Appalachian Mountain Club Final Report to the Forest Ecosystem Monitoring Collaborative
Project: Monitoring plant phenology & climate metrics in Northeast mountains; filling gaps in complex landscapes

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Introduction

The Appalachian Mountain Club (AMC) respectfully submits this final report to the Forest Ecosystem Monitoring Collaborative detailing the successes achieved by our project, *Monitoring plant phenology & climate metrics in Northeast mountains; filling gaps in complex landscapes,* from April 2022 to April 2024.

Summary of activities completed

1) Measuring plant phenology using three complementary methods (Table 1): AMC monitored species-level plant phenology using the National Phenology Network (NPN) protocol at five forested and three alpine sites (each with multiple plots) across the White Mountains. Observations of phenology have been entered in NPN Nature's Notebook from 2012 through our 2023 field season and are freely accessible to the public (https://www.usanpn.org/data/observational). Note that some data from 2024 have also been entered, as the project is ongoing. AMC's project has over 650,000 presence/absence phenology observations in NPN as of late May 2024. Figure 1 a-c shows the NPN Visualization Tool-generated activity curves for tree species monitored at NPN plots in New Hampshire, and Figure 2 a-b shows two woodland forb species flowering time for the 2022-2024 monitoring season. We also monitor species phenology using iNaturalist; over the course of this project from May 2022 to May 2024 we added 2,649 and 23,176 plant observation to our Alpine[1] and Appalachian Trail (A.T.)[2] projects respectively. Table 2 provides summary statistics for these projects including total observations to date in each project along with number of species, identifiers, and observers. iNaturalist data are accessible online and in perpetuity at inaturalist.org. Figure 3 shows alpine flowering distributions using both iNaturalist and NPN data.

Table 1. The project monitoring sites and ongoing (non-bolded) and new or upgraded (bolded) methods. Data access provided in footnote.

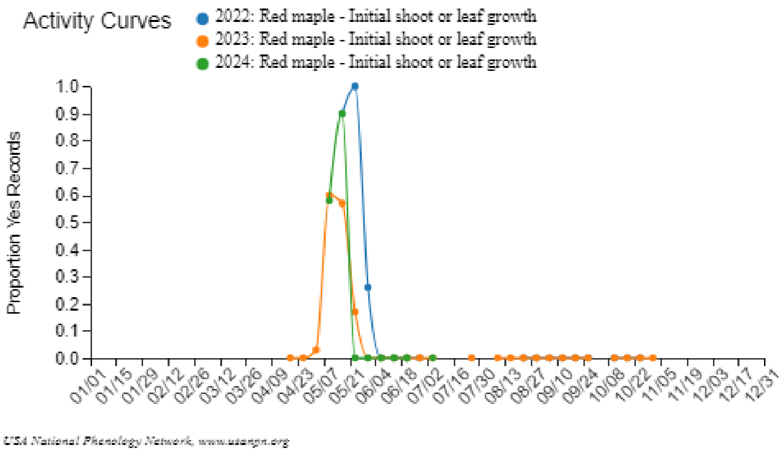
Monitoring Site	Species Level Phenology	Canopy Phenology	Air & Soil Temp/ Moisture (# sites)	Snow Depth
Pinkham Notch	NPN[1]	Plant Camera	**HOBO**	NWS COOP
Tuckerman Ravine Trail 2 sites	NPN		**HOBO (2)**	**AMC**
3 AMC Winter Hut	NPN		HOBO	NWS
Crawford Notch	NPN	**Plant Camera**	**HOBO**	NWS
AMC Maine Woods		**Plant Camera**	**HOBO (2)**	**AMC**
Region Wide	iNaturalist[2]			**Community Snow[4]**

[1]NPN Nature's Notebook: https://www.usanpn.org/data/observational [2]iNaturalist: https://www.inaturalist.org/
[3]PhenoCam Network: http://phenocam.us/ [4]Community Snow: https://communitysnowobs.org/snow-data/

