et al. 2016). With long-term phenology monitoring supplemented with thousands of community scientist observations through iNaturalist (an online platform that allows sharing of biodiversity observations and creates research-quality community science data), changes and shifts in phenological response to warming temperatures and other climate indicators can be identified along the Appalachian Mountain chain.

At about 2,198 miles long, the Appalachian Trail, or A.T., is the longest footpath in the world and travels through 14 states from its southern terminus, Springer Mountain, Georgia, to its northern terminus, Katahdin in Maine (ATC 2024). Over 3 million people visit the trail each year, making it an ideal monitoring corridor where shifts in phenology can be recorded over large-scale landscapes. The geologic history of the Appalachian Mountain Range began over a billion years ago and consists of many complex mountain-building episodes. The most significant activity for humans in the Appalachian region was in the Cenozoic Era with the Pleistocene glaciations when the Laurentide Ice Sheet advanced and retreated for roughly 2 million years, carving the landscape and ecoregions we see today. From the Southern Appalachian grassy balds, to the alpine zones of the Northeast, the A.T. is home to diverse flora that can be used to judge the biotic response to climate change.

The A.T. is the country's first national scenic trail. Created by the Appalachian Trail Conservancy (ATC) in the 1920s and 1930s, it became the first national scenic trail in 1968 (NPS 2023). This origin resulted in the ATC and Nation Park Service (NPS) having joint leadership in management of the trail. The ATC is responsible for most land-management and trail maintenance, and works with other non-profit groups for more localized stewardship. This leadership role of a non-profit group on a national scenic trail is unique to the A.T.. Many scenic trails do have non-profit groups that help with stewardship under the oversight of the NPS or other governmental agencies, for example, The New England Nation Scenic Trail. The ATC's significant role is due to the trail's size, history, and cultural significance to those who live along it. With the guidance of the ATC, the A.T. is managed by dozens of independent groups and hiking clubs as well as other Federal and state agencies (e.g., U.S. Forest Service and Baxter State Park). This management style creates partnerships between federal, state, and private groups whose connections are what allows the AMC to have the necessary reach and resources to perform research throughout the entire A.T. corridor.

As climate change alters natural habitats, northward or upslope migrations could occur in pursuit of more hospitable environments. A recent study reveals that upper elevations in the Northern Appalachians are warming and experiencing longer growing seasons; however, the highest peak is not warming as quickly as lower elevations (Murray et al. 2021). This contrasts with many global mountain sites that are seeing elevation-dependent warming (Pepin et al. 2022). Models show many birds, mammals, and amphibians will migrate north using the A.T. corridor as a greenway to adapt to warmer temperatures (Lawler et al. 2013). Plants are expected to adapt as well with some alpine species currently at the maximum elevation at which they can survive (Kimball et al. 2021). One recent study found evidence of treeline advance in the White Mountains of New Hampshire and suggests that areas at colder, higher elevations, are advancing faster than other treeline areas (Tourville et al. 2023), which would put pressure on alpine communities. Using plant phenology as a bioindicator requires understanding how its spatial variance relies on abiotic factors like temperature. Hopkins' Bioclimatic law hypothesizes a 4-day shift in phenological events for every 1° latitude north, 5° longitude west, and 120 meters in elevation increase (Hopkins, 1920). Therefore, expected variability in phenological events should occur in mountain landscapes. Mountains may also act as climate change refugia, areas that remain relatively buffered from climate change (Morelli et al. 2016). Observing plant phenology along the A.T., which serves as a mega transect in mountainous environments, allows us to investigate potential bioindicator species, spatial variability, and potential climate change refugia.

AMC has been monitoring phenology in the northeast mountains since 2004 utilizing staff, partner organizations, and volunteers to gather phenology data on paper data sheets. It has since evolved to follow the National Phenology Network's (NPN) protocol and established permanent plots around AMC's staffed facilities in the White Mountains of New Hampshire while incorporating the use of apps and smartphones into monitoring practices. In some cases, partner organizations have also set up permanent plots and similarly evolved to use NPN protocol (e.g., Tin Mountain Conservation Center for woodland plots and Baxter State Park as alpine partners). In recent years, monitoring through community science has expanded from the northeast mountains to the A.T. Corridor and the New England National Scenic Trail (NET) corridor using the platform iNaturalist. iNaturalist is a free smartphone app with over 4 million users as of January 2026. Organized by the California Academy of Sciences and the National Geographic Society, in 2023 iNaturalist became an independent nonprofit organization. Users can upload their photo or sound observation to receive a species ID based on the program's algorithm or the community of naturalists. Observations are made *research grade* once there are two corresponding species identifications. The iNaturalist geotagged images reduce location errors and eliminate the past challenge of inaccurate species ID from novice observers (MacKenzie et al. 2017). iNaturalist serves as a supplement to permanent plots as the NPN plots require consistent attention from skilled naturalists while having limited spatial distribution. Therefore, iNaturalist observations are being used to fill gaps between monitoring plots and expand spatial coverage. iNaturalist can provide data that characterize different or complementary patterns than plot studies; for example, one study revealed that iNaturalist observers recorded earlier flowering times than those reported from permanent plots (Murray et al. 2021).

With over 183 million research-grade observations as of January 2026, iNaturalist proves to be a valuable resource that scientists can use to answer questions about the natural world. Researchers can create projects on iNaturalist to capture observations of a specific species or geographical range. AMC's phenology projects on iNaturalist incorporate NPN's protocol as observation fields to identify the life cycle stage of an observation. AMC's iNaturalist project, *Flowers and Fauna along the Appalachian Trail Corridor,* began in 2018 and with dedicated funding in 2022, 2023, 2024, and 2025 has grown to its current 72,000+ observations. The goal is to establish a long-term dataset that can be expanded and analyzed year after year to determine changes in phenological response to changing climate along the A.T.

Methods

The project *Flowers and Fauna along the Appalachian Trail Corridor* serves as a regional expansion of an AMC-administered iNaturalist project, the *Northeast Alpine Flower Watch*. The study area expanded to the A.T. Corridor, a mapped buffer region along the trail that includes USGS HUC10 watersheds that intersect with the A.T. (Figure 1). The project investigates 9 species of woodland plants native to the corridor to be used as spring phenology indicators (Appendix A). This project was created by AMC's conservation research team and was further facilitated by 2023, 2024, and 2025 National Park Service Scientists in Parks interns.

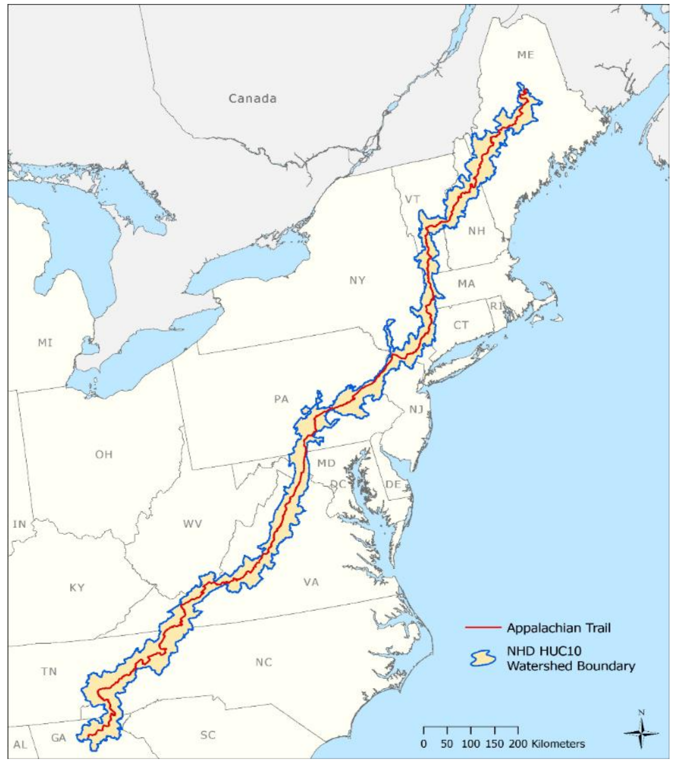

Figure 1. *Study area. The Appalachian National Scenic Trail corridor defined using 236 USGS HUC10 watersheds spanning 41933.78 square miles.*

Community Engagement

Outreach focused on recruiting hikers and other outdoor enthusiasts by introducing them to iNaturalist and encouraging participation in the project. Communication emphasized the iNaturalist platform's accessible and collaborative nature, highlighting that no specialized knowledge is required and that community members and researchers can assist with species identification. In addition to continuing outreach efforts from previous years, new emphasis was placed on building a team of volunteer curators to curate existing observations into the project.

Consistent with prior years, training was provided to AMC seasonal staff in the hut, shelters, and education departments on the importance and practicalities of adding observations. Contests with prize incentives were held among seasonal staff to encourage participation and increase observations of target species. Pocket guides featuring relevant species (Figure 2) were distributed to huts and the Pinkham Notch Visitor Center. In-person trainings were conducted at events across New England from May to November, reaching a broad audience of outdoor enthusiasts. Spatial gaps in

2024 iNaturalist data helped inform where outreach was prioritized in 2025. Responding to a lack of representation in Pennsylvania, a partnership was established with the Philadelphia Botanical Club, including a hybrid presentation at the club's December 2025 meeting. Additionally, an online webinar, *From Snow to Sprouts*, highlighted the connection between AMC's snow-depth monitoring and plant phenology research and explained how to get involved in community science.

