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Crowdsourcing Mountain Flowering for Climate Research

iNaturalist in the Hands of Hikers

Appalachian Mountain Club
Conservation Research

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Acknowledgements

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Cover Image: *Diapensia lapponica*, Sophia Gillies.

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Executive Summary

The Appalachian Mountain Club (AMC) and partners developed a crowdsourcing project on the iNaturalist platform called Northeast Alpine Flower Watch (NEAFW). This project's goal is to improve our understanding of alpine plant response to climate change by expanding alpine plant phenology monitoring. In 2019, hundreds of hikers took more than a thousand photos of flowering and fruiting alpine plants along mountain trails from Maine to New York. Specifically, the NEAFW project tallied 269 unique observers who contributed 2,691 photograph observations; 1,665 of which were of our target alpine plants. And as of October 2021, observations have nearly doubled in the project to just over 5,200. To gauge the usefulness of iNaturalist observations we compare them with our ongoing National Phenology Network (NPN) plot-based alpine plant monitoring. Data analysis showed median open flower timing is earlier in iNaturalist observations than in NPN for most species suggesting random sampling by community scientists captures the earliest flowering. We also found that iNaturalist observers capture as many if not more individual plant observations over the season for most species, especially for those plants with showy or obvious flowers, and expanded the spatial coverage filling in gaps across mountain landscapes. Based on our results, we recommend iNaturalist as a useful tool for organizations and land managers to monitor mountain plant phenology, especially for those species with showy flowers.

Introduction

If you have ever walked or ridden to the top of Mount Washington or any mountain that reaches above the trees, you know the feeling of awe that comes from entering the alpine zone. For centuries, people have appreciated the recreational, spiritual, and ecological value Northeast (NE) alpine areas provide. Entering the land above the trees feels like entering another realm.

In addition to incredible views, these “islands in the sky” are also home to many unique plants and animals, including rare arctic-tundra plants and endemic butterflies. NE states’ Wildlife Action Plans and Natural Heritage inventories recognize them as distinct and critical ecosystems. Some of these species are found nowhere else in the United States and even the world.

The inhabitants of the Northeast alpine zone survived the last glacial melt. These species resisted extinction 9,000-5,000 years ago during the Holocene Climate Optimum (HCO), a climatically warmer period (Spears 1989; Miller and Spear 1999). However, the HCO warming did not exceed projections for future climate change**.** These alpine species are now at the maximum elevation where they can survive (Kimball et al. 2021). With projected changes in climate, some of these inhabitants may have nowhere to go, bring into question whether past resistance will last.

Our project aims to collect plant observations over many years. Researchers require long-term data sets to quantify plant responses to climate change. Phenology, or biological events that occur with changing seasons, is a helpful monitoring tool to track ecosystem response to climate and used internationally as a climate indicator.

Northeast mountain plant phenology can vary with the growing environment changing over short distances and microtopography lending to differences in exposures. Drivers of climate change, such as temperature and precipitation, vary with elevation, longitude, and latitude resulting in a need to track plant phenology across the region. For example, the Presidential Range, New Hampshire has previously been documented to exhibited slower warming and phenological responses compared to nearby valleys (Seidel et al. 2009; Kimball et al. 2014). The most recent trend analysis show the highest peak in this region, Mount Washington, is catching up in regard to warming particularly in spring, with other seasons still laging behind the regional trends (Murray et al. 2021). To understand mountain plant responses to climate change more fully, a greater number of observations across the region and over decades are needed.

Enter Citizen Science

We hypothesized that crowdsourcing citizen science, enabled by technology, could be used to accurately document peak flowering time and variability across the NE mountain environments. Citizen science is an established tool for producing reliable scientific outcomes and can also positively enhance science learning in participants (Bonney et al. 2009; Bonney et al. 2016). As volunteers participate in data collection and processing, they find deeper meaning in existing hobbies, build a sense of community, and shape a science-based foundation for conservation (Bonney et al. 2016, Haywood et al. 2016). Large-scale crowdsourcing data collection or online processing projects can produce large volumes of data but risk low volunteer retention (Law et al. 2017; Wiggins and Yurong 2016). Using motivational tools such as acknowledgment and attribution can improve participant retention (Rotman et al. 2012).