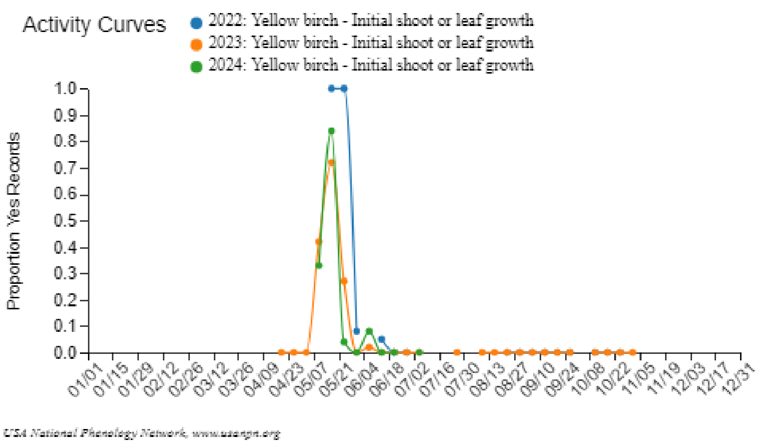
[1] https://www.inaturalist.org/projects/northeast-alpine-flower-watch
[2] https://www.inaturalist.org/projects/flowers-and-fauna-along-the-appalachian-trail-corridor

Figure 1. Example of AMC collected NPN data from the spring of 2022, 2023 and 2024 initial shoots/leaf for a) red maple *(Acer rubrum)* b) yellow birch (*Betula alleghaniensis*) and c) American beech (*Fagus grandifolia*).

a)



b)



c)

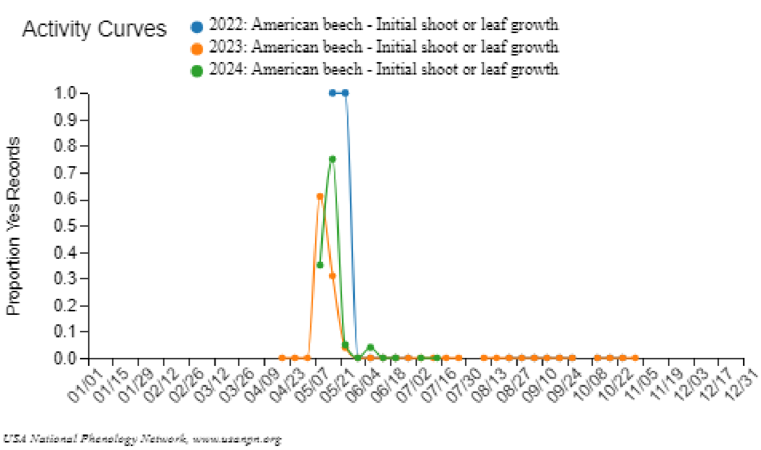
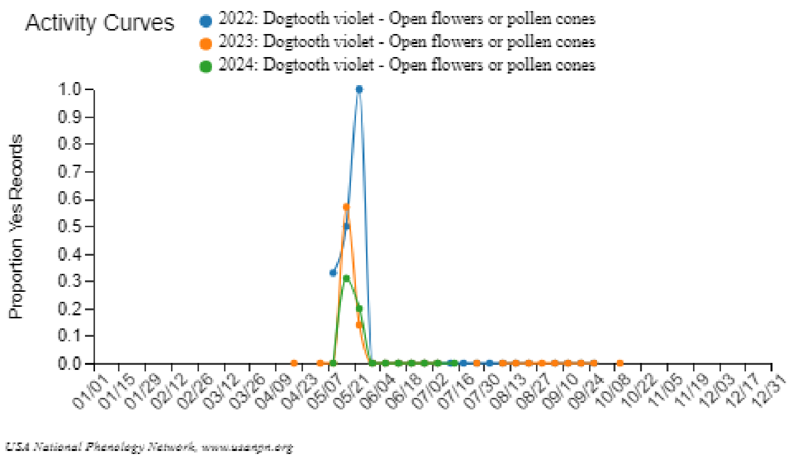


Figure 2. Example of AMC collected NPN data from the spring of 2022, 2023, and 2024 open flowers for a) dogtooth violet (trout lily, *Erythronium americanum*) and b) red trillium (*Trillium erectum*).

a)



