



Tracking Plant Phenology and Pollinator Diversity Across Alaskan National Parks

A Pilot Study

Natural Resource Report NPS/AKRO/NRR—2021/2291



ON THE COVER

Clockwise from top left: A. Mocorro Powell collecting pollinators in Denali NPP; long-horned beetle on common yarrow; K. Fuentes scoring phenophases on common yarrow in Klondike Gold Rush NHP; bumble bee on fireweed
NPS/Jessica Rykken

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Natural Resource Report NPS/AKRO/NRR—2021/2291

Jessica J. Rykken

National Park Service
Denali National Park and Preserve
PO Box 9
Denali Park, AK 99755

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Abstract

Climate change is a prevailing anthropogenic threat to pollinator communities in Alaska, with potential consequences including phenological mismatches in plant-pollinator interactions. Evidence for phenological mismatch takes many years of consistent sampling to collect, but we can learn more immediate details about variability in the phenology of plants and their pollinators across climatic gradients by sampling across a wide geographic range. Our regional approach in eight Alaskan national parks, spanning more than 11 degrees of latitude, focused on seven common and widespread plants in Alaska. Our objectives were to: (1) track phenology of host plant development across the growing season in 2–3 plant species within each park; (2) collect and compare pollinators from these same plant species; (3) compare phenology and pollinator diversity for each plant across parks; (4) develop and refine user-friendly, effective protocols for use by non-experts. During 2019 and 2020, a total of 599 plant phenology observations were made across nine sites in eight parks. The timing of first flowers and the duration between flowering and production of ripe fruits varied between plant species; common dandelion showed the most variation across parks. A total of 4,856 arthropods were collected from flowers across all plant species. Sampling efforts varied among plant species, but fairly consistent patterns of proportional abundance among major arthropod taxa were found on each plant species across parks. Flies comprised most of the catch for four plants (*Rhododendron groenlandicum*, *Rosa acicularis*, *Vaccinium vitis-idaea*, *Taraxacum officinale*), bees were the dominant group on *Chamerion angustifolium*, and hemipterans were most diverse and abundant on *Achillea millefolium*. At least 34 families of flies were collected overall, by far the most diverse pollinator group. The protocols we tested and baseline data we collected in this pilot project will lay the groundwork for future phenological research in Alaskan national parks.

Acknowledgments

This project would not have been possible without the support and workforce provided by all eight participating parks. Many heartfelt thanks to all the NPS staff (permanent and seasonal), interns, volunteers, partners, and citizen scientists who readily got down on their hands and knees to examine leaves, buds, flowers, and fruits all season long, and likely received some curious stares while sucking up insects with the bug vacuum. I acknowledge known participants below, at the risk of missing a few whose names did not appear on data sheets:

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Wrangell-St. Elias: Stevi Begley, Russ Scribner, YCC group

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Introduction

Climate change is a prevailing anthropogenic threat to pollinator communities in Alaska, with potential consequences including population declines (Loboda et al. 2017, Soroye et al. 2020, Halsch et al. 2021), species range shifts (Franzén and Öckinger 2012, Kerr et al. 2015), and asynchronous phenology in plant-pollinator interactions (Bartomeus et al. 2011, Kudo and Cooper 2019, Gérard et al. 2020). As an example of the latter effect, if host plants and their pollinators (e.g., hibernating bumble bee queens) respond to earlier spring warming and snow melt at different rates there may be less temporal overlap between open flowers offering nectar and pollen rewards and peak bee foraging (and pollinating) activity. This could ultimately result in reduced reproductive success and population declines for one or both groups in this mutualistic relationship.

Documenting phenological mismatches may take years of consistent observation of plants and their pollinators (Forrest 2014), or make use of existing historical data associated with plant and insect collections from herbaria and museums (Bartomeus et al. 2011). Findings from recent studies have been mixed. For example, Høye et al. (2013) documented trends of shorter flowering seasons and declining flower visitor abundance over 13 years in Greenland, and in Japan, Kudo and Ida (2013) found that spring ephemeral plants had reduced seed set over a 10–14 year period owing to lowered pollination services from bumble bees when spring came early. However, Sevenello et al. (2020) reported that the timing of bee activity and flowering responded similarly to variation in spring temperatures and snow melt in Quebec, and Bartomeus et al. (2011) concluded that advancing rates of emergence for a suite of eastern North American bees over the last 130 years were comparable to shifts in host plant flowering over the same time.

Over the past 60 years, Alaska has warmed more than twice as rapidly as the rest of the United States (Chapin et al. 2014). We know that climate change is bringing earlier warming in the spring and advancing snowmelt (Stone et al. 2002, Chapin et al. 2014), but there are few long term data on plant phenology or pollinator activity across the region. Recent and ongoing plant phenology studies include a number of citizen science-assisted efforts led by K. Spellman and C. Mulder at University of Alaska Fairbanks (Melibee <https://sites.google.com/a/alaska.edu/melibee-project>, Project BrownDown <https://sites.google.com/a/alaska.edu/projectbrowndown>, and Winterberry <https://sites.google.com/alaska.edu/winterberry>), which have also included investigating herbaria records for historical phenology data. Mulder and Spellman (2019) documented earlier leaf-out and flowering for 29 native species of forbs and shrubs in interior Alaska in an early-snowmelt year. Thus, we have accumulating evidence that changing climate in Alaska is affecting plant phenology, although pollinator associations for most of the plants being affected are unknown.

Existing data on insect pollinator diversity, distribution, phenology, and host plant associations in Alaska are scarce. In several Alaskan national parks (e.g., Denali, Gates of the Arctic, Klondike Gold Rush, Kobuk Valley), preliminary inventories of a few important pollinator taxa (bees, syrphid flies) have been conducted over the last several years (Rykken 2015, 2017, 2020), as well as more structured studies along elevational gradients. However, there have been no systematic studies to associate the full suite of flower visitors, including pollinators, with specific host plants, nor to track

their activity patterns over the growing season. As we witness a rapidly changing climate in Alaska, there is some urgency to establishing baseline measures of these attributes across multiple regions of the state and to examine how they may vary across environmental and climatic gradients through time.

Alaskan national parks, encompassing diverse ecosystems from coastal Southeast forests to northern Arctic tundra, provide an ideal natural laboratory for learning more about pollinator-plant relationships. Our multi-park study was designed to gain a better understanding of the phenology of several common plants and the diversity of their pollinators within parks, and to examine how plant phenology and pollinators vary across the vast latitudinal and climatic gradients encompassed by all the parks. We also had practical goals to test and refine user-friendly field methods that could be adopted by park staff, interns, and volunteers for monitoring phenology and collecting arthropods. Thus, this pilot study was intended to provide primarily descriptive and qualitative baseline data that could be built upon more rigorously in future studies.

Specifically, our objectives were to:

- (1) Within parks: monitor the phenology of leaves and inflorescences in several common plant species across the growing season and make comparisons among species;
- (2) Within parks: document and compare the diversity of arthropod flower visitors associated with these same plant species;
- (3) Across parks: compare plant phenology and arthropod flower visitor diversity for each focal plant species across regions where it was sampled;
- (4) Develop and refine effective, easily repeatable methods for phenology monitoring and arthropod collection that can be used successfully by park staff, interns, and volunteers.

Methods

Study Area

Eight national parks participated in the study: Denali National Park and Preserve (DENA); Gates of the Arctic National Park and Preserve (GAAR); Glacier Bay National Park (GLBA); Kenai Fjords National Park (KEFJ); Klondike Gold Rush National Historical Park (KLGO); Lake Clark National Park and Preserve (LACL); Sitka National Historical Park (SITK); and Wrangell-St. Elias National Park and Preserve (WRST; Figure 1). GAAR had two separate sampling areas: Anaktuvuk Pass (GAAR-A) and Bettles (GAAR-B); the data for these two areas are considered separately in the report.



Figure 1. Map showing nine sampling areas (shown with black dots) in eight National Park Service units where plant phenology was monitored and flower-visiting arthropods were collected in 2019 and/or 2020.

Within each park, sites for monitoring plant phenology and conducting arthropod collections were generally located in easily accessible areas near park headquarters, a visitor center, or a ranger station (Table 1). An attempt was made to keep sites away from walls or buildings that may directly affect microclimate, however, many sites were located in somewhat disturbed sites (e.g., near roads or

parking lots) which may not represent “natural” conditions. Many parks had to switch plant plots between years in order to find healthier plants or avoid disturbance.

Table 1. Locations of plant phenology observation and arthropod collection sites in eight Alaskan national parks and duration/frequency of plant phenology sampling in 2019 and 2020. Most parks changed sites between years. Plant code abbreviations are defined in Table 2. Plants shaded in gray (also denoted with asterisk) indicate a site where inflorescences did not progress past bud stage (in KLGO, ACHMIL bloomed successfully in 2019 but not in 2020).

Park	Site name	Latitude	Longitude	Elevation	Plant	2019			2020		
						Start date	End date	# Observations	Start date	End date	# Observations
DENA	RR-xing	63.7366	-148.9139	525	ACHMIL	5/21/19	9/4/19	15	–	–	–
	RR-xing	63.7366	-148.9139	525	CHAANG*	5/21/19	9/4/19	15	–	–	–
	RR-xing	63.7366	-148.9139	525	TAROFF	5/21/19	9/4/19	15	–	–	–
	MSLC	63.7344	-148.9179	554	RHOGRO	4/28/19	9/4/19	19	–	–	–
	MSLC	63.7344	-148.9179	554	ROSACI	4/28/19	9/4/19	19	–	–	–
	MSLC	63.7344	-148.9179	554	VACVIT	4/28/19	9/4/19	19	–	–	–
	Burnpile	63.7324	-148.9038	454	ACHMIL	–	–	–	5/21/20	9/28/20	18
	Burnpile	63.7324	-148.9038	454	TAROFF	–	–	–	5/21/20	9/28/20	18
	Airstrip Rd.	63.7324	-148.9017	498	CHAANG	–	–	–	5/21/20	9/28/20	18
	Roadside #1	63.7244	-148.9459	623	ROSACI	–	–	–	5/12/20	9/28/20	20
	Roadside #2	63.7244	-148.9473	627	RHOGRO	–	–	–	5/12/20	9/28/20	20
	Roadside #2	63.7244	-148.9473	627	VACVIT	–	–	–	5/12/20	9/28/20	20
GAAR-A	Ranger Station	68.1420	-151.7367	655	CHAANG	6/15/19	8/5/19	8	–	–	–
	Ranger Station	68.1420	-151.7367	655	TAROFF	6/15/19	8/5/19	8	–	–	–
GAAR-B	Float pond road	66.9141	-151.5209	650	CHAANG	6/12/19	8/29/19	9	–	–	–
	NPS housing	66.9154	-151.5152	650	TAROFF	6/12/19	8/29/19	9	–	–	–
	Ridge trail	66.9153	-151.5322	650	VACVIT	6/12/19	8/29/19	9	–	–	–
GLBA	Modular	58.4566	-135.8671	10	ACHMIL	5/20/19	8/27/19	10	–	–	–
	Modular	58.4566	-135.8671	10	CHAANG*	5/20/19	8/27/19	10	–	–	–
	Modular	58.4566	-135.8671	10	TAROFF	5/20/19	8/27/19	10	–	–	–
	Beach meadow	58.4560	-135.8771	5	ACHMIL	–	–	–	5/28/20	10/13/20	13
	Beach meadow	58.4560	-135.8771	5	CHAANG*	–	–	–	5/28/20	10/13/20	13
	Beach meadow	58.4560	-135.8771	5	TAROFF	–	–	–	5/28/20	10/13/20	13

Table 1 (continued). Locations of plant phenology observation and arthropod collection sites in eight Alaskan national parks and duration/frequency of plant phenology sampling in 2019 and 2020. Most parks changed sites between years. Plant code abbreviations are defined in Table 2. Plants shaded in gray (also denoted with asterisk) indicate a site where inflorescences did not progress past bud stage (in KLGO, ACHMIL bloomed successfully in 2019 but not in 2020).

Park	Site name	Latitude	Longitude	Elevation	Plant	2019			2020		
						Start date	End date	# Observations	Start date	End date	# Observations
KEFJ	Parking lot	60.1886	-149.6307	138	ACHMIL	5/31/19	8/17/19	12	–	–	–
	Exit	60.1851	-149.6405	226	HERMAX	5/24/19	8/17/19	14	–	–	–
	Exit	60.1851	-149.6405	226	CHAANG	5/24/19	7/27/19	10	–	–	–
	Housing road	60.1888	-149.6265	81	CHAANG	7/27/19	8/17/19	4	–	–	–
	Exit Glacier 1	60.1888	-149.6335	128	HERMAX	–	–	–	6/1/20	6/8/20	2
	Exit Glacier 1_new	60.1886	-149.6331	110	HERMAX	–	–	–	6/15/20	8/31/20	12
	Exit Glacier 2	60.1887	-149.6306	124	CHAANG	–	–	–	6/1/20	9/16/20	16
	Exit Glacier 3	60.1886	-149.6305	124	ACHMIL	–	–	–	6/1/20	10/2/20	18
KLGO	Dyea 1	59.5017	-135.3519	7	CHAANG	5/9/19	7/31/19	12	–	–	–
	Dyea 2	59.5016	-135.3516	7	ACHMIL*	5/8/19	8/8/19	13	6/24/20	8/25/20	9
	Dyea 3	59.5024	-135.3524	6	CHAANG	–	–	–	6/24/20	8/25/20	9
LACL	Beaver pond trail	60.1966	-154.3096	79	CHAANG	6/19/19	8/6/19	6	6/12/20	9/22/20	10
	Point	60.2043	-154.3077	77	ROSACI	6/4/19	8/6/19	9	6/11/20	9/22/20	9
	Park complex 1	60.1978	-154.3208	93	RHOTOM	5/28/19	7/30/19	9	–	–	–
	Park complex 2	60.1956	-154.3217	82	RHOTOM	–	–	–	6/12/20	9/22/20	10
SITK	Sea walk	57.0486	-135.3212	4	TAROFF	5/9/19	5/17/19	2	–	–	–
	Sea walk	57.0486	-135.3212	4	HERMAX	5/9/19	5/17/19	2	–	–	–
	Beach trail	57.0450	-135.3136	7	CHAANG	5/9/19	7/17/19	7	–	–	–
	Beach trail	57.0450	-135.3136	7	TAROFF	5/30/19	6/13/19	2	–	–	–
	Beach trail	57.0450	-135.3136	7	HERMAX	5/30/19	7/17/19	5	–	–	–

Table 1 (continued). Locations of plant phenology observation and arthropod collection sites in eight Alaskan national parks and duration/frequency of plant phenology sampling in 2019 and 2020. Most parks changed sites between years. Plant code abbreviations are defined in Table 2. Plants shaded in gray (also denoted with asterisk) indicate a site where inflorescences did not progress past bud stage (in KLGO, ACHMIL bloomed successfully in 2019 but not in 2020).

Park	Site name	Latitude	Longitude	Elevation	Plant	2019			2020		
						Start date	End date	# Observations	Start date	End date	# Observations
WRST	Complex bluff	62.0190	-145.3614	385	CHAANG*	5/22/19	7/30/19	11	–	–	–
	Complex bluff	62.0190	-145.3614	385	RHOGRO*	5/22/19	7/30/19	11	–	–	–
	Complex bluff	62.0190	-145.3614	385	VACVIT	5/22/19	7/30/19	11	–	–	–
	Copper Center HQ	62.0192	-145.3629	397	CHAANG*	–	–	–	5/26/20	8/28/20	12
	Copper Center HQ	62.0192	-145.3629	397	RHOGRO	–	–	–	5/26/20	8/28/20	12
	Copper Center HQ	62.0192	-145.3629	397	VACVIT	–	–	–	5/26/20	8/28/20	12

Each park was responsible for their own plant phenology monitoring and arthropod collections. Work was carried out by permanent and seasonal staff, Geoscientist-in-Parks and Mosaics-in-Science interns, a YCC group, volunteers, and park partners. In April 2019, the principal investigator (PI) provided training, including a webinar for all participating parks introducing protocols for phenology monitoring, arthropod collection and shipping, and data submission. A box of sampling equipment was sent to each park (Section A in Rykken 2021).

Each park selected 2–3 focal plant species to monitor from the list in Table 2. Both of the similar-looking species of Labrador tea (*Rhododendron groenlandicum*—Bog Labrador tea and *R. tomentosum*—Narrow-leaf Labrador tea) were monitored in different parks. Cow parsnip (*Heracleum maximum*) was added to the initial list in 2019 to accommodate two parks (KEFJ and SITK) who could not find adequate populations of the other species. All parks were asked to include fireweed as one of their focal species. DENA monitored six plant species so the PI could familiarize herself first-hand with plant-specific protocols and potential challenges.