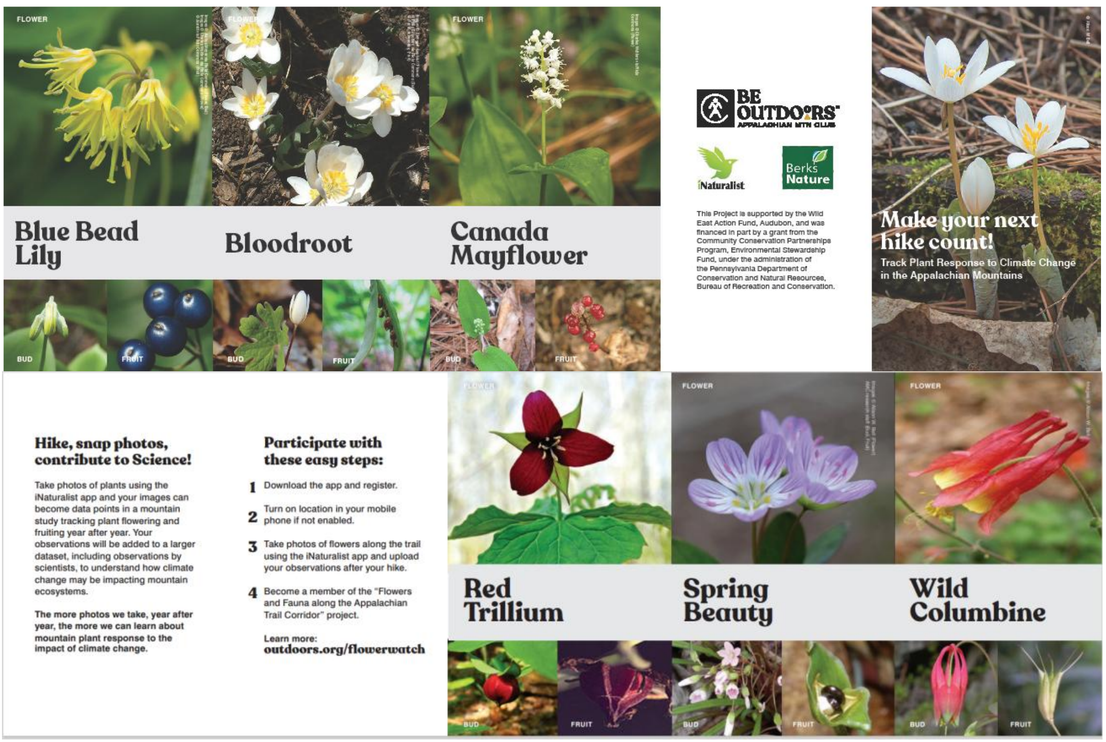

Figure 2. *Southern Woodlands pocket guide. Photos show bud, flowering, and fruiting stages of common species in the area. Additional pocket guides are shown in Appendix B.*

Due to the delayed timing of the Scientists in Parks internship term in 2025, which extended beyond the growing season of target species, outreach efforts shifted toward recruiting volunteer curators. This approach provided a remote opportunity for community scientists to contribute to the project during the late fall and winter months, while allowing us to incorporate species that were already being observed in high numbers by iNaturalist users but had not previously been formalized as focal species. Curator volunteers were trained to locate existing iNaturalist observations of target species within the study area, verify identifications to ensure research-grade status, answer phenology-related questions associated with each observation, and add suitable observations to the project. This strategy allowed continued data curation and project growth despite limited opportunities for new field observations late in the season.

Building on lessons from prior years, when curator recruitment relied primarily on large-group presentations supplemented by an instructional video and paper handout, the 2025 training model was redesigned to be more individualized and task-specific. Recruitment was conducted through emails to partner organizations and AMC individuals, project presentations, journal posts in the *Flowers and Fauna* project, and direct messages to active project members through iNaturalist. Interested volunteers were provided with an instructional video, a written handout, and a list of priority species from which to choose. Each volunteer then participated in a one-on-one virtual training session that included an overview of the phenology of their selected species, real-time curation of several observations, guidance on achieving strong spatial and temporal coverage, and time for questions. To promote sustained engagement and provide a clear endpoint for participation, a goal of 300 curated observations per species was established for completion by the end of the year. In addition to remote training, one in-person curation workshop was held at the Highland Center to train Alpine Steward volunteers to curate observations for the similar Northeast Alpine Flower Watch project.

Data Collection and Curation

Observations entered the project from existing members or through curation by AMC researchers and volunteers. To guide targeted curation, the spatial and temporal spread of data for each target species was mapped using RStudio (full code linked in Appendix C), and specific directions were given to curators to focus curation where there were gaps. As of January 2026, there are still over 27,000 potentially relevant observations in iNaturalist that can continue to be added to the project by curators.

To manage quality control, we used the following criteria for inclusion in the analysis dataset: observations were:

(1) "research grade" (with at least two corresponding identifications),
(2) geo and date tagged,
(3) fell within the A.T. corridor,
(4) had geolocation accuracy within 250 meters, and
(5) had phenology observation fields filled out.

Observations with obscured coordinates were also included if hidden coordinates were available to project managers.

To identify the phenophase (life cycle stage) in the observation, users have the option to fill out project-specific observation fields mirroring National Phenology Network protocol (Table 1). AMC's projects include a "past flower" field, which is not an NPN phenophase but helps identify the end of flowering.

Table 1. *Phenology fields mirroring NPN protocol and adopted from AMC's first iNaturalist project, the Northeast Alpine Flower Watch.*

[Source]: [Phenophase] *[Possible Response]*	**Definition**
NPN: Flowers or Flower Buds? *? / Yes / No*	One or more fresh open or unopened flowers or flower buds are visible on plant. Include flower buds or inflorescences that are swelling or expanding, but not those tightly closed and not actively growing (dormant). Do not include wilted or dried flowers.
NPN: Open Flowers? *? / Yes / No*	One or more open, fresh flowers are visible on plant. Flowers are considered "open" when reproductive parts (male stamens or female pistils) are visible between or within unfolded or open flower parts. Do not include wilted or dried flowers.
NPN: % of Fresh Flowers Open? *? / NA / <5% / 5-24% / 25-49% / 50-74% / 75-94% / 95% +*	What % of all fresh flowers (buds plus unopened plus open) on the plant are open? For species in which individual flowers are clustered in flower heads, spikes or catkins (inflorescences), estimate the % of all individual flowers that are open.
AMC: Past Flower? *? / Yes / No*	One or more petals have wilted or fallen off. The remaining ovaries may begin to swell and change color.
NPN: Fruits? *? / Yes / No*	One or more fruits at any stage of maturity are visible on the plant. However, once all of the fruits drop all of their seeds, do not report this phenophase even if the pods, capsules, or husks of the fruits remain (or "persist") on the plant.

Data Analysis

All data processing, statistical analyses, and figure generation were conducted in RStudio; full scripts are linked in Appendix C. Of the 72,661 observations currently in the project, 27,109 (41%) correspond to the nine target species listed in Appendix A. Although nine of the ten most observed species in the project remain among the focal species for this report, we intentionally did not restrict which taxa could be added to the project. This open approach encourages participation by iNaturalist users, including observations of animals as well as plants, and creates a more comprehensive dataset that can support future projects such as Bioblitzes. Of the 27,109 target species observations in the project, 70% met the criteria for inclusion in this report, and 40% both met the criteria for inclusion and were in the open flower phenophase. Analysis primarily focused on species with open flower phenophase as it was the dominant phenophase and is of ecological importance.

We summarized the number of open-flower observations by day of year (DOY) to characterize flowering phenophase timing. Flowering curves were generated with consideration of geographic variation in latitude and elevation. Elevation values were extracted at each observation's geographic coordinates using the *elevatr* package in R, which queries USGS 3DEP digital elevation models to assign elevation estimates to point locations. The A.T. corridor spans approximately 34°N to 46°N in latitude and reaches a maximum elevation of about 6,643 ft (2025 m)[7]. Because differences in flowering timing across latitude and elevation largely reflect underlying temperature gradients, this year we focused on temperature as a key environmental driver, noting that season length and spring temperatures are often especially important predictors of phenology (Tourville et al. 2024).

We tested for relationships between flowering time (DOY) and three potential predictor variables: spring mean temperature, species, and latitudinal region. Spring mean temperature was derived from PRISM climate data by extracting temperature values at each observation location and averaging monthly mean temperatures across the spring months (April–June) for the corresponding year. To assess temperature effects across broad spatial gradients, we evaluated how flowering time varied with spring mean temperature within three latitudinal bands: South (34–38°N), Mid-Atlantic (38–42°N), and North (42–46°N). We also used linear regressions of DOY against spring mean temperature for the nine focal species in RStudio to observe species-level differences in temperature sensitivity. Finally, we conducted linear regression analysis to examine the combined effects of species and region on flowering time.

Results

Outreach and Volunteer Recruitment

Outreach efforts reached approximately 7,700 people in 2025, a significant increase over the previous year, through the methods listed in Table 2. This year, outreach was focused on working with AMC hut staff and expanding huts-based programming around iNaturalist, reaching 6,968 people this year. We increased our emphasis on webinars, which proved to be an effective way to reach participants later in the season when in-person attendance tends to decline, while also engaging a broader spatial audience along the A.T. corridor. Webinar attendance rose substantially, from 26 participants in 2024 to 169 in 2025. In-person presentations also saw an increase from 76 audience members in 2024 to 84 in 2025.

Table 2. *Summary of 2025 outreach efforts. Methods, locations, and resulting audience numbers are displayed. *Indirect methods of outreach where exact audience numbers cannot be quantified.*

Recruitment Method	**Location(s)**	**Audience numbers**
Webinars	Online	169
Presentations	AMC and partner facilities	84
Huts programming	AMC huts	6,968
Web-based*	Online newsletters	Unknown
Pocket guide distribution*	AMC facilities	500+

Outreach efforts resulted in continued growth in project membership (Figure 3). Membership grew in 2025 due to consistent outreach efforts by AMC staff, volunteers, and partner organizations. A total of 1,023 members have joined since the project's creation in 2018, with 219 new members joining in 2025 alone, representing a 162% increase in annual membership growth compared to 2024. Together, these results highlight the effectiveness of shifting outreach strategies toward webinars, strengthened hut programming, and partner-based engagement.

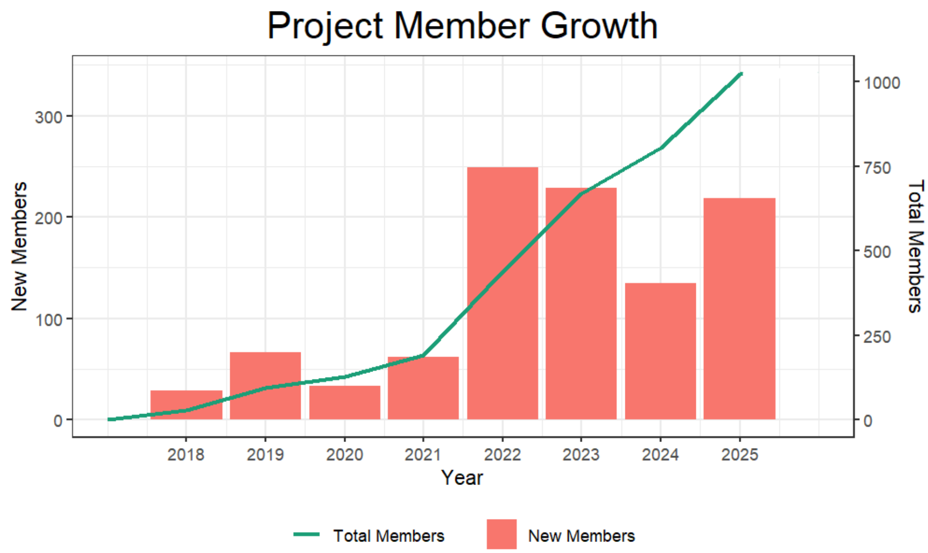

Figure 3. *Cumulative project member growth and totals by year. All data through 2025.*

Targeted Curation

Outreach for new curation volunteers resulted in 11 people expressing interest, six of whom remained active and completed their assignments of curating 300+ observations per assigned species by the end of 2025. In total, these six curator volunteers curated approximately 4,700 observations into the project across ten different species (Table 3). Two of these species—*Podophyllum peltatum* and *Arisaema triphyllum*—are focal species in this report, while the remaining species are of interest for parallel AMC research efforts.