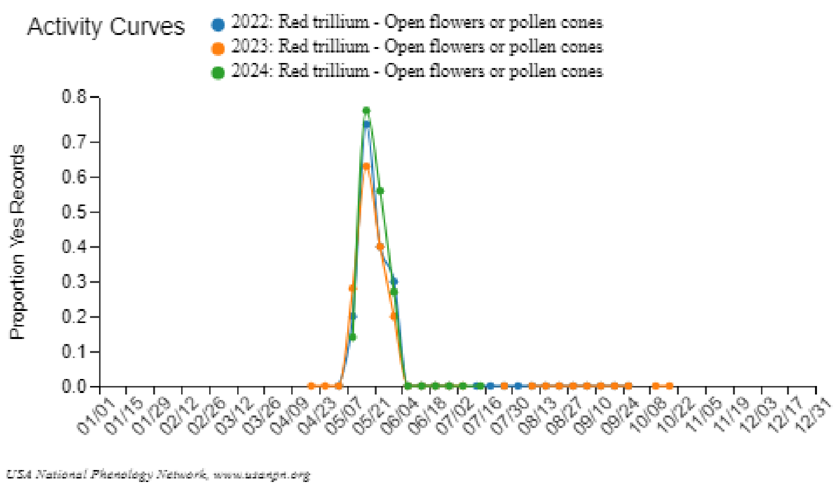
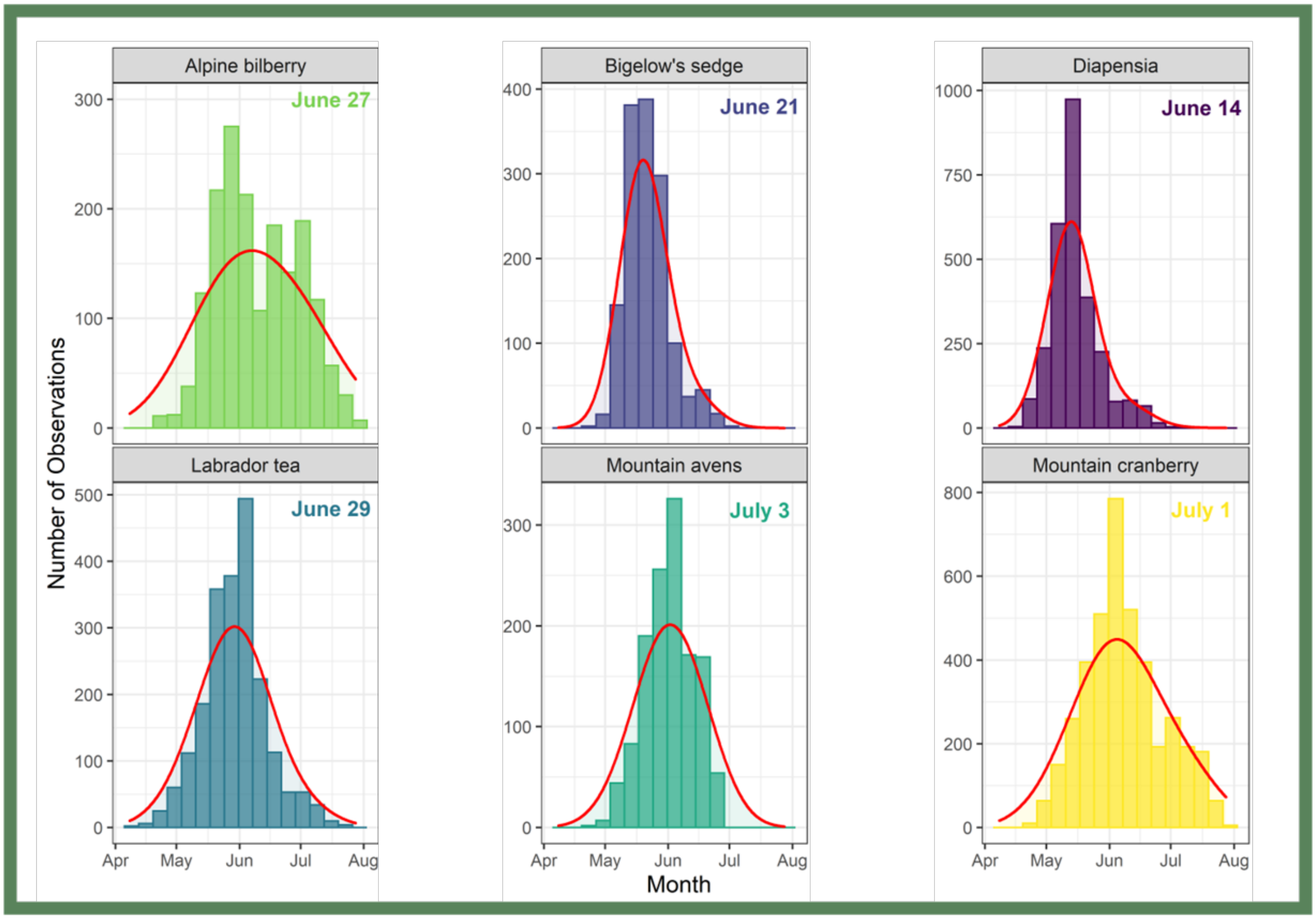