This project used crowdsourcing that incorporates technology, e.g., mobile phones/cameras with geolocation and iNaturalist to document peak flowering times in complex mountain terrain. It linked AMC's long-term National Phenology Network (NPN) monitoring plots, which have limited spatial distribution and volunteer participation due to the required high level of time commitment and skills, with an established and highly accessible approach of iNaturalist. Geotagging digital images reduced previously common location and species identification errors introduced by novice data collectors (MacKenzie et al. 2017), and iNaturalist app accessibility allowed the sustained and expanded collection of data for this dataset. As detailed below we found citizen scientists have enhanced our growing alpine flower phenology dataset providing insight into plant phenology in alpine areas and informing our analysis of NE's alpine ecosystems response to climate change. Further it has built awareness in the recreational community and increased their appreciation for the conservation of mountain landscapes and their likelihood of involving others in mountain conservation.

Methods

AMC and partners utilized two main methods to document alpine plant flowering phenology: plot-based observations and crowdsourcing photography with iNaturalist. The former monitoring was conducted 1-2 times per week, largely by staff and trained seasonal naturalists using NPN protocols to record reproductive phenology. Current alpine phenology monitoring partners and their locations with the existing number of NPN plots include:

Table 1. Location and number of NPN plots and which species are present.

Location	*Organization*	*# NPN Plots*	*Species*
White Mountains, NH	AMC	12	*Carex bigelowii, Diapensia lapponica, Geum peckii, Rhododendron groenlandicum, Vaccinium uliginosum, Vaccinium vitis-idaea*
Green Mountains, VT	Green Mountain Club	4	*Carex bigelowii, Diapensia lapponica, Rhododendron groenlandicum, Vaccinium uliginosum, Vaccinium vitis-idaea*
Katahdin, ME	Baxter State Park	4	*Carex bigelowii, Diapensia lapponica, Rhododendron groenlandicum, Vaccinium uliginosum, Vaccinium vitis-idaea*
Adirondacks, NY	Adirondack Mountain Club	6	*Carex bigelowii, Diapensia lapponica, Rhododendron groenlandicum, Vaccinium uliginosum*

This ongoing phenology monitoring using NPN protocols remains important to this project and provides core data to compare with iNaturalist observations. Volunteers, including AMC alpine stewards, volunteer naturalists, and partner organizations also, contribute to the plot-based NPN monitoring.

Diapensia lapponica, *Carex bigelowii*. *Vaccinium vitis-idaea*, *Vaccinium uliginosum*, and *Rhododendron* are the five co-dominant alpine plant species monitored[1]. In NH we also monitor *Geum peckii*, however this species is only found in the White Mountains and in one coastal area of Canada. A detailed description and identifying features are provide in Appendix A. These plants were selected due to their easy-to-observe reproductive phenology and wide representation of life history and ecological traits, including flower timing, functional types, and geographic distributions.

Monitoring regions

Study area: Northeast alpine areas are found in mountains in Maine, NH, VT and NY. They comprise of about 34 square km or about 13.13 sq miles (Kimball et al. 2014).