Table 3. *Number of observations curated and assigned species by curator.*

Curator	Observations Curated	Species Focus
jayryan59	1439	*Podophyllum peltatum*, *Arisaema triphyllum*
neena_g	1009	*Cypripedium acaule*, *Oxalis montana*
rtgardner3	900	*Impatiens pallida*, *Uvularia sessilifolia*
quigpat	614	*Polygonatum pubescens*, *Viola canadensis*
paxendra98	480	*Sibbaldiopsis tridentata*
loraxlucinda	339	*Streptopus lanceolatus*

To direct targeted curation, the spatial and temporal spread of observations for each target species was mapped using RStudio, and curators were given specific guidance to focus their efforts where data gaps were evident. For example, prior to targeted curation, observations of *Podophyllum peltatum* (mayapple) in the project were very sparse before 2023. The curator assigned to this species curated observations from 2015-2022 into the project, improving the temporal coverage of the data (Figure 4).

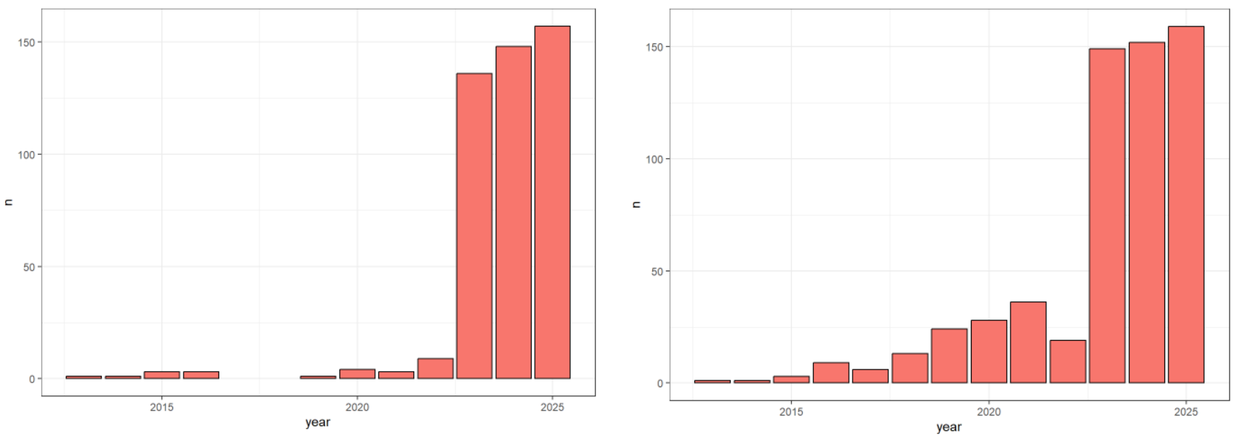

Figure 4. *Count of observations by year for* Podophyllum peltatum *in the project, before targeted curation (left) and after targeted curation (right)*

Summary of Phenology Observations

Of the 72,661 total observations currently in the project, 11,241 were added in 2025, representing a 140% increase over 2024. Observations in the project grew exponentially each year through 2022, then leveled off, with a pronounced decline in 2024 before rebounding in 2025 (Figure 5).

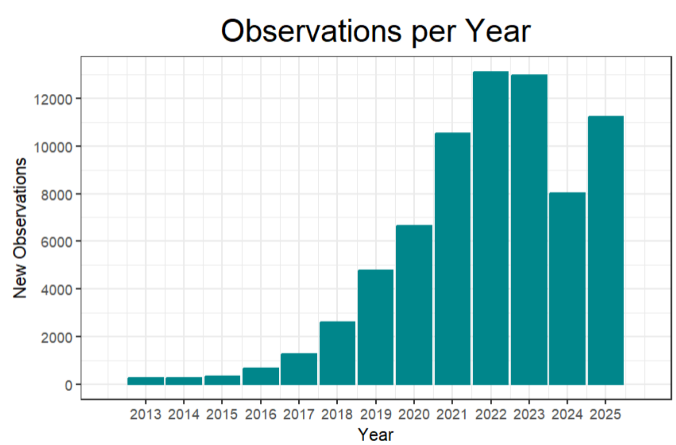

Figure 5. *Total number of observations added per year into the project.*[3]

[3] Observations can be added of older photos by manually selecting a location and date. Manually-added observations to the project date back to 1900, but were excluded from this graph.

Observations of the nine target species in this report accounted for 41% of all observations in the project. This relatively low proportion reflects both a narrowing of the focal species in this report—from 22 in 2023 to nine in 2025—and substantial recent curation of additional plant species now included on the project's broader target list. Many of these newly curated observations support parallel research efforts led by Dr. Morgan Southgate, AMC Postdoc, and are not part of the focal species analyzed here but may be integrated in future reports.

Some species of target plants were represented less frequently than others; for example, mayapple (*Podophyllum peltatum*), which was newly added as a focal species in 2025, comprised only 3% of target species observations (Figure 6). This likely reflects limited curation effort for this species to date, despite sufficient existing observations to justify its inclusion in the analysis. Unequal representation among target species is likely driven by a combination of observational and curation biases. iNaturalist observers tend to document widely known, visually distinctive species, such as the three-petaled trillium, more frequently. Conversely, users also often use the app to identify unfamiliar species, which can contribute to a more diverse but uneven sample set. Additionally, project curators actively added target species observations to the project, introducing an element of selection bias. Spatial differences in reported species may also reflect localized outreach efforts near AMC's facilities in the White Mountains, which likely biased observations towards species common near the northern end of the corridor.

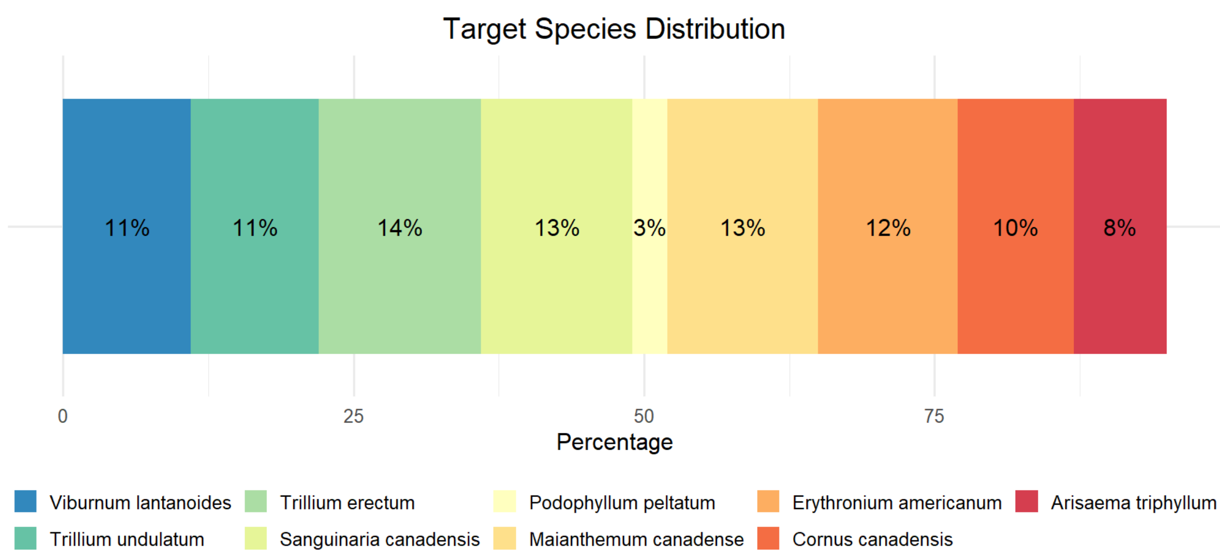

Figure 6. *Percentages of target species (all data through 2025). See Appendix A for species photos.*

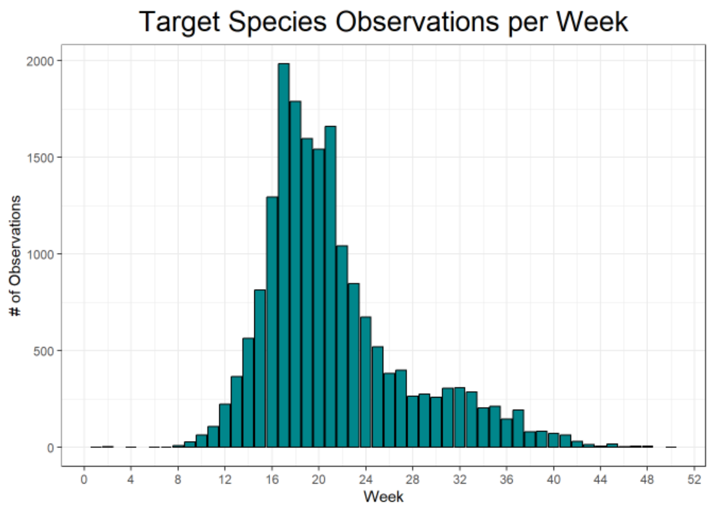

Figure 7. *Target observations collected by week (all data through 2025). Most observations of the target species fall during spring flowering and late-summer fruiting, in line with what the monitoring project is designed to track.*

Most observations of target species were reported in late April and early May each year (Figure 7), reflecting a strong bias toward documenting open flowers by both iNaturalist users and project curators. A second, smaller peak in observations occurred in August, corresponding to the fruiting stage of many species. This seasonal bias towards flowering and fruiting is consistent with patterns observed in other community science phenology assessments and aligns with analyses of peak open-flower timing (Piselli et al. 2022, Barve et al. 2020). AMC promotional materials also emphasize flower and fruiting phenophases, likely reinforcing this pattern in the data.