Table 2. iNaturalist project statistics as of July 25, 2024.

iNaturalist Project Title	Observations	Members	Participants	Species
Flowers and Fauna along the Appalachian Trail Corridor	51,849	780	8,503	3,380
Northeast Alpine Flower Watch	8,771	586	967	235

Figure 3. Temporal distribution and flowering range of alpine species in the White Mountains in New Hampshire from 2004-2022 using observations collected via hut NPN plots and iNaturalist (Mountain Watch programs). Median flowering date, noted in the top right corner of each plot, represents the middle of the observed flowering period. Species shown are *Vaccinium uliginsom* (Alpine Bilberry), *Carex bigelowii* (Bigelow's Sedge), *Diapensia lapponica* (Diapensia), *Rhododendron groenlandicum* (Labrador Tea), *Geum peckii* (Mountain Avens), and *Vaccinium vitis-ideae* (Mountain Cranberry).



The third phenology data source we collected is from our continued canopy-level digital photo series from inexpensive plant cameras at Pinkham and Crawford Notches. We use a modified phenopix R package that improves alignment and processing when camera views shifted due to winds or changed focus due to changes in camera series. Extracted and calculated green chromatic coordinates (Gcc) and red chromatic coordinates (Rcc) from the Pinkham and Crawford Notch, NH sites are shown below in Figure 5-6. Data show similar timing for start of season (Day of Year [DOY] 140; May 20) and peak red color (DOY 276; Oct 3). Our R code is available on AMC's github site (https://github.com/AMC-Research). AMC now has seven years of these data from Pinkham Notch and one full season at Crawford Notch with continued collection in 2024.

In Table 3 we compare our phenocam times-series with other sources of start of season measures and derived metrics from satellite products. correlation between SOS and mean spring temperature across all methods aligns with the expected biological response of earlier leaf-out with higher temperatures. This trend was particularly pronounced in satellite-derived indices, likely due to the broader spatial coverage and higher temporal frequency of these data compared to plot-based observations.

Phenocam-derived data were similar to satellite derived indices, both in terms of SOS estimates and their sensitivity to spring temperatures. This suggests that Phenocams could serve as a valuable tool for fine-scale phenological monitoring, complementing the broader-scale observations from satellite imagery. The ability to conduct data collection with Phenocams reduces the labor-intensive nature of plot-based monitoring, allowing for more extensive spatial coverage without a proportional increase in operational resources.
We found that phenocams generally correlated well with satellite derived metrics for greenup? as well as average spring temperatures indicating this methodology can be used as a climate change indicator for forest phenology. In a future analysis we will add additional years as well as examine individual species' NPN phenology compared to phenocam-derived Gcc and Rcc.

Figure 4. 2023 phenocam image data converted to Gcc and Rcc from a) Pinkham Notch, NH. Green arrow is the median breaking leaf bud from NPN plots in Pinkham Notch (DOY 147) and red arrow is the median leaf color change (DOY 282).
a)