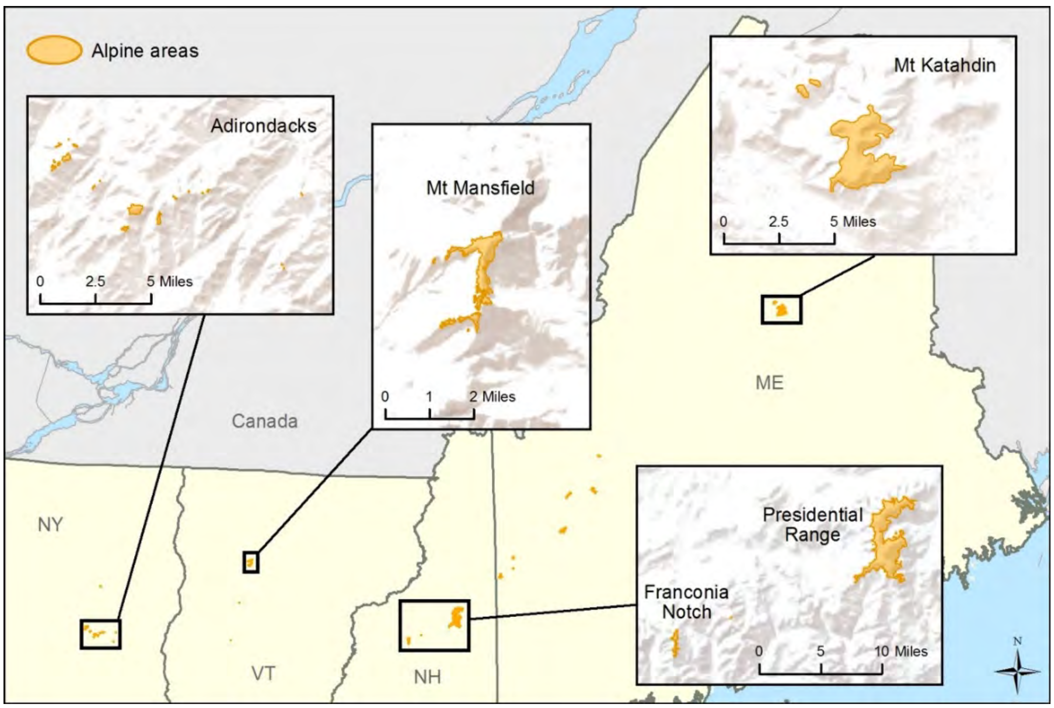


Figure 1. Alpine areas in the Northeast. Comprised of ~13 square miles.

iNaturalist Volunteer Recruiting and Engagement

Trainings and Recruitment

[1] *Rhododendron groenlandicum* was recently reclassified. Formally known as *Ledum groenlandicum.*

In the spring of 2019, AMC conducted multiple iNaturalist trainings including, public access webinars, in-person public access training, and volunteer training. Additionally, in the spring of 2019, AMC trained all incoming seasonal staff (e.g., Guides, A Mountain Classroom Educators, Huts) during department specific trainings.

Through AMC's backcountry facilities, our hut Naturalist held evening hour long programs on the Northeast Alpine Flower Watch project that included iNaturalist training using iPads. In addition, we held both online and in-person presentations, that covered an introduction to the issue of climate change and phenology and demonstrated the iNaturalist app.

Direct recruitment for data collection via mobile devices was done through existing volunteer networks such as AMC's annual volunteer trainings, chapter meetings, and from the thousands of guests using AMC's facilities. AMC also recruited hikers at popular trailheads that access the largest contiguous alpine area in the Northeast. Recruitment was accomplished through AMC's media outlets including our print and online magazine, social media, and email listserves. We also provided recruitment materials to partner organizations to use in their networks.

Retention

To help foster retention and repeat participation, AMC staff actively added observations, identified plants, and interacted with other participants on the iNaturalist platform. By participating in the iNaturalist community, we fostered engagement, answered questions, provided expert input, and advanced more observations to research grade level for use in the analysis. AMC continues to develop and maintain the iNaturalist Project page, pulling in appropriate Research Grade photos and assigning phenophase fields as needed. Additional volunteer opportunities using iNaturalist, such as identifying other plants or becoming a Curator for our Project, were encouraged with known volunteers.

iNaturalist Data Collection and Analysis

This project recruited hikers to take photos of flowering plants and submit them to iNaturalist while in alpine areas where there were also existing NPN plots. Only photos tagged with geographical coordinates were used, to reduce any location errors. Location errors can occur if the user has shut off their device's location, the time spent at the observation sites does not allow the GPS to update sufficiently, or as with any GPS receiver there is interference from overhead vegetation. Importantly the GPS accuracy is also tagged through the iNaturalist app, allowing us to filter observations by location accuracy. Some observations uploaded to iNaturalist lack any GPS accuracy information, which we did not eliminate as it is unknown whether they are accurate or not.

We focused on a select set of alpine species, see Table 1, and phenological status was attributed using the “added fields” in the iNaturalist platform. Species and phenophase identification errors were minimized through expert community-based validation on iNaturalist. The iNaturalist tool has automated species recognition, research grade status validation, and custom fields that can be populated with phenology information.

Phenophases that were attributed to observations in the iNaturalist project are shown below in Table 2. These phenophases mirror the NPN protocol, with the addition of Past Flower, which is not an NPN phenophase but AMC has used it historically with random one-time observations as a way to identify the end of the flowering phenophase. We did not include vegetation phenology, nor did we include all reproductive phenology phases defined by NPN methodology. Note that observations in iNaturalist from before 2019 can be added to our project as observations can be added retroactively by new members or project managers.

Table. 2 Phenophases and definitions.

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.

<u>Open Flower Data Analysis</u>

We focused our data analysis on open flower phenophase because it was the most abundant for each species. Only research grade data were used, and we filtered by GPS accuracy that is provided by the iNaturalist app, retaining only those with < 100 meters accuracy. To be more comparable to NPN plots that were all above an elevation of 1,200 meters only iNaturalist observations above this elevation were included. We calculated basic statistics of mean open flower timing and standard deviation, as well as plotted histograms of open flowering time for each species by method: e.g. iNaturalist and NPN. We used Mount

Washington Observatory summit temperature data to calculate the accumulated heat or accumulated growing degree days based on –4 °C threshold for each year from 2018-2021 to compare to iNaturalists observed average flowering time for Diapensia lapponica, the species we have the most data for.