Observations Across Space

The Appalachian Trail (A.T.) Corridor spans two Level 1 and eight Level 3 ecoregions[4] (Table 4), with elevations across these regions ranging from 124 to 6,643 feet (38 – 2,025 meters). Trail networks through the corridor provide ready-made elevation and ecoregion transects, which support the project's goal of studying phenological variation across mountainous landscapes. Following the approach of Tourville et al. (2024), this study divided the A.T. into three latitudinal portions for spatial analysis – Southern (34-38°N), Mid-Atlantic (38-42°N), and Northern (42-46°N). Although ecoregion-based analyses are a longer-term goal, the limited number of observations within many ecoregions currently constrains the ability to meaningfully compare them. As a result,

[4] https://www.epa.gov/eco-research/ecoregions

the Northern, Mid-Atlantic, and Southern latitudinal divisions are used here as the primary spatial framework.

Table 4. *Ecoregion along the entire A.T. corridor with the number of target observation species through 2025. Level 1 ecoregion bolded with corresponding level 3 region below.*

Ecoregion	*Number of observations*
Northern Forest	**16,395**
58 Northeastern Highlands	16,157
62 North Central Appalachians	238
Eastern Temperate Forest	**10,289**
45 Piedmont	80
59 Northeastern Coastal Zone	779
60 Northern Allegheny Plateau	8
64 Northern Piedmont	632
66 Blue Ridge	6,109
67 Ridge and Valley	2,592
69 Central Appalachians	7
82 Acadian Plains and Hills	82

Regional bias and clear observation hotspots were seen in the White Mountains of New Hampshire, the Green Mountains of Vermont, and the Blue Ridge Mountains near the southern terminus (Figure 8). High observation density in the White Mountains was expected, given more frequent local outreach efforts and the concentration of AMC staff near facilities in this region. Nearly 6 million people visit the White Mountains each year, with peak visitation in the summer months. Additional hotspots were observed in other high-traffic areas along the corridor, such as Great Smoky Mountains National Park in North Carolina and Tennessee. Although Pennsylvania and Virginia saw an increase in representation from past years, regions of sparse data persist in both states. Patterns from the Appalachian Trail Natural Resource Assessment forest cover map suggest that these low-density areas correspond to sections of the trail with reduced surrounding forest cover (Figure 9), showing that lower observation density may partly reflect reduced habitat availability and lower local abundance of target species in those regions.

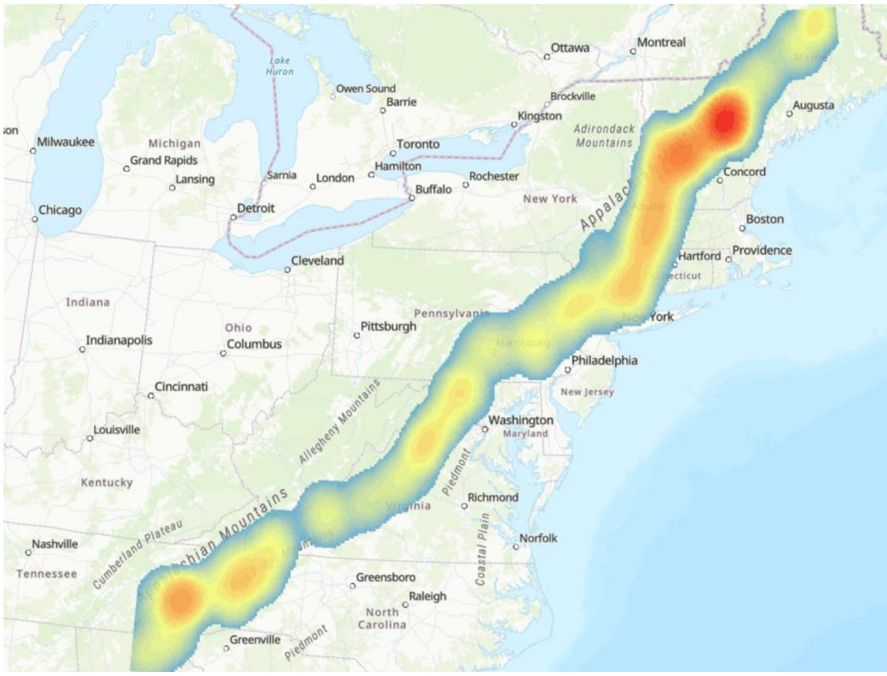

Figure 8. *Target species iNaturalist observation density along the A.T. corridor through 2025. Hotspots were seen in the Green Mountains of Vermont, the White Mountains of New Hampshire, and parts of the Blue Ridge Mountains.*

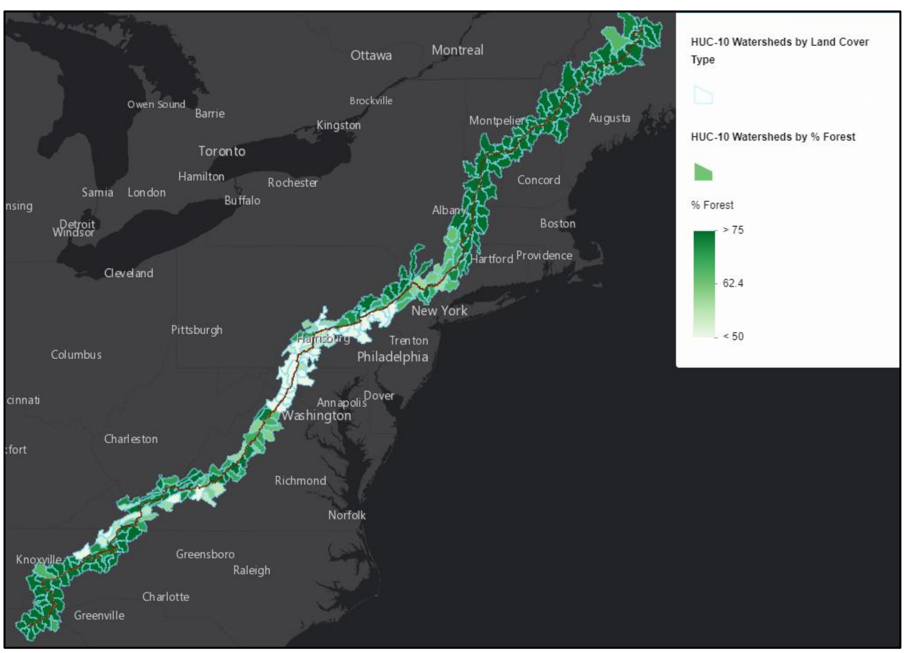

Figure 9. *Percent forest within HUC10 watersheds intersecting the A.T.. Source:* [Appalachian Trail Natural Resource Condition Assessment (arcgis.com)]

Open Flower Timing

Open flower observations were tallied using the "open flower" observation field, and flowering curves were generated for all 9 target species (Figure 10). Flowering for all target species in the project occurred between the end of March through early July. Flowering began earliest with *Sanguinaria canadensis* (bloodroot), which peaked around April 9. This was followed by *Erythronium americanum* (trout lily; April 28), *Podophyllum peltatum* (mayapple; May 2), *Trillium erectum* (red trillium; May 6), *Arisaema triphyllum* (jack-in-the-pulpit; May 13), *Viburnum lantanoides* (hobblebush; May 16), and *Trillium undulatum* (red trillium; May 19). The final wave of flowering included *Maianthemum canadense* (Canada mayflower; June 2) and *Cornus canadensis* (bunchberry; June 22).

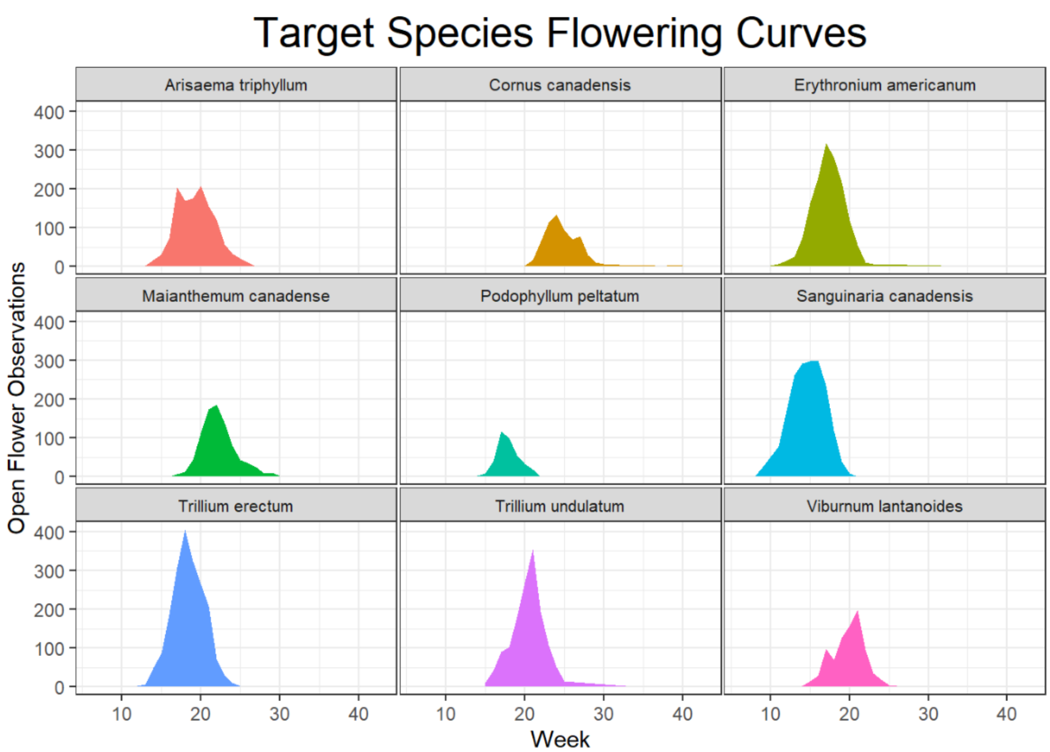

Figure 10. *Flowering curves for target species developed from iNaturalist observations (all data through 2025). Multiple peaks show variance in spring bloom depending on latitude and elevation. Weeks 10, 20, 30, and 40 correspond approximately to months March, May, July, and September.*

Flowering curves were also summarized statistically in Table 5, which reports the mean and standard deviation of flowering day of year (DOY), as well as the mean and standard deviation elevation at which each species was observed. The standard deviation DOY provides an estimate of how broad the flowering window is: species with smaller values tend to have more synchronized, concentrated blooms, while larger values indicate more extended or variable flowering periods. Curves reflect this pattern visually, with sharp peaks (e.g., *Trillium undulatum*) corresponding to narrow flowering windows and broader or multi-peaked curves (e.g., *Sanguinaria canadensis*) indicating more prolonged flowering (Figure 10).