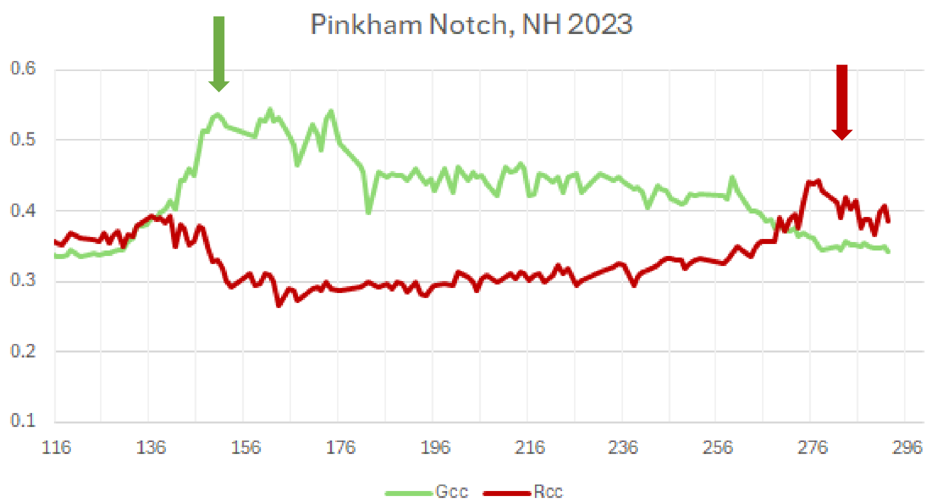


Table 3. Day of year (DOY, Julian day) for start of season (SOS) estimates from each observational method used in this study. SE represents 1 standard error around spring mean temperature for each year of observation. Bartlett phenocam is operated by the PhenoCam Network and located ~20 km south of Pinkham Notch; details: https://phenocam.nau.edu/webcam/sites/bartlett/.

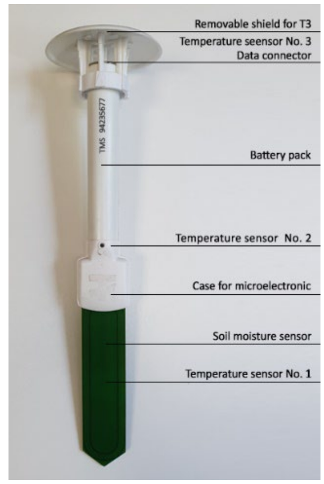
Year	AMC Phenocam	Canopy Observations	Landsat NDVI	MODIS NDVI	MODIS EVI	Bartlett Phenocam	Spring Mean Temperature	SE
2016	NA	151	147	142	138	NA	7.52	0.49
2017	133	142	132	133	145	135	7.58	0.54
2018	143	143	137	142	139	133	7.34	0.24
2019	154	156	145	147	151	140	6.84	0.41
2020	144	147	150	152	151	139	6.75	0.29
2021	141	151	131	132	139	129	9.35	0.72
2022	141	150	136	142	130	132	8.16	0.66
2023	143	147	140	141	140	134	7.85	0.58

2) Expanding Mountain Physical Measurements: AMC continued our HOBO data logger monitoring of air and soil temperature at 12 sites (3 with multiple plots). We also installed 4 new HOBO MicroStations that have these parameters plus soil moisture. The new sites include one co-located with the site at Pinkham, one at a site near Tuckerman Ravine Trail, and two in Maine (see site latitude and longitude for each new site in Table 3). The Maine sites also have a camera recording snow depth as snow observations are very limited in the Northeast. Maine sites leverage and expand coverage of the regional INSPIRES network, an NSF-funded project that installed climate sensor arrays in forested sites in Maine, New Hampshire, and Vermont.

Table 3. Latitude and Longitude of the 4 new HOBO MicroStations.

Monitoring Site	Latitude	Longitude
Tuckerman 1	44.25832	-71.253502
Huntington	44.266721	-71.275837
Medawisla 1	45.667727	-69.31691
Medawisla 2	45.646843	-69.31842

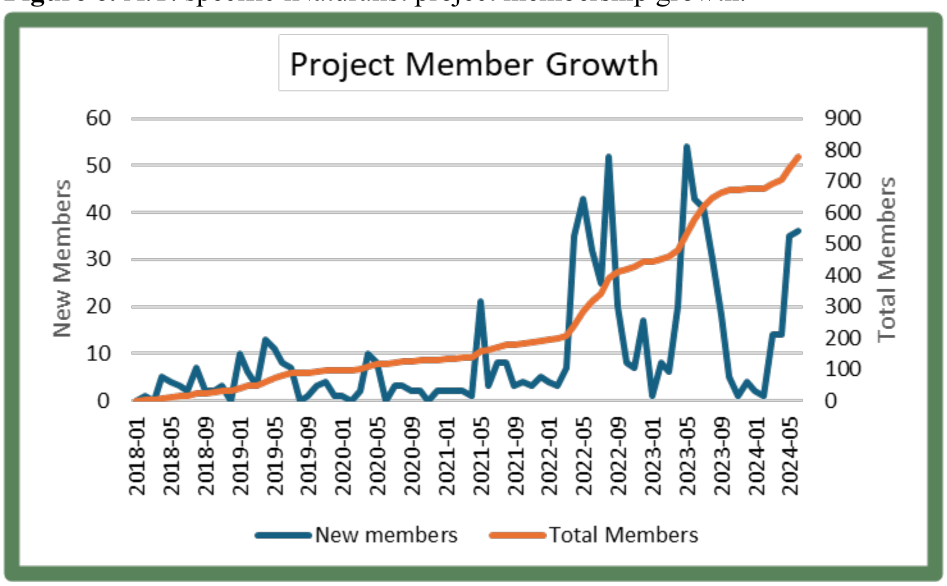
The Huntington Ravine site near Harvard Cabin has issues with animals chewing through wires and had a battery failure. Therefore, we only have one year of data from that site. While Microstation air temperatures compare very well with standard HOBO air temperatures, our assessment of the HOBO MicroStations are that the wires will remain an issue for data loss. We therefore have been shifting to using TMS dataloggers produced by TOMST (Figure 5) which have soil temperature and moisture and air temperature but no wires. We have co-located a number of extreme TMS with our existing HOBO network and expect to have comparison data starting in fall 2024.
Figure 5. TMS sensors/ datalogger