Table 2. Names and characteristics of focal plant species used for phenology monitoring and arthropod collections in eight Alaskan national parks in 2019 and 2020.

Common name	Latin name	Abbreviation	Flower color	Inflorescence	Leaf type	Growth form
Common yarrow	<i>Achillea millefolium</i>	ACHMIL	White/pink	Panicles of composite flowers	Simple summer-green	Perennial forb
Fireweed	<i>Chamerion angustifolium</i>	CHAANG	Pink	Tall raceme w/open flowers	Simple summer-green	Perennial forb
Cow parsnip	<i>Heracleum maximum</i>	HERMAX	White	Umbels of many open flowers	Compound summer-green	Perennial/ Biennial forb
Bog/Northern Labrador tea	<i>Rhododendron groenlandicum/tomentosum</i>	RHOGRO RHOTOM	White	Clusters of open flowers	Simple evergreen	Perennial shrub
Prickly rose	<i>Rosa acicularis</i>	ROSACI	Pink	Large, open single flowers	Compound summer-green	Perennial shrub
Common dandelion	<i>Taraxacum officinale</i>	TAROFF	Yellow	Single composite flower heads	Simple summer-green	Perennial shrub
Lingonberry or lowbush cranberry	<i>Vaccinium vitis-idaea</i>	VACVIT	White/pink	Single or clustered bell-shaped flowers	Simple evergreen	Perennial shrub

The initial list of plant species was selected to include nectar and pollen-producing species with a wide distribution in Alaska, growing in habitats that would be easily accessible (e.g., not high

alpine), with a variety of inflorescences, leaf types, growth forms, and bloom timing. We included one non-native species, common dandelion (*Taraxacum officinale*).

Plant phenology monitoring

Detailed instructions for monitoring plant phenology were documented and distributed to all participating parks (Section B in Rykken 2021). In brief, within each park, an easily accessible site was selected for each focal plant species (a single site could have more than one focal species), measuring approximately 100 m², but larger if plants were widely dispersed. A site description sheet was filled out upon establishment of each site (Section C in Rykken 2021). Within the site, five individual plants of the focal species (spaced at least 2 m apart) were selected to monitor on a weekly schedule. Table 1 shows plant species monitored by each park and duration and frequency of observations. Phenophases (discrete, observable life stages; see photos below) for each plant were scored with the aid of a phenophase photo guide and a phenology observation data sheet (Sections D, E in Rykken 2021). Phenophases for both leaves (buds, unfurling leaves, fully open leaves, old leaves for evergreen plants) and inflorescences (buds, open flowers, petal drop, unripe fruits, ripe fruits, dispersed fruits) were recorded (Section D in Rykken 2021 for examples). Our phenology monitoring methodology and materials (i.e., photo guides and data sheets) were borrowed and adapted from an existing Alaskan citizen science program, Project BrownDown (<https://sites.google.com/a/alaska.edu/projectbrowndown/citizen-science-protocol>) lead by K. Spellman and C. Mulder at the University of Alaska Fairbanks. Each phenophase scoring event for one focal plant species (including 5 individual plants) at one site on one date composed a single observation. Mean phenophase scores were calculated for each observation using methods described in the Analysis section below.



K. Fuentes scoring phenophases for common yarrow in KLGO. (NPS/JESSICA RYKKEN)

Weather data

In order to compare one climatic variable, temperature, between sampling areas in different parks, we retrieved mean monthly air temperature from nearby weather stations with accessible data via <https://xmacis.rcc-acis.org> (Table 3). For Anaktuvuk Pass (GAAR-A), the nearest weather station with reliable data was Chimney Lake, 67 km southeast of Anaktuvuk Pass and at 944 m elevation (Pam Sousanes, pers. comm.). While these temperature measurements do not represent site-specific conditions in each park (i.e., weather stations may differ in elevation or aspect), they were the best available weather data. DENA, GLBA, LACL, KLGO, and KEFJ deployed microclimate loggers at each site in 2020, but the time span that they were in use was not adequate to make comparisons through the growing season or with the previous season.

Table 3. Weather stations used for accessing mean monthly air temperature between May and August, 2019 and 2020.

Phenology sampling site	Weather station	Approximate distance between sampling sites and weather station (km)
DENA	McKinley Park, COOP 505778, GHCN USC00505778	3.5
GAAR-A	Chimney Lake RAWs (GAAR), GHCN USR0000ACHM	67.4
GAAR-B	Bettles COOP 500761, GHCN USW00026533	0.3
GLBA	Gustavus COOP 503475, GHCN	10.5
KEFJ	Exit Glacier Snotel site (near visitor center)	1.8
KLGO	Skagway COOP 508525 GHCN USC00508525	5.7
LACL	Port Alsworth 1 SW COOP 507572, GHCN USW00026562	0.3
SITK	Sitka 1 NE COOP 508490, GHCN USW00025379	1.6
WRST	Gulkana Airport COOP 503465, GHCN USW00026425	16.3

Arthropod sampling

Arthropods were collected weekly or bi-weekly in or near the phenology monitoring sites while focal plant species were flowering (Table 4). Collections were not restricted to the individual plants being monitored (in fact, these plants were avoided to avoid damaging inflorescences with the vacuum). Detailed instructions for collecting, preserving, and shipping flower-visiting arthropods were documented and distributed to all participating parks (Section F in Rykken 2021). Participants were encouraged to sample on warm ($>13^{\circ}\text{C}$), calm, dry days when possible. At the outset of each arthropod sampling session, a pollinator collection sheet was filled out (Section G in Rykken 2021).

Table 4. Duration and frequency of insect collections from eight plant species in eight Alaskan national parks in 2019 and 2020. Locations of sampled sites for each plant can be found in Table 1. Plant code abbreviations are defined in Table 2.

Park	Plant	2019			2020		
		Start date	End date	# Collections	Start date	End date	# Collections
DENA	ACHMIL	6/28/19	8/8/19	5	7/14/20	8/17/20	5
	CHAANG	6/28/19	8/8/19	5	7/14/20	7/29/20	3
	RHOGRO	6/14/19	6/14/19	1	6/17/20	6/25/20	2
	ROSACI	6/14/19	6/28/19	2	6/25/20	6/25/20	1
	TAROFF	6/3/19	6/19/19	2	6/10/20	7/2/20	4
	VACVIT	6/14/19	6/14/19	1	–	–	–
GAAR-A	CHAANG	7/2/19	7/19/19	3	–	–	–
	TAROFF	6/20/19	7/19/19	5	–	–	–
GAAR-B	CHAANG	7/11/19	8/22/19	5	–	–	–
	TAROFF	6/12/19	6/12/19	1	–	–	–
	VACVIT	6/12/19	8/22/19	3	–	–	–
GLBA	ACHMIL	6/13/19	9/12/19	7	6/28/20	9/25/20	9
	TAROFF	5/20/19	6/13/19	2	6/5/20	6/5/20	1
KEFJ	ACHMIL	7/2/19	8/9/19	7	7/2/20	8/21/20	7
	CHAANG	7/28/19	8/9/19	3	7/15/20	8/13/20	4
	HERMAX	7/2/19	7/12/19	3	7/2/20	7/15/20	3
KLGO	ACHMIL	7/8/19	8/16/19	5	7/23/20	8/11/20	3
	CHAANG	7/8/19	8/16/19	5	7/23/20	8/11/20	3
LACL	CHAANG	7/8/19	7/30/19	3	7/17/20	7/23/20	2
	ROSACI	6/4/19	7/8/19	3	6/11/20	7/1/20	2
	RHOTOM	7/8/19	7/8/19	1	–	–	–
SITK	CHAANG	7/10/19	7/10/19	1	–	–	–
	HERMAX	6/13/19	7/10/19	3	–	–	–
WRST	CHAANG	7/2/19	7/2/19	1	7/18/20	8/13/20	3
	RHOGRO	6/21/19	7/2/19	2	6/15/20	7/3/20	3
	VACVIT	6/21/19	6/21/19	1	6/20/20	6/27/20	2

To minimize sampling bias, we provided parks with a modified hand-held vacuum (purchased at Bioquip.com) to suck arthropods directly from flowers; this method requires less skill and experience than net-collecting. Live specimens were collected directly into containers which could be then be frozen or dunked in ethanol. Sampling sessions were timed and limited to 20 minutes or as long as it took to collect ~100 specimens, whichever came first. The arthropod samples were intended to be more qualitative than quantitative as many variables could influence sample size on a given day, including weather, density of available flowers, and skill with the vacuum.



Left: M. Hake vacuuming arthropods from fireweed in KLGO. (NPS/KAITLYN FUENTES).

Right: Collecting tube from vacuum filled with flies and other insects. (NPS/JESSICA RYKKEN)

Specimen processing

Each arthropod sample and its associated label was preserved in ethanol or isopropyl alcohol in a Whirl-pak, then sent to DENA for processing. Samples were then sorted by taxonomic order, with most insects and mites separated into ethanol-filled vials. However, bees, most beetles, some wasps and ants, and all flower flies (Family Syrphidae) were dried and pinned or point-mounted. The resolution of identification varied among taxa. All bees were identified to species or genus, as were some flower flies, wasps, and beetles. Most flies were identified to family or superfamily, as were hemipterans (true bugs, aphids, and relatives), some beetles, and most wasps and ants. Mites and springtails were identified only to order. We anticipate that taxonomic work will continue on some of these specimens in the future. The results presented in this report are at family level or higher, except for the bees.

All pinned specimens will be deposited in the entomology collections at the University of Alaska Fairbanks with loan agreements from individual parks.

Analysis

Calculating relative phenophase scores

To allow comparisons of reproductive phenophase conditions for a focal plant species across observations, plants, and parks, we first calculated a relative phenophase score for each plant in an observation using a weighted average as described in Spellman and Mulder (2016). First, each consecutive phenophase was assigned a weight: bud = 1; open flower = 2; petal drop = 3; unripe fruit = 4; ripe fruit = 5; dispersed fruit = 6. Then, a relative phenophase score for the plant was calculated as follows:

$$((\text{\#buds} \times 1) + (\text{\#open flowers} \times 2) + (\text{\#petal drops} \times 3) + (\text{\#unripe fruits} \times 4) + (\text{\#ripe fruits} \times 5) + (\text{\#dispersed fruits} \times 6)) / (\text{\#buds} + \text{\#open flowers} + \text{\#petal drops} + \text{\#unripe fruits} + \text{\#ripe fruits} + \text{\#dispersed fruits})$$

The relative phenophase scores (rps) from each of the five plants that composed an observation were then averaged for a mean rps. Only those plants that were developing reproductive structures were included in the mean, thus, in some cases where plants were not flowering, fewer than five plants were averaged.

Arthropod classification

To facilitate visual comparisons of arthropod diversity between plants and parks with charts and histograms, we lumped most taxa at the order level. The exceptions were several groups known to be significant pollinators: bees (Order Hymenoptera), syrphid flies, and muscoid flies (both in the Order Diptera); these were displayed as separate groups. Bees were identified to genus or species.

Arthropod comparisons

Because arthropod sampling efforts represented snapshots of insect activity and diversity on particular days (under various weather conditions) and some host plants were sampled much more intensively than others, we used relative abundances of various taxa to make comparisons between host plants and parks, rather than absolute numbers.

Results

Plant phenology

Nine sites in eight parks submitted a total of 599 plant phenology observations (Table 1). Scoring phenophases for some focal plant species proved more challenging than for others, but clear differences in reproductive phenology across some plants and parks was evident (Figs. 2, 3a–d).

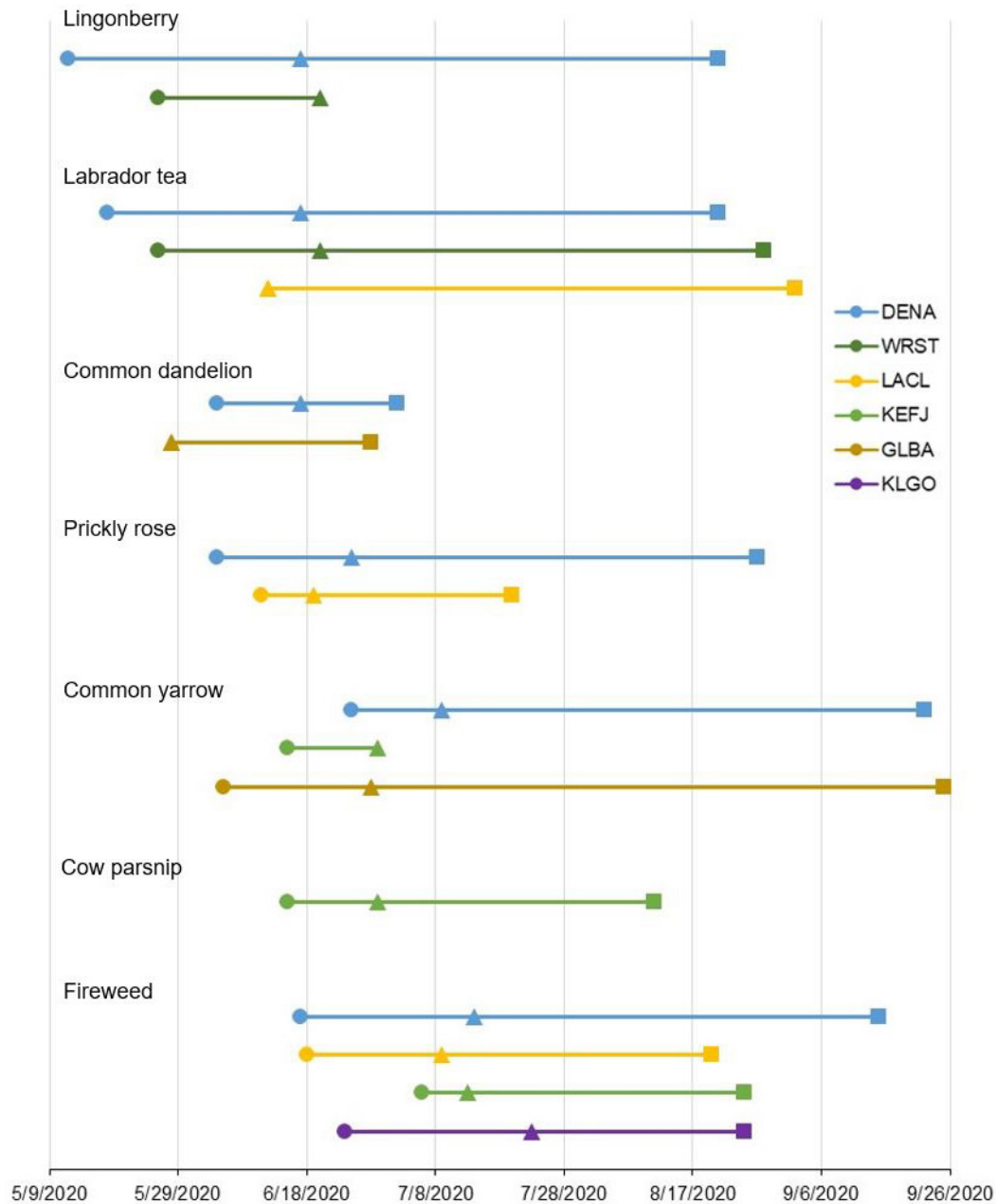


Figure 2. Date of first bud (circle), open flower (triangle), and ripe fruit (square) observed on one or more of five selected plants at a sampling site, for seven focal plant species, across six Alaskan national parks in 2020. In some cases, observations for a species began after the first buds had emerged or ended before ripe fruits were observed so symbols do not appear.