Table 5. *Average and standard deviation of day of year (DOY) and elevation for open flower observations by species in the A.T. Corridor iNaturalist project, through 2025.*

	Observation Count	Mean DOY	SD DOY	Mean Elevation (m)	SD Elevation (m)
Sanguinaria canadensis (bloodroot)	1877	99	15.4	411	315
Erythronium americanum (yellow trout lily)	1524	118	14.9	401	351
Podophyllum peltatum (mayapple)	377	122	10.0	538	347
Trillium erectum (red trillium)	1963	126	14.4	591	432
Arisaema triphyllum (jack-in-the-pulpit)	1278	133	17.5	476	344
Viburnum lantanoides (hobblebush)	859	136	14.4	872	510
Trillium undulatum (painted trillium)	1417	139	13.8	725	351
Maianthemum canadense (Canada mayflower)	876	153	15.6	636	463
Cornus canadensis (bunchberry)	637	173	22.1	789	405

Flowering Times by Region and Elevation

Given that the Appalachian Trail stretches more than 2,198 miles, regional differences in open-flower timing were expected. To account for geographic variation, flowering times were analyzed using both latitudinal and elevational stratification. Latitudinal bands were defined as South (34–38°N), Mid-Atlantic (38–42°N), and North (42–46°N), while elevation classes were defined as low (<500 m), mid (500–900 m), and high (>900 m).

Flowering curves were generated by latitude (Figure 11) and by elevation (Figure 12). As shown in Table 6, peak flowering occurred approximately 27 days later in the North compared to the Mid-Atlantic and South. Peak flowering at high elevations occurred 12 days later than low elevations. Open flower observations for target species totaled 2,788 in the South, 2,616 in the Mid-Atlantic, and 5,404 in the North. Across all latitudes, 5,728 observations occurred at low elevations, 2,972 at mid elevations, and 2,108 at high elevations.

Table 6. *Average and standard deviation of flowering times for latitudinal and elevational striations for 9 target species.*

	Average flowering day	**SD of flowering day**	**Observation Count**
North (42-46°)	142	19	5404
Mid-Atlantic (38-42°)	115	20	2616
South (34-38°)	114	21	2788
High Elevation (>900m)	136	28	2108
Mid Elevation (500-900m)	132	26	2972
Low Elevation (<500m)	124	21	5728

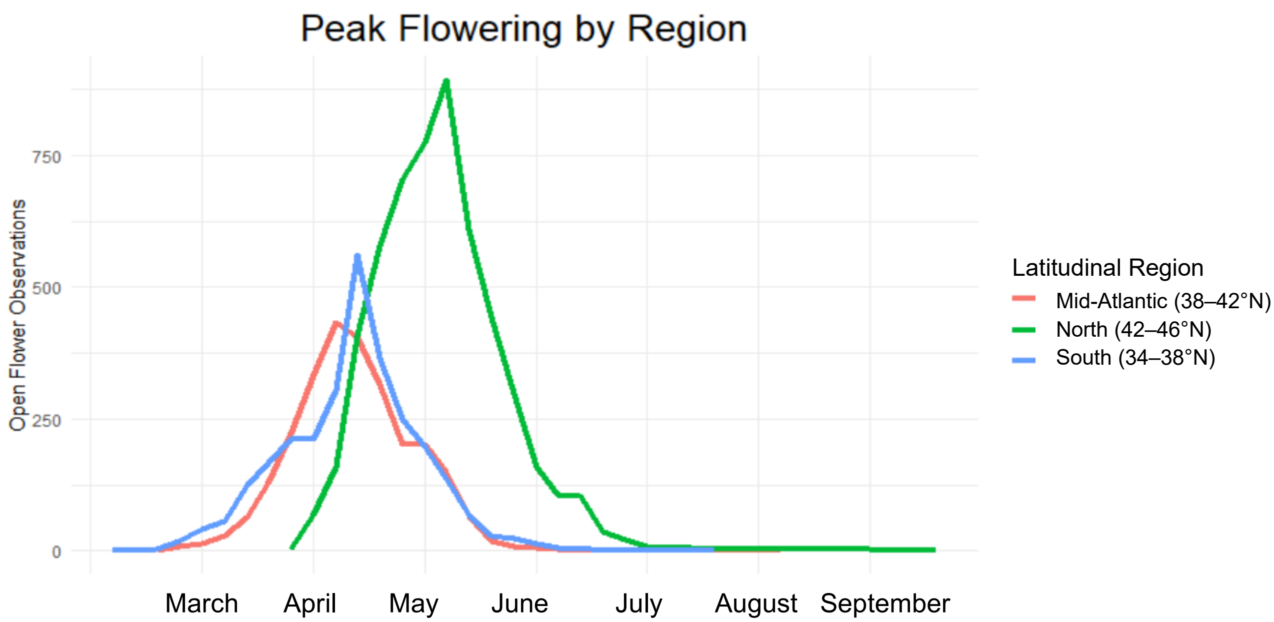

Figure 11. *Flowering curve for 8 target species separated by latitude. The latitudinal divisions are South (34-38°N), Mid-Atlantic (38-42°N), and North(42-46°N).*

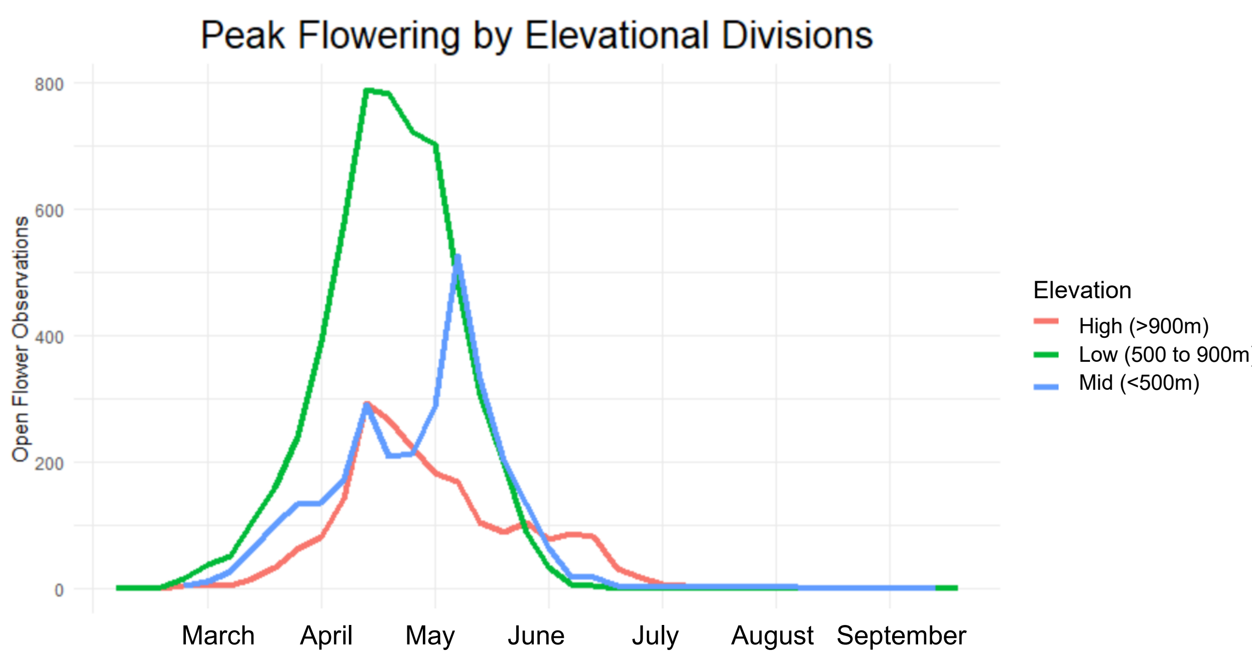

Figure 12. *Flowering curve for 8 target species separated by elevation. The elevational divisions are low (<500m), mid (500-900m), and high (>900m).*

Spring Temperature Effects on Flower Timing

To assess whether variation in spring temperatures influenced flowering phenology, linear regressions were conducted between mean spring temperature and mean open-flower day of year for each target species. Across species, higher mean spring temperatures were generally associated with earlier flowering, indicated by negative regression slopes between temperature and open-flower day of year. On average, flowering advanced by approximately 4.5 days per 1°C increase in spring temperature ($p < 0.001$, $R^2 = 0.4998$). This pattern suggests that temperature variability is a strong driver of phenological timing along the Appalachian Trail corridor.

Temperature sensitivity varied among regions (Figure 13). In the North, flowering advanced by 6.4 days per °C, compared to 5.0 days per °C in the Mid-Atlantic and 5.0 days per °C in the South (all relevant at $p < 0.001$). The steepest slope was observed in the North, suggesting that flowering phenology in this region is more sensitive to spring temperature variation.

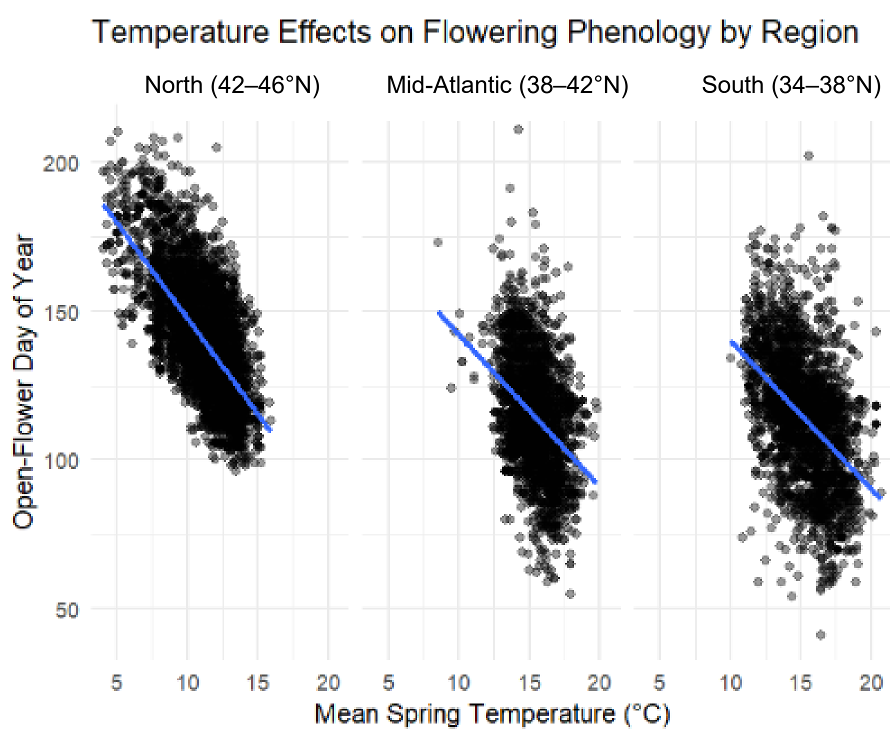

Figure 13. *Relationship between mean spring temperature and open-flower timing across the three latitudinal regions of the Appalachian Trail. Flowering generally occurred later in the north, with a steeper slope showing a stronger temperature sensitivity than in the Mid-Atlantic or South.*

Similarly, temperature sensitivity varied among elevational bands (Figure 14). At higher elevations (>900m), flowering advanced by 6.8 days per °C, compared to 5.8 days per °C at mid elevations (500-900m) and 5.8 days per °C at low elevations (<500m), all relevant at $p < 0.001$. This suggests that flowering phenology is more sensitive to spring temperature variation at higher elevations.