3) Two citizen science programs:

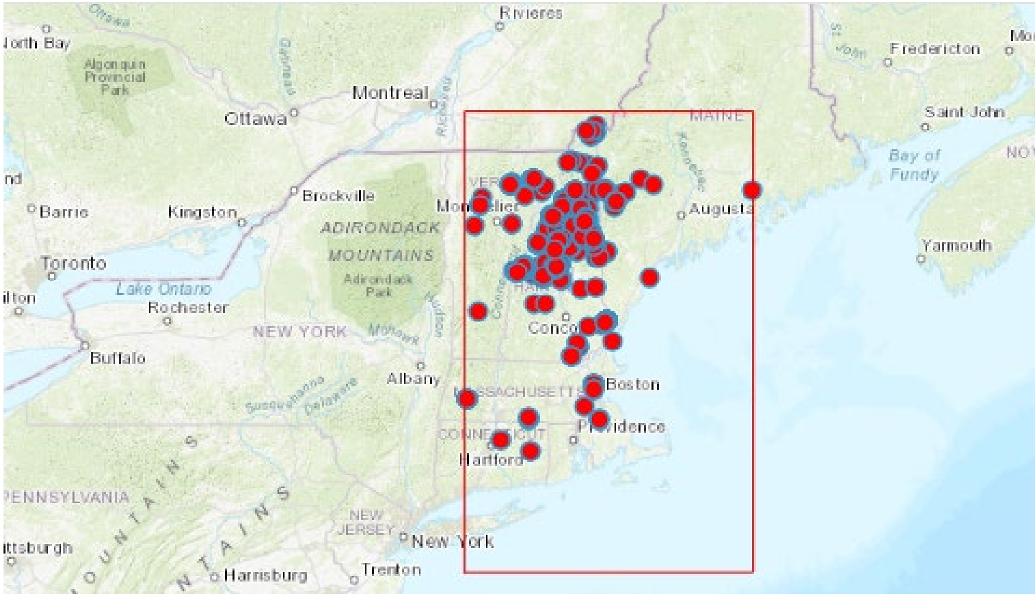
First, iNaturalist was used to gather understory reproductive phenology for a set of spring ephemerals and other early flowering species. As documented above, our projects obtained thousands of mountain-based flowering observations each year through iNaturalist. These were research-grade and coded with NPN-defined phenophase status. Participation in the AT project shows strong growth in new members, who are more likely to continue to participate (Figure 6). Most new members join in summer, and we observe large spikes (2-5X previous summer maxima) in new member growth with more direct promotion of this project.

Figure 6. A.T. specific iNaturalist project membership growth.



AMC has been promoting and fostering partnerships around NASA's Community Snow Observations (CSO) program with the goal of continued seasonal observations of much-needed snow depth measurement in Northeast mountains. In winter 2023/2024, we reached 672 observations, which is the highest number of observations yet for this region (as shown in Figure 10). A continuous outreach plan and partnerships where others can engage their own constituents remain key to keeping this program growing.

Figure 7. Northeast U.S. CSO participation. The map shows spatial distribution of citizen observers and bar chart shows the total number of snow observations for each winter since 2018.