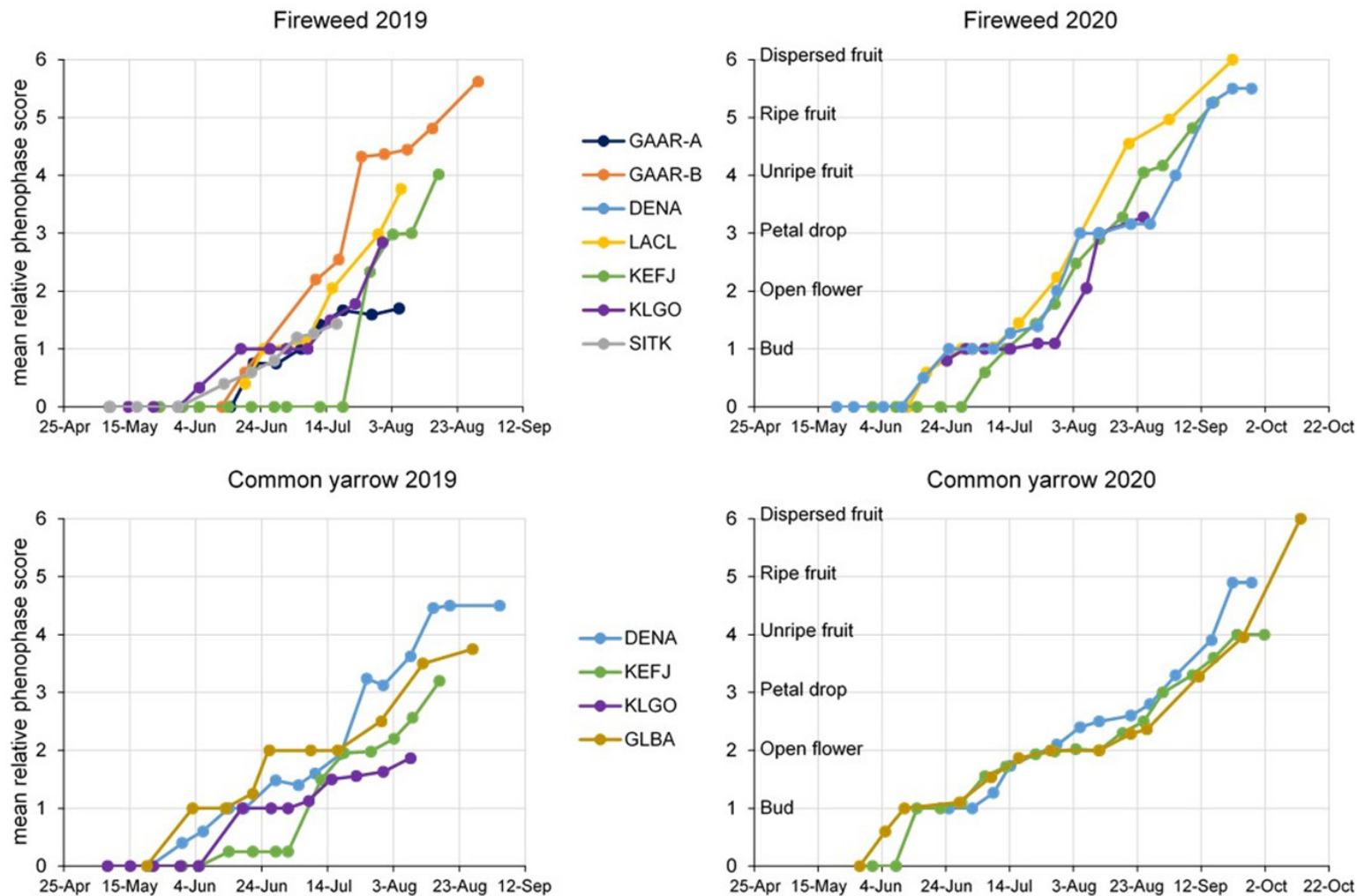


Figure 3a. Comparison of mean relative phenophase scores for reproductive structures of focal plant species in 2019 and 2020 across Alaskan national parks: Fireweed; Common yarrow. Each phenology observation in a park is represented by a colored dot. Color coding for parks is consistent throughout the graphs. The y-axes on the 2020 graphs provide a description for each of the consecutive phenophase scores, which are the same for 2019 graphs.

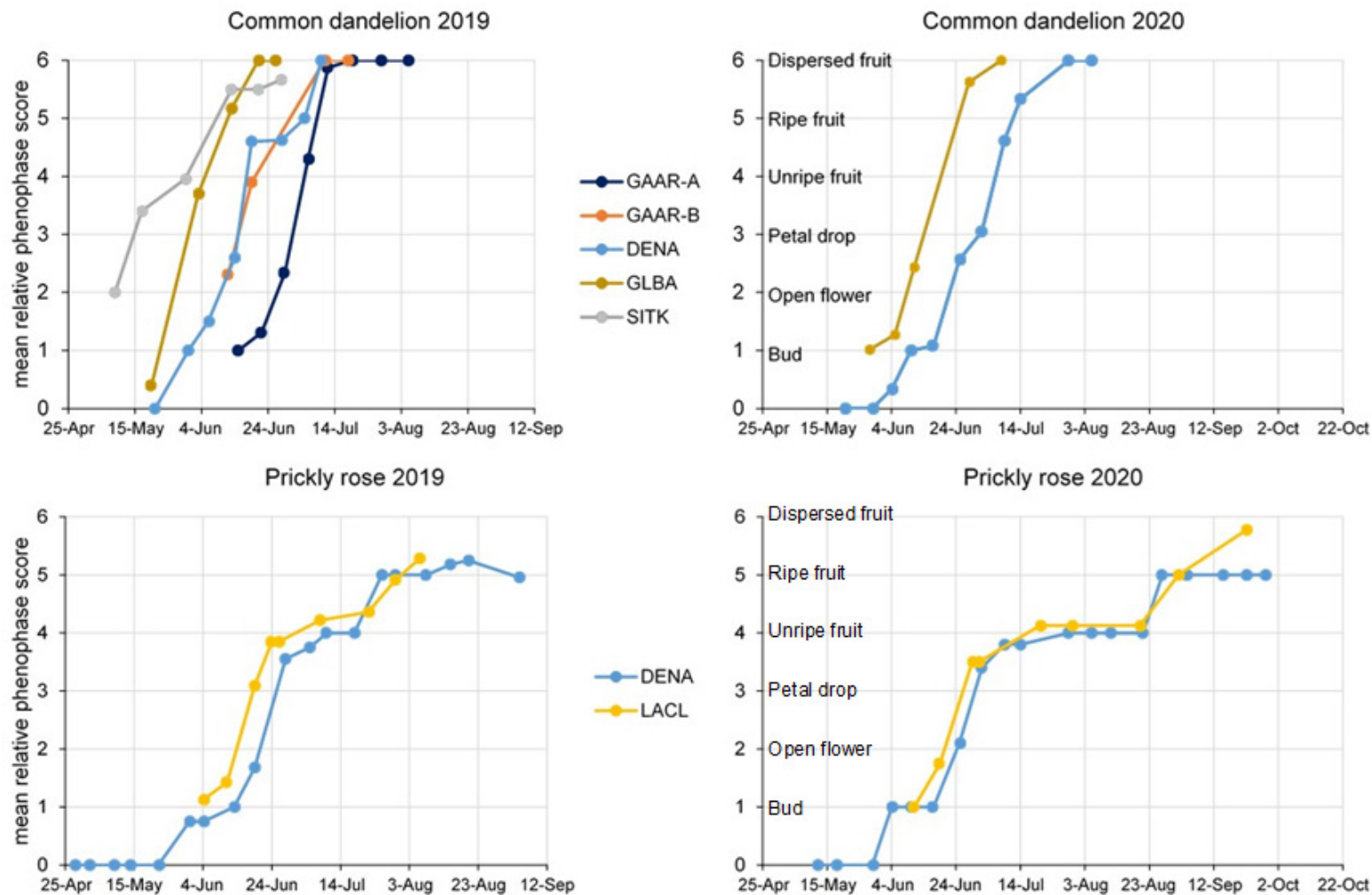


Figure 3b. Comparison of mean relative phenophase scores for reproductive structures of focal plant species in 2019 and 2020 across Alaskan national parks: Common dandelion; Prickly rose. Each phenology observation in a park is represented by a colored dot. Color coding for parks is consistent throughout the graphs. The y-axes on the 2020 graphs provide a description for each of the consecutive phenophase scores, which are the same for 2019 graphs.

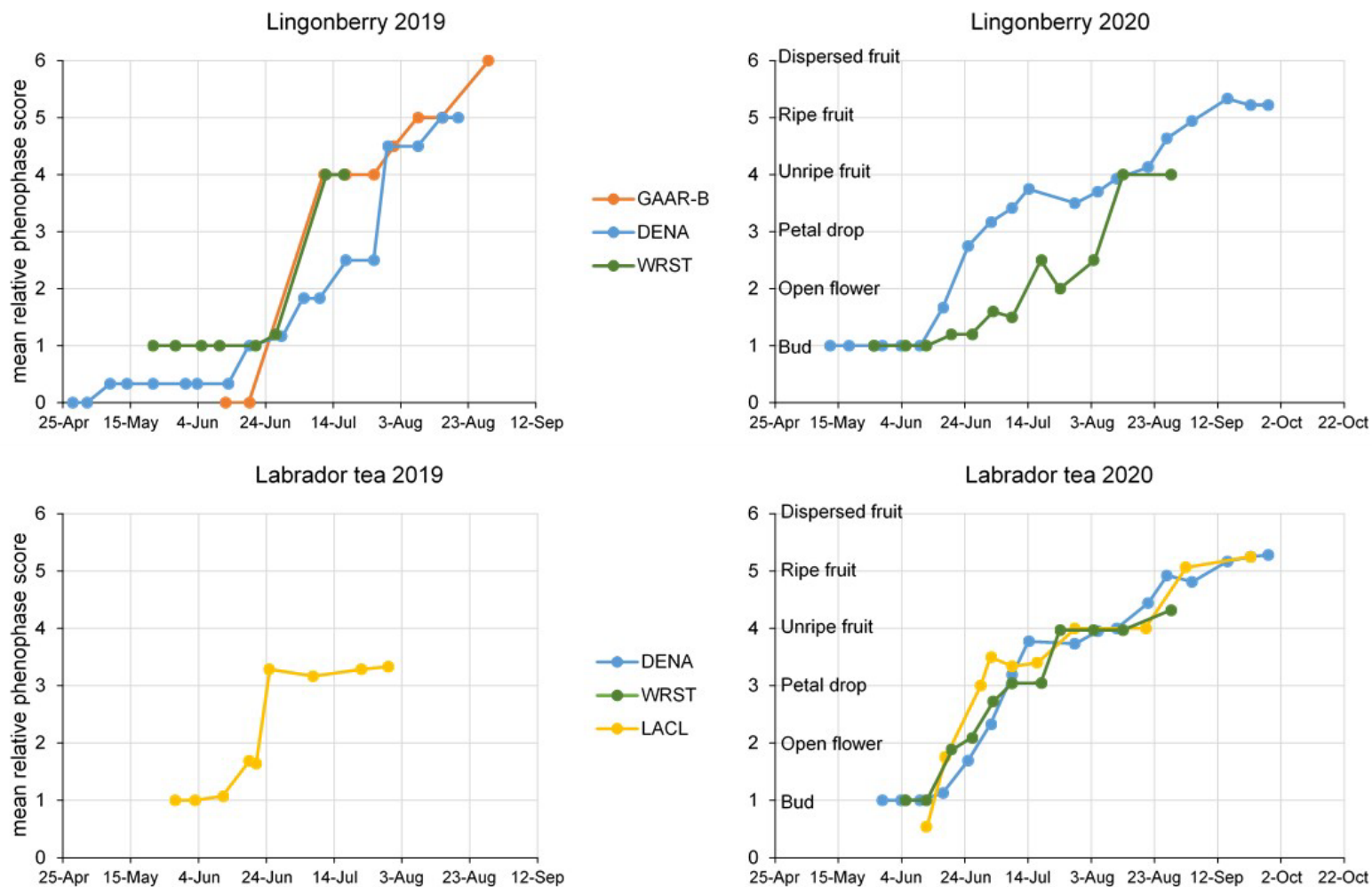


Figure 3c. Comparison of mean relative phenophase scores for reproductive structures of focal plant species in 2019 and 2020 across Alaskan national parks: Lingonberry; Labrador tea. Each phenology observation in a park is represented by a colored dot. Color coding for parks is consistent throughout the graphs. The y-axes on the 2020 graphs provide a description for each of the consecutive phenophase scores, which are the same for 2019 graphs. Note that 2 species of Labrador tea are represented in 2020, *Rhododendron tomentosum* in LACL, *R. groenlandicum* in DENA and WRST.

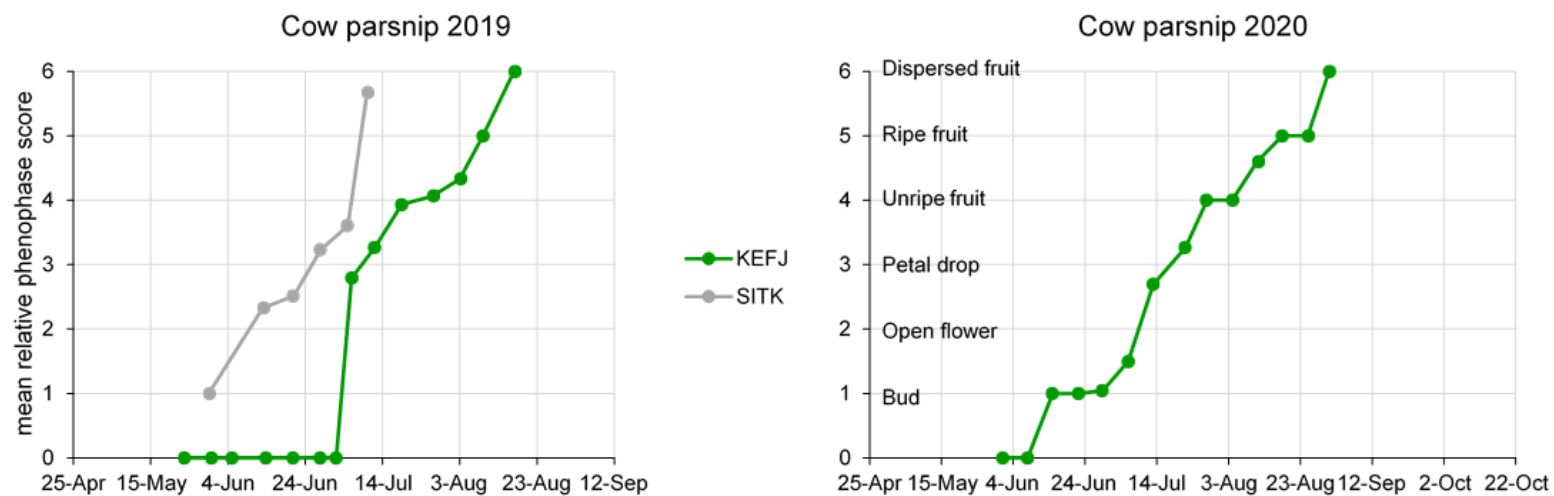


Figure 3d. Comparison of mean relative phenophase scores for reproductive structures of focal plant species in 2019 and 2020 across Alaskan national parks: Cow parsnip. Each phenology observation in a park is represented by a colored dot. Color coding for parks is consistent throughout the graphs. The y-axes on the 2020 graphs provide a description for each of the consecutive phenophase scores, which are the same for 2019 graphs.

Leaf phenology

A number of challenges monitoring leaf emergence and development (see Discussion) resulted in leaves being unsuitable for phenology comparisons. For example, in many cases, leaf-out had already begun when monitoring began.

Reproductive phenology

Timing of the first appearance of buds, open flowers, and ripe fruits in sampling plots varied among plant species and across parks, with the two evergreen shrubs, lingonberry and Labrador tea, showing their first buds in mid-May in DENA and late May in WRST in 2020 (Fig. 2). At the other end of the spectrum, fireweed buds were first observed in mid-June in DENA and LACL, not until a week later in KLGO, and early July in KEFJ. The shortest span of time between the first observed bud and first ripe seeds was 28 days for common dandelion in DENA, while the longest span between bud and ripe fruit was 112 days for common yarrow in GLBA. 2019 data were less complete and not plotted.

The mean relative phenophase score (rps) provides a more comprehensive assessment of the average phenophase across the five monitored plants within a sampling site, and differentially weights multiple phenophases within the same plant. Trajectories for the mean rps across the growing season in 2019 and 2020 for different plants and parks are shown in Figures 3a–d. Below is a general summary of patterns for each plant.

Fireweed (*Chamerion angustifolium*):

In 2019, selected plants did not flower in several parks (DENA, GLBA, WRST), and the mean rps for fireweed in most of the remaining parks did not advance beyond 4 (unripe fruit). Initial plants selected in KEFJ did not produce buds and were replaced in mid-July. In GAAR-B, at least some of the fireweed plants had dispersed their seeds by the last week of August. In 2020, monitoring was successful in LACL, KEFJ, and DENA. Initial flower bud development in KEFJ plants was approximately 3 weeks later than in the other parks, but all parks had at least some plants with dispersed seeds by mid-September.