Results

Volunteer training and participation

In 2019, through both virtual and in-person educational outreach and trainings for AMC staff, volunteers and interested community members we educated over 1,125 people about iNaturalist. By the end of 2019 the NEAFW program had grown to 246 members and 364 iNaturalist unique observers. Due to extenuating circumstances in 2020, there were no trainings and outreach was halted. Trainings and educational outreach resumed in 2021 as resources allowed. As of September of 2021, those numbers have reached 355 members and 679 observers, Figure 2.

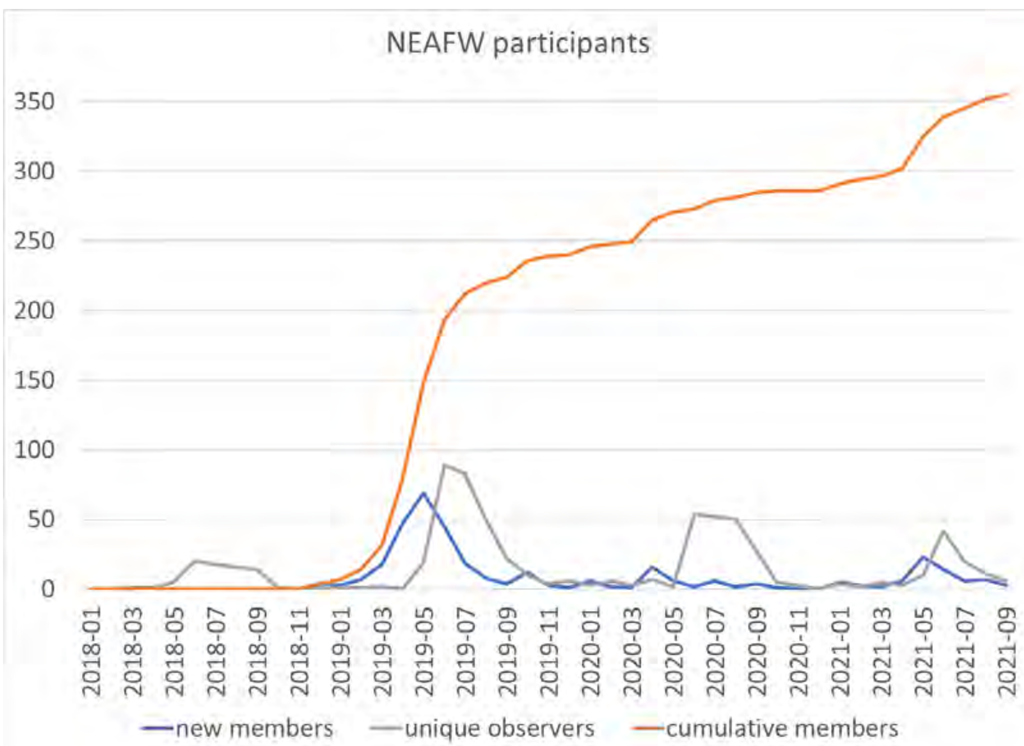
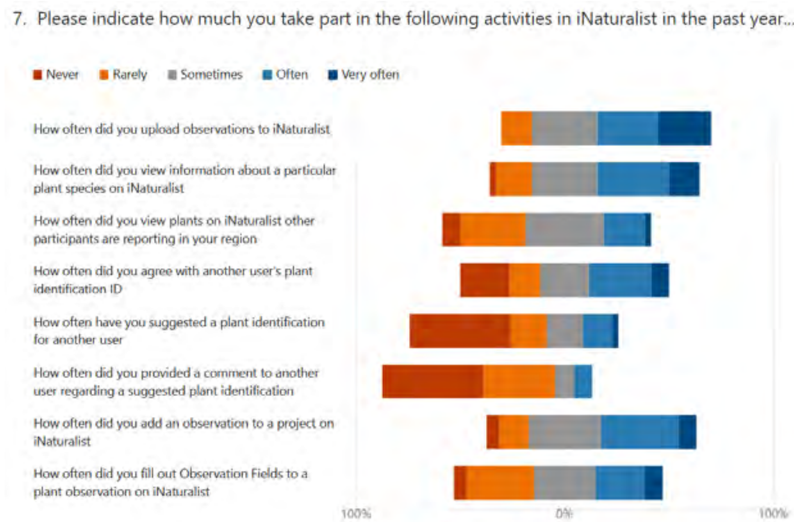


Figure 2. Northeast Alpine Flower Watch (NEAFW) participants, updated through Sept. 2021

Volunteer Survey

In 2019 AMC distributed a survey through email contacts from trainings and posted a link to the survey on the iNaturalist project journal. Survey results showed that in addition to the benefits scientists receive with an increased volume of data, iNaturalist participants also benefitted in positive ways. Survey questions and results can be provide, with many questions using a Likert scale. We had 35 responses.