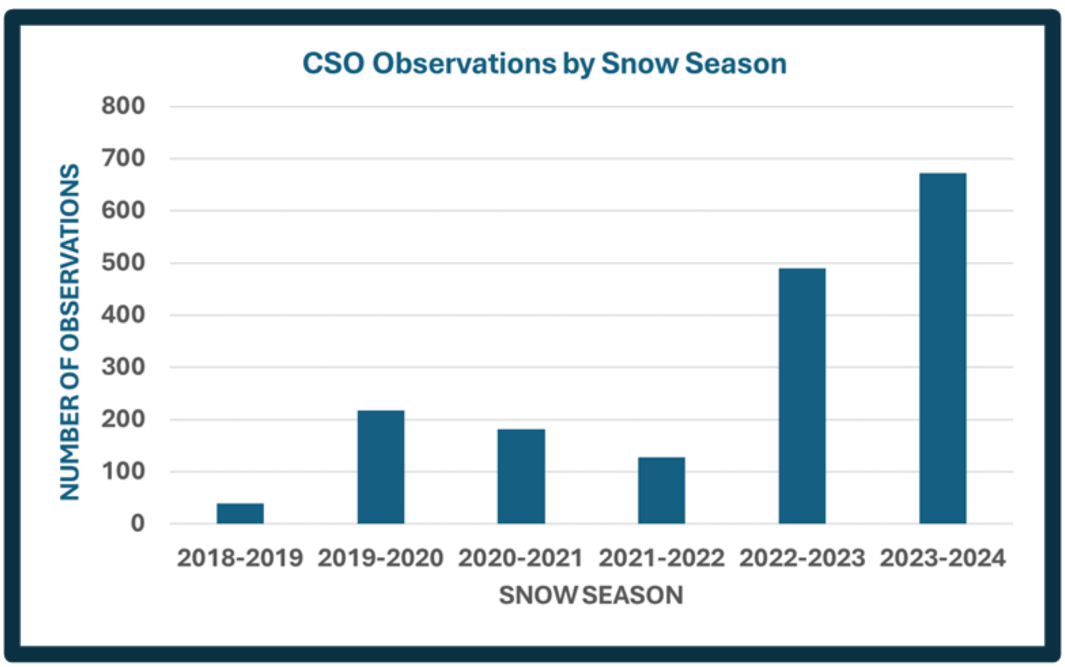
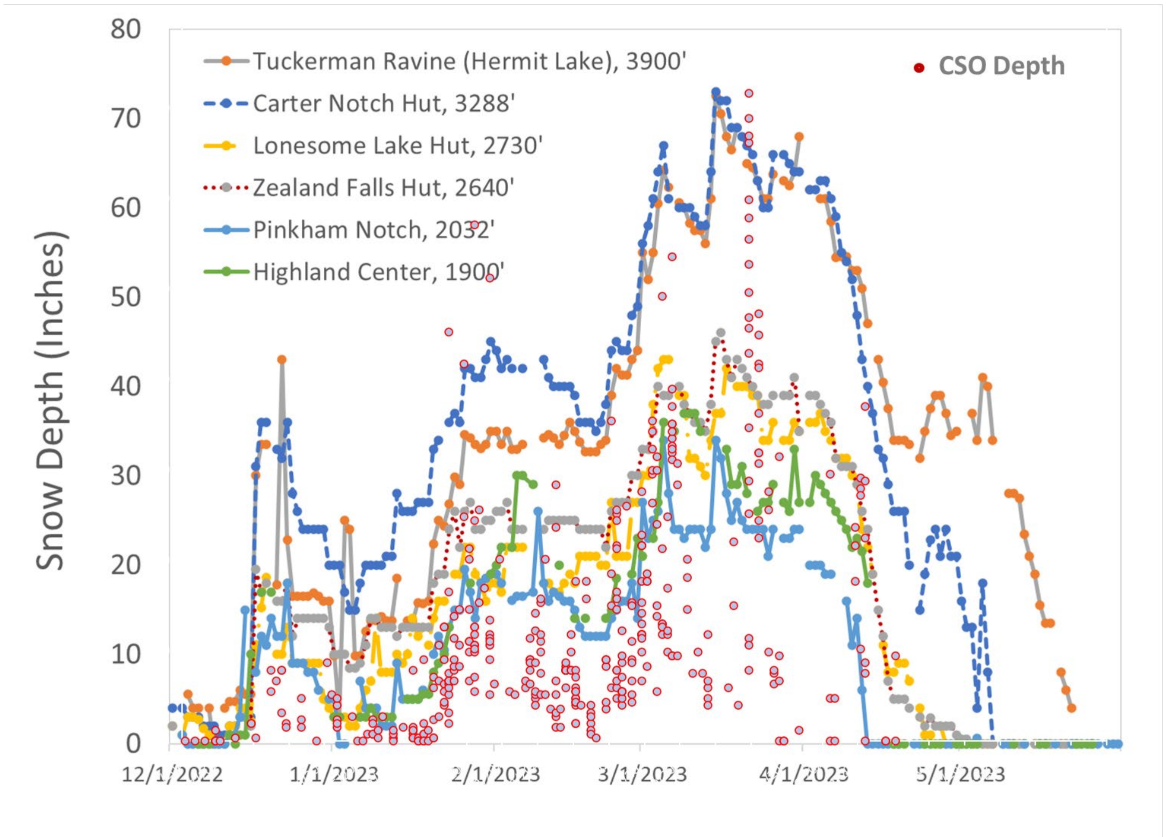