Common yarrow (*Achillea millefolium*):

In 2019, only the plants in DENA developed ripe fruits (mean rps >4). In 2020, the trajectory of reproductive development for common yarrow was similar across the three parks (DENA, KEFJ, and GLBA). Budding began in early-mid June; DENA plants developed ripe fruits by September 22 and GLBA had observed dispersed seeds by mid-October.

Common dandelion (*Taraxacum officinale*):

Common dandelion developed more rapidly than any of the other focal plants, across all parks in both years. In 2019, five parks monitored this species, although SITK and GAAR-B began observations when plants were already flowering. In general, the trajectory for mean rps over the season was similarly shaped across all parks, and there was a pattern of delayed development with increasing latitude. This was also the case in 2020, in which only GLBA and DENA monitored this species.

Prickly rose (*Rosa acicularis*):

Two parks, LACL and DENA, monitored this species. The shapes of the trajectories for mean rps over the season were similar between parks in both years. Buds were present by early June in 2019 and 2020, however, the mean rps reached 5 (ripe fruit) by late July in 2019, and not until late August in 2020.

Lingonberry (*Vaccinium vitis-idaea*):

In 2019, plants had a mean rps of 4 (unripe fruit) by mid-July in WRST and GAAR-B, but DENA lagged with plants still having open flowers and petal drop. Berries were ripe on the plants by early August in GAAR-B and mid-August in DENA, they did not ripen in WRST. In 2020, berries also did not ripen in WRST, and in DENA the mean rps did not reach 5 (ripe fruit) until early September.

Labrador tea:

Note that LACL monitored *Rhododendron tomentosum*, while DENA and WRST monitored *R. groenlandicum*. In 2019, WRST and DENA were unsuccessful in monitoring this species (plants did not flower). LACL monitored it through the petal drop phase (mean rps = 3), which it reached by the last week of June. In 2020, the mean rps for Labrador tea was similar across all three parks. Fruits were ripe by late August in DENA and LACL, but most did not ripen in WRST.

Cow parsnip (*Heracleum maximum*):

In 2019, buds were evident in SITK by early June, when observations started, and development of flowers and fruits was rapid, with most fruits dispersed by mid-July (when the plants were accidentally destroyed). In KEFJ, the plants initially selected did not have buds, so new plants were selected in early July. In both 2019 and 2020 in KEFJ, a relatively small proportion of flowers developed into fruits; fruits did not ripen until early August in 2019 and mid-August in 2020.

Weather data

In 2019, mean monthly air temperature was lowest for all months (May–August) at the northern-most site (GAAR-A), but the other site in the same park (GAAR-B) had the highest mean temp in June and July (Fig. 4). The highest park-wide spreads of mean monthly temperatures ($>9.6^{\circ}\text{C}$) were in May and August, at the beginning and end of the growing season; this was mostly driven by the much cooler temperatures in GAAR-A (Fig. 4). Seven parks had relatively similar mean monthly temperatures in May ($7.4\text{--}9.1^{\circ}\text{C}$), but more spread in the following three months (Fig. 4). All parks peaked in mean monthly air temperature in July.

In 2020, when only six parks participated in sampling (DENA, GLBA, KEFJ, KLGO, LACL, WRST), KLGO had the highest mean temperatures in all months (as it did in May and August in 2019), and DENA had the lowest, except in June (Fig. 4). Mean air temperatures were lower in June and July in every park in 2020 than in 2019 (Fig. 4).

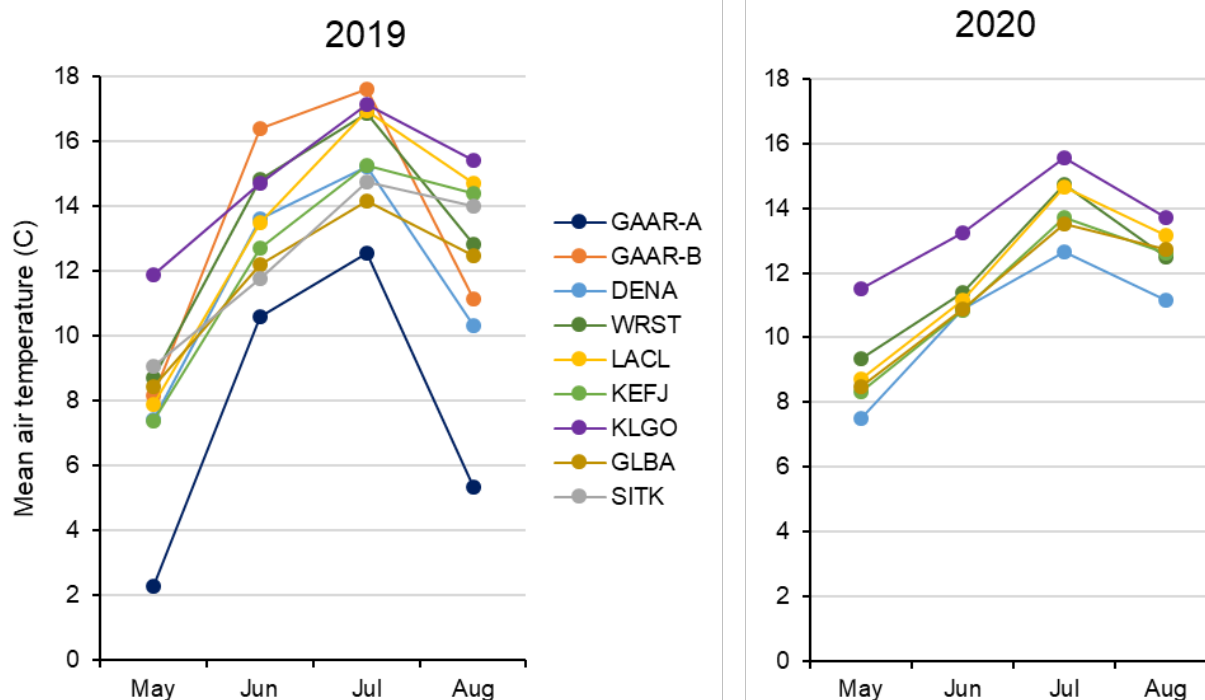


Figure 4. Dots represent mean monthly air temperature from May to August at nine sites in eight Alaskan national parks in 2019 and in six participating parks in 2020.

As an example of how plant phenology data might be compared across a climatic gradient, we plotted the date of the first observed open flower for several plant species (where flowering was successful in more than 3 parks) against the mean air temperature of the month when first flowers appeared overall. For common yarrow and Labrador tea in 2020, mean June temperatures were quite similar across parks (Fig. 5). Common dandelion in 2019 and fireweed in 2020 showed some pattern of delayed first flowering with decreasing mean air temperature across parks (Fig. 5). However, KLGO had a relatively high mean July air temperature with first fireweed flowers not observed until the third week of July, 9–14 days after the other parks (Fig. 5).

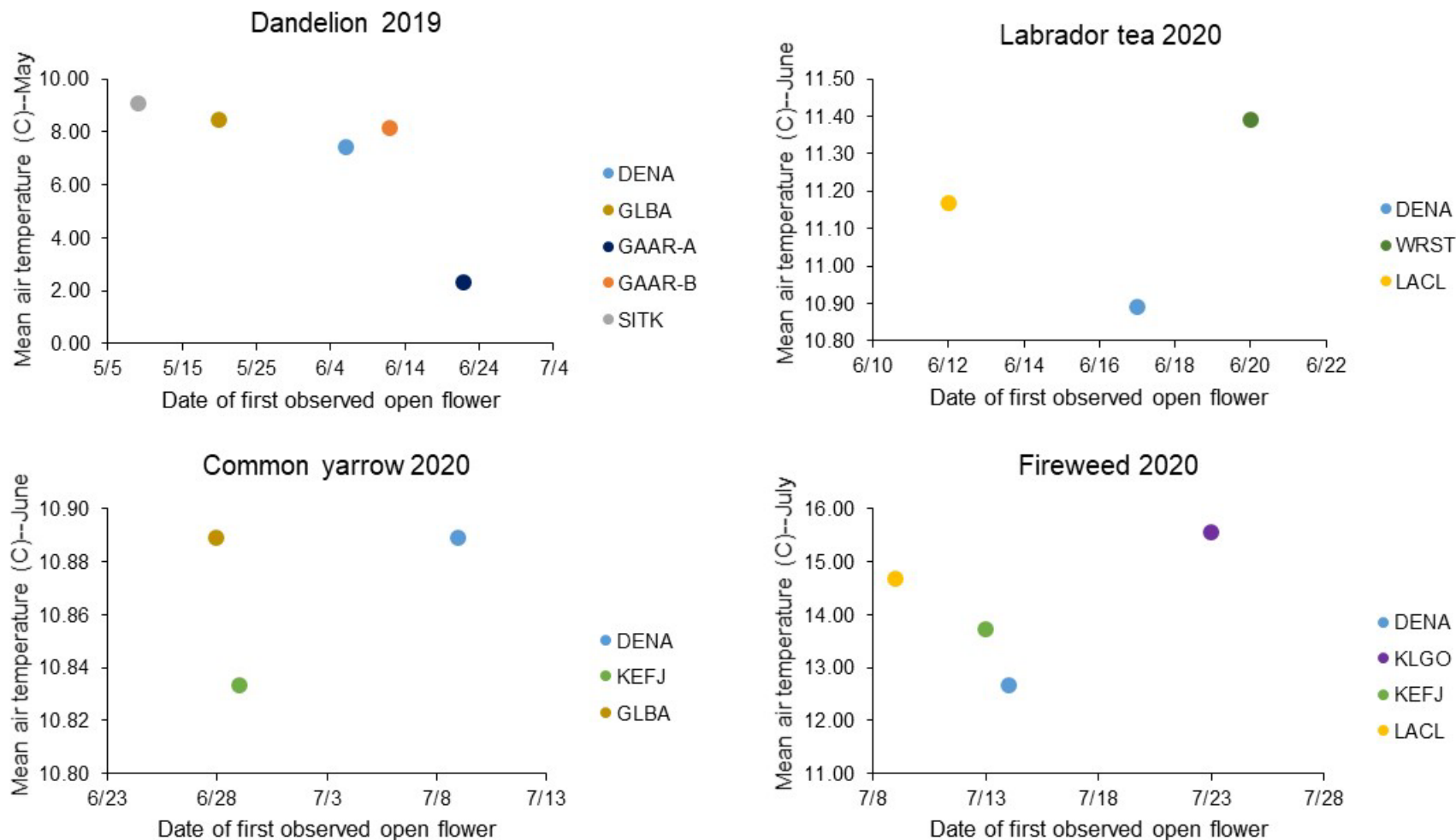


Figure 5. Relationship between mean air temperature and date of first observed open flower for four focal plant species across Alaskan national parks. Mean air temperature is for the month in which first flowers appeared across all parks sampled for that plant species (indicated on y-axis). Note that for Labrador tea, 2 species are represented: LACL sampled *Rhododendron tomentosum*, WRST and DENA sampled *R. groenlandicum*.

Flower-visiting arthropods

A total of 4,856 arthropods were collected from flowers of seven plant species across eight Alaskan national parks (Fig. 6, Tables 5, 6). Most are known to feed on nectar and/or pollen as adults (Table 5). They included arthropods from seven taxonomic orders: mites (Acari); beetles (Coleoptera); springtails (Collembola); flies (Diptera); true bugs, aphids, and relatives (Hemiptera); bees, wasps, ants, sawflies (Hymenoptera); and thrips (Thysanoptera). At a family level, flies were the most diverse order, represented by at least 34 families (some specimens were determined to superfamily or higher level only). Flies were also the most abundantly collected flower visitors overall, making up 47% of the total catch (Fig. 6).

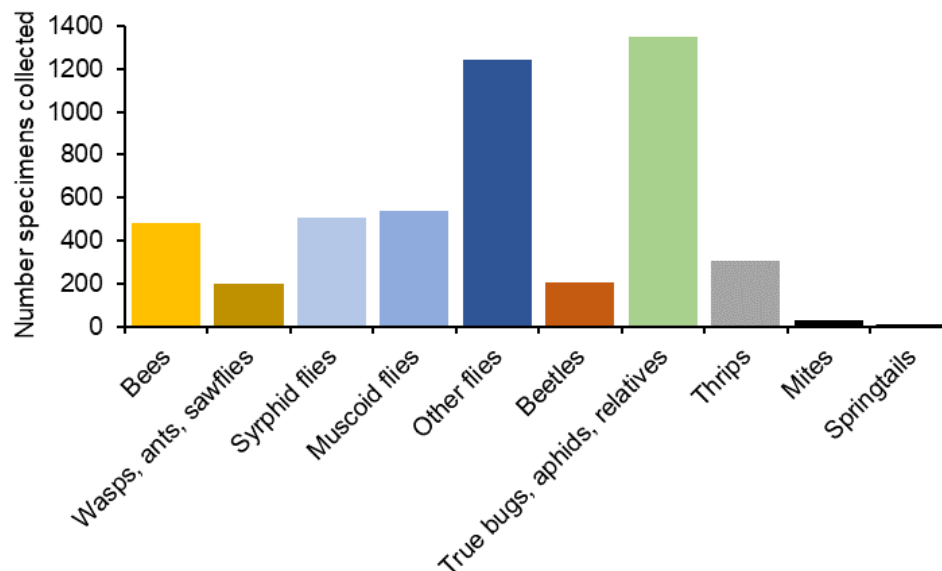


Figure 6. Counts of flower-visiting arthropods collected from seven plant species in eight Alaskan parks in 2019 and 2020. Note that the three blue-shaded bars all represent flies (Order Diptera).

Table 5. List of arthropod flower visitors collected from seven plant species in eight Alaskan national parks, including common names and known feeding habits. A = adult feeding habit, L = larval feeding habit, X = feeding habit shared by adult and immature stages (for insects with incomplete metamorphosis). For many arthropod taxa, larval feeding habits are better known.

Arthropod order	Arthropod super/family	Common name	Pollen/nectar	Herbivore	Fungi	Wood	Predator/ parasitoid	Parasite	Scavenger
Acari	–	Mites	X	X	X	–	X	X	X
Coleoptera (Beetles)	Cantharidae	Soldier beetles	A	–	–	–	A,L	–	–
	Carabidae	Ground beetles	–	–	–	–	A,L	–	–
	Cerambycidae	Long-horned beetles	A	A,L	A	L	–	–	–
	Chrysomelidae	Leaf beetles	A	A,L	–	–	–	–	–
	Coccinellidae	Ladybird beetles	A,L	A,L	A,L	–	A,L	–	–
	Cryptophagidae	Silken fungus beetles	A	–	A,L	–	–	–	–
	Elateridae	Click beetles	A	A,L	–	–	L	–	–
	Melandryidae	False darkling beetles	–	–	A,L	A,L	–	–	–
	Ptiliidae	Featherwinged beetles	–	–	A,L	–	–	–	–
	Staphylinidae	Rove beetles	A	–	A,L	–	A,L	–	A,L
Collembola	–	Springtails	X	X	–	–	–	–	X
Diptera (Flies)	Agromyzidae	Leaf miner flies	–	A,L	–	–	–	–	–
	Anthomyzidae	Anthomyzid flies	–	–	–	–	–	–	L
	Bibionidae	March flies	A	L	–	–	–	–	L
	Calliphoridae	Blow flies	A	–	–	–	L	L	A,L
	Cecidomyiidae	Gall and wood midges	A	L	L	–	L	L	L
	Ceratopogonidae	Biting midges	A	–	–	–	A,L	A	L
	Chironomidae	Non-biting midges	A	L	–	–	L	L	L
	Chloropidae	Grass flies	A	L	–	–	L	L	L
	Culicidae	Mosquitoes	A	–	–	–	L	A	L
	Dolichopodidae	Long-legged flies	A	L	–	–	A,L	–	–
	Drosophilidae	Vinegar flies	A	L	L	–	L	L	A,L
	Empididae	Dance flies	A	–	–	–	A,L	–	–

Table 5 (continued). List of arthropod flower visitors collected from seven plant species in eight Alaskan national parks, including common names and known feeding habits. A = adult feeding habit, L = larval feeding habit, X = feeding habit shared by adult and immature stages (for insects with incomplete metamorphosis). For many arthropod taxa, larval feeding habits are better known.