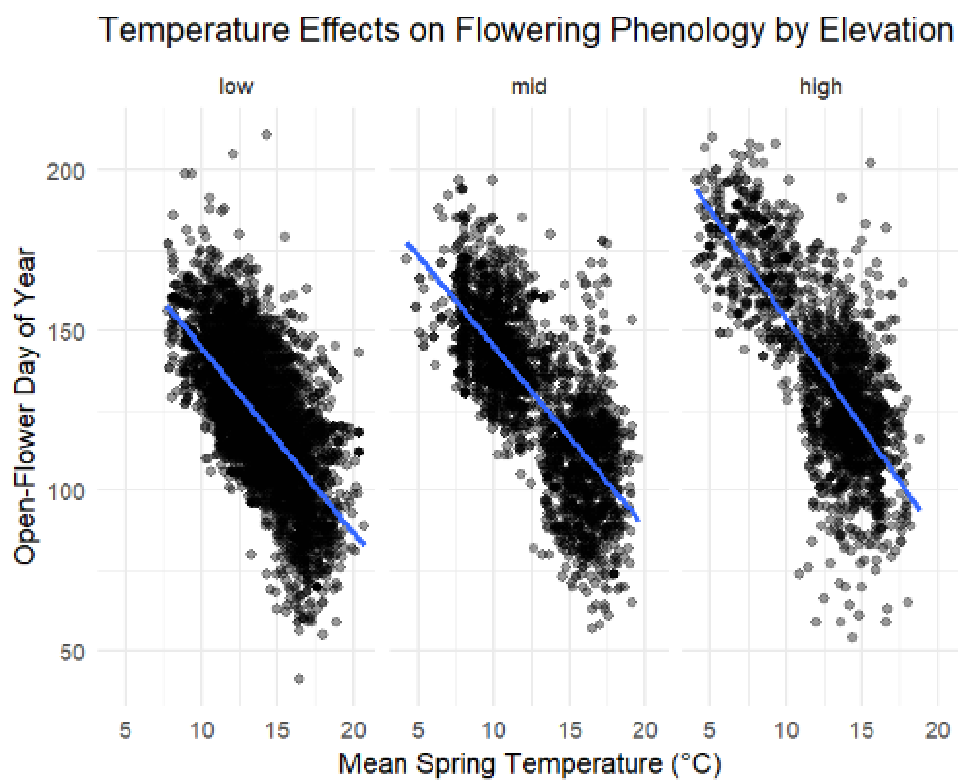

Figure 14. *Relationship between mean spring temperature and open-flower timing across the three elevational bands on the Appalachian Trail. Flowering generally occurred later at higher elevations and showed stronger temperature sensitivity (steeper slope) than at lower elevations.*

Species differed substantially in their responses to spring temperature (Figure 15; Table 7). Across all nine species, temperature sensitivities ranged from 3.1 to 5.2 days per °C, with early-flowering species generally (but not always) exhibiting steeper negative slopes than later-flowering species. To improve visual clarity, Figure 15 highlights four representative species spanning the flowering season:

- *Sanguinaria canadensis* (bloodroot; earliest flowering)
- *Erythronium americanum* (trout lily; early flowering)
- *Arisaema triphyllum* (jack-in-the-pulpit; mid-season flowering)
- *Cornus canadensis* (bunchberry; later flowering)

Among these species, bloodroot and trout lily showed the strongest temperature sensitivity, advancing flowering by 5.1 days per °C and 4.8 days per °C, respectively. Jack-in-the-pulpit exhibited an intermediate response (4.2 days per °C), while bunchberry showed a weaker but still significant relationship (3.1 days per °C). These differences indicate that early spring ephemerals are generally more responsive to temperature variation than later-flowering species.

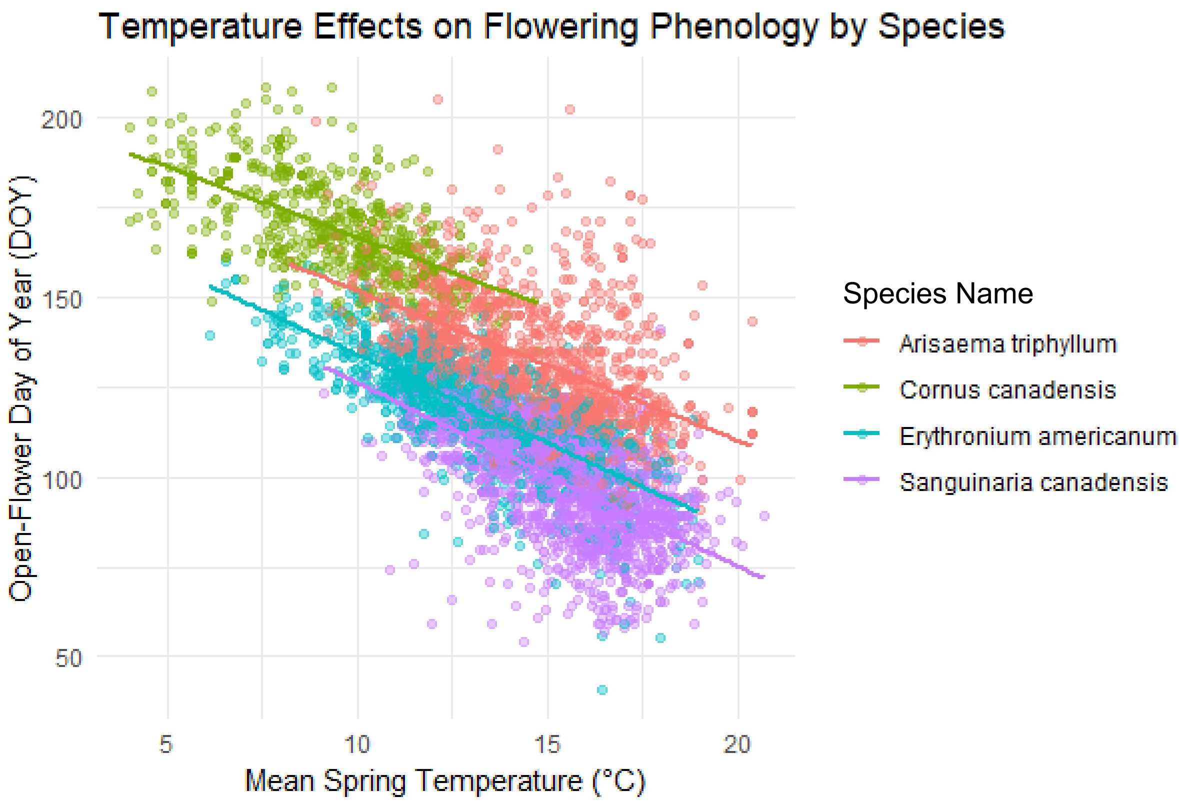

Figure 15. *Relationship between mean spring temperature and open-flower timing across four of the target species:* Arisaema triphyllum *(jack-in-the-pulpit),* Cornus canadensis *(bunchberry),* Erythronium americanum *(trout lily), and* Sanguinaria canadensis *(bloodroot).*

Table 7. *Linear regression results for day of year (DOY) of open flower observations vs. spring mean temperature by species. All relevant at p<0.001.*

Species	Days per °C
Cornus canadensis (bunchberry)	-3.1
Podophyllum peltatum (mayapple)	-3.9
Arisaema triphyllum (jack-in-the-pulpit)	-4.2
Trillium erectum (red trillium)	-4.4
Trillium undulatum (painted trillium)	-4.4
Maianthemum canadense (Canada mayflower)	-4.6
Erythronium americanum (yellow trout lily)	-4.8
Sanguinaria canadensis (bloodroot)	-5.1
Viburnum lantanoides (hobblebush)	-5.2
All Species Aggregated	-4.5

Additional analyses of spring mean temperature in relation to elevation and latitude are shown in Appendix C, Figures 1C–2C. Temporal trends in spring mean temperature and flowering day of year are shown in Appendix C, Figure 3C.

Discussion

The engagement of community scientists through iNaturalist was an effective approach for monitoring plant phenology across a large-scale landscape such as the Appalachian Trail (A.T.) Corridor. Outreach efforts by AMC staff and partners supported continued growth in participation, and as of December 2025, the *Flowers and Fauna along the Appalachian Trail Corridor* project included over 72,000 observations spanning more than 4,000 species from 11,200 contributors, including over 1,000 project members. By leveraging observations that pre-date the project's launch, this crowdsourced dataset enables phenology monitoring across the full length of the corridor and over nearly two decades.

Volunteer recruitment and project outreach, including in-person and virtual methods, added 219 new members in 2025, bringing total membership to 1,023. Outreach efforts through presentations, webinars, and huts-based programming reached over 7,700 people, more than 7 times the numbers from 2024. While most observations were recorded between 2020 and 2025, with a notable increase during the COVID-19 pandemic, curated records extend back to 1976. Community scientists tended to document visually distinctive species such as *Trillium erectum,* but targeted curation helped balance species representation across the dataset. Observations were also biased towards the flowering phenophase, reflecting users' preference for showy flowers; however, this bias aligns well with the project's focus on flower timing.

Spatial analysis confirmed observations across the entire corridor and in all 14 states, demonstrating the utility of community science for large-scale ecological monitoring. Dense clusters of observations occurred in high-traffic area such as the White Mountains and portions of the Blue Ridge Mountains, while sparser coverage in parts of Pennsylvania and Virginia may reflect lower forest cover and reduced availability of forest understory species. Spatiotemporal mapping of observations was also used to guide targeted curation, allowing curators to focus on species, regions, and time periods with data gaps. This strategic approach improved both the spatial and temporal spread of observations for focal species and strengthened the overall robustness of the dataset.