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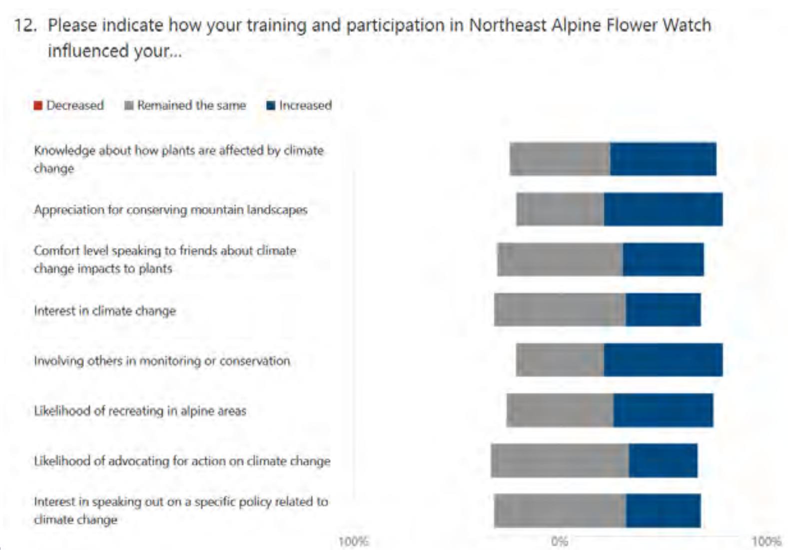

B

Figure 3. Participants survey responses to A) Question 7 and B) Question 12, both using the Likert scale.

While the survey had limited respondents, we can glean some initial information about user participation on iNaturalist and the influence of their participation on their views. Some of these key takeaways included:

- Participants often or very often viewed information about species and uploaded their observations to iNaturalist associated projects, Figure 3A.
- Participants rarely or never interacted with other users suggesting plant identifications or providing comments, Figure 3A.
- Participants indicated that their participation in Northeast Alpine Flower Watch increased their appreciation for the conservation of mountain landscapes and their likelihood of involving others in mountain conservation, Figure 3B.

We will continue to circulate the survey to increase respondents.

Plant Observations

In 2019 iNaturalist community scientists made 1,074 observations of our targeted alpine plants. Our staff made a total of 1,280 observations of these plants at permanent plots however it should be noted that these totals include repeat visits to the same individual plants through time. iNaturalist participants also observed a species in flower more often, as shown by the percentages in Table 4. Observations showed that of the species tracked in the Northeast Alpine Flower Watch the most identified species also had the showiest flowers, *Diapensia lapponica* and *Rhododendron groenlandicum.*

Table 3. Total number of observations and percentage as open flower for NPN and iNaturalist in 2019

Species	NPN		iNaturalist	
	# of Observations	% Open Flower	# of Observations	% Open Flower
Carex bigelowii	249	19%	62	29%
Diapensia lapponica	245	20%	393	47%
Geum peckii	33	30%	86	47%
Rhododendron groenlandicum	213	21%	196	42%
Vaccinium uliginosum	277	17%	168	32%
Vaccinium vitis-idaea	263	13%	169	27%
Total	**1,280**		**1,074**	

Overall, iNaturalist observers identified an earlier mean flowering time for monitored alpine species (Table 5, Figure 4). For most species of alpine plants, the ability to incorporate iNaturalist observations doubled the number of flowering observations that would have otherwise been collected, and in the case of Diapensia lapponica it iNaturalist observers tripled the observations (Table 4).

Table 4. Count and mean for 2019 open flower day of year (OFD) for NPN and iNaturalist (iNat) methods.

Species	NPN		iNaturalist	
	N	OFD Mean ± SD	N	OFD Mean ± SD
Carex bigelowii	48	190±21	14	170±6
Diapensia lapponica	49	170±6	170	166±7
****Geum peckii***	10	203±11	24	192±15
Rhododendron groenlandicum	45	189±9	55	186±8
Vaccinium uliginosum	46	191±11	41	178±8
Vaccinium vitis-idaea	35	196±10	33	193±6

* *G. peckii* only present in the White Mountains of NH.