Arthropod order	Arthropod super/family	Common name	Pollen/nectar	Herbivore	Fungi	Wood	Predator/ parasitoid	Parasite	Scavenger
Diptera (Flies) (continued)	Ephydriidae	Shore flies	A	L	–	–	A,L	–	A,L
	Lauxaniidae	Lauxaniid flies	A	–	A,L	–	–	–	L
	Lonchaeidae	Lance flies	–	L	L	–	L	–	L
	Muscoidea	House flies and relatives	A	L	–	–	A,L	A	A,L
	Mycetophilidae	Fungus gnats	A	–	L	–	L	–	–
	Phoridae	Scuttle flies	A	L	L	–	A,L	A,L	A,L
	Pipunculidae	Big-headed flies	A	–	–	–	L	–	–
	Psilidae	Rust flies	A	L	–	–	–	–	–
	Psychodidae	Moth flies	A	–	L	–	–	A	A,L
	Rhagionidae	Snipe flies	A	–	–	–	A,L	A	–
	Scatopsidae	Minute scavenger flies	A	–	–	–	–	–	A,L
	Sciaridae	Dark-winged fungus gnats	A	–	L	–	–	–	L
	Sciomyzidae	Marsh flies	–	–	–	–	L	L	L
	Simuliidae	Black flies	A	–	–	–	–	A	L
	Stratiomyidae	Soldier flies	A	–	–	–	L	–	L
	Syrphidae	Flower flies	A	L	L	–	L	–	L
	Tabanidae	Horse and deer flies	A	–	–	–	L	A	L
	Tachinidae	Parasitic flies	A	–	–	–	L	–	–
	Tephritidae	Fruit flies	A	L	–	–	–	–	–
	Tipulidae	Crane flies	A	L	–	–	L	–	–

Table 5 (continued). List of arthropod flower visitors collected from seven plant species in eight Alaskan national parks, including common names and known feeding habits. A = adult feeding habit, L = larval feeding habit, X = feeding habit shared by adult and immature stages (for insects with incomplete metamorphosis). For many arthropod taxa, larval feeding habits are better known.

Arthropod order	Arthropod super/family	Common name	Pollen/nectar	Herbivore	Fungi	Wood	Predator/ parasitoid	Parasite	Scavenger
Hemiptera (True bugs and relatives)	Acanthosomatidae	Shield bugs	–	X	–	–	–	–	–
	Anthocoridae	Minute pirate bugs	X	–	–	–	X	–	–
	Aphidoidea	Aphids and relatives	–	X	–	–	–	–	–
	Cercopidae	Spittle bugs	–	X	–	–	–	–	–
	Cicadellidae	Leafhoppers	–	X	–	–	–	–	–
	Lygaeoidea	Seed bugs and relatives	X	X	–	–	X	–	–
	Miridae	Plant bugs	X	X	–	–	X	–	X
	Psylloidea	Jumping plant lice	–	X	–	–	–	–	–
	Saldidae	Shore bugs	–	–	–	–	X	–	X
	Scutelleridae	Shield-backed bugs	–	X	–	–	–	–	–
Hymenoptera (Bees, wasps, ants)	Andrenidae	Mining bees	A,L	–	–	–	–	–	–
	Apidae	Bumble bees, honey bees	A,L	–	–	–	–	–	–
	Chalcidoidea	Parasitic wasps	A	–	–	–	L	–	–
	Colletidae	Polyester bees	A,L	–	–	–	–	–	–
	Crabronidae	Crabronid wasps	A	–	–	–	L	–	–
	Cynipoidea	Parasitic wasps	A	L	–	–	L	–	–
	Diapriidae	Parasitic wasps	A	–	–	–	L	–	–
	Formicidae	Ants	A,L	A,L	A,L	–	A,L	–	A,L
	Halictidae	Sweat bees	A,L	–	–	–	–	–	–
	Ichneumonoidea	Parasitic wasps	A	–	–	–	L	–	–
	Megachilidae	Leafcutter, mason bees	A,L	–	–	–	–	–	–
	Platygastroidea	Parasitic wasps	A	–	–	–	L	–	–
	Sphecidae	Sphecid wasps	A	–	–	–	L	–	–

Table 5 (continued). List of arthropod flower visitors collected from seven plant species in eight Alaskan national parks, including common names and known feeding habits. A = adult feeding habit, L = larval feeding habit, X = feeding habit shared by adult and immature stages (for insects with incomplete metamorphosis). For many arthropod taxa, larval feeding habits are better known.

Arthropod order	Arthropod super/family	Common name	Pollen/nectar	Herbivore	Fungi	Wood	Predator/ parasitoid	Parasite	Scavenger
Hymenoptera (Bees, wasps, ants) (continued)	Tenthredinidae	Common sawflies	A	L	–	–	A	–	–
	Vespidae	Yellowjackets and relatives	A	–	–	–	L	–	–
Thysanoptera	–	Thrips	X	X	X	–	X	–	–

Table 6. Specimen counts of arthropods collected from flowers of seven plant species in eight Alaskan national parks in 2019 and 2020. See Table 5 for common names of arthropods.

Arthropod order	Arthropod group	<i>Achillea millefolium</i> Common yarrow				<i>Chamerion angustifolium</i> Fireweed								<i>Heracleum maximum</i> Cow parsnip		<i>Rhododendron groenlandicum</i> Bog Labrador tea		<i>Rosa acicularis</i> Prickly rose		<i>Taraxacum officinale</i> Common dandelion				<i>Vaccinium vitis-idaea</i> Lingonberry		
		DENA	GLBA	KEFJ	KLGO	DENA	GAAR-A	GAAR-B	KEFJ	KLGO	LACL	SITK	WRST	KEFJ	SITK	DENA	WRST	DENA	LACL	DENA	GAAR-A	GAAR-B	GLBA	DENA	GAAR-B	WRST
Acari (Mites)	–	0	8	1	18	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	01	0	0	0	0	0
Coleoptera (Beetles)	Cantharidae	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
	Carabidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	Cerambycidae	21	0	0	0	2	0	0	0	0	2	0	1	0	0	2	1	1	0	19	0	0	0	0	0	0
	Chrysomelidae	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
	Coccinellidae	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cryptophagidae	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	Elateridae	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	4	0	1	0
	Melandryidae	0	0	0	4	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Ptiliidae	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Staphylinidae	1	84	1	0	0	0	0	1	0	0	0	0	37	1	0	0	0	0	0	0	0	2	0	0	0
Collembola (Springtails)	–	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera (Flies)	Acalyptratae unid.	0	2	0	0	0	0	1	0	4	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
	Agromyzidae	0	1	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	1
	Anthomyzidae	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Bibionidae	9	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Calliphoridae	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3	0	0	0	0	0
	Cecidomyiidae	0	3	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
	Ceratopogonidae	0	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Chironomidae	0	5	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0	3	0	0	0	0	0
	Chloropidae	0	73	0	3	0	1	0	0	13	0	0	0	0	0	0	0	0	0	0	2	0	3	0	0	0
	Culicidae	2	0	0	0	0	0	21	0	2	1	0	2	0	0	0	7	0	2	3	1	75	0	0	8	2
	Dolichopodidae	0	31	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
	Drosophilidae	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Empididae	1	141	4	29	0	1	0	1	14	0	0	0	3	1	19	2	5	1	0	1	0	215	0	0	3
	Ephydriidae	0	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Lauxaniidae	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Lonchaeidae	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
	Muscoidea	18	93	20	8	1	22	4	2	17	1	0	4	14	1	17	3	86	34	101	51	4	34	0	1	0
	Mycetophilidae	0	7	0	1	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	2	0	2	0
	Nematocera unid.	0	3	0	1	0	1	1	0	0	0	0	0	2	0	0	0	0	4	0	1	0	0	0	2	0
	Phoridae	0	6	0	0	0	0	0	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
	Pipunculidae	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Psilidae	0	6	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
	Psychodidae	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 6 (continued). Specimen counts of arthropods collected from flowers of seven plant species in eight Alaskan national parks in 2019 and 2020. See Table 5 for common names of arthropods.

Arthropod order	Arthropod group	Achillea millefolium Common yarrow				Chamerion angustifolium Fireweed								Heracleum maximum Cow parsnip		Rhododendron groenlandicum Bog Labrador tea		Rosa acicularis Prickly rose		Taraxacum officinale Common dandelion				Vaccinium vitis-idaea Lingonberry			
		DENA	GLBA	KEFJ	KLGO	DENA	GAAR-A	GAAR-B	KEFJ	KLGO	LACL	SITK	WRST	KEFJ	SITK	DENA	WRST	DENA	LACL	DENA	GAAR-A	GAAR-B	GLBA	DENA	GAAR-B	WRST	
Diptera (Flies) (continued)	Rhagionidae	0	0	2	0	0	0	0	1	0	0	0	0	3	0	0	0	0	0	0	2	0	0	0	0	0	
	Scatopsidae	0	115	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	Sciaridae	0	11	0	1	0	1	0	0	2	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	1	
	Sciomyzidae	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
	Simuliidae	0	0	0	1	0	0	2	1	1	0	0	2	0	0	0	2	0	0	0	0	0	0	0	0		
	Stratiomyidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0		
	Syrphidae	111	64	10	27	8	1	0	12	26	23	0	3	8	5	12	0	19	21	77	9	0	71	0	0	0	
	Tabanidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0		
	Tachinidae	9	24	1	0	5	0	0	0	10	0	0	2	0	0	2	0	0	0	0	0	0	0	1	0	0	
	Tephritidae	0	69	52	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	
	Tipulidae	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Hemiptera (True bugs and relatives)	Acanthosomatidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	
	Anthocoridae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Aphidoidea	1	5	25	0	13	0	0	7	17	0	0	1	7	0	1	1	2	0	11	0	0	1	0	0	17	
	Cercopidae	0	59	0	72	0	0	0	0	7	0	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	
	Cicadellidae	1	51	0	2	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	5	0	1	0	0	0	
	Hemiptera unid.	1	79	52	4	0	3	14	4	2	1	0	1	3	0	0	0	0	0	1	2	0	0	0	0	0	
	Lygaeoidea	0	0	139	58	0	0	0	2	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Miridae	3	167	27	183	5	2	7	7	51	3	0	5	30	2	2	0	1	0	13	1	1	2	0	1	0	
	Psylloidea	0	19	0	113	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	
	Saldidae	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Scutelleridae	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Hymenoptera (Bees, wasps, ants)	Andrenidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9	0	0	0	0	0	0	0	
	Apidae	9	2	21	3	24	23	1	169	86	38	1	38	1	2	0	0	0	6	6	16	0	3	1	0	0	
	Chalcidoidea	0	64	11	1	0	0	0	1	6	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	
	Colletidae	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	
	Crabronidae	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	
	Cynipoidea	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	
	Diapriidae	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Formicidae	0	0	1	1	0	0	0	0	6	1	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	
	Halictidae	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	
	Ichneumonoidea	1	21	3	1	0	0	1	2	6	0	0	1	7	0	1	1	1	2	5	3	0	2	0	0	0	0
	Megachilidae	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	
	Platygastroidea	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Sphecidae	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Table 6 (continued). Specimen counts of arthropods collected from flowers of seven plant species in eight Alaskan national parks in 2019 and 2020. See Table 5 for common names of arthropods.

Arthropod order	Arthropod group	<i>Achillea millefolium</i> Common yarrow				<i>Chamerion angustifolium</i> Fireweed								<i>Heracleum maximum</i> Cow parsnip		<i>Rhododendron groenlandicum</i> Bog Labrador tea		<i>Rosa acicularis</i> Prickly rose		<i>Taraxacum officinale</i> Common dandelion				<i>Vaccinium vitis-idaea</i> Lingonberry		
		DENA	GLBA	KEFJ	KLGO	DENA	GAAR-A	GAAR-B	KEFJ	KLGO	LACL	SITK	WRST	KEFJ	SITK	DENA	WRST	DENA	LACL	DENA	GAAR-A	GAAR-B	GLBA	DENA	GAAR-B	WRST
Hymenoptera (Bees, wasps, ants) (continued)	Tenthredinidae	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	2	1	1	0	0	0	0
	Vespidae	2	0	0	0	1	0	4	0	0	7	0	11	0	0	0	0	0	0	0	0	0	4	0	0	0
Thysanoptera (Thrips)	–	0	6	19	1	0	23	0	42	0	0	0	0	212	0	0	0	0	0	0	0	0	0	0	0	0
Total # taxa		20	43	20	29	10	10	14	16	28	10	2	14	15	10	11	10	11	12	12	20	5	18	3	8	9

Patterns across focal plant species

The proportions of arthropod taxa visiting flowers varied by plant species (Figs. 7a–c). Flies (syrphids, muscoids, and other flies) dominated the catch on four of the plants sampled: Labrador tea (86%), prickly rose (89%), common dandelion (84%), and lingonberry (58%). On common yarrow, flies were equal in proportion to hemipterans (44%). Cow parsnip yielded a large proportion of thrips (61%), and fireweed had by far the largest proportion of bees (43%).

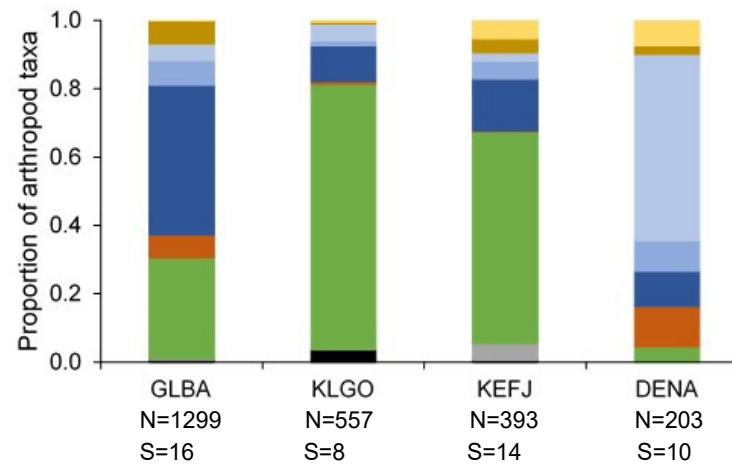
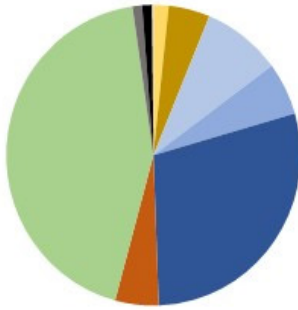
General patterns of arthropod abundance observed for different plants were mostly consistent across parks (Figs. 7a–c). Fireweed was sampled at eight sites in seven parks, with a total of 41 samples yielding 908 specimens (Fig. 7a). Bees made up 30–66% of the catch at all sites except for GAAR-B, where a single bumble bee was collected. Common yarrow was sampled at four parks (Fig. 7a), with 48 samples yielding 2,452 specimens. Two of the parks, KEFJ and KLGO, had high proportions of hemipterans (62% and 78%, respectively); GLBA had 29% hemipterans but was dominated by flies (56%); and DENA had few hemipterans but 74% flies, most of which were flower flies (Family Syrphidae). Common dandelion was also sampled at four sites (in three parks), with 15 samples yielding 797 specimens (Fig. 7b). Across all sites, flies comprised 71–96% of the total catch. Muscoid flies made up more than half of the flies in both DENA and GAAR-A, while in GAAR-B, mosquitoes (Family Culicidae) comprised most of the catch, and in GLBA, both flower flies (Family Syrphidae) and dance flies (Family Empididae, included in “Other flies”) were abundant.

The other four species of plants were each sampled in only two parks (lingonberry was sampled in a third park, DENA, but yielded only 3 specimens total, so was not represented in Figs. 7b, c). Cow parsnip was dominated by thrips in KEFJ, but thrips were not represented at all in the much smaller SITK sample (Fig. 7b). Labrador tea and prickly rose samples were dominated by flies in all parks (Fig. 7c). Lingonberry had few flower visitors collected at either GAAR-B or WRST, but while flies dominated in GAAR-B (mosquitoes and a few other families), WRST samples yielded about half flies and half aphids (Order Hemiptera; Fig. 7c).