Phenological analyses revealed clear differences in flowering timing among species, latitudinal regions, and elevational bands. Flowering curves showed distinct early-, mid-, and late-season bloomers, with *Sanguinaria canadensis* and *Erythronium americanum* emerging earliest; followed by *Podophyllum peltatum*, *Trillium erectum*, *Arisaema triphyllum*, *Viburnum lantanoides*, and *Trillium undulatum*; and later peaks for *Maianthemum canadense* and *Clintonia borealis*. These commonly observed species function as strong seasonal indicators and provide a useful foundation for tracking phenological shifts over time.

In addition to spatial gradients, flowering timing showed a consistent relationship with spring mean temperature. Across focal species, warmer spring temperatures were associated with earlier open-flower dates, indicating that temperature is a key driver of phenological timing within the A.T. corridor. This pattern was most pronounced in the Northern region and at higher elevations, where flowering advanced more rapidly with increasing temperature, suggesting heightened climate sensitivity in cooler environments. These results differ from Tourville et al (2024), which identified the mid-Atlantic as the most temperature-sensitive section of the A.T., potentially due to their inclusion of more species, multiple functional groups, and additional data sources such as NPN. Earlier-flowering species such as *Sanguinaria canadensis* (bloodroot) and *Erythronium americanum* (trout lily) exhibited greater sensitivity to temperature than later-flowering species such as *Arisaema triphyllum* (jack-in-the-pulpit) and *Cornus canadensis* (bunchberry). These differences suggest that early-season species may serve as particularly responsive bioindicators of climate change.

While we did not set out to detect the impact of climate change directly on flowering times, given the typical 30-year record needed for climate change trend detection, the project nonetheless establishes a strong baseline for future analyses. Exploratory analyses of long-term temperature trends and flowering timing are included in Appendix C and provide context for future climate change assessments. When combined with plot-based phenology monitoring and long-term weather station data, this dataset enables increasingly nuanced assessments of how temperature, latitude, elevation, and species type interact to shape flowering phenology (Tourville et al. 2024).

Recommendations

Expand and Diversify Outreach Efforts

Outreach to land trusts, nature preserves, and conservation organizations should be further developed. Many microsections of the A.T. corridor are managed by small organizations with existing educational programs where this project would be a natural fit. Creating a centralized list of private nonprofit lands intersecting the A.T. could help identify potential partners and guide relationship-building efforts.

Outreach materials should also be made more accessible to broader audiences. Continued development of print materials designed for a wider age range could encourage family participation. Building on the success of Spanish pocket field guides for Southern A.T. species, future development of Québec French pocket field guides for the Northern A.T. could engage additional communities along the corridor.

In addition, educational efforts should place greater emphasis on training observers to complete project-specific observation fields at the time of data entry. Improving observer familiarity with phenophase fields would reduce the need for retrospective curation.

Address Flowering Phenophase Bias

In this project, 57% of all target species observations occurred during the flowering phenophase. This bias was expected, as community scientists are more likely to notice and document showy flowers than dormant plants, a pattern also documented in other community science studies (Panchen et al. 2019). Additional bias is introduced by curators who prioritize flowering observations when adding records to the project.

While this bias does not currently compromise analyses focused on flowering timing, it should be considered if future research questions expand to other phenophases. One mitigation strategy would be to include images of dormant stages of target species in pocket field guides, which currently emphasize budding, flowering, and fruiting stages. Adjusting curation protocols and expanding educational resources could further help balance phenophase representation over time.

Minimize Spatial and Temporal Gaps

Although targeted outreach in 2025 improved representation in the Mid-Atlantic region, spatial gaps persist in parts of Pennsylvania and Virginia, and in-person outreach remains concentrated in the White Mountains. Continued efforts are needed to engage communities along the entire length of the trail.

We recommend sustaining recruitment of curation volunteers, as the individualized, task-specific training model proved effective at adding large volumes of high-quality data and filling spatial and temporal gaps through targeted curation. Ongoing use of spatiotemporal analyses to identify underrepresented regions, species, and time periods should continue to guide strategic curation priorities.

Continue and Refine Target Species

Based on results to date, we recommend continuing to use the nine focal species—*Arisaema triphyllum*, *Cornus canadensis*, *Erythronium americanum*, *Maianthemum canadense*, *Podophyllum peltatum*, *Sanguinaria canadensis*, *Trillium erectum*, *Trillium undulatum*, and *Viburnum lantanoides*—as bioindicators of climate-driven phenological change along the A.T. corridor. Their wide distributions and staggered flowering times make them well suited for tracking seasonal progression across latitudinal and elevational gradients.

However, four of the nine focal species have naturally lower representation in the Mid-Atlantic section of the trail. As additional species are curated into the dataset, reconsidering focal species selection to include plants with broader latitudinal distributions may improve overall spatial spread and provide stronger results. Expanding the set of focal species will also support more detailed assessments of species-specific phenological responses, helping identify potential “winners” and “losers” under changing climate conditions.

Integrate Additional Data Streams

Merging iNaturalist data with complementary phenology data streams can substantially strengthen future analyses. AMC has already begun this work by combining iNaturalist data with National Phenology Network (NPN) permanent plot data, which includes both understory and canopy phenology (Tourville et al. 2024), and we expect to update the A.T.-wide analysis under Dr. Southgate’s work. Building on this foundation, future efforts could incorporate Phenocam network imagery, which captures canopy closure, green-up, and senescence, to provide additional context for interpreting flower patterns observed along the A.T. corridor.

Expand Analytical Approaches

Future analyses could explore use of the “percent open flower” observation field to assess not only the timing but also the magnitude of spring bloom. In addition, incorporating ecoregion classifications could help determine whether flowering timing and species composition vary systematically across ecoregion categories, allowing more insight into the processes underlying the observed north-south contrasts in phenology.

Multi-linear regression could be conducted to understand the influence of spring temperature on flower timing across species, elevation, and latitude combined.

Conclusions

Using iNaturalist to study plant phenology along the Appalachian Trail corridor has proven to be a powerful and scalable approach for identifying plant species as bioindicators of climate change. Geotagged observations contributed by community scientists allow widespread monitoring and collection of research-grade data across one of North America's most ecologically significant landscapes. At the same time, participation in the project fosters a greater connection between people and place, as observers gain appreciation for natural spaces while finding deeper meaning in their hobbies.

With sustained outreach by project administrators and partners, and continued engagement from an expanding community of contributors, this project will grow into a robust, long-term phenology dataset spanning the full length of the Appalachian Trail, providing a strong foundation for detecting climate-driven shifts in plant phenology and for informing conservation and management strategies in a rapidly changing world.

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Supplemental Information

Appendix A. Target Species Table

Bloodroot *(Sanguinaria canadensis)*

Credit left to right: Shadow, Misty Garrick, Leila Dasher

Hobblebush *(Viburnum lantanoides)*

Credit left to right: Kent P. McFarland, James Welch, Brighton Lee

Canada Mayflower *(Maianthemum canadense)*

Credit left to right: ellenjones6, Susan Elliot, Sandy Wolkenberg

Yellow Trout Lily *(Erythronium americanum)*

Credit left to right: Colleen C, Bill Lucas, Suzanne Cadwell

Red Trillium *(Trillium erectum)*

Credit left to right: Lise F, Susan Elliot, davidpickett

Painted Trillium *(Trillium undulatum)*

Credit left to right: Laura Costello, roy pilcher, christina_thibeault

Canadian Bunchberry *(Cornus canadensis)*

Credit left to right: Kallum McDonald, Shane Johnson, Megan Blackmore

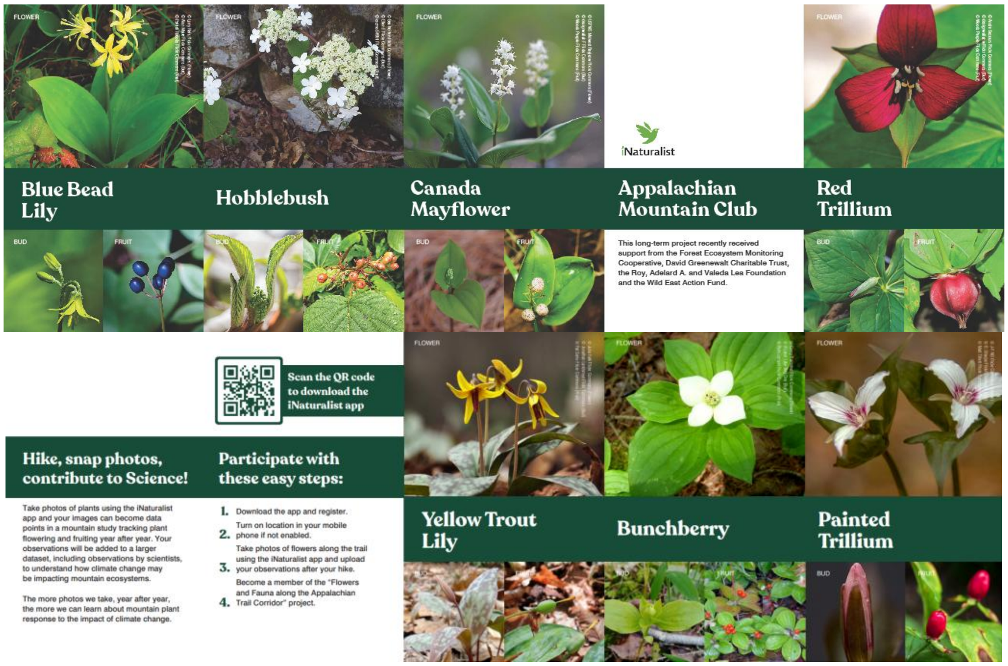
Jack-in-the-Pulpit *(Arisaema triphyllum)*