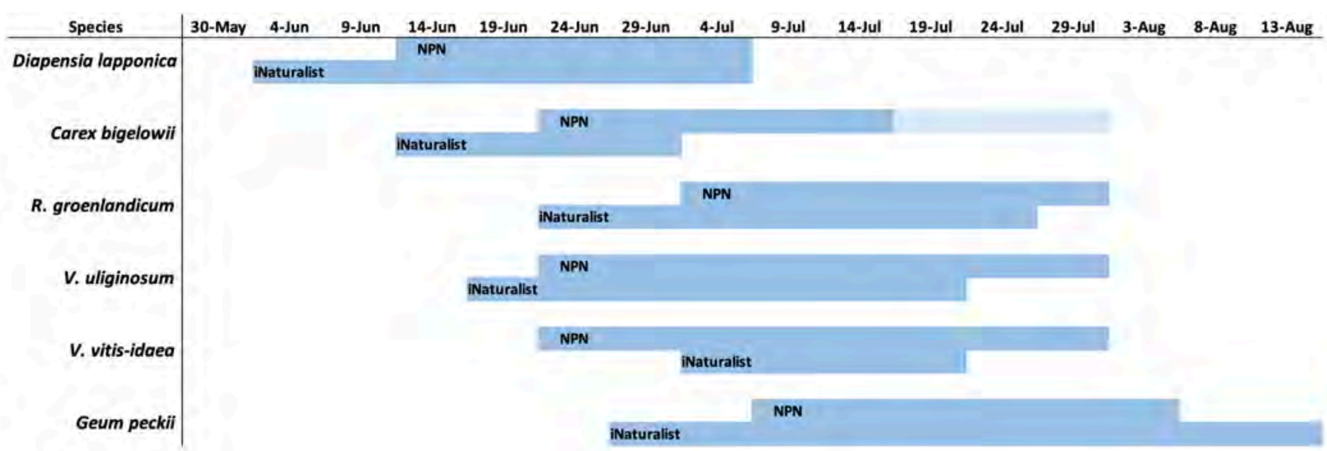

Figure 4: 2019 Flowering time for *Diapensia lapponica, Carex bigelowii, R. groenlandicum, V. uliginosum, V. vitis-idaea, and Geum peckii* based on iNaturalist vs. NPN species observations.

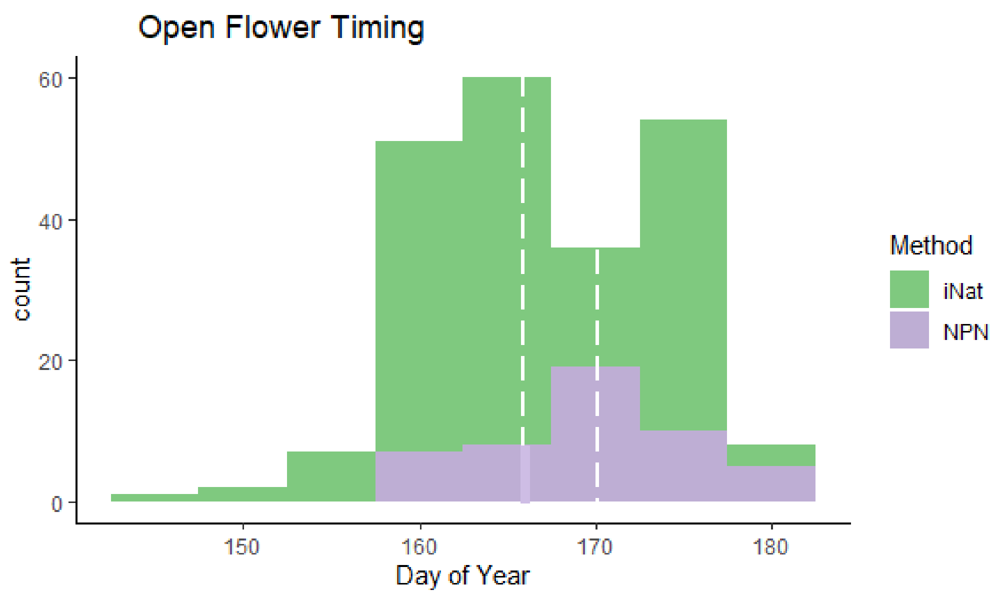

Figure 5. Open flower timing curve (or histogram with day of year vs. count of open flower observations) of *Diapensia lapponica* using two methods: iNaturalist (iNat) and NPN. Dashed white line is the median for each method.