Common yarrow (all parks combined)

N=2452

S=48



Fireweed (all parks combined)

N=908

S=41

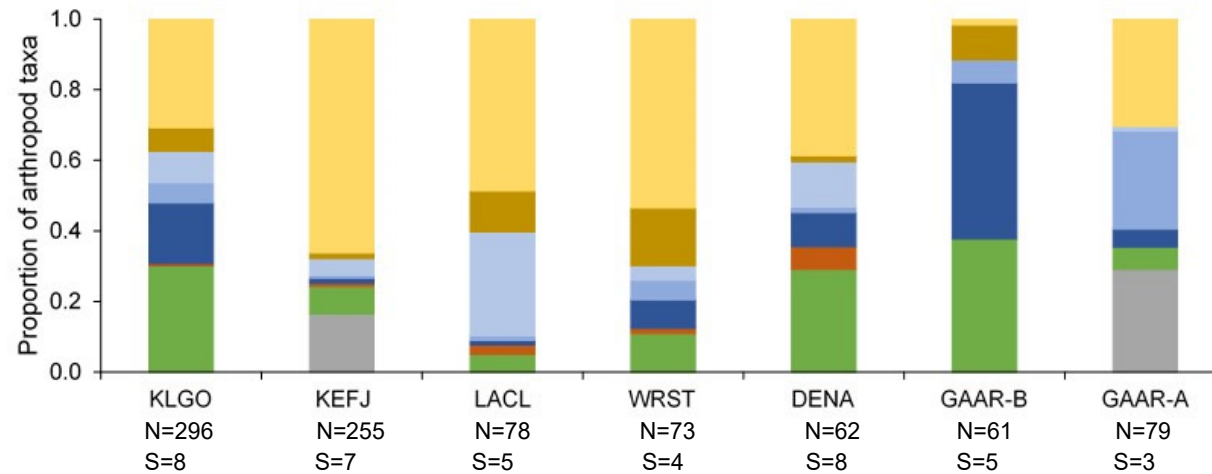
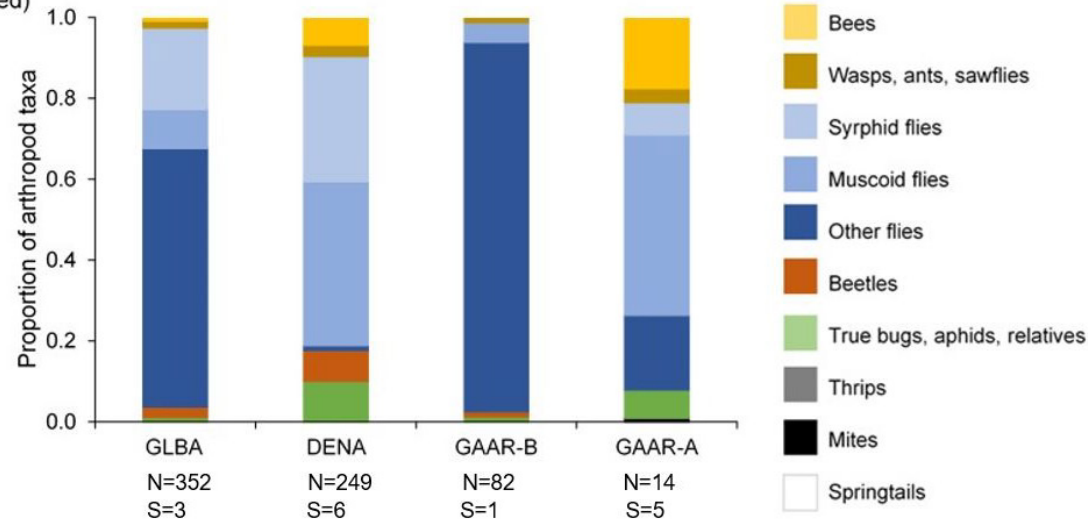
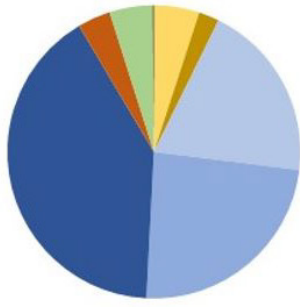


Figure 7a. Proportions of arthropod taxa collected from flowers of seven plant species in eight Alaskan national parks in 2019 and 2020: Common yarrow; Fireweed. Pie charts combine data from all parks for that plant species. Bars show park-specific data; parks are arranged in in order of increasing latitude, left to right. Parks collecting <10 specimens from a plant are not included. N = total # specimens collected; S = # collections.

Common dandelion (all parks combined)
N=797
S=15



Cow parsnip (all parks combined)
N=349
S=9

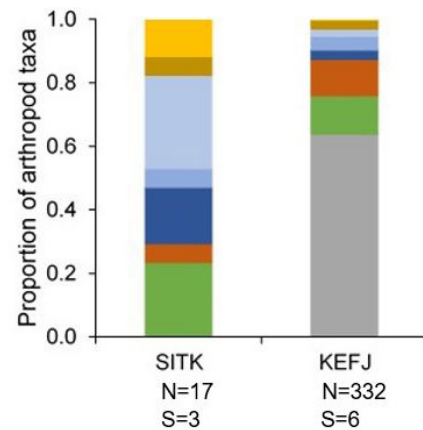
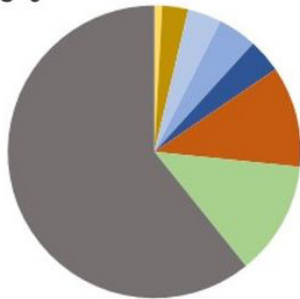


Figure 7b. Proportions of arthropod taxa collected from flowers of seven plant species in eight Alaskan national parks in 2019 and 2020: Common dandelion; Cow parsnip. Pie charts combine data from all parks for that plant species. Bars show park-specific data; parks are arranged in in order of increasing latitude, left to right. Parks collecting <10 specimens from a plant are not included. N = total # specimens collected; S = # collections.

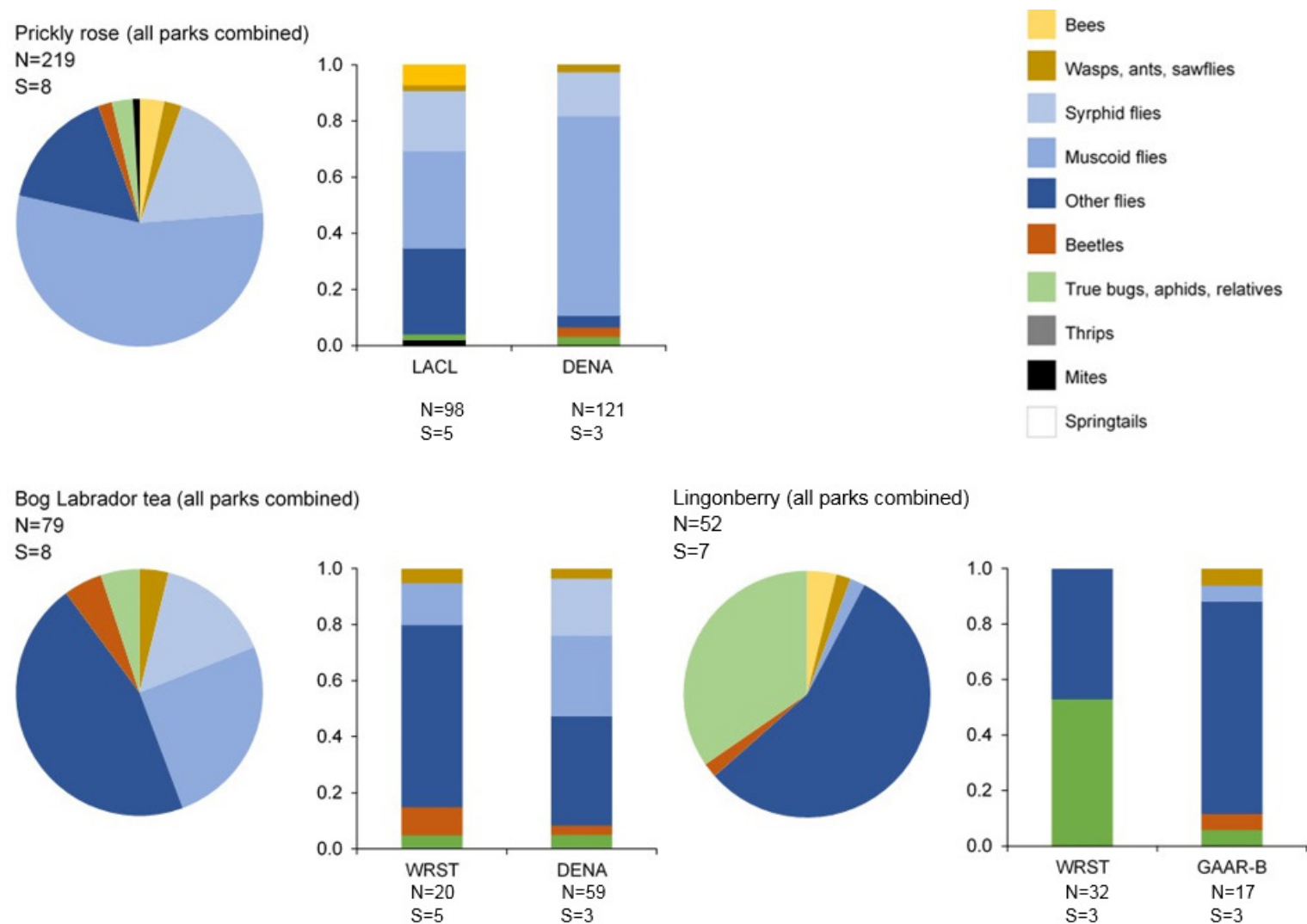


Figure 7c. Proportions of arthropod taxa collected from flowers of seven plant species in eight Alaskan national parks in 2019 and 2020: Prickly rose; Bog Labrador tea; Lingonberry. Pie charts combine data from all parks for that plant species. Bars show park-specific data; parks are arranged in order of increasing latitude, left to right. Parks collecting <10 specimens from a plant are not included. N = total # specimens collected; S = # collections.

Arthropod diversity and distribution

Assessing arthropod diversity at a higher taxonomic resolution (Table 6), several arthropod taxa were notable for their plant associations and/or geographical distributions. Among beetles, the cerambycid species *Gnathacmaeops pratensis*, was abundant on both common yarrow and common dandelion in DENA. Large numbers of small staphylinid beetles in the genus *Eusphalerum* were collected from common yarrow in GLBA and cow parsnip in KEFJ.

Among flies, mosquitoes (Family Culicidae) were collected in low numbers from all plant species except cow parsnip, but were very abundant on common dandelion in GAAR-B. Dance flies (Family Empididae) were one of the most abundantly collected and widely distributed fly taxa, found on all seven plant species, at all sites except GAAR-B, with very high counts on both common yarrow and common dandelion in GLBA. The other two fly taxa with similarly high numbers and widespread distribution were the muscoid flies and flower flies (Family Syrphidae). Flower flies were especially abundant on common yarrow, prickly rose, and common dandelion, but they were not collected on lingonberry. Fruit flies (Family Tephritidae) were collected in high numbers on common yarrow in both GLBA and KEFJ, but almost nowhere else. GLBA collected a total of 26 fly taxa from common yarrow and common dandelion, more than twice the fly diversity of any park except for KLGO.

Among the hemipterans, only aphids (Superfamily Aphidoidea) and plant bugs (Family Miridae) were found on all plant species. In addition to these two taxa, spittle bugs (Family Cercopidae), leafhoppers (Family Cicadellidae), seed bugs (Superfamily Lygaeoidea), and jumping plant lice (Superfamily Psylloidea) were all collected in high numbers from common yarrow. Only DENA had surprisingly few hemipterans on common yarrow.

The most abundantly collected parasitic wasps were the chalcidoids and ichneumonoids. The former were collected mostly from common yarrow, and only in southeastern and southcentral parks; the latter were much more widespread across plants and parks.

Thrips were collected in relatively high numbers on all three plants sampled in KEFJ (common yarrow, fireweed, and cow parsnip), and in GAAR-A on fireweed. They were not collected on any other plant species.

Bee diversity and distribution

A total of 480 bees comprising 23 species were collected across all plant species and parks (Fig. 8, Tables 6, 7). Because bees are relatively well-known taxonomically and they are extremely efficient pollinators, we identified them to genus or species (Table 7). All five bee families known from Alaska were represented by at least one species, but the family Apidae surpassed all others in diversity, with 15 identified species. In addition to the introduced honey bee (*Apis mellifera*), which was collected only in KLGO and SITK, 14 bumble bee species were found across all plants and parks (Table 8). Fireweed had the most bee species overall (18), including all 14 bumble bee species (Fig. 8, Table 8). Common yarrow and common dandelion had eight and seven bumble bee species, respectively, but common dandelion also had the highest diversity of other bees (Fig. 8, Table 8). Cow parsnip, prickly rose, and lingonberry had very few bees collected from their flowers (Fig. 8, Table 8).

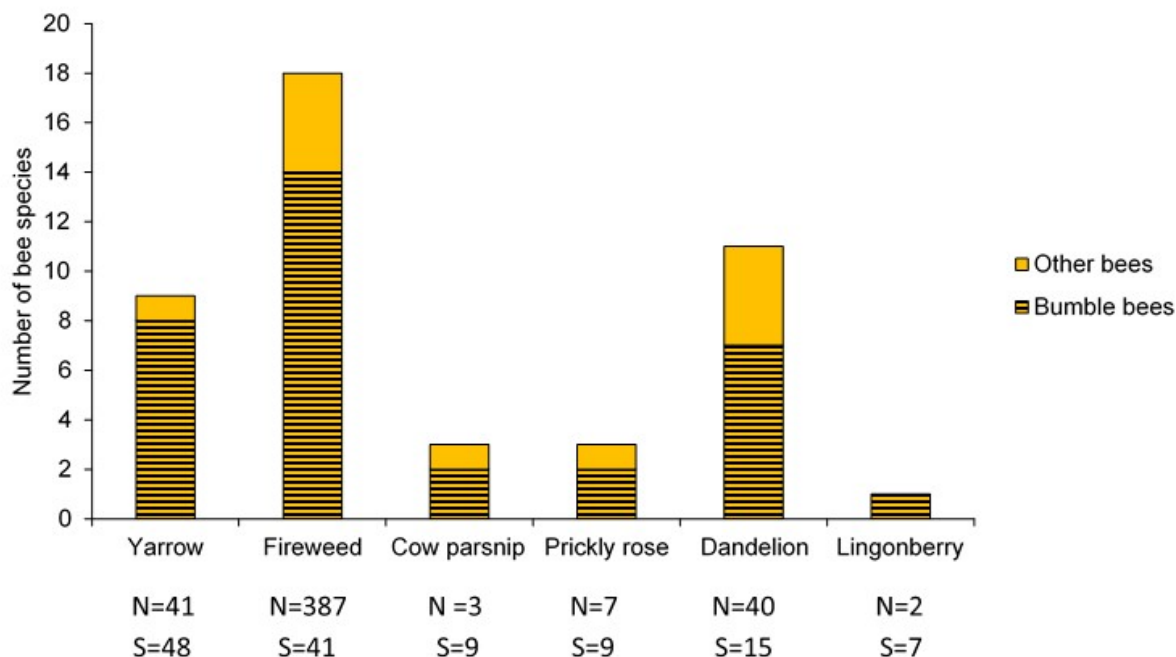


Figure 8. Species counts for bumble bees and other bees collected from flowers of seven plant species in eight Alaskan national parks in 2019 and 2020. N = total number of bees collected, S= total number of samples across all sites/parks.

Table 7. Bee species collected from flowers of seven plant species across eight Alaskan national parks in 2019 and 2020. Common names are listed for each species (or group) as well as nesting habits.

Family	Genus species	Common name	Solitary	Social	Parasitic
Andrenidae	<i>Andrena</i> sp.	Mining bee	x	—	—
	<i>Andrena milwaukeensis</i>	Mining bee	x	—	—
	<i>Panurginus</i> sp.	Mining bee	x	—	—
Apidae	<i>Apis mellifera</i>	Honey bee	—	x	—
	<i>Bombus cryptarum</i>	Cryptic bumble bee	—	x	—
	<i>Bombus flavidus</i>	Fernald cuckoo bumble bee	—	—	x
	<i>Bombus flavifrons</i>	Yellow head bumble bee	—	x	—
	<i>Bombus frigidus</i>	Frigid bumble bee	—	x	—
	<i>Bombus insularis</i>	Indiscriminate cuckoo bumble bee	—	—	x
	<i>Bombus jonellus</i>	White tail bumble bee	—	x	—
	<i>Bombus kirbiellus</i>	High country bumble bee	—	x	—
	<i>Bombus melanopygus</i>	Black tail bumble bee	—	x	—
	<i>Bombus mixtus</i>	Fuzzy-horned bumble bee	—	x	—
	<i>Bombus occidentalis</i>	Western bumble bee	—	x	—
	<i>Bombus polaris</i>	Polar bumble bee	—	x	—
	<i>Bombus sitkensis</i>	Sitka bumble bee	—	x	—

Table 7 (continued). Bee species collected from flowers of seven plant species across eight Alaskan national parks in 2019 and 2020. Common names are listed for each species (or group) as well as nesting habits.