Figure 8. Snow depth in the White Mountains, NH at AMC permanent plot locations (lines) and CSO observations (red dots) at random locations throughout the White Mountain National Forest.



4) Disadvantaged community engagement: AMC's research team has been working with AMC's educators to engage school groups and community members in citizen science monitoring in low income and disadvantaged communities in Coos County, NH, and Piscataquis County, ME, where AMC has already been implementing a climate change curriculum in schools. Both counties have median annual household incomes much lower than the respective annual income in each state[3]. On August 8, 2022, AMC Research Director Sarah Nelson co-led a teacher professional development workshop, "Teaching Climate Change", at an AMC lodge in Piscataquis County, ME. In addition to an overview of iNaturalist and sharing iNaturalist materials, Nelson led teachers through an activity, "Is the Maine Climate Changing? Using Evidence Based Approaches to Explore Data", which uses data products (graphs, maps, tables) at varying scales to lead students through the process of evaluating multiple lines of evidence and coming to consensus to address the overarching question. We continue to meet the challenges of working with schools that often are not able to transport students by bringing the tools to observe snow and phenology to them. Given AMC staff changes (with key NH staff leaving in the summer of 2023), we are revisiting our previous approach of providing snow stakes and cameras to schools for them to set up in their school yards. AMC is continuing to provide opportunities for hands-on experiences in our climate change programs to ~200 students annually, connecting them to the natural landscapes where they live and go to school. As results from this work are finalized, Research staff will summarize key findings for our educators for their use with school groups.

[3] Coos County median annual income is $47,117 vs. statewide median of $76,768; Piscataquis County is $40,890 vs. statewide $53,024

Conclusion

The *Monitoring plant phenology & climate metrics in Northeast mountains; filling gaps in complex landscapes* project contributed to our ongoing efforts to understand climate change in mountains. Data from this work contributed to the recent publication Tourville et al. (2024)[4] that examined multiple phenology datasets in a comprehensive analysis of flowering times and leaf out along the Appalachian Trail. Snow data collected here are still being analyzed and incorporated into larger dataset and baseline information, including the improvement of CSO snow distribution model over the White Mountains domain, supporting the Northeast Snow Survey (NESS) by identifying spatial patterns, and a collaboration effort with the Dartmouth professor Dr. Jonathan Chipman to examine snow melt timing across the northern Appalachians.

We have uploaded the required project datasets to the FEMC portal in accordance with the original project proposal's Data Management Plan (see graphic below). This includes the data and code used in association with NPN, iNaturalist, CSO, and Tree Canopy Gcc/Rcc projects. AMC plans to continue stewarding and adding to the data in these project repositories.

Your role	Project name	Preview link
Project Editor	Community AMC Snow Observations	View on site
Project Editor	AMC Tree Canopy	View on site
Project Editor	AMC NPN Phenology	View on site
Project Editor	INaturalist AMC Geolocated	View on site

We are grateful for the support of FEMC as we make progress on our plant phenology monitoring and climate variables monitoring, which is crucial to combatting climate change in the Northeast. If you have any questions about this final report, please contact Alexandra Molnar, Senior Institutional Funder Relations Officer, at 617-391-6641 or amolnar@outdoors.org. Thank you!

[4] Tourville, J.C., Murray, G.L.D, and Nelson, S.J. 2024. Distinct latitudinal patterns of shifting spring phenology across the Appalachian Trail Corridor. Ecology.