We also examined whether iNaturalist observation reflect typical interannual differences in springtime warm up. iNaturalist average flowering times for *Diapensia lapponica* in warmer years, 2018 and 2021 had earlier average flowering dates, 160 (June 9th) and 163 (June 12th), than cooler or slow to warm years 2019 and 2020, which had flowering dates of 166 (June 15th) and 169 (June 17th), respectively, Figure 6. This general pattern is somewhat expected and indicates iNaturalist data reflects spring variability. The fact that *D. lapponica* can flower at lower accumulated heat values in cooler years but does not flower when reaching those levels in the warmer years indicates other controls than spring warming are impacting flowering dates.

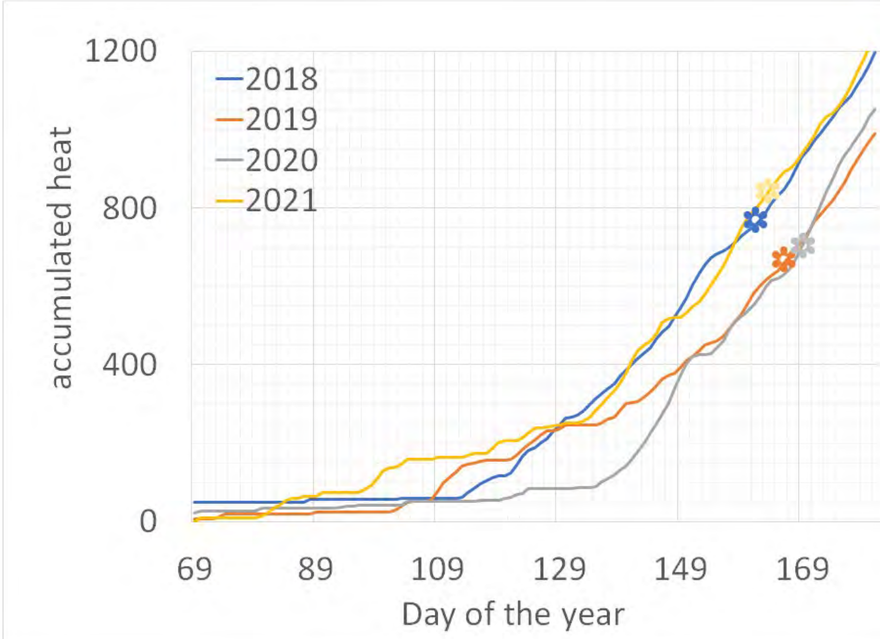

Figure 6. Lines are accumulated heat as growing degree days with a threshold of –4°C (established by Kimball et al. 2014) based on Mount Washington Observatory summit data and flower icons are the average day of year *Diapensia lapponica* open flower for those same years.

Discussion and Recommendations

AMC and partners were able to successfully expand the collection of alpine plant phenology data by asking hikers to use the citizen science platform iNaturalist. Using iNaturalist solved many of the challenges we encountered with earlier citizen science efforts where novice observers made location and species ID errors (MacKenzie et al. 2017). Geotagged images uploaded through iNaturalist ensures few date discrepancies and reduced location errors. The image itself is curated by the iNaturalist community greatly reducing species identification errors. Phenophase attribution was more often done by our own staff rather than a volunteer iNaturalist community member, which may result in fewer errors for phenophase ID but is more resource intensive. Our study had a limited number of plant species in a relatively small geographic area making this curation manageable. As we look to expand the use of iNaturalist consideration of the resources needed to curate larger volumes of species will be considered as will engaging and training volunteers to participate in these more detailed steps of the project. While volunteers contributed ~50% of all observations in our iNaturalist NEAFW project AMC and partner groups field staff, many not directly associated with the project, contributed the remainder. We believe there is great value in engaging field staff in this data collection, as they are in the alpine areas throughout the season and can be just as important data collectors as volunteers. Further because of the opportunistic nature of the data collection field staff do not need to feel burdened with an extra task but can be encouraged to make observations as possible.

The volume of observations for our targeted alpine species, especially abundant showy species with prominent flowers, significantly increased our dataset and our spatial coverage also expanded. iNaturalist observers recorded earlier flowering for most species than was documented at formally-designed plot (NPN) monitoring sites. Similarly, a study using eButterfly found opportunistic novice observers expanding the range species were observed and spotted species ~35 days earlier than professionals (Soroye et al. 2018). Our evaluation of one species' mean flowering time compared to heat accumulation for 4 different years also suggests that Naturalist open flowering data captures interannual spring conditions, indicating this tool and the flower phenology data it provides can be used as a climate change indicator.