Family	Genus species	Common name	Solitary	Social	Parasitic
Apidae (continued)	<i>Bombus lapponicus sylvicola</i>	Forest bumble bee	–	x	–
	<i>Bombus vancouverensis</i>	Two-form bumble bee	–	x	–
Colletidae	<i>Hylaeus annulatus</i>	Masked bee	x	–	–
Halictidae	<i>Lasioglossum</i> sp.	Sweat bee	x	–	–
Megachilidae	<i>Megachile ?relativa</i>	Leafcutter bee	x	–	–
	<i>Megachile lapponica</i>	Leafcutter bee	x	–	–
	<i>Osmia</i> sp.	Mason bee	x	–	–

Table 8. Specimen counts of bee species collected from flowers of seven plant species across eight Alaskan national parks in 2019 and 2020.

Family	Genus species	Achillea millefolium Common yarrow				Chamerion angustifolium Fireweed								Heracleum maximum Cow parsnip		Rosa acicularis Prickly rose	Taraxacum officinale Common dandelion			Vaccinium vitis-idaea Lingonberry
		DENA	GLBA	KEFJ	LACL	DENA	GAAR-A	GLBA	DENA	KLGO	LACL	SITK	WRST	KEFJ	SITK	LACL	DENA	GAAR-A	GLBA	DENA
Andrenidae	Andrena sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Andrena milwaukeeensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	Panurginus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0
Apidae	Apis mellifera	0	0	0	0	0	0	0	0	14	0	0	0	0	1	0	0	0	0	0
	Bombus cryptarum	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	1	0	0
	Bombus flavidus	0	0	0	0	0	0	0	1	1	0	0	3	0	0	0	1	0	0	0
	Bombus flavifrons	1	0	2	0	1	3	0	30	29	0	1	11	0	0	0	0	0	0	0
	Bombus frigidus	0	0	0	0	1	2	0	0	0	5	0	3	0	0	0	0	6	0	0
	Bombus insularis	0	0	3	0	0	0	0	3	1	5	0	2	0	0	0	1	0	2	0
	Bombus jonellus	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0
	Bombus kirbiellus	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
	Bombus melanopygus	0	2	1	3	2	0	0	8	27	6	0	0	0	1	1	0	0	1	1
	Bombus mixtus	2	0	7	0	14	0	0	74	1	18	0	11	0	0	0	3	0	0	0
	Bombus occidentalis	0	0	1	0	4	0	1	5	0	3	0	4	1	0	5	0	0	0	0
	Bombus polaris	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
	Bombus sitkensis	0	0	2	0	0	0	0	45	13	0	0	0	0	0	0	0	0	0	0
	Bombus sp.	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
	Bombus sylvicola	0	0	5	0	0	9	0	3	0	0	0	0	0	0	0	0	9	0	0
	Bombus vancouverensis	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
Colletidae	Hylaeus annulatus	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0
Halictidae	Lasioglossum sp.	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	1
Megachilidae	Megachile ?relativa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
	Megachile lapponica	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Osmia sp.	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Total # taxa		5	1	7	1	6	8	1	8	8	6	1	8	1	2	3	7	4	2	2

Discussion

More than 30 participants involved in this multi-park study successfully collected baseline data on the phenology of seven common Alaskan plant species, from Sitka in Southeast Alaska to Anaktuvuk Pass in the Brooks Range. They also collected close to 5,000 arthropod flower visitors from these focal plants, considerably expanding our knowledge of insect pollinator diversity and host plant associations in Alaska. The enthusiasm and detailed feedback provided by participants helped us test and refine our methodology over this two-year project.

Phenology of focal plants

At high latitudes with short growing seasons, leaf production and flowering are relatively rapid and synchronous across plant species in comparison to more temperate climates (Wipf 2010, Wolkovitch and Cleland 2011). Nevertheless, in this study, which included parks in southeast, interior, and arctic Alaska, we saw distinct differences in vegetative and reproductive phenology among the seven focal host plant species. This included the timing of first open flowers and the length of time between flowering and the production of ripe fruits, during which pollination takes place.

Our focal species included a variety of growth forms (shrubs, forbs), leaf types (evergreen, summergreen), and one non-native species. These variables are known to influence phenology as well as responses of plants to variations in climate (Mulder and Spellman 2019). For example, Labrador tea and lingonberry, both ericaceous evergreen shrubs, were among the earliest to flower, and flowering preceded the emergence of new leaves (as recorded in DENA, the only park with complete leaf data for these species). Because overwintering leaves can begin photosynthesizing early in spring when there is still risk of frost, there is less cost to evergreen species in delaying production of more vulnerable new leaves than for plants with summergreen leaves. Mulder and Spellman (2019) found that early-flowering species in interior Alaska responded more strongly to interannual variation in temperature than later-flowering species, but we did not have sufficient data across two years to support this.

Prickly rose was our only deciduous shrub. Unlike the evergreen shrubs, leaf-out for this species preceded flowering by one week in DENA, the only park where sampling began early enough to document leaf emergence. The timing of flowering and fruit production was similar in DENA and LACL in both years, but fruit ripening was delayed in both parks in 2020, when mean June and July temperatures were lower (but mean August temperatures were higher).

Among the forbs, common dandelion was the only non-native species. Common dandelion produced leaves and flowers earlier than the other forbs and developed quickly from flower to mature fruit. Of all the focal plant species, common dandelion showed the most variation in timing of phenophases across parks, and there was some suggestion that this variation was correlated with air temperature during the early growing season. High genetic diversity and/or phenotypic plasticity relative to climate may enhance the success of invasive species such as common dandelion in new environments (Wolkovitch and Cleland 2011).

In contrast to common dandelion, common yarrow flowered later in the season and had a much longer lag between flowering and ripe fruit production. The transitions of fruits from unripe to ripe to dispersed were difficult phenophases to discern in this species, and common yarrow plants are known to retain some fruits on the spent flower heads into winter, when they provide food for seed-eating birds. Thus, it is challenging to record the full phenological cycle of this plant. For the three parks that monitored common yarrow in 2020 (when data were more reliable), timing of phenophases was quite similar, and also delayed compared to 2019. Fireweed showed a little more variability in timing of phenophases across parks.

Mulder and Spellman (2019) monitored the phenology of 29 native and 12 non-native plants (including six of the focal plants from our study) in interior Alaska over three consecutive years and observed that both groups of plants advanced leaf-out and flowering in an early-snowmelt year, but warmer summers did not increase the rate of fruit development for either group. They also presented data showing that the start and end of the growing season in interior Alaska had varied by 30 and 45 days, respectively, over the previous 88 years. Thus increased inter-annual variation in environmental variables such as air temperature and snow melt are likely having effects on common plant species in Alaska, and while species responses to this variation may be synchronized across some groups, factors such as growth form, leaf type, and nativity are likely influencing species responses.

Many plant phenology studies focused on comparing native versus non-native species within a given region or examining shifts in phenology with climate variability have used data collected by citizen scientists (e.g., Wolkovitch and Cleland 2011, Spellman and Mulder 2016). National organizations such as the National Phenology Network and Project Budburst, as well as more local Alaskan projects such as Project BrownDown have galvanized an extensive network of teachers, students, and other nature enthusiasts to record and contribute observations on the phenology of plants in various regions of the U.S.

Our study similarly relied on a “voluntary” workforce to collect preliminary data for some common, widespread Alaskan plants found in national parks. What set the project apart from most other efforts was the addition of pollinator data for each of these focal plant species. Pollinators make a critical contribution to the life cycle of most plants, and without their services, fertilization and fruit production cannot occur. Thus, including pollinators in phenology studies by considering the diversity and activity cycles of their populations in relation to the timing of open flowers is a crucial step to better understanding the full ramifications of climate change on plant-pollinator reproductive success.

Challenges of monitoring phenology

We were fortunate to be able to borrow heavily from the expertise and phenology monitoring materials developed by K. Spellman and colleagues for citizen scientists participating in Project Browndown, including their photo guides and data sheets. Nevertheless, with nine sites and multiple participants recording phenology at many sites, it was challenging to ensure that everyone scored phenophases consistently week to week. Table 9 summarizes some of the commonly encountered problems for each of the seven focal host plant species.

Table 9. Common challenges encountered while scoring phenophases for seven focal plant species.

Plant species	Leaves	Flower bud	Open flower	Petal drop	Unripe fruit	Ripe fruit	Dispersed fruits/seeds	General notes
Common yarrow	in some plants, initial leaves grow in a thick cluster or rosette, difficult to tell separate plants	–	usually too many flowers to count, so switch to counting umbels	–	fruits are small and difficult to tell whether ripe or unripe; many fruits stay on flowerhead into winter; spent flower heads also stay on plant	fruits are small and difficult to tell whether ripe or unripe; many fruits stay on flowerhead into winter; spent flower heads also stay on plant	fruits are small and difficult to tell whether ripe or unripe; many fruits stay on flowerhead into winter; spent flower heads also stay on plant	plants often will not develop inflorescences
Fireweed	can be difficult to differentiate between initial, unfurling, and fully open leaves; a lot of leaves to count on large plants	tiny buds in early season difficult to count; some buds don't develop but stay on the stem	–	–	many unripe fruits don't develop into ripe fruits	these can be numerous and difficult to count because of the curling	these can be numerous and difficult to count because of the curling	plants often will not develop inflorescences; multiple phenophases present at once
Cow parsnip	–	–	usually too many flowers to count, so switch to counting umbels	many flowers did not develop past this stage	–	–	–	plant sap can cause rashes on skin if exposed to sunlight
Labrador tea	hard to differentiate between old and new leaves once the new leaves mature	challenging to tell leaf bud from flower bud	–	–	difficult to assess ripeness of fruit	difficult to assess ripeness of fruit	can be hard to tell if seeds have dispersed from seed pod	–

Table 9 (continued). Common challenges encountered while scoring phenophases for seven focal plant species.

Plant species	Leaves	Flower bud	Open flower	Petal drop	Unripe fruit	Ripe fruit	Dispersed fruits/seeds	General notes
Prickly rose	–	–	–	can be difficult to tell at what stage the developing fruit is; or if it will develop at all	can be difficult to tell at what stage the developing fruit is; or if it will develop at all	can be difficult to tell at what stage the developing fruit is; or if it will develop at all	hard to detect the pedicels free of fruit	–
Common dandelion	large rosettes of leaves can be challenging to count, and leaves from neighboring plants can be difficult to distinguish	–	–	closed flower head may contain a bud, withering petals, or unripe seeds; can be difficult to discern	closed flower head may contain a bud, withering petals, or unripe seeds; can be difficult to discern	–	–	development of flowers and fruits occurs very quickly, can be easy to miss some phenophases
Lingonberry	hard to differentiate between old and new leaves once the new leaves mature	challenging to tell leaf bud from flower bud	–	can be hard to see the ovary and pistil without petals	unripe fruits may not ripen	–	hard to detect the pedicels free of fruit	selected stems will often have either flower buds OR leaf buds

We encouraged participants to e-mail or call with questions, and this was also helpful for us to anticipate problems that others might have. The first season (2019) taught us that it was important to select new plants as soon as it became apparent that individual plants were not going to flower, which was often the case with fireweed and common yarrow, and sometimes with other species. Leaf phenophases also presented some problems. Subtle differences between unfurling and fully open leaves prompted us to lump these two phenophases for some species in 2020. Also, for evergreen species (Labrador tea and lingonberry), we devised better methods for marking the old leaves from the new, so they could be differentiated later in the season. Determining whether leaves on a plant had insect damage or were senescing was also difficult for many of the species.

In some parks (especially in 2020 with COVID-19 challenges), early season phenology monitoring (e.g., when leaves were first emerging) was not possible because seasonal staff did not begin work until after plant development was underway. The same was true for late season monitoring, if seasonal staff ended their jobs before fruits or seeds were ripe and/or dispersed.

Observer constancy throughout the season presented another challenge. In some cases, when the task of monitoring the same plants was shared between multiple observers (different people recording on different weeks), it was obvious from the weekly data sheets that phenophases were being scored inconsistently (i.e., structures scored as ripe fruits one week might be recorded as unripe fruits the following week); this also happened for some plants with single observers from week to week.

General patterns of arthropod diversity

Few large-scale pollinator studies in Alaska have explored the full diversity of arthropods visiting flowers of multiple host plants, most inventories have focused on bees and sometimes syrphid flies (e.g., Pampell et al. 2015, Rykken 2017). Our study showed that for most of the plants sampled, bees made up a relatively small component of the flower-visiting arthropod community. By far the most abundant and diverse insects collected were the flies (Diptera), they made up the largest proportion of flower visitors for four of the seven focal plant species. Hemipterans (which include true bugs, hoppers, aphids, and jumping plant lice) were also abundant on common yarrow and fireweed, and thrips (Thysanoptera) had a large presence on cow parsnip, but these two taxonomic orders combined represented less than half the family richness of flies.

There are numerous reasons that arthropods come to flowers. Many adult insects feed on nectar to provide energy for flight and other activities, some adult insects (including beetles, syrphid flies, and thrips) feed on pollen for a protein source. It is worth mentioning that most of these insects (bees being a notable exception) have very different feeding habits in their immature stages, which include parasitoids, predators, herbivores, and scavengers (Table 5). Some insects feed on other floral structures (e.g., petals or ovules) which may be more destructive than beneficial to the plant host. For example, some fruit flies in the family Tephritidae lay their eggs in composite flower heads and their larvae feed on the plant's ovules (Larson et al. 2001). Arthropods may also visit flowers to bask and raise their body temperature, especially in cooler climates (Kevan 1975), to seek shelter at night or in bad weather, or to find a mate or prey (Woodcock et al. 2014).

Not all flower visitors serve as good pollinators for their host plant. Bees are generally known to be the most efficient of the pollinating insects, in part because most bees are hairy and females have structures on their bodies to carry large quantities of pollen back to the nest to provision developing larvae. The efficient foraging behaviors of many bees within and between plants also facilitate transfer of pollen from anthers to receptive stigmas. However, many flies and other insects also have an important role to play in the transfer of pollen between plants, and may make up with high visitation densities and rates what they lack in individual efficiency (Kevan and Baker 1983, Tiusanen et al. 2016, Raguso 2020).

Especially in colder climates at high elevation and latitude, flies become a more abundant and important group of pollinators (Levesque and Burger 1982, Larson et al. 2001, Tiusanen et al. 2016). Syrphid flies and muscoid flies are known to be important for pollen transfer, and we collected them in relatively large numbers across most of the plants in our study, but the contribution of other fly families has received less attention (Orford et al. 2015). Dance flies (Family Empididae) were very abundant on common yarrow and common dandelion in our study, and although adults are primarily predators of other insects, their long, piercing mouthparts allow nectar-feeding from tubular corollas, some species also consume pollen (Larson et al. 2001). Among the flies that we collected, several other families were also present in relatively high numbers. Mosquitoes (Family Culicidae), especially males, are common nectar feeders, but these flies are not known to transport much pollen between plants, except for a specialist relationship with some orchids (Thien and Utech 1970). Minute scavenger flies (Family Scatopsidae) are often gregarious feeders of nectar and pollen but are not particularly known as pollinators (Larson et al. 2001). Grass flies (Family Chloropidae) are nectar feeders and some species are known to serve as pollinators (Larson et al. 2001). Fruit flies (Family Tephritidae), as discussed above, visit flowers to lay eggs but are likely not effective pollinators (Larson et al. 2001); we found them in high numbers on common yarrow.

Hemipterans were another abundant group on some plants, including common yarrow, fireweed, and lingonberry. Some of the true bugs (e.g., Family Miridae, Superfamily Lygaeoidea) are known to feed on nectar, especially from open flowers, but their role as pollinators is not well known (Kevan and Baker 1983). The hoppers (Families Cercopidae and Cicadellidae), aphids (Superfamily Aphidoidea), and jumping plant lice (Superfamily Psylloidea) are primarily plant sap consumers, and some may have been sucked up by the bug vacuum from stems or leaves near the flowers.

Thrips are small but conspicuous flower visitors; they are often gregarious feeders and thus can be collected in high numbers (as they were on cow parsnip in our study). Within the order Thysanoptera, thrips have varied feeding habits, but those that visit flowers consume nectar and pollen and likely effect some pollination (Proctor et al. 1996). Because they can damage leaves and petals, and may carry plant diseases, some thrips are regarded as pests on cultivated plants.

Beetles made up a relatively minor component of the flower-visiting arthropods on most of the focal plant species and overall family diversity was relatively low. There are several beetle families known to frequent flowers for nectar and pollen consumption as adults, and these include one subfamily of the long-horned beetles (Cerambycidae), the Lepturinae, which were collected from common yarrow and common dandelion in relatively high numbers. Rove beetles (Family Staphylinidae) were also

abundant on common yarrow and cow parsnip, and these were comprised almost entirely of the genus *Eusphalerum*, known to feed on nectar and pollen, sometimes in large aggregations (Zanetti 2014). Some of the beetles we collected are primarily predators (Family Carabidae, ground beetles, and Family Coccinellidae, ladybug beetles), likely in search of prey on the plants.