Credit left to right: Chris Rimmer, Julie Filiberti, Taylor Crews

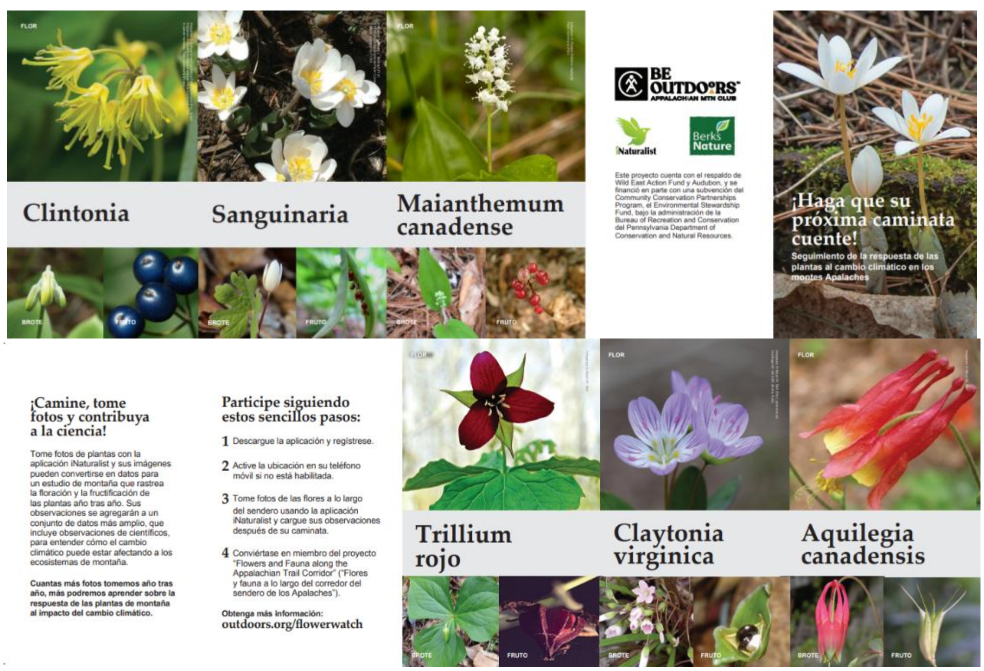
Mayapple *(Podophyllum peltatum)*

Credit left to right: k2018lena, Austin Pursley, Ben Clary

Appendix B. Pocket Guides



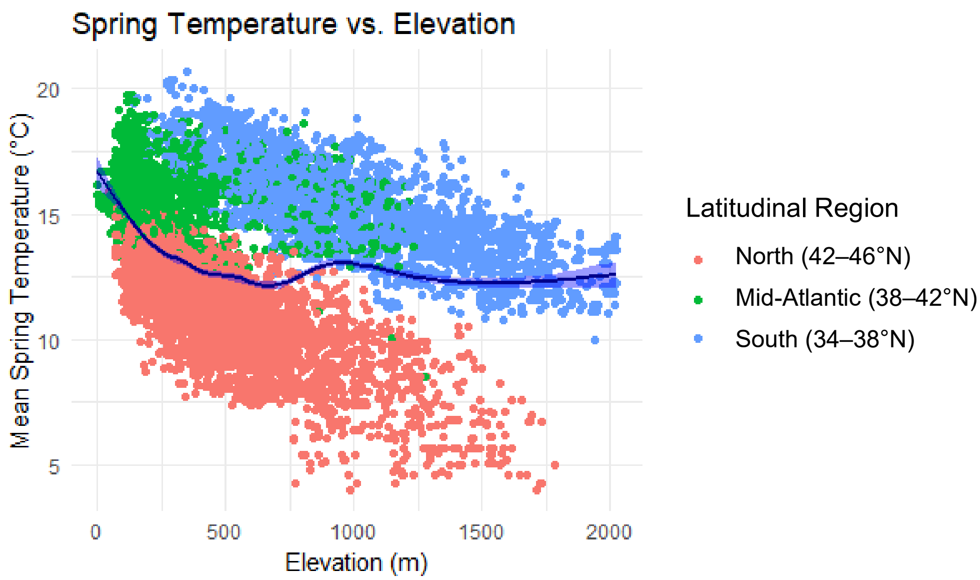
Supplementary Figure 1B. *Front and back of Northern Woodlands pocket guide. Photos show bud, flowering, and fruiting phenophase of common species in the area, including 6 target species.*



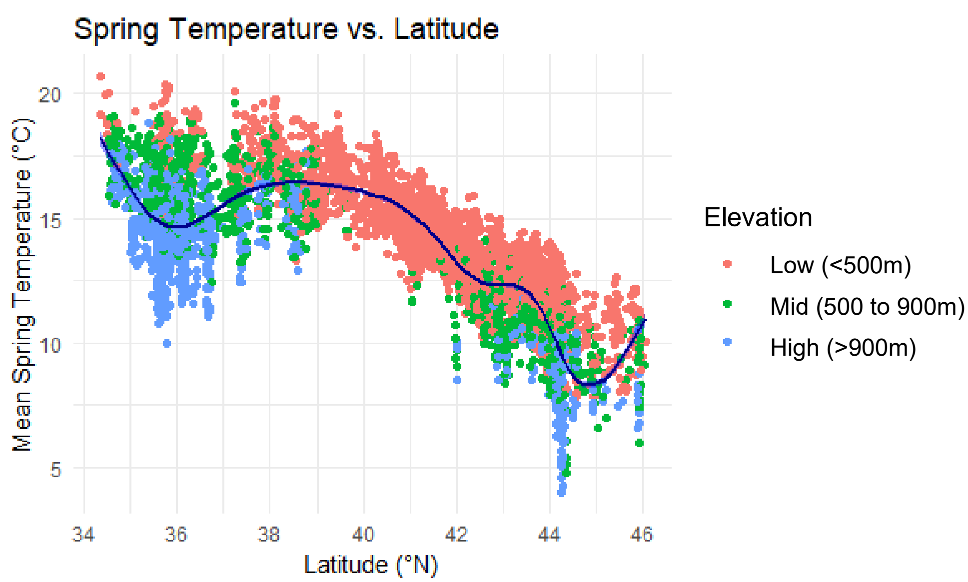
Supplementary Figure 2B. *Front and back of Spanish translation of Southern Woodlands pocket guide.*

Appendix C: Data Analysis Code & Supplementary Figures

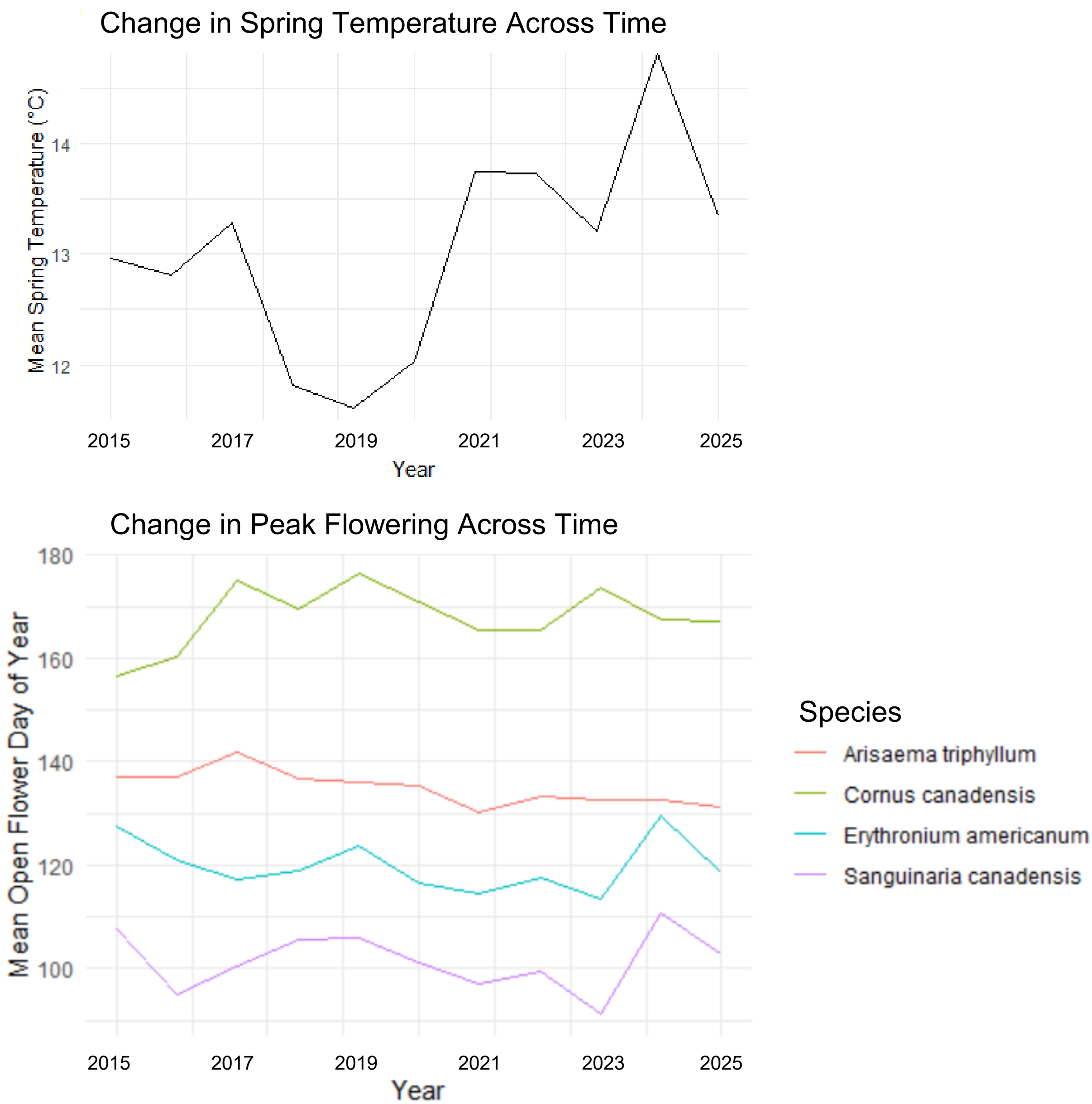
All R code used to conduct the data analysis in this report can be found publicly at this GitHub repository: https://github.com/AMC-Research/SIP_iNat_Report/tree/main.



Supplementary Figure 1C. *Relationship between mean spring temperature and elevation across all target species, showing a negative slope, indicating higher elevations generally have lower temperatures in the spring. The relationship varies in magnitude depending on latitudinal region, with the northern region showing the steepest slope.*



Supplementary Figure 2C. *Relationship between mean spring temperature and latitude across all target species, showing a negative slope indicating lower spring temperatures farther north on the trail. The relationship does not vary significantly across elevational bands.*



Supplementary Figure 3C. *While we do not have a long enough dataset yet for a strong analysis of the impact of climate change on plant phenology, these two graphs can provide a snapshot with the data we do have. The top graph shows the change in mean spring temperature by year over the past decade, while the bottom graph shows the change in flowering time by year over the past decade for four of our focal species. Earlier years have fewer observations in the project and may not map as accurately, but recent years (2022-2025) show a slight correlation, especially in the two spring ephemerals shown,* Erythronium americanum *(trout lily) and* Sanguinaria canadensis *(bloodroot), where a peak in spring temperature in 2024 occurred alongside later flowering.*