In conclusion we believe this project demonstrates that iNaturalist is a useful tool for remote field observations and phenological research. We encourage researchers and resource managers to use iNaturalist as tool for long term mountain plant phenology monitoring, especially for species with showy flowers. The accessibility of the iNaturalist app allows for the sustained collection and expanded geographic range of data by the public, the digital image geotagging feature reduces location and species identification errors, and "added field" additions help to create the phenophase data within the platform. Further, the use of iNaturalist by community members can build awareness and increase their appreciation for the conservation of mountain landscapes and their likelihood of involving others in mountain conservation. AMC staff proved to be essential contributors to data collection through iNaturalist, highlighting the importance of reaching out to and offering training for all communities that frequent the area of interest.

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Appendix A

Alpine Target Plants

<table>
<tr><td>
Photo by W. Brossard</td><td>Diapensia lapponica
- Forms low growing mats - 2 inches or less.
- Leaves are evergreen and slightly waxy.
- Tiny leaves, form tight rosettes that usually surround a flower or leaf bud.
- Leaves have a purple-red tint throughout the non-growing season.
- Flowers are large in comparison to the leaves.
- 5 white fused petals extend on stalk above the mat.
- Fruit eventually dries and forms a capsule that splits open to allow seed dispersal.</td></tr>
<tr><td>
Photo by D. Weihrauch</td><td>Alpine Bilberry (Vaccinium uliginosum var. alpinum)
- Deciduous, Low shrub - from an inch tall in exposed areas, to just over a foot in more-protected areas.
- Twigs deep red-purple with white threadlike striping
- Leaves emerge slightly before the flowers (Figure 3 inset).
- Leaves are nearly circular, (round at the tip, narrowing towards the base), waxless, and have a subtle deep blue-green hue, which becomes purple or red in the fall.
- Flowers emerge anywhere along the twig; usually solitary, but can be a cluster of 2-3.
- White to pale pink hanging bell-shaped flowers.
- Petals are fused, and will drop as a unit before the fruit begins to develop.
- Mature fruits look like dark blueberries.</td></tr>
</table>

Photo by N. Pizzo

Bigelow's Sedge (*Carex bigelowii*)
- Does not form large tufts like other common sedges.
- Leaves emerge together in small bunches from creeping underground rootstock.
- New leaves from this season are entirely green and usually emerge from the center of a clump of older dried leaves.
- Leaf blades are narrow (¼ the width of your pinky nail), but relatively wide compared to most alpine grass-like plants.
- Flowers are borne on a thin triangular stalk, which emerges after the leaves and eventually grows to be taller than the leaf blades (usually 6-12 inches).
- Flower stalk usually carries 1 (sometimes more) male spike at the top, and 2 (or more) female spikes below.
- Erect flower spikes are cylindrical; the female spike is a bit stouter than the male.
- Each spike is covered in dark purplish to black scales.
- Male spike produces highly visible cream-colored anthers (male flower part) and the female spike has more subtle white stigmas.
- As the fruits develop, the edge of the green seeds will emerge slightly from behind the dark scales

 Photo by L. Healey	**Mountain Cranberry (*Vaccinium vitis-idaea* ssp. minus)** - Evergreen. - Sub-shrub; rarely exceeds a few inches in height. - Leaf is round (including the tip), has a prominent midvein, is waxy, and relatively thick. Suggestive of a green coffee bean - Light pink bell-shaped flowers grow in drooping clusters from the tip of the stem. - The petals are fused, and will drop as a unit before the fruit begins to develop. **- Mature fruits are vibrant red berries.**
 Photo by D. Weihrauch	**Labrador Tea (*Rhododendron groenlandicum*)** - Evergreen shrub. - Generally a foot tall, but can be shorter in exposed areas and taller in protected areas - Leaves are long and narrow, leathery, and are rolled under at the margins. - Underside of leaf is covered with brown fuzz. - White flowers emerge from the tip of twig and grow in a round cluster. - Each flower has 5 petals with protruding stamens. - Drooping immature fruits are green, becoming reddish, then brown as they mature and dry.

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Photo by L. Healey</td>
<td>Mountain Avens (Geum peckii)
- Leaf and flower stems emerge directly from the ground.
- Large, shiny, herbaceous leaves.
- Leaf shape is round to kidney-shaped, with shallow lobes.
- Margin of leaf is serrated (saw-toothed).
- Tiny leaves grow along the leaf stem.
- Separate flower stems carry 1-5 large yellow buttercup-like flowers above the leaves.
- Each flower has 5 unfused petals (Figure 1) and can produce about50 seeds.
- Seeds are tear-shaped with an awn at the tip, and covered in long hairs.
- Leaves turn bright red to deep purple in the fall.</td>
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