Bees are the only members of the Hymenoptera that provision their young with nectar and pollen, but some sawflies, parasitoid wasps, stinging wasps, and ants are also nectar feeders. Some gall wasps (in the Superfamily Cynipoidea) visit flowers to lay eggs. The most abundant parasitoid wasps we recorded were the Ichneumonoidea, which were widespread across host plants, but common yarrow had an abundance of tiny chalcidoid wasps, known to prefer open, white flowers. Yellow jackets (Family Vespidae) were collected mostly from fireweed. Ants (Family Formicidae), of which we collected only a few, are generally not considered to be effective pollinators, partly because they have to walk between plants and thus probably lose much of the pollen they are carrying to ground vegetation. Some plants have extrafloral nectaries that lure ants away from the flowers (Kevan and Baker 1983).

Different plants attracted different types of insects. Flowers of the focal plant species varied in color (white, pink, yellow), arrangement (composite heads, umbels, racemes, single open, clusters, bell-shaped), scent, and accessibility of nectar (i.e., depth of corolla to nectary) and pollen. Insects may be attracted to particular combinations of these characters. Open white flowers with accessible nectaries are known to be favored by many insects with mouthparts not specialized for accessing deeper corollas (Kevan and Baker 1983). In our study, these included common yarrow, cow parsnip, and Labrador tea. Most flies in the suborder Nematocera prefer white open flowers (Kevan and Baker 1983). They include mostly small or delicate flies such as black flies (Family Simuliidae), fungus gnats (Family Mycetophilidae), gall and wood midges (Family Cecidomyiidae), and biting midges (Family Ceratopogonidae). While relatively low in abundance, 11 nematoceran fly families were collected off common yarrow, more than twice the diversity associated with any other plant species. In contrast, two families of flies with elongate, piercing mouthparts, mosquitoes (also nematoceran) and dance flies, were collected in high numbers off common dandelion, a composite flower with deeper nectaries. Prickly rose, though pink in color, has open flowers with accessible nectar and pollen, and also appears to be favored by flies; in our study, prickly rose visitors were comprised primarily of muscoid flies, syrphid flies, and non-biting midges (Family Chironomidae).

Other insects known to be attracted to white open flowers include beetles, small parasitoid wasps, which were most abundant on common yarrow in our study, and thrips which were primarily collected on cow parsnip (Kevan and Baker 1983, Proctor et al. 1996). Most groups of hemipterans were also abundant on common yarrow flowers relative to other plant species. However, plant bugs (Family Miridae) were found across all plant species, as were aphids

Bees visit many types of flowers, and with their long tongues they can access pollen and nectar from both open flowers and flowers with much deeper corollas. In our study, bumble bees were collected primarily off fireweed, which has pink open flowers (bumble bees often favor flowers in the pink-blue-purple range), but lower numbers of bumble bees, along with some solitary bees, were also collected on common yarrow and common dandelion. Bumble bees maximize their foraging

efficiency on fireweed by first landing on the lower flowers of the raceme, where nectar is most abundant, and working their way up successively higher flowers until they fly off to the next plant. This behavior is also beneficial to the plants, which are protandrous, with older, lower flowers having receptive stigmas to receive pollen from arriving bees, and newer, upper flowers shedding pollen for the foraging bee to carry off to a new flower (Galen and Plowright 1985). Bumble bees are also the primary pollinators for lingonberry, although our collections did not reflect this. The bell-shaped flowers of this plant have poricidal anthers which require intense vibration to release their pollen, and bumble bees are able to perform this critical “buzz pollination.”

Because sampling efforts varied considerably across focal plant species and parks, it was not possible to draw quantitative conclusions about differences in arthropod communities across host plants or different regions. In general, our data suggested that for plant species dominated by flies (Labrador tea, prickly rose, common dandelion), flies were dominant on those plants in all parks where they were sampled; likewise, fireweed yielded an abundance of bumble bees at seven of the eight sites where it was sampled, the anomaly being GAAR-B, which was likely an artifact of sampling. The four parks sampling common yarrow varied in their relative proportions of flies and hemipterans, with KLGO and KEFJ having the highest proportions of hemipterans, and DENA collecting almost none. Lastly, cow parsnip was dominated by thrips in KEFJ but not in SITK, though a much lower sample size in SITK (5% of KEFJ) makes this comparison suspect.

Bee diversity

Bees were the only pollinator group identified down to genus or species. Fireweed had the highest bee diversity overall, comprised primarily of bumble bees (14 species). Considering the comparatively low bumble bee catches on common yarrow and common dandelion (about 10% of fireweed totals), these plants also yielded a relatively high diversity of bumble bees (8 and 7 species, respectively). There are 23 species of bumble bees currently known from Alaska (Sikes and Rykken 2020), and our species list included an expected mix of arctic/alpine bees (e.g., *Bombus polaris*, *B. kirbiellus*), bees found south of the Alaska range, (e.g., *B. sitkensis*, *B. vancouverensis*), and more widespread bees (e.g., *B. mixtus*, *B. flavifrons*). Also included were two “cuckoo” bumble bee species, *B. insularis* and *B. flavidus*. Unlike other bumble bees that have social colonies founded by queens and tended by workers, these parasitic bees have no caste system. Instead, female cuckoo bees invade the nests of other social bumble bee species, usually kill the queen, and then usurp the workers to raise the cuckoo young. We collected almost all male cuckoo bees on common dandelion, common yarrow, and fireweed, and found one or the other species at all parks except SITK or GAAR. Females are less commonly collected, presumably because they are in the nest tended by host workers.

Honey bees (*Apis mellifera*), which are not native to Alaska (or anywhere in North America), showed up on fireweed in KLGO and on cow parsnip in SITK. The sampling sites in these parks were located in or near human-developed areas, and the foraging bees were likely coming in from nearby human-maintained hives.

While solitary bees make up the vast majority of bee diversity in warmer climates, in Alaska we have comparatively few species and they are far less conspicuous than the large, colorful, abundant

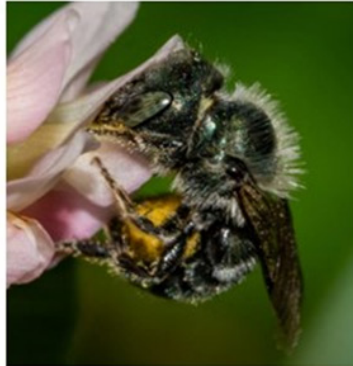
bumble bees. In our study, although solitary bees made up a relatively small proportion of the total bee catch, they represented four additional bee families. As a group, they were collected from five plant species and five parks. These included mining bees in the genera *Andrena* and *Panurginus*, both of which nest in the ground. Most of these were collected off common dandelion in DENA, but one *Andrena* came off prickly rose in LACL. Tiny masked bees in the genus *Hylaeus* (collected from common dandelion in GAAR-A and common yarrow in DENA) often nest in hollow twigs or stems. Sweat bees in the genus *Lasioglossum* are also ground nesters, and they were collected from fireweed in KLGO and lingonberry in DENA. Leafcutter bees in the genus *Megachile* and mason bees in the genus *Osmia* both use existing cavities for nesting; as their name suggests, leafcutters line their nests with pieces of leaves. These bees were collected from fireweed and common dandelion.

Delving deeper into bee diversity, distributions, and host-plant associations at a species level allows a more nuanced assessment of patterns that is not afforded with family level identifications.

Unfortunately, the taxonomy of many groups collected in this study, including most flies and many of the parasitic wasps, is extremely challenging. While higher resolution identifications of some groups, like beetles and many hemipterans are feasible, for the remainder, it is only practical for now to identify to family level.



Flower-visiting flies, left to right: Top row, grass fly (Family Chloropidae; © KATJA SCHULZ), mosquito (Family Culicidae; © NAOKITAKEBAYASHI), dance fly (Family Empididae; © SFOTH); 2nd row, minute scavenger flies (Family Scatopsidae; © ZIHUADEAN), fruit fly (Family Tephritidae; © MHKING), muscoid fly (Superfamily Muscoidea; © CONNIE TAYLOR); 3rd row, fungus gnat (Family Mycetophilidae; © NATHAN NYX), flower fly (Family Syrphidae; © ROBERT WEEDEN), flower fly (Family Syrphidae; © MATT MUIR)



Bees, left to right: Top row, forest bumble bee (*Bombus sylvicola*; © MATT MUIR), cryptic bumble bee (*Bombus cryptarum*; © JASON GRANT), indiscriminate cuckoo bumble bee (*Bombus insularis*; © MTROOTS); 2nd row, masked bee (*Hylaeus annulatus*; © MARK CHAO), mason bee (*Osmia*; © BOB15NOBLE), mining bee (*Panurginus*; © RSEALY); 3rd row, mining bee (*Andrena milwaukeensis*; © AFRASER), leafcutter bee (*Megachile relativa*; © MHKING), cellophane bee (*Colletes*; © MATT MUIR)



Insect flower visitors, left to right: Top row, aphids (Superfamily Aphidoidea; NPS/JESSICA RYKKEN), rove beetles (Family Staphylinidae; © RENÉ AMMAN), plant bug (Family Miridae; © MATT MUIR); 2nd row, leafhopper (Family Cicadellidae; © ROBERT WEEDEN), long-horned beetle (Family Cerambycidae; © JOAN HAGAR); 3rd row, yellowjacket (Family Vespidae; © MATT MUIR), thrips (Order Thysanoptera; © MATT MUIR), common sawfly (Family Tenthredinidae; © MATT MUIR); 4th row, jumping plant louse (Superfamily Psylloidea; © BRIDGET SPENCER), ichneumonid wasp (Family Ichneumonoidea; © MATT MUIR), chalcid wasp (Superfamily Chalcidoidea; © MATT BOWSER).

Successes and challenges of characterizing arthropod flower visitors

Many considerations went into designing a protocol for collecting insects off the focal plant species. Because we were asking parks to conduct this work, we were not expecting that participants would have prior experience catching insects. Generally, passive pan traps (or “bee bowls”) are a good method for collecting insects with inexperienced volunteers, as they require little skill to deploy and can catch many insects in a relatively short period of time. However, we wanted to collect directly from flowers to make plant-pollinator associations. Netting is the most common method for active collecting of this sort but requires skill and experience. To minimize sampling bias among collectors of varying skills, we decided to try a hand-held “bug vacuum.” Not surprisingly, this method turned out to have both benefits and challenges.

On the positive side, the vacuums were relatively easy to operate without much practice and collected adequate numbers of insects. An especially good feature was that insects were sucked directly into a collecting tube within the vacuum, which could be removed and capped at the end of the sample without risk of losing any specimens. This in contrast to net collecting, where the process of extracting specimens from the net and transferring them to a kill jar is time-consuming and can result in being stung or losing or damaging the insect. Vacuums also worked well for collecting small, cryptic insects that might be missed altogether or difficult to catch with a net.

The vacuums did require some practice. Some insects (e.g., syrphid flies) were extremely “flighty” and difficult to catch without practice. Other insects, such as the long-horned beetles, were firmly attached to the flowers and not easily removed with suction alone. Some flowers were more challenging to vacuum. For example, the large floppy petals on prickly rose were prone to fold up and around an insect in the middle of the flower, thus protecting it from being sucked into the vacuum. While the collecting tube is a very practical feature of the vacuum, the fact that the captured insects remained alive in the tube until it was frozen or dunked in ethanol, meant that delicate insects (like some of the nematoceran flies) were susceptible to damage by frenzied activity inside the tube. Lastly, the model of vacuum we used had rechargeable batteries that lasted only about 15 minutes before a noticeable decrease in suction.

As with any sampling technique, some biases or artifacts were difficult to control. Active collecting, at best, provides only a snapshot of insect diversity for the 20 minutes spent vacuuming. Although we encouraged participants to collect only on relatively warm ($>13^{\circ}\text{C}$), dry, calm days, when insects are most active, this was not always possible logistically or because of persistent bad weather. This also makes it difficult to collect consistent samples for monitoring activity over time. One idea for future studies may be to use a passive trapping technique (e.g., pan traps) to complement active collecting. While the pan trap samples do not allow direct host plant association, they can show abundance patterns over time of taxa known to occur on flowers from active sampling.

As mentioned above, the “trapability” of insects can vary considerably across taxa, and this means some taxa will be underrepresented in samples. Many flies and wasps were quick to fly off when approached, while most of the sucking hemipteran insects, thrips, mites, ants, and beetles were more stationary, and thus easier to collect. Collecting some beetles was challenging because they were difficult to pry loose from the flower.

Conclusions and recommendations

- The protocols tested and refined in this pilot study allowed us to characterize the phenology of seven common, widespread Alaskan plants across a broad geographic area, as well as the pollinator diversity associated with these plants. Plant growth form, leaf type, and nativity appeared to be associated with different phenology patterns within and across parks.
- Successful plant phenology monitoring requires consistent, careful observations week to week, throughout the entire growing season. Sampling sites within a park should be kept consistent year to year. Observers should receive plant-specific instruction before the season starts and be encouraged to ask questions (including photographs) once monitoring is underway. Ideally, one or two people (together) should be responsible for collecting data over the season. Data sheets should be submitted to the PI weekly so that any problems can be identified and corrected quickly. The data sheet from the previous week should be taken out when monitoring plant phenophases to keep scoring consistent.
- Each of the seven focal plant species presented unique challenges for identifying and quantifying phenophases and for collecting arthropods. Overall, cow parsnip and common dandelion emerged as the best candidates for both tasks (Table 10), although our sample size for cow parsnip was low.

Table 10. Rating for ease of phenology monitoring and arthropod collection on seven focal plant species (1 = most challenging; 2 = some significant challenges; 3 = worked well).

Plant species	Phenology	Arthropod collection
Common yarrow (<i>Achillea millefolium</i>)	2	3
Fireweed (<i>Chamerion angustifolium</i>)	2	3
Cow parsnip (<i>Heracleum maximum</i>)	3	3
Labrador tea (<i>Rhododendron groenlandicum/tomentosum</i>)	2	2
Prickly rose (<i>Rosa acicularis</i>)	3	2
Common dandelion (<i>Taraxacum officinale</i>)	3	3
Lingonberry (<i>Vaccinium vitis-idaea</i>)	2	1

- Additional plants to consider for phenology monitoring and pollinator sampling include accessible, widespread members of the Asteraceae family (e.g., northern goldenrod—*Solidago multiradiata*, black-tipped groundsel—*Senecio lugens*); the Fabaceae family (e.g., northern oxytrope—*Oxytropis campestris*, alpine milk vetch—*Astragalus alpinus*, Arctic lupine—*Lupinus arcticus*); the Rosaceae family (e.g., *Potentilla fruticosa*); willows in the Salicaceae family (e.g., *Salix pulchra* or *S. glauca*); deeper-corolla flowers attractive to long-tongued pollinators like bumble bees (e.g., monkshood—*Aconitum delphinifolium*, larkspur—*Delphinium glaucum*, bluebells—*Mertensia paniculata*); and other berries in the Ericaceae family (e.g., bog blueberry—*Vaccinium uliginosum*).
- Flies (Order Diptera) made up the most diverse and abundant group of flower visitors overall. Many flies are known to be effective pollinators, especially at northern latitudes, yet flies receive far less attention than bees in pollinator research, outreach, or conservation programs. The curation and taxonomy of most flies is extremely challenging, nevertheless, we should increase our efforts to include more fly families in pollinator surveys, monitoring efforts, and ecological studies.
- In order to track pollinator activity across the season on different plant species, consistent sampling is important. In addition to weekly active collecting directly from flowers, which is influenced by weather, time of day, and collector experience, it may be beneficial to add a passive trapping method such as pan trapping. Pan traps integrate conditions over multiple days and require no skill to set out. In conjunction with active collections, pan traps would provide valuable data on abundance and activity patterns of selected pollinator taxa over time.
- Microclimate variables (e.g., air temperature) will be more accurately captured by deploying air temperature dataloggers at each sampling site, rather than relying on weather station data. Ideally, loggers should be placed at sites early in the season to capture the accumulation of growing degree days.
- Ultimately, we hope that the protocols tested and data collected in this pilot study will inform and inspire more structured, quantitative studies on plant phenology and pollinator diversity (including finer-scaled identification of arthropod taxa) in Alaskan national parks. Such studies will allow comparisons of plant and pollinator phenology across broad gradients of latitude, elevation, and climatic variables, providing insights into how changing climate may affect plant-pollinator relationships.

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1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525